Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

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Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

Energy used in the residential and commercial sectors provides a wide range of services, including heating, cooling, lighting, refrigeration, cooking, and numerous other end uses. The U.S. Energy Information Administration (EIA) conducts two buildings-sector surveys—the *Residential Energy Consumption Survey* (RECS) and the *Commercial Buildings Energy Consumption Survey* (CBECS)—that provide information on the equipment stock and energy consumption within existing buildings. However, these surveys do not directly gather other information that we need to project future energy consumption, such as equipment cost information or nameplate efficiency ratings.

The Residential Demand Module (RDM) and the Commercial Demand Module (CDM) of the National Energy Modeling System (NEMS) use equipment cost and performance technology menus that represent competing options for most of the major end uses. The contracted reports in Appendixes A–D provide the information basis on which these menus can be built, focusing on cost and efficiency characterizations across equipment and fuel types. Previous editions of the *Annual Energy Outlook* (AEO) used similar contracted reports.

Multiple equipment classes and types are represented in these menus so that the projected equipment stock can change over time in response to fuel prices and other factors that affect equipment choice, such as appliance standards. The equipment menus interact with other NEMS parameters to determine market shares, equipment efficiency levels, cost estimates, and equipment interactions,[1] and they are used to translate service demand into energy demand.

Appendixes A and B constitute one set of reports that characterizes most major residential equipment and commercial heating, cooling, and water heating equipment. Appendix A is used in developing Reference case projections, while Appendix B is used in developing advanced technology cases.[2] These assumptions will be developed and implemented during the AEO2025 cycle.

Appendixes C and D constitute another set of reports that characterizes residential and commercial lighting, as well as commercial ventilation and refrigeration equipment. Appendix C is used in developing the Reference case, while Appendix D is used in developing advanced technology cases. These assumptions were developed and implemented during the AEO2023 cycle.

When referencing the contracted reports in Appendixes A, B, C, and D, you should cite them as reports by Guidehouse and Leidos, prepared for the U.S. Energy Information Administration.

[1] Examples of equipment interactions are solar water heaters that supplement traditional water heaters, clothes washers that reduce the need for clothes drying, and water heaters that provide dishwashers and clothes washers with heated water.

[2] In addition to the Reference case, we also develop sensitivities to explore different assumptions for the cost and performance of future technologies. For the more optimistic cases, some equipment achieves lower life-cycle costs through improved efficiency or lower upfront costs, or both. The contracted reports provide a base case and an advanced case for modeling the AEO Reference case along with the more optimistic cases. We use the advanced case assumptions to develop side cases for AEO reports that include such analyses.

APPENDIX A

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

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Objective

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The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- Installed base in 2012 and 2018 (for commercial products) or 2015 and 2020 (for residential products) and current market (2022)
  - Review literature, standards, installed base, contractor, and manufacturer information
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product
- Forecast of technology improvements that are projected to be available through 2050
  - Review trends in standards, product enhancements, and Research and Development (R&D)
  - Project impact of product improvements and enhancement to technology

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Methodology

Input from industry stakeholders, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- Only currently published efficiency standards and regulations are considered when predicting technology developments; unpublished future regulatory action is not predicted.
- All costs are shown in 2022 dollars (2022$).
- Ranges, when given, represent the span of typical values for a given parameter (e.g., installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

Definitions

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The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 and 2018 (for commercial products) or 2015 and 2020 (for residential products) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- Current Standard: The minimum efficiency (or maximum energy use) that is required (allowed) by current U.S. Department of Energy (DOE) standards, when applicable.
- ENERGY STAR: The minimum efficiency that is required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. The performance data that are presented are representative of certified products that just meet current ENERGY STAR specifications.
- Typical: Efficiency and cost values are for the average, or "typical," product being sold in the particular timeframe. This may represent either the shipments-weighted average product performance or the most common product on the market.
- High: Efficiency and cost values are for the product with the highest efficiency available in the particular timeframe.

The market for the reviewed products has changed since this analysis was previously conducted.[1] These changes are noted and reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is more efficient than the average product in the installed base in 2012 (commercial) or 2015 (residential):
  - Residential sector: boilers, central air conditioners, room air conditioners, gas-fired furnaces (North), gas-fired furnaces (Rest of Country), oil-fired furnaces, electric resistance furnaces, heat pump water heaters, gas-fired instantaneous water heaters, natural gas cooktops, natural gas ovens, refrigerator-freezers, freezers, clothes dryers, clothes washers, and dishwashers
  - Commercial sector: gas-fired furnaces, oil-fired boilers, commercial rooftop heat pumps, commercial ground-source heat pumps, gas-fired instantaneous water heater, natural gas and electric ranges, griddles, and ovens
- More stringent Federal standards have taken effect for the following products:
  - Gas-fired and oil-fired boilers in 2021
  - Rooftop air conditioners and rooftop heat pumps in 2018
- Federal standards are slated to take effect in the coming years for the following products:
  - Central air conditioners, residential air-source heat pumps, gas-fired furnaces, oil-fired furnaces, gas-fired boilers, oil-fired boilers, rooftop air conditioners, and rooftop heat pumps in 2023
  - Portable air conditioners in 2025
- ENERGY STAR continues to raise the bar with revised criteria for:
  - Central air conditioners, residential air-source heat pumps, rooftop air conditioners, rooftop heat pumps, residential water heaters, and dishwashers in 2023

Note: The previous analysis is available in the EIA Technology Forecast Updates (2018) report.

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Residential Space Heating and Cooling

Residential Gas-Fired Furnaces (North)

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North) V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)[1]	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	90	95	99	95	99	95	99	95	99
Electric Consumption (kWh/y)[2]	374	374	386	636	631	725	631	725	631	725	631	725
Average Life (y)[3]	17	17	17	17	17	17	17	17	17	17	17	17
	26	26	26	26	26	26	26	26	26	26	26	26
Retail Equipment Cost (2022$)	1,300	1,300	1,080	1,200	1,220	1,390	1,220	1,390	1,220	1,390	1,220	1,390
Total Installed Cost (2022$)	2,880	2,880	3,690	4,130	4,150	4,320	4,150	4,320	4,150	4,320	4,150	4,320
Annual Maintenance Cost (2022$)	60	60	120	130	130	130	130	130	130	130	130	130

1. Typical input capacity is represented in terms of thousand British thermal units (kBtu) per hour (i.e., kBtu/h).
2. Electric consumption, represented in terms of kilowatt hours per year (kWh/y), accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
3. In the Residential Furnaces EERE 2022 Notice of Proposed Rulemaking (NOPR) Technical Support Document (TSD), an average lifetime of 22.5 years is calculated for gas-fired furnaces (North). Lifetime range was calculated using the Weibull Distribution in the Residential Furnaces EERE 2022 NOPR.

Note:
Models on the market can be either weatherized or non-weatherized. The majority (74%) are non-weatherized, and the values in the table use only non-weatherized data.
Electric consumption and cost values for 2022 and beyond are for a national sample and use the Residential Furnaces EERE 2022 NOPR Life-Cycle-Cost (LCC) spreadsheet.
Electric consumption and costs for the 2030, 2040, and 2050 high values are estimated based on the maximum-efficiency level analyzed in Residential Furnaces EERE 2022 NOPR, which is 98% annual fuel utilization efficiency (AFUE).
The current standard went into effect in November 2015.
ENERGY STAR V. 4.1 went into effect in February 2013.
The range for average life represents the span of typical values.

Residential Gas-Fired Furnaces (Rest of Country)

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (ROC) V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	90	90	99	95	99	95	99	95	99
Electric Consumption (kWh/y)[1]	279	279	386	636	636	725	631	725	631	725	631	725
Average Life (y)[2]	16	16	16	16	16	16	16	16	16	16	16	16
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	1,260	1,260	1,080	1,200	1,200	1,390	1,220	1,390	1,220	1,390	1,220	1,390
Total Installed Cost (2022$)	2,380	2,380	3,690	4,130	4,130	4,320	4,150	4,320	4,150	4,320	4,150	4,320
Annual Maintenance Cost (2022$)	40	40	120	130	130	130	130	130	130	130	130	130

1. Electric consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
2. In the Residential Furnaces EERE 2022 NOPR, an average lifetime of 21.5 years is calculated for gas-fired furnaces (Rest of Country). Lifetime range was calculated using the Weibull Distribution in the Residential Furnaces EERE 2022 NOPR.

Note:
Models on the market can be either weatherized or non-weatherized. The majority (74%) are non-weatherized, and the values in the table use only non-weatherized data.
Electric consumption and cost values for 2022 and beyond are for a national sample and use the Residential Furnaces EERE 2022 NOPR LCC spreadsheet.
Electric consumption and costs for the 2030, 2040, and 2050 high values are estimated based on the maximum-efficiency level analyzed in Residential Furnaces EERE 2022 NOPR, which is 98% AFUE.
The current standard went into effect in November 2015.
ENERGY STAR V. 4.1 went into effect in February 2013.
The range for average life represents the span of typical values.

Residential Gas-Fired Furnaces

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- Current Federal standards for non-weatherized gas furnaces:
  - AFUE ≥ 80%
- ENERGY STAR V. 4.1 criteria for gas furnaces:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
  - Furnaces must be equipped with electronically commutated fan motor and have less than or equal to 2.0% air leakage
- Most efficient unit currently available: 99.0% AFUE. The current market is nearly evenly split between non-condensing units (AFUE≤82%) and condensing units (AFUE≥90%).
- The maximum AFUE for non-condensing gas furnaces is 82%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have high-grade stainless steel (AL 29-4C) heat exchangers.
- Many condensing furnaces are available as direct vent and sealed combustion systems, which do not use room air for combustion, but instead draw combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) fan motors or electronically commutated motors (ECMs). The type of motor affects the electrical consumption of the furnace as well as the seasonal energy efficiency ratio (SEER) / energy efficiency ratio (EER) of the associated air conditioner.
  - The 2016 Energy Conservation Standards for Residential Furnace Fans Final Rule requires that all furnaces use ECM fans.
  - Most non-weatherized gas furnaces employ ECMs and can fully modulate rather than cycling on and off. Because they modulate, there is an increase in total fan-on time.

Residential Gas-Fired Furnaces

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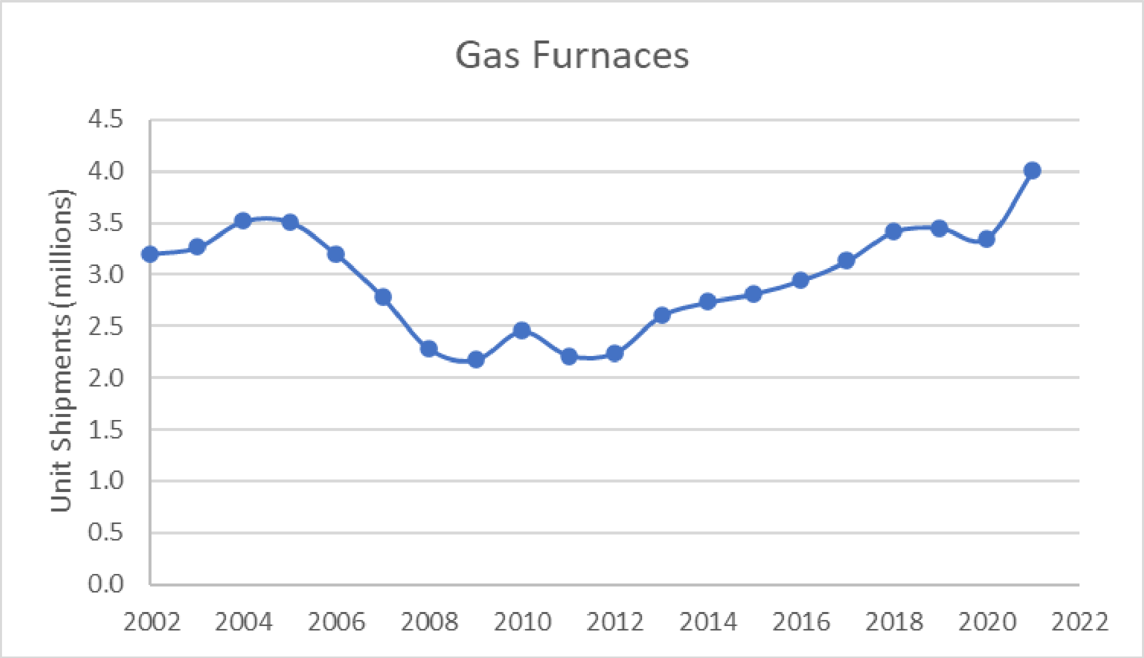
Annual shipments reached 3.5 million units in 2005 and then declined each year until 2009, leveling off at about 2.25 million units. Since 2012, shipments have increased steadily and reached a peak of 4.0 million units in 2021.



Source: *Air-Conditioning, Heating, and Refrigeration Institute (AHRI)*

Residential Oil-Fired Furnaces

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	83	83	83	85	85	97	85	97	85	97	85	97
Electric Consumption (kWh/y)[1]	477	477	477	466	466	410	466	410	466	410	466	410
Average Life (y)[2]	20	20	20	20	20	20	20	20	20	20	20	20
	33	33	33	33	33	33	33	33	33	33	33	33
Retail Equipment Cost (2022$)	2,620	2,620	2,620	2,650	2,650	3,170	2,650	3,170	2,650	3,170	2,650	3,170
	3,450	3,450	3,450	3,490	3,490	4,090	3,490	4,090	3,490	4,090	3,490	4,090
Total Installed Cost (2022$)	3,250	3,250	3,250	3,480	3,480	5,140	3,480	5,140	3,480	5,140	3,480	5,140
	6,520	6,520	6,520	6,820	6,820	10,110	6,820	10,110	6,820	10,110	6,820	10,110
Annual Maintenance Cost (2022$)	80	80	80	80	80	240	80	240	80	240	80	240

1. Electric consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
2. Lifetime range was calculated using the Weibull Distribution in Residential Furnaces EERE 2011.

Note:
The current standard went into effect in May 2013.
ENERGY STAR V. 4.1 went into effect in February 2013.
Ranges represent the span of typical values for a given parameter.

Residential Oil-Fired Furnaces

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- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR V. 4.1 criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient unit currently available: 96.7% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these secondary heat exchangers use a high-grade stainless steel (AL 29-4C).
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, condensing oil furnaces typically require frequent cleaning and maintenance.

Residential Oil-Fired Furnaces

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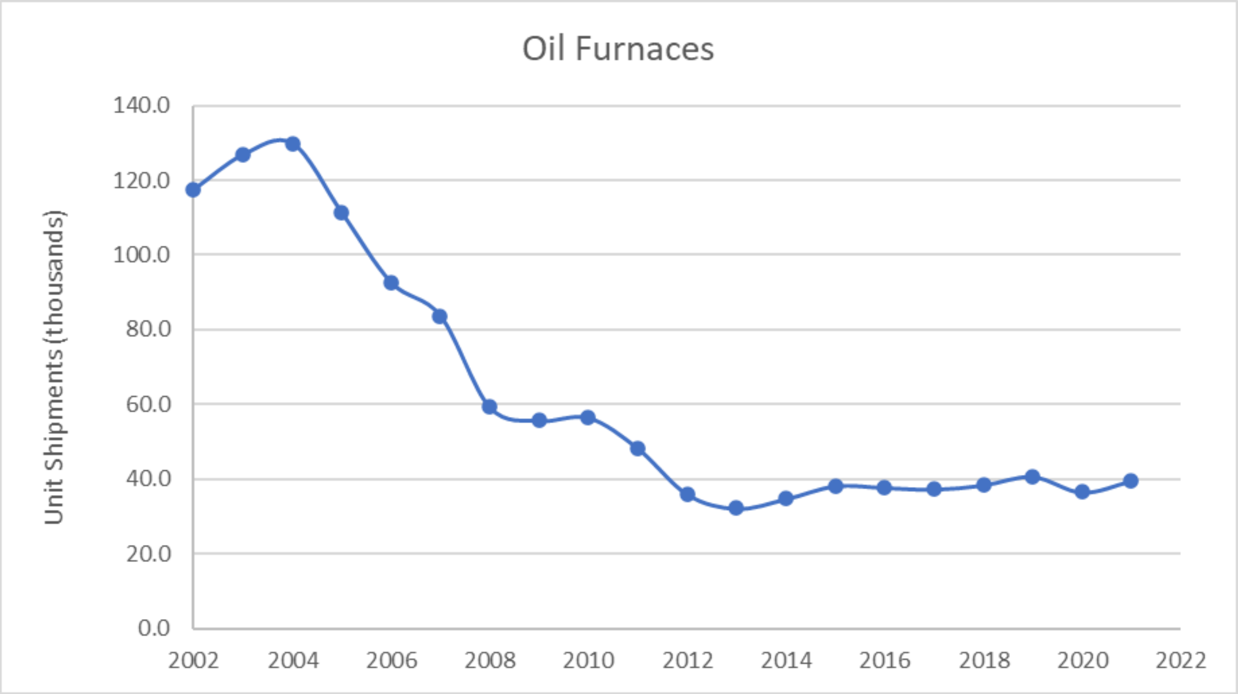
Annual shipments declined rapidly after 2004, likely due, at least in part, to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely leveled off.



Source: *AHRI*

Residential Gas-Fired Boilers

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DATA	2015	2020[1]	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	100	100	100	100	100	100	100	100	100	100	100	100
AFUE (%)	82	95	84	95	90	96	95	96	95	96	95	96
Electric Consumption (kWh/y)[3]	197	506	282	506	527	502	506	502	506	502	506	502
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)	2,540	2,890	1,820	2,890	2,440	3,670	2,890	3,670	2,890	3,670	2,890	3,670
Total Installed Cost (2022$)	7,760	5,940	8,700	5,940	6,700	6,710	5,940	6,710	5,940	6,710	5,940	6,710
Annual Maintenance Cost (2022$)[4]	110	160	150	160	160	160	160	160	160	160	160	160

1. The 2020 AFUE is estimated based on EERE 2022 preliminary analysis, which estimates that gas-fired boilers with the highest market share in 2020 have an AFUE of 95%.
2. The 2030, 2040, 2050 projections are estimated based on the EERE 2022 preliminary analysis, which notes that majority of the market is expected to be condensing, if new standards are not implemented. The EERE 2022 preliminary analysis estimates a minimum efficiency of 95% AFUE for condensing units.
3. Electric Consumption accounts for the electricity consumption of auxiliary electrical components including circulating pump, the boiler pump (condensing boilers only), the draft inducer (if present), and the ignitor. It also accounts for the electricity consumption of auxiliary equipment such as a condensate pump and heat tape, which are sometimes installed with higher efficiency boilers. Additionally, it accounts for the additional cooling load due to heat loss from the boiler and water heater as a result of water heating during the cooling season.
4. Maintenance cost is the routine annual cost to the consumer of general maintenance for product operation. Maintenance cost is higher for condensing boilers for the inspection of condensate system and replacement of condensate neutralizer filter.

Note:
The current standard went into effect in January 2021.
ENERGY STAR V. 3.0 went into effect in December 2013.
Water boilers considered. Steam boilers also exist but make up a small percentage of the market.
The range for average life represents the span of typical values.

Residential Gas-Fired Boilers

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- Federal standard for gas-fired hot-water boilers (more common than steam):
  - AFUE ≥ 84%
  - Standard went into effect on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 90%
- Most efficient gas-fired boiler available: 96.4% AFUE
- Gas-fired boilers have lost market share to furnaces and heat pumps over the past 30 years.
- U.S. gas hot water boiler sales are split approximately 60/40 between condensing and non-condensing.[1] Condensing boilers typically have heat exchangers made of stainless steel, and non-condensing boilers typically have heat exchangers made of cast iron.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems or sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (e.g., heat exchanger, gas valve, burner, sensors, and/or controls).

Source: EERE 2022 Preliminary Analysis TSD, Chapter 3

Residential Gas-Fired Boilers

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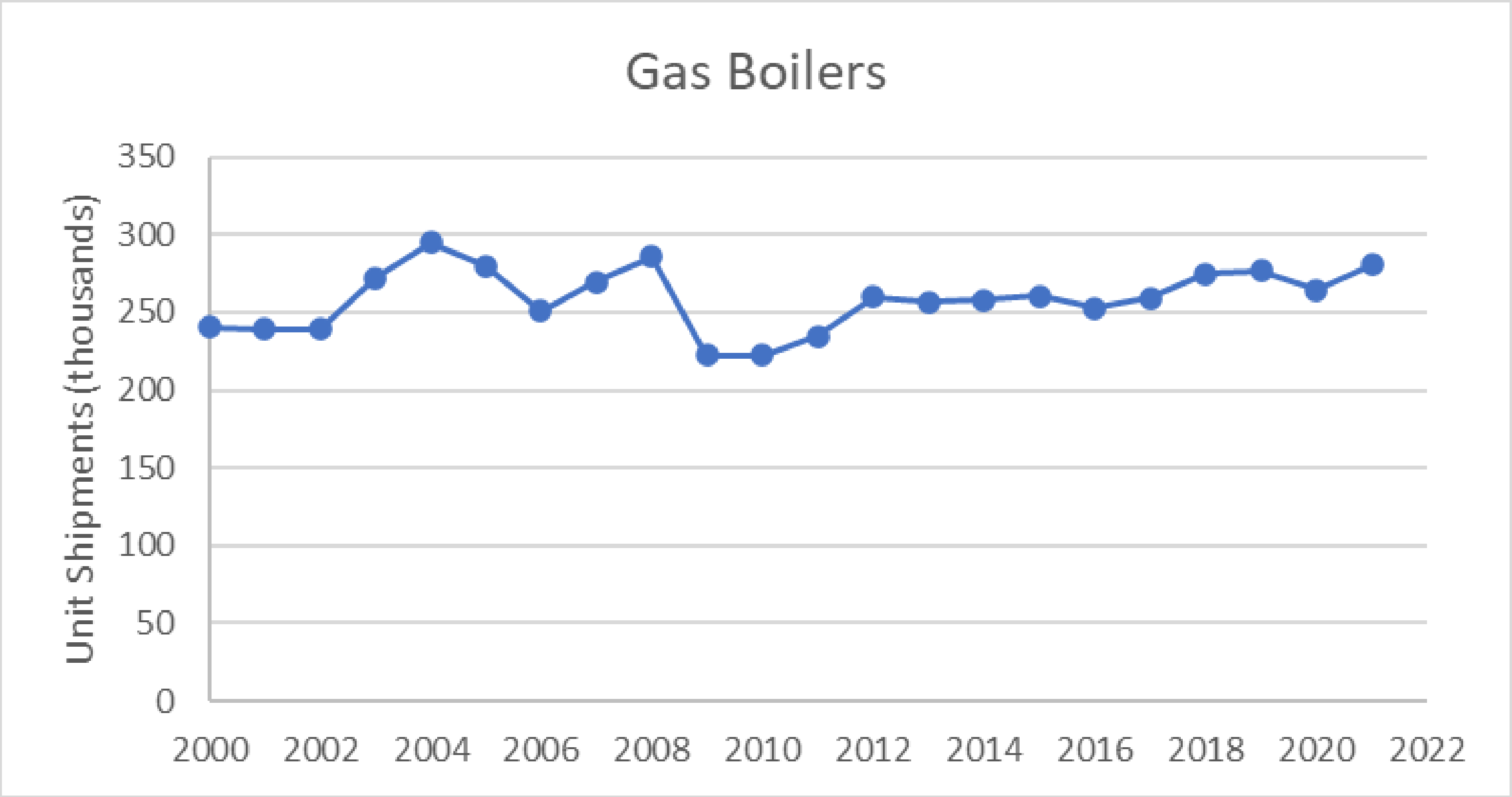
Annual shipments had a significant decrease following the 2009 financial crisis and a steady recovery in the years since.



Source: *Boilers EERE 2022 Preliminary Analysis*

Residential Oil-Fired Boilers

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DATA	2015	2020[1]	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	84	86	86	86	87	88	86	88	86	88	86	88
Electric Consumption (kWh/y)[3]	230	310	310	310	307	305	310	305	310	305	310	305
Average Life (y)[4]	18	18	18	18	18	18	18	18	18	18	18	18
	28	28	28	28	28	28	28	28	28	28	28	28
Retail Equipment Cost (2022$)	4,850	3,590	3,590	3,590	3,680	3,770	3,590	3,770	3,590	3,770	3,590	3,770
Total Installed Cost (2022$)	9,800	5,510	5,510	5,510	5,600	5,690	5,510	5,690	5,510	5,690	5,510	5,690
Annual Maintenance Cost (2022$)[4]	160	170	170	170	170	170	170	170	170	170	170	170

1. The 2020 AFUE is estimated based on EERE 2022 preliminary analysis, which estimates that oil-fired boilers with the highest market share in 2020 have an AFUE of 86%.
2. The 2030, 2040, 2050 projections are estimated based on the EERE 2022 preliminary analysis, which notes that majority of the market is expected to be at 86% AFUE, if new standards are not implemented.
3. Electric Consumption accounts for the electricity consumption of auxiliary electrical components including circulating pump, the ignitor, condensate pump, and heat tape, which are sometimes installed with higher efficiency boilers. Additionally, it accounts for the additional cooling load due to heat loss from the boiler and water heater as a result of water heating during the cooling season.
4. Maintenance cost is the routine annual cost to the consumer of general maintenance for product operation.

Note:

The current standard went into effect in January 2021.

ENERGY STAR V. 3.0 went into effect in December 2013.

Water boilers considered. Steam boilers also exist but make up a small percentage of the market.

The range for average life represents the span of typical values.

Residential Oil-Fired Boilers

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- Federal standard for oil-fired hot-water boilers (more common than steam):
  - AFUE ≥ 86%
  - Standard went into effect on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 87%
- Most efficient oil-fired boiler available: 88% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers made of cast iron or steel.
- No condensing oil-fired boilers currently exist in the U.S. market. The high sulfur content in fuel-oil causes heat exchanger fouling if the flue gases from an oil-fired boiler were to condense. As a result, condensing oil-fired boilers would require more frequent maintenance and repair, if installed.

Residential Oil-Fired Boilers

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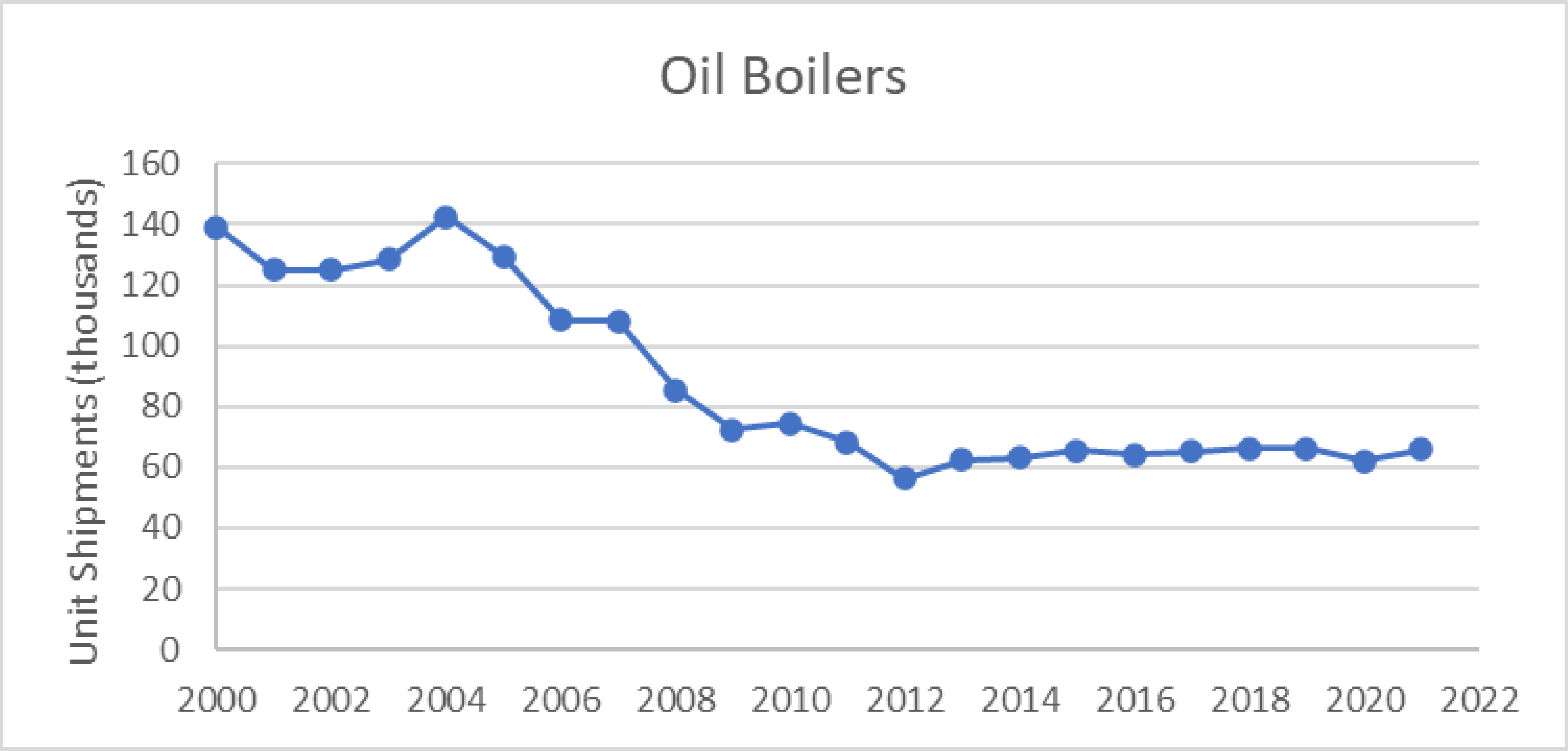
Annual shipments declined rapidly after 2004, likely due, at least in part, to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely leveled off.



Source: *Boilers EERE 2022 Preliminary Analysis*

Residential Electric Resistance Furnaces

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DATA	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	68	68	68	68	68	68	68
AFUE (%)	98	98	100	100	100	100	100
Average Life (y)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)[1]	760	760	950	950	950	950	950
Total Installed Cost (2022$)[1]	1,290	1,290	1,480	1,480	1.480	1,480	1,480
Annual Maintenance Cost (2022$)[1]	50	50	50	50	50	50	50

1. Costs for a 100% AFUE unit are assumed to be equal to the costs of a 98% AFUE unit.

Note:
The current standard went into effect in January 1992.
The range for average life represents the span of typical values.

Residential Electric Resistance Furnaces

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- Federal standards for electric furnaces:
  - AFUE ≥ 78%
  - Standby and off mode power consumption ≤ 10 watts
- According to preliminary Residential Energy Consumption Survey (RECS) data released May 2022, electric central warm-air furnaces are the main source of space heating in approximately 17.5 million U.S. homes or about 14%.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/h), with 20 kW (68 kBtu/h) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss, and any jacket losses are contained within the home.
  - ASHRAE Standard 103, the test method for furnaces incorporated by reference into the federal test procedure, specifies that for electric furnaces AFUE = 100 – 1.7 x jacket losses. Jacket losses can be determined either through testing or assumed to be 1%. Thus, the minimum AFUE of electric furnaces is 98.3%.

Residential Electric Resistance Unit Heaters

DATA	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	3.5	3.5	5.1	5.1	5.1	5.1
Efficiency (%)	100	100	100	100	100	100
Average Life (y)[1]	15	15	15	15	15	15
	30	30	30	30	30	30
Retail Equipment Cost (2022$)[2]	90	90	85	85	85	85
	240	240	340	340	340	340
Total Installed Cost (2022$)[3]	150	150	390	390	390	390
	320	320	1,190	1,190	1,190	1,190
Annual Maintenance Cost (2022$)[4]	-	-	-	-	-	-

1. Assumes similar lifetime to Electric Furnaces on the basis that both products have heating elements that burn out and lead to product failure.
2. The lower bound of the equipment costs represents the average retail price listed at the typical capacity for electric baseboard heaters through a retailer website. The upper bound represents the average retail price for compact recessed electric wall heaters at the same capacity.
3. Range represents the estimated minimum and maximum installation costs.
4. Maintenance costs are negligible.

Residential Electric Resistance Unit Heaters

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- Electric resistance unit heaters include electric wall and baseboard heaters. Plug-in space heaters are not included.
- There are currently no federal efficiency requirements for electric resistance unit heaters.
- According to preliminary RECS data released May 2022, electric resistance unit heaters are the main source of space heating in approximately 8.25 million U.S. homes or about 7%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/h), with 1,500 watts (5.1 kBtu/h) being the most typical for units on the market.
- Electric resistance heating is considered 100% energy efficient; all incoming electric energy is converted to heat.

Residential Central Air Conditioners – North (Not Hot-Dry or Hot-Humid)

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DATA	2015	2020	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER[1]	12.5	13.9	13.0	14.1	15.0	17.0	14.1	16.0	17.0	14.4	17.0	14.4	17.0	14.4	17.0
SEER2[2]	11.9	13.2	NA	13.4	NA	16.2	13.4	15.2	16.2	13.7	16.2	13.7	16.2	13.7	16.2
Average Life (y)	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	2,410	2,670	2,580	2,700	3,110	3,950	2,680	3,750	3,950	2,760	3,950	2,760	3,950	2,760	3,950
Total Installed Cost (2022$)	4,000	4,300	5,250	5,320	5,520	5,980	5,310	5,880	5,980	5,350	5,980	5,350	5,980	5,350	5,980
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for residential air-source heat pumps, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify a different metric for central air conditioners (SEER2). SEER to SEER2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.

Note:
The previous standard went into effect in January 2015. The current standard went into effect in January 2023.
ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.
Ranges represent the span of typical values for a given parameter.

Residential Central Air Conditioners – South (Hot-Dry and Hot-Humid)

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DATA	2015	2020	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER[1]	13.0	14.4	14.0	14.6	15.0	17.0	15.1	16.0	17.0	15.1	17.0	15.1	17.0	15.1	17.0
SEER2[2]	12.4	13.7	NA	13.9	NA	16.2	14.3	15.2	16.2	14.3	16.2	14.3	16.2	14.3	16.2
Average Life (y)	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	2,410	2,760	2,680	2,850	3,110	3,950	3,110	3,750	3,950	3,190	3,950	3,190	3,950	3,190	3,950
Total Installed Cost (2022$)	4,000	4,390	5,310	5,390	5,520	5,980	5,520	5,880	5,980	5,570	5,980	5,570	5,980	5,570	5,980
Annual Maintenance Cost (2022$)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for residential air-source heat pumps, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify a different metric for central air conditioners (SEER2). SEER to SEER2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.

Note:
The previous standard went into effect in January 2015. The current standard went into effect in January 2023.
ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.
Ranges represent the span of typical values for a given parameter.

Residential Central Air Conditioners

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- The previous standards took effect in 2015; amended standards for all product classes went into effect in January 2023.
  - Amended standards are based on new metrics (SEER2, EER2).
  - SEER2 values are generally expected to be lower than SEER because a higher external static pressure is required during testing, which reduces measured performance.
- Systems installed in the Southwest (CA, AZ, NM, and NV) must also meet an EER standard that varies by cooling capacity and system configuration.

Residential Central Air Conditioners

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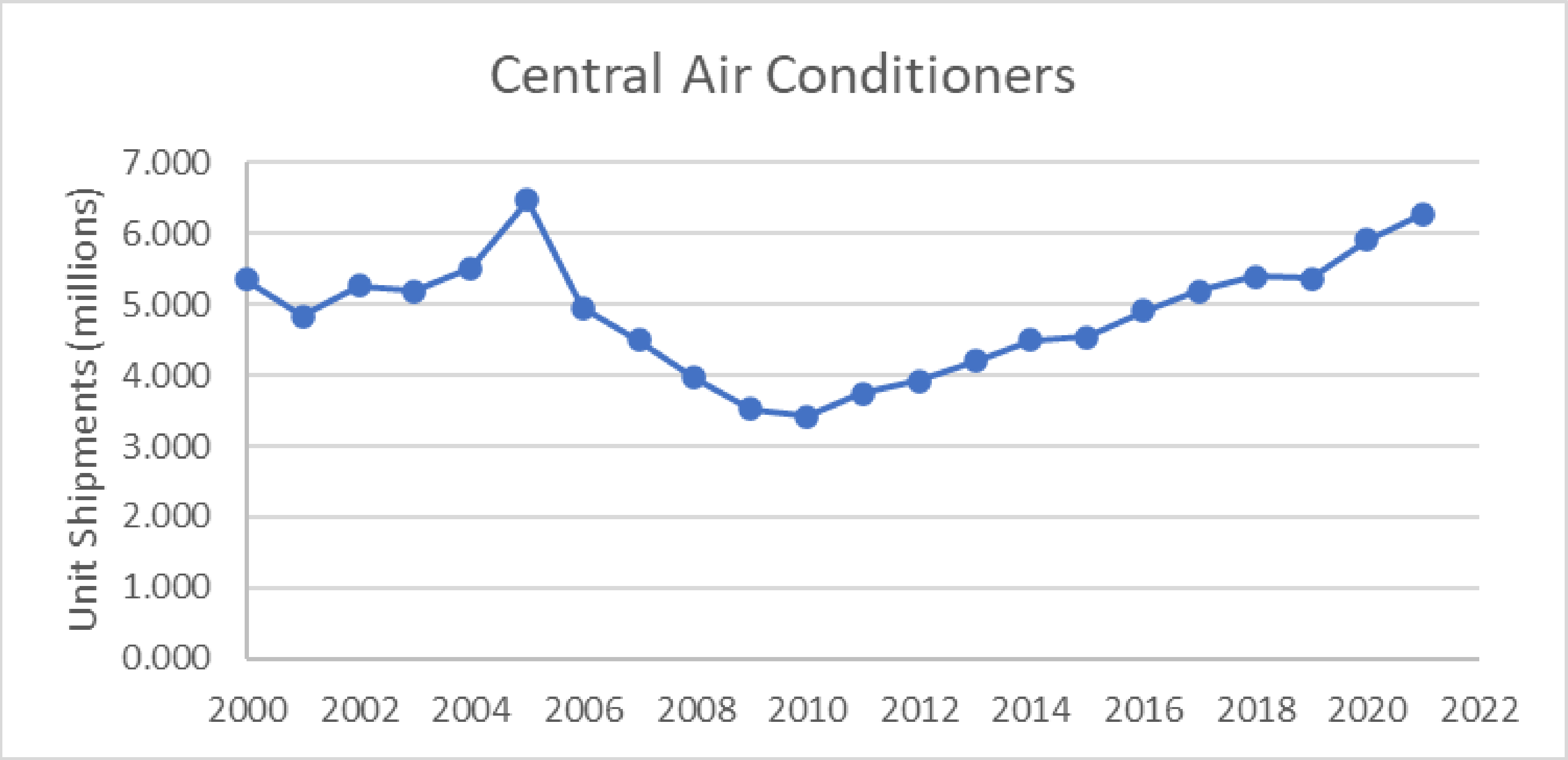
Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006. Annual shipments have been steadily increasing since 2010 and have almost reached the previous high in 2021.



Source: *AHRI*

Residential Room Air Conditioners

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DATA	2015	2020	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.2	High[1]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	10	10	10	10	10	10	10	10	10	10	10.0	10.0
CEER (Btu/Wh)	10.9	10.9	10.9	12.0	12.0	15.7	12.0	15.7	12.0	15.7	12.0	15.7
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2022$)	560	330	330	340	340	450	340	450	340	450	340	450
	710	480	480	480	480	590	480	590	480	590	480	590
Total Installed Cost (2022$)	640	490	490	490	490	600	490	600	490	600	490	600
	830	630	630	640	640	750	640	750	640	750	640	750
Annual Maintenance Cost (2022$)[3]	0	0	0	0	0	0	0	0	0	0	0	0

1. RAC EERE 2022 NOPR has analysis for combined energy efficiency ratio (CEER) of 16 Btu/Wh, which represents variable speed room air conditioners. However, maximum CEER identified in DOE's Compliance Certification Database (CCD) in August 2022 was 15.7 Btu/Wh. Accordingly, the high CEER is estimated to be 15.7 for 2022 and beyond. Cost values for a representative unit with a CEER of 16 Btu/Wh were used.
2. The 2030, 2040, 2050 projections are estimated based on RAC EERE 2022 NOPR, which notes that in the absence of no new standards, room air conditioners with a CEER of 12 Btu/Wh are expected to have the maximum market share.
3. Maintenance costs are negligible per RAC EERE 2011 and RAC EERE 2022 NOPR.

Note:
All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
The current standard went into effect in June 2014.
ENERGY STAR V. 4.2 went into effect in October 2015.
Ranges represent the span of typical values for a given parameter (for example, installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

Residential Room Air Conditioners

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- Analyzed the most common type of room air conditioners: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - CEER ≥ 10.9 (beginning June 1, 2014)
- CEER incorporates energy use in cooling mode and standby and off modes.
- ENERGY STAR V. 4.2 criteria for Product Class 3:
  - CEER ≥ 12.0 (effective October 26, 2015)
- Efficiency improvements in room air conditioners are attained by:
  - Higher efficiency compressor and fan motors (including variable speed motors), and
  - An increased heat transfer area in the evaporator and condenser using larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

Residential Room Air Conditioners

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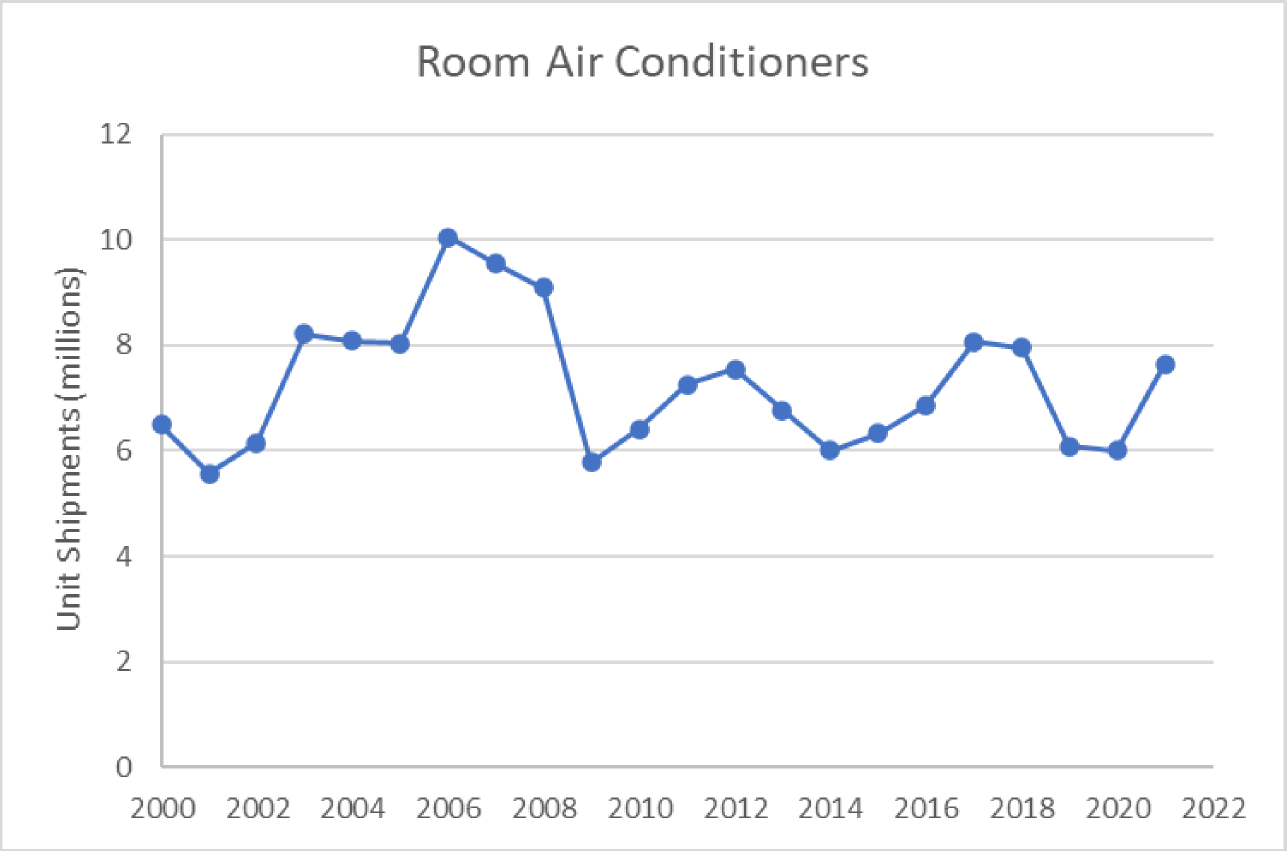
Annual shipments dropped sharply in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have largely leveled off in the years since, fluctuating between 6 and 8 million.



Source: *RAC EERE 2022 NOPR*

Residential Portable Air Conditioners

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DATA	2015	2020	2022[4]		2025		2030		2040		2050	
	Installed Base	Installed Base	Typical	High[5]	New Standard	High[5]	Typical	High[5]	Typical	High[5]	Typical	High[5]
Typical Capacity (kBtu/h)[1]	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
CEER[2]	5.6	5.6	5.5	7.6	6.7	7.6	6.7	7.6	6.7	7.6	6.7	7.6
Average Life (y)	7	7	7	7	7	7	7	7	7	7	7	7
	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	700	700	700	810	760	810	760	810	760	810	760	810
Total Installed Cost (2022$)[3]	700	700	700	810	760	810	760	810	760	810	760	810
Annual Maintenance Cost (2022$)[3]	0	0	0	0	0	0	0	0	0	0	0	0

1. All values are for the average capacity for single-duct and dual-duct portable air conditioners available on the market.
2. CEER is calculated for typical capacity using the equation provided in PAC EERE 2020.
3. Installation and maintenance costs are negligible.
4. The 2022 Typical estimates are based on PAC EERE 2020, which estimated majority of the market to be at EL1 in 2022 for the no-new standards case, which translates to a CEER of 5.5 for this analysis.
5. All High values are based on the most-efficient models available in the market, as specified in PAC EERE 2020.

Note:
A final rule for portable air cleaners published in January 2020 with an effective date of January 2025.
Costs are interpolated from the costs presented in PAC EERE 2020.
Range for lifetime represents typical values.

Residential Portable Air Conditioners

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- A final rule establishing new energy conservation standards for portable air conditioners published in January 2020 with an effective date of January 2025.
- The final rule outlined an equation-based conservation standard (in CEER) for both single-duct and dual-duct portable ACs, based on the seasonally adjusted cooling capacity (SACC)

$$\text{Minimum CEER} = \text{PR} \times \frac{\text{SACC}}{(3.7117 \times \text{SACC}^{0.6384})}$$

- Efficiency improvements in portable air conditioners are attained by:
  - Higher efficiency compressor and fan motors (including variable speed motors), and
  - An increased heat transfer area in the evaporator and condenser using larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

Residential Portable Air Conditioners

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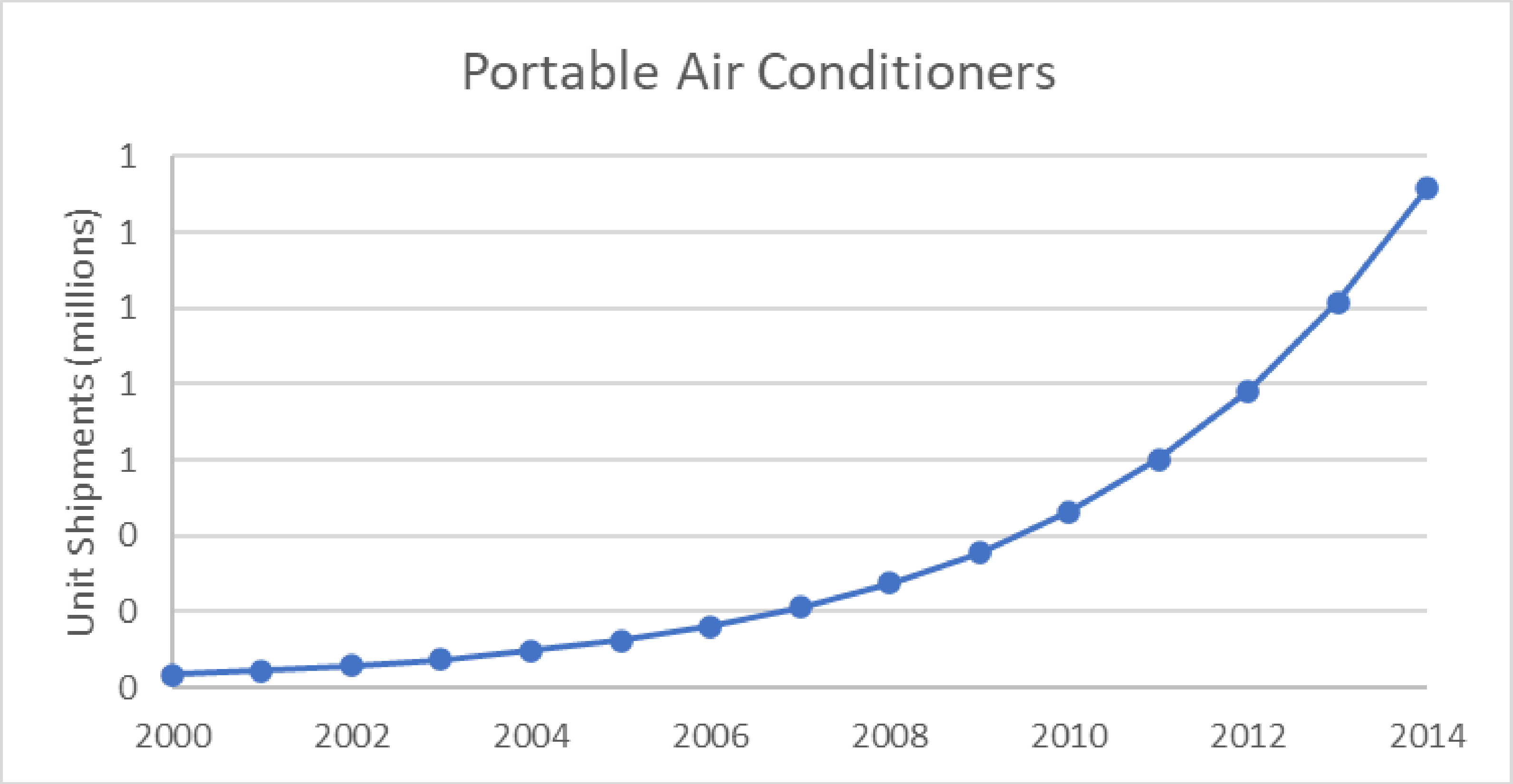
Annual shipments have seen an exponential growth through 2014. Shipments data since 2014 is not publicly available but it is expected that portable air conditioners shipments may have increased in recent years in response to indoor air quality concerns following COVID-19.



Source: *PAC EERE 2020*

Residential Swamp Coolers

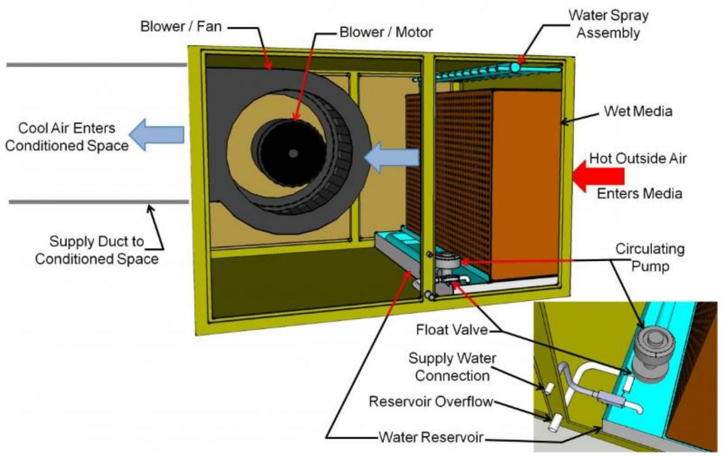
DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Air Flow Rate (CFM)	3,800	3,800	3,800	4,700	3,800	4,700	3,800	4,700	3,800	4,700
Power (Hp)	1/3	1/3	1/3	1/2	1/3	1/2	1/3	1/2	1/3	1/2
Average Life (y)[1]	10	10	10	10	10	10	10	10	10	10
	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	960	960	960	1,100	960	1,100	960	1,100	960	1,100
Total Installed Cost (2022$)	1,360	1,360	1,360	1,540	1,360	1,540	1,360	1,540	1,360	1,540
Annual Maintenance Cost (2022$)	330	330	330	330	330	330	330	330	330	330

1. Average lifetime provided by major swamp cooler installer in the U.S. Southwest.

Note:
Efficiency values were determined based on a sample of window-mounted swamp coolers.
Lifetime range represents span of typical values.

Residential Swamp Coolers

- Evaporative cooling (i.e., "swamp coolers") is a technology that takes advantage of water evaporation to cool incoming air. Energy is required to change water from a liquid to a vapor (i.e., the heat of vaporization), and in doing so, temperature of the air is reduced. Evaporative cooling is best suited for hot, dry climates.
- Swamp coolers come in a variety of different configurations, including centrally ducted units that are mounted outside a building or roof; window evaporative coolers that are window-mount units that pull in warm outdoor air, pass it through wet media to remove heat, and blow out the cooled air; or portable plug-in units. Window units were considered for this analysis due to the high model share count on distributor websites.
- The U.S. Environmental Protection Agency (EPA) has cautioned against using swamp coolers in wildfire-impacted areas in smoky conditions because it can result in more smoke bring brought inside.
- Swamp coolers are not a DOE-covered product.
- Swamp cooler metrics include power of the fan/blower, measured in horsepower (hp), and air flow rate, measured in cubic feet per minute (CFM).



Single-inlet direct swamp cooler. Source: PNNL

Residential Air-Source Heat Pumps

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DATA	2015	2020	2022				2023				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	ENERGY STAR Cold Climate Criteria	High[4]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)[1]	13.1	15.3	14.0	15.3	15.0	22.6	15.0	16.0	NA	22.6	16.0	22.6	16.5	22.6	17.0	22.6
SEER2[2]	12.4	14.5	NA	14.5	NA	21.5	14.3	15.2	15.2	21.5	15.2	21.5	15.7	21.5	16.2	21.5
HSPF (Heating)[1]	7.9	8.6	8.2	8.6	8.5	12.4	8.8	9.2	NA	12.4	9.2	12.4	9.3	12.4	9.3	12.4
HSPF2[2]	6.7	7.3	NA	7.3	NA	10.6	7.5	7.8	8.1	10.6	7.8	10.6	7.9	10.6	7.9	10.6
Average Life (y)	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Retail Equipment Cost (2022$)[1]	3,290	4,270	3,970	4,270	4,110	6,740	4,110	4,380	4,380	6,740	4,380	6,740	5,000	6,740	5,100	6,740
Total Installed Cost (2022$)[1]	5,790	6,880	6,730	6,880	6,810	8,620	6,810	6,940	6,940	8,620	6,940	8,620	7,240	8,620	7,330	8,620
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "blower-coil" systems, meaning they include a blower. Note coil-only systems were analyzed for residential central air conditioners, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify different metrics for Air-Source Heat Pumps (SEER2 and heating seasonal performance factor 2 (HSPF2)). SEER to SEER2 and HSPF to HSPF2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.
4. High costs derived from developing a cost-efficiency curve between retail/installed costs and SEER.

Note:

The previous standard went into effect in January 2015. The current standard went into effect in January 2023.

ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.

Ranges represent the span of typical values for maintenance costs.

Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.88, 2, 1).

Residential Air-Source Heat Pumps

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- The previous standards took effect in 2015; amended standards for all product classes went into effect in January 2023.
  - Amended standards are based on new metrics (SEER2, EER2, HSPF2).
  - SEER2 values are generally expected to be lower than SEER because a higher external static pressure is required during testing, which reduces measured performance.
- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- Variable-speed compressors improve efficiency of heat pumps by reducing cyclic losses and by operating above their nominal speed, boosting heating capacity, and reducing the need for supplementary electric resistance heat.
- In addition to meeting the SEER2 and HSPF2 requirements, air source heat pumps must demonstrate low ambient performance to earn the Cold Climate designation by meeting the following:
  - Coefficient of Performance (COP) at 5 degrees Fahrenheit (°F) ≥ 1.75, measured in accordance with Appendix M1 $H4_2$ test
  - Percent of Heating Capacity at 5 °F ≥ 70% of that at 47 °F, with the 5 °F capacity measured per Appendix M1 $H4_2$ test and the 47 °F capacity measured as the nominal heating capacity per Appendix M1 (i.e., from the Appendix M1 $H1_N$ test for units having a variable-speed compressor where the compressor speed shall be the maximum speed that the system controls would operate at 47 °F, otherwise from the Appendix M1 $H1_2$ test)
  - Perform a controls verification procedure (CVP) to confirm that the above performance metrics measured at the Appendix M1 low ambient test point at 5 °F are achieved by the native controls operating as they would in a customer’s home

Residential Air-Source Heat Pumps

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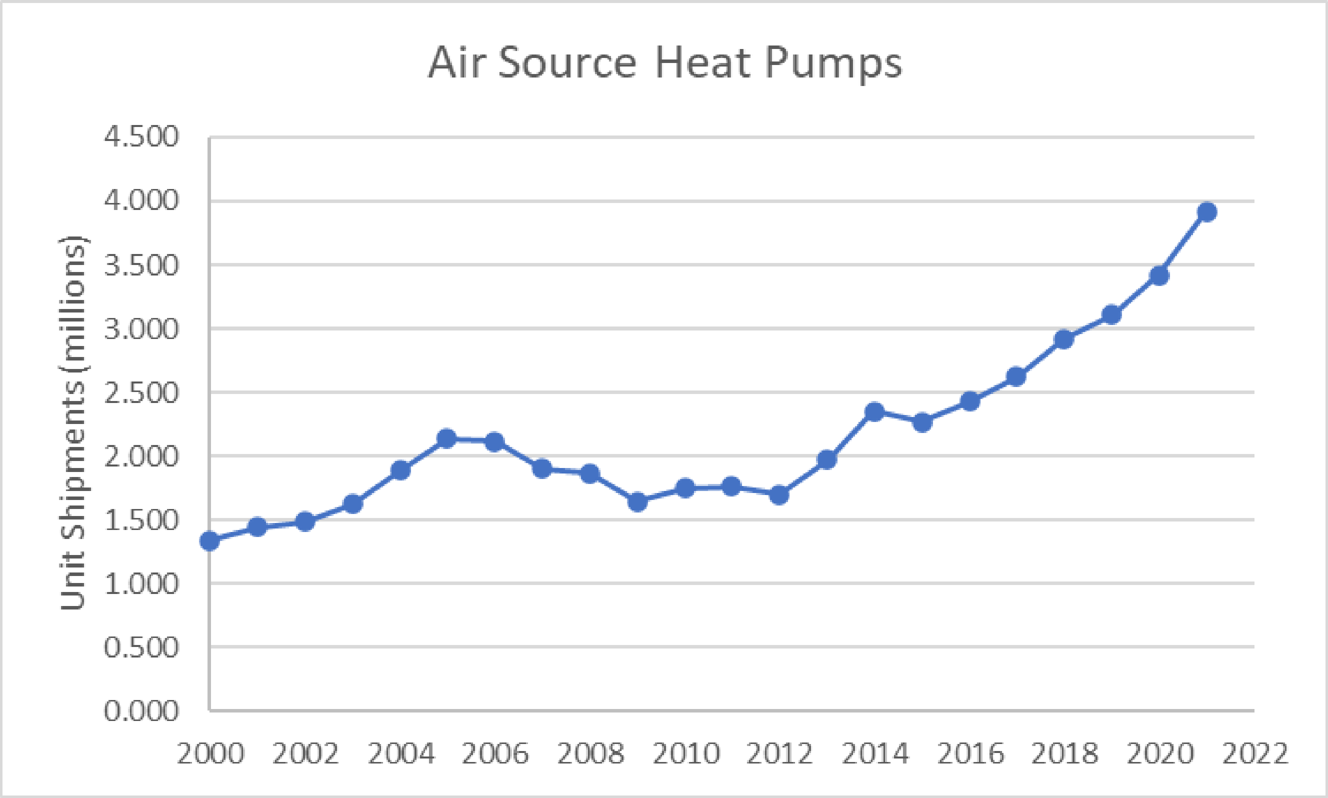
From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units. In 2014 annual shipments surpassed the 2005 peak and have been increasing uniformly since then.



Source: *AHRI*

Residential Central Air Conditioners and Air-Source Heat Pumps

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- Principal energy efficiency drivers for central air conditioners and heat pumps:
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- When the heat pump or air conditioner's capacity exceeds the heating or cooling load, the unit starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.
- Typical high-efficiency unit (≥ 16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller heat exchangers, and thus, smaller enclosures.
- Efficiency levels > 21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

Residential Ductless Mini-Split Air-Source Heat Pumps

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DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)[1]	12	12	12	12	12	12	12	12	12	12
SEER	16.0	16.0	21.9	33.1	21.9	33.1	21.9	33.1	21.9	33.1
EER	12.5	12.5	13.0	19.1	13.0	19.1	13.0	19.1	13.0	19.1
HSPF	10.0	10.0	11.1	14.0	11.1	14.0	11.1	14.0	11.1	14.0
Average Life (y)[2]	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Retail Equipment Cost (2022$)	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580
Total Installed Cost (2022$)	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030
Annual Maintenance Cost (2022$)[3]	100	100	100	100	100	100	100	100	100	100

1. Representative capacity determined from most frequent capacity in AHRI database
2. Assumed same lifespan and maintenance cost as air-source heat pumps given the technology is similar between air-source and ductless mini-split heat pumps, and ductwork itself is not expected to fail.
3. Annual maintenance covers the same services identified for air-source heat pumps.

Note:
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.88, 2, 1).

Residential Ductless Mini-Split Air-Source Heat Pumps

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- Ductless systems can be useful in "spot cooling" certain high-use areas of a home, such as a living room, bedroom, or office.
- Mini-split heat pumps are generally more efficient (often > 20 SEER) and smaller in cooling capacity (often ≤ 24 kBtu/h) compared to split-system heat pumps.
  - A mini-split heat pump could be equal in capacity and efficiency to a split-system heat pump as there are no inherent design changes between split-system and mini-split heat pumps, aside from the ductwork. Mini-split heat pumps tend to be more efficient and smaller in capacity due to their prevalence for spot cooling, but the same technologies are used between the two product categories.
- Due to the similarities in design, cost estimations were determined based on smaller capacity (24 kBtu/h) split-system heat pumps and Gordian's RSMeans Data – Building Construction Costs 2023. Efficiency data was analyzed using the AHRI directory, which provides disaggregation of data on the basis of ducted and ductless heat pumps.
- Annual maintenance covers the same services identified for air-source heat pumps.

Residential Ground-Source Heat Pumps

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.2	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)[1]	3.1	3.7	3.2	3.6	3.6	4.5	3.6	4.5	3.6	4.5	3.6	4.5
EER (Cooling)[2]	13.3	17.3	14.1	17.3	17.1	22.0	17.3	22.0	17.3	22.0	17.3	22.0
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	4,650	5,470	4,820	5,470	5,410	6,530	5,470	6,530	5,470	6,530	5,470	6,530
Total Installed Cost (2022$)	14,060	14,880	14,230	14,880	14,880	15,940	14,880	15,940	14,880	15,940	14,880	15,940
	22,290	23,120	22,470	23,120	23,120	24,170	23,120	24,170	23,120	24,170	23,120	24,170
Annual Maintenance Cost (2022$)	90	90	90	90	90	90	90	90	90	90	90	90

1. COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop ground source heat pumps (GSHP) operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.
2. EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note:
Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs. 4-ton) and slightly higher installation costs for commercial GSHP. DOE does not distinguish between residential and commercial units in its regulations.
Current standards went into effect on October 9, 2015. COP and EER ratings are converted from the “water loop” test condition to “ground loop.”
ENERGY STAR V. 3.2 went into effect January 1, 2012.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay parameters: (17.04, 1.64, 1).

Residential Ground-Source Heat Pumps

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- Heating COP does not correlate with cooling EER.
- The ENERGY STAR criteria for water-to-air ground-source heat pumps are:

Type	Heating COP	Cooling EER
Closed Loop	3.6	17.1
Open Loop	4.1	21.1
Direct Expansion	3.6	16

- The most common GSHP is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed ECMs improve performance on high-end models.

Residential Natural Gas Heat Pumps

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DATA	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60	60
COP (Heating)	1.3	1.3	1.3	1.3	1.3	1.3
COP (Cooling)	0.6	0.7	0.7	0.7	0.7	0.7
Annual Electric Use (kWh/y)[1]	1,500	1,500	1,500	1,500	1,500	1,500
Average Life (y)	12	12	12	12	12	12
	18	18	18	18	18	18
Retail Equipment Cost (2022$)[2]	12,940	12,940	12,940	12,940	12,940	12,940
	14,350	14,350	14,350	14,350	14,350	14,350
Total Installed Cost (2022$)[2]	14,700	14,700	14,700	14,700	14,700	14,700
	17,290	17,290	17,290	17,290	17,290	17,290
Annual Maintenance Cost (2022$)	200	200	200	200	200	200

1. Annual electric use accounts for the electricity consumption of components such as the heat pump fan.

Note:

Ranges represent the span of typical values observed in the market.

Residential Natural Gas Heat Pumps

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- Residential natural gas heat pumps are not currently subject to DOE regulations. The California Energy Commission's (CEC) Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for natural gas heat pumps.
- Natural gas heat pumps are much more popular in other parts of the world, such as Europe. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized natural gas heat pumps with sales operations in the U.S.. Robur units are 5-ton nominal cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included in this analysis.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the U.S. It is possible to couple either technology to the ground (ground-source) rather than the atmosphere (air-source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air-source absorption heat pump is considerably lower than for an electric air-source heat pump. Heating efficiency of an air-source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however, the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

Residential Cordwood Stoves

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DATA	2015[1]	2020[2]	2022[3]		2030[4]		2040[4]		2050[4]	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)[5]	63	71	71	80	71	80	71	80	71	80
Efficiency (Catalytic) (HHV)[5]	72	76	76	81	76	81	76	81	76	81
Average Life (y)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$) (Non-Catalytic)	2,880	1,670	1,670	2,300	1,670	2,300	1,670	2,300	1,670	2,300
Retail Equipment Cost (2022$) (Catalytic)	3,540	3,040	3,040	3,830	3,040	3,830	3,040	3,830	3,040	3,830
Total Installed Cost (2022$) (Non-Catalytic)[6]	8,290	7,090	7,090	7,710	7,090	7,710	7,090	7,710	7,090	7,710
Total Installed Cost (2022$) (Catalytic)[6]	8,950	8,460	8,460	9,240	8,460	9,240	8,460	9,240	8,460	9,240
Annual Maintenance Cost (2022$) (Non-Catalytic)[7]	190	190	190	190	190	190	190	190	190	190
Annual Maintenance Cost (2022$) (Catalytic)[7]	280	280	280	280	280	280	280	280	280	280

1. For 2015, assumed EPA default efficiencies, which were used by EPA to approximate the efficiency of stoves before the 2015 EPA rule required efficiency testing.
2. For 2020, assumed same efficiencies as estimated for 2022 given the most recent EPA rule went into effect in May 2020.
3. The 2022 High value is the highest EPA certified efficiency. The 2022 Typical value is the average of EPA certified efficiencies.
4. For 2030-2050, it is assumed that the same conditions as current would persist because no impending efficiency requirements are expected from EPA, given recency of 2020 rulemaking and current market factors.
5. Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
6. Installed costs include the cost of hearth and stainless-steel chimney liner - materials and labor.
7. For catalytic stoves, annual maintenance cost includes periodic cost of replacing the catalytic combustor.

Note:
The range for average life represents the span of typical values.

Residential Cordwood Stoves

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- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames to enable more complete combustion and reduce emissions.
- In 2015, EPA published an update to its New Source Performance Standards (NSPS), decreasing the emissions limit (previously set by 1988 EPA rule) to 4.5 grams per hour (g/h) for both catalytic and non-catalytic stoves. The new rule did not institute efficiency standards but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- In 2020, the NSPS limit for new room heaters was lowered to 2.5 g/h if tested with cord wood.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Multiple test standards are commonly used to assess stove efficiency, and data from product literature does not generally identify the efficiency test method.
- It is not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Accordingly, installed costs can be twice that of the wood stove itself.

Residential Cordwood Stoves

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Cordwood stove shipments have averaged 123,000 per year since 1999 and have fluctuated approximately in accordance with fuel oil costs.

Source: *HPBA, no post-2012 sales data was publicly available at time of publication.*

Residential Wood Pellet Stoves

DATA	2015[1]	2020[2]	2022[3]		2030[4]		2040[4]		2050[4]	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)[5]	70	73	73	85	73	85	73	85	73	85
Annual Electricity Consumption (kWh)[6]	600	600	600	600	600	600	600	600	600	600
Average Life (y)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	3,900	3,120	3,120	4,000	3,120	4,000	3,120	4,000	3,120	4,000
Total Installed Cost (2022$)[7]	5,550	4,520	4,520	5,400	4,520	5,400	4,520	5,400	4,520	5,400
Annual Maintenance Cost (2022$)	310	310	310	310	310	310	310	310	310	310

1. For 2015, assumed EPA default efficiencies, which were used by EPA to approximate the efficiency of stoves before the 2015 EPA rule required efficiency testing.
2. For 2020, assumed same efficiencies as estimated for 2022 given the most recent EPA rule went into effect in May 2020.
3. The 2022 High value is the highest EPA certified efficiency. The 2022 Typical value is the average of EPA certified efficiencies.
4. For 2030-2050, it is assumed that the same conditions as current would persist because no impending efficiency requirements are expected from EPA, given recency of 2020 rulemaking and current market factors.
5. Efficiency includes combustion and heat transfer efficiency and is based on the HHV of the fuel.
6. The annual electric consumption estimates assume 6 months/year @ 100kW/mo based on DOE estimates.
7. Installed cost includes cost of hearth and vent pipe - materials and labor.

Note:
The range for average life represents the span of typical values.

Residential Wood Pellet Stoves

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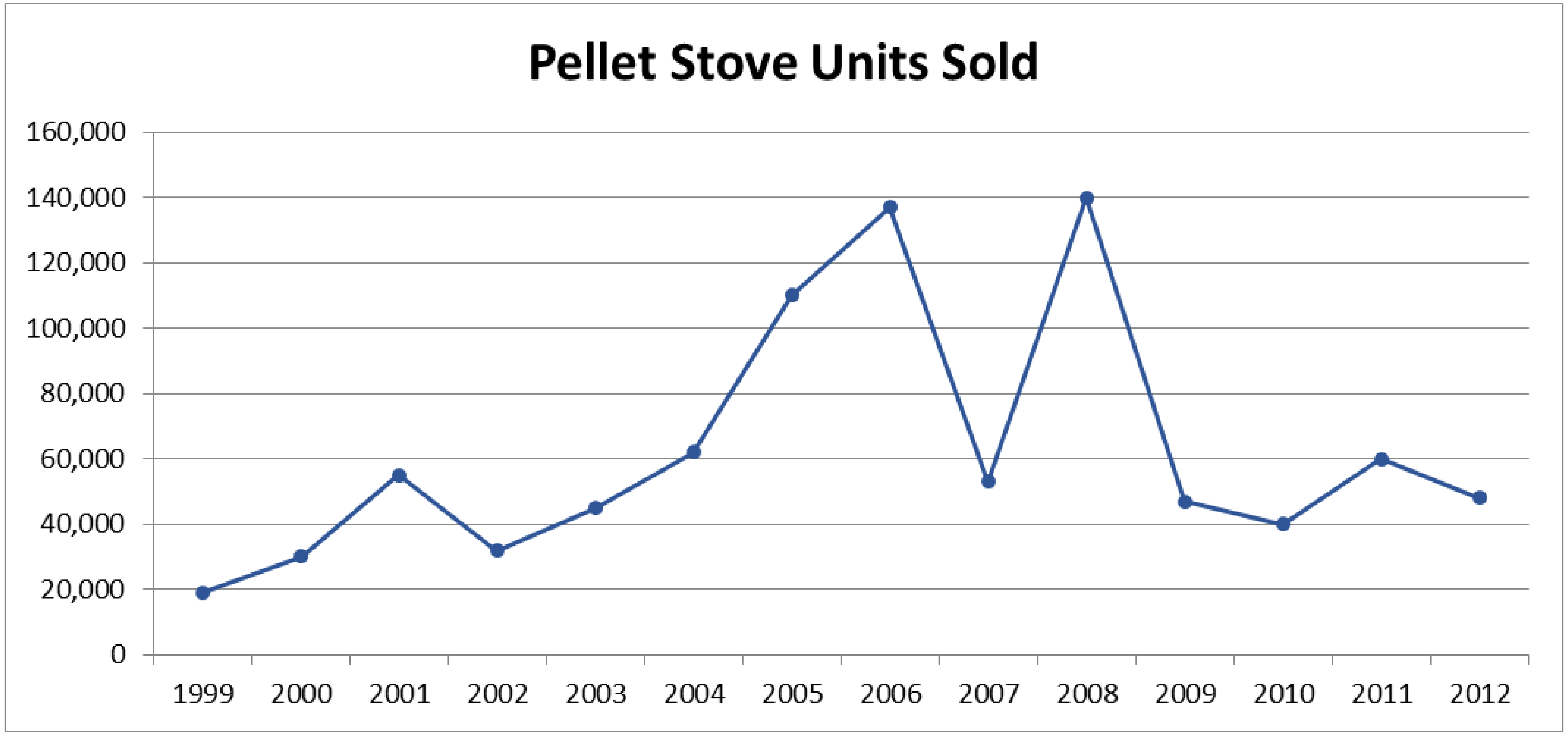
- In 2015, EPA published an update to its NSPS, limiting emissions for wood pellet stoves to 4.5 g/h. Prior to the 2015 EPA rule, most pellet stoves were exempt from EPA's NSPS requirements. The new rule did not institute efficiency standards but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method.
- It is not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Residential Wood Pellet Stoves

Wood pellet stove shipments grew substantially in the 2005 – 2008 time period but have averaged only 40,000 – 60,000 units since that time.



Source: *HPBA, no post-2012 sales data was publicly available at time of publication.*

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Residential Water Heating

Residential Gas-Fired Storage Water Heaters

DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.0	High	ENERGY STAR V. 5.0	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	40	40	40	40	40	40	40	40	40
Uniform Energy Factor (UEF)[1]	0.58	0.63	0.61	0.61	0.66	0.84	0.83	0.61	0.84	0.61	0.84	0.61	0.84
Average Life (y)	13	13	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Retail Equipment Cost (2022$)	590	880	420	420	490	720	700	420	720	420	720	420	720
	650	1,410	990	990	1,110	1,650	1,590	990	1,650	990	1,650	990	1,650
Total Installed Cost (2022$)	1,240	1,650	740	740	800	1,140	1,130	740	1,140	740	1,140	740	1,140
	1,240	2,880	1,690	1,690	1,850	3,130	3,160	1,690	3,130	1,690	3,130	1,690	3,130
Annual Maintenance Cost (2022$)[2]	20	20	20	20	20	20	20	20	20	20	20	20	20

1. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.
2. Maintenance includes manufacturer recommendation for the water heater to be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency, and prolong product life. Available evidence indicates that this is performed in 10% of households.

Note:

Ranges represent the span of typical values.
Current standards went into effect April 16, 2015.
ENERGY STAR V. 4.0 went into effect January 5, 2022.
ENERGY STAR V. 5.0 will go into effect April 18, 2023
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.1, 1.76, 1).

Residential Gas-Fired Storage Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

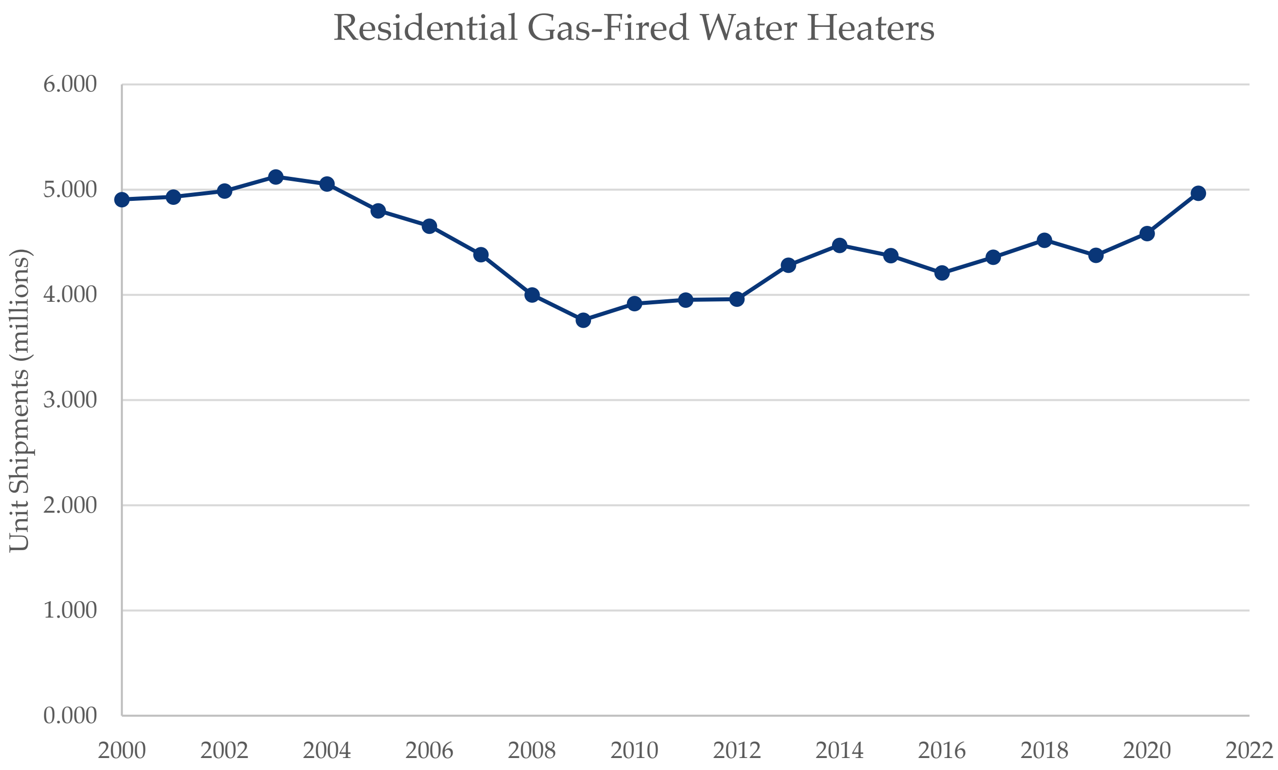
Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.3456-(0.002*Gal)	No models on the market	NA
	Low	UEF=0.5982-(0.0019*Gal)	0.54 for a 29-gallon water heater	NA
	Medium	UEF=0.6483-(0.0017*Gal)	0.58 for a 38-gallon water heater	0.64
	High	UEF=0.692-(0.0013*Gal)	0.64 for a 48-gallon water heater	0.68
> 55 gal and ≤ 100 gal	Very Small	UEF=0.647-(0.0006*Gal)	No models on the market	NA
	Low	UEF=0.7689-(0.0005*Gal)	No models on the market	NA
	Medium	UEF=0.7897-(0.0004*Gal)	No models on the market	0.78
	High	UEF=0.8072-(0.0003*Gal)	No models on the market	0.80

- There are currently no models on the market above 55 gallons (gal) due to the high UEF, which would require using condensing or gas-fired heat pump (e.g., absorption) technology to achieve.
- The cost of installation is typically $600 to $1200, which exceeds that of electric water heaters. This difference can be attributed to multiple differences; for example, gas-fired heaters require an extra 1.5 hours of labor for 2 plumbers.
- Condensing units are high efficiency and use PVC venting instead of stainless-steel. Condensing units also use an electrical supply for electronic ignition and power venting. Some building codes require condensate neutralizer filters.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Gas-Fired Storage Water Heaters

Shipments were flat at 5 million units per year through 2004, then declined gradually over 5 years to a new plateau at 4 million units until rising again back to 5 million units in 2021.



Source: *AHRI*

Residential Oil-Fired Water Heaters

Final

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DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	32	32	32	32	32	32	32	32	32	32	32
Uniform Energy Factor[1]	0.51	0.67	0.64	0.66	0.68	0.66	0.68	0.66	0.68	0.66	0.68
Average Life (y)	13	13	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Retail Equipment Cost (2022$)	1,590	1,880	1,380	1,400	1,480	1,400	1,480	1,400	1,480	1,400	1,480
	1,710	2,410	2,810	2,870	3,030	2,870	3,030	2,870	3,030	2,870	3,030
Total Installed Cost (2022$)	2,350	2,650	2,620	2,650	2,730	2,650	2,730	2,650	2,730	2,650	2,730
	2,470	3,350	4,050	4,120	4,280	4,120	4,280	4,120	4,280	4,120	4,280
Annual Maintenance Cost (2022$)[2]	210	210	210	210	210	210	210	210	210	210	210

1. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.
2. Oil-fired storage water heaters are typically cleaned and maintained under maintenance contracts. The annual cost of typical maintenance is based on maintenance contract prices from different oil-fired product suppliers as specified in the CWH EERE 2022 Preliminary Analysis.

Note:
Ranges represent span of typical values.
Current standards went into effect April 16, 2015.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (16.2, 1.70, 1).

Residential Oil-Fired Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≤ 50 gal	Very Small	UEF=0.2509-(0.0012*Gal)	No models on the market	NA
	Low	UEF=0.533-(0.0016*Gal)	No models on the market	NA
	Medium	UEF=0.6078-(0.0016*Gal)	No models on the market	NA
	High	UEF=0.6815-(0.0014*Gal)	0.64 for a 29-gallon water heater	NA

- There are no ENERGY STAR requirements for oil-fired storage water heaters.
- Annual shipments of residential oil-fired storage water heaters are approximately 4,000, which is less than 1% of shipments of residential gas-fired storage water heaters.
- Oil-fired storage water heaters often have smaller tanks with larger input ratings relative to natural gas-fired and electric storage water heaters.
- No condensing residential oil-fired storage water heaters currently exist in the U.S. market. Condensing oil-fired water heaters are generally not considered technologically feasible because the sulfur content in fuel oil leads to the condensate becoming corrosive.
- Residential oil-fired water heaters utilize power burners and have at least some level of electrical power consumption.
- The most efficient models on the market use a proprietary "turbo-flue" design to increase heat transfer to water.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Oil-Fired Water Heaters

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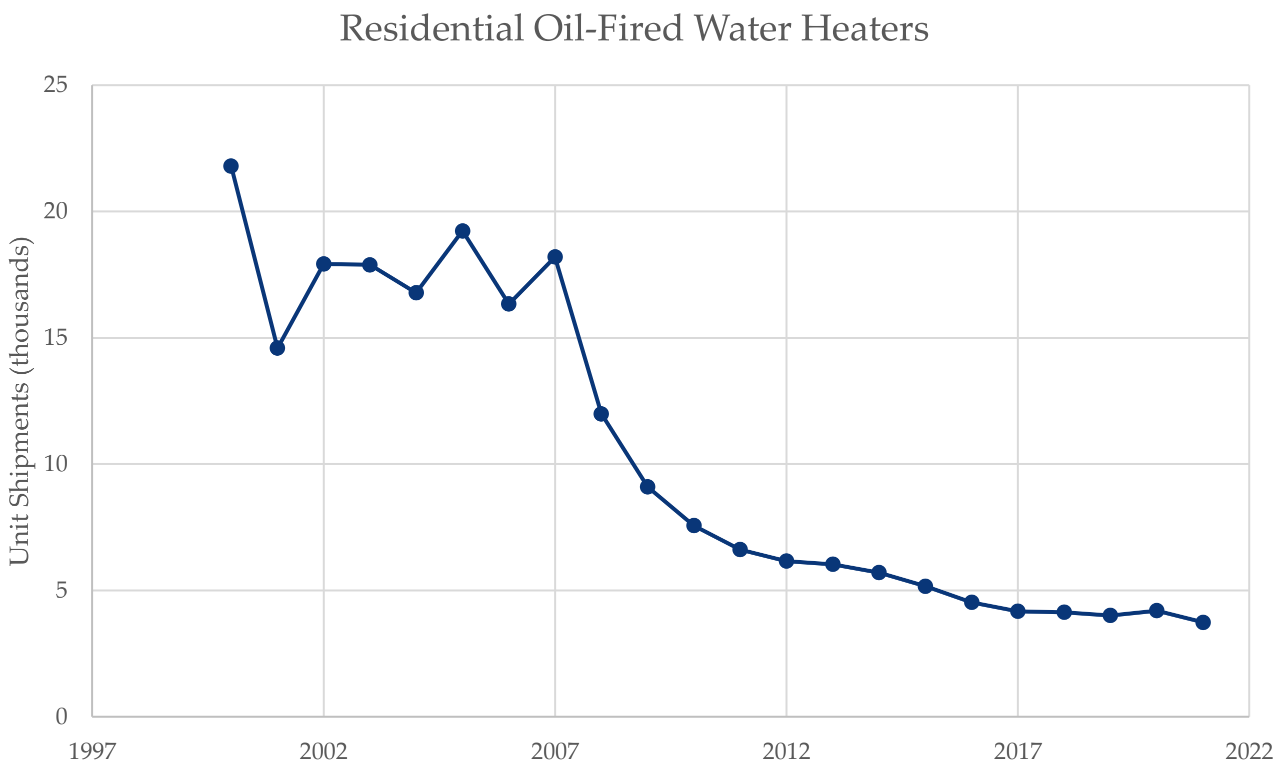
Shipments peaked at about 22,000 units in 2000 and have decreased since then, with an exponential decay occurring since 2007. Only about 4,000 units were shipped in 2021.



Source: *CWH EERE 2022 Preliminary Analysis*

Residential Electric Resistance Storage Water Heaters

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DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	36	36	36	36	36	36	36	36	36	36	36
Uniform Energy Factor[1]	0.88	0.93	0.92	0.92	0.93	0.92	0.93	0.92	0.93	0.92	0.93
Average Life (y)	13	13	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Retail Equipment Cost (2022$)	290	350	330	330	600	330	600	330	600	330	600
	530	650	760	760	850	760	850	760	850	760	850
Total Installed Cost (2022$)	590	710	500	500	550	500	550	500	550	500	550
	940	1,290	1,310	1,310	1,430	1,310	1,430	1,310	1,430	1,310	1,430
Annual Maintenance Cost (2022$)[2]	20	20	20	20	20	20	20	20	20	20	20

1. Beginning in 2016, the efficiency metric for water heaters changed from energy factor (EF) to UEF based on DOE test procedures. The UEF values for the installed base in 2015 are converted values equivalent to 0.90 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market.
2. Similar to gas-fired and oil-fired storage water heaters, manufacturers recommend that electric storage water heaters be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency, and prolong product life. The available evidence indicates that this practice is done in 10% of households.

Note:

Ranges represent span of typical values.

Current standards went into effect April 16, 2015.

Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.7, 1.57, 1).

Residential Electric Resistance Storage Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.8808-(0.0008*Gal)	No models on the market	2.00
	Low	UEF=0.9254-(0.0003*Gal)	0.92 for a 27-gallon water heater	2.00
	Medium	UEF=0.9307-(0.0002*Gal)	0.92 for a 45-gallon water heater	2.00
	High	UEF=0.9349-(0.0001*Gal)	0.93 for a 50-gallon water heater	2.00
> 55 gal and ≤ 120 gal	Very Small	UEF=1.9236-(0.0011*Gal)	No models on the market	2.20
	Low	UEF=2.0440-(0.0011*Gal)	No models on the market	2.20
	Medium	UEF=2.1171-(0.0011*Gal)	2.05 for a 58-gallon water heater	2.20
	High	UEF=2.2418-(0.0011*Gal)	2.15 for a 80-gallon water heater	2.20

- The federal standards for residential electric storage water heaters apply to both electric resistance storage water heaters and heat pump water heaters.
  - The Federal standard levels for the ≤ 55-gallon range are achievable through electric resistance and heat pump technology.
  - The Federal standards for the > 55-gallon range and all ENERGY STAR levels are only achievable through heat pump technology.
- Typical storage volumes range from 25-55 gallons for electric resistance storage water heaters and 45-80 gallons for heat pump water heaters (HPWHs).

Residential Electric Resistance Storage Water Heaters

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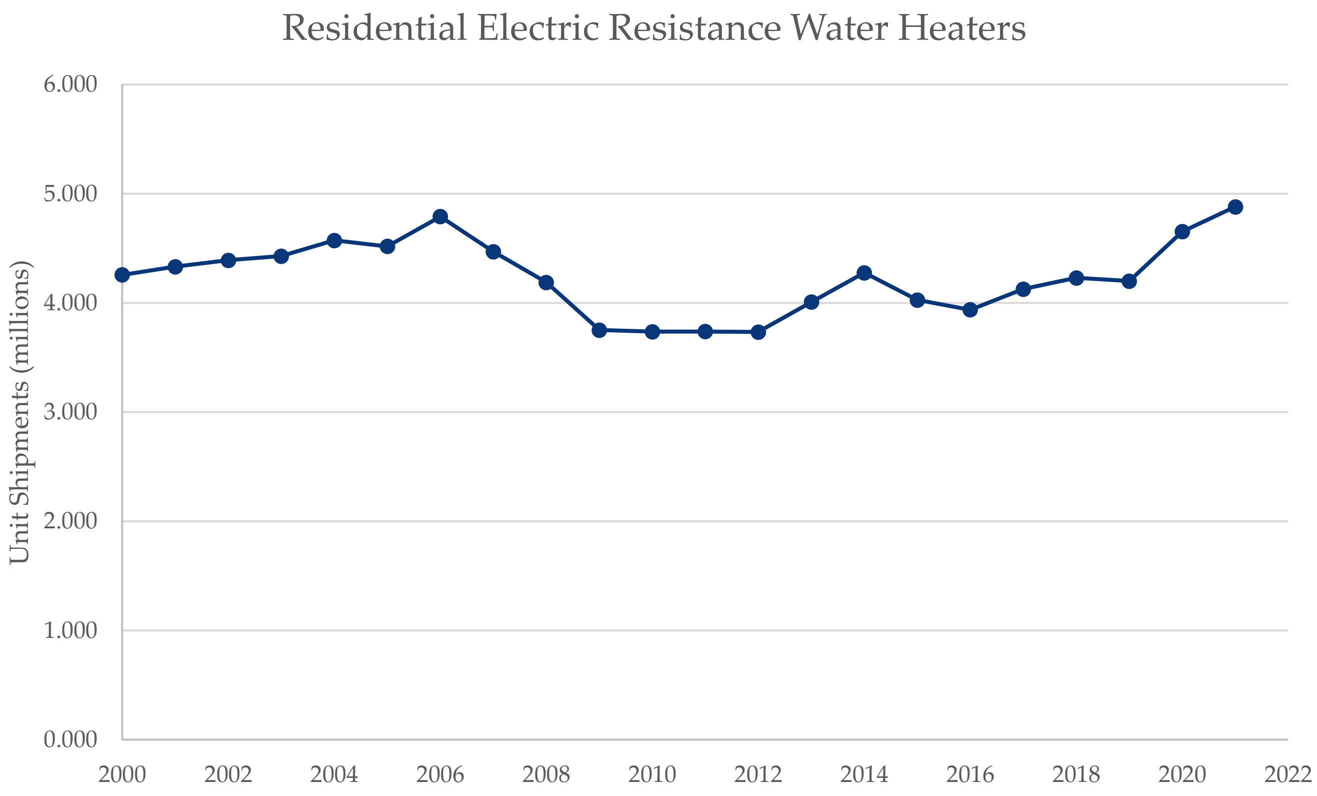
Shipments peaked in 2006 then dropped a total of 22 percent over three years. Shipments have gradually increased since then and were at the highest level in 2021.



Source: *AHRI*

Residential Heat Pump Water Heaters

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DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	36	36	36	36	36	36	36	36	36	36	36
Uniform Energy Factor[1]	2.05	3.28	3.33	3.30	3.73	3.33	3.73	3.33	3.73	3.33	3.73
Average Life (y)	13	13	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Retail Equipment Cost (2022$)[2]	1,290	1,410	630	630	670	630	670	630	670	630	670
	1,650	1,760	1,440	1,440	1,670	1,370	1,590	1,300	1,510	1,240	1,430
Total Installed Cost (2022$)[2]	1,710	1,880	870	870	980	870	980	870	980	870	980
	2,940	3,000	2,230	2,230	2,450	2,120	2,330	2,010	2,210	1,910	2,100
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20

1. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market.
2. It is expected that costs for HPWHs will decrease over time as these products become more common. This analysis estimates these cost decreases for the higher range of costs.
3. For heat pump water heater design options, DOE assumed higher maintenance cost to take into account annual cleaning of the air filter, preventative maintenance cost to check the evaporator and refrigeration system, inspection of the condensate withdrawal system, and replacement of the condensate neutralizer filter, if applicable. However, this maintenance is estimated to occur in only 10% of households, so overall maintenance cost is similar to that of other electric resistance water heaters.

Note:
Ranges represent span of typical values.
ENERGY STAR V. 4.0 went into effect January 5, 2022.
Assume same lifetime as electric resistance water heaters.

Residential Heat Pump Water Heaters

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- Technology improvements have advanced efficiency and reliability, but the high first-cost and lack of awareness among consumers and contractors still precludes high-volume market penetration.
- New Federal standards that came into effect in April 2015 effectively mandate heat pump technology for electric storage water heaters with storage volume > 55 gallons.
- Integrated models are the most common configuration for residential HPWHs. Several major water heater manufacturers produce such models, and other competitors offer integrated or add-on units (for existing electric or indirect storage water heaters).
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' COP are usually between 2.5 and 4.
- Heat pumps raise the water temperature more slowly than resistive heating elements, so most models use backup resistive elements along with the heat pump when hot water demand is high. Most HPWHs allow the consumer to control whether resistive elements are used in periods of high demand (e.g., "hybrid mode" or "heat pump only mode").

Residential Heat Pump Water Heaters

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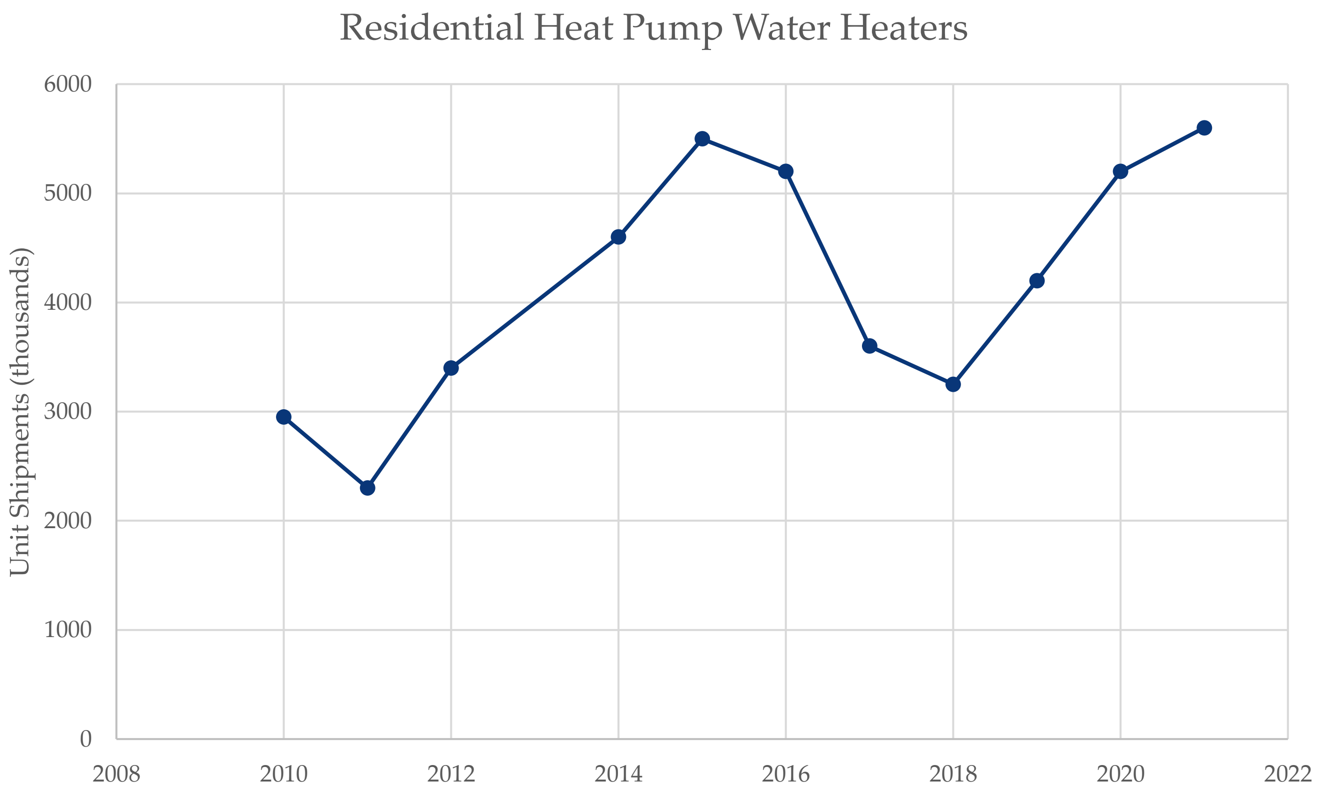
Shipments make up a small portion of electric resistance heaters, with a peak of only about 5,500 units, occurring in both 2015 and 2021.



Source: *ENERGY STAR*

Residential Solar Water Heaters

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DATA	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	ENERGY STAR V. 4.0	Typical	Typical	Typical	Typical
Typical Capacity (ft^2)[1]	42	42	40	40	40	40	40
	65	65	54.4	54.4	54.4	54.4	54.4
Solar Uniform Energy Factor (SUEF)[2]	3.0	3.0	3.0	99.0	99.0	99.0	99.0
Average Life (y)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)	7,710	7,710	6,430	6,430	6,430	6,430	6,430
Total Installed Cost (2022$)	10,650	10,650	8,060	8,060	8,060	8,060	8,060
Annual Maintenance Cost (2022$)[3]	80	80	80	80	80	80	80

1. Capacity selections are based on the range observed from medium draw units in the ENERGY STAR database. Medium draw represented the largest portion of units.
2. An SUEF of 3.0 is the required threshold for ENERGY STAR certification, yet a value of 99 was the most common observed SUEF among medium draw units. Note that an SUEF of 99 indicates that no backup heating was required for the applicable draw pattern, and all energy was provided by the solar collector. Since SUEF is a measure of hot water energy out divided by electrical or gas backup energy in, it will be infinite for cases where the collector provides all the hot water needed for the draw pattern – the Solar Rating and Certification Corporation's (SRCC's) OG-300 software is written to assign an SUEF of 99 to this case.
3. Annual maintenance is expected to be 0.5% to 1% of the total installation for 2022, 2030, 2040, and 2050.

Note:

Ranges represent span of typical values.

ENERGY STAR V. 4.0 went into effect January 5, 2022.

Residential Solar Water Heaters

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- Solar water heaters are not subject to federal energy conservation standards. The ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SUEF ≥ 3.0	ICC 900/SRCC 300-2020 Solar Thermal System Standard, Appendix A: Solar Uniform Energy Factor Procedure for Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Solar water heaters can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the U.S. are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water. Direct systems were observed as the most common product type and subject of this analysis.
- In 2020, stakeholders from the solar thermal industry developed the Solar Uniform Energy Factor (SUEF) Specification for solar water heaters to align with the UEF metric used by DOE for other water heating technologies.
- SUEF is also the metric used by the current ENERGY STAR Specification, and it replaced the Solar Energy Factor (SEF) metric.
- Over two-third of the current solar water heater market is in the southern or western U.S. (including Hawaii). A collector area of 42 square feet (ft^2) would be typical for these areas. Colder areas of the U.S. would require a larger collector (e.g., 65 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

Residential Solar Water Heaters

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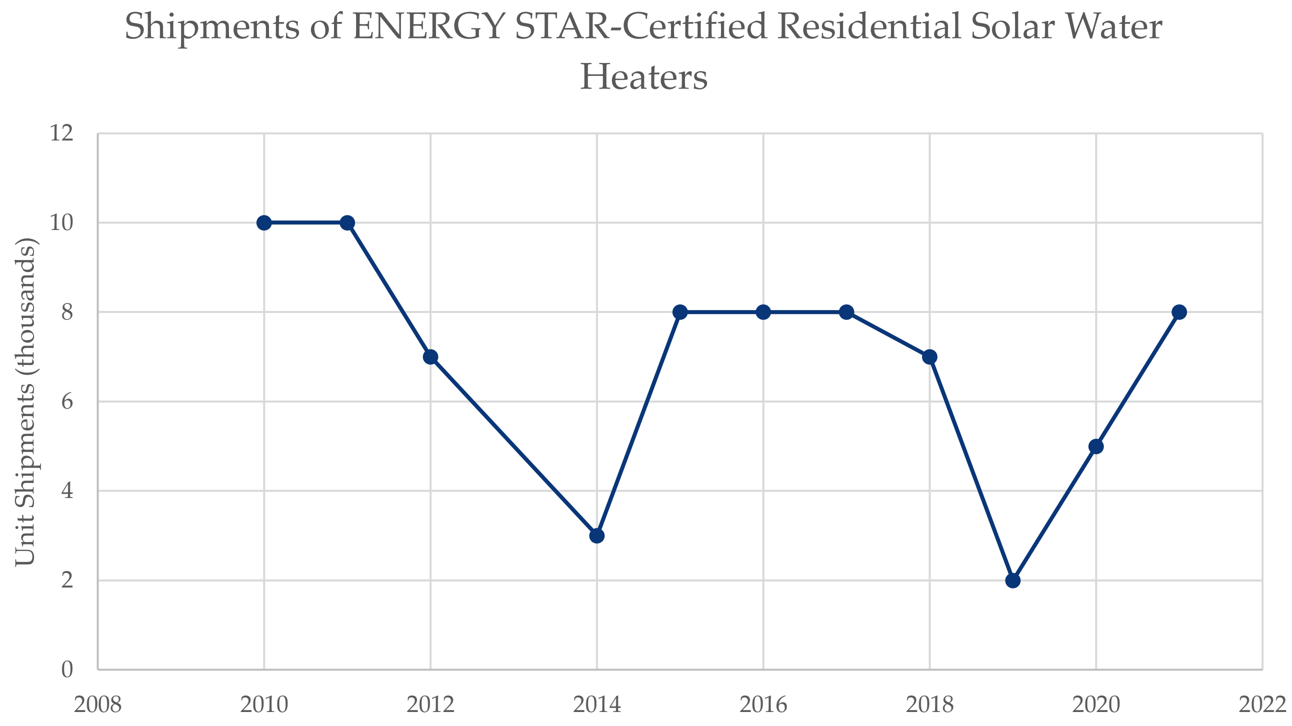
The shipments data below only represents ENERGY STAR-certified solar water heaters, as ENERGY STAR did not provide a market penetration rate. Solar water heaters have a small market share, with only 10,000 shipments at the peak in 2010 and 2011.



Source: *ENERGY STAR*

Residential Gas-Fired Instantaneous Water Heaters

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DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.0	High	ENERGY STAR V. 5.0	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199	199
Uniform Energy Factor (UEF)[1]	0.81	0.89	0.81	0.92	0.87	0.97	0.95	0.92	0.97	0.92	0.97	0.92	0.97
Average Life (y)	19	19	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)	1,410	1,180	430	580	580	610	610	580	610	580	610	580	610
	1,760	1,410	1,020	1,360	1,350	1,430	1,430	1,360	1,430	1,360	1,430	1,360	1,430
Total Installed Cost (2022$)	2,590	1,760	920	1,070	950	1,090	1,090	1,070	1,090	1,070	1,090	1,070	1,090
	3,820	3,350	2,860	3,160	3,140	3,230	3,220	3,160	3,230	3,160	3,230	3,160	3,230
Annual Maintenance Cost (2022$)[2]	90	90	90	90	90	90	90	90	90	90	90	90	90

1. Analysis is based on an average of low, medium, and high draw pattern units, as this is most reflective of the market.
2. Annual maintenance includes deliming to minimize deposition of sediment in the heat exchanger, maintain operating efficiency and prolong product life. Also includes additional tasks, including inspection of the ignition device, gas valve, controls, thermostat, and venting.

Note:

Ranges represent span of typical values.
Current standards went into effect April 16, 2015.
ENERGY STAR V. 4.0 went into effect January 5, 2022.
ENERGY STAR V. 5.0 will go into effect April 18, 2023.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (21.3, 1.76, 1).

Residential Gas-Fired Instantaneous Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
<2 gal and >50,000 Btu/h	Very Small	UEF=0.80	No models on the market	0.87
	Low	UEF=0.81	No models on the market	0.87
	Medium	UEF=0.81	0.81	0.87
	High	UEF=0.81	0.81	0.87

- The ENERGY STAR levels require the use of condensing technology.
- All of the major water heater manufacturers now offer an instantaneous water heater model.
- The maintenance costs include cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Gas-Fired Instantaneous Water Heaters

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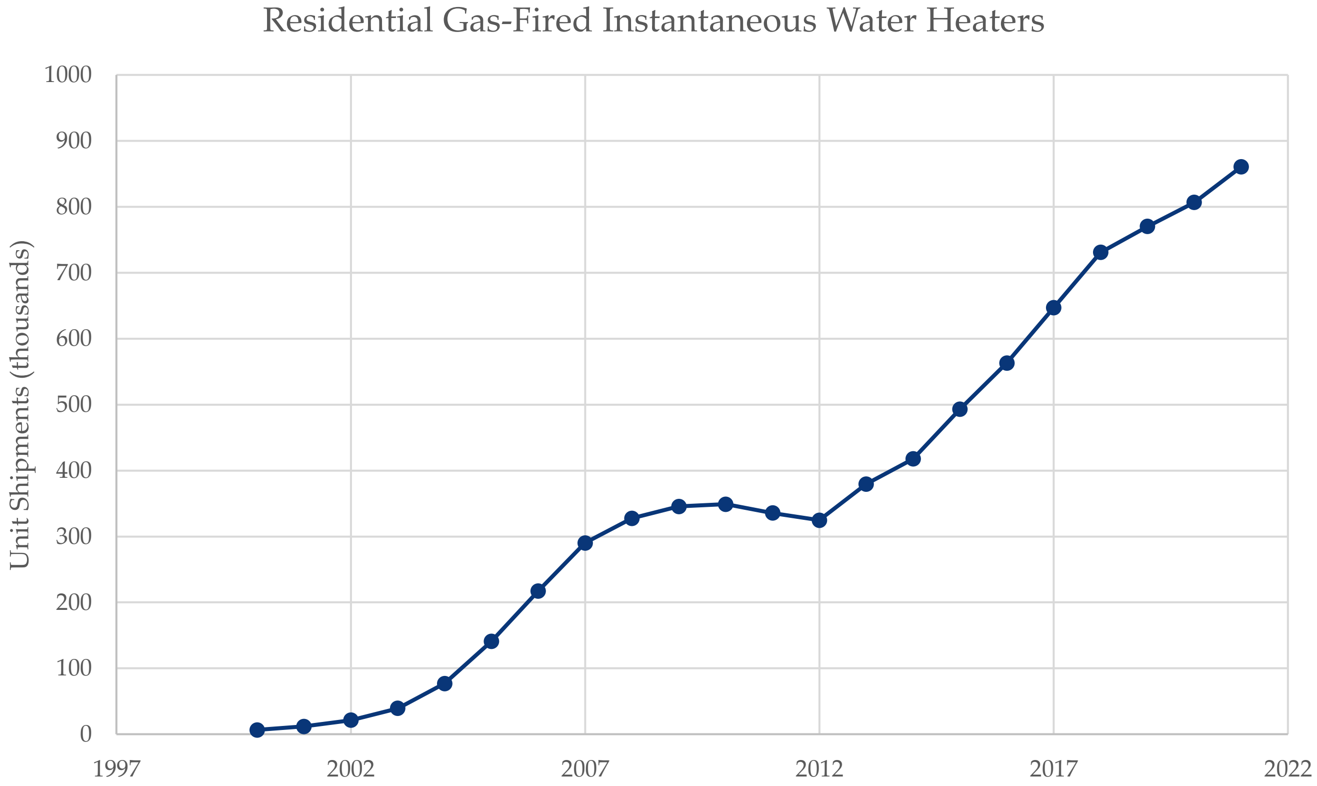
Shipments for Gas-Fired Instantaneous Water Heaters have grown steadily with nearly no shipments in 2000 and a peak of about 850,000 units in 2021.



Source: *CWH EERE 2022 Preliminary Analysis*

Residential Electric Instantaneous Water Heaters

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DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Representative Input Rate (kW)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Uniform Energy Factor (UEF)[1]	0.96	0.96	0.91	0.96	0.98	0.96	0.98	0.96	0.98	0.96	0.98
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)	260	260	260	260	260	260	260	260	260	260	260
Total Installed Cost (2022$)	520	520	520	520	520	520	520	520	520	520	520
Annual Maintenance Cost (2022$)[2]	90	90	90	90	90	90	90	90	90	90	90

1. Analysis is based on an average of low, medium, and very small draw pattern units, as this is most reflective of the market.
2. Annual maintenance costs not provided in CWH EERE 2022 Preliminary Analysis. Maintenance costs determined from the following calculation: GIWH - (GSWH - ESWH) - i.e., the difference factor in maintenance between gas and electric storage heat pumps applied to gas instantaneous heat pumps.

Note:
Current standards went into effect April 16, 2015.
Assume same lifetime as gas-fired instantaneous water heaters.

Residential Electric Instantaneous Water Heaters

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- The Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes
<2 gal	Very Small	UEF=0.91	0.91
	Low	UEF=0.91	0.91
	Medium	UEF=0.91	No models on the market
	High	UEF=0.92	No models on the market

- Electric instantaneous water heaters use electric resistance heating elements to heat water when there is a demand. Resistive heating elements are virtually 100% efficient, and the small storage capacities of these products means that they do not lose significant amounts of heat to the environment.
- The federal standards for these products require UEFs of 0.91 for very small, low, and medium draw pattern models and 0.92 for high draw pattern models.
- Most products currently on the market are in the very small draw pattern or the low draw pattern because electric resistance elements can only supply a limited quantity of heat on an instantaneous basis due to circuit amperage limitations.
- Many products are designed for point-of-use applications, such that the water heater only supplies water to one faucet or showerhead.

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Residential Appliances

Residential Refrigerator-Freezers (Top)

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DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/y)[3]	512	401	411	401	370	358	401	358	401	358	401	358
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	670	750	740	750	760	760	750	760	750	760	750	760
Total Installed Cost (2022$)	670	750	740	750	760	760	750	760	750	760	750	760
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 3 is used for this analysis (Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. The 2015 installed base energy consumption value is based on an adjusted volume of 21 cubic feet (ft^3). Energy consumption values for the 2020 installed base and 2022 and beyond are based on an adjusted volume of 22 ft^3, representing the current market.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect in September 2014.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers (Side)

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DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	26	26	25	25	25	25	25	25	25	25	25	25
Energy Consumption (kWh/y)[3]	893	693	705	693	635	610	693	610	693	610	693	610
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	1,400	1,130	1,130	1,130	1,160	1,470	1,130	1,470	1,130	1,470	1,130	1,470
Total Installed Cost (2022$)	1,400	1,130	1,130	1,130	1,160	1,470	1,130	1,470	1,130	1,470	1,130	1,470
Annual Maintenance Cost (2022$)[4]	30	20	20	20	20	30	20	30	20	30	20	30

1. Product Class 7 is used for this analysis (Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 32 ft^3 for all analysis years.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect in September 2014.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers (Bottom)

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DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/y)[3]	547	473	521	473	469	430	473	430	473	430	473	430
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	1,190	920	920	920	920	930	920	930	920	930	920	930
Total Installed Cost (2022$)	1,190	920	920	920	920	930	920	930	920	930	920	930
Annual Maintenance Cost (2022$)[4]	30	20	20	20	20	20	20	20	20	20	20	20

1. Product Class 5 is used for this analysis (Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 23 ft^3 for all analysis years.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:

Current standard went into effect in September 2014.

ENERGY STAR V. 5.1 went into effect in September 2014.

Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers

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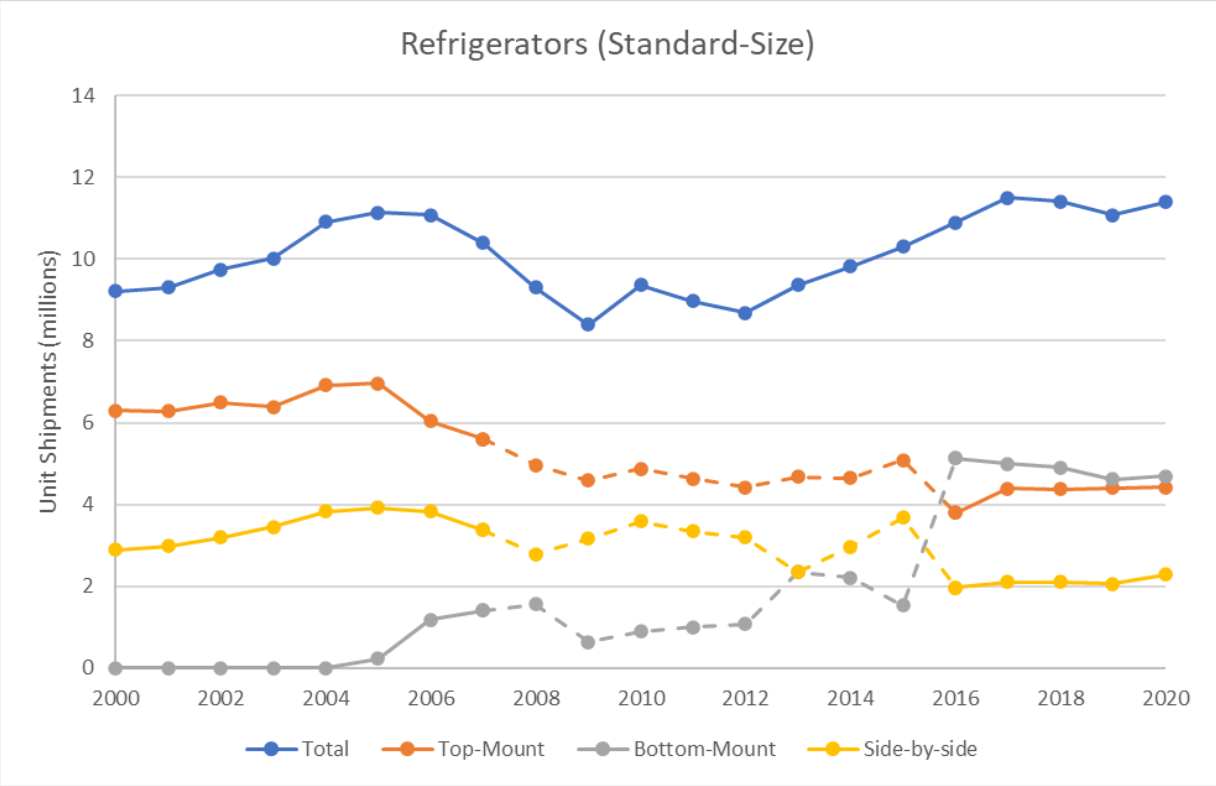
- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 32 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence and configuration (through-the-door or inside cabinet) of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard
- Energy efficiency opportunities for refrigerators include:
  - More efficient compressor, including variable speed compressors
  - Brushless direct current (DC) fan motor (also known as ECM motor)
  - Variable defrost
  - Larger condenser
  - Dual evaporators
  - Vacuum-insulated panels
  - Refrigerants (Isobutane vs. R134a)

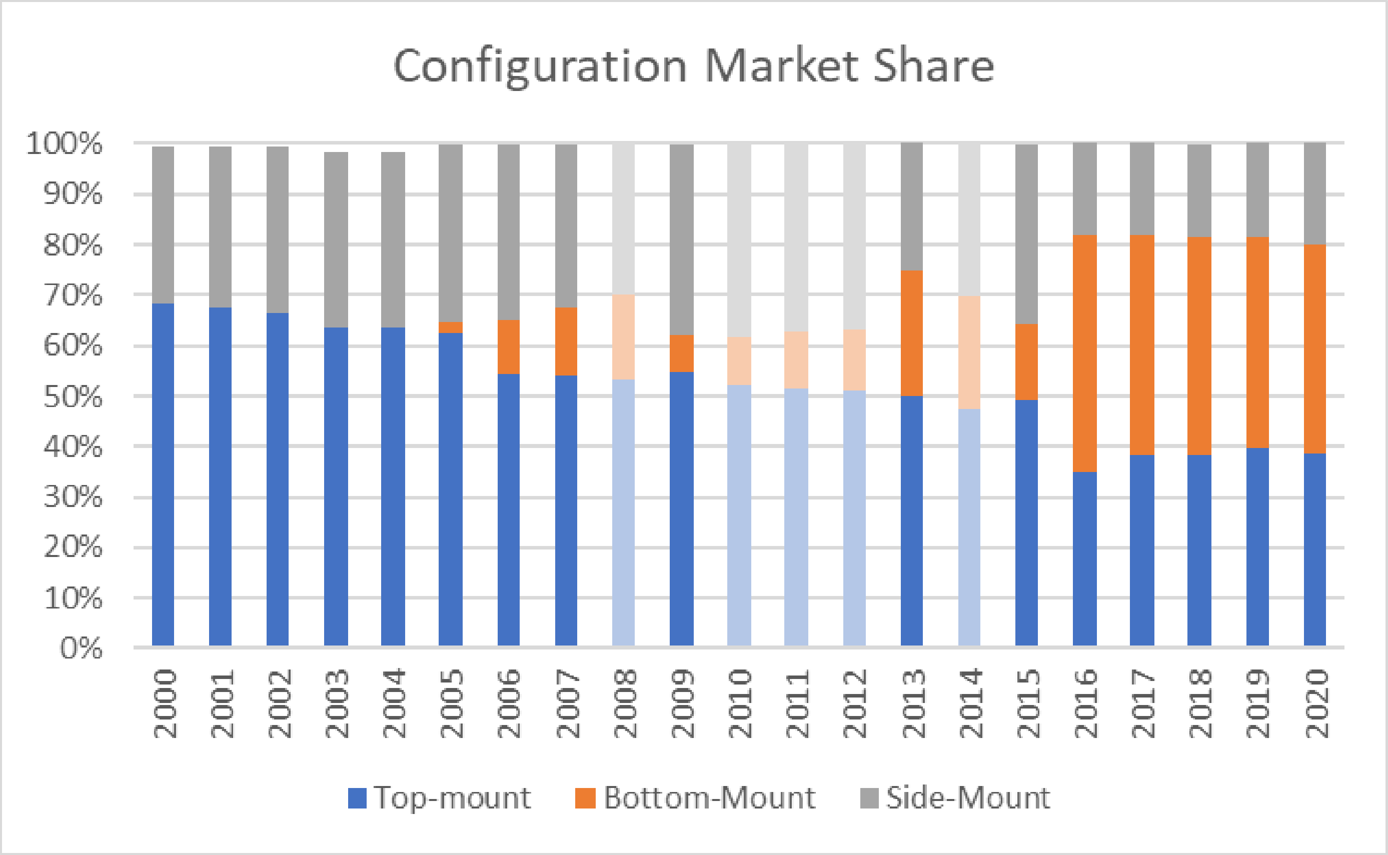
[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume)

Annual shipment volumes have rebounded from a sharp decline between 2006 and 2009, reaching approximately 11.4 million units in 2020.



Source: *Appliance Magazine*; *DOE's CCD, as of December 2017; ENERGY STAR Unit Shipment Data (2017-2020); Guidehouse analysis.* Dashed lines are a combination of interpolated and available data.

Bottom-mount units have gained market share, surpassing top-mount units since 2016.



Sources: *RF EERE 2021 Preliminary Analysis; DOE's CCD, as of December 2017; Guidehouse analysis.* Lightly shaded bars indicate interpolated data.

Final

Residential Freezers (Chest)

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DATA[1]	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	16	15	15	15	15	15	15	15	15	15	15
Energy Consumption (kWh/y)[3]	360	297	297	297	287	297	287	297	287	297	287
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	510	590	680	680	690	680	690	680	690	680	690
Total Installed Cost (2022$)	510	590	680	680	690	680	690	680	690	680	690
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 10 is used for this analysis (Chest freezers and all other freezers except compact freezers).
2. The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 26 ft^3, which is the average adjusted volume for units with a rounded total refrigerated volume of 15 ft^3 per the DOE CCD.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

Note:

Current standard went into effect in September 2014.

ENERGY STAR excluded as no products at the typical capacity are ENERGY STAR compliant.

Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (21.96, 1.83, 1).

Residential Freezers (Upright)

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DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	17	17	18	18	18	18	18	18	18	18	18	18
Energy Consumption (kWh/y)[3]	615	446	497	493	448	441	493	441	493	441	493	441
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	690	880	830	830	830	830	830	830	830	830	830	830
Total Installed Cost (2022$)	690	880	830	830	830	830	830	830	830	830	830	830
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 9 is used for this analysis (Upright freezers with automatic defrost).
2. The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 31 ft^3, which is the average adjusted volume for units with a rounded total refrigerated volume of 18 ft^3 per the DOE CCD.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan electronics).

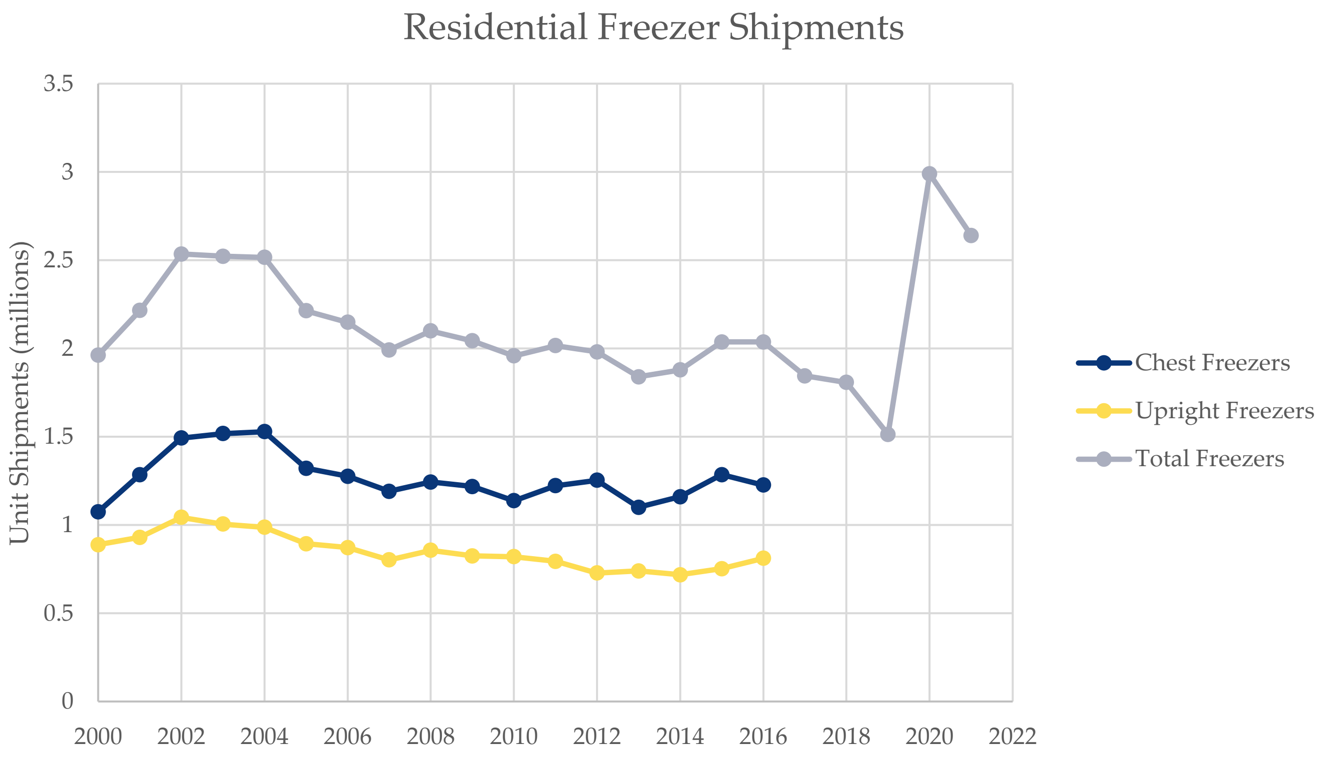
Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect September 2014.
Assume same lifetime as chest freezers.

Residential Freezers

- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 10 product classes based on size (standard or compact), orientation (chest or upright), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence of automatic icemaker
    - Current analysis focuses on the two representative product classes analyzed in the recent rulemaking, chest and upright freezers.
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
    - Chest freezers and all other freezers except compact freezers (PC 9): 9.88AV + 143.7
    - Upright freezers with automatic defrost (PC 10): 12.43AV + 326.1
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard
  - No ENERGY STAR compliant products at the typical capacity for chest freezers
- Energy efficiency opportunities for freezers include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. shaded pole motor (SPM) and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)

[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Shipment volumes held steady between 2007 to 2016 at about 2 million units per year. Shipments jumped to 3 million units in 2020. Chest freezers represent about 60% of the market.



Sources: *Appliance Magazine* from 2000 to 2016; *ENERGY STAR from 2017 to 2021*

Residential Natural Gas Cooktops

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23
Integrated Annual Energy Consumption (kBtu/y)[1]	1,061	914	914	730	914	730	914	730	914	730
Cooking Efficiency (%)	40	45	45	52	45	52	45	52	45	52
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	290	310	310	330	310	330	310	330	310	330
Total Installed Cost (2022$)[2]	420	460	460	480	460	480	460	480	460	480
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (IAEC) (kBtu/h). The Consumer Cooking Products EERE 2020 notice of proposed determination (NOPD) used for 2020 and beyond in this analysis also determined IAEC using a different test procedure than the Consumer Cooking Products EERE 2016 SNOPR.
2. Equipment and installed costs are for cooktops only (not combined range units).
3. Annual maintenance costs are negligible.

Note:

The range for typical capacity represents the span of typical values.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Ovens

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DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kBtu/y)[1]	2,038	1,960	1,960	1,831	1,960	1,831	1,960	1,831	1,960	1,831
Cooking Efficiency (%)	6.6	6.9	6.9	7.3	6.9	7.3	6.9	7.3	6.9	7.3
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	740	770	770	810	770	810	770	810	770	810
Total Installed Cost (2022$)[2]	870	920	920	950	920	950	920	950	920	950
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). The 2015 IAEC value is reflective of freestanding standard gas ovens, which was previously determined to be the most representative product class. IAEC for 2020 and beyond is reflective of freestanding self-clean gas ovens, which is the product class that makes up the majority of historical and projected gas oven shipments.
2. Equipment and installed costs are for ovens only (not combined ranges). Costs are reflective of freestanding self-clean oven units with single oven component, which represent the majority of the market.
3. Maintenance costs are negligible.

Note:

Ranges represent the span of typical values for a given parameter.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Ranges

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DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity of Cooktop Component (kBtu/h)	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23
Typical Capacity of Oven Component (kBtu/h)	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume of Oven Component (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kBtu/y)[1]	3,099	2,874	2,874	2,561	2,874	2,561	2,874	2,561	2,874	2,561
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$) [2]	750	770	770	850	770	850	770	850	770	850
Total Installed Cost (2022$) [2]	900	920	920	1,000	920	1,000	920	1,000	920	1,000
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. IAEC of a natural gas range is calculated as the sum of the IAEC for a natural gas cooktop and natural gas oven. IAEC of the oven component is reflective of freestanding self-clean gas ovens, which represent the majority of the market. The 2015 IAEC value of the oven component is reflective of freestanding standard gas ovens, which was previously determined to be the most representative product class.
2. Retail and installed cost are reflective of a typical unit with standard 30-inch width and 4 to 5 cooking top heating elements. Based on data from DOE rulemakings, Gordian's RSMeans Data – Building Construction Costs 2023, and distributors, total installed cost is estimated to be around $150 more than retail equipment cost.
3. Maintenance costs are negligible.

Note:

Ranges represent the span of typical values for a given parameter.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Cooktops, Ovens, and Ranges

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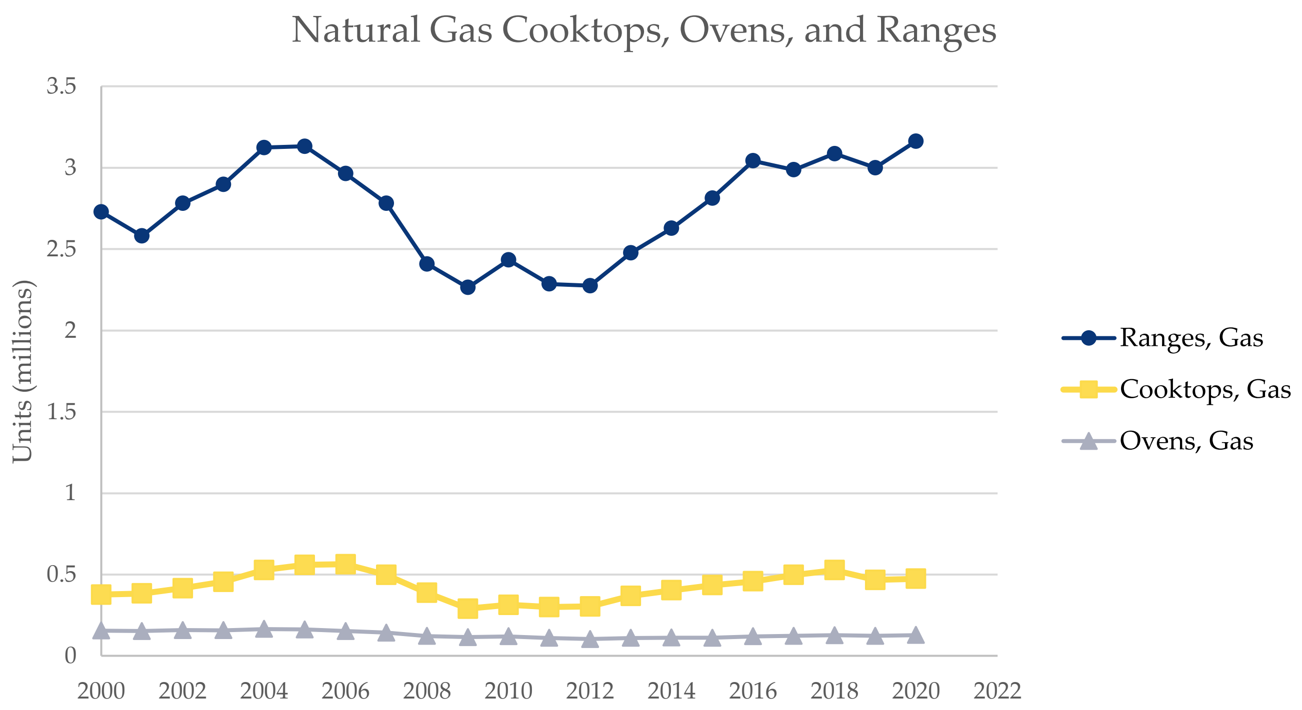
- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- Since January 1, 1990, gas cooking products with an electrical supply cord have been required to not be equipped with a constant burning pilot light. This requirement extended to gas cooking products without an electrical supply cord, as of April 9, 2012.
- DOE published a final rule in 2009[1] in which it determined that no standard for cooking efficiency would be cost-justified.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including gas cooktops and ovens[2].
- On September 2, 2016, DOE proposed performance-based standards for gas cooktops and ovens that would take effect in 2020, if adopted.
- DOE established the new IAEC metric, in kBtu/y, to replace cooking efficiency (%).
- On December 14, 2020, DOE initially determined that amended energy conservation standards for consumer conventional cooking products would not be economically justified and would not result in significant conservation of energy[3].
- On February 2, 2023, DOE proposed new and amended energy conservation standards for consumer conventional cooking products[4].
- The IAEC of a range is calculated as the sum of the IAECs for cooktops and ovens. However, retail and installation costs for a range are similar to the cost of an oven.

[1]Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers); Final Rule. 74 FR 16040.
[2]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.
[3]Energy Conservation Standards for Consumer Conventional Cooking Products; Notice of proposed determination (NOPD). 85 FR 80982.
[4]Energy Conservation Standards for Consumer Conventional Cooking Products; SNOPR. 88 FR 6818.

Shipments have been rising since 2012. In 2020, gas range shipments surpassed the peak reached in 2005.



Source: *Appliance Magazine and Consumer Cooking Products EERE 2022 SNOPR*

Residential Electric Cooktops

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (W)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700
Integrated Annual Energy Consumption (kWh/y)[1]	155	155	155	119	155	119	155	119	155	119
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$)[2]	470	470	470	810	470	810	470	810	470	810
Total Installed Cost (2022$)[2]	620	620	620	1,230	620	1,230	620	1,230	620	1,230
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). IAEC was determined using DOE rulemaking data for the most representative product class, electric smooth element cooking tops, which covers cooking tops with electric resistance heating elements and cooking tops with induction heating elements.
2. Equipment and installed costs are for cooktops only (not combined range units). Costs were determined using DOE rulemaking data for the most representative product class, electric smooth cooking tops, which includes cooking tops with electric resistance heating elements and cooking tops with induction heating elements. A high-end unit with induction technology is expected to have a greater retail equipment cost and greater installation cost in order to implement this technology.
3. Maintenance costs are negligible.

Note:
The range for typical capacity represents the span of typical values.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Ovens

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DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (W)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kWh/y)[1]	355	355	355	278	355	278	355	278	355	278
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$)[2]	630	630	630	730	630	730	630	730	630	730
Total Installed Cost (2022$)[2]	770	770	770	870	770	870	770	870	770	870
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). IAEC was determined using DOE rulemaking data for freestanding electric self-clean ovens, which represent the majority of the market.
2. Equipment and installed costs are for ovens only (not combined ranges). Costs are reflective of freestanding self-clean oven units with single oven component, which represent the majority of the market.
3. Maintenance costs are negligible.

Note:

Ranges represent the span of typical values for a given parameter.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Ranges

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DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity of Cooktop Component (W)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700
Typical Capacity of Oven Component (W)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Typical Cavity Volume of Oven Component (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kWh/y)[1]	510	510	510	397	510	397	510	397	510	397
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$) [2]	630	630	630	900	630	900	630	900	630	900
Total Installed Cost (2022$) [2]	770	770	770	1,050	770	1,050	770	1,050	770	1,050
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. IAEC of an electric range is calculated as the sum of the IAEC for an electric cooktop and an electric oven. IAEC of the electric cooktop component was determined using DOE rulemaking data for the most representative product class, electric smooth element cooking tops, which covers cooking tops with electric resistance heating elements and cooking tops with induction heating elements. IAEC of the electric oven component was determined using DOE rulemaking data for freestanding electric self-clean ovens, which represent the majority of the market.
2. Retail and installed cost are reflective of standard units that are 30-inch wide and have 4 to 5 cooking top heating elements. Based on data from DOE rulemakings, Gordian's RSMeans Data – Building Construction Costs 2023, and distributors, total installed cost is estimated to be around $140 more than retail equipment cost for a typical unit, and $150 more than retail equipment cost for a high-end unit. A high-end unit with an induction cooking top component is expected to have a greater retail equipment cost and greater installation cost in order to implement this technology.
3. Maintenance costs are negligible.

Note:
Ranges represent the span of typical values for a given parameter.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Cooktops, Ovens, and Ranges

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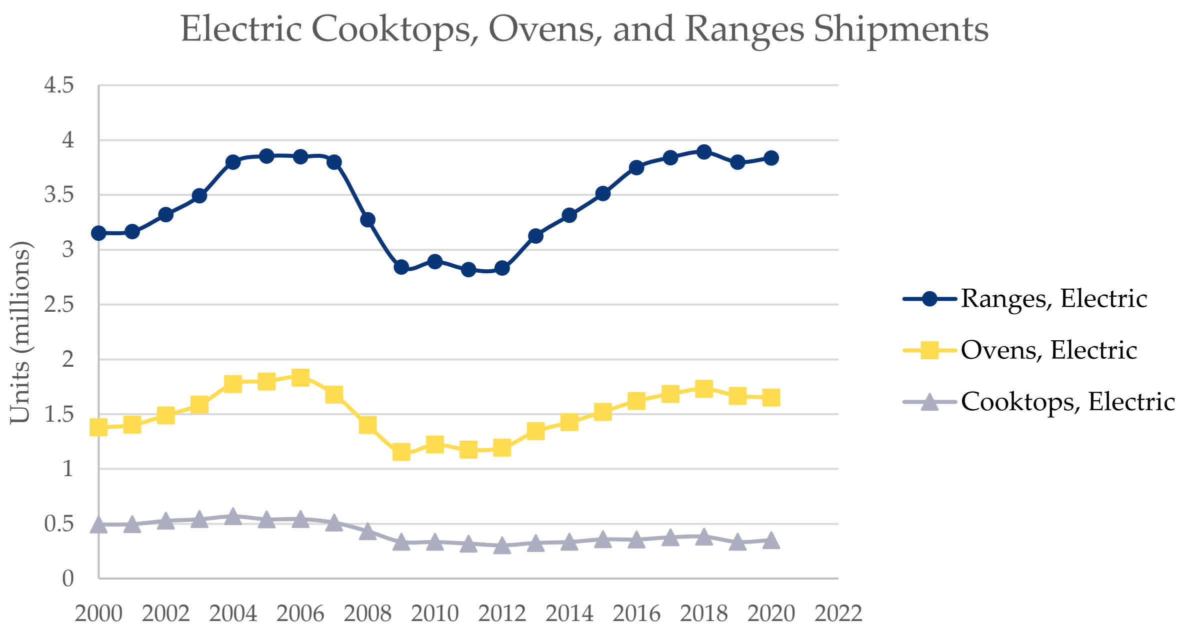
- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including electric cooktops and ovens[1].
- On September 2, 2016, DOE proposed performance-based standards for electric cooktops and ovens that would take effect in 2020 if adopted.
- DOE established the new IAEC metric, in kWh/y, to replace cooking efficiency (%).
- On December 14, 2020, DOE initially determined that amended energy conservation standards for consumer conventional cooking products would not be economically justified and would not result in a significant conservation of energy[2].
- On February 2, 2023, DOE proposed new and amended energy conservation standards for consumer conventional cooking products[3].
- The IAEC of a range is calculated as the sum of the IAECs for cooktops and ovens. However, retail and installation costs for a range are similar to the cost of an oven.

[1]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.
[2]Energy Conservation Standards for Consumer Conventional Cooking Products; Notice of proposed determination (NOPD). 85 FR 80982.
[3]Energy Conservation Standards for Consumer Conventional Cooking Products; SNOPR. 88 FR 6818.

Shipments of electric cooking products reached a peak in 2006. Shipments of ranges and ovens have been rising again since 2012. In 2018, electric range shipments surpassed the peak reached in 2006.



Source: *Consumer Cooking Products EERE 2022 SNOPR*

Residential Clothes Dryers (Electric)

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1[1]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7.4	7.4	7.4	7.4	7.4	4.5	7.4	4.5	7.4	4.5	7.4	4.5
Combined Energy Factor, D1 (lb/kWh)[2]	3.59	3.73	3.73	3.73	NA	3.93	3.73	3.93	3.73	3.93	3.73	3.93
Combined Energy Factor, D2 (lb/kWh)[2]	3.59	3.93	3.73	3.93	3.93	11.00	3.93	11.00	3.93	11.00	3.93	11.00
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	580	580	580	580	580	980	580	980	580	980	580	980
Total Installed Cost (2022$)	710	710	710	710	710	1,110	710	1,110	710	1,110	710	1,110
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-	-	-

1. ENERGY STAR V. 1.1 applies to vented and ventless standard electric clothes dryers.
2. The efficiency metric changed from EF to combined energy factor (CEF) in 2015. The 2015 Installed Base CEF data accounts for units tested to appendix D1 and appendix D2, because data specific to each appendix is not available for that year.
3. Maintenance costs are negligible. DOE estimated that on average 2.7 percent of electric and 3.3 percent of gas residential clothes dryers are repaired each year. (EERE 2014)

Note:
DOE test procedures for consumer clothes dryers appear at title 10 of the Code of Federal Regulations part 430, subpart B, appendix D1 and appendix D2. The second test method, appendix D2, was finalized in a final rule published by DOE on August 14, 2013. For current standard testing, units must be tested according to either the appendix D1 or the appendix D2 test method. ENERGY STAR V. 1.1 requires certified units to be tested according to the appendix D2 test method. The appendix D1 and appendix D2 test methods determine CEF differently.
The current standard went into effect in January 2015.
ENERGY STAR V. 1.1 went into effect in May 2017.
The range for average life represents the span of typical values.

Residential Clothes Dryers (Gas)

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1[1]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Combined Energy Factor, D1 (lb/kWh)[2]	3.18	3.30	3.30	3.30	NA	3.48	3.30	3.48	3.30	3.48	3.30	3.48
Combined Energy Factor, D2 (lb/kWh)[2]	3.18	3.48	3.30	3.48	3.48	3.50	3.48	3.50	3.48	3.50	3.48	3.50
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	660	670	660	670	670	670	670	670	670	670	670	670
Total Installed Cost (2022$)	860	870	870	870	870	870	870	870	870	870	870	870
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-	-	-

1. ENERGY STAR V. 1.1 applies to vented and ventless standard electric clothes dryers.
2. The efficiency metric changed from EF to CEF in 2015. The 2015 Installed Base CEF data accounts for units tested to appendix D1 and appendix D2, because data specific to each appendix is not available for that year.
3. Maintenance costs are negligible. DOE estimated that on average 2.7 percent of electric and 3.3 percent of gas residential clothes dryers are repaired each year. (EERE 2014)

Note:
DOE test procedures for consumer clothes dryers appear at title 10 of the Code of Federal Regulations part 430, subpart B, appendix D1 and appendix D2. The second test method, appendix D2, was finalized in a final rule published by DOE on August 14, 2013. For current standard testing, units must be tested according to either the appendix D1 or the appendix D2 test method. ENERGY STAR V. 1.1 requires certified units to be tested according to the appendix D2 test method. The appendix D1 and appendix D2 test methods determine CEF differently.
The current standard went into effect in January 2015.
ENERGY STAR V. 1.1 went into effect in May 2017.
The range for average life represents the span of typical values.

Residential Clothes Dryers

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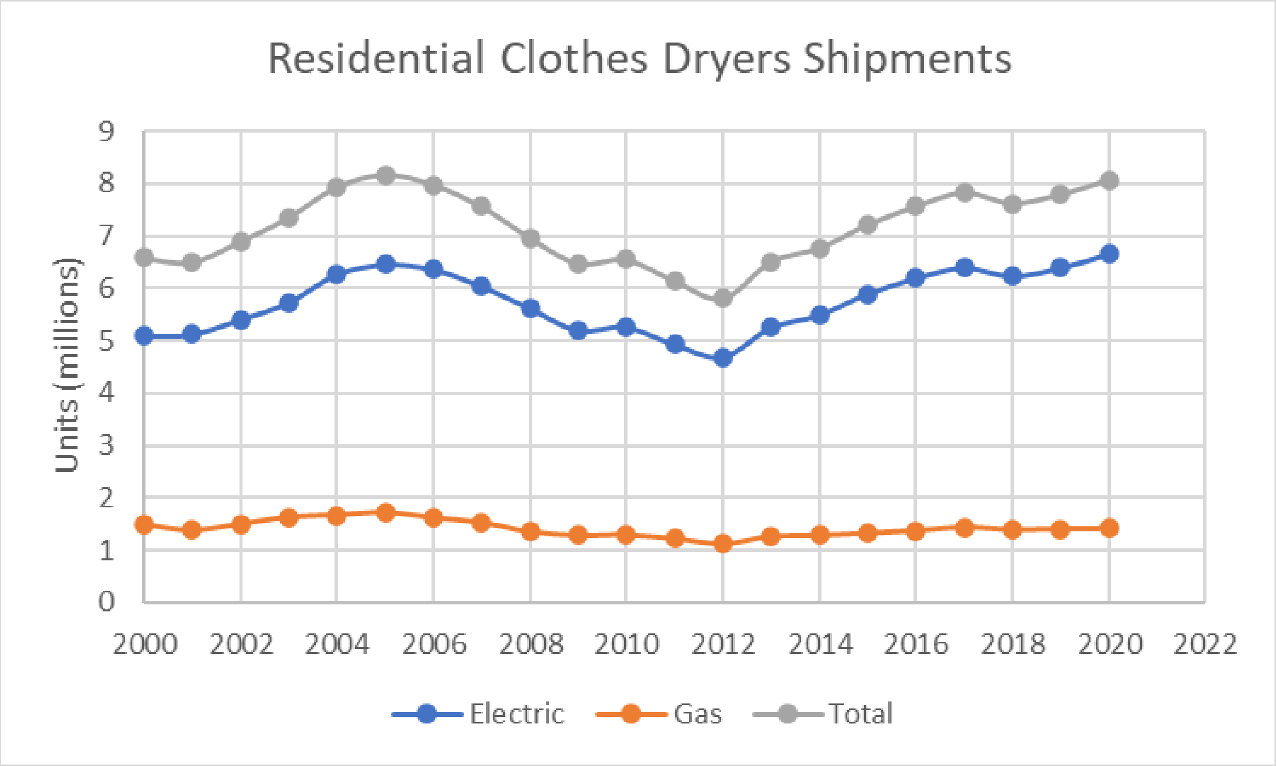
- Current standards[1] in effect since 2015:
  - For standard-size electric units : CEF ≥ 3.73 pound per kilowatt hours (lb/kWh)
  - For gas units: CEF ≥ 2.30 lb/kWh
  - Units may be tested according to the test method in appendix D1 or appendix D2, which was finalized in 2013.
- The main differences between appendix D1 and appendix D2 are:
  - Appendix D2 includes test methods that more accurately measure the effects of automatic cycle termination and that may result in differences in the total measured energy consumption of the test cycle as compared to the test methods in appendix D1.
  - Appendix D2 contains instructions for the testing of timer dryers, which include a lower final moisture content (FMC) of the test load as compared to the version of appendix D1 used for the 2011 rulemaking analysis.
- Efficiency improvement technologies for clothes dryers include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination
  - Heat pump (for electric clothes dryers)
- EPA developed ENERGY STAR V. 1.1, which became effective in 2017 and requires units to be tested according to the test method in appendix D2.
- Standard-size heat pump clothes dryers with CEF values up to 11.0 are currently available in the U.S. market. High initial cost has limited market penetration, but some utilities are offering rebates to support market penetration.

[1]Energy Conservation Standards for Consumer Clothes Dryers. 10 CFR 430.32(h).

Shipment volumes have been on the rise since 2012. Gas dryers continue to account for about one-fifth of the market.



Source: *Consumer Clothes Dryers EERE 2022 NOPR*

Residential Clothes Washers (Front)

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 8.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.7	4.1	3.4	4.5	4.5	5.0	4.5	5.0	4.5	5.0	4.5	5.0
Integrated Modified Energy Factor (ft^3/kWh/cycle)[1]	2.16	2.76	1.84	2.76	2.76	3.10	2.76	3.10	2.76	3.10	2.76	3.10
Integrated Water Factor (gal/cycle/ft^3)[2]	4.7	3.2	4.7	3.2	3.2	2.7	3.2	2.7	3.2	2.7	3.2	2.7
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	17	14	16	14	14	14	14	14	14	14	14	14
Hot Water Energy (kWh/cycle)	0.21	0.17	0.36	0.12	0.12	0.13	0.12	0.13	0.12	0.13	0.12	0.13
Machine Energy (kWh/cycle)	0.17	0.14	0.15	0.12	0.12	0.17	0.12	0.17	0.12	0.17	0.12	0.17
Dryer Energy (kWh/cycle)	1.31	1.24	1.34	1.17	1.17	1.56	1.17	1.56	1.17	1.56	1.17	1.56
Retail Equipment Cost (2022$)	735	1,000	705	930	930	950	930	950	930	950	930	950
Total Installed Cost (2022$)	915	1,175	880	1,130	1,130	1,150	1,130	1,150	1,130	1,150	1,130	1,150
Annual Maintenance Cost (2022$)	15	15	15	15	15	15	15	15	15	15	15	15

1. The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.
2. The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

Note:
The current standard went into effect in January 2018.
ENERGY STAR V. 8.1 went into effect in February 2018.
The range for average life represents the span of typical values.

Residential Clothes Washers (Top)

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DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 8.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.3	3.4	3.5	3.5	4.4	5.5	3.5	5.5	3.5	5.5	3.5	5.5
Integrated Modified Energy Factor (ft^3/kWh/cycle)[1]	1.14	1.57	1.57	1.57	2.06	2.76	1.57	2.76	1.57	2.76	1.57	2.76
Integrated Water Factor (gal/cycle/ft^3)[2]	9.2	6.5	6.5	6.5	4.3	3.2	6.5	3.2	6.5	3.2	6.5	3.2
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	30	22	23	23	19	18	23	18	23	18	23	18
Hot Water Energy (kWh/cycle)	0.90	0.39	0.41	0.41	0.38	0.24	0.41	0.24	0.41	0.24	0.41	0.24
Machine Energy (kWh/cycle)	0.25	0.13	0.14	0.14	0.12	0.13	0.14	0.13	0.14	0.13	0.14	0.13
Dryer Energy (kWh/cycle)	1.73	1.63	1.68	1.68	1.64	1.61	1.68	1.61	1.68	1.61	1.68	1.61
Retail Equipment Cost (2022$)	590	590	520	520	640	725	520	725	520	725	520	725
Total Installed Cost (2022$)	765	765	715	715	840	920	715	920	715	920	715	920
Annual Maintenance Cost (2022$)	15	15	15	15	15	15	15	15	15	15	15	15

1. The efficiency metric changed from Modified Energy Factor to IMEF in 2015.
2. The efficiency metric changed from Water Factor to IWF in 2015.

Note:
The current standard went into effect in January 2018.
ENERGY STAR V. 8.1 went into effect in February 2018.
The range for average life represents the span of typical values.

Residential Clothes Washers

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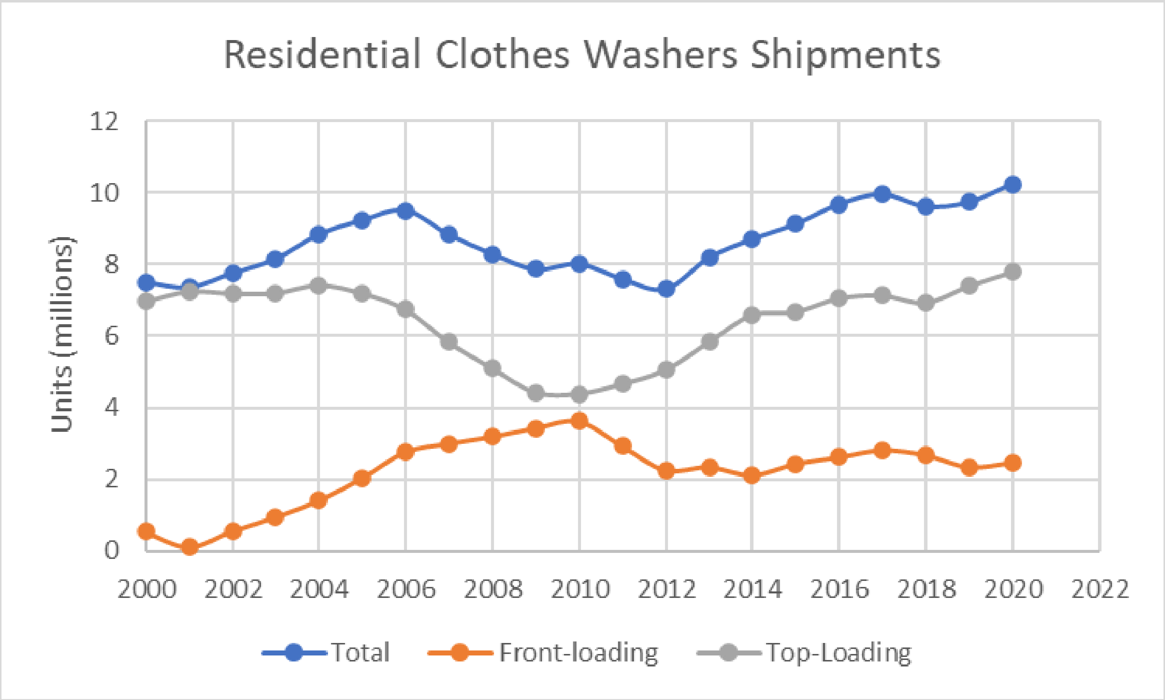
- The analysis treats front- and top-loading models separately due to their different energy use characteristics.
- Federal standards[1] for standard-capacity clothes washers (≥ 1.6 ft^3):

	Integrated Modified Energy Factor		Integrated Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard (effective 1/1/2018)	≥ 1.57	≥ 1.84	≤ 6.5	≤ 4.7
Current ENERGY STAR V. 8.1 (effective 4/22/2021)	≥ 2.06	≥ 2.76	≤ 4.3	≤ 3.2

- In 2020, about 40% of top-loading models and almost all front-loading models achieved the ENERGY STAR level.
- Energy efficiency improvement technologies for clothes washers include:
  - — Higher efficiency motors and higher spin speeds
  - — Better load sensing for adaptive water fill control
  - — Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance
- Maintenance costs include replacement or repair of the drain pump, control board, motor, rubber gaskets, or control panel knobs.
- The products on the market with the highest IMEF have significantly larger capacity and therefore use more energy per cycle than typical, smaller capacity products but still perform more efficiently on a per volume basis.

[1] Energy Conservation Standards for Consumer Clothes Washers. 10 CFR 430.32(g).

Shipments have been on the rise since 2012 and reached a peak of about 10 million in 2020. Since 2012, top-loading and front-loading units represent approximately 75% and 25% of shipments, respectively.



Source: *AHAM Shipment Data; RCW EERE 2021 Preliminary Analysis*

Residential Dishwashers

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DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 6.0	High	ENERGY STAR V. 7.0	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/y)	295	270	307	270	270	225	240	240	225	240	225	240	225
Water Consumption (gal/cycle)	4.25	3.50	5.00	3.50	3.50	2.40	3.20	3.20	2.40	3.20	2.40	3.20	2.40
Water Heating Energy Use (kWh/y)[1]	154	125	176	123	123	84	112	123	84	123	84	123	84
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	440	380	310	340	340	500	430	340	500	340	500	340	500
Total Installed Cost (2022$)	840	570	490	520	520	690	610	520	690	520	690	520	690
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-	-	-	-	-	-	-	-

1. Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
2. Maintenance costs are negligible.

Note:

All values in table reflect 215 cycles/year according to the current test procedure at 10 CFR 430 Appendix C1.
The current standard went into effect in May 2013.
ENERGY STAR V. 6.0 went into effect in January 2016.
ENERGY STAR V. 7.0 will go into effect in July 2023.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.9, 1.8, 1).

Residential Dishwashers

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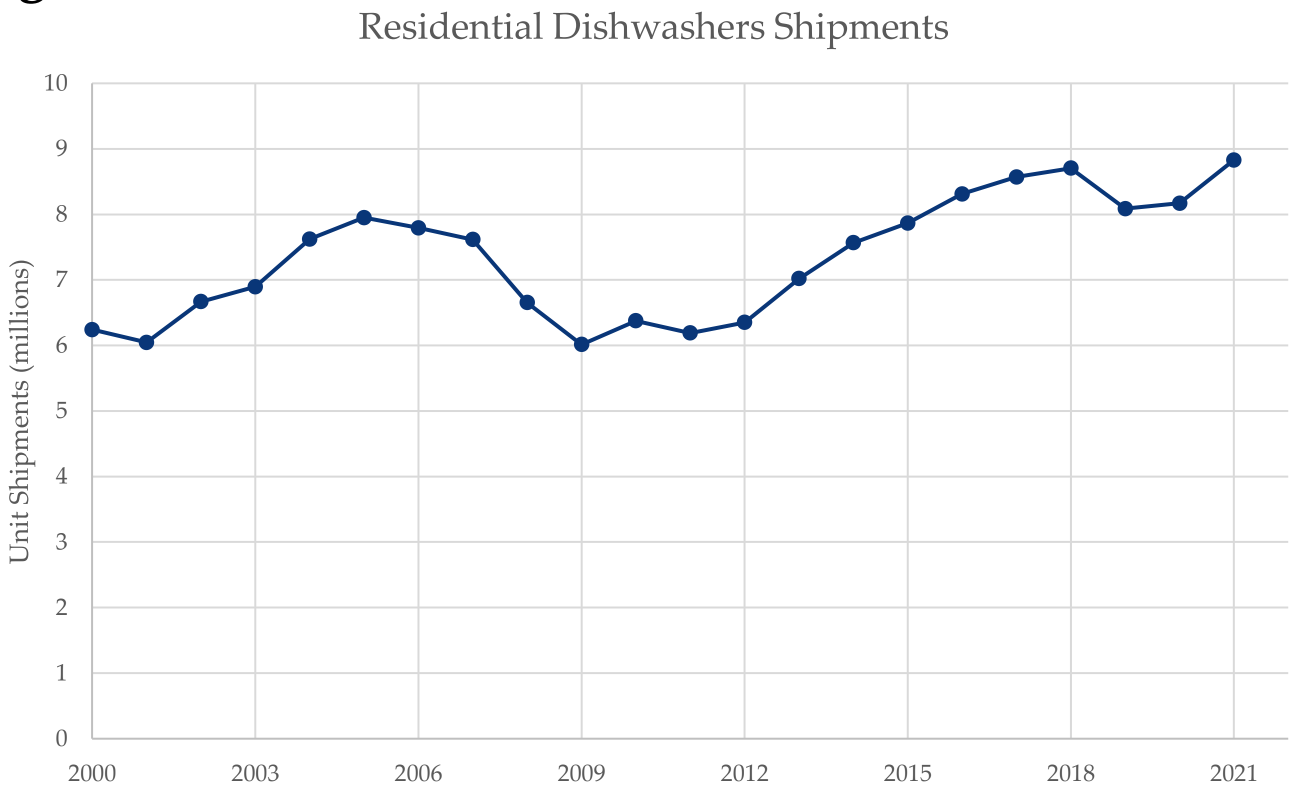
- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year):
  - Federal Standards:
    - May 30, 2013: ≤ 307 kWh/y, ≤ 5.0 gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Jan. 29, 2016: ≤ 270 kWh/y (5% allowance for connected), ≤ 3.5 gal/cycle (V. 6.0)
    - July 19, 2023: ≤ 240 kWh/y, ≤ 3.2 gal/cycle (V. 7.0, effective August 2023)
- ENERGY STAR has maintained a very high market share for several years (93% in 2021), so sales-weighted average efficiency has tracked ENERGY STAR levels.
  - Due to the historically high market penetration of ENERGY STAR products, it is expected that manufacturers will make the necessary adjustments so ENERGY STAR V. 7.0 levels will be typical in future projections.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater, as well as standby and off-mode energy.
  - ENERGY STAR established a cleaning performance test method. While cleaning performance reporting is currently optional, V. 7.0 requires a cleaning index of 65 or higher for ENERGY STAR certification.
  - In January 2023, DOE established a test procedure at Appendix C2, which would go into effect at the time of any amended energy conservation standards. Appendix C2 establishes a minimum cleaning index threshold of 70 as a condition for a valid test cycle. The cleaning index threshold of 70 established by DOE is equivalent to the cleaning index threshold of 65 specified in ENERGY STAR V. 7.0.
- Efficiency improvement technologies for dishwashers include:
  - Better soil sensing
  - Control strategies
  - Water distribution (small pipes, fine filter, small sump, multiple spray arms, alternating water use) and controls (flow meter, temperature sensor)
  - Inline water heater (to minimize sump volume)
  - Separate drain pump, high-efficiency, variable-speed circulation pump motor
  - Condensation drying (rather than power dry)

Shipments increased steadily from the early 1990s until the 2008-2009 recession. Shipments have resumed similar growth since then.



Source: *DW EERE 2022 Preliminary Analysis*

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Commercial Space Heating and Cooling

Commercial Gas-Fired Furnaces

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DATA	2012	2018	2022			2023[1]		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)[2]	400	400	250	250	250	250	250	250	250	250
Thermal Efficiency (%)[3]	80	80	80	81	81	81	81	81	81	81
Typical Output Capacity (kBtu/h)	320	320	200	203	203	203	203	203	203	203
Average Life (y)	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost (2022$)	1,230	1,230	1,230	1,260	1,260	1,260	1,260	1,260	1,260	1,260
Total Installed Cost (2022$)	2,540	2,540	2,540	2,580	2,580	2,580	2,580	2,580	2,580	2,580
Total Installed Cost (2022$/kBtu/h)	8	8	13	13	13	13	13	13	13	13
Annual Maintenance Cost (2022$)	200	200	200	200	200	200	200	200	200	200
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1	1	1	1

1. In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces (CWAF) took effect. These projections reflect the 2023 minimum thermal efficiency requirement for gas-fired furnaces, 81%.
2. When this analysis was previously conducted in EIA Technology Forecast Updates (2018), a typical input capacity of 400 kBtu/h was listed. An updated typical input capacity value of 250 kBtu/h was determined through an evaluation of the units in the DOE CCD as of August 2022. CWAF EERE 2015 also listed a representative input capacity of 250 kBtu/h.
3. DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Note:

The previous standard went into effect in January 1994. The current standard went into effect in January 2023.

Commercial Gas-Fired Furnaces

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- Until 2022, the Federal standard required minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applied to all units manufactured on or after January 1, 1994, with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increased to 81% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial furnaces are typically non-condensing with thermal efficiencies ranging from 80% to 81%. Condensing commercial furnaces, which can achieve up to 95% thermal efficiency, were previously introduced to the market but are not currently available due to cost and reliability concerns. The highest thermal efficiency included in DOE's CCD at this time is 81%.
- Besides capacity, commercial units can differ from residential furnaces in terms of the control system (i.e., integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.

Commercial Gas-Fired Furnaces

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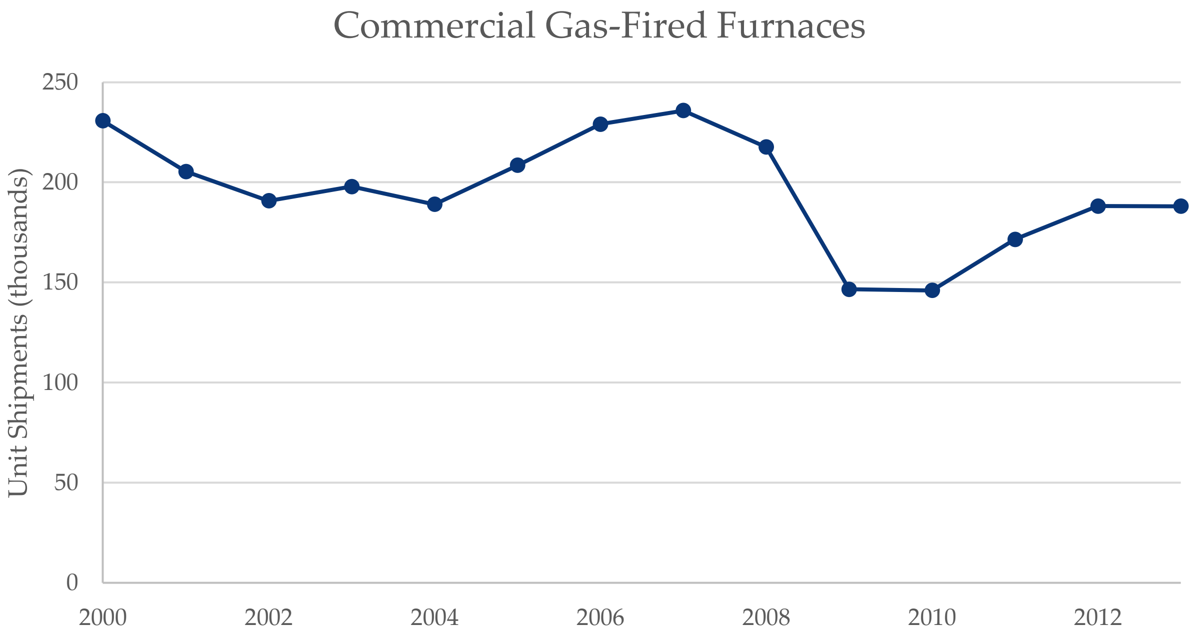
Annual shipments reached a peak of 235.9 thousand units in 2007. Following a decline in shipments after 2007, shipments increased to 188.1 thousand units in 2013. Shipment data after 2013 is not available.



Source: *AHRI*

Commercial Oil-Fired Furnaces

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DATA	2012	2018	2022			2023[1]	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	250	250	250	250	250	250	250	250	250	250
Thermal Efficiency (%)[2]	81	82	81	82	85	82	82	85	82	85	82	85
Typical Output Capacity (kBtu/h)	324	328	203	205	213	205	205	213	205	213	205	213
Average Life (y)	23	23	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost (2022$)	5,500	5,560	5,500	5,560	6,020	5,560	5,560	6,020	5,560	6,020	5,560	6,020
Total Installed Cost (2022$)	7,740	7,810	7,740	7,810	8,380	7,810	7,810	8,380	7,810	8,380	7,810	8,380
Total Installed Cost (2022$/kBtu/h)	24	24	38	38	39	38	38	39	38	39	38	39
Annual Maintenance Cost (2022$)	360	360	360	360	370	360	360	370	360	370	360	370
Annual Maintenance Cost (2022$/kBtu/h)	1	1	2	2	2	2	2	2	2	2	2	2

1. In 2023, the new Energy Conservation Standards for CWAF took effect. These projections reflect the 2023 minimum thermal efficiency requirement for oil-fired furnaces, 82%.
2. DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Note:
The previous standard went into effect in January 1994. The current standard went into effect in January 2023.

Commercial Oil-Fired Furnaces

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- Until 2022, the Federal standard required minimum 81% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applied to all units manufactured on or after January 1, 1994, with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increased to 82% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial oil-fired furnaces have thermal efficiencies ranging from 81% to 85% and are non-condensing (i.e., not designed for condensation of flue gases).
- Besides capacity, commercial units can differ in terms of the control system (i.e., integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Commercial Oil-Fired Furnaces

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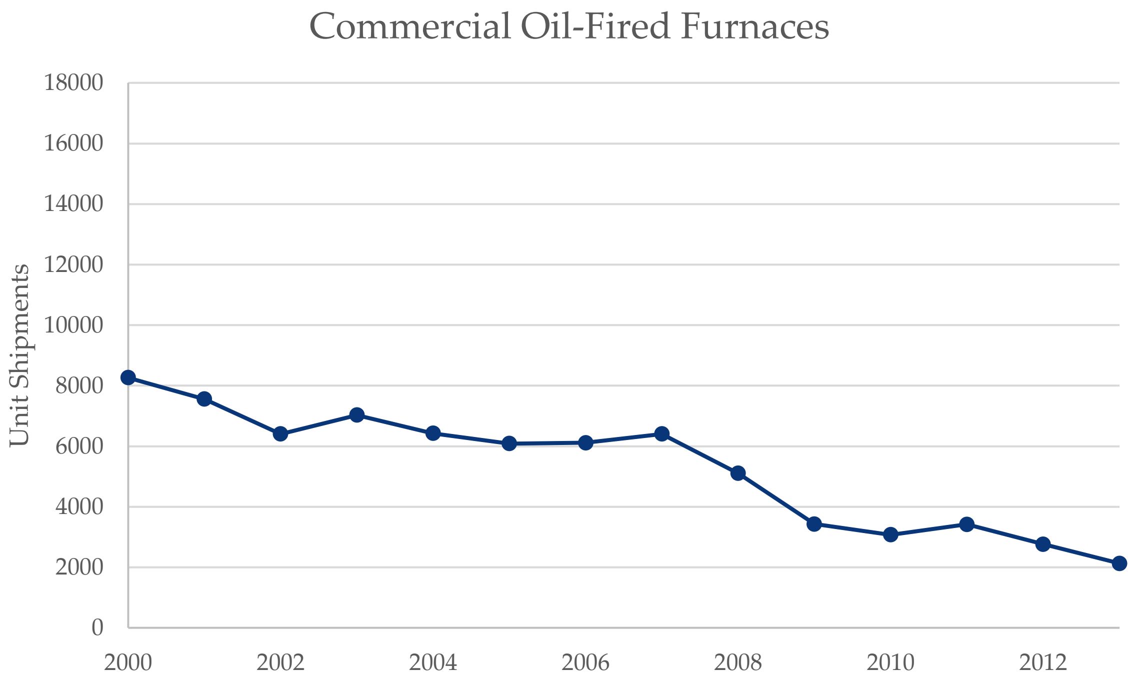
Annual shipments for commercial oil-fired furnaces have steadily decreased over time to 2,127 units in 2013. Shipment data after 2013 is not available.



Source: *AHRI*

Commercial Electric Resistance Heaters

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DATA	2012		2018		2022		2030		2040		2050	
	Installed Base: Small	Installed Base: Large	Installed Base: Small	Installed Base: Large	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBtu/h)[1]	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	100	100	100	100	100	100	100	100	100	100	100	100
Average Life (y)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	1,000	6,320	1,000	6,320	500	4,630	500	4,630	500	4,630	500	4,630
Total Installed Cost (2022$)	1,240	7,470	1,240	7,470	660	5,470	660	5,470	660	5,470	660	5,470
Total Installed Cost (2022$/kBtu/h)	73	44	73	44	39	32	39	32	39	32	39	32
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-	-	-	-	-	-	-
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-	-	-	-	-	-	-

1. Capacity is output.
2. Annual Maintenance Cost is negligible.

Commercial Electric Resistance Heaters

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- This analysis examined standard suspended electric wall and ceiling unit heaters, which are more common in commercial settings than baseboard electric heaters that were considered for the residential analysis.
- Electric unit heaters range in capacity from 2 to 80 kW (7 to 270 kBtu/h), with 5 to 50 kW (17 to 170 kBtu/h) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion.
- Installation time and costs are estimated to be minimal.

Commercial Electric Boilers

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DATA	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kW)[1]	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (y)	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	11,620	11,590	9,790	9,790	9,790	9,790
Total Installed Cost (2022$)[2]	17,500	13,820	11,950	11,950	11,950	11,950
Total Installed Cost (2022$/kBtu/h)	31	25	21	21	21	21
Annual Maintenance Cost (2022$)[2]	170	130	130	130	130	130
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-

1. Capacity is output.
2. Retail and installed costs for 2022 and forecasts for 2030 and beyond are based on Gordian's RSMeans Data – Building Construction Costs 2023. Maintenance costs are same as EIA Technology Forecast Updates (2018), updated to reflect 2022$. The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/h. Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.

Commercial Electric Boilers

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- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/h.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkalizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Commercial Gas-Fired Boilers

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DATA	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard[1]	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)[2]	77	85	80	85	99	84	85	99	85	99	85	99	85	99
Average Life (y)	30	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	15,530	25,910	19,150	25,910	42,670	24,320	25,910	42,670	25,910	42,670	25,910	42,670	25,910	42,670
Total Installed Cost (2022$)	24,600	38,330	30,470	38,330	55,230	35,650	38,330	55,230	38,330	55,230	38,330	55,230	38,330	55,230
Total Installed Cost (2022$/kBtu/h)	40	56	48	56	70	53	56	70	56	70	56	70	56	70
Annual Maintenance Cost (2022$)[3]	1,710	2,100	2,100	2,100	2,140	2,100	2,100	2,140	2,100	2,140	2,100	2,140	2,100	2,140
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3	3	3	3

1. The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) gas-fired hot water commercial packaged boilers, which are the most common type of boilers available on the market.
2. DOE's efficiency metric for most boiler types accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead, for hot water boilers with heat input > 2,500,000 Btu/h.
3. Maintenance costs for 2018 and post-2018 are based on Commercial Packaged Boilers EERE 2020. The annualized maintenance costs estimated in the final rule differ for condensing vs. non-condensing boilers. Appendix 8E of the Commercial Packaged Boilers EERE 2020 TSD provides additional information on how the values are calculated.

Note:

The previous standard went into effect in March 2012.

The current standard went into effect in January 2023.

In December 2016, DOE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. This rule published in January 2020 with an effective date for January 2023.

Commercial Gas-Fired Boilers

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- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not) – for steam boilers
- The most common type of commercial gas-fired boilers are small gas-fired hot water boilers with 300,000-2,500,000 Btu/h rated heat input.
- Similar technologies to those used in the residential gas-fired boilers market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. Some gas-fired boilers also condense water vapor from the flue gases to improve heating efficiency.
- DOE published a final rule for commercial packaged boilers in January 2020 that updated the efficiency ratings of gas-fired commercial packaged boilers beginning January 2023.

Commercial Gas-Fired Boilers

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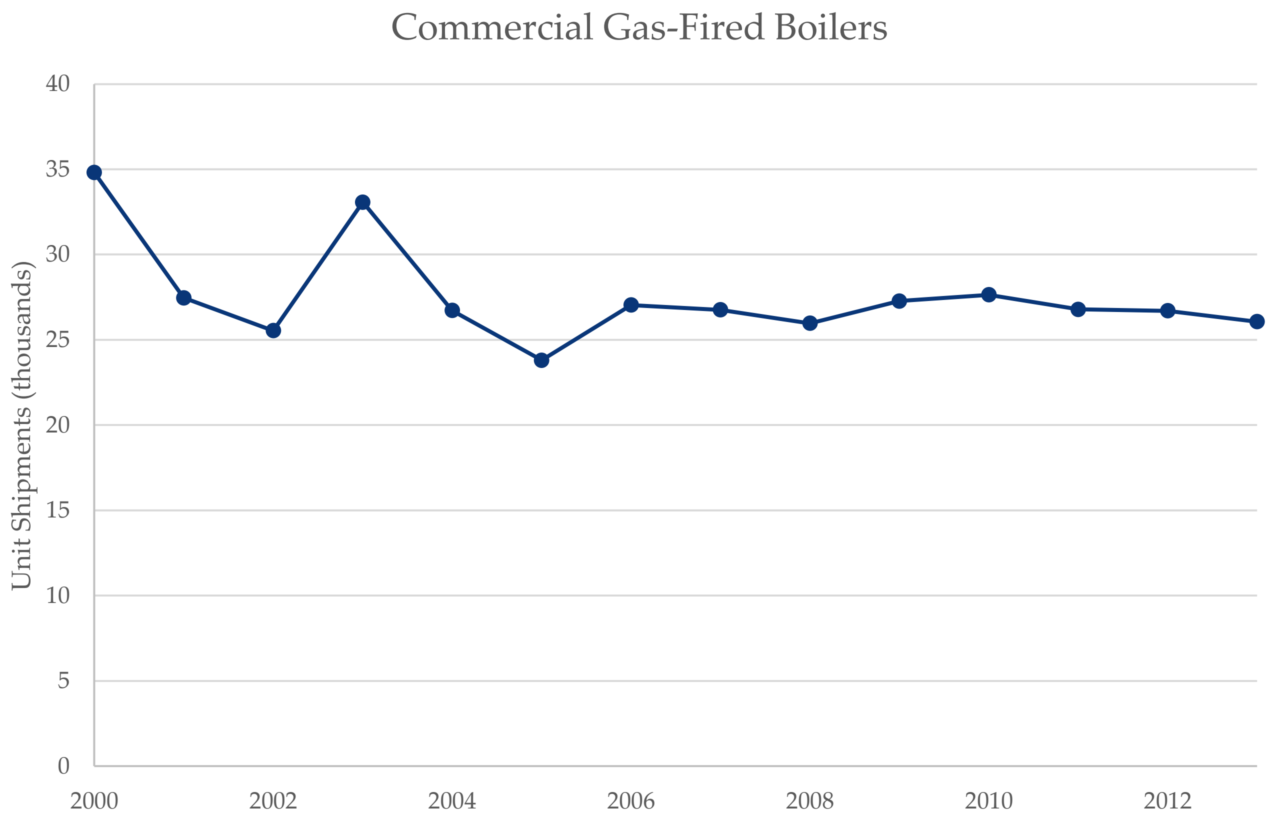
Shipments of commercial gas-fired boilers peaked in 2000 and have been steadily declining since 2010. Shipment data after 2013 is not available.



Source: *Commercial Packaged Boilers EERE 2020*

Commercial Oil-Fired Boilers

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DATA	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard[1]	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)[2]	81	85	82	85	97	87	87	97	87	97	87	97	87	97
Average Life (y)	30	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	16,830	26,810	23,190	26,810	51,480	29,730	29,730	51,480	29,730	51,480	29,730	51,480	29,730	51,480
Total Installed Cost (2022$)	22,000	37,240	33,100	37,240	62,910	40,160	40,160	62,910	40,160	62,910	40,160	62,910	40,160	62,910
Total Installed Cost (2022$/kBtu/h)	23	55	50	55	81	58	58	81	58	81	58	81	58	81
Annual Maintenance Cost (2022$)[3]	1,710	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690
Annual Maintenance Cost (2022$/kBtu/h)	2	4	4	4	3	4	4	3	4	3	4	3	4	3

1. The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) oil-fired hot water commercial packaged boilers, which are the most common type of boilers available on the market.
2. DOE's efficiency metric for most boiler types accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead, for hot water boilers with heat input > 2,500,000 Btu/h.
3. Maintenance costs for 2018 and post-2018 are based on Commercial Packaged Boilers EERE 2020. The annualized maintenance costs estimated in the final rule differ for condensing vs. non-condensing boilers. Appendix 8E of the Commercial Packaged Boilers EERE 2020 TSD provides additional information on how the values are calculated.

Note:

The previous standard went into effect in March 2012.

The current standard went into effect in January 2023.

In December 2016, DOE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. This rule published in January 2020 with an effective date for January 2023.

Commercial Oil-Fired Boilers

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- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- The most common type of commercial oil-fired boilers are small hot water boilers with 300,000-2,500,000 Btu/h rated heat input.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- DOE published a final rule for commercial packaged boilers in January 2020 that updated the efficiency ratings of oil-fired commercial packaged boilers beginning January 2023.

Commercial Oil-Fired Boilers

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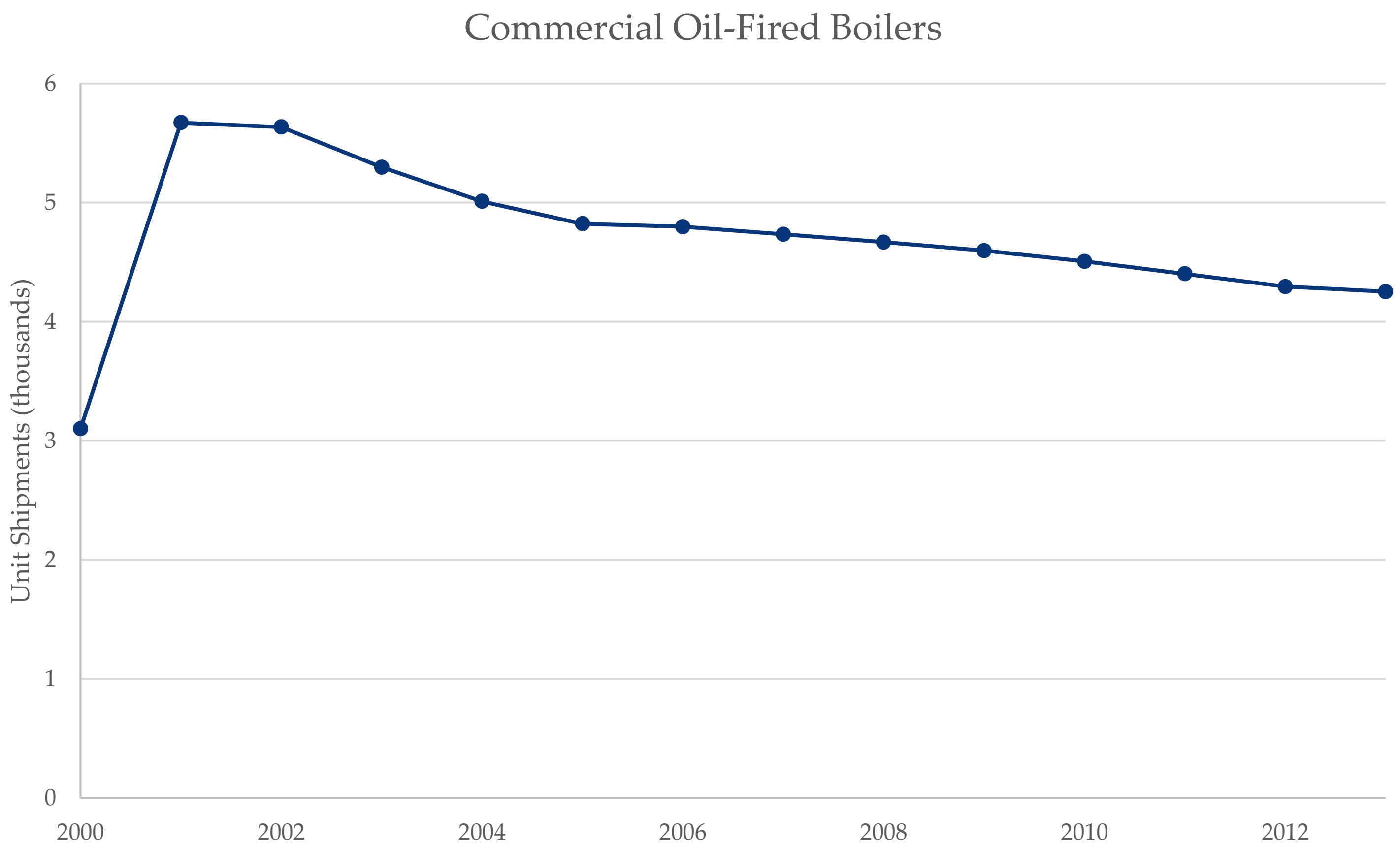
Shipments of commercial oil-fired boilers peaked in 2001 and have been decreasing since then.



Source: *Commercial Packaged Boilers EERE 2020*

Commercial Centrifugal Chillers (Water-Cooled)

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DATA	2012	2018	2022[2]			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[1]	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)	0.66	0.53	0.56	0.52	0.45	0.49	0.42	0.46	0.41	0.45	0.40
Efficiency [IPLV] (kW/ton)	0.61	0.37	0.50	0.31	0.30	0.30	0.28	0.29	0.26	0.28	0.25
COP [full-load]	5.4	6.6	6.3	6.8	7.8	7.2	8.4	7.6	8.6	7.8	8.8
COP [IPLV]	5.9	9.5	7.0	11.3	11.7	11.7	12.6	12.1	13.5	12.6	14.1
Average Life (y)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$/ton)	380	500	480	500	680	590	760	660	780	690	810
Total Installed Cost (2022$/ton)	440	560	480	560	740	640	820	720	840	740	870
	500	590	540	590	760	670	830	740	860	760	880
Total Installed Cost (2022$/kBtu/h)	39	48	43	48	63	55	69	61	71	63	73
Annual Maintenance Cost (2022$/ton)	30	30	30	30	30	30	30	30	30	30	30
	40	40	40	40	40	40	40	40	40	40	40
Annual Maitnenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. Capacity is output.
2. ASHRAE 90.1 data are for units larger than 400 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019). Typical and high efficiency levels are determined based on the range of products currently available on the market.

Note:

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the integrated part-load value (IPLV)) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

Ranges represent the span of typical values for a given parameter.

Commercial Centrifugal Chillers (Water-Cooled)

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- ASHRAE 90.1-2019 stipulates minimum efficiencies for centrifugal chillers separately from positive displacement water-cooled chillers. They are separated into 5 size categories, with categories divided at: 150, 300, 400, and 600 tons; ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly high full-load consumption in exchange for much lower part-load consumption. For example, for a 600-ton unit:
  - Path A: ≥ 0.56 kW/ton full-load and ≥ 0.50 kW/ton IPLV
  - Path B: ≥ 0.585 kW/ton full-load and ≥ 38 kW/ton IPLV
- Federal Energy Management Program (FEMP) recommendations, last updated in 2020, match ASHRAE 90.1-2019.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e.g., crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.
- Water-cooled chiller ratings do not include energy consumption of the cooling tower and therefore are not directly comparable to rating for air-cooled chillers. Water-cooled centrifugal chillers were selected for analysis due to a higher model share on the AHRI directory in comparison to air-cooled chillers.

Commercial Reciprocating Chillers (Air-Cooled Only)

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DATA	2012	2018	2022[2]			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[1]	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)	1.26	1.19	1.19	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)	1.13	0.86	0.86	0.86	0.80	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load]	2.8	3.0	3.0	3.0	3.5	3.1	3.5	3.1	3.5	3.1	3.5
COP [IPLV]	3.1	4.1	4.1	4.1	4.5	4.4	4.5	4.4	4.5	4.4	4.5
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	725	820	820	820	1,030	820	1,030	820	1,030	820	1,030
	600	730	730	730	880	730	880	730	880	730	880
Total Installed Cost (2022$/ton)	800	880	880	880	1,180	880	1,180	880	1,180	880	1,180
	700	760	760	760	1,090	760	1,090	760	1,090	760	1,090
Total Installed Cost (2022$/kBtu/h)	63	68	68	68	95	68	95	68	95	68	95
Annual Maintenance Cost (2022$/ton)	45	45	50	50	50	45	50	45	50	45	50
	25	25	30	30	30	25	30	25	30	25	30
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. Capacity is output.
2. ASHRAE 90.1 data are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019). Typical and high efficiency levels are determined based on the range of products currently available on the market.

Note:

This analysis covers air-cooled chillers only.

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

Ranges represent the span of typical values for a given parameter.

Commercial Reciprocating Chillers (Air-Cooled Only)

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- Reciprocating chillers are most cost effective for small loads (30 to 150-ton range). However, reciprocating chiller market share continues to be supplanted by screw and scroll chillers. This trend has accelerated with the phase out of R-22, which was the refrigerant of choice for reciprocating products, which has in turn driven major manufacturers to replace their reciprocating product lines with scroll products (rather than redesign reciprocating products for new refrigerants). As a result, product options are very limited.
- Reciprocating chillers can be used in either air-cooled or water-cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including reciprocating chillers, while water-cooled chillers are separated by positive displacement (e.g., reciprocating) versus centrifugal models. Air-cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 13.7 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 15.8 IPLV EER
- FEMP (2022) recommendations for air-cooled chillers are:
  - Path A (<150 tons): ≥ 10.89 EER full-load and ≥ 13.7 IPLV EER
  - Path B (<150 tons): ≥ 9.7 EER full-load and ≥ 16.86 IPLV EER (same as 90.1-2019)
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Commercial Screw Chillers (Air-Cooled Only)

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019[1]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)	1.26	1.18	1.19	1.15	0.92	1.13	0.91	1.04	0.86	0.98	0.81
Efficiency [IPLV] (kW/ton)	1.13	0.84	0.86	0.81	0.55	0.79	0.53	0.72	0.49	0.68	0.45
COP [full-load]	2.8	3.0	3.0	3.1	3.8	3.1	3.9	3.4	4.1	3.6	4.3
COP [IPLV]	3.1	4.2	4.1	4.4	6.4	4.5	6.6	4.9	7.2	5.2	7.8
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	760	970	1,130	1,130	1,230	1,140	1,230	1,180	1,250	1,200	1,270
	620	850	770	770	870	780	870	820	890	840	910
Total Installed Cost (2022$/ton)	910	1,150	1,250	1,250	1,350	1,260	1,350	1,300	1,370	1,320	1,390
	850	940	820	820	920	830	920	870	940	890	960
Total Installed Cost (2022$/kBtu/h)	73	87	86	86	95	87	95	90	96	92	98
Annual Maintenance Cost (2022$/ton)	50	50	50	50	50	50	50	50	50	50	50
	20	20	20	20	20	20	20	20	20	20	20
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. ASHRAE 90.1 data for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019).

Note:

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

Ranges represent the span of typical values for a given parameter.

Commercial Screw Chillers (Air-Cooled Only)

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- Screw chillers are common in 150 to 500-ton capacities but are most cost effective for small (<300 tons) loads; screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water-cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including screw chillers, while water-cooled chillers are separated by positive displacement (e.g., screw) versus centrifugal models. Air-cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a ≥ 150-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 14.0 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 16.1 IPLV EER
- FEMP recommendations for air-cooled chillers (updated June 2020) are:
  - Path A (≥ 150 tons): ≥ 10.7 EER full-load and ≥ 14.0 IPLV EER
  - Path B (≥ 150 tons): ≥ 9.7 EER full-load and ≥ 16.4 IPLV EER
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers

Commercial Scroll Chillers (Air-Cooled Only)

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019[1]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	50	50	50	50	50	50	50	50	50	50	50
	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)	1.23	1.16	1.19	1.15	1.07	1.11	1.06	1.07	1.02	1.02	0.97
Efficiency [IPLV] (kW/ton)	0.99	0.77	0.88	0.77	0.70	0.73	0.68	0.71	0.65	0.69	0.62
COP [full-load]	2.9	3.0	3.0	3.1	3.3	3.2	3.3	3.3	3.4	3.4	3.6
COP [IPLV]	3.7	4.6	4.0	4.6	5.0	4.8	5.2	5.0	5.4	5.1	5.7
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	680	1,000	1,060	1,060	1,160	1,120	1,160	1,150	1,200	1,200	1,240
	560	820	530	530	630	590	630	620	670	670	710
Total Installed Cost (2022$/ton)	970	1,210	1,170	1,170	1,270	1,230	1,270	1,260	1,310	1,310	1,350
	850	970	860	860	960	920	960	950	1,000	1,000	1,040
Total Installed Cost (2022$/kBtu/h)	76	91	85	85	93	90	93	92	96	96	100
Annual Maintenance Cost (2022$/ton)	60	60	60	60	60	60	60	60	60	60	60
	40	40	40	40	40	40	40	40	40	40	40
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4

1. ASHRAE 90.1 data for units less than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019).

Note:
For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.
ASHRAE 90.1 went into effect in October 2019.
Ranges represent the span of typical values for a given parameter.

Commercial Scroll Chillers (Air-Cooled Only)

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- Scroll chillers range in size from ~20 tons to ~200 tons and can be used in either air-cooled or water-cooled applications. They are the most common type of chiller for small chiller plants. The scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including scroll chillers, while water-cooled chillers are separated by positive displacement (e.g., scroll) versus centrifugal models. Air-cooled chiller efficiencies are distinct for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 13.7 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated June 2020) are:
  - Path A (< 150 tons): ≥ 10.7 EER full-load and ≥ 13.7 IPLV EER
  - Path B (< 150 tons): ≥ 9.7 EER full-load and ≥ 15.9 IPLV EER
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers
  - Variable speed compressor (or other modulation controls)
- With the phase out of R-22, manufacturers have replaced many of their small reciprocating chiller products with equivalent scroll products, making them a primary choice for small tonnage applications.

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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DATA	2012		2018		2022				2030		2040		2050	
	Installed Base: Absorption	Installed Base: Engine-Driven	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1-2019 Absorption	CA Title 24 – Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
Typical Capacity (tons)[1]	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP [full-load]	1.1	1.7	1.2	1.7	1.0	1.2	1.2	1.7	1.3	1.8	1.4	1.8	1.4	1.8
COP [IPLV]	NA	NA	1.6	2.6	1.0	2.0	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6
Average Life (y)	23	25	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost (2022$/ton)	1,060	1,000	1,060	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000
	880	880	880	880	870	880	870	880	870	880	870	880	870	880
Total Installed Cost (2022$/ton)	1,290	1,240	1,180	1,240	1,110	1,240	1,110	1,240	1,110	1,240	1,110	1,240	1,110	1,240
	1,000	1,000	1,000	1,000	850	1,000	850	1,000	850	1,000	850	1,000	850	1,000
Total Installed Cost (2022$/kBtu/h)	95	93	91	93	82	93	82	93	82	93	82	93	82	93
Annual Maintenance Cost (2022$/ton)	40	60	40	60	40	60	40	60	40	60	40	60	40	60
	20	40	20	40	20	40	20	40	20	40	20	40	20	40
Annual Maintenance Cost (2022$/kBtu/h)	3	4	3	4	3	4	3	4	3	4	3	4	3	4

1. Capacity is output.

Note:

This analysis assumes a water-cooled chiller; both gas-fired chiller types (absorption and engine-driven) are shown. COP values for double-effect absorption chillers are shown.

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

CA Title 24 went into effect in January 2020.

Ranges represent the span of typical values for a given parameter.

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis covers only water-cooled chillers of two varieties: absorption and engine-driven vapor compression (direct-fired only; indirect steam or hot water driven units are excluded).
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect systems. Triple effect chillers, though not commercially available, can boost cooling COP 30-50% beyond double effect chillers. Some companies have worked on prototype direct-fired triple effect absorption chillers, but prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers suggests that this technology will not likely have an impact on the market in the near-term.
- Gas-fired engine-driven chillers pair conventional vapor compression systems (typically screw or centrifugal compressors) with natural gas powered-reciprocating engines. They exhibit higher peak cooling COP than absorbers, and engine modulation results in better part-load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine-driven chillers allow the opportunity to recover waste heat for useful purposes.
- Maintenance costs for engine-driven chillers are higher than for other chillers because they include all the typical components of a vapor compression chiller in addition to an engine; the engine maintenance costs vary depending on the annual run hours of the unit.
- Limited sales data suggest that the U.S. market for gas-fired chillers is very limited and is mostly for replacement units, not for new installations. Recent increases in electric chiller efficiency have narrowed the operating cost differential with gas chillers. Asia has the majority of the global gas-fired chiller market.
- Gas-fired chiller installations are particularly valuable in locations where electric rates are high and gas prices are low (i.e., low spark spread), where digester or landfill gas sources are available, or where waste heat sources are available (e.g., an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Commercial Rooftop Air Conditioners

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DATA	2012	2018	2022[4]				2023				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.1	High	New Standard	Typical	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Part Load Efficiency (IEER)[1]	12.4	12.9	12.9	12.9	14.0	23.3	14.8	14.8	18.0	23.3	15.1	23.3	15.1	23.3	15.1	23.3
Efficiency (EER)[2]	10.6	11.5	11.5	11.5	12.2	12.8	12.2	12.2	12.7	12.8	12.2	12.8	12.2	12.8	12.2	12.8
Efficiency Conversion	3.6	3.8	3.8	3.8	4.1	6.8	4.3	4.3	5.3	6.8	4.4	6.8	4.4	6.8	4.4	6.8
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	7,760	8,280	8,280	8,280	9,090	12,210	9,490	9,490	10,340	12,210	9,590	12,210	9,590	12,210	9,590	12,210
Total Installed Cost (2022$)	10,350	11,870	11,870	11,870	13,020	17,600	13,560	13,560	14,970	17,600	13,720	17,600	13,720	17,600	13,720	17,600
Total Installed Cost (2022$/kBtu/h)	115	132	132	132	145	196	151	151	166	196	152	196	152	196	152	196
Annual Maintenance Cost (2022$)[3]	370	370	370	370	370	370	370	370	370	370	370	370	370	370	370	370
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

1. Values shown are for air-cooled small commercial packaged air conditioners with either electric resistance heating or no heating within the same enclosure. DOE published a direct final rule for commercial packaged air conditioners and heat pumps in January 2016 with initial standards becoming effective in 2018 and additional standards becoming effective in 2023. As part of this rulemaking, DOE changed the regulated metric from EER to integrated energy efficiency ratio (IEER).
2. DOE investigated the relationship between IEER and EER. Because the relationship between IEER and EER is weak, this analysis estimates EER values based on the average of the values seen at a given IEER.
3. Examples of annual maintenance services include, check tensions, condition, and alignment of belts and adjust as necessary; lubricate shaft and motor bearings; replace air filters; clean coils, drain pan and piping, blowers, fan motors as required; check refrigerant pressure and compressor oil level; etc.
4. The 2022 typical efficiency is based on the average IEER from DOE's CCD. The 2022 high efficiency is based on the most-efficient model in DOE's CCD, but costs are estimated based on the most efficient unit analyzed in CUAC EERE 2016, which had an IEER of 21.5.

Note:
EER is the ratio of the cooling capacity (in Btu/h) to the power input (in watts) and provides a measure of the efficiency of equipment operating at full load (i.e., 100 percent cooling capacity) in high-ambient-temperature conditions (i.e., 95 °F). IEER is a single number part-load efficiency based on weighting of EER at various load capacities. Efficiency Conversion is the conversion of IEER from a [(Btu/h)/W] metric to a metric in the same units.
The previous standard went into effect in January 2018. The current standard went into effect in January 2023.
ENERGY STAR V. 3.1 went into effect in January 2018. ENERGY STAR V. 4.0 went into effect in January 2023.

Commercial Rooftop Air Conditioners

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- Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2018 Min. IEER	Federal Standard Effective 1/1/2023 Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	12.9	14.8
	Any other type	12.7	14.6
Large (≥ 135 and < 240)	Electric resistance or none	12.4	14.2
	Any other type	12.2	14.0

- This analysis focused on small air-cooled commercial packaged rooftop air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- Amended standards in terms of IEER for all equipment classes took effect in January 2018. More stringent standards in terms of IEER for all equipment classes took effect in January 2023.

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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DATA	2012[1]	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (tons)	18	11	11	11	11	11
Heating COP	1.4	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.9	1.2	1.2	1.2	1.2	1.2
Average Life (y)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	3,350	2,820	3,710	3,710	3,710	3,710
Total Installed Cost ($/ton)	3,820	3,290	4,110	4,110	4,110	4,110
Total Installed Cost ($/kBtu/h)	318	274	343	343	343	343
Annual Maintenance Cost (2022$)	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	6	6	6	6	6	6

1. The 2012 typical capacity and cooling COP were estimated as a simple average between obsolete pre-2003 units and 2013 units, which first became available in 2010; this assumes that each vintage represents about half of the installed base.

Note:
Only one product was available in 2012; the market has grown slightly in years since. Typical capacity and COP for 2018 and later are averages of units available as of 2017.

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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- There are only a few gas-fired engine-driven rooftop units currently available in the U.S. market. The first unit was introduced in 2010. It is an 11-ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

Commercial Rooftop Heat Pumps

Final

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DATA	2012	2018	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.1	High	New Standard	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Part Load Efficiency (IEER)[1]	12.0	11.3	12.2	14.3	12.8	20.3	14.1	15.3	20.3	14.4	20.3	15.3	20.3	15.3	20.3
EER	10.2	11.2	11.3	11.5	11.8	13.0	12.0	11.8	13.0	11.7	13.1	11.7	13.1	11.7	13.1
COP (Heating)	3.3	3.3	3.3	3.4	3.4	3.7	3.4	3.5	3.7	3.4	3.7	3.5	3.7	3.5	3.7
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	7,490	7,490	9,000	10,250	9,380	12,920	10,160	10,600	12,920	10,290	12,920	10,600	12,920	10,600	12,920
Total Installed Cost (2022$)	9,350	9,350	12,900	14,940	13,530	18,860	14,810	15,520	18,860	15,000	18,860	15,510	18,860	15,510	18,860
Total Installed Cost (2022$/kBtu/h)	104	104	143	166	150	210	165	172	210	167	210	172	210	172	210
Annual Maintenance Cost (2022$)	380	380	380	380	380	380	380	380	380	380	380	380	380	380	380
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

1. Values shown are for air-cooled small commercial packaged heat pumps with either electric resistance heating or no heating within the same enclosure. DOE published a direct final rule for commercial packaged air conditioners and heat pumps in January 2016 with initial standards becoming effective in 2018 and additional standards becoming effective in 2023. As part of this rulemaking, DOE changed the regulated metric from EER to IEER.

Note:
The previous standard went into effect in January 2018. The current standard went into effect in January 2023.
ENERGY STAR V. 3.1 went into effect in January 2018. ENERGY STAR V. 4.0 went into effect in January 2023.

Commercial Rooftop Heat Pumps

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- Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2018 Min. IEER	Federal Standard Effective 1/1/2023 Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	12.2	14.1
	Any other type	12.0	13.9
Large (≥ 135 and < 240)	Electric resistance or none	11.6	13.5
	Any other type	11.4	13.3

- This analysis focused on small air-cooled commercial packaged rooftop heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.
- Amended standards in terms of IEER for all equipment classes took effect in 2018. More stringent standards in terms of IEER for all equipment classes took effect in 2023.

Commercial Ground-Source Heat Pumps

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)[1]	3.1	3.7	3.2	3.5	3.6	3.5	3.6	3.5	3.6	3.5	3.6
EER (Cooling)[2]	12.7	17.4	14.1	17.0	21.6	17.0	21.6	17.0	21.6	17.0	21.6
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	10,470	6,470	5,590	6,470	7,880	6,470	7,880	6,470	7,880	6,470	7,880
Total Installed Cost (2022$)	19,760	18,230	17,350	18,230	19,650	18,230	19,650	18,230	19,650	18,230	19,650
	44,820	26,520	25,580	26,520	27,880	26,520	27,880	26,520	27,880	26,520	27,880
Total Installed Cost (2022$/kBtu/h)	673	466	447	466	495	466	495	466	495	466	495
Annual Maintenance Cost (2022$)	180	180	180	180	180	180	180	180	180	180	180
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4

1. COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.
2. EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note:
Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs. 4-ton) and slightly higher installation costs for commercial GSHP. DOE does not distinguish between residential and commercial units in its regulations.

Commercial Ground-Source Heat Pumps

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- The most common commercial ground-source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions require 77 °F entering water temperature and 80.6 °F entering air temperature. More typical peak design criteria would be 80-90 °F entering water temperature and 75 °F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part-load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR criteria for ground-source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed ECM fan motors also improve overall energy efficiency.

Packaged Terminal Air Conditioners

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High[2]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)[1]	9	9	9	9	9	9	9	9	9	9	9
Efficiency (EER)	11.3	11.3	11.3	11.3	13.1	11.3	13.1	11.3	13.1	11.3	13.1
Efficiency	3.3	3.3	3.3	3.3	3.8	3.3	3.8	3.3	3.8	3.3	3.8
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost (2022$)	1,460	1,460	1,460	1,460	1,560	1,460	1,560	1,460	1,560	1,460	1,560
Total Installed Cost (2022$)	1,740	1,740	1,740	1,740	1,840	1,740	1,840	1,740	1,840	1,740	1,840
Total Installed Cost (2022$/kBtu/h)	193	193	193	193	204	193	204	193	204	193	204
Annual Maintenance Cost (2022$)	70	70	70	70	70	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	8	8	8	8	8	8	8	8	8	8	8

1. Typical capacity is representative of units with the most shipments. It was also the representative cooling capacity for DOE's analysis in packaged terminal air conditioners (PTAC) and packaged terminal heat pumps (PTHP) EERE 2022 NOPD.
2. High values for 2022 and beyond are based on the max-tech level from PTAC & PTHP EERE 2022 NOPD.

Note:

The current standard went into effect in January 2017.

Packaged Terminal Air Conditioners

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- PTAC are a self-contained, ductless air conditioning system used for commercial applications.
- Analysis was conducted for the standard equipment class at the representative cooling capacity of 9000 Btu/h.

Cooling Capacity (kBtu/h)	Equipment Size	Equipment Class	Federal Standard EER
PTAC	Standard	< 7000	11.9
		≥7,000 Btu/h and ≤15,000 Btu/h	14.0 – (0.3 x Cap)
		> 15,000 Btu/h	9.5

Final

Packaged Terminal Heat Pumps

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical[2]	High[3]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)[1]	9	9	9	9	9	9	9	9	9	9	9
Efficiency (EER)	11.3	11.3	11.3	11.3	13.1	11.5	13.1	11.5	13.1	11.5	13.1
Efficiency	3.3	3.3	3.3	3.3	3.8	3.4	3.8	3.4	3.8	3.4	3.8
COP (Heating)	3.2	3.2	3.2	3.2	3.6	3.3	3.6	3.3	3.6	3.3	3.6
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost (2022$)	1,620	1,620	1,620	1,620	1,720	1,630	1,720	1,630	1,720	1,630	1,720
Total Installed Cost (2022$)	1,910	1,910	1,910	1,910	2,010	1,910	2,010	1,910	2,010	1,910	2,010
Total Installed Cost (2022$/kBtu/h)	212	212	212	212	223	212	223	212	223	212	223
Annual Maintenance Cost (2022$)	70	70	70	70	70	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	8	8	8	8	8	8	8	8	8	8	8

1. Typical capacity is representative of units with the most shipments. It was also the representative cooling capacity for DOE's analysis in PTAC & PTHP EERE 2022 NOPD.
2. Typical values for 2022 and beyond are based on the efficiency level that has the largest market share per PTAC & PTHP EERE 2022 NOPD.
3. High values for 2022 and beyond are based on the max-tech level from PTAC & PTHP EERE 2022 NOPD.

Note:
The current standard went into effect in October 2012.

Packaged Terminal Heat Pumps

- PTHP are self-contained heat pumps primarily used for commercial applications.
- Analysis was conducted for the standard equipment class at the representative cooling capacity of 9000 Btu/h.

Cooling Capacity (kBtu/h)	Equipment Size	Equipment Class	Federal Standard EER	Federal Standard COP
PTHP	Standard	< 7000	11.9	3.3
		≥7,000 Btu/h and ≤15,000 Btu/h	14.0 – (0.3 x Cap)	3.7 – (0.052 x Cap)
		> 15,000 Btu/h	9.5	2.9
PTHP	Non-Standard	< 7000	9.3	2.7
		≥7,000 Btu/h and ≤15,000 Btu/h	10.8 – (0.213 x Cap)	2.9 – (0.026 x Cap)
		> 15,000 Btu/h	7.6	2.5

Commercial Water Heating

Commercial Gas-Fired Storage Water Heaters

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DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199
Thermal Efficiency (%)[1]	81	82	80	82	94	99	95	99	95	99	95	99
Average Life (y)	13	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	3,870	3,890	3,850	3,890	4,180	4,290	4,200	4,290	4,200	4,290	4,200	4,290
	5,170	5,200	5,140	5,200	5,530	5,650	5,550	5,650	5,550	5,650	5,550	5,650
Total Installed Cost (2022$)	5,170	5,190	5,140	5,190	6,630	6,730	6,640	6,730	6,640	6,730	6,640	6,730
	8,440	8,460	8,410	8,460	8,590	8,710	8,610	8,710	8,610	8,710	8,610	8,710
Total Installed Cost (2022$/kBtu/h)	42	42	43	42	41	39	40	39	40	39	40	39
Annual Maintenance Cost (2022$)[2]	320	320	320	320	330	330	330	330	330	330	330	330
Annual Maintenance Cost (2022$/kBtu/h)	2	2	2	2	2	2	2	2	2	2	2	2

1. Different levels of standby loss were not included in this analysis.
2. Maintenance consists of sediment and scale removal once or twice per year and replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Note:
The current standard went into effect in October 2015.
ENERGY STAR V. 2.0 went into effect in October 2018.
The range of retail and installed costs represent the range from replacement market to new construction market.

Commercial Gas-Fired Storage Water Heaters

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- Input capacity > 155 kBtu/h and storage capacity ≤ 140 gal
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss (Btu/h): 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are typically constructed similarly to residential units, though with higher input capacities (and often higher storage volumes).
- High-efficiency units include condensing heat exchangers (typically stainless or enameled steel) to extract additional heat by condensing water vapor in flue gases. Condensing units also include an inducer fan system or power burner. The heat exchanger is typically contained within the tank, but some designs consist of an external heating module attached to a storage tank. Condensing units are expected to be the majority market share by 2030.
- Maintenance consists of sediment and scale removal once or twice per year and replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Commercial Gas-Fired Storage Water Heaters

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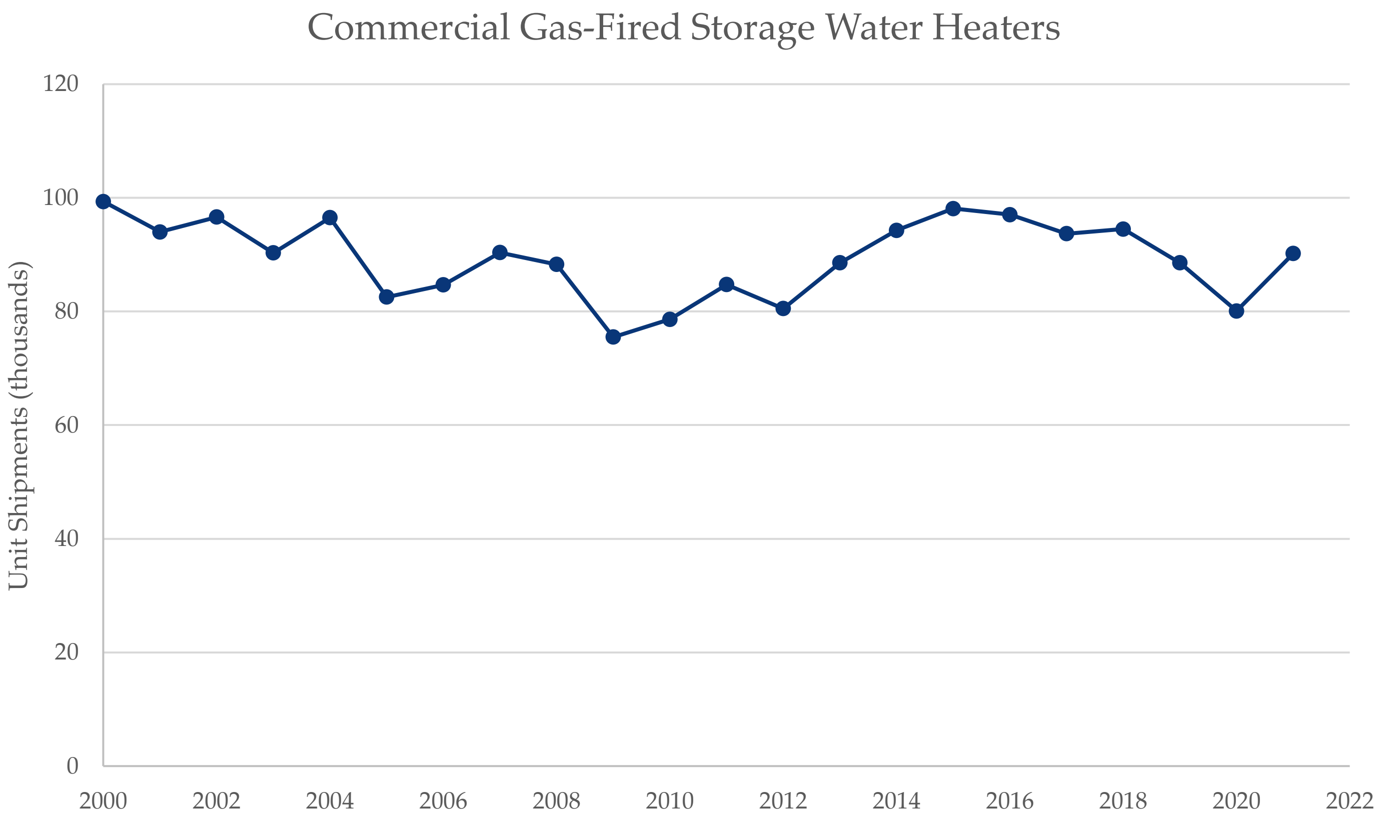
Annual shipments have fluctuated from 99,000 units in 2000 to 75,000 units in 2009, back to 99,000 units in 2015 and gradually decreasing since then until 2020.



Source: CWH EERE 2022 NOPR and AHRI

Commercial Electric Resistance Storage Water Heaters

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DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	119	119	119	119	119	119	119
Typical Input Capacity (kW)[1]	18	18	18	18	18	18	18
Typical Input Capacity (kBtu/h)	60	60	60	60	60	60	60
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (y)	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	3,180	3,180	3,180	3,180	3,180	3,180	3,180
	3,750	3,750	3,750	3,750	3,750	3,750	3,750
Total Installed Cost (2022$)	4,460	4,460	4,460	4,460	4,460	4,460	4,460
	4,690	4,690	4,690	4,690	4,690	4,690	4,690
Total Installed Cost (2022$/kBtu/h)	76	76	76	76	76	76	76
Annual Maintenance Cost (2022$)	50	50	50	50	50	50	50
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1

1. Different levels of standby loss were not included in this analysis.

Note:
No new standards rulemaking has been initiated for commercial electric resistance water heaters since CWH EERE 2016 NOPR. Accordingly, the results are the same as EIA Technology Forecast Updates (2018), updated to 2022$.
The range of retail equipment and installed costs represents the range from replacement market to new construction market.

Commercial Electric Resistance Storage Water Heaters

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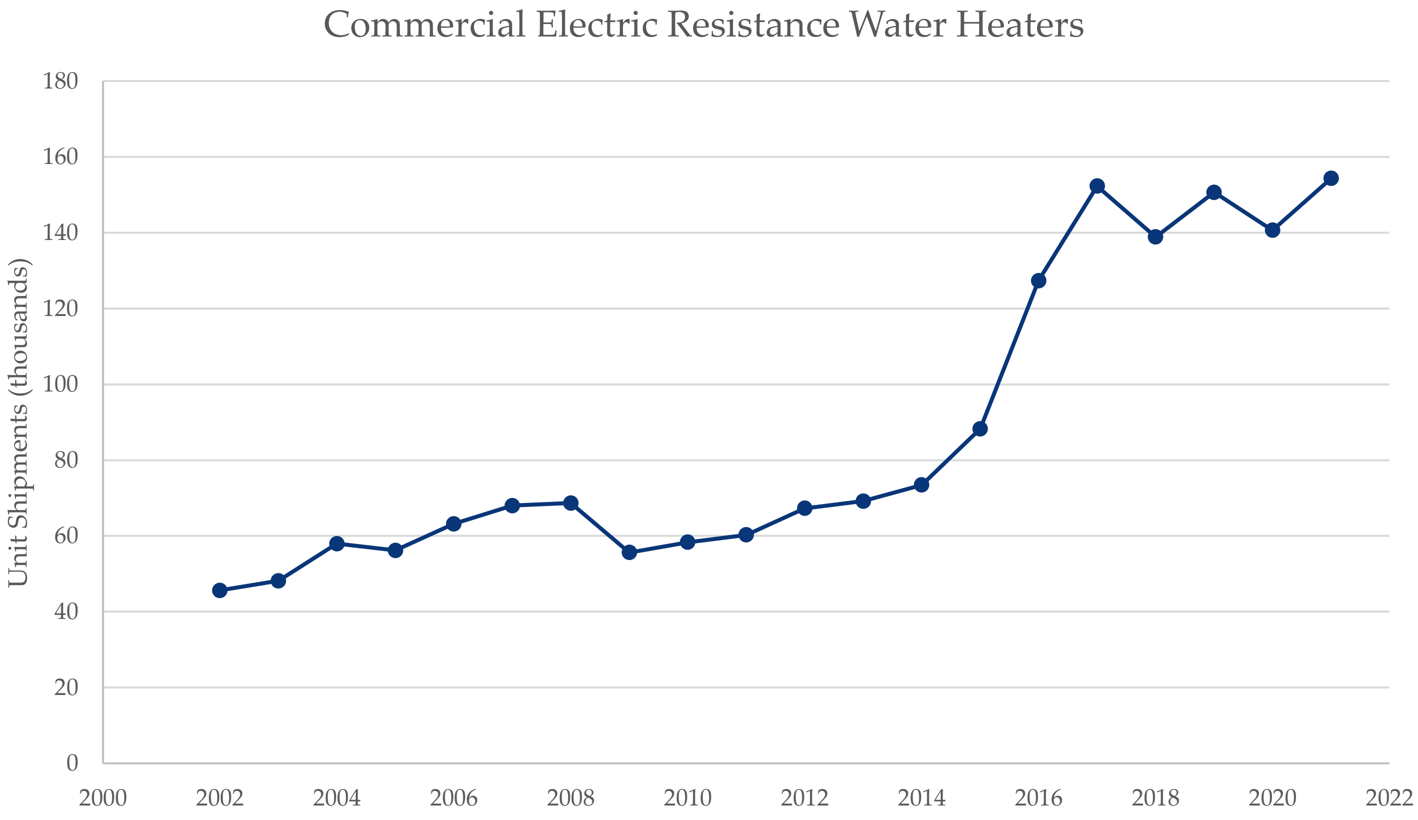
- Federal standard:
  - Maximum standby loss (%/h) : 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units have an efficiency ≥ 98%
- Storage capacity: typically, 50 to 120 gallons, though smaller and larger units exist for specialized applications
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- There is very little variation in thermal efficiency on the market; variation in standby loss is typically due to tank design and insulation thickness.
- Maintenance consists of sediment and scale removal once or twice per year.

Commercial Electric Resistance Storage Water Heaters

Annual shipments increased by almost 50% between 2002 and 2008. After a small dip in shipments in 2009, annual shipments have increased by about 173% between 2009 and 2017, stabilizing between 140-150 thousand shipments per year since then.



Source: AHRI

Commercial Heat Pump Water Heaters

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DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.0	Typical	Typical	Typical
Water Flow Rate (gal/min)[1]	34	34	34	34	34	34	34
Typical Output Capacity (kW)[1]	50	50	50	50	50	50	50
Typical Output Capacity (kBtu/h)	171	171	171	171	171	171	171
Coefficient of Performance (COP_h)	3.9	3.9	3.9	3.0	3.9	3.9	3.9
Average Life (y)	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	55,406	55,406	55,406	55,406	55,406	55,406	55,406
Total Installed Cost (2022$)[2]	59,940	59,940	59,940	59,940	59,940	59,940	59,940
Total Installed Cost (2022$/kBtu/h)	351	351	351	351	351	351	351
Annual Maintenance Cost (2022$)[2]	120	120	120	120	120	120	120
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1

1. Water flow rate scales with typical capacity. The storage tanks must be purchased and installed separately from the HP unit. The typical output and flow rate provided are near the median of the products available on the market currently.
2. Costs are same as EIA Technology Forecast Updates (2018), updated to 2022$. Updated representative costs for commercial heat pump water heaters are not available due to the extremely small market for these products.

Note:

ENERGY STAR V. 2.0 went into effect in October 2018.

Commercial Heat Pump Water Heaters

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- Typical commercial HPWHs (CHPWHs) are add-on units designed to be used with a storage tank(s); integrated CHPWHs have emerged on the market (i.e., heat pump module and storage tank combined in one unit) in recent years.
- CHPWHs serve only a small portion of the commercial water heating (CWH) market, with the ENERGY STAR database listing only two manufacturers, each with one basic model listed.
- CHPWHs can extract heat from either air or water for heating potable water ("air-source" or "water-source"). The capacity of air-source CHPWHs falls at lower ambient air temperatures.
- Air-source CHPWHs cool the surrounding air, which can be desirable when installed indoors in applications with a year-round cooling load (e.g., a commercial kitchen).
- Output capacities for CHPWHs range from 17 kW to over 70 kW for air-source units and over 600 kW for water-source units.
- Some commercial applications require water as hot as 180 °F, such as dishwashing; however, most CHPWHs cannot deliver hot water at temperatures higher than 150 °F.
- There are no current Federal standards for CHPWHs, but DOE prescribes a test procedure for determining COP_h for CHPWHs.
- The most recent ENERGY STAR V. 2.0 specification for CWH equipment went into effect in October 2018. It specifies a COP_h level of 3.0 for CHPWHs.

Commercial Oil-Fired Storage Water Heaters

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DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	85	85	85	85	85	85	85	85	85	85
Typical Input Capacity (kBtu/h)	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)[1]	79	81	80	81	82	81	82	81	82	81	82
Average Life (y)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2022$)	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470
Total Installed Cost (2022$)	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120
Total Installed Cost (2022$/kBtu/h)	26	25	26	25	25	25	25	25	25	25	25
Annual Maintenance Cost (2022$)	200	200	200	200	200	200	200	210	210	210	210
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1	1	1	1	1

1. Different levels of standby loss were not included in this analysis.

Note:

The commercial oil-fired water heaters market is very small; currently, there are only 4 basic models in DOE’s CCD. DOE's rulemaking analysis for oil-fired water heaters has not been updated since 2001. The retail, installed, and maintenance costs have been updated from EIA Technology Forecast Updates (2018) to 2022$.

The current standard went into effect in October 2015.

Commercial Oil-Fired Storage Water Heaters

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- Input capacity > 155 kBtu/h and storage capacity ≤ 140 gal
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest thermal efficiency on the market is 82%.
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- Maintenance costs include sediment and scale removal once or twice per year.
- The market for commercial oil-fired storage water heaters is very small; shipments are approximately 3% of shipments for commercial gas-fired storage water heaters.

Commercial Electric Booster Water Heaters

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DATA	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Typical Output Capacity (kBtu/h)	1,374	1,374	1,374	1,374	1,374	1,374
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (y)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost (2022$)[1]	1,530	1,530	1,920	1,920	1,920	1,920
	3,290	3,530	4,560	4,560	4,560	4,560
Total Installed Cost (2022$) [1]	1,730	1,730	2,120	2,120	2,120	2,120
	3,490	3,730	4,760	4,760	4,760	4,760
Total Installed Cost (2022$/kBtu/h)	2	2	3	3	3	3
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-

1. The 2012 and 2018 installed base costs are the same as EIA Technology Forecast Updates (2018), updated to 2022$. Retail costs for 2022 and later are based on the range of costs for products on the market today. Installed costs assume a $200 installation price.
2. Maintenance costs are negligible.

Commercial Gas-Fired Booster Water Heaters

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DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	3	3	3	3	3	3	3
	5	5	5	5	5	5	5
Typical Output Capacity (kBtu/h)	500	500	500	500	500	500	500
Thermal Efficiency (%)[1]	80	80	80	80	80	80	80
Average Life (y)	5	5	5	5	5	5	5
	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)[2]	5,530	5,760	7,130	7,130	7,130	7,130	7,130
	8,000	9,060	11,120	11,120	11,120	11,120	11,120
Total Installed Cost (2022$)[2]	5,830	6,060	7,430	7,430	7,430	7,430	7,430
	8,300	9,360	11,420	11,420	11,420	11,420	11,420
Total Installed Cost (2022$/kBtu/h)	14	15	19	19	19	19	19
Annual Maintenance Cost (2022$)	160	160	160	160	160	160	160
Annual Maintenance Cost (2022$/kBtu/h)	0	0	0	0	0	0	0

1. While EIA Technology Forecast Updates (2018) included high values reflecting condensing models, models currently available in the market do not exceed 80% efficiency.
2. The 2012 and 2018 installed base costs are the same as EIA Technology Forecast Updates (2018), updated to 2022$. Retail costs for 2022 and later are based on the range of costs for products on the market today. Installed costs assume a $300 installation price.

Commercial Booster Water Heaters

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- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140 °F water, and the booster water heater may increase that temperature to 180-195 °F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- Commercial booster water heaters are regulated by DOE as either storage or instantaneous water heaters, depending on the ratio of input capacity to storage volume. Units with input capacity < 4,000 Btu/h per gallon of stored water are storage water heaters; all other units are instantaneous water heaters.
- DOE's regulations do not currently include standards for electric instantaneous water heaters, but standards are included for electric storage water heaters, gas-fired instantaneous water heaters, and gas-fired storage water heaters.
- Condensing gas-fired booster water heaters, those with an efficiency of 90% of more, were analyzed previously. There are no condensing units currently on the market. Condensing gas-fired booster water heaters can only operate if the incoming water temperature is below 130 °F so there is enough heat transfer to condense.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Shipments are small due to the limited number of applications.

Commercial Gas-Fired Instantaneous Water Heaters

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DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High[2]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	250	250	250	250	250	250	250	250	250	250	250	250
	399	399	399	399	399	399	399	399	399	399	399	399
Thermal Efficiency (%)	80	92	80	92	94	99	96	99	96	99	96	99
Average Life (y)	17	17	17	17	17	17	17	17	17	17	17	17
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)[1]	1,630	1,840	1,630	1,840	1,880	7,990	1,930	7,990	1,930	7,990	1,930	7,990
	4,400	8,610	4,400	8,610	9,000	9,990	9,400	9,990	9,400	9,990	9,400	9,990
Total Installed Cost (2022$)[1]	2,430	3,980	2,430	3,980	4,010	13,000	4,070	13,000	4,070	13,000	4,070	13,000
	10,380	13,560	10,380	13,560	13,950	14,950	14,350	14,950	14,350	14,950	14,350	14,950
Total Installed Cost (2022$/kBtu/h)	25	29	25	29	29	44	30	44	30	44	30	44
Annual Maintenance Cost (2022$)[3]	90	100	90	100	100	820	100	820	100	820	100	820
	760	820	760	820	820	830	830	830	830	830	830	830
Annual Maintenance Cost (2022$/kBtu/h)	2	2	2	2	2	3	1	3	1	3	1	3

1. Commercial gas-fired instantaneous water heaters are categorized into two groups: tankless water heater and hot water supply boiler. Tankless units are similar in design to residential tankless units. The hot water supply boiler has a much higher input and is similar in design to boilers. The large variation of total input capacity and design causes a large range of costs. The range of retail, installed, and maintenance costs represent the differences in design, as well as the cost ranges arising from replacement versus new construction markets.
2. High efficiency was determined based on DOE's CCD. The most efficient tankless water heater has a thermal efficiency of 96%. The most efficient hot water supply boiler has a thermal efficiency of 99%.
3. Maintenance consists replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Note:
For the installed base, current standard, and typical costs, low values represent costs for tankless water heaters in the replacement market while high values represent costs for hot water supply boilers in the new construction market. The range of costs for the High values are estimated costs for hot water supply boilers in the replacement and new construction market.
ENERGY STAR V. 2.0 went into effect in October 2018.

Commercial Gas-Fired Instantaneous Water Heaters

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- Storage Capacity < 10 gallons and ≥ 10 gallons
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 x (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
- Wall-mounted ("tankless") units typically do not exceed ~400,000 Btu/h and are similar in design to residential tankless units. Floor-mounted units ("circulating" or "volume" water heaters) are similar in design to boilers and can have input capacities in the millions of Btu/h. Floor-mounted units are typically installed with a storage tank.
- Despite high available input capacities, some installations use multiple units staged together, which may have reliability and/or efficiency benefits.
- Similar to storage water heaters, higher efficiencies are achieved with condensing operation, which requires a condensing heat exchanger and inducer fan or power burner. Some units include both non-condensing and condensing heat exchangers, while others include a single condensing heat exchanger.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.

Commercial Gas-Fired Instantaneous Water Heaters

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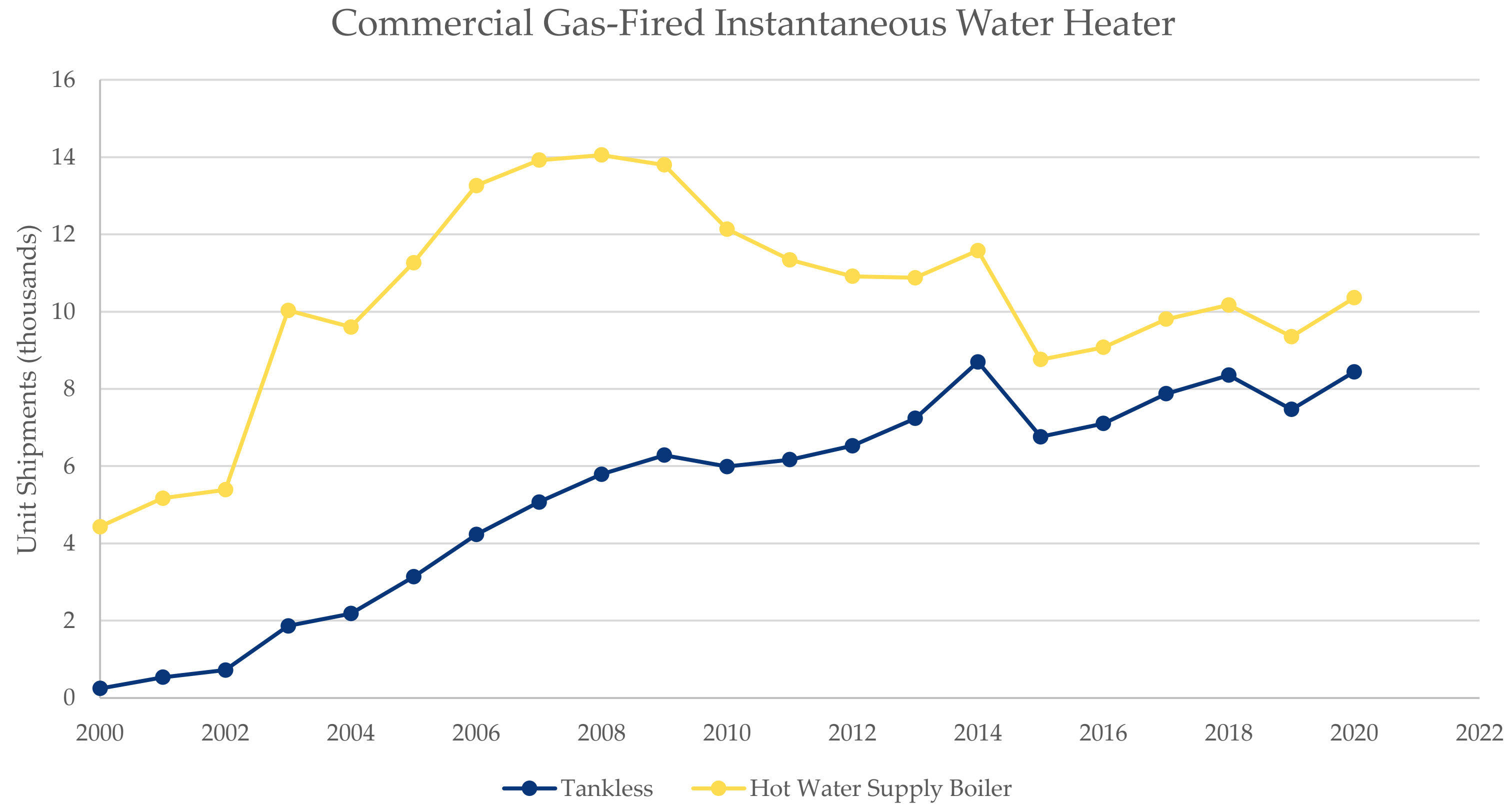
Annual shipments for gas-fired instantaneous tankless water heaters have gradually increased since 2000 while those for gas-fired instantaneous hot water supply boiler water heaters peaked in 2008 and have been decreasing since then, recently stabilizing around 10,000 annual shipments.



Source: CWH EERE 2022 NOPR

Commercial Solar Water Heaters

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DATA	2012	2018	2022		2023	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	ENERGY STAR V. 5.0	Typical	Typical	Typical
Typical Capacity (sq. ft.)[1]	85	85	85	85	85	85	85	85
Typical Capacity (m^2)	7.90	7.90	7.90	7.90	7.90	7.90	7.90	7.90
Typical Capacity (Input) (kBtu/h) – North	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05
Typical Capacity (Input) (kBtu/h) – South	6.74	6.74	6.74	6.74	6.74	6.74	6.74	6.74
Solar Uniform Energy Factor (SUEF)[2]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Average Life (y)	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)[3]	10,470	10,470	10,280	10,280	10,280	10,280	10,280	10,280
Total Installed Cost (2022$)[3]	14,180	14,180	12,640	12,640	12,640	12,640	12,640	12,640
Total Installed Cost (2022$/kBtu/h) – North	936	936	834	834	834	834	834	834
Total Installed Cost (2022$/kBtu/h) – South	702	702	626	626	626	626	626	626
Annual Maintenance Cost (2022$)[4]	100	100	100	100	100	100	100	100
Annual Maintenance Cost (2022$/kBtu/h) - North	7	7	7	7	7	7	7	7
Annual Maintenance Cost (2022$/kBtu/h) - South	5	5	5	5	5	5	5	5

1. Typical capacity refers to the solar collector panel area. It was determined using the SRCC database as the average value of the largest bin (in terms of capacity) with the greatest number of units.
2. In 2020, the efficiency metric for solar water heaters changed from SEF to SUEF. There is no equation or scaling factor readily available to translate SEF to SUEF. Accordingly, for the 2012 and 2018 installed base, SUEF was determined using the 2020 ENERGY STAR data set assuming the typical SEF/SUEF value was similar between 2012-2020. For 2022 and beyond, due to lack of SUEF data, it is assumed that a typical electric backup unit would meet the ENERGY STAR criteria. ENERGY STAR specifies a minimum SUEF of 3.0 for electric backup units and 1.8 for gas backup units.
3. Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>two-third of the current market). Higher capacity/cost systems are required in colder/cloudier regions. The 2012 and 2018 installed base costs are updated from EIA Technology Forecast Updates (2018) to 2022$.
4. Annual maintenance is expected to be 0.5% to 1% of the total installation.

Note:

ENERGY STAR V. 4.0 went into effect in January 2022. ENERGY STAR V. 5.0 will go into effect in April 2023 but the ENERGY STAR criteria for solar water heaters will remain the same in ENERGY STAR V. 5.0.

Commercial Solar Water Heaters

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- In 2020, a diverse group of stakeholders from the solar thermal industry developed the SUEF Specification for solar water heaters. The goal of this specification is to align with the UEF metric used by DOE for other water heating technologies.
- SUEF is also the metric used by the current ENERGY STAR Specification, and it replaced the SEF metric.
- EIA Technology Forecast Updates (2018) presented results using SEF and solar fraction (SF). SEF is currently not used in either the ENERGY STAR or SRCC databases; accordingly, this report presents results according to SUEF. SF is the portion of the total conventional hot water heating load (delivered energy and tank standby losses). SF varies from 0 to 1.0. Typical solar fraction values are 0.5–0.75.
- There is no equation or scaling factor readily available to translate SEF to SUEF. Accordingly, for the 2012 and 2018 installed base, SUEF was determined using the 2020 ENERGY STAR data set assuming the typical SEF/SUEF value was similar between 2012-2020. For 2022 and beyond, SUEF is the average SUEF for solar water heaters with a "high-usage" draw pattern from the current ENERGY STAR qualified product list.
- Commercial solar water heaters are typically custom designed for a specific installation.
- Commercial solar water heaters may include backup heating, from sources such as electric resistance or hydronic heat (supplied from a gas-fired boiler or geothermal heat pump).
- Storage volumes of tanks for commercial solar water heaters can span from 140 gallons to over 2,000 gallons.
- SRCC’s OG-300 can be used to certify commercial systems, but most commercial systems are larger and unique; this certification program is mostly used for residential solar water heaters.
  - Many incentive programs require that solar collectors for commercial systems be certified to SRCC’s certification program for collectors, OG-100.

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Commercial Cooking Products

Commercial Natural Gas Range with Griddle and Oven

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DATA	2012	2018	2022			2023	2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.2[1]	High	ENERGY STAR V. 3.0[2]	Typical	High	Typical	High	Typical	High
Griddle - Cooking Energy Efficiency (%)	30	30	40	38	69	NA	40	69	40	69	40	69
Oven - Cooking Energy Efficiency (%)	35	35	35	46	69	49	35	69	35	69	35	69
Range - Cooking Energy Efficiency (%)	30	30	30	NA	40	NA	30	40	30	40	30	40
Combined Energy Efficiency (%)[3]	31	31	35	NA	58	NA	35	58	35	58	35	58
Griddle - Normalized Idle Energy Rate (Btu/h/ft^2)	3,000	3,000	3,000	2,650	1,724	NA	3,000	1,724	3,000	1,724	3,000	1,724
Oven - Idle Energy Rate (Btu/h)	18,000	18,000	18,000	12,000	3,516	9,500	18,000	3,516	18,000	3,516	18,000	3,516
Range - Idle Energy Rate (Btu/h)	3,600	3,600	3,600	NA	1,900	NA	3,600	1,900	3,600	1,900	3,600	1,900
Combined Idle Energy Rate (Btu/h)[3]	10,350	10,350	10,350	NA	4,178	NA	10,350	4,178	10,350	4,178	10,350	4,178
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Total Installed Cost (2022$)	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940
Total Installed Cost (2022$/kBtu/h)	864	864	864	NA	2,140	NA	864	2,140	864	2,140	864	2,140
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
2. ENERGY STAR V. 3.0 updated the requirements for commercial ovens from V. 2.2, effective January 2023. Data shown is reflective of a standard full-size convection oven that holds 5 or more pans.
3. Combined energy efficiency and combined idle energy rate are calculated as a weighted average of each component using typical daily operating hours sourced from Food Service Technology Center (FSTC). Typical daily operating hours are assumed to be 12 hours for the griddle component, 8 hours for the oven component, and 12 hours for the range component.
4. Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
5. Maintenance costs are negligible.

Note:

ENERGY STAR V. 2.2 went into effect in October 2015. ENERGY STAR V. 3.0 went into effect in January 2023.

Commercial Electric Range with Griddle and Oven

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DATA	2012	2018	2022			2023	2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.2[1]	High	ENERGY STAR V. 3.0[2]	Typical	High	Typical	High	Typical	High
Griddle - Cooking Energy Efficiency (%)	65	70	72	70	91	NA	72	91	72	91	72	91
Oven - Cooking Energy Efficiency (%)	65	65	65	71	86	76	65	86	65	86	65	86
Range - Cooking Energy Efficiency (%)	75	75	75	NA	87	NA	75	87	75	87	75	87
Combined Energy Efficiency (%)[3]	69	71	71	NA	88	NA	71	88	71	88	71	88
Griddle - Normalized Idle Energy Rate (kW/ft^2)	0.44	0.34	0.30	0.32	0.21	NA	0.30	0.21	0.30	0.21	0.30	0.21
Oven - Idle Energy Rate (kW)	1.5	1.5	1.5	1.6	0.6	1.4	1.5	0.6	1.5	0.6	1.5	0.6
Range - Idle Energy Rate (kW)[4]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Combined Idle Energy Rate (kW)[3]	1.7	1.4	1.3	1.4	0.8	NA	1.3	0.8	1.3	0.8	1.3	0.8
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[5]	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230
Total Installed Cost (2022$)	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410
Total Installed Cost (2022$/kBtu/h)	2,019	2,362	2,533	2,375	4,423	NA	2,533	4,423	2,533	4,423	2,533	4,423
Annual Maintenance Cost (2022$)[6]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
2. ENERGY STAR V. 3.0 updated the requirements for commercial ovens from V. 2.2, effective January 2023. Data shown is reflective of a standard full-size convection oven that holds 5 or more pans.
3. Combined energy efficiency and combined idle energy rate are calculated as a weighted average of each component using typical daily operating hours sourced from FSTC. Typical daily operating hours are assumed to be 12 hours for the griddle component, 8 hours for the oven component, and 12 hours for the range component.
4. No data on electric range top idle energy rates.
5. Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
6. Maintenance costs are negligible.

Note:
ENERGY STAR V. 2.2 went into effect in October 2015. ENERGY STAR V. 3.0 goes into effect in January 2023.

Final

Commercial Ranges with Griddle and Oven

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- Combined product that typically includes 2-6 range tops, a 24 in. x 24 in. griddle surface, and one or two half- or full-size ovens.
- Combined product is not covered by ENERGY STAR. However, the individual product ENERGY STAR V. 2.2 specifications are provided below.

Product	ENERGY STAR V. 2.2 Requirements	Gas	Electric
Griddle	Cooking Energy Efficiency	≥ 38%	≥ 70%
	Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 0.320 kW per ft^2
Oven	Cooking Energy Efficiency	≥ 46%	≥ 71%
	Idle Energy Rate	≤ 12,000 Btu/h	Half size: ≤1.00 kW Full size: ≤1.60 kW

- ENERGY STAR does not provide certification for range tops.
- There are no Federal standards for commercial cooking products.
- Product pricing in this market do not scale with efficiency, but rather depend on a number of other factors such as brand name, aesthetics, and additional features.

Commercial Ranges with Griddle and Oven

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- ENERGY STAR V. 3.0 requirements for commercial ovens went into effect in January 2023:

Product	ENERGY STAR Requirements	Gas	Electric
Oven	Cooking Energy Efficiency	≥ 49%	Half size: ≥ 71% Full size: ≥ 76%
	Idle Energy Rate	≤ 9,500 Btu/h	Half size: ≤1.00 kW Full size ≥ 5 Pans: ≤1.40 kW Full size ≤ 5 Pans: ≤1.00 kW

Commercial Ranges with Griddle and Oven

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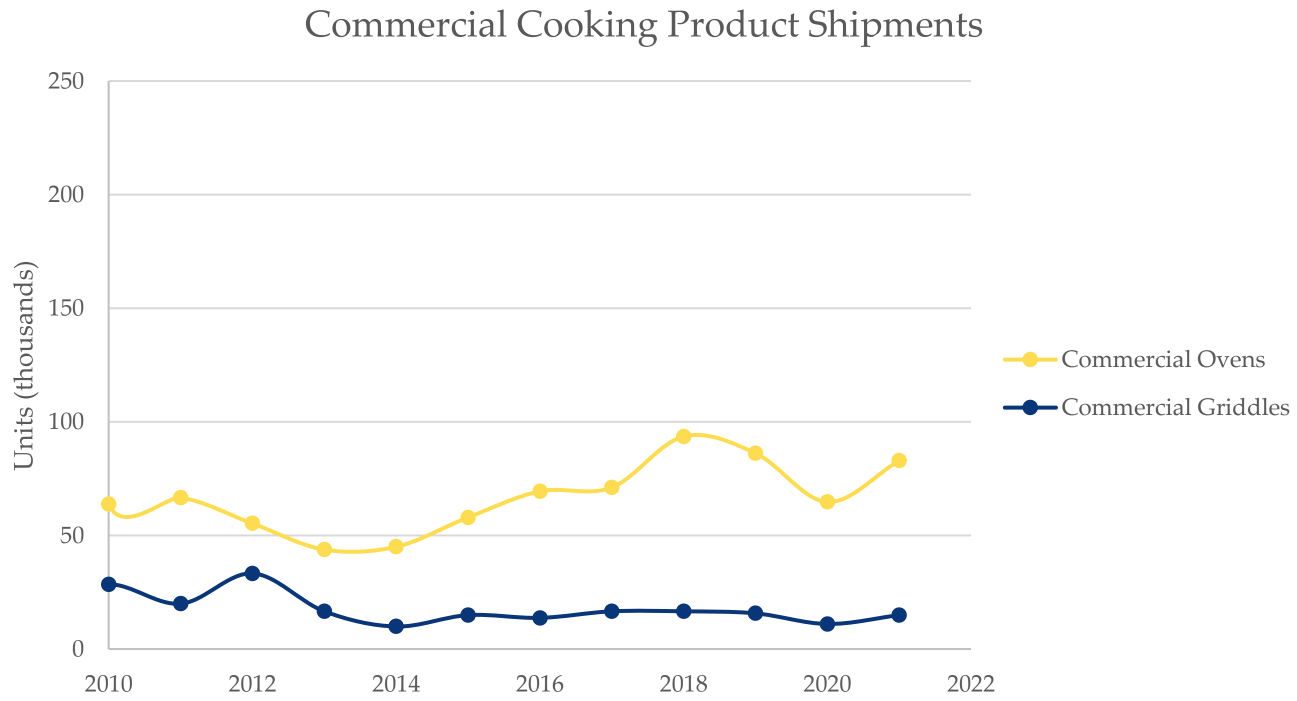
Commercial oven shipments have gradually increased since 2013, decreasing recently, in 2020. Commercial griddle shipments have remained steady since 2014.



Source: *ENERGY STAR (Unit Shipment Data)*

Commercial Hot Food Holding Cabinets – Small

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DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)[1]	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Maximum Idle Energy Rate (W)[2]	312	312	312	312	168	168	312	168	312	168	312	168
Annual Energy Use (kWh/y)[3]	1,025	1,025	1,025	1,025	552	552	1,025	552	1,025	552	1,025	552
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	3,200	3,200	3,200	3,200	3,800	3,800	3,200	3,800	3,200	3,800	3,200	3,800
Total Installed Cost (2022$)[5]	3,200	3,200	3,200	3,200	3,800	3,800	3,200	3,800	3,200	3,800	3,200	3,800
Total Installed Cost (2022$/kBtu/h)	8,016	8,016	8,016	8,016	17,677	17,677	8,016	17,677	8,016	17,677	8,016	17,677
Annual Maintenance Cost (2022$) [5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The small size class covers units with interior volume less than 13 ft^3. Interior volume for the small size class was determined based on the units in the ENERGY STAR database, accessed February 2023.
2. Maximum idle energy rate is a function of interior volume. For the small size class, ENERGY STAR and high values were determined for a representative 7.8 ft^3 using the ENERGY STAR database, accessed February 2023. The typical value was assumed to be equivalent to the state standard for a representative 7.8 ft^3 unit.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year. The small size class is assumed to use the same number of annual usage hours as the medium size class.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:

ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets – Medium

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DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft³)[1]	21.4	21.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
Maximum Idle Energy Rate (W)[2]	900	856	896	896	299	298	896	298	896	298	896	298
Annual Energy Use (kWh/y)[3]	2,957	2,812	2,943	2,943	982	979	2,943	979	2,943	979	2,943	979
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	2,940	4,530	4,600	4,600	5,000	5,000	4,600	5,000	4,600	5,000	4,600	5,000
Total Installed Cost (2022$)[5]	2,940	4,530	4,600	4,600	5,000	5,000	4,600	5,000	4,600	5,000	4,600	5,000
Total Installed Cost (2022$/kBtu/h)	2,553	4,136	4,012	4,012	13,078	13,113	4,012	13,113	4,012	13,113	4,012	13,113
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The medium size class covers units with interior volume between 13 ft^3 to 28 ft^3. For the medium size class, the interior volume increase from 21.4 ft^3 to 22.4 ft^3 in 2022 reflects the current representative product volume reported by FEMP, last updated December 2021.
2. Maximum idle energy rate is a function of interior volume. For the medium size class, the maximum idle energy rate for 2022 onward is reflective of a representative 22.4 ft^3 unit, using the latest FEMP data from December 2021.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:
ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets – Large

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)[1]	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Maximum Idle Energy Rate (W)[2]	1,333	1,333	1,760	1,333	400	310	1,333	310	1,333	310	1,333	310
Annual Energy Use (kWh/y)[3]	4,380	4,380	5,782	4,380	1,314	1,018	4,380	1,018	4,380	1,018	4,380	1,018
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	5,500	5,500	5,500	5,500	6,000	6,000	5,500	6,000	5,500	6,000	5,500	6,000
Total Installed Cost (2022$)[5]	5,500	5,500	5,500	5,500	6,000	6,000	5,500	6,000	5,500	6,000	5,500	6,000
Total Installed Cost (2022$/kBtu/h)	3,224	3,224	2,442	3,224	11,723	15,126	3,224	15,126	3,224	15,126	3,224	15,126
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The large size class covers units with interior volume greater than or equal to 28 ft^3. Interior volume for the large size class was determined based on the units in the ENERGY STAR database, accessed February 1, 2023.
2. Maximum idle energy rate is a function of interior volume. For the large size class, ENERGY STAR and high values were determined using the ENERGY STAR database, and the typical value uses the assumption that ENERGY STAR units are reported to be 70% more efficient than typical units.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year. The large size class is assumed to use the same number of annual usage hours as the medium size class.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:
ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets

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- Hot food holding cabinets are used in commercial kitchens to keep food warm until it is served.
- While available in many shapes and sizes, interior volumes around 21.4 ft^3 were reported as typical in many settings in EIA Technology Forecast Updates (2018). FEMP currently lists 22.4 ft^3 as a representative unit size.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is “Idle Energy Consumption Rate” in Watts, measured using ASTM Standard F2140-11.
- There are no Federal standards for hot food holding cabinets, but seven States have identical standards.
  - The first State standard took effect in California in 2006; this standard is now considered the typical or “baseline” product. It is also equivalent to the ENERGY STAR V. 1.0 Specification that went into effect in August 2003.
  - ENERGY STAR V. 2.0 went into effect in October 2011.
- Maximum Idle Energy Consumption Rate for products $12 \leq V < 28$:

  — State standards: $\leq 40 \times V$ (baseline)

  — ENERGY STAR V. 2.0: $\leq 2.0 \times V + 254$ (about 65% below baseline)

  where V is interior volume in ft^3.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).

Commercial Hot Food Holding Cabinets

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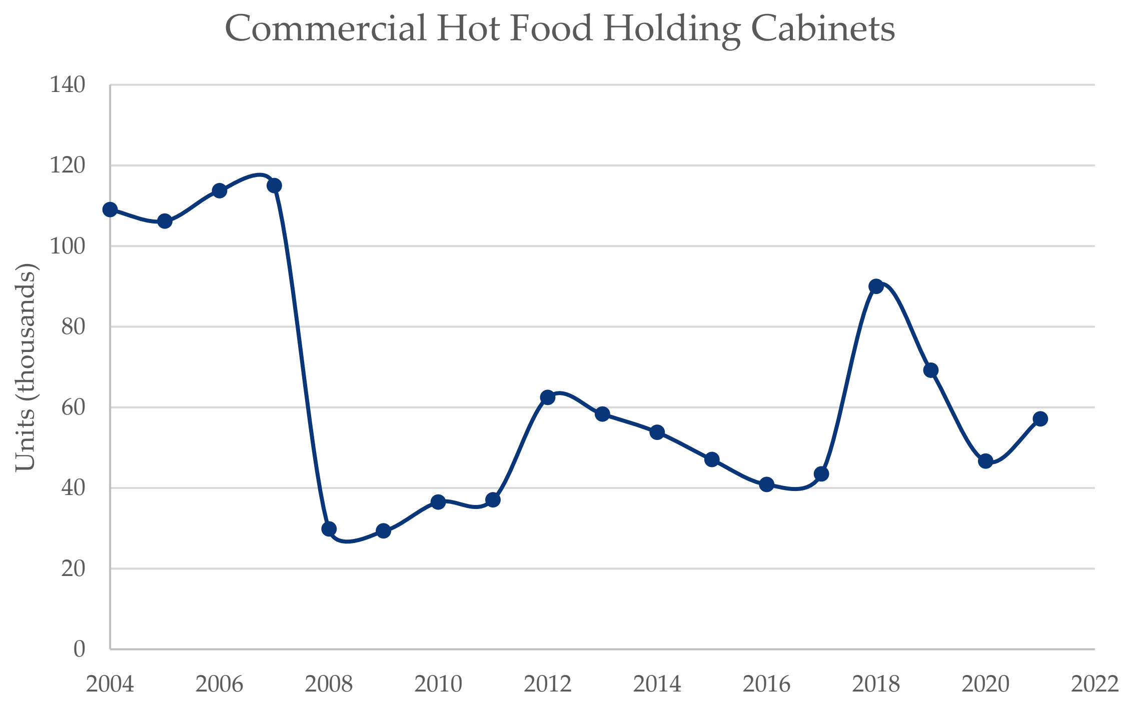
Commercial hot food holding cabinet shipments peaked in 2007 at 115,000 units, followed by a peak of 90,000 units in 2019.



Source: *ENERGY STAR (Unit Shipment Data)*

Appendix A
Data Sources

Guidehouse
1676 International Drive
McLean, VA 22102

And

Leidos
11951 Freedom Drive
Reston, VA 20190

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Residential Space Heating and Cooling

Residential Gas-Fired Furnaces (North)

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North) V. 4.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2022 NOPR								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD	Residential Furnaces EERE 2022 NOPR		
Electric Consumption (kWh/y)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Average Life (y)	Residential Furnaces EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Gas-Fired Furnaces (Rest of Country)

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (ROC) V. 4.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2022 NOPR								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD	Residential Furnaces EERE 2022 NOPR		
Electric Consumption (kWh/y)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Average Life (y)	Residential Furnaces EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Oil-Fired Furnaces

SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2011								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD			
Electric Consumption (kWh/y)	Residential Furnaces EERE 2011								
Average Life (y)									
Retail Equipment Cost (2022$)									
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

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Residential Gas-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.0</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="7">Boilers EERE 2016</td><td colspan="8">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>AFUE (%)</td><td colspan="2">Boilers EERE 2022 Preliminary Analysis</td><td>DOE CCD</td><td>ENERGY STAR V. 3.0</td><td colspan="4">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Electric Consumption (kWh/y)</td><td colspan="8" rowspan="5">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Oil-Fired Boilers

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical / High		
Typical Input Capacity (kBtu/h)	Boilers EERE 2016	Boilers EERE 2022 Preliminary Analysis							
AFUE (%)		Boilers EERE 2022 Preliminary Analysis		DOE CCD	ENERGY STAR V. 3.0	Boilers EERE 2022 Preliminary Analysis			
Electric Consumption (kWh/y)		Boilers EERE 2022 Preliminary Analysis							
Average Life (y)									
Retail Equipment Cost (2022$)									
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Electric Resistance Furnaces

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical		
Typical Input Capacity (kBtu/h)	Distributors				Guidehouse		
AFUE (%)	DOE / ASHRAE						
Average Life (y)	Distributors						
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)	Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse					
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse						

Residential Electric Resistance Unit Heaters

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SOURCES	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical		
Typical Capacity (kBtu/h)	Distributors		Utilities/Distributors	Guidehouse		
Efficiency (%)	DOE		DOE			
Average Life (y)	Guidehouse		Guidehouse			
Retail Equipment Cost (2022$)			Distributors			
Total Installed Cost (2022$)			Home Remodeling Service			
Annual Maintenance Cost (2022$)			Guidehouse			

Residential Central Air Conditioners – North (Not Hot-Dry or Hot-Humid)

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SOURCES	2015	2020	2022				2023			2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	CAC and HP EERE 2016									Guidehouse		
SEER	CAC and HP EERE 2016 / Guidehouse		CFR	DOE CCD	ENERGY STAR V. 5.0	CAC and HP EERE 2016	RESNET		CAC and HP EERE 2016			
SSER2	RESNET						CAC and HP EERE 2016	ENERGY STAR V. 6.1	RESNET			
Average Life (y)	CAC and HP EERE 2016											
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)	CAC and HP EERE 2016 / Less (2021)											
Annual Maintenance Cost (2022$)	CAC and HP EERE 2016											

Residential Central Air Conditioners – South (Hot-Dry and Hot-Humid)

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SOURCES	2015	2020	2022				2023			2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	CAC and HP EERE 2016									Guidehouse		
SEER	CAC and HP EERE 2016 / Guidehouse		CFR	DOE CCD	ENERGY STAR V. 5.0	CAC and HP EERE 2016	RESNET		CAC and HP EERE 2016			
SSER2	RESNET						CAC and HP EERE 2016	ENERGY STAR V. 6.1	RESNET			
Average Life (y)	CAC and HP EERE 2016											
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)	CAC and HP EERE 2016 / Less (2021)											
Annual Maintenance Cost (2022$)	CAC and HP EERE 2016											

Residential Room Air Conditioners

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.2</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="2">Distributors</td><td colspan="10">RAC EERE 2022 NOPR</td></tr>
<tr><td>CEER (Btu/Wh)</td><td colspan="2">Guidehouse</td><td>CFR</td><td>DOE CCD</td><td>ENERGY STAR V. 4.2</td><td>DOE CCD</td><td>RAC EERE 2022 NOPR</td><td>DOE CCD</td><td>RAC EERE 2022 NOPR</td><td>DOE CCD</td><td>RAC EERE 2022 NOPR</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td rowspan="4">RAC EERE 2011</td><td colspan="11" rowspan="4">RAC EERE 2022 NOPR</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Portable Air Conditioners

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SOURCES	2015	2020	2022		2025		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	New Standard	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	PAC EERE 2020/Guidehouse											
CEER												
Average Life (y)												
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Swamp Coolers

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SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
CFM	Product Literature / Guidehouse				Guidehouse					
Power (Hp)										
Average Life (y)	TLC Plumbing / Guidehouse									
Retail Equipment Cost (2022$)	Product Literature / Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse									
Total Installed Cost (2022$)										
Annual Maintenance Cost (2022$)										

Residential Air-Source Heat Pumps

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	2015	2020	2022				2023				2030	2040	2050
SOURCES	**Installed Base**	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR V. 5.0**	**High**	**New Standard**	**ENERGY STAR V. 6.1**	**ENERGY STAR Cold Climate Criteria**	**High**	**Typical/High**		
Typical Capacity (kBtu/h)	CACs and HPs EERE 2016 Direct Final Rule												
SEER (Cooling)	CACs and HPs EERE 2016 Direct Final Rule/ Guidehouse		CFR	DOE CCD/ Guidehouse	ENERGY STAR V. 5.0	CACs and HPs EERE 2016 Direct Final Rule	CACs and HPs EERE 2016 Direct Final Rule/ Guidehouse	ENERGY STAR V. 6.1	ENERGY STAR V. 6.1	CACs and HPs EERE 2016 Direct Final Rule	CACs and HPs EERE 2016 Direct Final Rule/Guidehouse		
HSPF (Heating)													
Average Life (y)	CACs and HPs EERE 2016 Direct Final Rule										Guidehouse		
Retail Equipment Cost (2022$)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													

Residential Ductless Mini-Split Air-Source Heat Pumps

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SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	AHRI/Guidehouse				Guidehouse					
SEER										
EER										
HSPF										
Average Life (y)	CACs and HPs EERE 2016 Direct Final Rule									
Retail Equipment Cost (2022$)	Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse									
Total Installed Cost (2022$)										
Annual Maintenance Cost (2022$)	CACs and HPs EERE 2016 Direct Final Rule									

Residential Ground-Source Heat Pumps

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.2</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="2">Water-Source Unitary Heat Pumps EERE 2015 Final Rule / DOE CCD</td><td colspan="10" rowspan="7">Guidehouse</td></tr>
<tr><td>COP (Heating)</td><td rowspan="2">AHRI Database</td><td rowspan="2">AHRI Database / DOE CCD</td></tr>
<tr><td>EER (Cooling)</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Natural Gas Heat Pumps

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SOURCES	2015	2020	2022	2030	2040	2050
	Installed Base		Typical			
Typical Capacity (kBtu/h)	Manufacturer		Guidehouse			
COP (Heating)	Product Literature					
COP (Cooling)						
Annual Electric Use (kWh/y)						
Average Life (y)	Guidehouse					
Retail Equipment Cost (2022$)	PERC					
Total Installed Cost (2022$)	Guidehouse					
Annual Maintenance Cost (2022$)						

Residential Cordwood Stoves

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SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	Distributors / Product Literature				Guidehouse					
Efficiency (Non-Catalytic) (HHV)	Guidehouse / Literature	EPA Certified Wood Stove Database (Room Heaters)								
Efficiency (Catalytic) (HHV)										
Average Life (y)	Guidehouse									
Retail Equipment Cost (2022$)	Product Literature/Dealers									
Total Installed Cost (2022$)	Dealers	Dealers/Guidehouse								
Annual Maintenance Cost (2022$)	Dealers/Guidehouse									

Residential Wood Pellet Stoves

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="2">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="6">Guidehouse</td></tr>
<tr><td>Efficiency (HHV)</td><td>EPA Default/ Literature/ Guidehouse</td><td colspan="9">EPA Certified Wood Stove Database (Room Heaters)</td></tr>
<tr><td>Average Life (y)</td><td colspan="10">Guidehouse</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="10">Product Literature/ Dealers</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="10" rowspan="2">Dealers/Guidehouse</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Water Heating

Residential Gas-Fired Storage Water Heaters

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>ENERGY STAR V. 5.0</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (gal)</td><td rowspan="2">Guidehouse</td><td>CWH EERE 2010 Final Rule /AHRI</td><td colspan="5">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>DOE CCD</td><td colspan="2">CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">CWH EERE 2010 Final Rule</td><td colspan="5" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td>Distributors</td><td>CWH EERE 2010 Final Rule</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td>EIA Technology Forecast Updates (2018)</td><td>CWH EERE 2010 Final Rule</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="2">CWH EERE 2010 Final Rule</td></tr>
</table>

Residential Oil-Fired Water Heaters

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SOURCES	2015	2020	2022			2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical / High		
Typical Capacity (gal)	AHRI	CWH EERE 2010 Final Rule/AHRI	CWH EERE 2022 Preliminary Analysis			Guidehouse		
Uniform Energy Factor	Guidehouse	AHRI/DOE CCD						
Average Life (y)	CWH EERE 2010 Final Rule							
Retail Equipment Cost (2022$)								
Total Installed Cost (2022$)								
Annual Maintenance Cost (2022$)								

Residential Electric Resistance Storage Water Heaters

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SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	AHRI	CWH EERE 2010 Final Rule/AHRI	CWH EERE 2022 Preliminary Analysis			Guidehouse					
Uniform Energy Factor	Guidehouse	AHRI/ DOE CCD									
Average Life (y)	CWH EERE 2010 Final Rule										
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)											

Residential Heat Pump Water Heaters

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (gal)</td><td rowspan="2">Guidehouse</td><td>AHRI</td><td colspan="3">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>DOE CCD</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">CWH EERE 2010 Final Rule</td><td colspan="3" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td>CWH EERE 2010 Final Rule</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="2" rowspan="2">CWH EERE 2010 Final Rule</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Solar Water Heaters

SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	ENERGY STAR V. 4.0	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Guidehouse		ENERGY STAR		Guidehouse		
Solar Uniform Energy Factor (SUEF)			DOE				
Average Life (y)	DOE / Guidehouse						
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023				
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse		DOE				

Residential Gas-Fired Instantaneous Water Heaters

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>ENERGY STAR V. 5.0</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td>AHRI</td><td>CWH EERE 2010 Final Rule /AHRI</td><td colspan="5">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>Guidehouse</td><td>DOE CCD</td><td colspan="2">CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">CWH EERE 2010 Final Rule</td><td colspan="5" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Electric Instantaneous Water Heaters

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SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	Guidehouse		CWH EERE 2022 Preliminary Analysis			Guidehouse					
Uniform Energy Factor			CWH EERE 2022 Preliminary Analysis/DOE CCD								
Average Life (y)			Gordian's RSMeans Data – Building Construction Costs 2023								
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)			Guidehouse								

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Residential Appliances

Residential Refrigerator-Freezers (Top)

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SOURCES	2015	2020	2022				2030		2040		2050	
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR V. 5.1**	**High**	**Typical**	**High**	**Typical**	**High**	**Typical**	**High**
Typical Capacity (ft^3)	RF EERE 2011 / Guidehouse	RF EERE 2021 Preliminary Analysis / Guidehouse					RF EERE 2021 Preliminary Analysis / Guidehouse					
Energy Consumption (kWh/y)		DOE CCD/ Guidehouse	CFR	DOE CCD	ENERGY STAR	DOE CCD						
Average Life (y)		RF EERE 2021 Preliminary Analysis / Guidehouse										
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Refrigerator-Freezers (Side)

Final

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SOURCES	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft³)	RF EERE 2011 / Guidehouse	RF EERE 2021 Preliminary Analysis / Guidehouse					RF EERE 2021 Preliminary Analysis / Guidehouse					
Energy Consumption (kWh/y)		DOE CCD/ Guidehouse	CFR	DOE CCD	ENERGY STAR	DOE CCD						
Average Life (y)		RF EERE 2021 Preliminary Analysis / Guidehouse										
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Final

Residential Refrigerator-Freezers (Bottom)

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SOURCES	2015	2020	2022				2030		2040		2050	
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR V. 5.1**	**High**	**Typical**	**High**	**Typical**	**High**	**Typical**	**High**
Typical Capacity (ft³)	RF EERE 2011 / Guidehouse	RF EERE 2021 Preliminary Analysis / Guidehouse					RF EERE 2021 Preliminary Analysis / Guidehouse					
Energy Consumption (kWh/y)		DOE CCD/ Guidehouse	CFR	DOE CCD	ENERGY STAR	DOE CCD						
Average Life (y)		RF EERE 2021 Preliminary Analysis / Guidehouse										
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Freezers (Chest)

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="3">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft³)</td><td colspan="2">RF EERE 2011 / Guidehouse</td><td colspan="3">RF EERE Preliminary Analysis 2021/DOE CCD</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>Energy Consumption (kWh/y)</td><td colspan="2">Guidehouse</td><td>RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021/DOE CCD</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">RF EERE 2011 / Guidehouse</td><td colspan="2" rowspan="4">RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="3">RF EERE Preliminary Analysis 2021/DOE CCD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Freezers (Upright)

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2022</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 5.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td colspan="2">RF EERE 2011/ Guidehouse</td><td colspan="4">RF EERE Preliminary Analysis 2021/ DOE CCD</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>Energy Consumption (kWh/y)</td><td colspan="2">Guidehouse</td><td>RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021/ DOE CCD</td><td>ENERGY STAR</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="5">RF EERE 2011 / Guidehouse</td><td colspan="3" rowspan="5">RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="4">RF EERE Preliminary Analysis 2021/ DOE CCD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr></tr>
</table>

Residential Natural Gas Cooktops

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature				Guidehouse		
Integrated Annual Energy Consumption (kBtu/y)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						
Cooking Efficiency (%)	Guidehouse						
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD						
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2016 SNOPR / Consumer Cooking Products EERE 2020 NOPD						
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Natural Gas Ovens

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Consumer Cooking Products EERE 2016 SNOPR / Product Literature				Guidehouse		
Typical Cavity Volume (ft^3)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD			Guidehouse		
Integrated Annual Energy Consumption (kBtu/y)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD			Guidehouse		
Cooking Efficiency (%)	Guidehouse				Guidehouse		
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD	Consumer Cooking Products EERE 2020 NOPD			Guidehouse		
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD			Guidehouse		
Total Installed Cost (2022$)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD			Guidehouse		
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR				Guidehouse		

Residential Natural Gas Ranges

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="2">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity of Cooktop Component (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="3" rowspan="8">Guidehouse</td></tr>
<tr><td>Typical Capacity of Oven Component (kBtu/h)</td><td colspan="4">Consumer Cooking Products EERE 2016 SNOPR / Product Literature</td></tr>
<tr><td>Typical Cavity Volume of Oven Component (ft^3)</td><td>Consumer Cooking Products EERE 2020 NOPD</td><td colspan="3" rowspan="3">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Integrated Annual Energy Consumption (kBtu/y)</td><td>Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
<tr><td>Average Life (y)</td><td>Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="4" rowspan="2">Guidehouse / Distributors / Gordian’s RSMeans Data – Building Construction Costs 2023</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="4">Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
</table>

Residential Electric Cooktops

SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (W)	Consumer Cooking Products EERE 2016 SNOPR / Distributors				Guidehouse		
Integrated Annual Energy Consumption (kWh/y)	Consumer Cooking Products EERE 2020 NOPD						
Average Life (y)							
Retail Equipment Cost (2022$)							
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Electric Ovens

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="2">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (W)</td><td colspan="4">Consumer Cooking Products EERE 2016 SNOPR / Distributors</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>Typical Cavity Volume (ft³)</td><td rowspan="2">Consumer Cooking Products EERE 2016 SNOPR</td><td colspan="3" rowspan="5">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Integrated Annual Energy Consumption (kWh/y)</td></tr>
<tr><td>Average Life (y)</td><td>Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="4">Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
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Residential Electric Ranges

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity of Cooktop Component (W)	Consumer Cooking Products EERE 2016 SNOPR / Distributors				Guidehouse		
Typical Capacity of Oven Component (W)							
Typical Cavity Volume of Oven Component (ft^3)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD					
Integrated Annual Energy Consumption (kWh/y)							
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD						
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2020 NOPD						
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Electric Clothes Dryers

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SOURCES	2015	2020	2022				2030	2040	2040
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1	High	Typical / High		
Typical Capacity (ft³)	DOE CCD					Guidehouse / DOE CCD / ENERGY STAR	Guidehouse		
CEF, D1 (lb/kWh)	Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse	DOE CCD	Consumer Clothes Dryers EERE 2022 NOPR	DOE CCD	ENERGY STAR V. 1.1	DOE CCD			
CEF, D2 (lb/kWh)						ENERGY STAR			
Average Life (y)	Consumer Clothes Dryers EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse								
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)	Consumer Clothes Dryers EERE 2022 NOPR								

Residential Natural Gas Clothes Dryers

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1	High	Typical / High		
Typical Capacity (ft^3)	DOE CCD						Guidehouse		
CEF, D1 (lb/kWh)	Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse	DOE CCD	Consumer Clothes Dryers EERE 2022 NOPR	DOE CCD	ENERGY STAR V. 1.1	DOE CCD			
CEF2, D2 (lb/kWh)									
Average Life (y)	Consumer Clothes Dryers EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse								
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)	Consumer Clothes Dryers EERE 2022 NOPR								

Residential Clothes Washers (Front)

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 8.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td>Guidehouse</td><td rowspan="3">DOE CCD / Guidehouse</td><td>DOE CCD</td><td rowspan="3">DOE CCD</td><td>DOE CCD</td><td rowspan="3">DOE CCD</td><td colspan="3" rowspan="11">Guidehouse</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Guidehouse</td><td rowspan="2">RCW EERE 2021 Preliminary Analysis</td><td rowspan="2">ENERGY STAR V. 8.1</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">RCW EERE 2021 Preliminary Analysis</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6" rowspan="4">Guidehouse / RCW EERE 2021 Preliminary Analysis</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
<tr><td>Dryer Energy (kWh/cycle)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">EIA Technology Forecast Updates (2018)</td><td colspan="5">RCW EERE 2021 Preliminary Analysis/ Distributors</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="5">RCW EERE 2021 Preliminary Analysis/ Guidehouse</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6">RCW EERE 2021 Preliminary Analysis / Guidehouse</td></tr>
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Residential Clothes Washers (Top)

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SOURCES	2015 Installed Base	2020 Installed Base	2022 Current Standard	2022 Typical	2022 ENERGY STAR V. 8.1	2022 High	2030 Typical / High	2040 Typical / High	2050 Typical / High
Typical Capacity (ft^3)	Guidehouse	Guidehouse	DOE CCD	DOE CCD	DOE CCD	DOE CCD	Guidehouse		
Integrated Modified Energy Factor (ft^3/kWh/cycle)	AHAM / Guidehouse	RCW EERE 2021 Preliminary Analysis			ENERGY STAR V. 8.1	DOE CCD			
Integrated Water Factor (gal/cycle/ft^3)									
Average Life (y)	RCW EERE 2021 Preliminary Analysis								
Water Consumption (gal/cycle)	RCW EERE 2021 Preliminary Analysis / Guidehouse								
Hot Water Energy (kWh/cycle)	Guidehouse	RCW EERE 2021 Preliminary Analysis / Guidehouse							
Machine Energy (kWh/cycle)									
Dryer Energy (kWh/cycle)									
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)								
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)	RCW EERE 2021 Preliminary Analysis / Guidehouse								

Residential Dishwashers

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 6.0</th><th>High</th><th>ENERGY STAR V. 7.0</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Annual Energy Use (kWh/y)</td><td rowspan="2">AHAM 2014 / DW EERE 2012 Final Rule</td><td rowspan="2">Guidehouse / DOE CCD / ENERGY STAR</td><td rowspan="2">CFR</td><td rowspan="2">Guidehouse / DOE CCD / ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">DW EERE 2022 Preliminary Analysis</td><td rowspan="2">ENERGY STAR</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>Water Consumption (gal/cycle)</td></tr>
<tr><td>Water Heating Energy Use (kWh/y)</td><td>AHAM 2014 / DW EERE 2012 Final Rule</td><td>DW EERE 2016 Direct Final Rule</td><td colspan="5" rowspan="4">DW EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">DW EERE 2016 Direct Final Rule/Guidehouse</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">DW EERE 2012 Final Rule</td><td rowspan="2">DW EERE 2016 Direct Final Rule</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
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Commercial Space Heating and Cooling

Commercial Gas-Fired Furnaces

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th>New Standard</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="2">AHRI</td><td>CWAF EERE 2015</td><td colspan="4">DOE CCD</td><td colspan="4" rowspan="9">Guidehouse</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>DOE CCD</td><td>CFR</td><td colspan="2">DOE CCD</td><td>CFR</td></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td colspan="6">Guidehouse</td></tr>
<tr><td>Average Life (y)</td><td colspan="6" rowspan="6">CWAF EERE 2015</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Oil-Fired Furnaces

<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th>New Standard</th><th>Typical</th><th colspan="3">Typical/High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="2">AHRI</td><td rowspan="2">DOE CCD</td><td colspan="4">DOE CCD</td><td rowspan="9" colspan="4">Guidehouse</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>10 CFR 431.77</td><td colspan="2">DOE CCD</td><td>10 CFR 431.77</td></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td colspan="6">Guidehouse</td></tr>
<tr><td>Average Life (y)</td><td rowspan="6" colspan="6">CWAF EERE 2015</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Electric Resistance Heaters

<table>
<tr><th rowspan="2">SOURCES</th><th colspan="2">2012</th><th colspan="2">2018</th><th colspan="2">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Small</th><th>Large</th><th>Small</th><th>Large</th><th>Small</th><th>Large</th><th>Small</th><th>Large</th><th>Small</th><th>Large</th><th>Small</th><th>Large</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="6">Distributors/Guidehouse</td><td colspan="6" rowspan="8">Guidehouse</td></tr>
<tr><td>Efficiency (%)</td><td colspan="6">Guidehouse/DOE</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">Technology Cost and Performance File for Commercial Model for AEO2010</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="4" rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="2" rowspan="3">Gordian's RSMeans Data – Building Construction Costs 2023</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6" rowspan="2">Guidehouse</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
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Commercial Electric Boilers

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical			
Typical Capacity (kW)	BSRIA		Guidehouse			
Efficiency (%)	EERE / Guidehouse					
Average Life (y)	ASHRAE 2007 HVAC Applications	ASHRAE 2015 HVAC Applications	ASHRAE 2019 HVAC Applications			
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse			
Total Installed Cost (2022$)			Gordian's RSMeans Data – Building Construction Costs 2023			
Total Installed Cost (2022$/kBtu/h)						
Annual Maintenance Cost (2022$)			EIA Technology Forecast Updates (2018)			
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Gas-Fired Boilers

SOURCES	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**High**	**New Standard**	**Typical**	**High**	**Typical**	**High**	**Typical**	**High**	**Typical**	**High**
Typical Input Capacity (kBtu/h)	Guidehouse	Comm. Packaged Boilers EERE 2020												
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Guidehouse	Comm. Packaged Boilers EERE 2020 / Guidehouse	DOE CCD			Comm. Packaged Boilers EERE 2020/Guidehouse								
Average Life (y)	Comm. Heating, AC, WH EERE 2009	Comm. Packaged Boilers EERE 2020												
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)													
Total Installed Cost (2022$)														
Total Installed Cost (2022$/kBtu/h)														
Annual Maintenance Cost (2022$)	Comm. Heating, AC, WH EERE 2009													
Annual Maintenance Cost (2022$/kBtu/h)														

Commercial Oil-Fired Boilers

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SOURCES	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	Guidehouse	Comm. Packaged Boilers EERE 2020												
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Guidehouse	Comm. Packaged Boilers EERE 2020 / Guidehouse	DOE CCD			Comm. Packaged Boilers EERE 2020/Guidehouse								
Average Life (y)	Comm. Heating, AC, WH EERE 2009	Comm. Packaged Boilers EERE 2020												
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)													
Total Installed Cost (2022$)														
Total Installed Cost (2022$/kBtu/h)														
Annual Maintenance Cost (2022$)	Comm. Heating, AC, WH EERE 2009													
Annual Maintenance Cost (2022$/kBtu/h)														

Commercial Centrifugal Chillers (Water-Cooled)

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	IPCC/ARB/TEAP/Guidehouse					Guidehouse					
Efficiency (kW/ton)	ASHRAE 90.1-2010/FEMP/eSource/Product Literature	ASHRAE 90.1-2019/Product Lit									
COP											
Average Life (y)	2007 ASHRAE Applications Handbook	2015 ASHRAE Applications Handbook A37 Table 4									
Retail Equipment Cost (2022$/ton)	EIA Technology Forecast Updates (2018)	Gordian's RSMeans Data – Building Construction Costs 2023									
Total Installed Cost (2022$/ton)											
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$/ton)	Guidehouse/Alabama Power										
Annual Maitnenance Cost (2022$/kBtu/h)											

Commercial Reciprocating Chillers (Air-Cooled Only)

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	BSRIA/DEER		Guidehouse			Guidehouse					
Efficiency (kW/ton)	ASHRAE 90.1-2010/DEER/ FEMP/Product Literature	ASHRAE 90.1-2016 (>150 TR)	ASHRAE 90.1-2019		Product Lit						
COP	ASHRAE 90.1-2010/DEER/ FEMP/Product Literature	ASHRAE 90.1-2016 (>150 TR)									
Average Life (y)	Manufacturers	2015 ASHRAE Applications Handbook A37 Table 4									
Retail Equipment Cost (2022$/ton)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023								
Total Installed Cost (2022$/ton)											
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$/ton)	Guidehouse/Alabama Power										
Annual Maintenance Cost (2022$/kBtu/h)											

Commercial Screw Chillers (Air-Cooled Only)

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>ASHRAE 90.1-2019</th><th>Typical</th><th>High</th><th colspan="3">Typical/High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="5">Guidehouse</td><td colspan="3" rowspan="9">Guidehouse</td></tr>
<tr><td>Efficiency (kW/ton)</td><td rowspan="2">Guidehouse</td><td rowspan="2">ASHRAE 90.1-2016 (>150 TR)</td><td rowspan="2">ASHRAE 90.1-2019 (>150 TR)</td><td rowspan="2">ASHRAE 90.1-2019 (>150 TR)/Product Lit</td><td rowspan="2">Product Lit</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (y)</td><td>Manufacturers</td><td colspan="4">FacilitiesNet</td></tr>
<tr><td>Retail Equipment Cost (2022$/ton)</td><td colspan="2" rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="3" rowspan="3">Gordian’s RSMeans Data – Building Construction Costs 2023 / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/ton)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/ton)</td><td colspan="5" rowspan="2">Guidehouse/Alabama Power</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Scroll Chillers (Air-Cooled Only)

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SOURCE	2012	2018	2022			2030	2040	2050
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical / High		
Typical Capacity (tons)	Guidehouse/Manufacturers					Guidehouse		
Efficiency [full-load/IPLV] (kW/ton)	Guidehouse	Product Lit/ Guidehouse	ASHRAE 90.1-2019 (>150 TR)	Product Lit/ Guidehouse	Product Lit			
COP [full-load/IPLV]								
Average Life (y)	Manufacturers							
Retail Equipment Cost (2022$/ton)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse					
Total Installed Cost (2022$/ton)								
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$/ton)	Guidehouse/Alabama Power							
Annual Maintenance Cost (2022$/kBtu/h)								

Final

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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<table>
<tr><th rowspan="2">SOURCES</th><th colspan="2">2012</th><th colspan="2">2018</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base: Absorption</th><th>Installed Base: Engine-Driven</th><th>Installed Base: Absorption</th><th>Installed Base: Engine-Driven</th><th>ASHRAE 90.1-2019 Absorption</th><th>CA Title 24 – Engine-Driven</th><th>Absorption</th><th>Engine-Driven</th><th colspan="3">Absorption/Engine-Driven</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="8">BSRIA/Distributors</td><td colspan="3" rowspan="9">Guidehouse</td></tr>
<tr><td>COP [full-load]</td><td colspan="2" rowspan="2">Product Literature/ Guidehouse</td><td colspan="2" rowspan="2">Product Lit</td><td rowspan="2">ASHRAE 90.1-2019 Direct-fired Double Effect</td><td rowspan="2">CA Title 24 Gas Engine Standard</td><td colspan="2" rowspan="2">Product Lit</td></tr>
<tr><td>COP [IPLV]</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">2007 ASHRAE Applications Handbook/ Distributors</td><td colspan="6">2015 ASHRAE Applications Handbook A37 Table 4</td></tr>
<tr><td>Retail Equipment Cost (2022$/ton)</td><td colspan="4" rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="4" rowspan="3">Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/ton)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/ton)</td><td colspan="8" rowspan="2">Guidehouse/Alabama Power</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Rooftop Air Conditioners

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th colspan="4">2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.1</th><th>High</th><th>New Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td>AHRI / Guidehouse</td><td colspan="9">CUAC EERE 2016</td><td colspan="6" rowspan="3">CUAC EERE 2016 / Guidehouse</td></tr>
<tr><td>Part Load Efficiency (IEER)</td><td colspan="4">CUAC EERE 2016</td><td>ENERGY STAR</td><td colspan="3">CUAC EERE 2016</td><td>ENERGY STAR</td><td>CUAC EERE 2016</td></tr>
<tr><td>Efficiency (EER)</td><td colspan="10">CUAC EERE 2016 / Guidehouse</td></tr>
<tr><td>Efficiency Conversion</td><td colspan="16">Calculated</td></tr>
<tr><td>Average Life (y)</td><td colspan="16">CUAC EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">Distributors / Guidehouse / DEER, 2008</td><td colspan="15" rowspan="2">CUAC EERE 2016</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td><td colspan="16">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="16">CUAC EERE 2016</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td><td colspan="16">Calculated</td></tr>
</table>

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base		Typical			
Typical Capacity (tons)	EIA Technology Forecast Updates (2018)		Guidehouse			
Heating COP						
Cooling COP						
Average Life (y)						
Retail Equipment Cost ($/ton)			Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse			
Total Installed Cost ($/ton)						
Total Installed Cost ($/kBtu/h)						
Annual Maintenance Cost (2022$)						
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Rooftop Heat Pumps

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th colspan="3">2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.1</th><th>High</th><th>New Standard</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="9">EECUHP EERE 2016</td><td colspan="6" rowspan="3">CUHP EERE 2016 / Guidehouse</td></tr>
<tr><td>Part Load Efficiency (IEER)</td><td colspan="4" rowspan="2">CUHP EERE 2016 / Guidehouse</td><td rowspan="2">ENERGY STAR</td><td colspan="2" rowspan="2">CUHP EERE 2016</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">CUHP EERE 2016</td></tr>
<tr><td>COP (Heating)</td></tr>
<tr><td>Average Life (y)</td><td rowspan="7">EIA Technology Forecast Updates (2018)</td><td colspan="14" rowspan="7">CUHP EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Ground-Source Heat Pumps

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	U.S. DOE/EIA	Water-Source Unitary Heat Pumps EERE 2015 Final Rule				Guidehouse					
COP (Heating)	Guidehouse	AHRI Database									
EER (Cooling)											
Average Life (y)	Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule										
Retail Equipment Cost (2022$)	Distributors/Guidehouse	Water-Source Unitary Heat Pumps 2015 EERE Final Rule / Guidehouse									
Total Installed Cost (2022$)	U.S. DOD/IGSHPA/MA DOER/CEFIA/ASHRAE										
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$)	Geothermal Heat Pump Consortium, Inc. (U.S. DOE Contract DE-FG07-95ID13347)										
Annual Maintenance Cost (2022$/kBtu/h)											

Packaged Terminal Air Conditioners

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	PTAC & PTHP EERE 2022 NOPD					PTAC & PTHP EERE 2022 NOPD / Guidehouse					
Efficiency (EER)											
Efficiency											
Average Life (y)											
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$)											
Annual Maintenance Cost (2022$/kBtu/h)											

Packaged Terminal Heat Pumps

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="5" rowspan="10">PTAC & PTHP EERE 2022 NOPD</td><td colspan="6" rowspan="10">PTAC & PTHP EERE 2022 NOPD / Guidehouse</td></tr>
<tr><td>Efficiency (EER)</td></tr>
<tr><td>Efficiency</td></tr>
<tr><td>COP (Heating)</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
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Commercial Water Heating

Commercial Gas-Fired Storage Water Heaters

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SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	EIA Technology Forecast Updates (2018)	CWH EERE 2022 NOPR										
Typical Input Capacity (kBtu/h)												
Thermal Efficiency (%)		DOE CCD / Guidehouse	CFR	DOE CCD/ Guidehouse	ENERGY STAR	DOE CCD	CWH EERE 2022 NOPR / Guidehouse					
Average Life (y)		CWH EERE 2022 NOPR										
Retail Equipment Cost (2022$)	CWH EERE 2022 NOPR											
Total Installed Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$)												
Annual Maintenance Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$/kBtu/h)												

Commercial Electric Resistance Storage Water Heaters

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SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical		
Typical Storage Capacity (gal)	Product Literature / Guidehouse	CWH EERE 2016 NOPR			Guidehouse		
Typical Input Capacity (kW)	Product Literature						
Typical Input Capacity (kBtu/h)							
Thermal Efficiency (%)	Guidehouse						
Average Life (y)	CWH EERE 2016 NOPR						
Retail Equipment Cost (2022$)	CWH EERE 2016 NOPR / Guidehouse	CWH EERE 2016 NOPR					
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)							
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Heat Pump Water Heaters

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SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.0	Typical	Typical	Typical
Water Flow Rate (gal/min)	Distributors/Guidehouse		Guidehouse				
Typical Output Capacity (kW)							
Typical Output Capacity (kBtu/h)							
Coefficient of Performance (COP_h)							
Average Life (y)	EERE/Guidehouse						
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)						
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)	Guidehouse						
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Oil-Fired Storage Water Heaters

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SOURCES	2012	2018	2022			2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical/High		
Typical Storage Capacity (gal)	AHRI / Guidehouse	DOE CCD/Guidehouse				Guidehouse		
Typical Input Capacity (kBtu/h)								
Thermal Efficiency (%)	Guidehouse		CFR	DOE CCD				
Average Life (y)	Commercial Heating, Air Conditioning and Water Heating Equipment EERE 2001							
Retail Equipment Cost (2022$)	Distributors / Guidehouse							
Total Installed Cost (2022$)								
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$)								
Annual Maintenance Cost (2022$/kBtu/h)								

Commercial Electric Booster Water Heaters

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (gal)	Product Literature / Guidehouse					
Typical Output Capacity (kBtu/h)						
Thermal Efficiency (%)						
Average Life (y)						
Retail Equipment Cost (2022$)						
Total Installed Cost (2022$)						
Total Installed Cost (2022$/kBtu/h)						
Annual Maintenance Cost (2022$)						
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Gas-Fired Booster Water Heaters

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SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	Product Literature / Guidehouse						
Typical Output Capacity (kBtu/h)							
Thermal Efficiency (%)							
Average Life (y)							
Retail Equipment Cost (2022$)							
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)							
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Gas-Fired Instantaneous Water Heaters

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SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	DOE CCD						DOE CCD / Guidehouse					
Thermal Efficiency (%)	Guidehouse/DOE CCD		DOE CCD		ENERGY STAR	DOE CCD						
Average Life (y)	CWH EERE 2022 NOPR											
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Total Installed Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$)												
Annual Maintenance Cost (2022$/kBtu/h)												

Commercial Solar Water Heaters

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SOURCES	2012	2018	2022		2023	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	ENERGY STAR V. 5.0	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Guidehouse					Guidehouse		
Typical Capacity (m^2)								
Typical Capacity (Input) (kBtu/h) - North								
Typical Capacity (Input) (kBtu/h) - South								
Solar Uniform Energy Factor (SUEF)	ENERGY STAR / Guidehouse							
Average Life (y)	SRCC / Guidehouse							
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse					
Total Installed Cost (2022$)								
Total Installed Cost (2022$/kBtu/h) - North	Guidehouse							
Total Installed Cost (2022$/kBtu/h) - South								
Annual Maintenance Cost (2022$)	DOE / Guidehouse							
Annual Maintenance Cost (2022$/kBtu/h) - North								
Annual Maintenance Cost (2022$/kBtu/h) - South								

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Commercial Cooking Products

Commercial Natural Gas Range with Griddle and Oven

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th>2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>ENERGY STAR V. 2.2</th><th>High</th><th>ENERGY STAR V. 3.0</th><th colspan="3">Typical/High</th></tr>
<tr><td>Griddle - Cooking Energy Efficiency (%)</td><td rowspan="3">Guidehouse</td><td rowspan="3">FSTC</td><td rowspan="2">ENERGY STAR / FSTC</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td>NA</td><td colspan="3" rowspan="13">Guidehouse</td></tr>
<tr><td>Oven - Cooking Energy Efficiency (%)</td><td>ENERGY STAR</td></tr>
<tr><td>Range - Cooking Energy Efficiency (%)</td><td>FEMP / CEC</td><td>NA</td><td>FEMP / CEC</td><td>NA</td></tr>
<tr><td>Combined Energy Efficiency (%)</td><td colspan="6">Guidehouse / FSTC</td></tr>
<tr><td>Griddle - Normalized Idle Energy Rate (Btu/h/ft²)</td><td>Guidehouse</td><td>FSTC</td><td>ENERGY STAR / FSTC</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td>NA</td></tr>
<tr><td>Oven - Idle Energy Rate (Btu/h)</td><td colspan="2">FEMP</td><td>ENERGY STAR</td><td>ENERGY STAR</td></tr>
<tr><td>Range - Idle Energy Rate (Btu/h)</td><td colspan="3">FSTC</td><td>NA</td><td>FSTC</td><td>NA</td></tr>
<tr><td>Combined Idle Energy Rate (Btu/h)</td><td colspan="6">Guidehouse / FSTC / Distributors</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">FSTC</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6">Distributors</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="6" rowspan="2">FSTC / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6" rowspan="2">FSTC</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
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Commercial Electric Range with Griddle and Oven

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SOURCES	2012 Installed Base	2018 Installed Base	2022 Typical	2022 ENERGY STAR V. 2.2	2022 High	2023 ENERGY STAR V. 3.0	2030 Typical/High	2040 Typical/High	2050 Typical/High
Griddle - Cooking Energy Efficiency (%)	Guidehouse	FSTC	FSTC / ENERGY STAR / Guidehouse	ENERGY STAR	ENERGY STAR	NA	Guidehouse		
Oven - Cooking Energy Efficiency (%)						ENERGY STAR			
Range - Cooking Energy Efficiency (%)				NA	CEC	NA			
Combined Energy Efficiency (%)	Guidehouse / FSTC								
Griddle - Normalized Idle Energy Rate (kW/ft^2)	Guidehouse	FSTC	FSTC / ENERGY STAR / Guidehouse	ENERGY STAR	ENERGY STAR	NA			
Oven - Idle Energy Rate (kW)						ENERGY STAR			
Range - Idle Energy Rate (kW)	NA								
Combined Idle Energy Rate (kW)	Guidehouse / FSTC / Distributors								
Average Life (y)	FSTC								
Retail Equipment Cost (2022$)	Distributors								
Total Installed Cost (2022$)	FSTC / Guidehouse								
Total Installed Cost (2022$/kBtu/h)									
Annual Maintenance Cost (2022$)	FSTC								
Annual Maintenance Cost (2022$/kBtu/h)									

Commercial Hot Food Holding Cabinets – Small

<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>State Standards</th><th>Typical</th><th>ENERGY STAR V. 2.0</th><th>High</th><th colspan="2">Typical/High</th></tr>
<tr><td>Interior Volume (ft^3)</td><td colspan="6">FEMP / ENERGY STAR</td><td colspan="2" rowspan="9">Guidehouse</td></tr>
<tr><td>Maximum Idle Energy Rate (W)</td><td>CEE / Guidehouse</td><td>FEMP</td><td>ASAP</td><td>ASAP / ENERGY STAR</td><td>ENERGY STAR V. 2.0</td><td>FEMP / ENERGY STAR</td></tr>
<tr><td>Annual Energy Use (kWh/y)</td><td colspan="6" rowspan="2">FEMP</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6">Distributors / ENERGY STAR Savings Calculator / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="6" rowspan="2">Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6" rowspan="2">FSTC</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Hot Food Holding Cabinets – Medium

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SOURCES	2012	2018	2022				2030	2040
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical/High	
Interior Volume (ft^3)	FEMP / ENERGY STAR						Guidehouse	
Maximum Idle Energy Rate (W)	CEE / Guidehouse	FEMP	ASAP	ASAP / ENERGY STAR	ENERGY STAR V. 2.0	FEMP / ENERGY STAR		
Annual Energy Use (kWh/y)	FEMP							
Average Life (y)								
Retail Equipment Cost (2022$)	Distributors / ENERGY STAR Savings Calculator / Guidehouse							
Total Installed Cost (2022$)	Guidehouse							
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$)	FSTC							
Annual Maintenance Cost (2022$/kBtu/h)								

Commercial Hot Food Holding Cabinets – Large

Final

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SOURCES	2012	2018	2022				2030	2040
	Installed Base	**Installed Base**	**State Standards**	**Typical**	**ENERGY STAR V. 2.0**	**High**	**Typical/High**	
Interior Volume (ft³)	FEMP / ENERGY STAR						Guidehouse	
Maximum Idle Energy Rate (W)	CEE / Guidehouse	FEMP	ASAP	ASAP / ENERGY STAR	ENERGY STAR V. 2.0	FEMP / ENERGY STAR		
Annual Energy Use (kWh/y)	FEMP							
Average Life (y)								
Retail Equipment Cost (2022$)	Distributors / ENERGY STAR Savings Calculator / Guidehouse							
Total Installed Cost (2022$)	Guidehouse							
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$)	FSTC							
Annual Maintenance Cost (2022$/kBtu/h)								

Appendix B
References

Guidehouse
1676 International Drive
McLean, VA 22102

And

Leidos
11951 Freedom Drive
Reston, VA 20190

References

- AHRI. Air Conditioners Monthly Shipments, Retrieved August 2022 from: https://ahrinet.org/statistics
- AHRI. Furnaces Historical Data, Retrieved August 2022 from: https://ahrinet.org/statistics
- Alabama Power (n.d.). Chillers: Compare Maintenance Costs. Retrieved September 2017 from: http://www.alabamapower.com/business/ways-to-save/chillers-space-cooling-options/compare-maintenance-costs.html
- ASAP. Hot Food Holding Cabinets. Retrieved October 2022 from https://appliance-standards.org/product/hot-food-holding-cabinets
- ASHRAE. (2004). ASHRAE Standard 90.1-2004. ASHRAE, Inc.
- ASHRAE. (2007). ANSI/ASHRAE/IESNA Standard 90.1-2007. ASHRAE, Inc.
- ASHRAE. (2016). ANSI/ASHRAE/IESNA Standard 90.1-2016. ASHRAE, Inc.
- ASHRAE. (2019). ANSI/ASHRAE/IESNA Standard 90.1-2019. ASHRAE, Inc.
- ASHRAE. (2015). 2015 ASHRAE Handbook – HVAC Applications. ASHRAE Inc.
- Building Services Research and Information Association & Ducker Research Company. (1997, 1998). U.S. Market for Central Plant Air Conditioning; Market for Ducted Warm Air Central Heating; U.S. Market for Hydronic Heating and Burners; U.S. Water Heating Market; U.S. Unitary and Close Control Air Conditioning.
- California Energy Commission. (2019). Building Energy Efficiency Standards for Residential and Nonresidential Buildings.
- CEC. (n.d.). California Energy Commission Appliance Efficiency Database. Retrieved 2004, September 2010, June 2013, and October 2022 from: http://www.appliances.energy.ca.gov/AdvancedSearch.aspx

References

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- CEE. (2009). "Commercial Hot Food Holding Cabinets Program Guide." Consortium for Energy Efficiency. April 2009.
- CFR. (n.d.). National energy conservation standards authorized under the Energy Policy and Conservation Act of 1975 (EPCA) and codified in the Code of Federal Regulations (CFR).
- DOE. (n.d.). *Estimating the Cost and Energy Efficiency of a Solar Water Heater*. Retrieved October 2022 from https://energy.gov/energysaver/estimating-cost-and-energy-efficiency-solar-water-heater
- DOE. (n.d.). Solar Water Heaters. Retrieved October 2022 from https://energy.gov/energysaver/solar-water-heaters
- Distributors. (n.d.). Guidehouse online research and discussions with distributors (e.g., Grainger, Home Depot, Lowe's, Sears, and others).
- EERE. (2001). Energy Efficiency Program for Commercial and Industrial Equipment; Efficiency Standards for Commercial Heating, Air Conditioning and Water Heating Equipment; Final Rule.
- EERE. (2007). Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers; Final Rule.
- EERE. (2008). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule.
- EERE. (2009). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards and Test Procedures for Commercial Heating, Air-Conditioning, and Water-Heating Equipment; Final Rule.
- EERE. (2010). Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule.

References

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- EERE. (2011). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Dryers and Room Air Conditioners; Direct Final Rule.
- EERE. (2011). Energy Conservation Program: Energy Conservation Standards for Residential Furnaces and Residential Central Air Conditioners and Heat Pumps; Direct Final Rule.
- EERE. (2011). Energy Conservation Program: Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers; Final Rule.
- EERE. (2012). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule.
- EERE. (2014). Energy Conservation Standards for Residential/Consumer Clothes Dryers.
- EERE. (2014). Energy Conservation Standards for Residential Conventional Cooking Products (Ovens).
- EERE. (2014). Energy Conservation Standards for Residential Furnaces.
- EERE. (2015). Energy Efficiency Program For Consumer Products And Commercial And Industrial Equipment: Commercial Warm Air Furnaces.
- EERE. (2015). Final Rule Technical Support Document: Energy Efficiency Program for Small, Large, and Very Large Commercial Package Air Conditioners.
- EERE. (2016). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces; Direct final rule and Technical Support Document.
- EERE. (2016). Energy Conservation Program: Energy Conservation Standards for Residential Boilers.

References

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- EERE. (2016). Final Rule Technical Support Document: Energy Efficiency Program for Residential Central Air Conditioners and Heat Pumps.
- EERE. (2016). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Commercial Water Heating Equipment: Notice of Proposed Rulemaking.
- EERE. (2017). Energy Conservation Standards for Residential Clothes Washers.
- EERE. (2020). Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers; Final rule
- EERE. (2020). Energy Conservation Program: Energy Conservation Standards for Portable Air Conditioners.
- EERE. (2020). Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Portable Air Conditioners.
- EERE. (2021). Energy Conservation Program: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers, and Freezers.; Preliminary Analysis
- EERE. (2021). Energy Conservation Program: Product Classes for Residential Dishwashers, Residential Clothes Washers, and Consumer Clothes Dryers.
- EERE. (2022). Energy Conservation Program: Energy Conservation Standards for Residential Boilers; Preliminary Analysis.
- EERE. (2022). Energy Conservation Program: Energy Conservation Standards for Room Air Conditioners; Notice of Proposed Rulemaking.
- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps; Notice of Proposed Determination.

References

- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Consumer Water Heaters; Preliminary Analysis.
- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Commercial Water Heating Equipment; Notice of Proposed Rulemaking.
- EIA – Technology Forecast Updates – Residential and Commercial Building Technologies. (2018). Retrieved August 2022 from: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf
- ENERGY STAR Savings Calculator (n.d.). "Savings Calculator for ENERGY STAR Qualified Commercial Kitchen Equipment." U.S. EPA and DOE. Retrieved June 2013 from http://www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing
- ENERGY STAR. (n.d.). Retrieved June 2013, September 2017, and October 2022, from ENERGY STAR Products: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
- EPA. USEPA Certified Wood Stove Database. Retrieved August 2022 from: https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.search
- FacilitiesNet. (2009). Properly Diagnosing Chiller Life Cycles. Retrieved September 2017 from: http://www.facilitiesnet.com/hvac/article/Properly-Diagnosing-Chiller-Life-Cycles--10645
- FEMP. (2012). "Federal Energy Management Program: Covered Product Category: Hot Food Holding Cabinets." Retrieved June 2013 from: http://www1.eere.energy.gov/femp/technologies/printable_versions/eep_hot_food.html
- FEMP. (2016, August). Purchasing Energy-Efficient Air-Cooled Chillers. Retrieved September 2017, from FEMP Technologies: https://www1.eere.energy.gov/femp/technologies/eep_ac_chillers.html

- FEMP. (2016, August). Purchasing Energy-Efficient Water-Cooled Electric Chillers. Retrieved September 2017, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-water-cooled-electric-chillers
- FEMP. (2020, June). Purchasing Energy-Efficient Air-Cooled Electric Chillers. Retrieved September 2022, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-air-cooled-electric-chillers
- FEMP. (2020, June). Purchasing Energy-Efficient Water-Cooled Electric Chillers. Retrieved September 2022, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-water-cooled-electric-chillers
- FEMP. (2021, December). Purchasing Energy-Efficient Hot Food Holding Cabinets. Retrieved October 2022 from FEMP Technologies: https://www.energy.gov/eere/femp/purchasing-energy-efficient-hot-food-holding-cabinets
- FSTC. (n.d.). Appliance Reports, Rangetop Performance Reports. Retrieved December 2017, from: https://fishnick.com/publications/appliancereports/rangetops/
- FSTC. (n.d.). Appliance Reports, Griddle Performance Reports. Retrieved December 2017, from: https://fishnick.com/publications/appliancereports/griddles/
- Gordian's RSMeans Data – Building Construction Costs 2023. Copyright RSMeans and Gordian. 30 Patewood Dr. Suite 350, Greenville, SC, 29615; All rights reserved.
- Guidehouse. (n.d.). In-House Expertise.
- Less et. al. (2021). The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes. Retrieved February 2023 from: https://eta-publications.lbl.gov/sites/default/files/final_walker_-_the_cost_of_decarbonization_and_energy.pdf
- IGSPHA. (n.d.). International Ground-Source Heat Pump Association. Retrieved 2007 from www.igshpa.okstate.edu

References

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- International Ground-Source Heat Pump Association (IGSHPA) Conference Proceedings. (2012, October). Measuring the Costs & Benefits of Nationwide Geothermal Heat Pump (GHP) Deployment – A Progress Report. Retrieved June 2013, from IGSHPA: http://www.igshpa.okstate.edu/membership/members_only/proceedings/2012/10-3-2012-0130-Session-C-Measuring-the-Costs-&-Benefits-of-Nationwide-Geothermal-Heat-Pump-(GHP)-Deployment-A-Progress-Report.pdf
- Manufacturers. (n.d.). Guidehouse discussions with product manufacturers.
- Product Literature. (n.d.). Literature from manufacturers and experts on specific products.
- Propane Education and Research Council (PERC). (2007). Assessment of Propane Fired Gas Air Conditioning, Heat Pumping and Dehumidification Technologies, Products, Markets and Economics
- Residential Energy Services Network. Draft PDS-01, MINHERS Addendum 71, SEER2/HSPF2 Conversions. Retrieved February 2023 from: https://www.resnet.us/about/standards/minhers/draft-pds-01-minhers-addendum-71-seer2-hspf2-conversions/
- Solar Rating and Certification Corporation (SRCC). (n.d.) Solar Uniform Energy Factor Specification. Retrieved October 2022 from: https://solar-rating.org/resources/suef/
- Technology Cost and Performance File for Commercial Model for AEO2010. (2009). (E. Boedecker, Compiler)
- U.S. Department of Energy's Compliance Certification Database. Retrieved August 2022 to February 2023 from: http://www.regulations.doe.gov/certification-data/

APPENDIX B

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

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March 3, 2023

DISCLAIMER

March 2023

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Objective

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The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- Installed base in 2012 and 2018 (for commercial products) or 2015 and 2020 (for residential products) and current market (2022)
  - Review literature, standards, installed base, contractor, and manufacturer information
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product
- Forecast of technology improvements that are projected to be available through 2050
  - Review trends in standards, product enhancements, and Research and Development (R&D)
  - Project impact of product improvements and enhancement to technology

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Methodology

Input from industry stakeholders, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- Only currently published efficiency standards and regulations are considered when predicting technology developments; unpublished future regulatory action is not predicted.
- All costs are shown in 2022 dollars (2022$).
- Ranges, when given, represent the span of typical values for a given parameter (e.g., installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

Advanced Case Assumptions

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The Advanced Case and Reference Case both assume current level of effort for standards. However, the Advanced Case assumes an increase in market incentive and federal R&D. The general approach for the Advanced Case is outlined below.

- The Advanced Case considers future changes to product groups such as:
  - Product or component changes that are fully developed but have not yet been commercialized
  - Expected incremental improvements in existing technologies due to increased R&D
  - Increased adoption of existing higher efficiency technology options due to increased market incentives
- The Advanced Case did *not* include future changes to product groups that are due to:
  - Prototype technology changes or products that are in preliminary research that may have performance improvements but have only been demonstrated in theoretical calculations

Definitions

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The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 and 2018 (for commercial products) or 2015 and 2020 (for residential products) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- Current Standard: The minimum efficiency (or maximum energy use) that is required (allowed) by current U.S. Department of Energy (DOE) standards, when applicable.
- ENERGY STAR: The minimum efficiency that is required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. The performance data that are presented are representative of certified products that just meet current ENERGY STAR specifications.
- Typical: Efficiency and cost values are for the average, or "typical," product being sold in the particular timeframe. This may represent either the shipments-weighted average product performance or the most common product on the market.
- High: Efficiency and cost values are for the product with the highest efficiency available in the particular timeframe.

The market for the reviewed products has changed since this analysis was previously conducted.[1] These changes are noted and reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is more efficient than the average product in the installed base in 2012 (commercial) or 2015 (residential):
  - Residential sector: boilers, central air conditioners, room air conditioners, gas-fired furnaces (North), gas-fired furnaces (Rest of Country), oil-fired furnaces, electric resistance furnaces, heat pump water heaters, gas-fired instantaneous water heaters, natural gas cooktops, natural gas ovens, refrigerator-freezers, freezers, clothes dryers, clothes washers, and dishwashers
  - Commercial sector: gas-fired furnaces, oil-fired boilers, commercial rooftop heat pumps, commercial ground-source heat pumps, gas-fired instantaneous water heater, natural gas and electric ranges, griddles, and ovens
- More stringent Federal standards have taken effect for the following products:
  - Gas-fired and oil-fired boilers in 2021
  - Rooftop air conditioners and rooftop heat pumps in 2018
- Federal standards are slated to take effect in the coming years for the following products:
  - Central air conditioners, residential air-source heat pumps, gas-fired furnaces, oil-fired furnaces, gas-fired boilers, oil-fired boilers, rooftop air conditioners, and rooftop heat pumps in 2023
  - Portable air conditioners in 2025
- ENERGY STAR continues to raise the bar with revised criteria for:
  - Central air conditioners, residential air-source heat pumps, rooftop air conditioners, rooftop heat pumps, residential water heaters, and dishwashers in 2023

Note: The previous analysis is available in the EIA Technology Forecast Updates (2018) report.

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Residential Space Heating and Cooling

Residential Gas-Fired Furnaces (North)

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Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North) V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)[1]	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	90	95	99	95	99	95	99	95	99
Electric Consumption (kWh/y)[2]	374	374	386	636	631	725	631	725	631	725	631	725
Average Life (y)[3]	17	17	17	17	17	17	17	17	17	17	17	17
	26	26	26	26	26	26	26	26	26	26	26	26
Retail Equipment Cost (2022$)	1,300	1,300	1,080	1,200	1,220	1,390	1,220	1,390	1,220	1,390	1,220	1,390
Total Installed Cost (2022$)	2,880	2,880	3,690	4,130	4,150	4,320	4,150	4,320	4,150	4,320	4,150	4,320
Annual Maintenance Cost (2022$)	60	60	120	130	130	130	130	130	130	130	130	130

1. Typical input capacity is represented in terms of thousand British thermal units (kBtu) per hour (i.e., kBtu/h).
2. Electric consumption, represented in terms of kilowatt hours per year (kWh/y), accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
3. In the Residential Furnaces EERE 2022 Notice of Proposed Rulemaking (NOPR) Technical Support Document (TSD), an average lifetime of 22.5 years is calculated for gas-fired furnaces (North). Lifetime range was calculated using the Weibull Distribution in the Residential Furnaces EERE 2022 NOPR.

Note:
Models on the market can be either weatherized or non-weatherized. The majority (74%) are non-weatherized, and the values in the table use only non-weatherized data.
Electric consumption and cost values for 2022 and beyond are for a national sample and use the Residential Furnaces EERE 2022 NOPR Life-Cycle-Cost (LCC) spreadsheet.
Electric consumption and costs for the 2030, 2040, and 2050 high values are estimated based on the maximum-efficiency level analyzed in Residential Furnaces EERE 2022 NOPR, which is 98% annual fuel utilization efficiency (AFUE).
The current standard went into effect in November 2015.
ENERGY STAR V. 4.1 went into effect in February 2013.
The range for average life represents the span of typical values.

Residential Gas-Fired Furnaces (Rest of Country)

Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (ROC) V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	90	90	99	95	99	95	99	95	99
Electric Consumption (kWh/y)[1]	279	279	386	636	636	725	631	725	631	725	631	725
Average Life (y) [2]	16	16	16	16	16	16	16	16	16	16	16	16
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	1,260	1,260	1,080	1,200	1,200	1,390	1,220	1,390	1,220	1,390	1,220	1,390
Total Installed Cost (2022$)	2,380	2,380	3,690	4,130	4,130	4,320	4,150	4,320	4,150	4,320	4,150	4,320
Annual Maintenance Cost (2022$)	40	40	120	130	130	130	130	130	130	130	130	130

1. Electric consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
2. In the Residential Furnaces EERE 2022 NOPR, an average lifetime of 21.5 years is calculated for gas-fired furnaces (Rest of Country). Lifetime range was calculated using the Weibull Distribution in the Residential Furnaces EERE 2022 NOPR.

Note:

Models on the market can be either weatherized or non-weatherized. The majority (74%) are non-weatherized, and the values in the table use only non-weatherized data.

Electric consumption and cost values for 2022 and beyond are for a national sample and use the Residential Furnaces EERE 2022 NOPR LCC spreadsheet.

Electric consumption and costs for the 2030, 2040, and 2050 high values are estimated based on the maximum-efficiency level analyzed in Residential Furnaces EERE 2022 NOPR, which is 98% AFUE.

The current standard went into effect in November 2015.

ENERGY STAR V. 4.1 went into effect in February 2013.

The range for average life represents the span of typical values.

Residential Gas-Fired Furnaces

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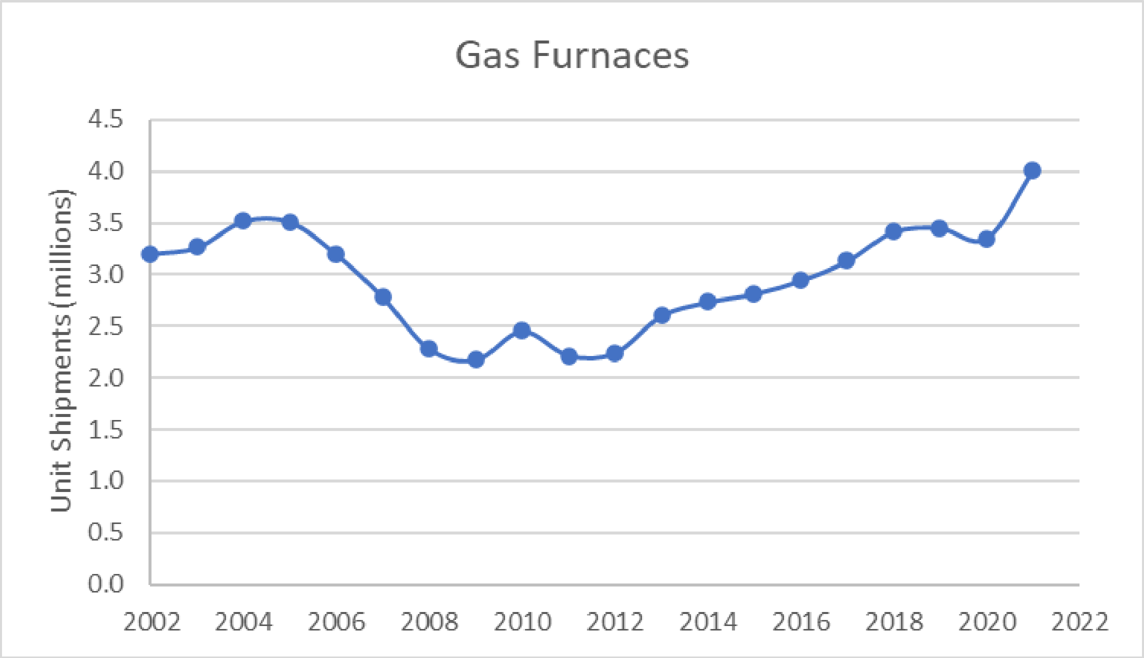
- Current Federal standards for non-weatherized gas furnaces:
  - AFUE ≥ 80%
- ENERGY STAR V. 4.1 criteria for gas furnaces:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
  - Furnaces must be equipped with electronically commutated fan motor and have less than or equal to 2.0% air leakage
- Most efficient unit currently available: 99.0% AFUE. The current market is nearly evenly split between non-condensing units (AFUE≤82%) and condensing units (AFUE≥90%).
- The maximum AFUE for non-condensing gas furnaces is 82%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have high-grade stainless steel (AL 29-4C) heat exchangers.
- Many condensing furnaces are available as direct vent and sealed combustion systems, which do not use room air for combustion, but instead draw combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) fan motors or electronically commutated motors (ECMs). The type of motor affects the electrical consumption of the furnace as well as the seasonal energy efficiency ratio (SEER) / energy efficiency ratio (EER) of the associated air conditioner.
  - The 2016 Energy Conservation Standards for Residential Furnace Fans Final Rule requires that all furnaces use ECM fans.
  - Most non-weatherized gas furnaces employ ECMs and can fully modulate rather than cycling on and off. Because they modulate, there is an increase in total fan-on time.

Residential Gas-Fired Furnaces

Annual shipments reached 3.5 million units in 2005 and then declined each year until 2009, leveling off at about 2.25 million units. Since 2012, shipments have increased steadily and reached a peak of 4.0 million units in 2021.



Source: *Air-Conditioning, Heating, and Refrigeration Institute (AHRI)*

Residential Oil-Fired Furnaces

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Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	83	83	83	85	85	97	85	97	85	97	85	97
Electric Consumption (kWh/y)[1]	477	477	477	466	466	410	466	410	466	410	466	410
Average Life (y)[2]	20	20	20	20	20	20	20	20	20	20	20	20
	33	33	33	33	33	33	33	33	33	33	33	33
Retail Equipment Cost (2022$)	2,620	2,620	2,620	2,650	2,650	3,170	2,650	3,170	2,650	3,170	2,650	3,170
	3,450	3,450	3,450	3,490	3,490	4,090	3,490	4,090	3,490	4,090	3,490	4,090
Total Installed Cost (2022$)	3,250	3,250	3,250	3,480	3,480	5,140	3,480	5,140	3,480	5,140	3,480	5,140
	6,520	6,520	6,520	6,820	6,820	10,110	6,820	10,110	6,820	10,110	6,820	10,110
Annual Maintenance Cost (2022$)	80	80	80	80	80	240	80	240	80	240	80	240

1. Electric consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
2. Lifetime range was calculated using the Weibull Distribution in Residential Furnaces EERE 2011.

Note:
The current standard went into effect in May 2013.
ENERGY STAR V. 4.1 went into effect in February 2013.
Ranges represent the span of typical values for a given parameter.

Residential Oil-Fired Furnaces

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- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR V. 4.1 criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient unit currently available: 96.7% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these secondary heat exchangers use a high-grade stainless steel (AL 29-4C).
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, condensing oil furnaces typically require frequent cleaning and maintenance.

Residential Oil-Fired Furnaces

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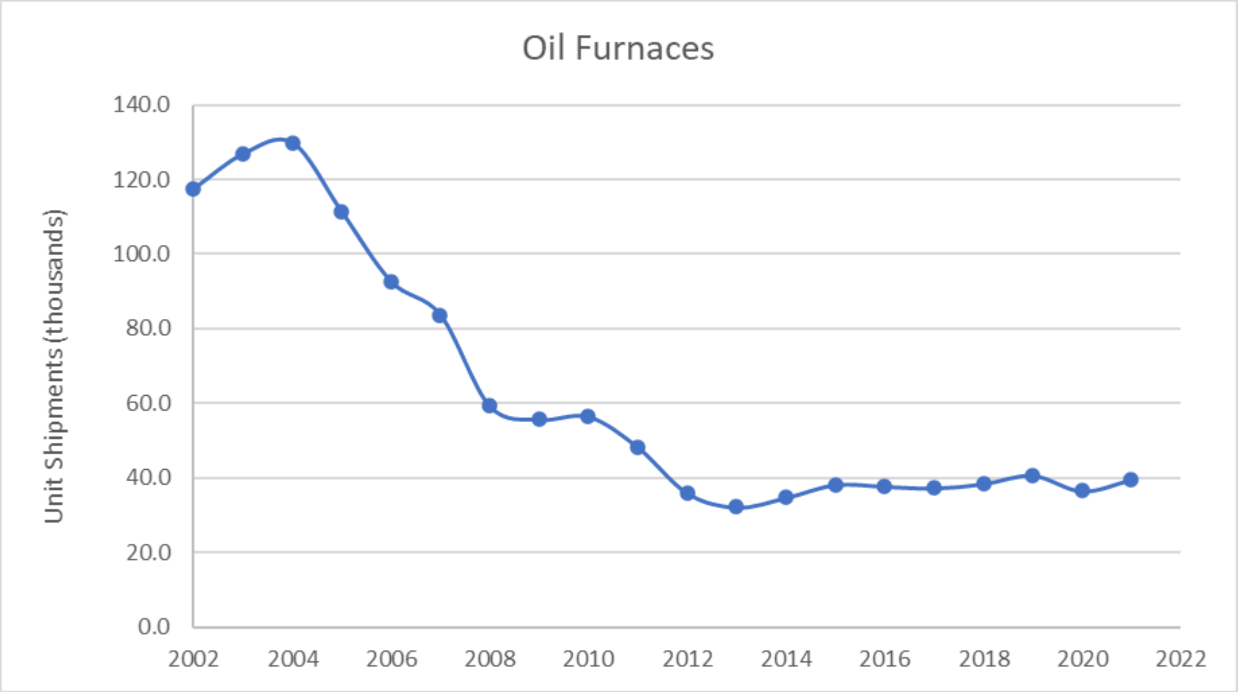
Annual shipments declined rapidly after 2004, likely due, at least in part, to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely leveled off.



Source: *AHRI*

Residential Gas-Fired Boilers

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Same as Reference Case

DATA	2015	2020[1]	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	100	100	100	100	100	100	100	100	100	100	100	100
AFUE (%)	82	95	84	95	90	96	95	96	95	96	95	96
Electric Consumption (kWh/y)[3]	197	506	282	506	527	502	506	502	506	502	506	502
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)	2,540	2,890	1,820	2,890	2,440	3,670	2,890	3,670	2,890	3,670	2,890	3,670
Total Installed Cost (2022$)	7,760	5,940	8,700	5,940	6,700	6,710	5,940	6,710	5,940	6,710	5,940	6,710
Annual Maintenance Cost (2022$)[4]	110	160	150	160	160	160	160	160	160	160	160	160

1. The 2020 AFUE is estimated based on EERE 2022 preliminary analysis, which estimates that gas-fired boilers with the highest market share in 2020 have an AFUE of 95%.
2. The 2030, 2040, 2050 projections are estimated based on the EERE 2022 preliminary analysis, which notes that majority of the market is expected to be condensing, if new standards are not implemented. The EERE 2022 preliminary analysis estimates a minimum efficiency of 95% AFUE for condensing units.
3. Electric Consumption accounts for the electricity consumption of auxiliary electrical components including circulating pump, the boiler pump (condensing boilers only), the draft inducer (if present), and the ignitor. It also accounts for the electricity consumption of auxiliary equipment such as a condensate pump and heat tape, which are sometimes installed with higher efficiency boilers. Additionally, it accounts for the additional cooling load due to heat loss from the boiler and water heater as a result of water heating during the cooling season.
4. Maintenance cost is the routine annual cost to the consumer of general maintenance for product operation. Maintenance cost is higher for condensing boilers for the inspection of condensate system and replacement of condensate neutralizer filter.

Note:
The current standard went into effect in January 2021.
ENERGY STAR V. 3.0 went into effect in December 2013.
Water boilers considered. Steam boilers also exist but make up a small percentage of the market.
The range for average life represents the span of typical values.

Residential Gas-Fired Boilers

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- Federal standard for gas-fired hot-water boilers (more common than steam):
  - AFUE ≥ 84%
  - Standard went into effect on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 90%
- Most efficient gas-fired boiler available: 96.4% AFUE
- Gas-fired boilers have lost market share to furnaces and heat pumps over the past 30 years.
- U.S. gas hot water boiler sales are split approximately 60/40 between condensing and non-condensing.[1] Condensing boilers typically have heat exchangers made of stainless steel, and non-condensing boilers typically have heat exchangers made of cast iron.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems or sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (e.g., heat exchanger, gas valve, burner, sensors, and/or controls).

Source: EERE 2022 Preliminary Analysis TSD, Chapter 3

Residential Gas-Fired Boilers

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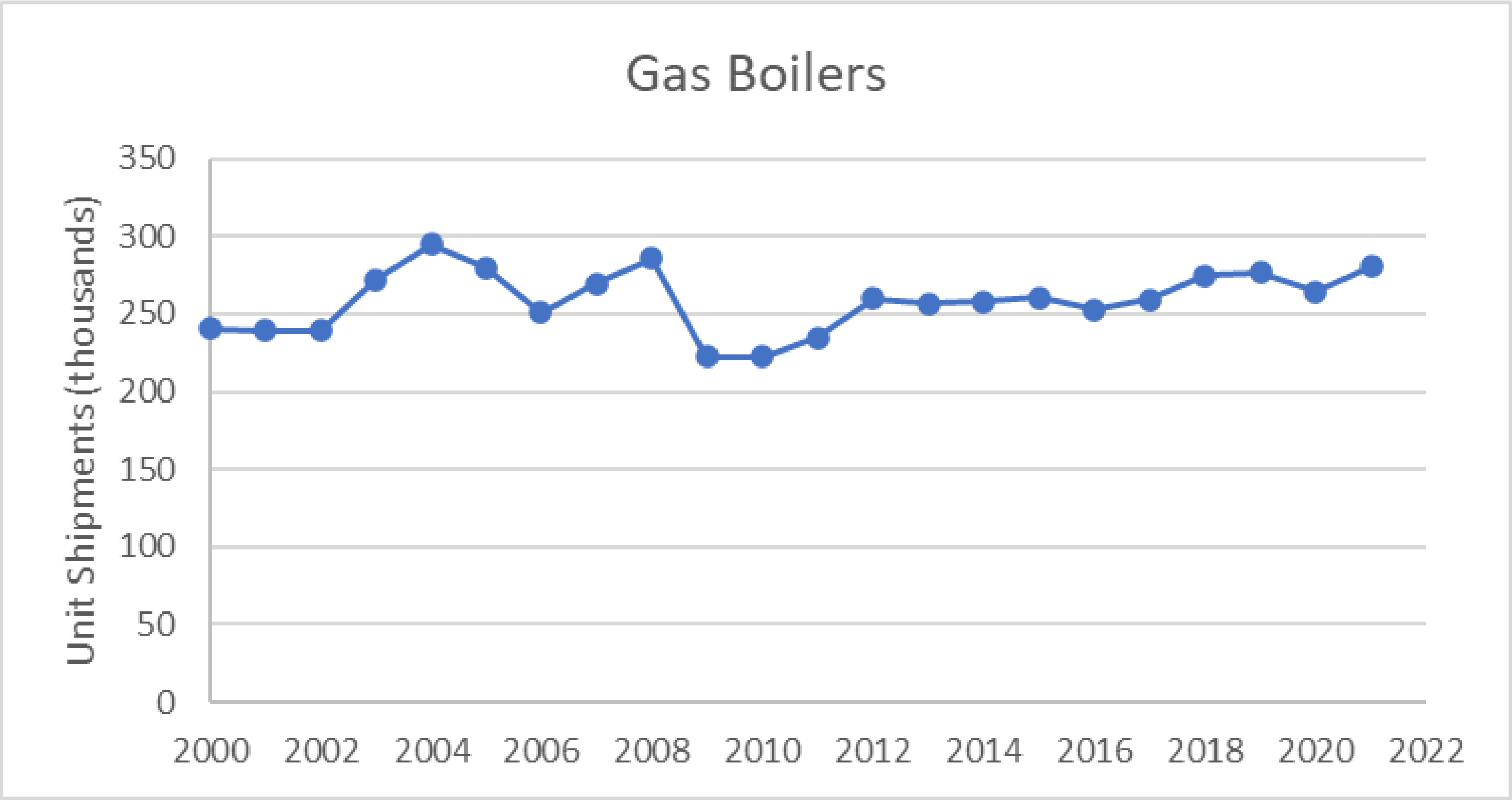
Annual shipments had a significant decrease following the 2009 financial crisis and a steady recovery in the years since.



Source: *Boilers EERE 2022 Preliminary Analysis*

Residential Oil-Fired Boilers

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Typical AFUE and costs increase to ENERGY STAR levels. High AFUE and costs increase to condensing units.

DATA	2015	2020[1]	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	84	86	86	86	87	88	87	95	87	95	87	95
Electric Consumption (kWh/y)[3]	230	310	310	310	307	305	307	265	307	265	307	265
Average Life (y)[4]	18	18	18	18	18	18	18	18	18	18	18	18
	28	28	28	28	28	28	28	28	28	28	28	28
Retail Equipment Cost (2022$)	4,850	3,590	3,590	3,590	3,680	3,770	3,680	6,890	3,680	6,890	3,680	6,890
Total Installed Cost (2022$)	9,800	5,510	5,510	5,510	5,600	5,690	5,600	11,910	5,600	11,910	5,600	11,910
Annual Maintenance Cost (2022$)[4]	160	170	170	170	170	170	170	170	170	170	170	170

1. The 2020 AFUE is estimated based on EERE 2022 preliminary analysis, which estimates that oil-fired boilers with the highest market share in 2020 have an AFUE of 86%.
2. The 2030, 2040, 2050 projections are estimated based on the EERE 2022 preliminary analysis, which notes that majority of the market is expected to be at 86% AFUE, if new standards are not implemented.
3. Electric Consumption accounts for the electricity consumption of auxiliary electrical components including circulating pump, the ignitor, condensate pump, and heat tape, which are sometimes installed with higher efficiency boilers. Additionally, it accounts for the additional cooling load due to heat loss from the boiler and water heater as a result of water heating during the cooling season.
4. Maintenance cost is the routine annual cost to the consumer of general maintenance for product operation.

Note:
The current standard went into effect in January 2021.
ENERGY STAR V. 3.0 went into effect in December 2013.
Water boilers considered. Steam boilers also exist but make up a small percentage of the market.
The range for average life represents the span of typical values.

Residential Oil-Fired Boilers

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- Federal standard for oil-fired hot-water boilers (more common than steam):
  - AFUE ≥ 86%
  - Standard went into effect on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 87%
- Most efficient oil-fired boiler available: 88% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers made of cast iron or steel.
- No condensing oil-fired boilers currently exist in the U.S. market. The high sulfur content in fuel-oil causes heat exchanger fouling if the flue gases from an oil-fired boiler were to condense. As a result, condensing oil-fired boilers would require more frequent maintenance and repair, if installed.
- Advanced Case: Increased incentives move typical efficiency products to ENERGY STAR levels by 2030. The current typical efficiency product is at 86% AFUE, while ENERGY STAR is at 87%, with only a small difference in costs. It is expected that with more market incentives, manufacturers will produce more products that can be ENERGY STAR certified at the 87% level.
- Advanced Case: High efficiencies expected to be at 95% AFUE for condensing oil-fired boilers. These models are already seen in Europe and would be expected to re-enter the U.S. market as well.

Residential Oil-Fired Boilers

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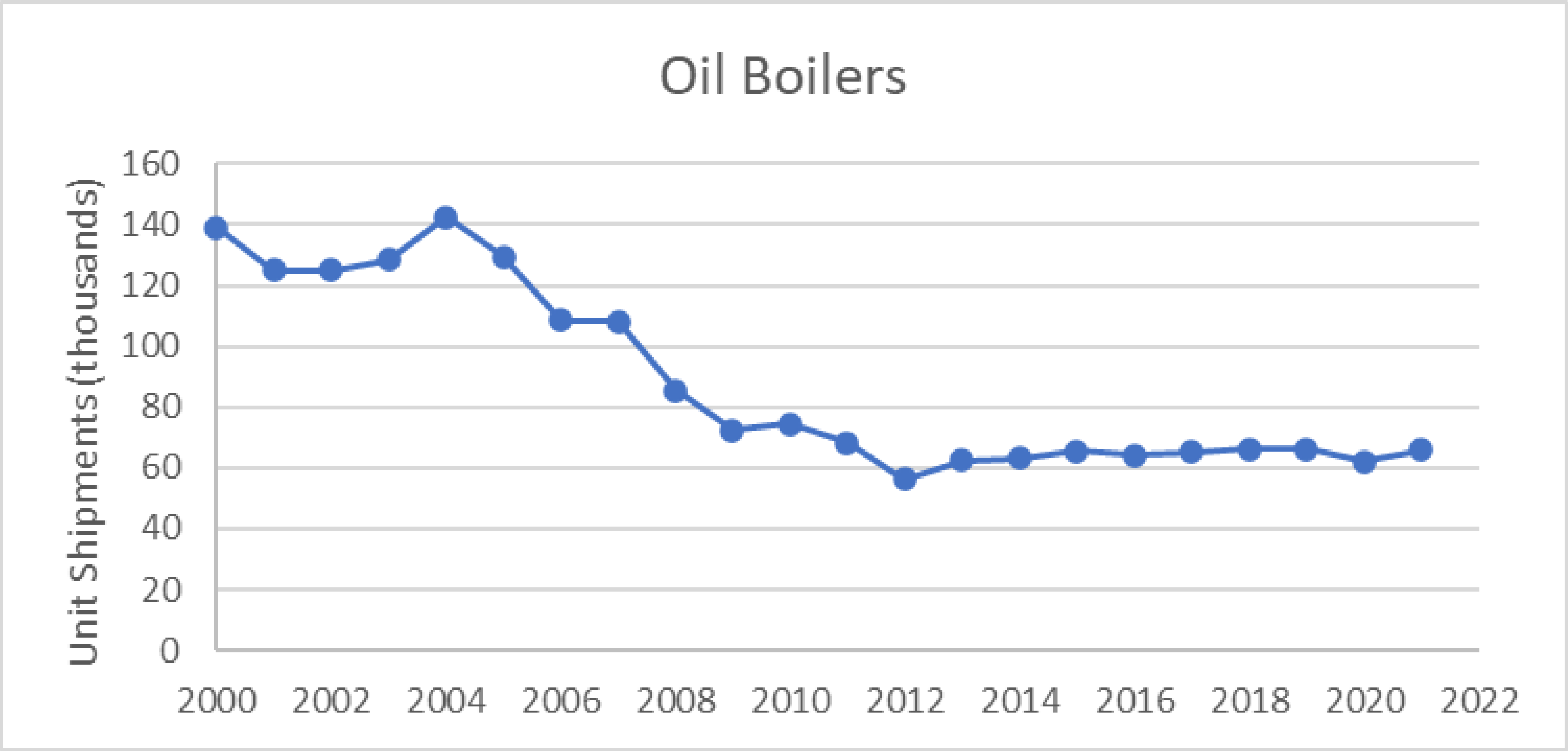
Annual shipments declined rapidly after 2004, likely due, at least in part, to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely leveled off.



Source: *Boilers EERE 2022 Preliminary Analysis*

Residential Electric Resistance Furnaces

Final

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Same as Reference Case

DATA	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	68	68	68	68	68	68	68
AFUE (%)	98	98	100	100	100	100	100
Average Life (y)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)[1]	760	760	950	950	950	950	950
Total Installed Cost (2022$)[1]	1,290	1,290	1,480	1,480	1,480	1,480	1,480
Annual Maintenance Cost (2022$)[1]	50	50	50	50	50	50	50

1. Costs for a 100% AFUE unit are assumed to be equal to the costs of a 98% AFUE unit.

Note:

The current standard went into effect in January 1992.

The range for average life represents the span of typical values.

Residential Electric Resistance Furnaces

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- Federal standards for electric furnaces:
  - AFUE ≥ 78%
  - Standby and off mode power consumption ≤ 10 watts
- According to preliminary Residential Energy Consumption Survey (RECS) data released May 2022, electric central warm-air furnaces are the main source of space heating in approximately 17.5 million U.S. homes or about 14%.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/h), with 20 kW (68 kBtu/h) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss, and any jacket losses are contained within the home.
  - ASHRAE Standard 103, the test method for furnaces incorporated by reference into the federal test procedure, specifies that for electric furnaces AFUE = 100 – 1.7 x jacket losses. Jacket losses can be determined either through testing or assumed to be 1%. Thus, the minimum AFUE of electric furnaces is 98.3%.

Residential Electric Resistance Unit Heaters

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Same as Reference Case

DATA	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	3.5	3.5	5.1	5.1	5.1	5.1
Efficiency (%)	100	100	100	100	100	100
Average Life (y)[1]	15	15	15	15	15	15
	30	30	30	30	30	30
Retail Equipment Cost (2022$)[2]	90	90	85	85	85	85
	240	240	340	340	340	340
Total Installed Cost (2022$)[3]	150	150	390	390	390	390
	320	320	1,190	1,190	1,190	1,190
Annual Maintenance Cost (2022$)[4]	-	-	-	-	-	-

1. Assumes similar lifetime to Electric Furnaces on the basis that both products have heating elements that burn out and lead to product failure.
2. The lower bound of the equipment costs represents the average retail price listed at the typical capacity for electric baseboard heaters through a retailer website. The upper bound represents the average retail price for compact recessed electric wall heaters at the same capacity.
3. Range represents the estimated minimum and maximum installation costs.
4. Maintenance costs are negligible.

Residential Electric Resistance Unit Heaters

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- Electric resistance unit heaters include electric wall and baseboard heaters. Plug-in space heaters are not included.
- There are currently no federal efficiency requirements for electric resistance unit heaters.
- According to preliminary RECS data released May 2022, electric resistance unit heaters are the main source of space heating in approximately 8.25 million U.S. homes or about 7%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/h), with 1,500 watts (5.1 kBtu/h) being the most typical for units on the market.
- Electric resistance heating is considered 100% energy efficient; all incoming electric energy is converted to heat.

Residential Central Air Conditioners – North (Not Hot-Dry or Hot-Humid)

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2015	2020	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER[1]	12.5	13.9	13.0	14.1	15.0	17.0	14.1	16.0	17.0	15.0	17.0	15.5	17.0	15.5	17.0
SEER2[2]	11.9	13.2	NA	13.4	NA	16.2	13.4	15.2	16.2	14.3	16.2	14.7	16.2	14.7	16.2
Average Life (y)	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	2,410	2,670	2,580	2,700	3,110	3,950	2,680	3,750	3,950	2,760	3,950	2,760	3,950	2,760	3,950
Total Installed Cost (2022$)	4,000	4,300	5,250	5,320	5,520	5,980	5,310	5,880	5,980	5,350	5,980	5,350	5,980	5,350	5,980
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for residential air-source heat pumps, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify a different metric for central air conditioners (SEER2). SEER to SEER2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.

Note:
The previous standard went into effect in January 2015. The current standard went into effect in January 2023.
ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.
Ranges represent the span of typical values for a given parameter.

Final

Residential Central Air Conditioners – South (Hot-Dry and Hot-Humid)

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2015	2020	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER[1]	13.0	14.4	14.0	14.6	15.0	17.0	15.1	16.0	17.0	15.5	17.0	16.0	17.0	16.0	17.0
SEER2[2]	12.4	13.7	NA	13.9	NA	16.2	14.3	15.2	16.2	14.7	16.2	15.2	16.2	15.2	16.2
Average Life (y)	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	2,410	2,760	2,680	2,850	3,110	3,950	3,110	3,750	3,950	3,190	3,950	3,190	3,950	3,190	3,950
Total Installed Cost (2022$)	4,000	4,390	5,310	5,390	5,520	5,980	5,520	5,880	5,980	5,570	5,980	5,570	5,980	5,570	5,980
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for residential air-source heat pumps, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify a different metric for central air conditioners (SEER2). SEER to SEER2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.

Note:
The previous standard went into effect in January 2015. The current standard went into effect in January 2023.
ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.
Ranges represent the span of typical values for a given parameter.

Residential Central Air Conditioners

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- The previous standards took effect in 2015; amended standards for all product classes went into effect in January 2023.
  - Amended standards are based on new metrics (SEER2, EER2).
  - SEER2 values are generally expected to be lower than SEER because a higher external static pressure is required during testing, which reduces measured performance.
- Systems installed in the Southwest (CA, AZ, NM, and NV) must also meet an EER standard that varies by cooling capacity and system configuration.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Residential Central Air Conditioners

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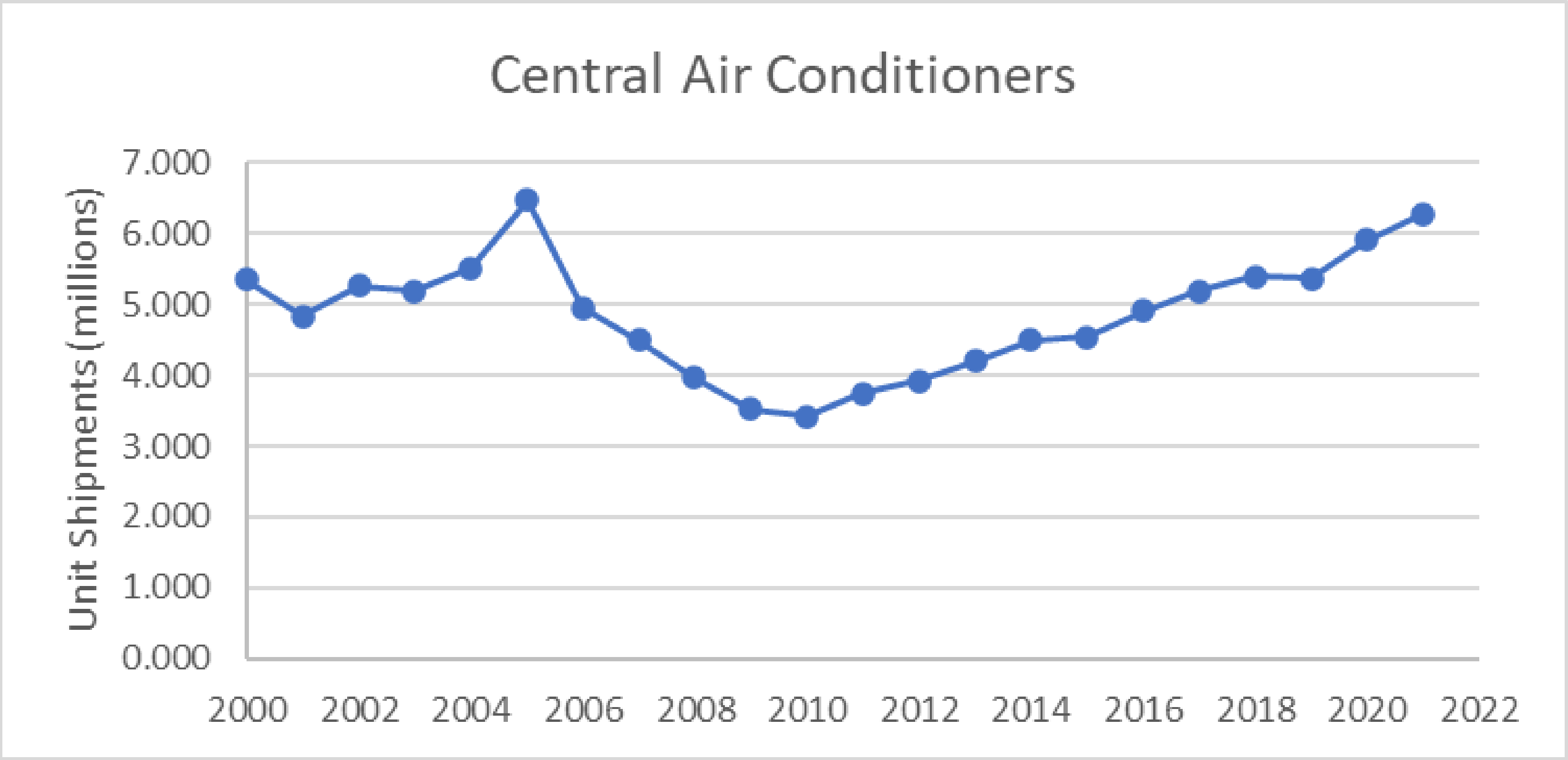
Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006. Annual shipments have been steadily increasing since 2010 and have almost reached the previous high in 2021.



Source: *AHRI*

Residential Room Air Conditioners

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Increased efficiency with corresponding cost increases.

DATA	2015	2020	2022				2030[2]		2040[2]		2050[2]	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.2	High[1]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	10	10	10	10	10	10	10	10	10	10	10.0	10.0
CEER (Btu/Wh)	10.9	10.9	10.9	12.0	12.0	15.7	16.0	16.5	17.0	17.5	17.5	18.0
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2022$)	560	330	330	340	340	450	450	450	460	460	470	470
	710	480	480	480	480	590	590	590	610	610	620	620
Total Installed Cost (2022$)	640	490	490	490	490	600	600	600	610	610	630	630
	830	630	630	640	640	750	750	750	760	760	770	770
Annual Maintenance Cost (2022$)[3]	0	0	0	0	0	0	0	0	0	0	0	0

1. RAC EERE 2022 NOPR has analysis for combined energy efficiency ratio (CEER) of 16 Btu/Wh, which represents variable speed room air conditioners. However, maximum CEER identified in DOE's Compliance Certification Database (CCD) in August 2022 was 15.7 Btu/Wh. Accordingly, the high CEER is estimated to be 15.7 for 2022 and beyond. Cost values for a representative unit with a CEER of 16 Btu/Wh were used.
2. The 2030, 2040, 2050 projections are estimated based on RAC EERE 2022 NOPR, which notes that in the absence of no new standards, room air conditioners with a CEER of 12 Btu/Wh are expected to have the maximum market share.
3. Maintenance costs are negligible per RAC EERE 2011 and RAC EERE 2022 NOPR.

Note:

All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).

The current standard went into effect in June 2014.

ENERGY STAR V. 4.2 went into effect in October 2015.

Ranges represent the span of typical values for a given parameter (for example, installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

Residential Room Air Conditioners

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- Analyzed the most common type of room air conditioners: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - CEER ≥ 10.9 (beginning June 1, 2014)
- CEER incorporates energy use in cooling mode and standby and off modes.
- ENERGY STAR V. 4.2 criteria for Product Class 3:
  - CEER ≥ 12.0 (effective October 26, 2015)
- Efficiency improvements in room air conditioners are attained by:
  - Higher efficiency compressor and fan motors (including variable speed motors), and
  - An increased heat transfer area in the evaporator and condenser using larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more efficient motors and compressors, larger cross-section heat exchangers, adoption of variable speed technologies) are expected to increase efficiency with corresponding increases in cost.

Residential Room Air Conditioners

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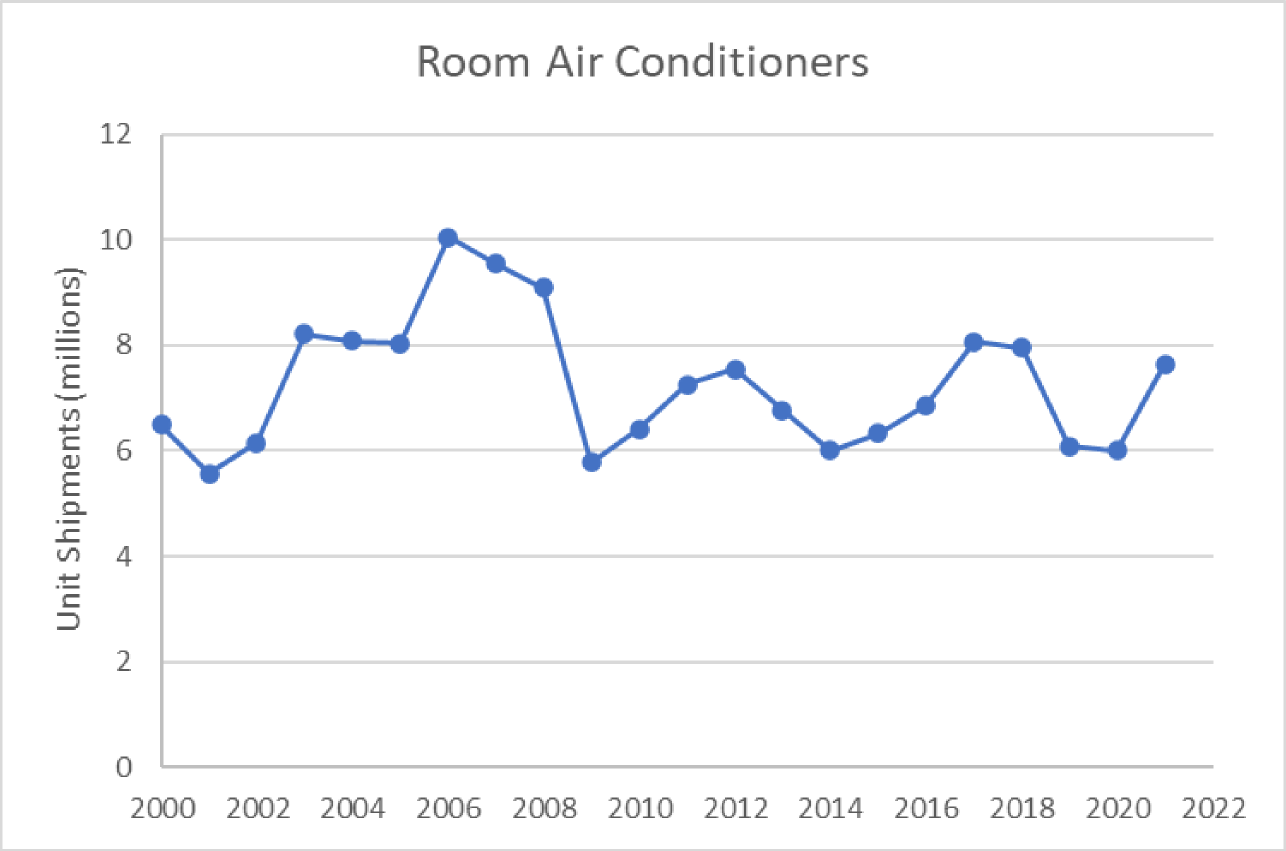
Annual shipments dropped sharply in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have largely leveled off in the years since, fluctuating between 6 and 8 million.



Source: *RAC EERE 2022 NOPR*

Residential Portable Air Conditioners

Increased efficiency with corresponding cost increases.

DATA	2015	2020	2022[4]		2025		2030		2040		2050	
	Installed Base	Installed Base	Typical	High[5]	New Standard	High[5]	Typical	High[5]	Typical	High[5]	Typical	High[5]
Typical Capacity (kBtu/h)[1]	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
CEER[2]	5.6	5.6	5.5	7.6	6.7	7.6	7.8	8.8	8.9	10.1	10.2	11.6
Average Life (y)	7	7	7	7	7	7	7	7	7	7	7	7
	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	700	700	700	810	760	810	810	810	820	820	830	830
Total Installed Cost (2022$)[3]	700	700	700	810	760	810	810	810	820	820	830	830
Annual Maintenance Cost (2022$)[3]	0	0	0	0	0	0	0	0	0	0	0	0

1. All values are for the average capacity for single-duct and dual-duct portable air conditioners available on the market.
2. CEER is calculated for typical capacity using the equation provided in PAC EERE 2020.
3. Installation and maintenance costs are negligible.
4. The 2022 Typical estimates are based on PAC EERE 2020, which estimated majority of the market to be at EL1 in 2022 for the no-new standards case, which translates to a CEER of 5.5 for this analysis.
5. All High values are based on the most-efficient models available in the market, as specified in PAC EERE 2020.

Note:
A final rule for portable air cleaners published in January 2020 with an effective date of January 2025.
Costs are interpolated from the costs presented in PAC EERE 2020.
Range for lifetime represents typical values.

Residential Portable Air Conditioners

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- A final rule establishing new energy conservation standards for portable air conditioners published in January 2020 with an effective date of January 2025.
- The final rule outlined an equation-based conservation standard (in CEER) for both single-duct and dual-duct portable ACs, based on the seasonally adjusted cooling capacity (SACC)

$$\text{Minimum CEER} = \text{PR} \times \frac{\text{SACC}}{(3.7117 \times \text{SACC}^{0.6384})}$$

- Efficiency improvements in portable air conditioners are attained by:
  - Higher efficiency compressor and fan motors (including variable speed motors), and
  - An increased heat transfer area in the evaporator and condenser using larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more efficient motors and compressors, larger cross-section heat exchangers, adoption of variable speed technologies) are expected to increase efficiency with corresponding increases in cost.

Residential Portable Air Conditioners

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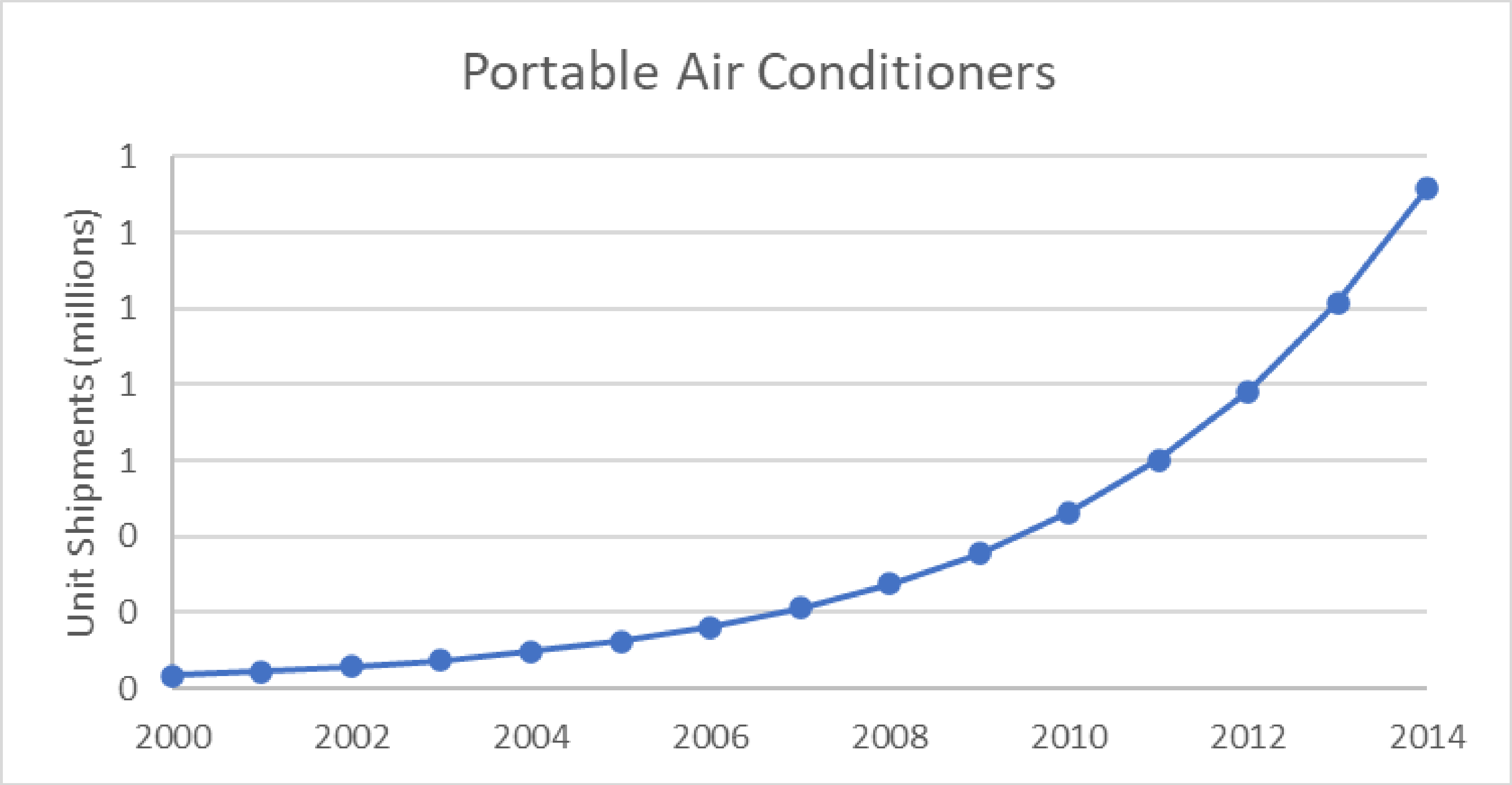
Annual shipments have seen an exponential growth through 2014. Shipments data since 2014 is not publicly available but it is expected that portable air conditioners shipments may have increased in recent years in response to indoor air quality concerns following COVID-19.



Source: *PAC EERE 2020*

Residential Swamp Coolers

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Same as reference case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Air Flow Rate (CFM)	3,800	3,800	3,800	4,700	3,800	4,700	3,800	4,700	3,800	4,700
Power (Hp)	1/3	1/3	1/3	1/2	1/3	1/2	1/3	1/2	1/3	1/2
Average Life (y)[1]	10	10	10	10	10	10	10	10	10	10
	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	960	960	960	1,100	960	1,100	960	1,100	960	1,100
Total Installed Cost (2022$)	1,360	1,360	1,360	1,540	1,360	1,540	1,360	1,540	1,360	1,540
Annual Maintenance Cost (2022$)	330	330	330	330	330	330	330	330	330	330

1. Average lifetime provided by major swamp cooler installer in the U.S. Southwest.

Note:
Efficiency values were determined based on a sample of window-mounted swamp coolers.
Lifetime range represents span of typical values.

Residential Swamp Coolers

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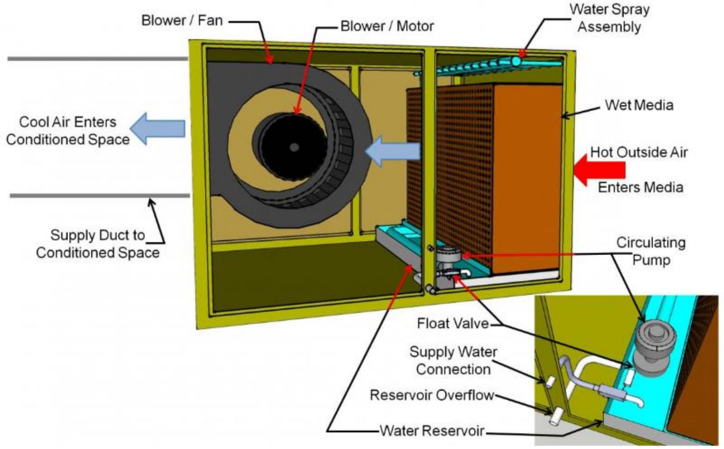
- Evaporative cooling (i.e., "swamp coolers") is a technology that takes advantage of water evaporation to cool incoming air. Energy is required to change water from a liquid to a vapor (i.e., the heat of vaporization), and in doing so, temperature of the air is reduced. Evaporative cooling is best suited for hot, dry climates.
- Swamp coolers come in a variety of different configurations, including centrally ducted units that are mounted outside a building or roof; window evaporative coolers that are window-mount units that pull in warm outdoor air, pass it through wet media to remove heat, and blow out the cooled air; or portable plug-in units. Window units were considered for this analysis due to the high model share count on distributor websites.
- The U.S. Environmental Protection Agency (EPA) has cautioned against using swamp coolers in wildfire-impacted areas in smoky conditions because it can result in more smoke bring brought inside.
- Swamp coolers are not a DOE-covered product.
- Swamp cooler metrics include power of the fan/blower, measured in horsepower (hp), and air flow rate, measured in cubic feet per minute (CFM).



Single-inlet direct swamp cooler. Source: PNNL

Residential Air-Source Heat Pumps

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Higher typical efficiencies with the same costs as reference case despite increased efficiency

DATA	2015	2020	2022				2023				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.0	High	New Standard	ENERGY STAR V. 6.1	ENERGY STAR Cold Climate Criteria	High[4]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)[1]	13.1	15.3	14.0	15.3	15.0	22.6	15.0	16.0	NA	22.6	16.5	22.6	17.0	22.6	17.5	22.6
SEER2[2]	12.4	14.5	NA	14.5	NA	21.5	14.3	15.2	15.2	21.5	15.7	21.5	16.2	21.5	16.6	21.5
HSPF (Heating)[1]	7.9	8.6	8.2	8.6	8.5	12.4	8.8	9.2	NA	12.4	9.3	12.4	9.3	12.4	9.4	12.4
HSPF2[2]	6.7	7.3	NA	7.3	NA	10.6	7.5	7.8	8.1	10.6	7.9	10.6	7.9	10.6	8.0	10.6
Average Life (y)	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Retail Equipment Cost (2022$)[1]	3,290	4,270	3,970	4,270	4,110	6,740	4,110	4,380	4,380	6,740	4,380	6,740	5,000	6,740	5,100	6,740
Total Installed Cost (2022$)[1]	5,790	6,880	6,730	6,880	6,810	8,620	6,810	6,940	6,940	8,620	6,940	8,620	7,240	8,620	7,330	8,620
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

1. Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for "blower-coil" systems, meaning they include a blower. Note coil-only systems were analyzed for residential central air conditioners, which is why the "High" SEER levels are higher for heat pumps than for air conditioners.
2. In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps took effect. The new standards specify different metrics for Air-Source Heat Pumps (SEER2 and heating seasonal performance factor 2 (HSPF2)). SEER to SEER2 and HSPF to HSPF2 conversions were determined using the RESNET website.
3. Annual maintenance include preventative maintenance and services provided by HVAC professionals for maintaining product operation. Examples include, calibrate and level thermostat, clean filters, clean indoor and condenser coil, flush/treat condensate drain with anti-algae, inspect condenser coil, monitor operating pressure of refrigerant, inspect fan blade, etc.
4. High costs derived from developing a cost-efficiency curve between retail/installed costs and SEER.

Note:
The previous standard went into effect in January 2015. The current standard went into effect in January 2023.
ENERGY STAR V. 5.0 went into effect in September 2015. ENERGY STAR V. 6.1 went into effect in January 2023.
Ranges represent the span of typical values for maintenance costs.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.88, 2, 1).

Residential Air-Source Heat Pumps

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- The previous standards took effect in 2015; amended standards for all product classes went into effect in January 2023.
  - Amended standards are based on new metrics (SEER2, EER2, HSPF2).
  - SEER2 values are generally expected to be lower than SEER because a higher external static pressure is required during testing, which reduces measured performance.
- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- Variable-speed compressors improve efficiency of heat pumps by reducing cyclic losses and by operating above their nominal speed, boosting heating capacity, and reducing the need for supplementary electric resistance heat.
- In addition to meeting the SEER2 and HSPF2 requirements, air source heat pumps must demonstrate low ambient performance to earn the Cold Climate designation by meeting the following:
  - Coefficient of Performance (COP) at 5 degrees Fahrenheit (°F) ≥ 1.75, measured in accordance with Appendix M1 $H4_2$ test
  - Percent of Heating Capacity at 5 °F ≥ 70% of that at 47 °F, with the 5 °F capacity measured per Appendix M1 $H4_2$ test and the 47 °F capacity measured as the nominal heating capacity per Appendix M1 (i.e., from the Appendix M1 $H1_N$ test for units having a variable-speed compressor where the compressor speed shall be the maximum speed that the system controls would operate at 47 °F, otherwise from the Appendix M1 $H1_2$ test)
  - Perform a controls verification procedure (CVP) to confirm that the above performance metrics measured at the Appendix M1 low ambient test point at 5 °F are achieved by the native controls operating as they would in a customer's home
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Residential Air-Source Heat Pumps

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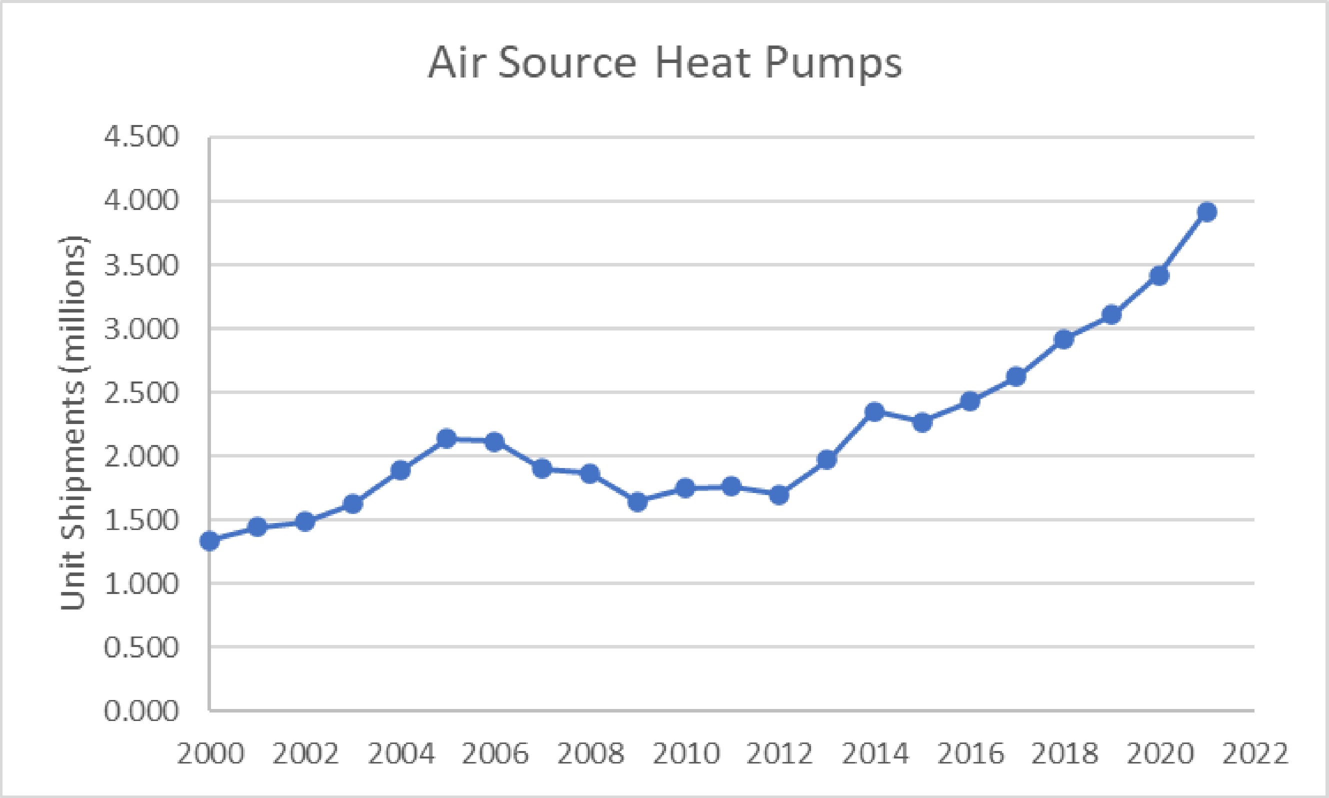
From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units. In 2014 annual shipments surpassed the 2005 peak and have been increasing uniformly since then.



Source: *AHRI*

Residential Central Air Conditioners and Air-Source Heat Pumps

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- Principal energy efficiency drivers for central air conditioners and heat pumps:
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- When the heat pump or air conditioner's capacity exceeds the heating or cooling load, the unit starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.
- Typical high-efficiency unit (≥ 16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller heat exchangers, and thus, smaller enclosures.
- Efficiency levels > 21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

Residential Ductless Mini-Split Air-Source Heat Pumps

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Same as reference case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)[1]	12	12	12	12	12	12	12	12	12	12
SEER	16.0	16.0	21.9	33.1	21.9	33.1	21.9	33.1	21.9	33.1
EER	12.5	12.5	13.0	19.1	13.0	19.1	13.0	19.1	13.0	19.1
HSPF	10.0	10.0	11.1	14.0	11.1	14.0	11.1	14.0	11.1	14.0
Average Life (y)[2]	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Retail Equipment Cost (2022$)	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580	1,580
Total Installed Cost (2022$)	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030	2,030
Annual Maintenance Cost (2022$)[3]	100	100	100	100	100	100	100	100	100	100

1. Representative capacity determined from most frequent capacity in AHRI database
2. Assumed same lifespan and maintenance cost as air-source heat pumps given the technology is similar between air-source and ductless mini-split heat pumps, and ductwork itself is not expected to fail.
3. Annual maintenance covers the same services identified for air-source heat pumps.

Note:
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.88, 2, 1).

Residential Ductless Mini-Split Air-Source Heat Pumps

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- Ductless systems can be useful in "spot cooling" certain high-use areas of a home, such as a living room, bedroom, or office.
- Mini-split heat pumps are generally more efficient (often > 20 SEER) and smaller in cooling capacity (often ≤ 24 kBtu/h) compared to split-system heat pumps.
  - A mini-split heat pump could be equal in capacity and efficiency to a split-system heat pump as there are no inherent design changes between split-system and mini-split heat pumps, aside from the ductwork. Mini-split heat pumps tend to be more efficient and smaller in capacity due to their prevalence for spot cooling, but the same technologies are used between the two product categories.
- Due to the similarities in design, cost estimations were determined based on smaller capacity (24 kBtu/h) split-system heat pumps and Gordian's RSMeans Data – Building Construction Costs 2023. Efficiency data was analyzed using the AHRI directory, which provides disaggregation of data on the basis of ducted and ductless heat pumps.
- Annual maintenance covers the same services identified for air-source heat pumps.

Residential Ground-Source Heat Pumps

Final

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Same typical efficiencies with the lower costs as ref. case despite same efficiency.

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.2	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)[1]	3.1	3.7	3.2	3.6	3.6	4.5	3.6	4.5	3.6	4.5	3.6	4.5
EER (Cooling)[2]	13.3	17.3	14.1	17.3	17.1	22.0	17.3	22.0	17.3	22.0	17.3	22.0
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	4,650	5,470	4,820	5,470	5,410	6,530	4,920	5,880	4,920	5,880	4,920	5,880
Total Installed Cost (2022$)	14,060	14,880	14,230	14,880	14,880	15,940	13,390	14,350	13,390	14,350	13,390	14,350
	22,290	23,120	22,470	23,120	23,120	24,170	20,810	21,750	20,810	21,750	20,810	21,750
Annual Maintenance Cost (2022$)	90	90	90	90	90	90	90	90	90	90	90	90

1. COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop ground source heat pumps (GSHP) operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.
2. EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note:

Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs. 4-ton) and slightly higher installation costs for commercial GSHP. DOE does not distinguish between residential and commercial units in its regulations.

Current standards went into effect on October 9, 2015. COP and EER ratings are converted from the “water loop” test condition to “ground loop.”

ENERGY STAR V. 3.2 went into effect January 1, 2012.

Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (17.04, 1.64, 1).

Residential Ground-Source Heat Pumps

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- Heating COP does not correlate with cooling EER.
- The ENERGY STAR criteria for water-to-air ground-source heat pumps are:

Type	Heating COP	Cooling EER
Closed Loop	3.6	17.1
Open Loop	4.1	21.1
Direct Expansion	3.6	16

- The most common GSHP is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed ECMs improve performance on high-end models.
- Advanced Case: GSHP are already highly efficient and have not changed much in terms of efficiency in recent years. With increased R&D, it is anticipated that the equipment and installation costs will be reduced over time, but efficiency will likely stay the same.

Residential Natural Gas Heat Pumps

Final

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Same as reference case

DATA	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60	60
COP (Heating)	1.3	1.3	1.3	1.3	1.3	1.3
COP (Cooling)	0.6	0.7	0.7	0.7	0.7	0.7
Annual Electric Use (kWh/y)[1]	1,500	1,500	1,500	1,500	1,500	1,500
Average Life (y)[2]	12	12	12	12	12	12
	18	18	18	18	18	18
Retail Equipment Cost (2022$)[2]	12,940	12,940	12,940	12,940	12,940	12,940
	14,350	14,350	14,350	14,350	14,350	14,350
Total Installed Cost (2022$)[2]	14,700	14,700	14,700	14,700	14,700	14,700
	17,290	17,290	17,290	17,290	17,290	17,290
Annual Maintenance Cost (2022$)	200	200	200	200	200	200

1. Annual electric use accounts for the electricity consumption of components such as the heat pump fan.

Note:
Ranges represent the span of typical values observed in the market.

Residential Natural Gas Heat Pumps

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- Residential natural gas heat pumps are not currently subject to DOE regulations. The California Energy Commission's (CEC) Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for natural gas heat pumps.
- Natural gas heat pumps are much more popular in other parts of the world, such as Europe. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized natural gas heat pumps with sales operations in the U.S.. Robur units are 5-ton nominal cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included in this analysis.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the U.S. It is possible to couple either technology to the ground (ground-source) rather than the atmosphere (air-source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air-source absorption heat pump is considerably lower than for an electric air-source heat pump. Heating efficiency of an air-source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however, the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

Residential Cordwood Stoves

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Same as reference case

DATA	2015[1]	2020[2]	2022[3]		2030[4]		2040[4]		2050[4]	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)[5]	63	71	71	80	71	80	71	80	71	80
Efficiency (Catalytic) (HHV)[5]	72	76	76	81	76	81	76	81	76	81
Average Life (y)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$) (Non-Catalytic)	2,880	1,670	1,670	2,300	1,670	2,300	1,670	2,300	1,670	2,300
Retail Equipment Cost (2022$) (Catalytic)	3,540	3,040	3,040	3,830	3,040	3,830	3,040	3,830	3,040	3,830
Total Installed Cost (2022$) (Non-Catalytic)[6]	8,290	7,090	7,090	7,710	7,090	7,710	7,090	7,710	7,090	7,710
Total Installed Cost (2022$) (Catalytic)[6]	8,950	8,460	8,460	9,240	8,460	9,240	8,460	9,240	8,460	9,240
Annual Maintenance Cost (2022$) (Non-Catalytic)[7]	190	190	190	190	190	190	190	190	190	190
Annual Maintenance Cost (2022$) (Catalytic)[7]	280	280	280	280	280	280	280	280	280	280

1. For 2015, assumed EPA default efficiencies, which were used by EPA to approximate the efficiency of stoves before the 2015 EPA rule required efficiency testing.
2. For 2020, assumed same efficiencies as estimated for 2022 given the most recent EPA rule went into effect in May 2020.
3. The 2022 High value is the highest EPA certified efficiency. The 2022 Typical value is the average of EPA certified efficiencies.
4. For 2030-2050, it is assumed that the same conditions as current would persist because no impending efficiency requirements are expected from EPA, given recency of 2020 rulemaking and current market factors.
5. Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
6. Installed costs include the cost of hearth and stainless-steel chimney liner - materials and labor.
7. For catalytic stoves, annual maintenance cost includes periodic cost of replacing the catalytic combustor.

Note:
The range for average life represents the span of typical values.

Residential Cordwood Stoves

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- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames to enable more complete combustion and reduce emissions.
- In 2015, EPA published an update to its New Source Performance Standards (NSPS), decreasing the emissions limit (previously set by 1988 EPA rule) to 4.5 grams per hour (g/h) for both catalytic and non-catalytic stoves. The new rule did not institute efficiency standards but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- In 2020, the NSPS limit for new room heaters was lowered to 2.5 g/h if tested with cord wood.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Multiple test standards are commonly used to assess stove efficiency, and data from product literature does not generally identify the efficiency test method.
- It is not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Accordingly, installed costs can be twice that of the wood stove itself.

Residential Cordwood Stoves

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Cordwood stove shipments have averaged 123,000 per year since 1999 and have fluctuated approximately in accordance with fuel oil costs.

Source: *HPBA, no post-2012 sales data was publicly available at time of publication.*

Residential Wood Pellet Stoves

Same as reference case

DATA	2015[1]	2020[2]	2022[3]		2030[4]		2040[4]		2050[4]	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)[5]	70	73	73	85	73	85	73	85	73	85
Annual Electricity Consumption (kWh)[6]	600	600	600	600	600	600	600	600	600	600
Average Life (y)	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	3,900	3,120	3,120	4,000	3,120	4,000	3,120	4,000	3,120	4,000
Total Installed Cost (2022$)[7]	5,550	4,520	4,520	5,400	4,520	5,400	4,520	5,400	4,520	5,400
Annual Maintenance Cost (2022$)	310	310	310	310	310	310	310	310	310	310

1. For 2015, assumed EPA default efficiencies, which were used by EPA to approximate the efficiency of stoves before the 2015 EPA rule required efficiency testing.
2. For 2020, assumed same efficiencies as estimated for 2022 given the most recent EPA rule went into effect in May 2020.
3. The 2022 High value is the highest EPA certified efficiency. The 2022 Typical value is the average of EPA certified efficiencies.
4. For 2030-2050, it is assumed that the same conditions as current would persist because no impending efficiency requirements are expected from EPA, given recency of 2020 rulemaking and current market factors.
5. Efficiency includes combustion and heat transfer efficiency and is based on the HHV of the fuel.
6. The annual electric consumption estimates assume 6 months/year @ 100kW/mo based on DOE estimates.
7. Installed cost includes cost of hearth and vent pipe - materials and labor.

Note:
The range for average life represents the span of typical values.

Residential Wood Pellet Stoves

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- In 2015, EPA published an update to its NSPS, limiting emissions for wood pellet stoves to 4.5 g/h. Prior to the 2015 EPA rule, most pellet stoves were exempt from EPA's NSPS requirements. The new rule did not institute efficiency standards but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method.
- It is not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Residential Wood Pellet Stoves

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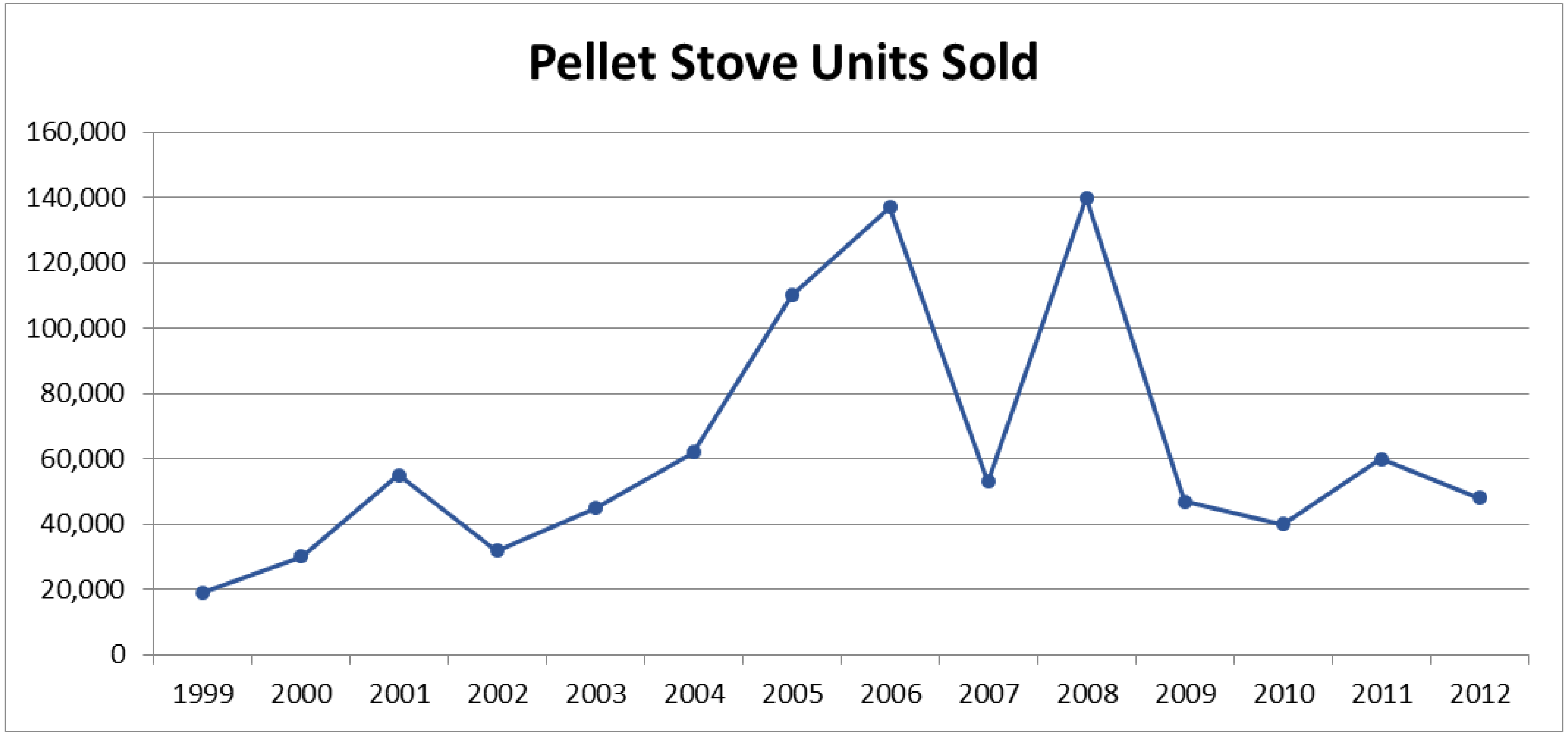
Wood pellet stove shipments grew substantially in the 2005 – 2008 time period but have averaged only 40,000 – 60,000 units since that time.



Source: *HPBA, no post-2012 sales data was publicly available at time of publication.*

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Residential Water Heating

Residential Gas-Fired Storage Water Heaters

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Increased typical efficiencies with associated increase in costs to reflect condensing units.

DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.0	High	ENERGY STAR V. 5.0	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	40	40	40	40	40	40	40	40	40
Uniform Energy Factor (UEF)[1]	0.58	0.63	0.61	0.61	0.66	0.84	0.83	0.78	0.84	0.78	1.33	0.78	1.33
Average Life (y)	13	13	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Retail Equipment Cost (2022$)	590	880	420	420	490	720	700	420	720	420	720	420	720
	650	1,410	990	990	1,110	1,650	1,590	990	1,650	990	1,650	990	1,650
Total Installed Cost (2022$)	1,240	1,650	740	740	800	1,140	1,130	740	1,140	740	1,140	740	1,140
	1,240	2,880	1,690	1,690	1,850	3,130	3,160	1,690	3,130	1,690	3,130	1,690	3,130
Annual Maintenance Cost (2022$)[2]	20	20	20	20	20	20	20	20	20	20	20	20	20

1. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.
2. Maintenance includes manufacturer recommendation for the water heater to be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency, and prolong product life. Available evidence indicates that this is performed in 10% of households.

Note:
Ranges represent the span of typical values.
Current standards went into effect April 16, 2015.
ENERGY STAR V. 4.0 went into effect January 5, 2022
ENERGY STAR V. 5.0 will go into effect April 18, 2023
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.1, 1.76, 1).

Residential Gas-Fired Storage Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.3456-(0.002*Gal)	No models on the market	NA
	Low	UEF=0.5982-(0.0019*Gal)	0.54 for a 29-gallon water heater	NA
	Medium	UEF=0.6483-(0.0017*Gal)	0.58 for a 38-gallon water heater	0.64
	High	UEF=0.692-(0.0013*Gal)	0.64 for a 48-gallon water heater	0.68
> 55 gal and ≤ 100 gal	Very Small	UEF=0.647-(0.0006*Gal)	No models on the market	NA
	Low	UEF=0.7689-(0.0005*Gal)	No models on the market	NA
	Medium	UEF=0.7897-(0.0004*Gal)	No models on the market	0.78
	High	UEF=0.8072-(0.0003*Gal)	No models on the market	0.80

- There are currently no models on the market above 55 gallons (gal) due to the high UEF, which would require using condensing or gas-fired heat pump (e.g., absorption) technology to achieve.
- The cost of installation is typically $600 to $1200, which exceeds that of electric water heaters. This difference can be attributed to multiple differences; for example, gas-fired heaters require an extra 1.5 hours of labor for 2 plumbers.
- Condensing units are high efficiency and use PVC venting instead of stainless-steel. Condensing units also use an electrical supply for electronic ignition and power venting. Some building codes require condensate neutralizer filters.
- Advanced Case: Condensing gas-fired storage water heaters are expected to dominate the market by 2030, with corresponding price increases.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Gas-Fired Storage Water Heaters

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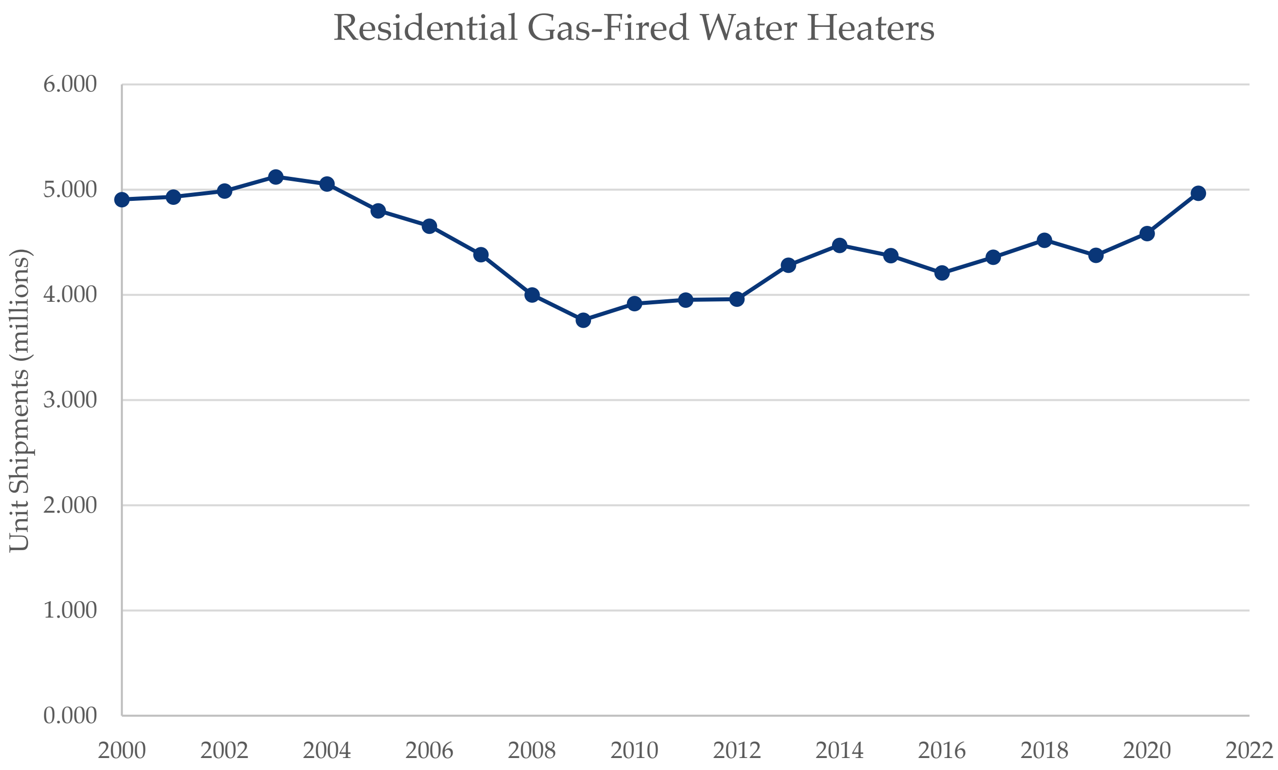
Shipments were flat at 5 million units per year through 2004, then declined gradually over 5 years to a new plateau at 4 million units until rising again back to 5 million units in 2021.



Source: *AHRI*

Residential Oil-Fired Water Heaters

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Same as Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	32	32	32	32	32	32	32	32	32	32	32
Uniform Energy Factor[1]	0.51	0.67	0.64	0.66	0.68	0.66	0.68	0.66	0.68	0.66	0.68
Average Life (y)	13	13	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Retail Equipment Cost (2022$)	1,590	1,880	1,380	1,400	1,480	1,400	1,480	1,400	1,480	1,400	1,480
	1,710	2,410	2,810	2,870	3,030	2,870	3,030	2,870	3,030	2,870	3,030
Total Installed Cost (2022$)	2,350	2,650	2,620	2,650	2,730	2,650	2,730	2,650	2,730	2,650	2,730
	2,470	3,350	4,050	4,120	4,280	4,120	4,280	4,120	4,280	4,120	4,280
Annual Maintenance Cost (2022$)[2]	210	210	210	210	210	210	210	210	210	210	210

1. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.
2. Oil-fired storage water heaters are typically cleaned and maintained under maintenance contracts. The annual cost of typical maintenance is based on maintenance contract prices from different oil-fired product suppliers as specified in the CWH EERE 2022 Preliminary Analysis.

Note:
Ranges represent span of typical values.
Current standards went into effect April 16, 2015.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (16.2, 1.70, 1).

Residential Oil-Fired Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≤ 50 gal	Very Small	UEF=0.2509-(0.0012*Gal)	No models on the market	NA
	Low	UEF=0.533-(0.0016*Gal)	No models on the market	NA
	Medium	UEF=0.6078-(0.0016*Gal)	No models on the market	NA
	High	UEF=0.6815-(0.0014*Gal)	0.64 for a 29-gallon water heater	NA

- There are no ENERGY STAR requirements for oil-fired storage water heaters.
- Annual shipments of residential oil-fired storage water heaters are approximately 4,000, which is less than 1% of shipments of residential gas-fired storage water heaters.
- Oil-fired storage water heaters often have smaller tanks with larger input ratings relative to natural gas-fired and electric storage water heaters.
- No condensing residential oil-fired storage water heaters currently exist in the U.S. market. Condensing oil-fired water heaters are generally not considered technologically feasible because the sulfur content in fuel oil leads to the condensate becoming corrosive.
- Residential oil-fired water heaters utilize power burners and have at least some level of electrical power consumption.
- The most efficient models on the market use a proprietary “turbo-flue” design to increase heat transfer to water.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Oil-Fired Water Heaters

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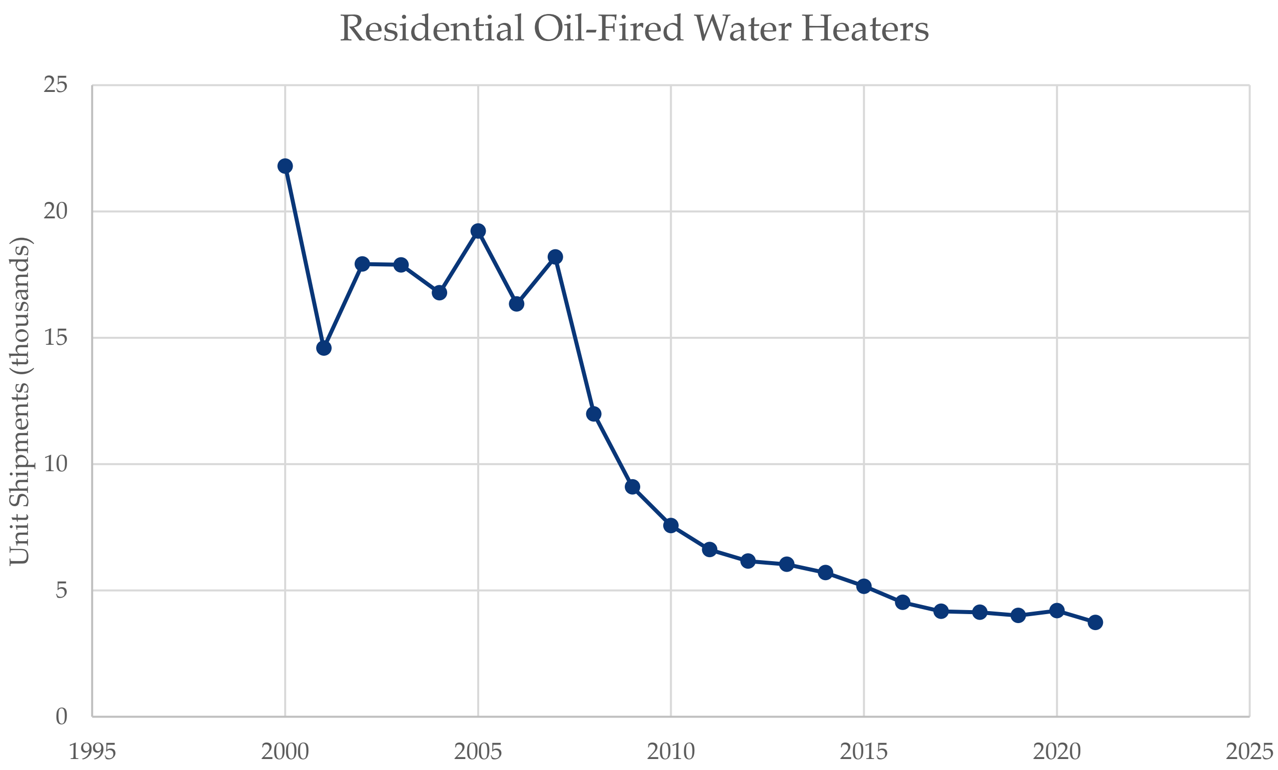
Shipments peaked at about 22,000 units in 2000 and have decreased since then, with an exponential decay occurring since 2007. Only about 4,000 units were shipped in 2021.



Source: *CWH EERE 2022 Preliminary Analysis*

Residential Electric Resistance Storage Water Heaters

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Same as Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor[1]	0.88	0.93	0.92	0.92	0.93	0.92	0.93	0.92	0.93	0.92	0.93
Average Life (y)	13	13	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Retail Equipment Cost (2022$)	290	350	330	330	600	330	600	330	600	330	600
	530	650	760	760	850	760	850	760	850	760	850
Total Installed Cost (2022$)	590	710	500	500	550	500	550	500	550	500	550
	940	1,290	1,310	1,310	1,430	1,310	1,430	1,310	1,430	1,310	1,430
Annual Maintenance Cost (2022$)[2]	20	20	20	20	20	20	20	20	20	20	20

1. Beginning in 2016, the efficiency metric for water heaters changed from energy factor (EF) to UEF based on DOE test procedures. The UEF values for the installed base in 2015 are converted values equivalent to 0.90 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market.
2. Similar to gas-fired and oil-fired storage water heaters, manufacturers recommend that electric storage water heaters be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency, and prolong product life. The available evidence indicates that this practice is done in 10% of households.

Note:
Ranges represent span of typical values.
Current standards went into effect April 16, 2015.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.7, 1.57, 1).

Residential Electric Resistance Storage Water Heaters

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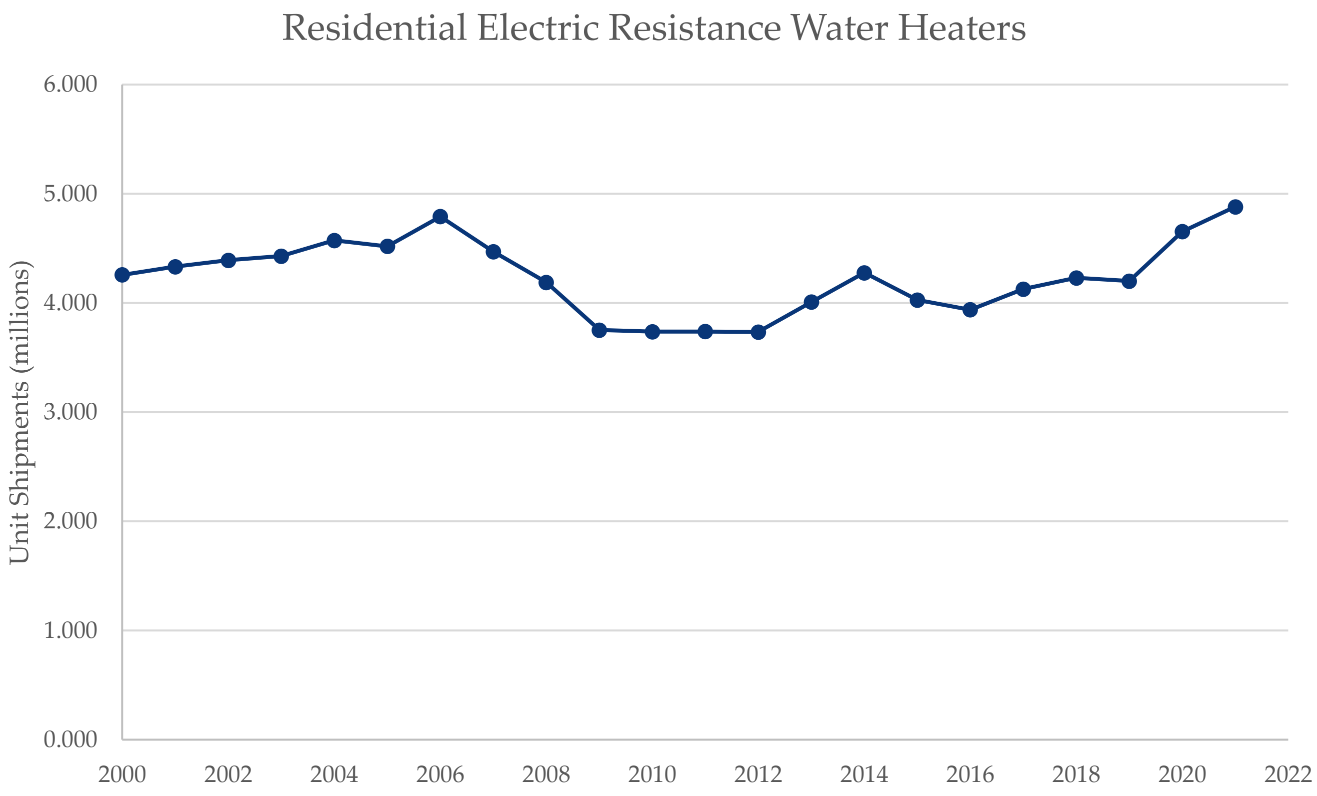
- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.8808-(0.0008*Gal)	No models on the market	2.00
	Low	UEF=0.9254-(0.0003*Gal)	0.92 for a 27-gallon water heater	2.00
	Medium	UEF=0.9307-(0.0002*Gal)	0.92 for a 45-gallon water heater	2.00
	High	UEF=0.9349-(0.0001*Gal)	0.93 for a 50-gallon water heater	2.00
> 55 gal and ≤ 120 gal	Very Small	UEF=1.9236-(0.0011*Gal)	No models on the market	2.20
	Low	UEF=2.0440-(0.0011*Gal)	No models on the market	2.20
	Medium	UEF=2.1171-(0.0011*Gal)	2.05 for a 58-gallon water heater	2.20
	High	UEF=2.2418-(0.0011*Gal)	2.15 for a 80-gallon water heater	2.20

- The federal standards for residential electric storage water heaters apply to both electric resistance storage water heaters and heat pump water heaters.
  - The Federal standard levels for the ≤ 55-gallon range are achievable through electric resistance and heat pump technology.
  - The Federal standards for the > 55-gallon range and all ENERGY STAR levels are only achievable through heat pump technology.
- Typical storage volumes range from 25-55 gallons for electric resistance storage water heaters and 45-80 gallons for heat pump water heaters (HPWHs).

Residential Electric Resistance Storage Water Heaters

Shipments peaked in 2006 then dropped a total of 22 percent over three years. Shipments have gradually increased since then and were at the highest level in 2021.



Source: *AHRI*

Residential Heat Pump Water Heaters

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Same as Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor[1]	2.05	3.28	3.33	3.30	3.73	3.33	3.73	3.33	3.73	3.33	3.73
Average Life (y)	13	13	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Retail Equipment Cost (2022$)[2]	1,290	1,410	630	630	670	630	670	630	670	630	670
	1,650	1,760	1,440	1,440	1,670	1,370	1,590	1,300	1,510	1,240	1,430
Total Installed Cost (2022$)[2]	1,710	1,880	870	870	980	870	980	870	980	870	980
	2,940	3,000	2,230	2,230	2,450	2,120	2,330	2,010	2,210	1,910	2,100
Annual Maintenance Cost (2022$)[3]	20	20	20	20	20	20	20	20	20	20	20

1. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market.
2. It is expected that costs for HPWHs will decrease over time as these products become more common. This analysis estimates these cost decreases for the higher range of costs.
3. For heat pump water heater design options, DOE assumed higher maintenance cost to take into account annual cleaning of the air filter, preventative maintenance cost to check the evaporator and refrigeration system, inspection of the condensate withdrawal system, and replacement of the condensate neutralizer filter, if applicable. However, this maintenance is estimated to occur in only 10% of households, so overall maintenance cost is similar to that of other electric resistance water heaters.

Note:
Ranges represent span of typical values.
ENERGY STAR V. 4.0 went into effect January 5, 2022.
Assume same lifetime as electric resistance water heaters.

Residential Heat Pump Water Heaters

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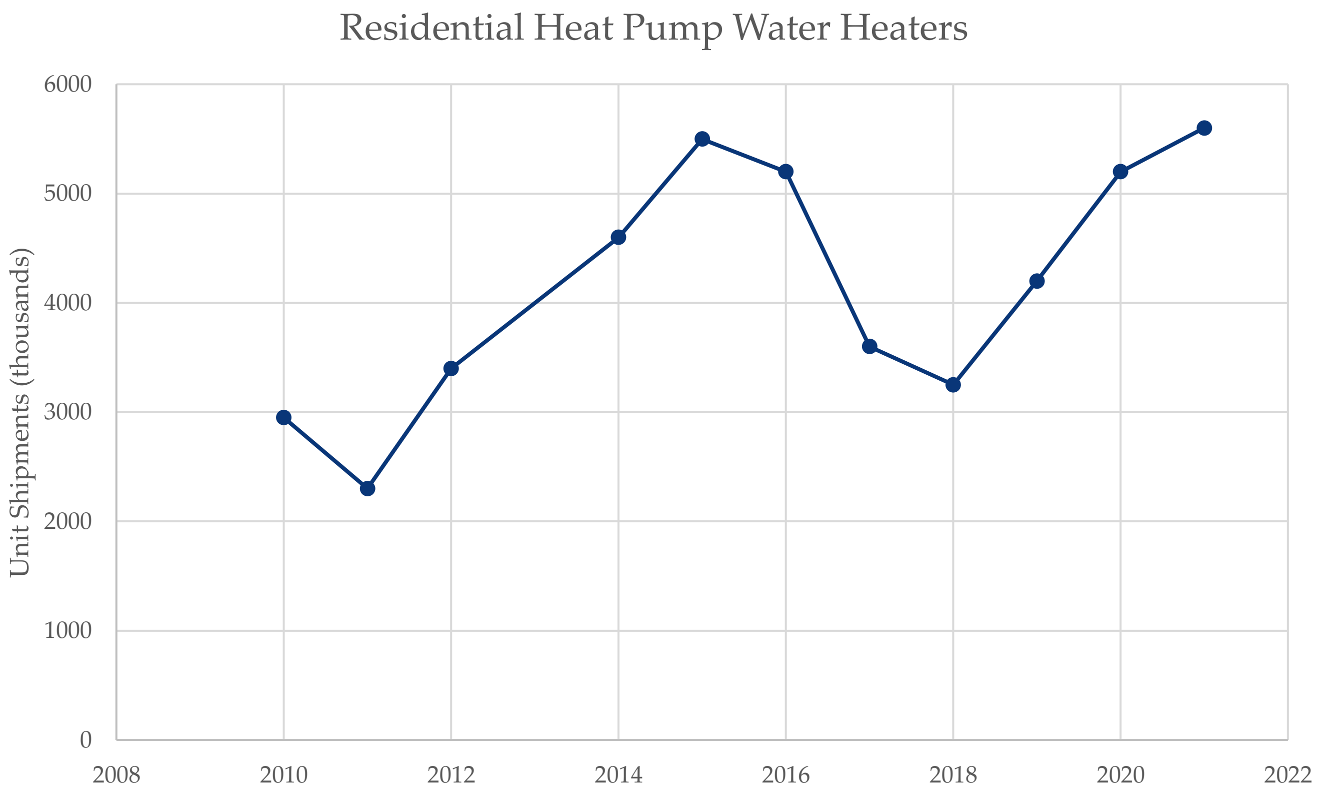
- Technology improvements have advanced efficiency and reliability, but the high first-cost and lack of awareness among consumers and contractors still precludes high-volume market penetration.
- New Federal standards that came into effect in April 2015 effectively mandate heat pump technology for electric storage water heaters with storage volume > 55 gallons.
- Integrated models are the most common configuration for residential HPWHs. Several major water heater manufacturers produce such models, and other competitors offer integrated or add-on units (for existing electric or indirect storage water heaters).
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' COP are usually between 2.5 and 4.
- Heat pumps raise the water temperature more slowly than resistive heating elements, so most models use backup resistive elements along with the heat pump when hot water demand is high. Most HPWHs allow the consumer to control whether resistive elements are used in periods of high demand (e.g., "hybrid mode" or "heat pump only mode").

Residential Heat Pump Water Heaters

Shipments make up a small portion of electric resistance heaters, with a peak of only about 5,500 units, occurring in both 2015 and 2021.



Source: *ENERGY STAR*

Residential Solar Water Heaters

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Same as Reference Case

DATA	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	ENERGY STAR V. 4.0	Typical	Typical	Typical	Typical
Typical Capacity (ft^2)[1]	42	42	40	40	40	40	40
	65	65	54.4	54.4	54.4	54.4	54.4
Solar Uniform Energy Factor (SUEF)[2]	3.0	3.0	3.0	99.0	99.0	99.0	99.0
Average Life (y)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2022$)	7,710	7,710	6,430	6,430	6,430	6,430	6,430
Total Installed Cost (2022$)	10,650	10,650	8,060	8,060	8,060	8,060	8,060
Annual Maintenance Cost (2022$)[3]	80	80	80	80	80	80	80

1. Capacity selections are based on the range observed from medium draw units in the ENERGY STAR database. Medium draw represented the largest portion of units.
2. An SUEF of 3.0 is the required threshold for ENERGY STAR certification, yet a value of 99 was the most common observed SUEF among medium draw units. Note that an SUEF of 99 indicates that no backup heating was required for the applicable draw pattern, and all energy was provided by the solar collector. Since SUEF is a measure of hot water energy out divided by electrical or gas backup energy in, it will be infinite for cases where the collector provides all the hot water needed for the draw pattern – the Solar Rating and Certification Corporation's (SRCC's) OG-300 software is written to assign an SUEF of 99 to this case.
3. Annual maintenance is expected to be 0.5% to 1% of the total installation for 2022, 2030, 2040, and 2050.

Note:

ENERGY STAR V. 4.0 went into effect January 5, 2022.

Residential Solar Water Heaters

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- Solar water heaters are not subject to federal energy conservation standards. The ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SUEF ≥ 3.0	ICC 900/SRCC 300-2020 Solar Thermal System Standard, Appendix A: Solar Uniform Energy Factor Procedure for Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Solar water heaters can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the U.S. are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water. Direct systems were observed as the most common product type and subject of this analysis.
- In 2020, stakeholders from the solar thermal industry developed the Solar Uniform Energy Factor (SUEF) Specification for solar water heaters to align with the UEF metric used by DOE for other water heating technologies.
- SUEF is also the metric used by the current ENERGY STAR Specification, and it replaced the Solar Energy Factor (SEF) metric.
- Over two-third of the current solar water heater market is in the southern or western U.S. (including Hawaii). A collector area of 42 square feet (ft^2) would be typical for these areas. Colder areas of the U.S. would require a larger collector (e.g., 65 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

Residential Solar Water Heaters

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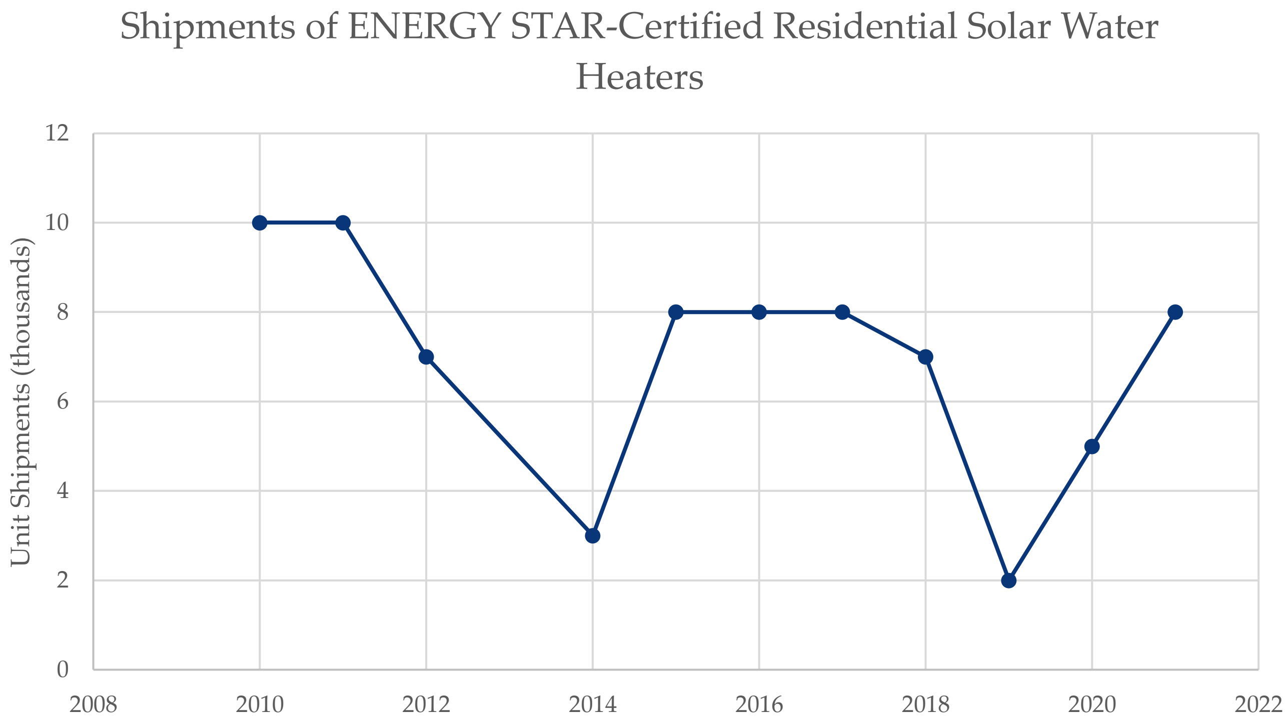
The shipments data below only represents ENERGY STAR-certified solar water heaters, as ENERGY STAR did not provide a market penetration rate. Solar water heaters have a small market share, with only 10,000 shipments at the peak in 2010 and 2011.



Source: *ENERGY STAR*

Residential Gas-Fired Instantaneous Water Heaters

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency

DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.0	High	ENERGY STAR V. 5.0	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199	199
Uniform Energy Factor (UEF)[1]	0.81	0.89	0.81	0.92	0.87	0.97	0.95	0.96	0.97	0.96	0.97	0.96	0.97
Average Life (y)	19	19	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)	1,410	1,180	430	580	580	610	610	580	610	580	610	580	610
	1,760	1,410	1,020	1,360	1,350	1,430	1,430	1,360	1,430	1,360	1,430	1,360	1,430
Total Installed Cost (2022$)	2,590	1,760	920	1,070	950	1,090	1,090	1,070	1,090	1,070	1,090	1,070	1,090
	3,820	3,350	2,860	3,160	3,140	3,230	3,220	3,160	3,230	3,160	3,230	3,160	3,230
Annual Maintenance Cost (2022$)[2]	90	90	90	90	90	90	90	90	90	90	90	90	90

1. Analysis is based on an average of low, medium, and high draw pattern units, as this is most reflective of the market.
2. Annual maintenance includes deliming to minimize deposition of sediment in the heat exchanger, maintain operating efficiency and prolong product life. Also includes additional tasks, including inspection of the ignition device, gas valve, controls, thermostat, and venting.

Note:
Current standards went into effect April 16, 2015.
ENERGY STAR V. 4.0 went into effect January 5, 2022.
ENERGY STAR V. 5.0 will go into effect April 18, 2023.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (21.3, 1.76, 1).

Residential Gas-Fired Instantaneous Water Heaters

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- The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
<2 gal and >50,000 Btu/h	Very Small	UEF=0.80	No models on the market	0.87
	Low	UEF=0.81	No models on the market	0.87
	Medium	UEF=0.81	0.81	0.87
	High	UEF=0.81	0.81	0.87

- The ENERGY STAR levels require the use of condensing technology.
- All of the major water heater manufacturers now offer an instantaneous water heater model.
- The maintenance costs include cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.
- Advanced Case: Increased market incentives are expected to drive further adoption of condensing products, thereby raising the typical efficiency, while increased R&D is expected to improve cost.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Gas-Fired Instantaneous Water Heaters

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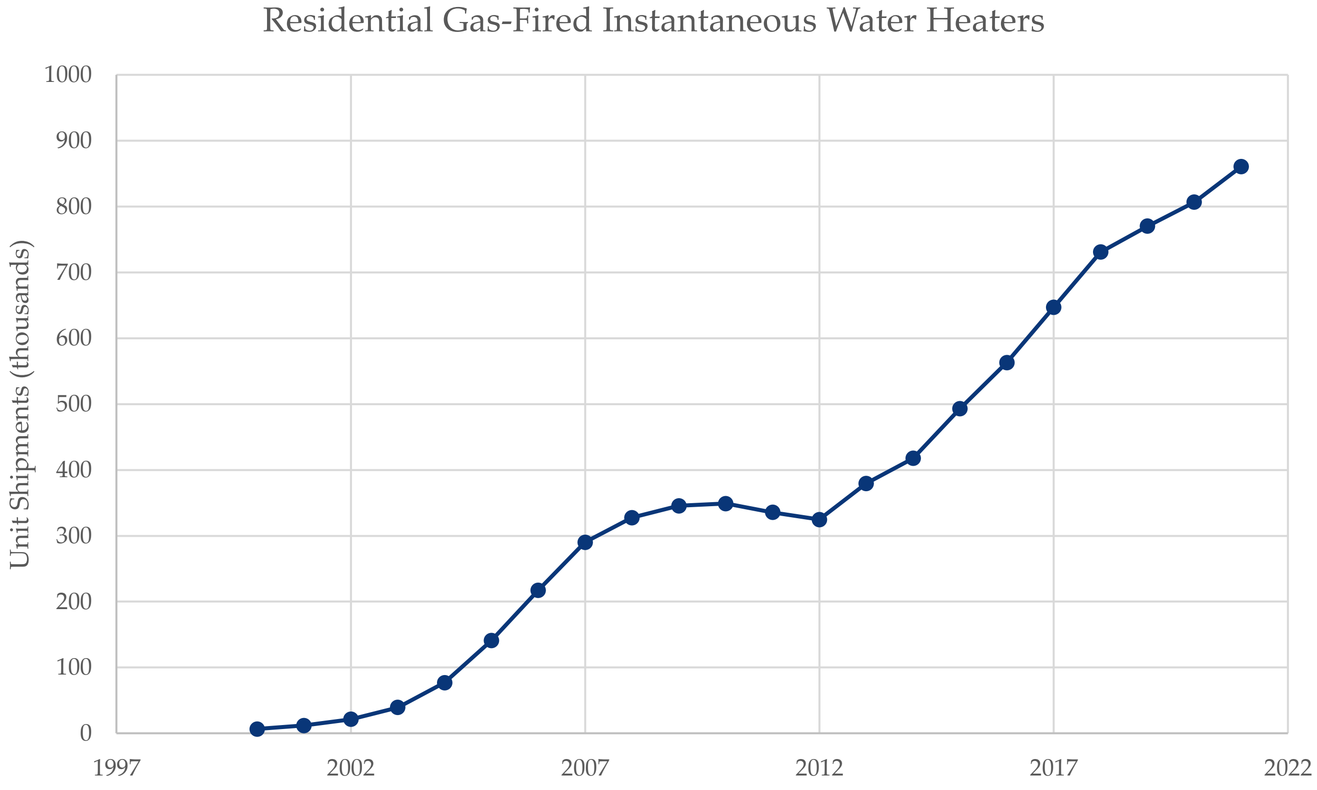
Shipments for Gas-Fired Instantaneous Water Heaters have grown steadily with nearly no shipments in 2000 and a peak of about 850,000 units in 2021.



Source: *CWH EERE 2022 Preliminary Analysis*

Residential Electric Instantaneous Water Heaters

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Same as Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Representative Input Rate (kW)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Uniform Energy Factor (UEF)[1]	0.96	0.96	0.91	0.96	0.98	0.96	0.98	0.96	0.98	0.96	0.98
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)	260	260	260	260	260	260	260	260	260	260	260
Total Installed Cost (2022$)	520	520	520	520	520	520	520	520	520	520	520
Annual Maintenance Cost (2022$)[2]	90	90	90	90	90	90	90	90	90	90	90

1. Analysis is based on an average of low, medium, and very small draw pattern units, as this is most reflective of the market.
2. Annual maintenance costs not provided in CWH EERE 2022 Preliminary Analysis. Maintenance costs determined from the following calculation: GIWH - (GSWH - ESWH) - i.e., the difference factor in maintenance between gas and electric storage heat pumps applied to gas instantaneous heat pumps.

Note:
Current standards went into effect April 16, 2015.
Assume same lifetime as gas-fired instantaneous water heaters.

Residential Electric Instantaneous Water Heaters

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- The Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes
<2 gal	Very Small	UEF=0.91	0.91
	Low	UEF=0.91	0.91
	Medium	UEF=0.91	No models on the market
	High	UEF=0.92	No models on the market

- Electric instantaneous water heaters use electric resistance heating elements to heat water when there is a demand. Resistive heating elements are virtually 100% efficient, and the small storage capacities of these products means that they do not lose significant amounts of heat to the environment.
- The federal standards for these products require UEFs of 0.91 for very small, low, and medium draw pattern models and 0.92 for high draw pattern models.
- Most products currently on the market are in the very small draw pattern or the low draw pattern because electric resistance elements can only supply a limited quantity of heat on an instantaneous basis due to circuit amperage limitations.
- Many products are designed for point-of-use applications, such that the water heater only supplies water to one faucet or showerhead.

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Residential Appliances

Residential Refrigerator-Freezers (Top)

Final

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/y)[3]	512	401	411	401	370	358	370	358	370	358	370	358
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	670	750	740	750	760	760	750	760	750	760	750	760
Total Installed Cost (2022$)	670	750	740	750	760	760	750	760	750	760	750	760
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 3 is used for this analysis (Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. The 2015 installed base energy consumption value is based on an adjusted volume of 21 cubic feet (ft^3). Energy consumption values for the 2020 installed base and 2022 and beyond are based on an adjusted volume of 22 ft^3, representing the current market.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect in September 2014.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers (Side)

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	26	26	25	25	25	25	25	25	25	25	25	25
Energy Consumption (kWh/y)[3]	893	693	705	693	635	610	635	610	635	610	635	610
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	1,400	1,130	1,130	1,130	1,160	1,470	1,130	1,470	1,130	1,470	1,130	1,470
Total Installed Cost (2022$)	1,400	1,130	1,130	1,130	1,160	1,470	1,130	1,470	1,130	1,470	1,130	1,470
Annual Maintenance Cost (2022$)[4]	30	20	20	20	20	30	20	30	20	30	20	30

1. Product Class 7 is used for this analysis (Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 32 ft^3 for all analysis years.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect in September 2014.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers (Bottom)

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/y)[3]	547	473	521	473	469	430	469	430	469	430	469	430
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	1,190	920	920	920	920	930	920	930	920	930	920	930
Total Installed Cost (2022$)	1,190	920	920	920	920	930	920	930	920	930	920	930
Annual Maintenance Cost (2022$)[4]	30	20	20	20	20	20	20	20	20	20	20	20

1. Product Class 5 is used for this analysis (Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service).
2. The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 23 ft^3 for all analysis years.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect in September 2014.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (10.26, 1.28, 5.13).

Residential Refrigerator-Freezers

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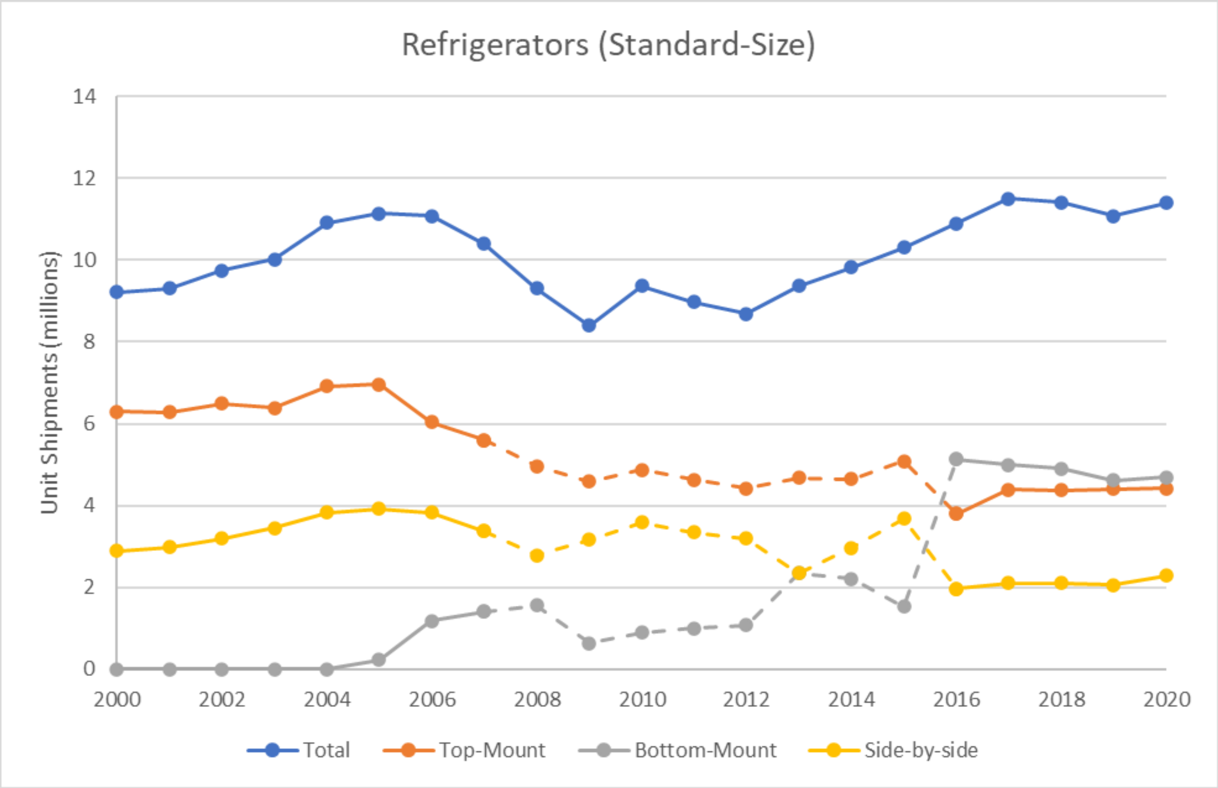
- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 32 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence and configuration (through-the-door or inside cabinet) of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard
- Energy efficiency opportunities for refrigerators include:
  - More efficient compressor, including variable speed compressors
  - Brushless direct current (DC) fan motor (also known as ECM motor)
  - Variable defrost
  - Larger condenser
  - Dual evaporators
  - Vacuum-insulated panels
  - Refrigerants (Isobutane vs. R134a)
- Advanced Case: Increased market incentives will push product sales towards the ENERGY STAR level, but the technologies used to meet ENERGY STAR are already well-known and prices will likely not rise as manufacturing volumes increase at higher efficiencies.

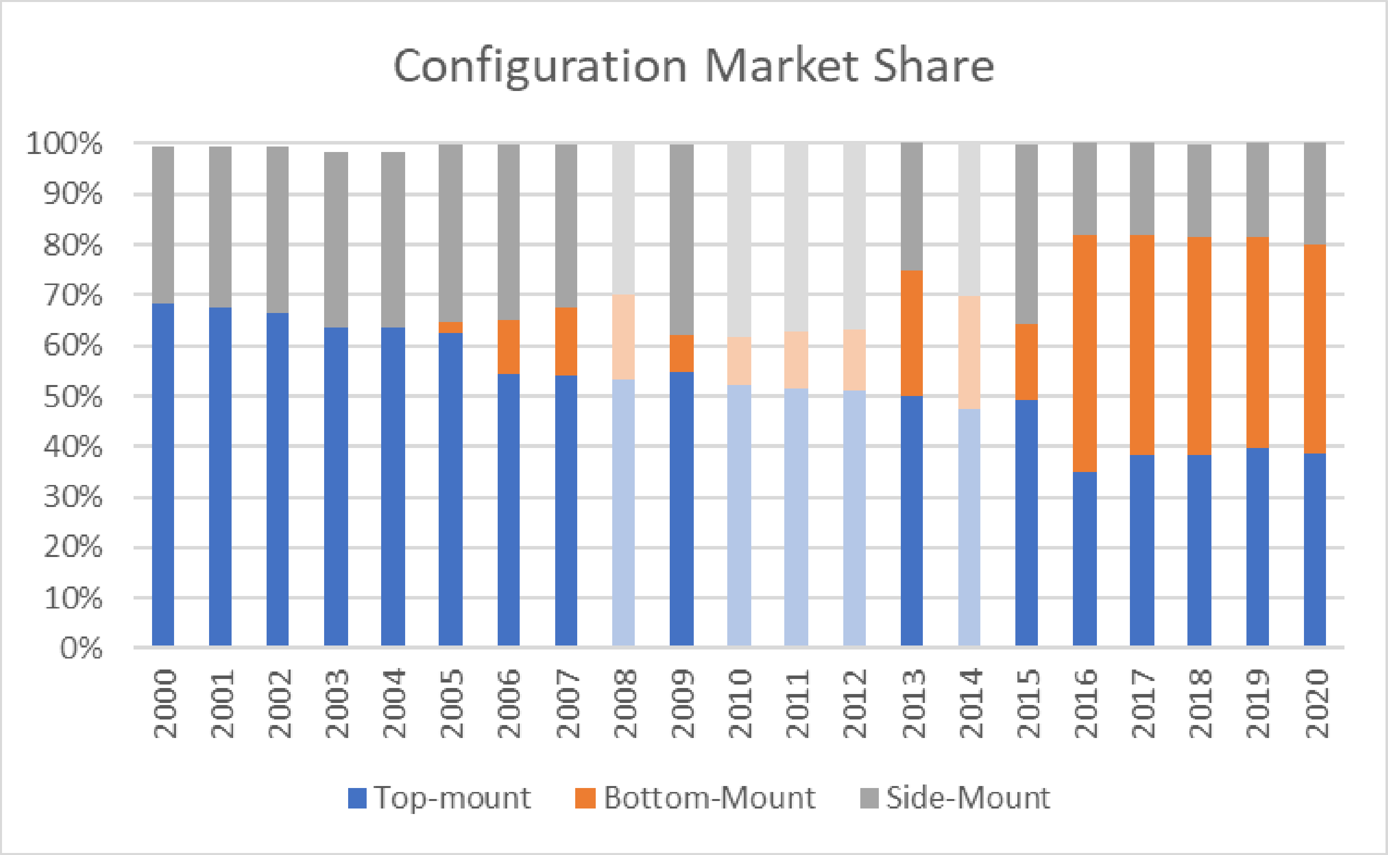
[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume)

Annual shipment volumes have rebounded from a sharp decline between 2006 and 2009, reaching approximately 11.4 million units in 2020.



Source: *Appliance Magazine; DOE's CCD, as of December 2017; ENERGY STAR Unit Shipment Data (2017-2020); Guidehouse analysis.* Dashed lines are a combination of interpolated and available data.

Bottom-mount units have gained market share, surpassing top-mount units since 2016.



Sources: *RF EERE 2021 Preliminary Analysis; DOE's CCD, as of December 2017; Guidehouse analysis.* Lightly shaded bars indicate interpolated data.

Residential Freezers (Chest)

Final

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Same as Reference Case

DATA[1]	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	16	15	15	15	15	15	15	15	15	15	15
Energy Consumption (kWh/y)[3]	360	297	297	297	287	297	287	297	287	297	287
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	510	590	680	680	690	680	690	680	690	680	690
Total Installed Cost (2022$)	510	590	680	680	690	680	690	680	690	680	690
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 10 is used for this analysis (Chest freezers and all other freezers except compact freezers).
2. The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 26 ft^3, which is the average adjusted volume for units with a rounded total refrigerated volume of 15 ft^3 per the DOE CCD.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

Note:
Current standard went into effect in September 2014.
ENERGY STAR excluded as no products at the typical capacity are ENERGY STAR compliant.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (21.96, 1.83, 1).

Residential Freezers (Upright)

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA[1]	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)[2]	17	17	18	18	18	18	18	18	18	18	18	18
Energy Consumption (kWh/y)[3]	615	446	497	493	448	441	448	441	448	441	448	441
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	690	880	830	830	830	830	830	830	830	830	830	830
Total Installed Cost (2022$)	690	880	830	830	830	830	830	830	830	830	830	830
Annual Maintenance Cost (2022$)[4]	10	10	10	10	10	10	10	10	10	10	10	10

1. Product Class 9 is used for this analysis (Upright freezers with automatic defrost).
2. The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
3. Based on an adjusted volume of 31 ft^3, which is the average adjusted volume for units with a rounded total refrigerated volume of 18 ft^3 per the DOE CCD.
4. Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan electronics).

Note:
Current standard went into effect in September 2014.
ENERGY STAR V. 5.1 went into effect September 2014.
Assume same lifetime as chest freezers.

Residential Freezers

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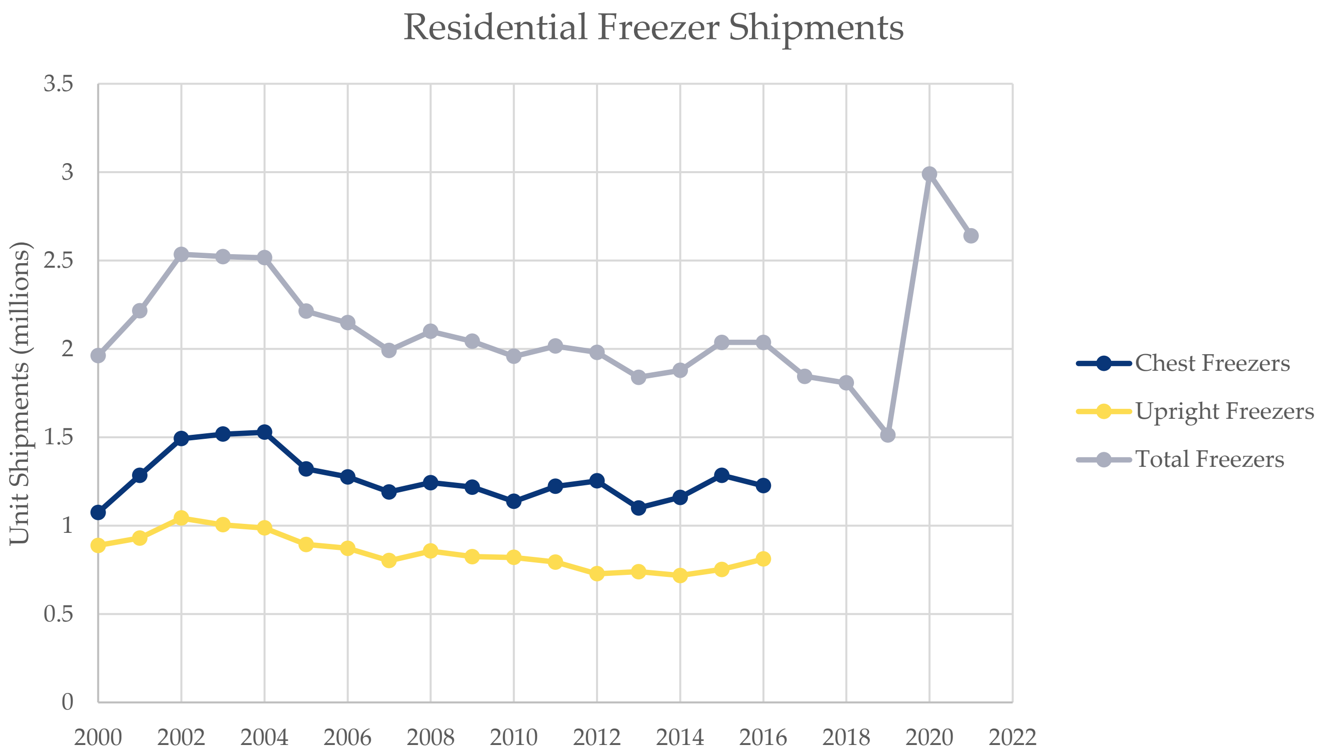
- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 10 product classes based on size (standard or compact), orientation (chest or upright), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence of automatic icemaker
    - Current analysis focuses on the two representative product classes analyzed in the recent rulemaking, chest and upright freezers.
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
    - Chest freezers and all other freezers except compact freezers (PC 9): 9.88AV + 143.7
    - Upright freezers with automatic defrost (PC 10): 12.43AV + 326.1
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard
  - No ENERGY STAR compliant products at the typical capacity for chest freezers
- Energy efficiency opportunities for freezers include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. shaded pole motor (SPM) and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)
- Advanced Case: Increased market incentives will push product sales of upright freezers towards the ENERGY STAR level, but the technologies used to meet ENERGY STAR are already well-known and prices will likely not rise as manufacturing volumes increase at higher efficiencies. Unlikely to occur for chest freezers due to such a low existing market penetration of ENERGY STAR products.

[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Shipment volumes held steady between 2007 to 2016 at about 2 million units per year. Shipments jumped to 3 million units in 2020. Chest freezers represent about 60% of the market.



Sources: *Appliance Magazine* from 2000 to 2016; *ENERGY STAR from 2017 to 2021*

Residential Natural Gas Cooktops

Final

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23
Integrated Annual Energy Consumption (kBtu/y)[1]	1,061	914	914	730	914	730	914	730	914	730
Cooking Efficiency (%)	40	45	45	52	45	52	45	52	45	52
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	290	310	310	330	310	330	310	330	310	330
Total Installed Cost (2022$)[2]	420	460	460	480	460	480	460	480	460	480
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (IAEC) (kBtu/h). The Consumer Cooking Products EERE 2020 notice of proposed determination (NOPD) used for 2020 and beyond in this analysis also determined IAEC using a different test procedure than the Consumer Cooking Products EERE 2016 SNOPR.
2. Equipment and installed costs are for cooktops only (not combined range units).
3. Annual maintenance costs are negligible.

Note:
The range for typical capacity represents the span of typical values.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Ovens

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kBtu/y)[1]	2,038	1,960	1,960	1,831	1,960	1,831	1,960	1,831	1,960	1,831
Cooking Efficiency (%)	6.6	6.9	6.9	7.3	6.9	7.3	6.9	7.3	6.9	7.3
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	740	770	770	810	770	810	770	810	770	810
Total Installed Cost (2022$)[2]	870	920	920	950	920	950	920	950	920	950
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). The 2015 IAEC value is reflective of freestanding standard gas ovens, which was previously determined to be the most representative product class. IAEC for 2020 and beyond is reflective of freestanding self-clean gas ovens, which is the product class that makes up the majority of historical and projected gas oven shipments.
2. Equipment and installed costs are for ovens only (not combined ranges). Costs are reflective of freestanding self-clean oven units with single oven component, which represent the majority of the market.
3. Maintenance costs are negligible.

Note:

Ranges represent the span of typical values for a given parameter.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Ranges

Final

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity of Cooktop Component (kBtu/h)	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23
Typical Capacity of Oven Component (kBtu/h)	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume of Oven Component (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kBtu/y)[1]	3,099	2,874	2,874	2,561	2,874	2,561	2,874	2,561	2,874	2,561
Average Life (y)	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$) [2]	750	770	770	850	770	850	770	850	770	850
Total Installed Cost (2022$) [2]	900	920	920	1,000	920	1,000	920	1,000	920	1,000
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. IAEC of a natural gas range is calculated as the sum of the IAEC for a natural gas cooktop and natural gas oven. IAEC of the oven component is reflective of freestanding self-clean gas ovens, which represent the majority of the market. The 2015 IAEC value of the oven component is reflective of freestanding standard gas ovens, which was previously determined to be the most representative product class.
2. Retail and installed cost are reflective of a typical unit with standard 30-inch width and 4 to 5 cooking top heating elements. Based on data from DOE rulemakings, Gordian's RSMeans Data – Building Construction Costs 2023, and distributors, total installed cost is estimated to be around $150 more than retail equipment cost.
3. Maintenance costs are negligible.

Note:
Ranges represent the span of typical values for a given parameter.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (14.56, 5.73).

Residential Natural Gas Cooktops, Ovens, and Ranges

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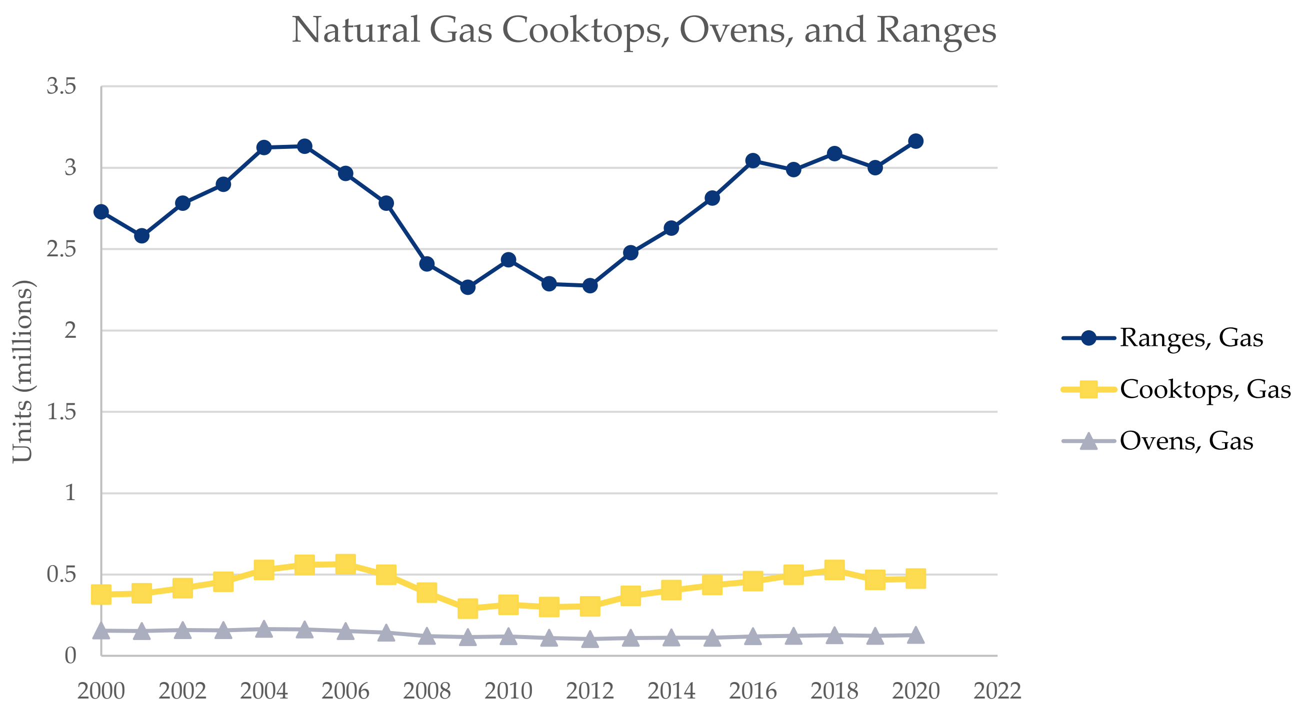
- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- Since January 1, 1990, gas cooking products with an electrical supply cord have been required to not be equipped with a constant burning pilot light. This requirement extended to gas cooking products without an electrical supply cord, as of April 9, 2012.
- DOE published a final rule in 2009[1] in which it determined that no standard for cooking efficiency would be cost-justified.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including gas cooktops and ovens[2].
- On September 2, 2016, DOE proposed performance-based standards for gas cooktops and ovens that would take effect in 2020, if adopted.
- DOE established the new IAEC metric, in kBtu/y, to replace cooking efficiency (%).
- On December 14, 2020, DOE initially determined that amended energy conservation standards for consumer conventional cooking products would not be economically justified and would not result in significant conservation of energy[3].
- On February 2, 2023, DOE proposed new and amended energy conservation standards for consumer conventional cooking products[4].
- The IAEC of a range is calculated as the sum of the IAECs for cooktops and ovens. However, retail and installation costs for a range are similar to the cost of an oven.

[1]Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers); Final Rule. 74 FR 16040.
[2]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.
[3]Energy Conservation Standards for Consumer Conventional Cooking Products; Notice of proposed determination (NOPD). 85 FR 80982.
[4]Energy Conservation Standards for Consumer Conventional Cooking Products; SNOPR. 88 FR 6818.

Shipments have been rising since 2012. In 2020, gas range shipments surpassed the peak reached in 2005.



Source: *Appliance Magazine and Consumer Cooking Products EERE 2022 SNOPR*

Residential Electric Cooktops

Final

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (W)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700
Integrated Annual Energy Consumption (kWh/y)[1]	155	155	155	119	155	119	155	119	155	119
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$)[2]	470	470	470	810	470	810	470	810	470	810
Total Installed Cost (2022$)[2]	620	620	620	1,230	620	1,230	620	1,230	620	1,230
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). IAEC was determined using DOE rulemaking data for the most representative product class, electric smooth element cooking tops, which covers cooking tops with electric resistance heating elements and cooking tops with induction heating elements.
2. Equipment and installed costs are for cooktops only (not combined range units). Costs were determined using DOE rulemaking data for the most representative product class, electric smooth cooking tops, which includes cooking tops with electric resistance heating elements and cooking tops with induction heating elements. A high-end unit with induction technology is expected to have a greater retail equipment cost and greater installation cost in order to implement this technology.
3. Maintenance costs are negligible.

Note:
The range for typical capacity represents the span of typical values.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Ovens

Final

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (W)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kWh/y)[1]	355	355	355	278	355	278	355	278	355	278
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$)[2]	630	630	630	730	630	730	630	730	630	730
Total Installed Cost (2022$)[2]	770	770	770	870	770	870	770	870	770	870
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to IAEC (kBtu/y). IAEC was determined using DOE rulemaking data for freestanding electric self-clean ovens, which represent the majority of the market.
2. Equipment and installed costs are for ovens only (not combined ranges). Costs are reflective of freestanding self-clean oven units with single oven component, which represent the majority of the market.
3. Maintenance costs are negligible.

Note:

Ranges represent the span of typical values for a given parameter.

Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Ranges

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Same as Reference Case

DATA	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity of Cooktop Component (W)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700
Typical Capacity of Oven Component (W)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Typical Cavity Volume of Oven Component (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kWh/y)[1]	510	510	510	397	510	397	510	397	510	397
Average Life (y)	17	17	17	17	17	17	17	17	17	17
Retail Equipment Cost (2022$)[2]	630	630	630	900	630	900	630	900	630	900
Total Installed Cost (2022$)[2]	770	770	770	1,050	770	1,050	770	1,050	770	1,050
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-

1. IAEC of an electric range is calculated as the sum of the IAEC for an electric cooktop and an electric oven. IAEC of the electric cooktop component was determined using DOE rulemaking data for the most representative product class, electric smooth element cooking tops, which covers cooking tops with electric resistance heating elements and cooking tops with induction heating elements. IAEC of the electric oven component was determined using DOE rulemaking data for freestanding electric self-clean ovens, which represent the majority of the market.
2. Retail and installed cost are reflective of standard units that are 30-inch wide and have 4 to 5 cooking top heating elements. Based on data from DOE rulemakings, Gordian's RSMeans Data – Building Construction Costs 2023, and distributors, total installed cost is estimated to be around $140 more than retail equipment cost for a typical unit, and $150 more than retail equipment cost for a high-end unit. A high-end unit with an induction cooking top component is expected to have a greater retail equipment cost and greater installation cost in order to implement this technology.
3. Maintenance costs are negligible.

Note:
Ranges represent the span of typical values for a given parameter.
Average life is determined using a Weibull distribution characterized by the following scale (α) and shape (β) parameters: (16.88, 6.99).

Residential Electric Cooktops, Ovens, and Ranges

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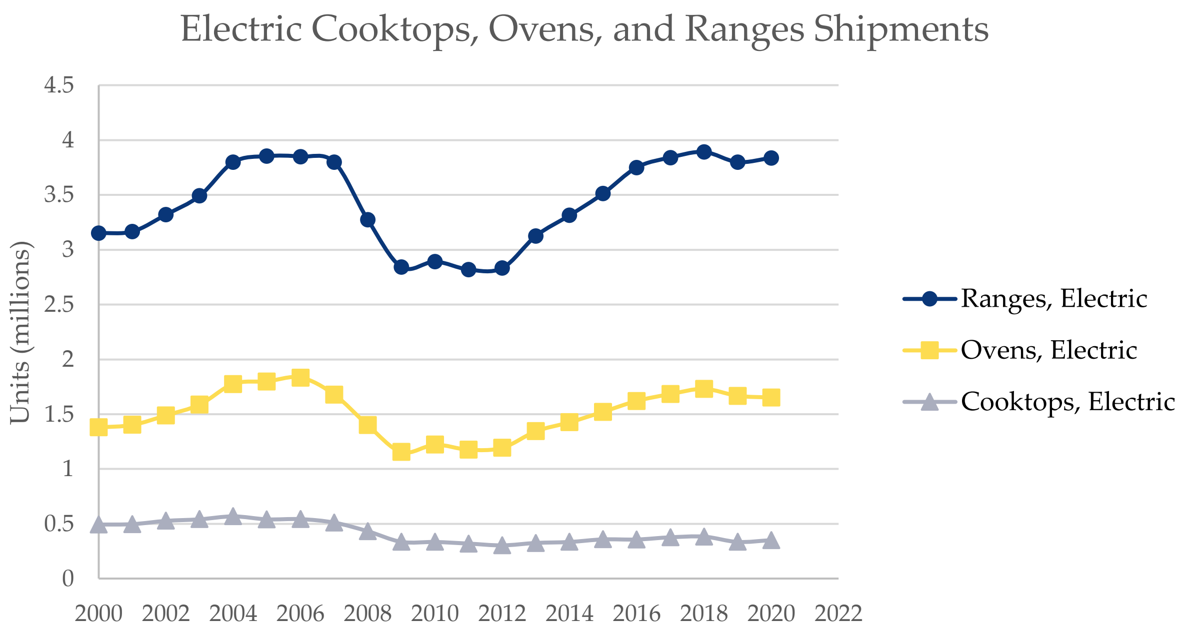
- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including electric cooktops and ovens[1].
- On September 2, 2016, DOE proposed performance-based standards for electric cooktops and ovens that would take effect in 2020 if adopted.
- DOE established the new IAEC metric, in kWh/y, to replace cooking efficiency (%).
- On December 14, 2020, DOE initially determined that amended energy conservation standards for consumer conventional cooking products would not be economically justified and would not result in a significant conservation of energy[2].
- On February 2, 2023, DOE proposed new and amended energy conservation standards for consumer conventional cooking products[3].
- The IAEC of a range is calculated as the sum of the IAECs for cooktops and ovens. However, retail and installation costs for a range are similar to the cost of an oven.

[1]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.
[2]Energy Conservation Standards for Consumer Conventional Cooking Products; Notice of proposed determination (NOPD). 85 FR 80982.
[3]Energy Conservation Standards for Consumer Conventional Cooking Products; SNOPR. 88 FR 6818.

Residential Electric Cooktops, Ovens, and Ranges

Shipments of electric cooking products reached a peak in 2006. Shipments of ranges and ovens have been rising again since 2012. In 2018, electric range shipments surpassed the peak reached in 2006.



Source: *Consumer Cooking Products EERE 2022 SNOPR*

Residential Clothes Dryers (Electric)

Final

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1[1]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7.4	7.4	7.4	7.4	7.4	4.5	7.4	4.5	7.4	4.5	7.4	4.5
Combined Energy Factor, D1 (lb/kWh)[2]	3.59	3.73	3.73	3.73	NA	3.93	3.73	3.93	3.73	3.93	3.73	3.93
Combined Energy Factor, D2 (lb/kWh)[2]	3.59	3.93	3.73	3.93	3.93	11.00	5.34	11.00	6.48	11.00	7.38	11.00
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	580	580	580	580	580	980	580	980	580	980	580	980
Total Installed Cost (2022$)	710	710	710	710	710	1,110	710	1,110	710	1,110	710	1,110
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-	-	-

1. ENERGY STAR V. 1.1 applies to vented and ventless standard electric clothes dryers.
2. The efficiency metric changed from EF to combined energy factor (CEF) in 2015. The 2015 Installed Base CEF data accounts for units tested to appendix D1 and appendix D2, because data specific to each appendix is not available for that year.
3. Maintenance costs are negligible. DOE estimated that on average 2.7 percent of electric and 3.3 percent of gas residential clothes dryers are repaired each year. (EERE 2014)

Note:

DOE test procedures for consumer clothes dryers appear at title 10 of the Code of Federal Regulations part 430, subpart B, appendix D1 and appendix D2. The second test method, appendix D2, was finalized in a final rule published by DOE on August 14, 2013. For current standard testing, units must be tested according to either the appendix D1 or the appendix D2 test method. ENERGY STAR V. 1.1 requires certified units to be tested according to the appendix D2 test method. The appendix D1 and appendix D2 test methods determine CEF differently.

The current standard went into effect in January 2015.

ENERGY STAR V. 1.1 went into effect in May 2017.

The range for average life represents the span of typical values.

Residential Clothes Dryers (Gas)

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Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 1.1[1]	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Combined Energy Factor, D1 (lb/kWh)[2]	3.18	3.30	3.30	3.30	NA	3.48	3.30	3.48	3.30	3.48	3.30	3.48
Combined Energy Factor, D2 (lb/kWh)[2]	3.18	3.48	3.30	3.48	3.48	3.50	3.48	3.50	3.48	3.50	3.48	3.50
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	660	670	660	670	670	670	670	670	670	670	670	670
Total Installed Cost (2022$)	860	870	870	870	870	870	870	870	870	870	870	870
Annual Maintenance Cost (2022$)[3]	-	-	-	-	-	-	-	-	-	-	-	-

1. ENERGY STAR V. 1.1 applies to vented and ventless standard electric clothes dryers.
2. The efficiency metric changed from EF to CEF in 2015. The 2015 Installed Base CEF data accounts for units tested to appendix D1 and appendix D2, because data specific to each appendix is not available for that year.
3. Maintenance costs are negligible. DOE estimated that on average 2.7 percent of electric and 3.3 percent of gas residential clothes dryers are repaired each year. (EERE 2014)

Note:

DOE test procedures for consumer clothes dryers appear at title 10 of the Code of Federal Regulations part 430, subpart B, appendix D1 and appendix D2. The second test method, appendix D2, was finalized in a final rule published by DOE on August 14, 2013. For current standard testing, units must be tested according to either the appendix D1 or the appendix D2 test method. ENERGY STAR V. 1.1 requires certified units to be tested according to the appendix D2 test method. The appendix D1 and appendix D2 test methods determine CEF differently.

The current standard went into effect in January 2015.

ENERGY STAR V. 1.1 went into effect in May 2017.

The range for average life represents the span of typical values.

Residential Clothes Dryers

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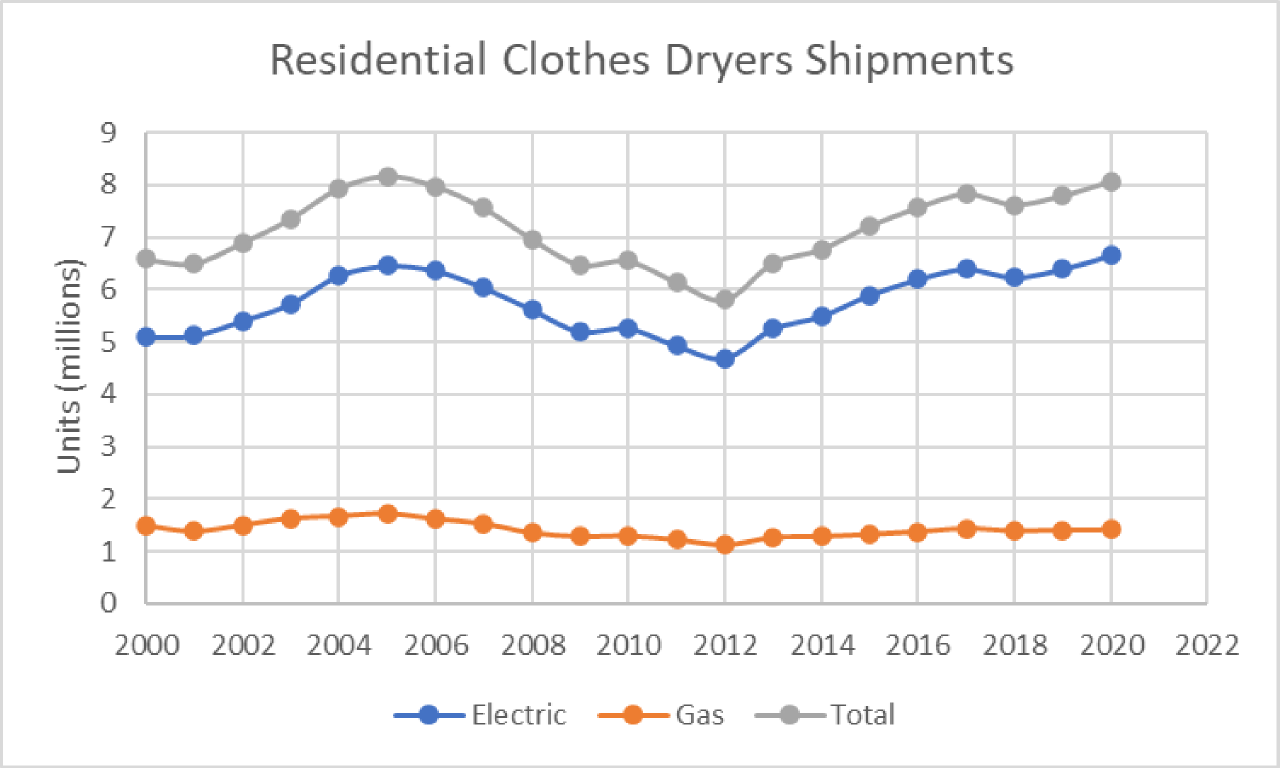
- Current standards[1] in effect since 2015:
  - For standard-size electric units : CEF ≥ 3.73 pound per kilowatt hours (lb/kWh)
  - For gas units: CEF ≥ 2.30 lb/kWh
  - Units may be tested according to the test method in appendix D1 or appendix D2, which was finalized in 2013.
- The main differences between appendix D1 and appendix D2 are:
  - Appendix D2 includes test methods that more accurately measure the effects of automatic cycle termination and that may result in differences in the total measured energy consumption of the test cycle as compared to the test methods in appendix D1.
  - Appendix D2 contains instructions for the testing of timer dryers, which include a lower final moisture content (FMC) of the test load as compared to the version of appendix D1 used for the 2011 rulemaking analysis.
- Efficiency improvement technologies for clothes dryers include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination
  - Heat pump (for electric clothes dryers)
- EPA developed ENERGY STAR V. 1.1, which became effective in 2017 and requires units to be tested according to the test method in appendix D2.
- Standard-size heat pump clothes dryers with CEF values up to 11.0 are currently available in the U.S. market. High initial cost has limited market penetration, but some utilities are offering rebates to support market penetration.
- Advanced Case: Due to increases in market incentives, the residential electric clothes dryers market will see an increase in adoption of heat pump dryers that improve the typical efficiency products.

[1]Energy Conservation Standards for Consumer Clothes Dryers. 10 CFR 430.32(h).

Shipment volumes have been on the rise since 2012. Gas dryers continue to account for about one-fifth of the market.



Source: *Consumer Clothes Dryers EERE 2022 NOPR*

Residential Clothes Washers (Front)

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Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 8.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.7	4.1	3.4	4.5	4.5	5.0	4.5	5.0	4.5	5.0	4.5	5.0
Integrated Modified Energy Factor (ft^3/kWh/cycle)[1]	2.16	2.76	1.84	2.76	2.76	3.10	2.76	3.10	2.76	3.10	2.76	3.10
Integrated Water Factor (gal/cycle/ft^3)[2]	4.7	3.2	4.7	3.2	3.2	2.7	3.2	2.7	3.2	2.7	3.2	2.7
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	17	14	16	14	14	14	14	14	14	14	14	14
Hot Water Energy (kWh/cycle)	0.21	0.17	0.36	0.12	0.12	0.13	0.12	0.13	0.12	0.13	0.12	0.13
Machine Energy (kWh/cycle)	0.17	0.14	0.15	0.12	0.12	0.17	0.12	0.17	0.12	0.17	0.12	0.17
Dryer Energy (kWh/cycle)	1.31	1.24	1.34	1.17	1.17	1.56	1.17	1.56	1.17	1.56	1.17	1.56
Retail Equipment Cost (2022$)	735	1,000	705	930	930	950	930	950	930	950	930	950
Total Installed Cost (2022$)	915	1,175	880	1,130	1,130	1,150	1,130	1,150	1,130	1,150	1,130	1,150
Annual Maintenance Cost (2022$)	15	15	15	15	15	15	15	15	15	15	15	15

1. The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.
2. The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

Note:

The current standard went into effect in January 2018.
ENERGY STAR V. 8.1 went into effect in February 2018.
The range for average life represents the span of typical values.

Residential Clothes Washers (Top)

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Same as Reference Case

DATA	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 8.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.3	3.4	3.5	3.5	4.4	5.5	3.5	5.5	3.5	5.5	3.5	5.5
Integrated Modified Energy Factor (ft^3/kWh/cycle)[1]	1.14	1.57	1.57	1.57	2.06	2.76	1.57	2.76	1.57	2.76	1.57	2.76
Integrated Water Factor (gal/cycle/ft^3)[2]	9.2	6.5	6.5	6.5	4.3	3.2	6.5	3.2	6.5	3.2	6.5	3.2
Average Life (y)	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	30	22	23	23	19	18	23	18	23	18	23	18
Hot Water Energy (kWh/cycle)	0.90	0.39	0.41	0.41	0.38	0.24	0.41	0.24	0.41	0.24	0.41	0.24
Machine Energy (kWh/cycle)	0.25	0.13	0.14	0.14	0.12	0.13	0.14	0.13	0.14	0.13	0.14	0.13
Dryer Energy (kWh/cycle)	1.73	1.63	1.68	1.68	1.64	1.61	1.68	1.61	1.68	1.61	1.68	1.61
Retail Equipment Cost (2022$)	590	590	520	520	640	725	520	725	520	725	520	725
Total Installed Cost (2022$)	765	765	715	715	840	920	715	920	715	920	715	920
Annual Maintenance Cost (2022$)	15	15	15	15	15	15	15	15	15	15	15	15

1. The efficiency metric changed from Modified Energy Factor to IMEF in 2015.
2. The efficiency metric changed from Water Factor to IWF in 2015.

Note:
The current standard went into effect in January 2018.
ENERGY STAR V. 8.1 went into effect in February 2018.
The range for average life represents the span of typical values.

Residential Clothes Washers

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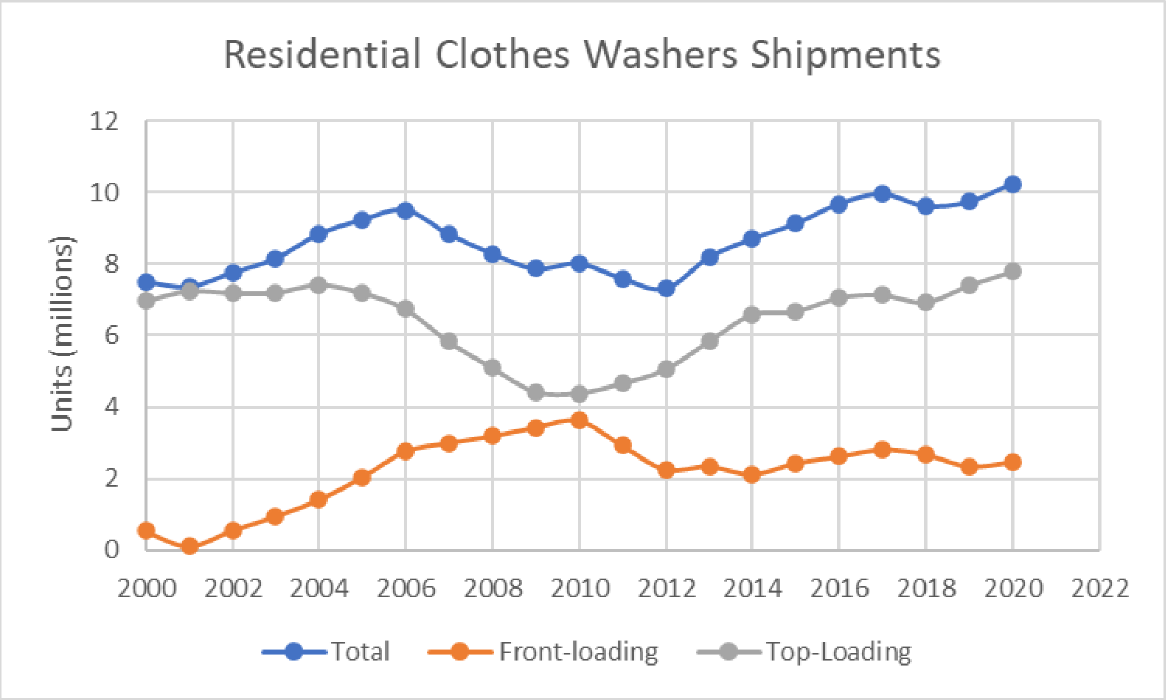
- The analysis treats front- and top-loading models separately due to their different energy use characteristics.
- Federal standards[1] for standard-capacity clothes washers (≥ 1.6 ft^3):

	Integrated Modified Energy Factor		Integrated Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard (effective 1/1/2018)	≥ 1.57	≥ 1.84	≤ 6.5	≤ 4.7
Current ENERGY STAR V. 8.1 (effective 4/22/2021)	≥ 2.06	≥ 2.76	≤ 4.3	≤ 3.2

- In 2020, about 40% of top-loading models and almost all front-loading models achieved the ENERGY STAR level.
- Energy efficiency improvement technologies for clothes washers include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing for adaptive water fill control
  - Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance
- Maintenance costs include replacement or repair of the drain pump, control board, motor, rubber gaskets, or control panel knobs.
- The products on the market with the highest IMEF have significantly larger capacity and therefore use more energy per cycle than typical, smaller capacity products but still perform more efficiently on a per volume basis.

[1]Energy Conservation Standards for Consumer Clothes Washers. 10 CFR 430.32(g).

Shipments have been on the rise since 2012 and reached a peak of about 10 million in 2020. Since 2012, top-loading and front-loading units represent approximately 75% and 25% of shipments, respectively.



Source: *AHAM Shipment Data; RCW EERE 2021 Preliminary Analysis*

Residential Dishwashers

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Same as Reference Case

DATA	2015	2020	2022				2023	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 6.0	High	ENERGY STAR V. 7.0	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/y)	295	270	307	270	270	225	240	240	225	240	225	240	225
Water Consumption (gal/cycle)	4.25	3.50	5.00	3.50	3.50	2.40	3.20	3.20	2.40	3.20	2.40	3.20	2.40
Water Heating Energy Use (kWh/y)[1]	154	125	176	123	123	84	112	123	84	123	84	123	84
Average Life (y)	15	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)	440	380	310	340	340	500	430	340	500	340	500	340	500
Total Installed Cost (2022$)	840	570	490	520	520	690	610	520	690	520	690	520	690
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-		-	-	-	-	-	-

1. Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
2. Maintenance costs are negligible.

Note:
All values in table reflect 215 cycles/year according to the current test procedure at 10 CFR 430 Appendix C1.
The current standard went into effect in May 2013.
ENERGY STAR V. 6.0 went into effect in January 2016.
ENERGY STAR V. 7.0 will go into effect in July 2023.
Average life is determined using a Weibull distribution characterized by the following scale (α), shape (β), and delay (θ) parameters: (15.9, 1.8, 1).

Residential Dishwashers

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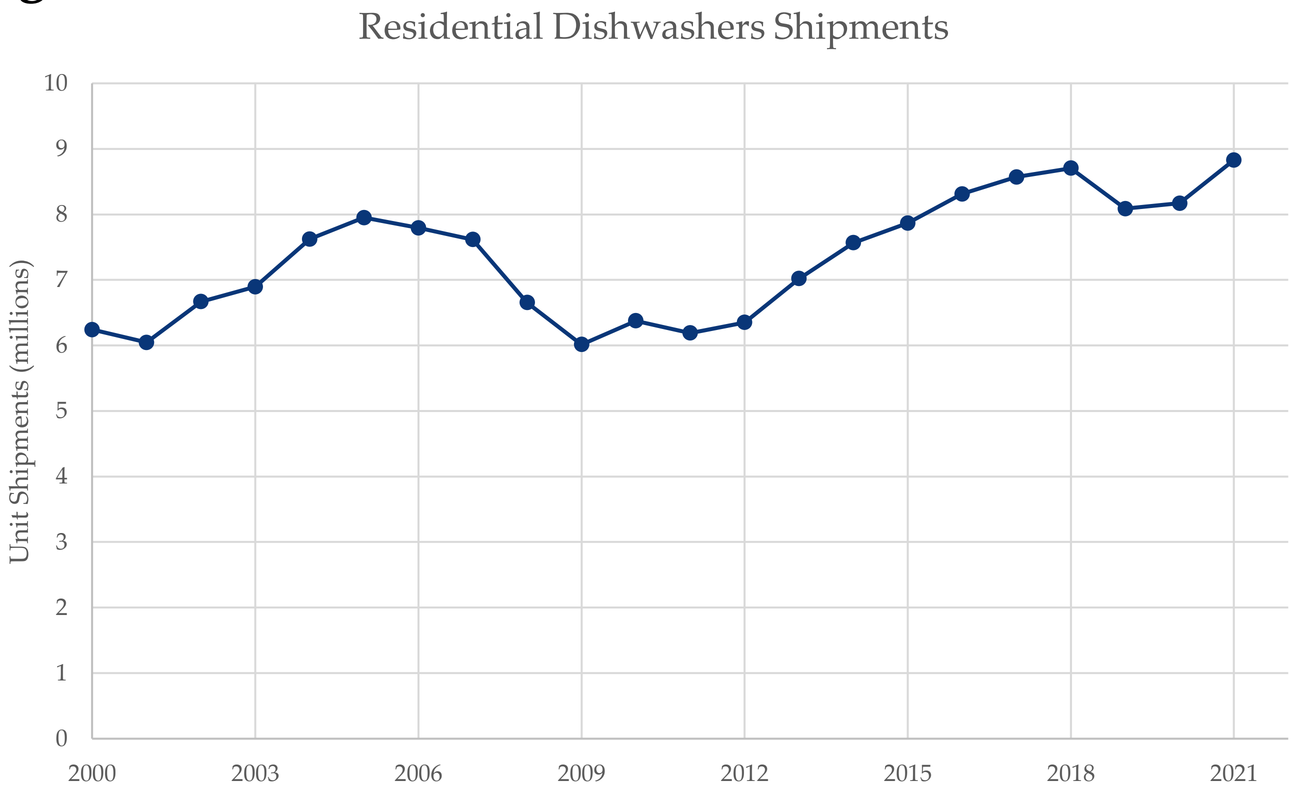
- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year):
  - Federal Standards:
    - May 30, 2013: ≤ 307 kWh/y, ≤ 5.0 gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Jan. 29, 2016: ≤ 270 kWh/y (5% allowance for connected), ≤ 3.5 gal/cycle (V. 6.0)
    - July 19, 2023: ≤ 240 kWh/y, ≤ 3.2 gal/cycle (V. 7.0, effective August 2023)
- ENERGY STAR has maintained a very high market share for several years (93% in 2021), so sales-weighted average efficiency has tracked ENERGY STAR levels.
  - Due to the historically high market penetration of ENERGY STAR products, it is expected that manufacturers will make the necessary adjustments so ENERGY STAR V. 7.0 levels will be typical in future projections.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater, as well as standby and off-mode energy.
  - ENERGY STAR established a cleaning performance test method. While cleaning performance reporting is currently optional, V. 7.0 requires a cleaning index of 65 or higher for ENERGY STAR certification.
  - In January 2023, DOE established a test procedure at Appendix C2, which would go into effect at the time of any amended energy conservation standards. Appendix C2 establishes a minimum cleaning index threshold of 70 as a condition for a valid test cycle. The cleaning index threshold of 70 established by DOE is equivalent to the cleaning index threshold of 65 specified in ENERGY STAR V. 7.0.
- Efficiency improvement technologies for dishwashers include:
  - Better soil sensing
  - Control strategies
  - Water distribution (small pipes, fine filter, small sump, multiple spray arms, alternating water use) and controls (flow meter, temperature sensor)
  - Inline water heater (to minimize sump volume)
  - Separate drain pump, high-efficiency, variable-speed circulation pump motor
  - Condensation drying (rather than power dry)

Shipments increased steadily from the early 1990s until the 2008-2009 recession. Shipments have resumed similar growth since then.



Source: *DW EERE 2022 Preliminary Analysis*

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Commercial Space Heating and Cooling

Commercial Gas-Fired Furnaces

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High thermal efficiency increase is possible with increased costs.

DATA	2012	2018	2022			2023[1]		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)[2]	400	400	250	250	250	250	250	250	250	250
Thermal Efficiency (%)[3]	80	80	80	81	81	81	81	95	81	95
Typical Output Capacity (kBtu/h)	320	320	200	203	203	203	203	238	203	238
Average Life (y)	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost (2022$)	1,230	1,230	1,230	1,260	1,260	1,260	1,260	3,340	1,260	3,340
Total Installed Cost (2022$)	2,540	2,540	2,540	2,580	2,580	2,580	2,580	5,230	2,580	5,230
Total Installed Cost (2022$/kBtu/h)	6	6	10	10	10	10	10	21	10	21
Annual Maintenance Cost (2022$)	200	200	200	200	200	200	200	210	200	210
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1	1	1	1

1. In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces (CWAF) took effect. These projections reflect the 2023 minimum thermal efficiency requirement for gas-fired furnaces, 81%.
2. When this analysis was previously conducted in EIA Technology Forecast Updates (2018), a typical input capacity of 400 kBtu/h was listed. An updated typical input capacity value of 250 kBtu/h was determined through an evaluation of the units in the DOE CCD as of August 2022. CWAF EERE 2015 also listed a representative input capacity of 250 kBtu/h.
3. DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Note:
The previous standard went into effect in January 1994. The current standard went into effect in January 2023.

Commercial Gas-Fired Furnaces

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- Until 2022, the Federal standard required minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applied to all units manufactured on or after January 1, 1994, with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increased to 81% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial furnaces are typically non-condensing with thermal efficiencies ranging from 80% to 81%. Condensing commercial furnaces, which can achieve up to 95% thermal efficiency, were previously introduced to the market but are not currently available due to cost and reliability concerns. The highest thermal efficiency included in DOE's CCD at this time is 81%.
- Besides capacity, commercial units can differ from residential furnaces in terms of the control system (i.e., integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- Advanced Case: Increased high efficiencies are feasible due to market incentives to re-introduce condensing commercial gas-fired furnaces through additional investment, research, and development. No significant changes otherwise.

Commercial Gas-Fired Furnaces

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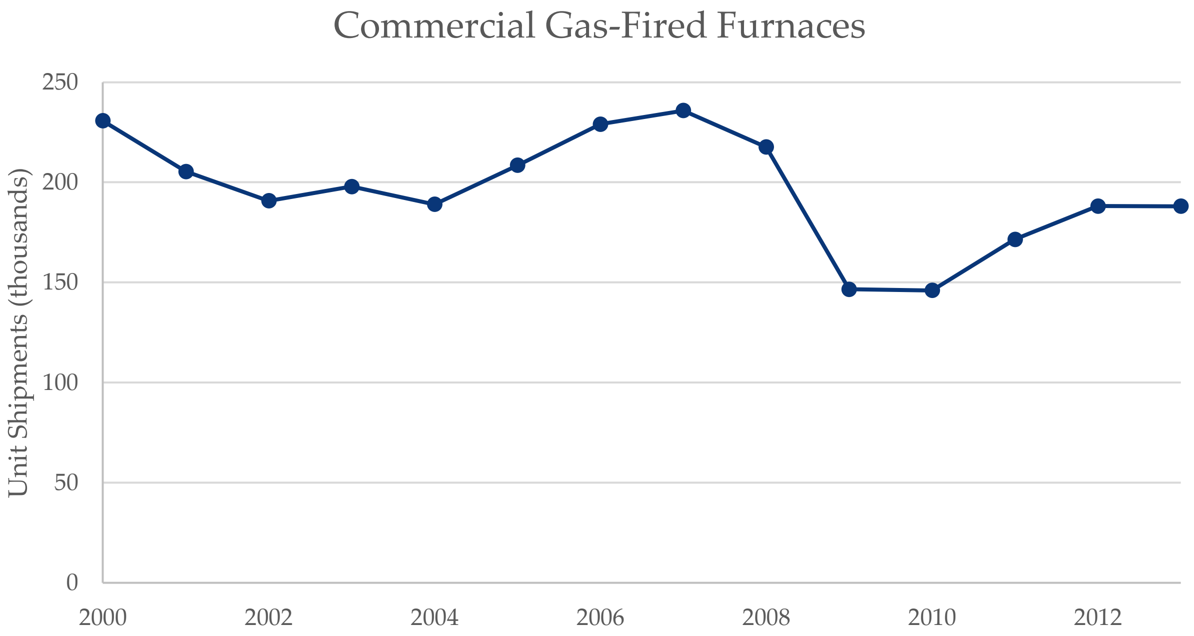
Annual shipments reached a peak of 235.9 thousand units in 2007. Following a decline in shipments after 2007, shipments increased to 188.1 thousand units in 2013. Shipment data after 2013 is not available.



Source: *AHRI*

Commercial Oil-Fired Furnaces

Final

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Same as Reference Case

DATA	2012	2018	2022			2023[1]	2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	250	250	250	250	250	250	250	250	250	250
Thermal Efficiency (%)[2]	81	82	81	82	85	82	82	85	82	85	82	85
Typical Output Capacity (kBtu/h)	324	328	203	205	213	205	205	213	205	213	205	213
Average Life (y)	23	23	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost (2022$)	5,500	5,560	5,500	5,560	6,020	5,560	5,560	6,020	5,560	6,020	5,560	6,020
Total Installed Cost (2022$)	7,740	7,810	7,740	7,810	8,380	7,810	7,810	8,380	7,810	8,380	7,810	8,380
Total Installed Cost (2022$/kBtu/h)	24	24	38	38	39	38	38	39	38	39	38	39
Annual Maintenance Cost (2022$)	360	360	360	360	370	360	360	370	360	370	360	370
Annual Maintenance Cost (2022$/kBtu/h)	1	1	2	2	2	2	2	2	2	2	2	2

1. In 2023, the new Energy Conservation Standards for CWAF took effect. These projections reflect the 2023 minimum thermal efficiency requirement for oil-fired furnaces, 82%.
2. DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.

Note:
The previous standard went into effect in January 1994. The current standard went into effect in January 2023.

Commercial Oil-Fired Furnaces

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- Until 2022, the Federal standard required minimum 81% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applied to all units manufactured on or after January 1, 1994, with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increased to 82% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial oil-fired furnaces have thermal efficiencies ranging from 81% to 85% and are non-condensing (i.e., not designed for condensation of flue gases).
- Besides capacity, commercial units can differ in terms of the control system (i.e., integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Commercial Oil-Fired Furnaces

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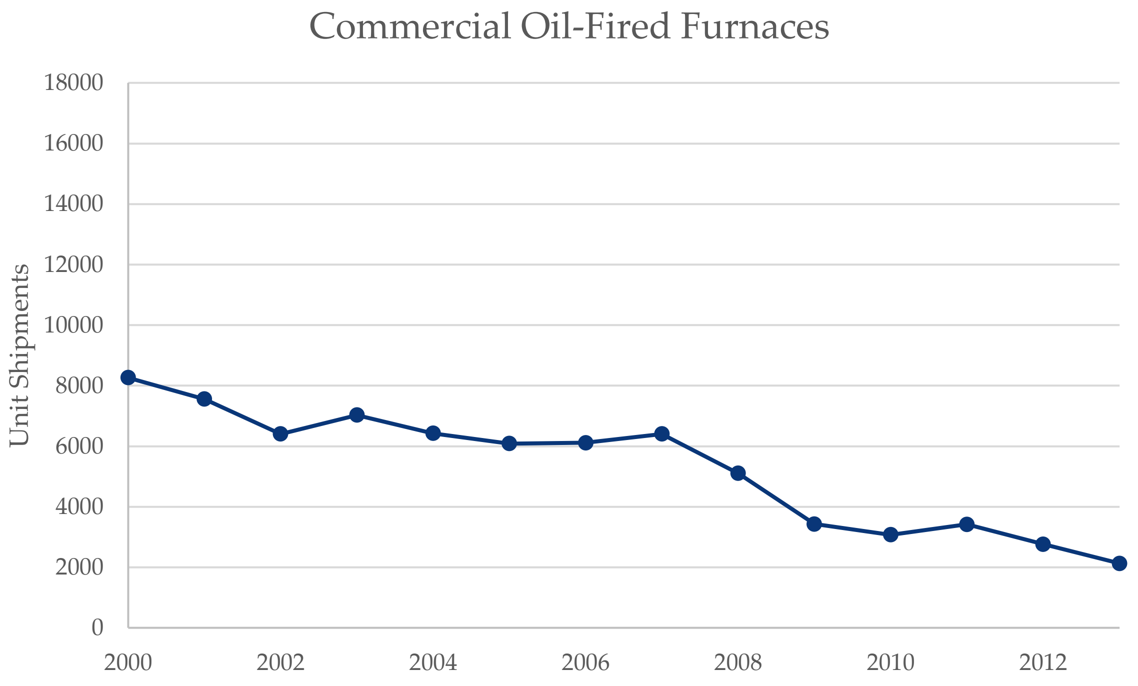
Annual shipments for commercial oil-fired furnaces have steadily decreased over time to 2,127 units in 2013. Shipment data after 2013 is not available.



Source: *AHRI*

Commercial Electric Resistance Heaters

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Same as Reference Case

DATA	2012		2018		2022		2030		2040		2050	
	Installed Base: Small	Installed Base: Large	Installed Base: Small	Installed Base: Large	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBtu/h)[1]	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	100	100	100	100	100	100	100	100	100	100	100	100
Average Life (y)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2022$)	1,000	6,320	1,000	6,320	500	4,630	500	4,630	500	4,630	500	4,630
Total Installed Cost (2022$)	1,240	7,470	1,240	7,470	660	5,470	660	5,470	660	5,470	660	5,470
Total Installed Cost (2022$/kBtu/h)	73	44	73	44	39	32	39	32	39	32	39	32
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-	-	-	-	-	-	-
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-	-	-	-	-	-	-

1. Capacity is output.
2. Annual Maintenance Cost is negligible.

Commercial Electric Resistance Heaters

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- This analysis examined standard suspended electric wall and ceiling unit heaters, which are more common in commercial settings than baseboard electric heaters that were considered for the residential analysis.
- Electric unit heaters range in capacity from 2 to 100 kW (7 to 340 kBtu/h), with 5 to 50 kW (17 to 170 kBtu/h) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion.
- Installation time and costs are estimated to be minimal.

Commercial Electric Boilers

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Same as Reference Case

DATA	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (kW)[1]	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (y)	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	11,620	11,590	9,790	9,790	9,790	9,790
Total Installed Cost (2022$)[2]	17,500	13,820	11,950	11,950	11,950	11,950
Total Installed Cost (2022$/kBtu/h)	31	25	21	21	21	21
Annual Maintenance Cost (2022$)[2]	170	130	130	130	130	130
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-

1. Capacity is output.
2. Retail and installed costs for 2022 and forecasts for 2030 and beyond are based on Gordian's RSMeans Data – Building Construction Costs 2023. Maintenance costs are same as EIA Technology Forecast Updates (2018), updated to reflect 2022$. The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/h. Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.

Commercial Electric Boilers

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- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/h.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkalizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Commercial Gas-Fired Boilers

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Higher typical efficiencies with corresponding cost increases

DATA	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard[1]	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)[2]	77	85	80	85	99	84	85	99	93	99	95	99	95	99
Average Life (y)	30	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	15,530	25,910	19,150	25,910	42,670	24,320	25,910	42,670	37,860	42,670	38,950	42,670	38,950	42,670
Total Installed Cost (2022$)	24,600	38,330	30,470	38,330	55,230	35,650	38,330	55,230	50,410	55,230	51,510	55,230	51,510	55,230
Total Installed Cost (2022$/kBtu/h)	40	56	48	56	70	53	56	70	68	70	68	70	68	70
Annual Maintenance Cost (2022$)[3]	1,710	2,100	2,100	2,100	2,140	2,100	2,100	2,140	2,140	2,140	2,140	2,140	2,140	2,140
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3	3	3	3

1. The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) gas-fired hot water commercial packaged boilers, which are the most common type of boilers available on the market.
2. DOE's efficiency metric for most boiler types accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead, for hot water boilers with heat input > 2,500,000 Btu/h.
3. Maintenance costs for 2018 and post-2018 are based on Commercial Packaged Boilers EERE 2020. The annualized maintenance costs estimated in the final rule differ for condensing vs. non-condensing boilers. Appendix 8E of the Commercial Packaged Boilers EERE 2020 TSD provides additional information on how the values are calculated.

Note:
The previous standard went into effect in March 2012.
The current standard went into effect in January 2023.
In December 2016, DOE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. This rule published in January 2020 with an effective date for January 2023.

Commercial Gas-Fired Boilers

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- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not) – for steam boilers
- The most common type of commercial gas-fired boilers are small gas-fired hot water boilers with 300,000-2,500,000 Btu/h rated heat input.
- Similar technologies to those used in the residential gas-fired boilers market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. Some gas-fired boilers also condense water vapor from the flue gases to improve heating efficiency.
- DOE published a final rule for commercial packaged boilers in January 2020 that updated the efficiency ratings of gas-fired commercial packaged boilers beginning January 2023.
- Advanced Case: Condensing gas-fired boilers are expected to dominate the market by 2030, with corresponding price increases.

Commercial Gas-Fired Boilers

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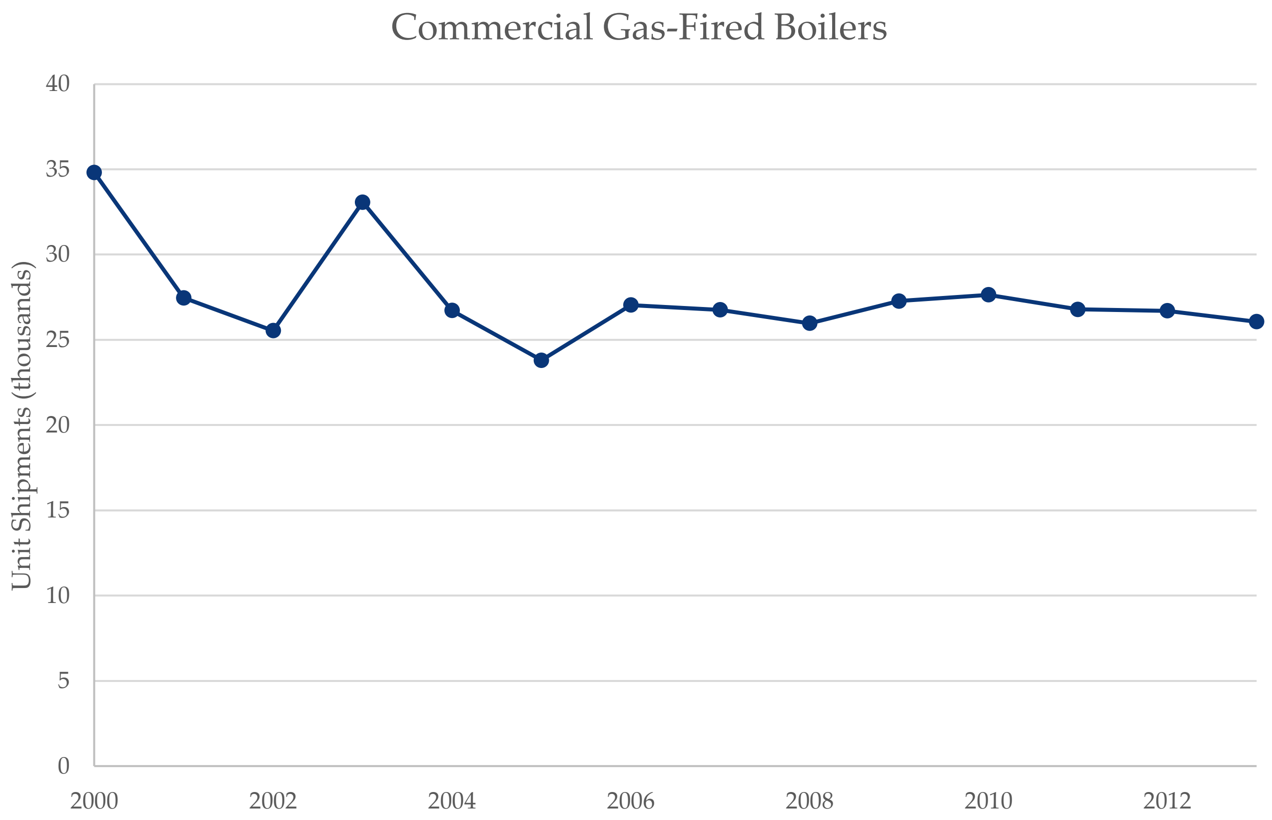
Shipments of commercial gas-fired boilers peaked in 2000 and have been steadily declining since 2010. Shipment data after 2013 is not available.



Source: *Commercial Packaged Boilers EERE 2020*

Commercial Oil-Fired Boilers

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard[1]	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)[2]	81	85	82	85	97	87	87	97	92	97	92	97	92	97
Average Life (y)	30	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)	16,830	26,810	23,190	26,810	51,480	29,730	29,730	51,480	29,730	51,480	29,730	51,480	29,730	51,480
Total Installed Cost (2022$)	22,000	37,240	33,100	37,240	62,910	40,160	40,160	62,910	40,160	62,910	40,160	62,910	40,160	62,910
Total Installed Cost (2022$/kBtu/h)	23	55	50	55	81	58	58	81	55	81	55	81	55	81
Annual Maintenance Cost (2022$)[3]	1,710	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690	2,690
Annual Maintenance Cost (2022$/kBtu/h)	2	4	4	4	3	4	4	3	4	3	4	3	4	3

1. The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) oil-fired hot water commercial packaged boilers, which are the most common type of boilers available on the market.
2. DOE's efficiency metric for most boiler types accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead, for hot water boilers with heat input > 2,500,000 Btu/h.
3. Maintenance costs for 2018 and post-2018 are based on Commercial Packaged Boilers EERE 2020. The annualized maintenance costs estimated in the final rule differ for condensing vs. non-condensing boilers. Appendix 8E of the Commercial Packaged Boilers EERE 2020 TSD provides additional information on how the values are calculated.

Note:

The previous standard went into effect in March 2012.

The current standard went into effect in January 2023.

In December 2016, DOE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. This rule published in January 2020 with an effective date for January 2023.

Commercial Oil-Fired Boilers

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- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- The most common type of commercial oil-fired boilers are small hot water boilers with 300,000-2,500,000 Btu/h rated heat input.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- DOE published a final rule for commercial packaged boilers in January 2020 that updated the efficiency ratings of oil-fired commercial packaged boilers beginning January 2023.
- Advanced Case: Increased adoption of condensing oil-fired boilers by 2030. However, due to low demand and a shrinking market, costs are expected to remain the same.

Commercial Oil-Fired Boilers

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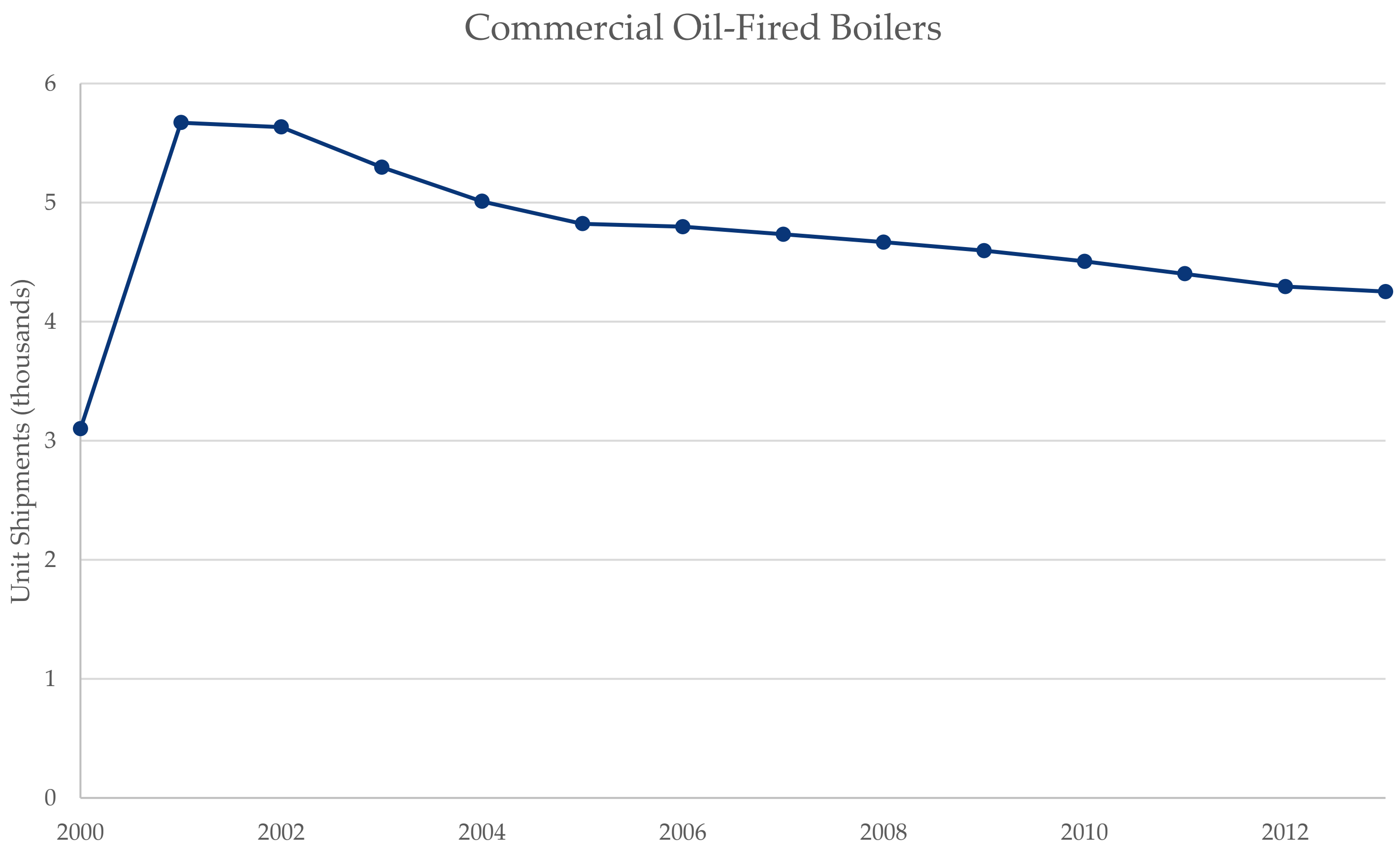
Shipments of commercial oil-fired boilers peaked in 2001 and have been decreasing since then.



Source: *Commercial Packaged Boilers EERE 2020*

Commercial Centrifugal Chillers (Water-Cooled)

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022[2]			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[1]	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)	0.66	0.53	0.56	0.52	0.45	0.48	0.42	0.45	0.41	0.44	0.40
Efficiency [IPLV] (kW/ton)	0.61	0.37	0.50	0.31	0.30	0.30	0.28	0.29	0.26	0.28	0.25
COP [full-load]	5.4	6.6	6.3	6.8	7.8	7.3	8.4	7.8	8.6	8.0	8.8
COP [IPLV]	5.9	9.5	7.0	11.3	11.7	11.7	12.6	12.1	13.5	12.6	14.1
Average Life (y)	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$/ton)	380	500	480	500	680	590	760	660	780	690	810
Total Installed Cost (2022$/ton)	440	560	480	560	740	640	820	720	840	740	870
	500	590	540	590	760	670	830	740	860	760	880
Total Installed Cost (2022$/kBtu/h)	39	48	43	48	63	55	69	61	71	63	73
Annual Maintenance Cost (2022$/ton)	30	30	30	30	30	30	30	30	30	30	30
	40	40	40	40	40	40	40	40	40	40	40
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. Capacity is output.
2. ASHRAE 90.1 data are for units larger than 400 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019). Typical and high efficiency levels are determined based on the range of products currently available on the market.

Note:

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the integrated part-load value (IPLV)) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

Ranges represent the span of typical values for a given parameter.

Commercial Centrifugal Chillers (Water-Cooled)

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- ASHRAE 90.1-2019 stipulates minimum efficiencies for centrifugal chillers separately from positive displacement water-cooled chillers. They are separated into 5 size categories, with categories divided at: 150, 300, 400, and 600 tons; ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly high full-load consumption in exchange for much lower part-load consumption. For example, for a 600-ton unit:
  - Path A: ≥ 0.56 kW/ton full-load and ≥ 0.50 kW/ton IPLV
  - Path B: ≥ 0.585 kW/ton full-load and ≥ 38 kW/ton IPLV
- Federal Energy Management Program (FEMP) recommendations, last updated in 2020, match ASHRAE 90.1-2019.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e.g., crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.
- Water-cooled chiller ratings do not include energy consumption of the cooling tower and therefore are not directly comparable to rating for air-cooled chillers. Water-cooled centrifugal chillers were selected for analysis due to a higher model share on the AHRI directory in comparison to air-cooled chillers.
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Reciprocating Chillers (Air-Cooled Only)

Final

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Same as Reference Case

DATA	2012	2018	2022[2]			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[1]	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)	1.26	1.19	1.19	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)	1.13	0.86	0.86	0.86	0.80	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load]	2.8	3.0	3.0	3.0	3.5	3.1	3.5	3.1	3.5	3.1	3.5
COP [IPLV]	3.1	4.1	4.1	4.1	4.5	4.4	4.5	4.4	4.5	4.4	4.5
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	725	820	820	820	1,030	820	1,030	820	1,030	820	1,030
	600	730	730	730	880	730	880	730	880	730	880
Total Installed Cost (2022$/ton)	800	880	880	880	1,180	880	1,180	880	1,180	880	1,180
	700	760	760	760	1,090	760	1,090	760	1,090	760	1,090
Total Installed Cost (2022$/kBtu/h)	63	68	68	68	95	68	95	68	95	68	95
Annual Maintenance Cost (2022$/ton)	45	45	50	50	50	45	50	45	50	45	50
	25	25	30	30	30	25	30	25	30	25	30
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. Capacity is output.
2. ASHRAE 90.1 data are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019). Typical and high efficiency levels are determined based on the range of products currently available on the market.

Note:

This analysis covers air-cooled chillers only.

For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.

ASHRAE 90.1 went into effect in October 2019.

Ranges represent the span of typical values for a given parameter.

Commercial Reciprocating Chillers (Air-Cooled Only)

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- Reciprocating chillers are most cost effective for small loads (30 to 150-ton range). However, reciprocating chiller market share continues to be supplanted by screw and scroll chillers. This trend has accelerated with the phase out of R-22, which was the refrigerant of choice for reciprocating products, which has in turn driven major manufacturers to replace their reciprocating product lines with scroll products (rather than redesign reciprocating products for new refrigerants). As a result, product options are very limited.
- Reciprocating chillers can be used in either air-cooled or water-cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including reciprocating chillers, while water-cooled chillers are separated by positive displacement (e.g., reciprocating) versus centrifugal models. Air-cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 13.7 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 15.8 IPLV EER
- FEMP (2022) recommendations for air-cooled chillers are:
  - Path A (<150 tons): ≥ 10.89 EER full-load and ≥ 13.7 IPLV EER
  - Path B (<150 tons): ≥ 9.7 EER full-load and ≥ 16.86 IPLV EER (same as 90.1-2019)
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Commercial Screw Chillers (Air-Cooled Only)

Final

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019[1]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)	1.26	1.18	1.19	1.15	0.92	1.11	0.91	0.99	0.86	0.93	0.77
Efficiency [IPLV] (kW/ton)	1.13	0.84	0.86	0.81	0.55	0.77	0.53	0.65	0.49	0.61	0.43
COP [full-load]	2.8	3.0	3.0	3.1	3.8	3.2	3.9	3.6	4.1	3.8	4.6
COP [IPLV]	3.1	4.2	4.1	4.4	6.4	4.5	6.6	5.4	7.2	5.7	8.2
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	760	970	1,130	1,130	1,230	1,140	1,230	1,180	1,250	1,200	1,270
	620	850	770	770	870	780	870	820	890	840	910
Total Installed Cost (2022$/ton)	910	1,150	1,250	1,250	1,350	1,260	1,350	1,300	1,370	1,320	1,390
	850	940	820	820	920	830	920	870	940	890	960
Total Installed Cost (2022$/kBtu/h)	73	87	86	86	95	87	95	90	96	92	98
Annual Maintenance Cost (2022$/ton)	50	50	50	50	50	50	50	50	50	50	50
	20	20	20	20	20	20	20	20	20	20	20
Annual Maintenance Cost (2022$/kBtu/h)	3	3	3	3	3	3	3	3	3	3	3

1. ASHRAE 90.1 data for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019).

Note:
For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.
ASHRAE 90.1 went into effect in October 2019.
Ranges represent the span of typical values for a given parameter.

Commercial Screw Chillers (Air-Cooled Only)

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- Screw chillers are common in 150 to 500-ton capacities but are most cost effective for small (<300 tons) loads; screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water-cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including screw chillers, while water-cooled chillers are separated by positive displacement (e.g., screw) versus centrifugal models. Air-cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a ≥ 150-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 14.0 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 16.1 IPLV EER
- FEMP recommendations for air-cooled chillers (updated June 2020) are:
  - Path A (≥ 150 tons): ≥ 10.7 EER full-load and ≥ 14.0 IPLV EER
  - Path B (≥ 150 tons): ≥ 9.7 EER full-load and ≥ 16.4 IPLV EER
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Scroll Chillers (Air-Cooled Only)

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Higher typical efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	ASHRAE 90.1-2019[1]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)	50	50	50	50	50	50	50	50	50	50	50
	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)	1.23	1.16	1.19	1.15	1.07	1.08	1.03	1.04	0.99	0.99	0.94
Efficiency [IPLV] (kW/ton)	0.99	0.77	0.88	0.77	0.70	0.71	0.66	0.69	0.63	0.67	0.60
COP [full-load]	2.9	3.0	3.0	3.1	3.3	3.3	3.4	3.4	3.6	3.6	3.7
COP [IPLV]	3.7	4.6	4.0	4.6	5.0	5.0	5.3	5.1	5.6	5.3	5.8
Average Life (y)	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$/ton)	680	1,000	1,060	1,060	1,160	1,120	1,160	1,150	1,200	1,200	1,240
	560	820	530	530	630	590	630	620	670	670	710
Total Installed Cost (2022$/ton)	970	1,210	1,170	1,170	1,270	1,230	1,270	1,260	1,310	1,310	1,350
	850	970	860	860	960	920	960	950	1,000	1,000	1,040
Total Installed Cost (2022$/kBtu/h)	76	91	85	85	93	90	93	92	96	96	100
Annual Maintenance Cost (2022$/ton)	60	60	60	60	60	60	60	60	60	60	60
	40	40	40	40	40	40	40	40	40	40	40
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4

1. ASHRAE 90.1 data for units less than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2019).

Note:
For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.
ASHRAE 90.1 went into effect in October 2019.
Ranges represent the span of typical values for a given parameter.

Commercial Scroll Chillers (Air-Cooled Only)

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- Scroll chillers range in size from ~20 tons to ~200 tons and can be used in either air-cooled or water-cooled applications. They are the most common type of chiller for small chiller plants. The scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2019 stipulates minimum efficiencies for all air-cooled chillers together, including scroll chillers, while water-cooled chillers are separated by positive displacement (e.g., scroll) versus centrifugal models. Air-cooled chiller efficiencies are distinct for more and less than 150 tons. ASHRAE 90.1-2019 also distinguishes between whether the unit will be optimized for full-load (Path A) or part-load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100-ton unit:
  - Path A: ≥ 10.1 EER full-load and ≥ 13.7 IPLV EER
  - Path B: ≥ 9.7 EER full-load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated June 2020) are:
  - Path A (< 150 tons): ≥ 10.7 EER full-load and ≥ 13.7 IPLV EER
  - Path B (< 150 tons): ≥ 9.7 EER full-load and ≥ 15.9 IPLV EER
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers
  - Variable speed compressor (or other modulation controls)
- With the phase out of R-22, manufacturers have replaced many of their small reciprocating chiller products with equivalent scroll products, making them a primary choice for small tonnage applications.
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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Same as Reference Case

DATA	2012		2018		2022				2030		2040		2050	
	Installed Base: Absorption	Installed Base: Engine-Driven	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1-2019 Absorption	CA Title 24 – Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
Typical Capacity (tons)[1]	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP [full-load]	1.1	1.7	1.2	1.7	1.0	1.2	1.2	1.7	1.3	1.8	1.4	1.8	1.4	1.8
COP [IPLV]	NA	NA	1.6	2.6	1.0	2.0	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6
Average Life (y)	23	25	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost (2022$/ton)	1,060	1,000	1,060	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000
	880	880	880	880	870	880	870	880	870	880	870	880	870	880
Total Installed Cost (2022$/ton)	1,290	1,240	1,180	1,240	1,110	1,240	1,110	1,240	1,110	1,240	1,110	1,240	1,110	1,240
	1,000	1,000	1,000	1,000	850	1,000	850	1,000	850	1,000	850	1,000	850	1,000
Total Installed Cost (2022$/kBtu/h)	95	93	91	93	82	93	82	93	82	93	82	93	82	93
Annual Maintenance Cost (2022$/ton)	40	60	40	60	40	60	40	60	40	60	40	60	40	60
	20	40	20	40	20	40	20	40	20	40	20	40	20	40
Annual Maintenance Cost (2022$/kBtu/h)	3	4	3	4	3	4	3	4	3	4	3	4	3	4

1. Capacity is output.

Note:
This analysis assumes a water-cooled chiller; both gas-fired chiller types (absorption and engine-driven) are shown. COP values for double-effect absorption chillers are shown.
For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications), the seasonal performance (represented by the IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full-load, are well represented by the full-load efficiency value.
ASHRAE 90.1 went into effect in October 2019.
CA Title 24 went into effect in January 2020.
Ranges represent the span of typical values for a given parameter.

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis covers only water-cooled chillers of two varieties: absorption and engine-driven vapor compression (direct-fired only; indirect steam or hot water driven units are excluded).
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect systems. Triple effect chillers, though not commercially available, can boost cooling COP 30-50% beyond double effect chillers. Some companies have worked on prototype direct-fired triple effect absorption chillers, but prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers suggests that this technology will not likely have an impact on the market in the near-term.
- Gas-fired engine-driven chillers pair conventional vapor compression systems (typically screw or centrifugal compressors) with natural gas powered-reciprocating engines. They exhibit higher peak cooling COP than absorbers, and engine modulation results in better part-load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine-driven chillers allow the opportunity to recover waste heat for useful purposes.
- Maintenance costs for engine-driven chillers are higher than for other chillers because they include all the typical components of a vapor compression chiller in addition to an engine; the engine maintenance costs vary depending on the annual run hours of the unit.
- Limited sales data suggest that the U.S. market for gas-fired chillers is very limited and is mostly for replacement units, not for new installations. Recent increases in electric chiller efficiency have narrowed the operating cost differential with gas chillers. Asia has the majority of the global gas-fired chiller market.
- Gas-fired chiller installations are particularly valuable in locations where electric rates are high and gas prices are low (i.e., low spark spread), where digester or landfill gas sources are available, or where waste heat sources are available (e.g., an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Commercial Rooftop Air Conditioners

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Higher efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022[4]				2023				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.1	High	New Standard	Typical	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Part Load Efficiency (IEER)[1]	12.4	12.9	12.9	12.9	14.0	23.3	14.8	14.8	18.0	23.3	16.0	23.3	16.5	23.3	17.5	23.3
Efficiency (EER)[2]	10.6	11.5	11.5	11.5	12.2	12.8	12.2	12.2	12.7	12.8	12.6	12.8	12.6	12.8	12.7	12.8
Efficiency Conversion	3.6	3.8	3.8	3.8	4.1	6.8	4.3	4.3	5.3	6.8	4.7	6.8	4.8	6.8	5.1	6.8
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	7,760	8,280	8,280	8,280	9,090	12,210	9,490	9,490	10,340	12,210	9,590	12,210	9,590	12,210	9,590	12,210
Total Installed Cost (2022$)	10,350	11,870	11,870	11,870	13,020	17,600	13,560	13,560	14,970	17,600	13,720	17,600	13,720	17,600	13,720	17,600
Total Installed Cost (2022$/kBtu/h)	115	132	132	132	145	196	151	151	166	196	152	196	152	196	152	196
Annual Maintenance Cost (2022$)[3]	370	370	370	370	370	370	370	370	370	370	370	370	370	370	370	370
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

1. Values shown are for air-cooled small commercial packaged air conditioners with either electric resistance heating or no heating within the same enclosure. DOE published a direct final rule for commercial packaged air conditioners and heat pumps in January 2016 with initial standards becoming effective in 2018 and additional standards becoming effective in 2023. As part of this rulemaking, DOE changed the regulated metric from EER to integrated energy efficiency ratio (IEER).
2. DOE investigated the relationship between IEER and EER. Because the relationship between IEER and EER is weak, this analysis estimates EER values based on the average of the values seen at a given IEER.
3. Examples of annual maintenance services include, check tensions, condition, and alignment of belts and adjust as necessary; lubricate shaft and motor bearings; replace air filters; clean coils, drain pan and piping, blowers, fan motors as required; check refrigerant pressure and compressor oil level; etc.
4. The 2022 typical efficiency is based on the average IEER from DOE's CCD. The 2022 high efficiency is based on the most-efficient model in DOE's CCD, but costs are estimated based on the most efficient unit analyzed in CUAC EERE 2016, which had an IEER of 21.5.

Note:
EER is the ratio of the cooling capacity (in Btu/h) to the power input (in watts) and provides a measure of the efficiency of equipment operating at full load (i.e., 100 percent cooling capacity) in high-ambient-temperature conditions (i.e., 95 °F). IEER is a single number part-load efficiency based on weighting of EER at various load capacities. Efficiency Conversion is the conversion of IEER from a [(Btu/h)/W] metric to a metric in the same units.
The previous standard went into effect in January 2018. The current standard went into effect in January 2023.
ENERGY STAR V. 3.1 went into effect in January 2018. ENERGY STAR V. 4.0 went into effect in January 2023.

Commercial Rooftop Air Conditioners

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- Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2018 Min. IEER	Federal Standard Effective 1/1/2023 Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	12.9	14.8
	Any other type	12.7	14.6
Large (≥ 135 and < 240)	Electric resistance or none	12.4	14.2
	Any other type	12.2	14.0

- This analysis focused on small air-cooled commercial packaged rooftop air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- Amended standards in terms of IEER for all equipment classes took effect in January 2018. More stringent standards in terms of IEER for all equipment classes took effect in January 2023.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

Final

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Same as Reference Case

DATA	2012[1]	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (tons)	18	11	11	11	11	11
Heating COP	1.4	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.9	1.2	1.2	1.2	1.2	1.2
Average Life (y)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	3,350	2,820	3,710	3,710	3,710	3,710
Total Installed Cost ($/ton)	3,820	3,290	4,110	4,110	4,110	4,110
Total Installed Cost ($/kBtu/h)	318	274	343	343	343	343
Annual Maintenance Cost (2022$)	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	6	6	6	6	6	6

1. The 2012 typical capacity and cooling COP were estimated as a simple average between obsolete pre-2003 units and 2013 units, which first became available in 2010; this assumes that each vintage represents about half of the installed base.

Note:
Only one product was available in 2012; the market has grown slightly in years since. Typical capacity and COP for 2018 and later are averages of units available as of 2017.

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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- There are only a few gas-fired engine-driven rooftop units currently available in the U.S. market. The first unit was introduced in 2010. It is an 11-ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

Commercial Rooftop Heat Pumps

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Higher efficiencies with same costs as reference case despite increased efficiency

DATA	2012	2018	2022				2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.1	High	New Standard	ENERGY STAR V. 4.0	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Part Load Efficiency (IEER)[1]	12.0	11.3	12.2	14.3	12.8	20.3	14.1	15.3	20.3	14.4	20.3	15.3	20.3	15.3	20.3
EER	10.2	11.2	11.3	11.5	11.8	13.0	12.0	11.8	13.0	11.7	13.1	11.7	13.1	11.7	13.1
COP (Heating)	3.3	3.3	3.3	3.4	3.4	3.7	3.4	3.5	3.7	3.4	3.7	3.5	3.7	3.5	3.7
Average Life (y)	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	7,490	7,490	9,000	10,250	9,370	12,920	10,160	10,600	12,920	10,290	12,920	10,600	12,920	10,600	12,920
Total Installed Cost (2022$)	9,340	9,340	12,900	14,940	13,530	18,860	14,810	15,510	18,860	15,000	18,860	15,510	18,860	15,510	18,860
Total Installed Cost (2022$/kBtu/h)	104	104	143	166	150	210	165	172	210	167	210	172	210	172	210
Annual Maintenance Cost (2022$)	380	380	380	380	380	380	380	380	380	380	380	380	380	380	380
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

1. Values shown are for air-cooled small commercial packaged heat pumps with either electric resistance heating or no heating within the same enclosure. DOE published a direct final rule for commercial packaged air conditioners and heat pumps in January 2016 with initial standards becoming effective in 2018 and additional standards becoming effective in 2023. As part of this rulemaking, DOE changed the regulated metric from EER to IEER.

Note:

The previous standard went into effect in January 2018. The current standard went into effect in January 2023.

ENERGY STAR V. 3.1 went into effect in January 2018. ENERGY STAR V. 4.0 went into effect in January 2023.

Commercial Rooftop Heat Pumps

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- Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2018 Min. IEER	Federal Standard Effective 1/1/2023 Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	12.2	14.1
	Any other type	12.0	13.9
Large (≥ 135 and < 240)	Electric resistance or none	11.6	13.5
	Any other type	11.4	13.3

- This analysis focused on small air-cooled commercial packaged rooftop heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.
- Amended standards in terms of IEER for all equipment classes took effect in 2018. More stringent standards in terms of IEER for all equipment classes took effect in 2023.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Commercial Ground-Source Heat Pumps

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Same efficiencies with lower costs than reference case despite same efficiency

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)[1]	3.1	3.7	3.2	3.5	3.6	3.5	3.6	3.5	3.6	3.5	3.6
EER (Cooling)[2]	12.7	17.4	14.1	17.0	21.6	17.0	21.6	17.0	21.6	17.0	21.6
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2022$)	10,470	6,470	5,590	6,470	7,880	6,470	7,880	6,470	7,880	6,470	7,880
Total Installed Cost (2022$)	19,760	18,230	17,350	18,230	19,650	16,410	17,690	16,410	17,690	16,410	16,410
	44,820	26,520	25,580	26,520	27,880	23,870	25,090	23,870	25,090	23,870	23,870
Total Installed Cost (2022$/kBtu/h)	673	466	447	466	495	420	446	420	446	420	420
Annual Maintenance Cost (2022$)	180	180	180	180	180	180	180	180	180	180	180
Annual Maintenance Cost (2022$/kBtu/h)	4	4	4	4	4	4	4	4	4	4	4

1. COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.
2. EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note:
Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs. 4-ton) and slightly higher installation costs for commercial GSHP. DOE does not distinguish between residential and commercial units in its regulations.

Commercial Ground-Source Heat Pumps

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- The most common commercial ground-source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions require 77 °F entering water temperature and 80.6 °F entering air temperature. More typical peak design criteria would be 80-90 °F entering water temperature and 75 °F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part-load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR criteria for ground-source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed ECM fan motors also improve overall energy efficiency.
- Advanced Case: Ground-source heat pumps are already highly efficient and have not changed much in terms of efficiency in recent years. With increased R&D, it is anticipated that the equipment and installation costs will be reduced over time, but efficiency will likely stay the same.

Packaged Terminal Air Conditioners

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Same as Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High[2]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)[1]	9	9	9	9	9	9	9	9	9	9	9
Efficiency (EER)	11.3	11.3	11.3	11.3	13.1	11.3	13.1	11.3	13.1	11.3	13.1
Efficiency	3.3	3.3	3.3	3.3	3.8	3.3	3.8	3.3	3.8	3.3	3.8
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost (2022$)	1,460	1,460	1,460	1,460	1,560	1,460	1,560	1,460	1,560	1,460	1,560
Total Installed Cost (2022$)	1,740	1,740	1,740	1,740	1,840	1,740	1,840	1,740	1,840	1,740	1,840
Total Installed Cost (2022$/kBtu/h)	193	193	193	193	204	193	204	193	204	193	204
Annual Maintenance Cost (2022$)	70	70	70	70	70	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	8	8	8	8	8	8	8	8	8	8	8

1. Typical capacity is representative of units with the most shipments. It was also the representative cooling capacity for DOE's analysis in packaged terminal air conditioners (PTAC) and packaged terminal heat pumps (PTHP) EERE 2022 NOPD.
2. High values for 2022 and beyond are based on the max-tech level from PTAC & PTHP EERE 2022 NOPD.

Note:

The current standard went into effect in January 2017.

Packaged Terminal Air Conditioners

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- PTAC are a self-contained, ductless air conditioning system used for commercial applications.
- Analysis was conducted for the standard equipment class at the representative cooling capacity of 9000 Btu/h.

Cooling Capacity (kBtu/h)	Equipment Size	Equipment Class	Federal Standard EER
PTAC	Standard	< 7000	11.9
		≥7,000 Btu/h and ≤15,000 Btu/h	14.0 – (0.3 x Cap)
		> 15,000 Btu/h	9.5

Packaged Terminal Heat Pumps

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Higher efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical[2]	High[3]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)[1]	9	9	9	9	9	9	9	9	9	9	9
Efficiency (EER)	11.3	11.3	11.3	11.3	13.1	11.5	13.1	12.0	13.1	12.4	13.1
Efficiency	3.3	3.3	3.3	3.3	3.8	3.4	3.8	3.5	3.8	3.6	3.8
COP (Heating)	3.2	3.2	3.2	3.2	3.6	3.3	3.6	3.4	3.6	3.5	3.6
Average Life (y)	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost (2022$)	1,620	1,620	1,620	1,620	1,720	1,630	1,720	1,630	1,720	1,630	1,720
Total Installed Cost (2022$)	1,910	1,910	1,910	1,910	2,010	1,910	2,010	1,910	2,010	1,910	2,010
Total Installed Cost (2022$/kBtu/h)	212	212	212	212	223	212	223	212	223	212	223
Annual Maintenance Cost (2022$)	70	70	70	70	70	70	70	70	70	70	70
Annual Maintenance Cost (2022$/kBtu/h)	8	8	8	8	8	8	8	8	8	8	8

1. Typical capacity is representative of units with the most shipments. It was also the representative cooling capacity for DOE's analysis in PTAC & PTHP EERE 2022 NOPD.
2. Typical values for 2022 and beyond are based on the efficiency level that has the largest market share per PTAC & PTHP EERE 2022 NOPD.
3. High values for 2022 and beyond are based on the max-tech level from PTAC & PTHP EERE 2022 NOPD.

Note:
The current standard went into effect in October 2012.

Packaged Terminal Heat Pumps

- PTHP are self-contained heat pumps primarily used for commercial applications.
- Analysis was conducted for the standard equipment class at the representative cooling capacity of 9000 Btu/h.

Cooling Capacity (kBtu/h)	Equipment Size	Equipment Class	Federal Standard EER	Federal Standard COP
PTHP	Standard	< 7000	11.9	3.3
		≥7,000 Btu/h and ≤15,000 Btu/h	14.0 – (0.3 x Cap)	3.7 – (0.052 x Cap)
		> 15,000 Btu/h	9.5	2.9
PTHP	Non-Standard	< 7000	9.3	2.7
		≥7,000 Btu/h and ≤15,000 Btu/h	10.8 – (0.213 x Cap)	2.9 – (0.026 x Cap)
		> 15,000 Btu/h	7.6	2.5

- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

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Commercial Water Heating

Commercial Gas-Fired Storage Water Heaters

Final

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Same as Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199
Thermal Efficiency (%)[1]	81	82	80	82	94	99	95	99	95	99	95	99
Average Life (y)	13	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	3,870	3,890	3,850	3,890	4,180	4,290	4,200	4,290	4,200	4,290	4,200	4,290
	5,170	5,200	5,140	5,200	5,530	5,650	5,550	5,650	5,550	5,650	5,550	5,650
Total Installed Cost (2022$)	5,170	5,190	5,140	5,190	6,630	6,730	6,640	6,730	6,640	6,730	6,640	6,730
	8,440	8,460	8,410	8,460	8,590	8,710	8,610	8,710	8,610	8,710	8,610	8,710
Total Installed Cost (2022$/kBtu/h)	42	42	43	42	41	39	40	39	40	39	40	39
Annual Maintenance Cost (2022$)[2]	320	320	320	320	330	330	330	330	330	330	330	330
Annual Maintenance Cost (2022$/kBtu/h)	2	2	2	2	2	2	2	2	2	2	2	2

1. Different levels of standby loss were not included in this analysis.
2. Maintenance consists of sediment and scale removal once or twice per year and replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Note:
The current standard went into effect in October 2015.
ENERGY STAR V. 2.0 went into effect in October 2018.
The range of retail and installed costs represent the range from replacement market to new construction market.

Commercial Gas-Fired Storage Water Heaters

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- Input capacity > 155 kBtu/h and storage capacity ≤ 140 gal
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss (Btu/h): 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are typically constructed similarly to residential units, though with higher input capacities (and often higher storage volumes).
- High-efficiency units include condensing heat exchangers (typically stainless or enameled steel) to extract additional heat by condensing water vapor in flue gases. Condensing units also include an inducer fan system or power burner. The heat exchanger is typically contained within the tank, but some designs consist of an external heating module attached to a storage tank. Condensing units are expected to be the majority market share by 2030.
- Maintenance consists of sediment and scale removal once or twice per year and replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Commercial Gas-Fired Storage Water Heaters

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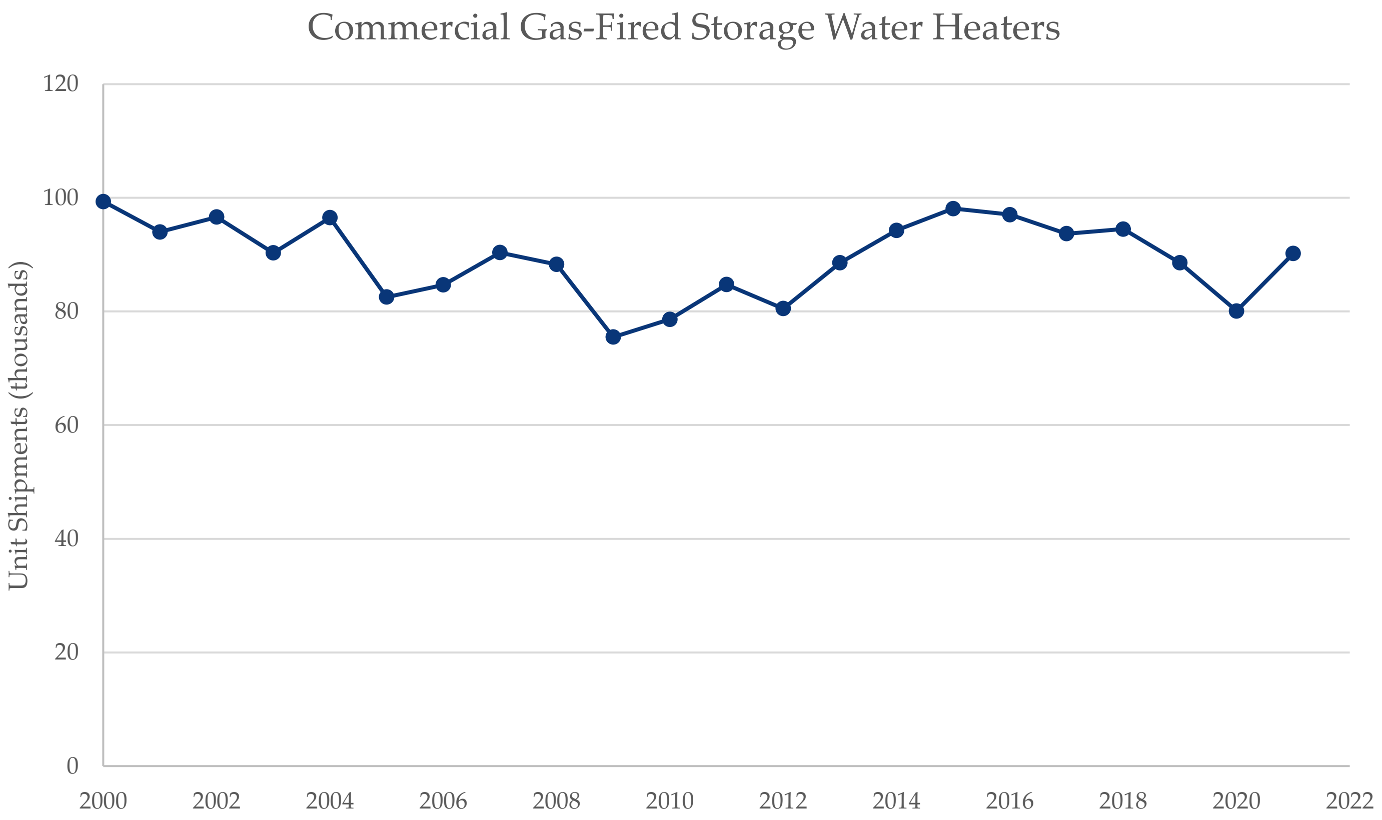
Annual shipments have fluctuated from 99,000 units in 2000 to 75,000 units in 2009, back to 99,000 units in 2015 and gradually decreasing since then until 2020.



Source: CWH EERE 2022 NOPR and AHRI

Commercial Electric Resistance Storage Water Heaters

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Same as Reference Case

DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	119	119	119	119	119	119	119
Typical Input Capacity (kW)[1]	18	18	18	18	18	18	18
Typical Input Capacity (kBtu/h)	60	60	60	60	60	60	60
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (y)	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)	3,180	3,180	3,180	3,180	3,180	3,180	3,180
	3,750	3,750	3,750	3,750	3,750	3,750	3,750
Total Installed Cost (2022$)	4,460	4,460	4,460	4,460	4,460	4,460	4,460
	4,690	4,690	4,690	4,690	4,690	4,690	4,690
Total Installed Cost (2022$/kBtu/h)	76	76	76	76	76	76	76
Annual Maintenance Cost (2022$)	50	50	50	50	50	50	50
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1

1. Different levels of standby loss were not included in this analysis.

Note:
No new standards rulemaking has been initiated for commercial electric resistance water heaters since CWH EERE 2016 NOPR. Accordingly, the results are the same as EIA Technology Forecast Updates (2018), updated to 2022$.
The range of retail equipment and installed costs represents the range from replacement market to new construction market.

Commercial Electric Resistance Storage Water Heaters

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- Federal standard:
  - Maximum standby loss (%/h) : 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units have an efficiency ≥ 98%
- Storage capacity: typically, 50 to 120 gallons, though smaller and larger units exist for specialized applications
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- There is very little variation in thermal efficiency on the market; variation in standby loss is typically due to tank design and insulation thickness.
- Maintenance consists of sediment and scale removal once or twice per year.

Commercial Electric Resistance Storage Water Heaters

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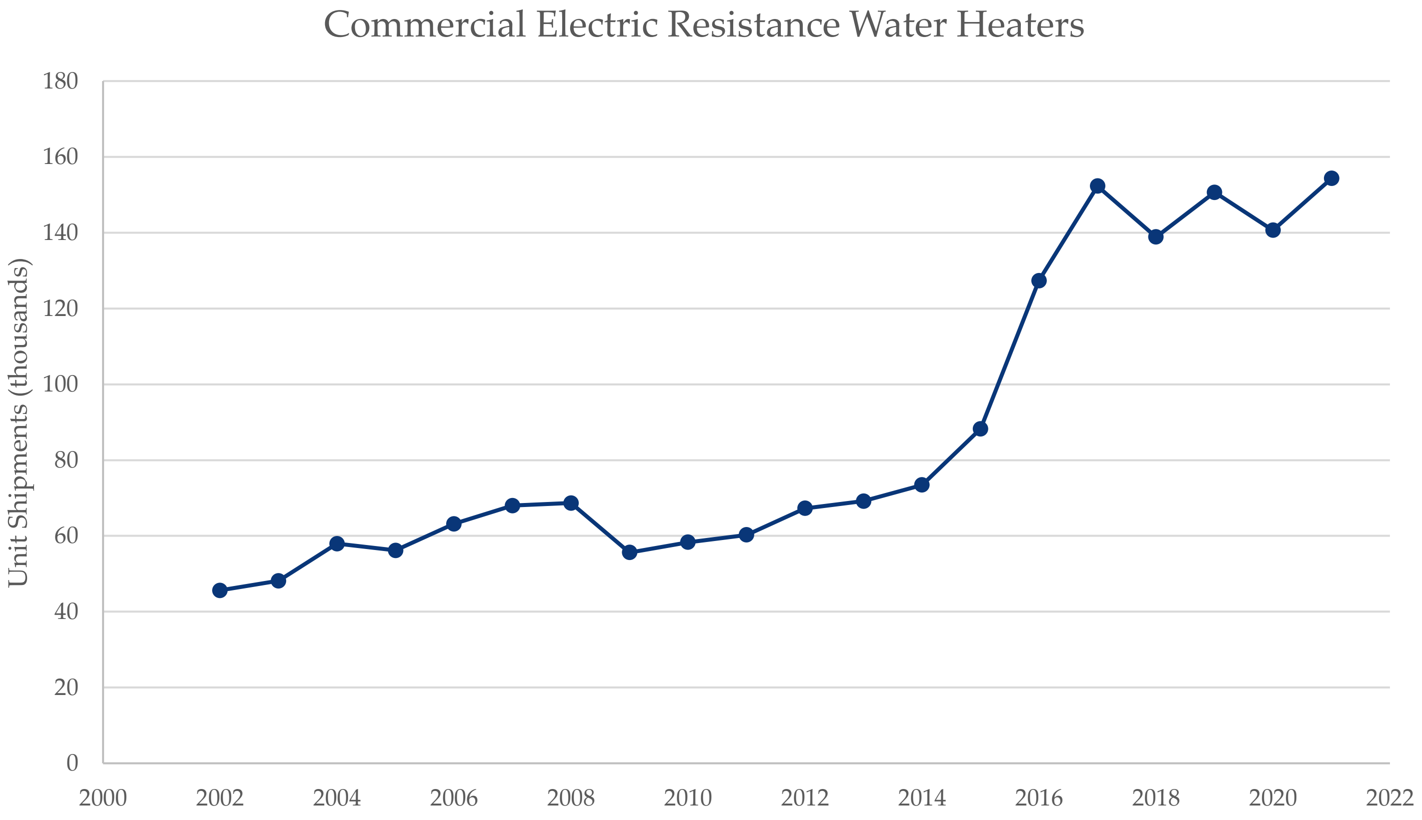
Annual shipments increased by almost 50% between 2002 and 2008. After a small dip in shipments in 2009, annual shipments have increased by about 173% between 2009 and 2017, stabilizing between 140-150 thousand shipments per year since then.



Source: *AHRI*

Commercial Heat Pump Water Heaters

Final

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Higher typical efficiencies with the same costs as reference case despite increased efficiency

DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.0	Typical	Typical	Typical
Water Flow Rate (gal/min)[1]	34	34	34	34	34	34	34
Typical Output Capacity (kW)[1]	50	50	50	50	50	50	50
Typical Output Capacity (kBtu/h)	171	171	171	171	171	171	171
Coefficient of Performance (COP_h)	3.9	3.9	3.9	3.0	4	4.2	4.4
Average Life (y)	15	15	15	15	15	15	15
Retail Equipment Cost (2022$)[2]	55,406	55,406	55,406	55,406	55,406	55,406	55,406
Total Installed Cost (2022$)[2]	59,935	59,935	59,935	59,935	59,935	59,935	59,935
Total Installed Cost (2022$/kBtu/h)	350	350	350	350	350	350	350
Annual Maintenance Cost (2022$)[2]	120	120	120	120	120	120	120
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1

1. Water flow rate scales with typical capacity. The storage tanks must be purchased and installed separately from the HP unit. The typical output and flow rate provided are near the median of the products available on the market currently.
2. Costs are same as EIA Technology Forecast Updates (2018), updated to 2022$. Updated representative costs for commercial heat pump water heaters are not available due to the extremely small market for these products.

Note:
ENERGY STAR V. 2.0 went into effect in October 2018.

Commercial Heat Pump Water Heaters

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- Typical commercial HPWHs (CHPWHs) are add-on units designed to be used with a storage tank(s); integrated CHPWHs have emerged on the market (i.e., heat pump module and storage tank combined in one unit) in recent years.
- CHPWHs serve only a small portion of the commercial water heating (CWH) market, with the ENERGY STAR database listing only two manufacturers, each with one basic model listed.
- CHPWHs can extract heat from either air or water for heating potable water (“air-source” or “water-source”). The capacity of air-source CHPWHs falls at lower ambient air temperatures.
- Air-source CHPWHs cool the surrounding air, which can be desirable when installed indoors in applications with a year-round cooling load (e.g., a commercial kitchen).
- Output capacities for CHPWHs range from 17 kW to over 70 kW for air-source units and over 600 kW for water-source units.
- Some commercial applications require water as hot as 180 °F, such as dishwashing; however, most CHPWHs cannot deliver hot water at temperatures higher than 150 °F.
- There are no current Federal standards for CHPWHs, but DOE prescribes a test procedure for determining COP_h for CHPWHs.
- The most recent ENERGY STAR V. 2.0 specification for CWH equipment went into effect in October 2018. It specifies a COP_h level of 3.0 for CHPWHs.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Commercial Oil-Fired Storage Water Heaters

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Same as Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	85	85	85	85	85	85	85	85	85	85
Typical Input Capacity (kBtu/h)	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)[1]	79	81	80	81	82	81	82	81	82	81	82
Average Life (y)	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2022$)	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470
Total Installed Cost (2022$)	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120
Total Installed Cost (2022$/kBtu/h)	26	25	26	25	25	25	25	25	25	25	25
Annual Maintenance Cost (2022$)	200	200	200	200	200	200	200	210	210	210	210
Annual Maintenance Cost (2022$/kBtu/h)	1	1	1	1	1	1	1	1	1	1	1

1. Different levels of standby loss were not included in this analysis.

Note:

The commercial oil-fired water heaters market is very small; currently, there are only 4 basic models in DOE's CCD. DOE's rulemaking analysis for oil-fired water heaters has not been updated since 2001. The retail, installed, and maintenance costs have been updated from EIA Technology Forecast Updates (2018) to 2022$.

The current standard went into effect in October 2015.

Commercial Oil-Fired Storage Water Heaters

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- Input capacity > 155 kBtu/h and storage capacity ≤ 140 gal
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest thermal efficiency on the market is 82%.
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- Maintenance costs include sediment and scale removal once or twice per year.
- The market for commercial oil-fired storage water heaters is very small; shipments are approximately 3% of shipments for commercial gas-fired storage water heaters.

Commercial Electric Booster Water Heaters

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Same as Reference Case

DATA	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Typical Output Capacity (kBtu/h)	1,374	1,374	1,374	1,374	1,374	1,374
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (y)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost (2022$)[1]	1,530	1,530	1,920	1,920	1,920	1,920
	3,290	3,530	4,560	4,560	4,560	4,560
Total Installed Cost (2022$) [1]	1,730	1,730	2,120	2,120	2,120	2,120
	3,490	3,730	4,760	4,760	4,760	4,760
Total Installed Cost (2022$/kBtu/h)	2	2	3	3	3	3
Annual Maintenance Cost (2022$)[2]	-	-	-	-	-	-
Annual Maintenance Cost (2022$/kBtu/h)	-	-	-	-	-	-

1. The 2012 and 2018 installed base costs are the same as EIA Technology Forecast Updates (2018), updated to 2022$. Retail costs for 2022 and later are based on the range of costs for products on the market today. Installed costs assume a $200 installation price.
2. Maintenance costs are negligible.

Commercial Gas-Fired Booster Water Heaters

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Higher efficiencies with corresponding cost increases

DATA	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	3	3	3	3	3	3	3
	5	5	5	5	5	5	5
Typical Output Capacity (kBtu/h)	500	500	500	500	500	500	500
Thermal Efficiency (%)[1]	80	80	80	80	80	91	80
Average Life (y)	5	5	5	5	5	5	5
	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)[2]	5,530	5,760	7,130	7,130	7,130	9,500	7,130
	8,000	9,060	11,120	11,120	11,120	12,500	11,120
Total Installed Cost (2022$)[2]	5,830	6,060	7,430	7,430	7,430	9,800	7,430
	8,300	9,360	11,420	11,420	11,420	12,800	11,420
Total Installed Cost (2022$/kBtu/h)	14	15	19	19	19	23	19
Annual Maintenance Cost (2022$)	160	160	160	160	160	160	160
Annual Maintenance Cost (2022$/kBtu/h)	0	0	0	0	0	0	0

1. While EIA Technology Forecast Updates (2018) included high values reflecting condensing models, models currently available in the market do not exceed 80% efficiency.
2. The 2012 and 2018 installed base costs are the same as EIA Technology Forecast Updates (2018), updated to 2022$. Retail costs for 2022 and later are based on the range of costs for products on the market today. Installed costs assume a $300 installation price.

Commercial Booster Water Heaters

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- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140 °F water, and the booster water heater may increase that temperature to 180-195 °F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- Commercial booster water heaters are regulated by DOE as either storage or instantaneous water heaters, depending on the ratio of input capacity to storage volume. Units with input capacity < 4,000 Btu/h per gallon of stored water are storage water heaters; all other units are instantaneous water heaters.
- DOE's regulations do not currently include standards for electric instantaneous water heaters, but standards are included for electric storage water heaters, gas-fired instantaneous water heaters, and gas-fired storage water heaters.
- Condensing gas-fired booster water heaters, those with an efficiency of 90% of more, were analyzed previously. There are no condensing units currently on the market. Condensing gas-fired booster water heaters can only operate if the incoming water temperature is below 130 °F so there is enough heat transfer to condense.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Shipments are small due to the limited number of applications.
- Advanced Case: increased high efficiencies are possible due to market incentives to re-introduce condensing commercial gas-fired booster water heaters through additional investment, research, and development. No significant changes otherwise.

Commercial Gas-Fired Instantaneous Water Heaters

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Same as Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High[2]	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	250	250	250	250	250	250	250	250	250	250	250	250
	399	399	399	399	399	399	399	399	399	399	399	399
Thermal Efficiency (%)	80	92	80	92	94	99	96	99	96	99	96	99
Average Life (y)	17	17	17	17	17	17	17	17	17	17	17	17
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2022$)[1]	1,630	1,840	1,630	1,840	1,880	7,990	1,930	7,990	1,930	7,990	1,930	7,990
	4,400	8,610	4,400	8,610	9,000	9,990	9,400	9,990	9,400	9,990	9,400	9,990
Total Installed Cost (2022$)[1]	2,430	3,980	2,430	3,980	4,010	13,000	4,070	13,000	4,070	13,000	4,070	13,000
	10,380	13,560	10,380	13,560	13,950	14,950	14,350	14,950	14,350	14,950	14,350	14,950
Total Installed Cost (2022$/kBtu/h)	25	29	25	29	29	44	30	44	30	44	30	44
Annual Maintenance Cost (2022$)[3]	90	100	90	100	100	820	100	820	100	820	100	820
	760	820	760	820	820	830	830	830	830	830	830	830
Annual Maintenance Cost (2022$/kBtu/h)	2	2	2	2	2	3	1	3	1	3	1	3

1. Commercial gas-fired instantaneous water heaters are categorized into two groups: tankless water heater and hot water supply boiler. Tankless units are similar in design to residential tankless units. The hot water supply boiler has a much higher input and is similar in design to boilers. The large variation of total input capacity and design causes a large range of costs. The range of retail, installed, and maintenance costs represent the differences in design, as well as the cost ranges arising from replacement versus new construction markets.
2. High efficiency was determined based on DOE's CCD. The most efficient tankless water heater has a thermal efficiency of 96%. The most efficient hot water supply boiler has a thermal efficiency of 99%.
3. Maintenance consists replacement of miscellaneous components such as gaskets and sealants. Condensing units have an additional cost for replacement of condensate neutralizer media every two years.

Note:
For the installed base, current standard, and typical costs, low values represent costs for tankless water heaters in the replacement market while high values represent costs for hot water supply boilers in the new construction market. The range of costs for the High values are estimated costs for hot water supply boilers in the replacement and new construction market.
ENERGY STAR V. 2.0 went into effect in October 2018.

Commercial Gas-Fired Instantaneous Water Heaters

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- Storage Capacity < 10 gallons and ≥ 10 gallons
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 x (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
- Wall-mounted ("tankless") units typically do not exceed ~400,000 Btu/h and are similar in design to residential tankless units. Floor-mounted units ("circulating" or "volume" water heaters) are similar in design to boilers and can have input capacities in the millions of Btu/h. Floor-mounted units are typically installed with a storage tank.
- Despite high available input capacities, some installations use multiple units staged together, which may have reliability and/or efficiency benefits.
- Similar to storage water heaters, higher efficiencies are achieved with condensing operation, which requires a condensing heat exchanger and inducer fan or power burner. Some units include both non-condensing and condensing heat exchangers, while others include a single condensing heat exchanger.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.

Commercial Gas-Fired Instantaneous Water Heaters

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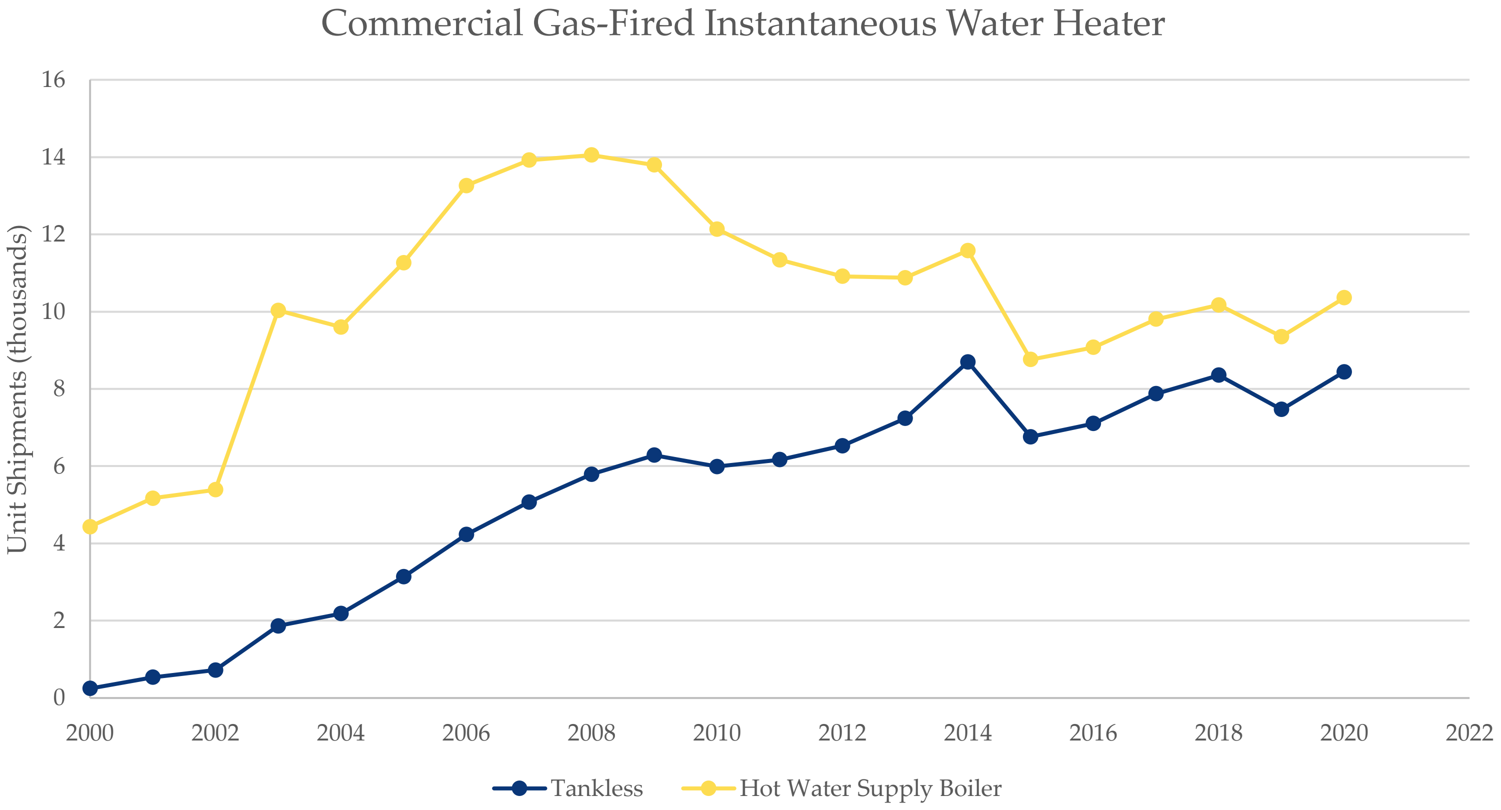
Annual shipments for gas-fired instantaneous tankless water heaters have gradually increased since 2000 while those for gas-fired instantaneous hot water supply boiler water heaters peaked in 2008 and have been decreasing since then, recently stabilizing around 10,000 annual shipments.



Source: CWH EERE 2022 NOPR

Commercial Solar Water Heaters

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Same as Reference Case

DATA	2012	2018	2022		2023	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	ENERGY STAR V. 5.0	Typical	Typical	Typical
Typical Capacity (sq. ft.)[1]	85	85	85	85	85	85	85	85
Typical Capacity (m^2)	7.90	7.90	7.90	7.90	7.90	7.90	7.90	7.90
Typical Capacity (Input) (kBtu/h) – North	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05
Typical Capacity (Input) (kBtu/h) – South	6.74	6.74	6.74	6.74	6.74	6.74	6.74	6.74
Solar Uniform Energy Factor (SUEF)[2]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Average Life (y)	20	20	20	20	20	20	20	20
Retail Equipment Cost (2022$)[3]	10,470	10,470	10,280	10,280	10,280	10,280	10,280	10,280
Total Installed Cost (2022$)[3]	14,180	14,180	12,640	12,640	12,640	12,640	12,640	12,640
Total Installed Cost (2022$/kBtu/h) – North	936	936	834	834	834	834	834	834
Total Installed Cost (2022$/kBtu/h) – South	702	702	626	626	626	626	626	626
Annual Maintenance Cost (2022$)[4]	100	100	100	100	100	100	100	100
Annual Maintenance Cost (2022$/kBtu/h) - North	7	7	7	7	7	7	7	7
Annual Maintenance Cost (2022$/kBtu/h) - South	5	5	5	5	5	5	5	5

1. Typical capacity refers to the solar collector panel area. It was determined using the SRCC database as the average value of the largest bin (in terms of capacity) with the greatest number of units.
2. In 2020, the efficiency metric for solar water heaters changed from SEF to SUEF. There is no equation or scaling factor readily available to translate SEF to SUEF. Accordingly, for the 2012 and 2018 installed base, SUEF was determined using the 2020 ENERGY STAR data set assuming the typical SEF/SUEF value was similar between 2012-2020. For 2022 and beyond, due to lack of SUEF data, it is assumed that a typical electric backup unit would meet the ENERGY STAR criteria. ENERGY STAR specifies a minimum SUEF of 3.0 for electric backup units and 1.8 for gas backup units.
3. Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>two-third of the current market). Higher capacity/cost systems are required in colder/cloudier regions. The 2012 and 2018 installed base costs are updated from EIA Technology Forecast Updates (2018) to 2022$.
4. Annual maintenance is expected to be 0.5% to 1% of the total installation.

Note:

ENERGY STAR V. 4.0 went into effect in January 2022. ENERGY STAR V. 5.0 will go into effect in April 2023 but the ENERGY STAR criteria for solar water heaters will remain the same in ENERGY STAR V. 5.0.

Commercial Solar Water Heaters

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- In 2020, a diverse group of stakeholders from the solar thermal industry developed the SUEF Specification for solar water heaters. The goal of this specification is to align with the UEF metric used by DOE for other water heating technologies.
- SUEF is also the metric used by the current ENERGY STAR Specification, and it replaced the SEF metric.
- EIA Technology Forecast Updates (2018) presented results using SEF and solar fraction (SF). SEF is currently not used in either the ENERGY STAR or SRCC databases; accordingly, this report presents results according to SUEF. SF is the portion of the total conventional hot water heating load (delivered energy and tank standby losses). SF varies from 0 to 1.0. Typical solar fraction values are 0.5–0.75.
- There is no equation or scaling factor readily available to translate SEF to SUEF. Accordingly, for the 2012 and 2018 installed base, SUEF was determined using the 2020 ENERGY STAR data set assuming the typical SEF/SUEF value was similar between 2012-2020. For 2022 and beyond, SUEF is the average SUEF for solar water heaters with a "high-usage" draw pattern from the current ENERGY STAR qualified product list.
- Commercial solar water heaters are typically custom designed for a specific installation.
- Commercial solar water heaters may include backup heating, from sources such as electric resistance or hydronic heat (supplied from a gas-fired boiler or geothermal heat pump).
- Storage volumes of tanks for commercial solar water heaters can span from 140 gallons to over 2,000 gallons.
- SRCC's OG-300 can be used to certify commercial systems, but most commercial systems are larger and unique; this certification program is mostly used for residential solar water heaters.
  - Many incentive programs require that solar collectors for commercial systems be certified to SRCC's certification program for collectors, OG-100.

Commercial Cooking Products

Commercial Natural Gas Range with Griddle and Oven

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022			2023	2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.2[1]	High	ENERGY STAR V. 3.0[2]	Typical	High	Typical	High	Typical	High
Griddle - Cooking Energy Efficiency (%)	30	30	40	38	69	NA	42	69	44	69	46	69
Oven - Cooking Energy Efficiency (%)	35	35	35	46	69	49	39	69	42	69	47	69
Range - Cooking Energy Efficiency (%)	30	30	30	NA	40	NA	33	40	36	40	39	40
Combined Energy Efficiency (%)[3]	31	31	35	NA	58	NA	38	58	41	58	44	58
Griddle - Normalized Idle Energy Rate (Btu/h/ft^2)	3,000	3,000	3,000	2,650	1,724	NA	2,700	1,724	2,450	1,724	2,200	1,724
Oven - Idle Energy Rate (Btu/h)	18,000	18,000	18,000	12,000	3,516	9,500	16,200	3,516	14,600	3,516	13,150	3,516
Range - Idle Energy Rate (Btu/h)	3,600	3,600	3,600	NA	1,900	NA	3,250	1,900	2,950	1,900	2,650	1,900
Combined Idle Energy Rate (Btu/h)[3]	10,350	10,350	10,350	NA	4,178	NA	9,319	4,178	8,431	4,178	7,581	4,178
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Total Installed Cost (2022$)	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940	8,940
Total Installed Cost (2022$/kBtu/h)	864	864	864	NA	2,140	NA	959	2,140	1,060	2,140	1,179	2,140
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
2. ENERGY STAR V. 3.0 updated the requirements for commercial ovens from V. 2.2, effective January 2023. Data shown is reflective of a standard full-size convection oven that holds 5 or more pans.
3. Combined energy efficiency and combined idle energy rate are calculated as a weighted average of each component using typical daily operating hours sourced from Food Service Technology Center (FSTC). Typical daily operating hours are assumed to be 12 hours for the griddle component, 8 hours for the oven component, and 12 hours for the range component.
4. Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
5. Maintenance costs are negligible.

Note:
ENERGY STAR V. 2.2 went into effect in October 2015. ENERGY STAR V. 3.0 went into effect in January 2023.

Commercial Electric Range with Griddle and Oven

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022			2023	2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.2[1]	High	ENERGY STAR V. 3.0[2]	Typical	High	Typical	High	Typical	High
Griddle - Cooking Energy Efficiency (%)	65	70	72	70	91	NA	74	91	76	91	78	91
Oven - Cooking Energy Efficiency (%)	65	65	65	71	86	76	67	86	69	86	71	86
Range - Cooking Energy Efficiency (%)	75	75	75	NA	87	NA	77	87	80	87	81	87
Combined Energy Efficiency (%)[3]	69	71	71	NA	88	NA	73	88	76	88	77	88
Griddle - Normalized Idle Energy Rate (kW/ft^2)	0.44	0.34	0.30	0.32	0.21	NA	0.29	0.21	0.28	0.21	0.27	0.21
Oven - Idle Energy Rate (kW)	1.5	1.5	1.5	1.6	0.6	1.4	1.4	0.6	1.3	0.6	1.2	0.6
Range - Idle Energy Rate (kW)[4]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Combined Idle Energy Rate (kW)[3]	1.7	1.4	1.3	1.4	0.8	NA	1.3	0.8	1.2	0.8	1.1	0.8
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[5]	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230	11,230
Total Installed Cost (2022$)	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410
Total Installed Cost (2022$/kBtu/h)	2,019	2,362	2,533	2,375	4,423	NA	2,662	4,423	2,805	4,423	2,964	4,423
Annual Maintenance Cost (2022$)[6]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
2. ENERGY STAR V. 3.0 updates the requirements for commercial ovens from V. 2.2, effective January 12, 2023. Data shown is reflective of a standard full-size convection oven that holds 5 or more pans.
3. Combined energy efficiency and combined idle energy rate are calculated as a weighted average of each component using typical daily operating hours sourced from FSTC. Typical daily operating hours are assumed to be 12 hours for the griddle component, 8 hours for the oven component, and 12 hours for the range component.
4. No data on electric range top idle energy rates.
5. Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
6. Maintenance costs are negligible.

Note:
ENERGY STAR V. 2.2 went into effect in October 2015. ENERGY STAR V. 3.0 goes into effect in January 2023.

Commercial Ranges with Griddle and Oven

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- Combined product that typically includes 2-6 range tops, a 24 in. x 24 in. griddle surface, and one or two half- or full-size ovens.
- Combined product is not covered by ENERGY STAR. However, the individual product ENERGY STAR V. 2.2 specifications are provided below.

Product	ENERGY STAR V. 2.2 Requirements	Gas	Electric
Griddle	Cooking Energy Efficiency	≥ 38%	≥ 70%
	Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 0.320 kW per ft^2
Oven	Cooking Energy Efficiency	≥ 46%	≥ 71%
	Idle Energy Rate	≤ 12,000 Btu/h	Half size: ≤1.00 kW Full size: ≤1.60 kW

- ENERGY STAR does not provide certification for range tops.
- There are no Federal standards for commercial cooking products.
- Product pricing in this market do not scale with efficiency, but rather depend on a number of other factors such as brand name, aesthetics, and additional features.

Commercial Ranges with Griddle and Oven

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- ENERGY STAR V. 3.0 requirements for commercial ovens went into effect in January 2023:

Product	ENERGY STAR Requirements	Gas	Electric
Oven	Cooking Energy Efficiency	≥ 49%	Half size: ≥ 71% Full size: ≥ 76%
	Idle Energy Rate	≤ 9,500 Btu/h	Half size: ≤1.00 kW Full size ≥ 5 Pans: ≤1.40 kW Full size ≤ 5 Pans: ≤1.00 kW

- Advanced Case: Increased market incentives are expected to drive efficiency improvements. However, because cost does not scale with efficiency, there is no significant expected change in cost.

Commercial Ranges with Griddle and Oven

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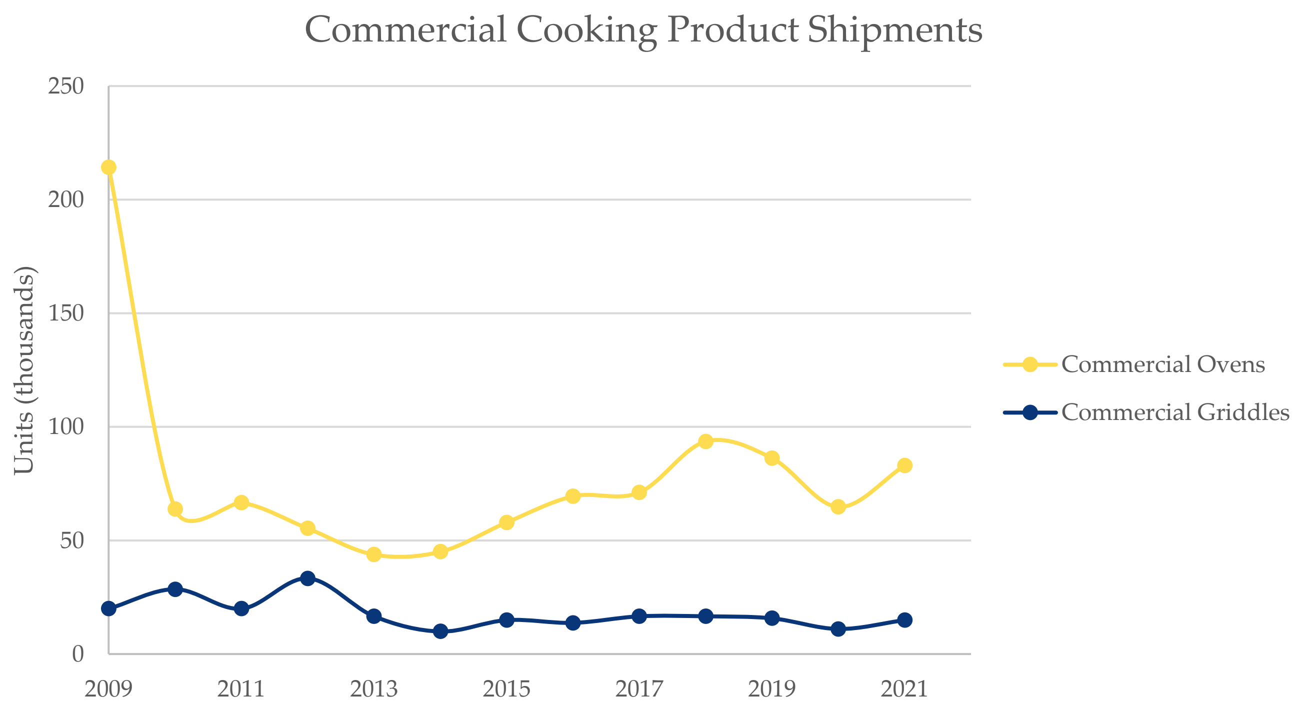
Commercial oven shipments have gradually increased since 2013, following a peak in 2009. Commercial griddle shipments have remained steady since 2014.



Source: *ENERGY STAR (Unit Shipment Data)*

Commercial Hot Food Holding Cabinets – Small

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)[1]	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Maximum Idle Energy Rate (W)[2]	312	312	312	312	168	168	250	168	200	168	200	168
Annual Energy Use (kWh/y)[3]	1,025	1,025	1,025	1,025	552	552	820	552	656	552	656	552
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	3,200	3,200	3,200	3,200	3,800	3,800	3,200	3,800	3,200	3,800	3,200	3,800
Total Installed Cost (2022$)[5]	3,200	3,200	3,200	3,200	3,800	3,800	3,200	3,800	3,200	3,800	3,200	3,800
Total Installed Cost (2022$/kBtu/h)	8,016	8,016	8,016	8,016	17,677	17,677	10,020	17,677	12,524	17,677	12,524	17,677
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The small size class covers units with interior volume less than 13 ft^3. Interior volume for the small size class was determined based on the units in the ENERGY STAR database, accessed February 2023.
2. Maximum idle energy rate is a function of interior volume. For the small size class, ENERGY STAR and high values were determined for a representative 7.8 ft^3 using the ENERGY STAR database, accessed February 2023. The typical value was assumed to be equivalent to the state standard for a representative 7.8 ft^3 unit.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year. The small size class is assumed to use the same number of annual usage hours as the medium size class.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:
ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets – Medium

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)[1]	21.4	21.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4
Maximum Idle Energy Rate (W)[2]	900	856	896	896	299	298	717	298	573	298	459	298
Annual Energy Use (kWh/y)[3]	2,957	2,812	2,943	2,943	982	979	2,355	979	1,884	979	1,507	979
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	2,940	4,530	4,600	4,600	5,000	5,000	4,600	5,000	4,600	5,000	4,600	5,000
Total Installed Cost (2022$)[5]	2,940	4,530	4,600	4,600	5,000	5,000	4,600	5,000	4,600	5,000	4,600	5,000
Total Installed Cost (2022$/kBtu/h)	2,553	4,136	4,012	4,012	13,078	13,113	5,015	13,113	6,269	13,113	7,836	13,113
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The medium size class covers units with interior volume between 13 ft^3 to 28 ft^3. For the medium size class, the interior volume increase from 21.4 ft^3 to 22.4 ft^3 in 2022 reflects the current representative product volume reported by FEMP, last updated December 2021.
2. Maximum idle energy rate is a function of interior volume. For the medium size class, the maximum idle energy rate for 2022 onward is reflective of a representative 22.4 ft^3 unit, using the latest FEMP data from December 2021.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:

ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets – Large

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency

DATA	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)[1]	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Maximum Idle Energy Rate (W)[2]	1,333	1,333	1,760	1,333	400	310	1,067	310	853	310	683	310
Annual Energy Use (kWh/y)[3]	4,380	4,380	5,782	4,380	1,314	1,018	3,504	1,018	2,803	1,018	2,243	1,018
Average Life (y)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2022$)[4]	5,500	5,500	5,500	5,500	6,000	6,000	5,500	6,000	5,500	6,000	5,500	6,000
Total Installed Cost (2022$)[5]	5,500	5,500	5,500	5,500	6,000	6,000	5,500	6,000	5,500	6,000	5,500	6,000
Total Installed Cost (2022$/kBtu/h)	3,224	3,224	2,442	3,224	11,723	15,126	4,030	15,126	5,037	15,126	6,296	15,126
Annual Maintenance Cost (2022$)[5]	–	–	–	–	–	–	–	–	–	–	–	–
Annual Maintenance Cost (2022$/kBtu/h)	–	–	–	–	–	–	–	–	–	–	–	–

1. Interior volume is characterized by the product size classes reported by ENERGY STAR. The large size class covers units with interior volume greater than or equal to 28 ft^3. Interior volume for the large size class was determined based on the units in the ENERGY STAR database, accessed February 1, 2023.
2. Maximum idle energy rate is a function of interior volume. For the large size class, ENERGY STAR and high values were determined using the ENERGY STAR database, and the typical value uses the assumption that ENERGY STAR units are reported to be 70% more efficient than typical units.
3. Annual energy use is determined using the latest FEMP data from December 2021, which assumes that a typical 22.4 ft^3 commercial hot food holding cabinet uses an average of 9 hours per day and 365 days per year. The large size class is assumed to use the same number of annual usage hours as the medium size class.
4. Retail equipment costs were determined using distributor information for undercounter, half-size, and full-size hot food holding cabinets.
5. Additional installation costs and maintenance costs are negligible.

Note:

ENERGY STAR V. 2.0 went into effect in October 2011 and was revised in December 2022. Massachusetts, Nevada, and Rhode Island state standards have adopted the ENERGY STAR V. 2.0 criteria that went into effect in October 2011. The majority of state standards (California, Colorado, Connecticut, DC, Maryland, New Hampshire, Oregon, Rhode Island, Vermont, and Washington) implement the ENERGY STAR V. 1.0 specification that went into effect in August 2003, which is recorded in the table. ENERGY STAR V. 1.0 specifies a maximum idle energy rate of 40 W per cubic foot of interior volume.

Commercial Hot Food Holding Cabinets

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- Hot food holding cabinets are used in commercial kitchens to keep food warm until it is served.
- While available in many shapes and sizes, interior volumes around 21.4 ft^3 were reported as typical in many settings in EIA Technology Forecast Updates (2018). FEMP currently lists 22.4 ft^3 as a representative unit size.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is "Idle Energy Consumption Rate" in Watts, measured using ASTM Standard F2140-11.
- There are no Federal standards for hot food holding cabinets, but seven States have identical standards.
  - The first State standard took effect in California in 2006; this standard is now considered the typical or "baseline" product. It is also equivalent to the ENERGY STAR V. 1.0 Specification that went into effect in August 2003.
  - ENERGY STAR V. 2.0 went into effect in October 2011.
- Maximum Idle Energy Consumption Rate for products $12 \le V < 28$:
  - — State standards: $\le 40 \times V$ (baseline)
  - — ENERGY STAR V. 2.0: $\le 2.0 \times V + 254$ (about 65% below baseline)

  where V is interior volume in ft^3.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).
- Advanced Case: Increased market incentives are expected to drive efficiency improvements. However, because cost does not scale with efficiency, there is no significant expected change in cost.

Commercial Hot Food Holding Cabinets

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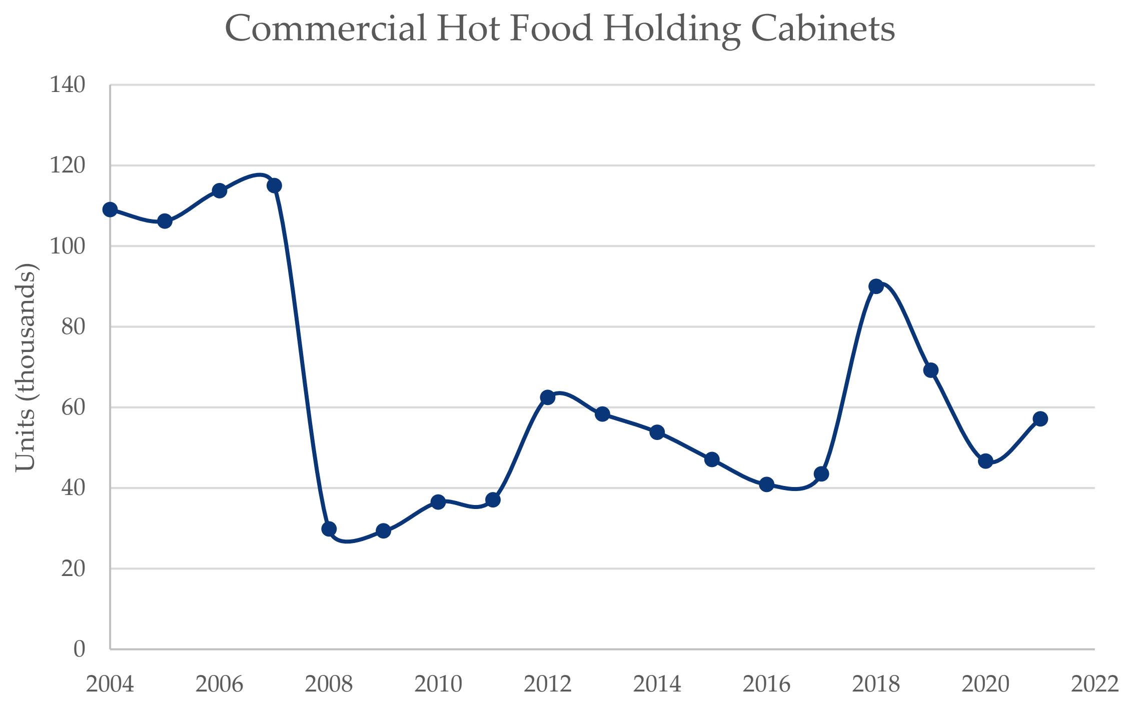
Commercial hot food holding cabinet shipments peaked in 2007 at 115,000 units, followed by a peak of 90,000 units in 2019.



Source: *ENERGY STAR (Unit Shipment Data)*

Appendix A
Data Sources

Guidehouse
1676 International Drive
McLean, VA 22102

And

Leidos
11951 Freedom Drive
Reston, VA 20190

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Residential Space Heating and Cooling

Residential Gas-Fired Furnaces (North)

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR (North) V. 4.1**	**High**	**Typical / High**		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2022 NOPR								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD	Residential Furnaces EERE 2022 NOPR		
Electric Consumption (kWh/y)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Average Life (y)	Residential Furnaces EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Total Installed Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Annual Maintenance Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						

Residential Gas-Fired Furnaces (Rest of Country)

SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR (ROC) V. 4.1**	**High**	**Typical / High**		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2022 NOPR								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD	Residential Furnaces EERE 2022 NOPR		
Electric Consumption (kWh/y)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Average Life (y)	Residential Furnaces EERE 2022 NOPR								
Retail Equipment Cost (2022$)	Residential Furnaces EERE 2016		Residential Furnaces EERE 2022 NOPR						
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Oil-Fired Furnaces

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 4.1	High	Typical / High		
Typical Input Capacity (kBtu/h)	Residential Furnaces EERE 2011								
AFUE (%)	CFR			DOE CCD	ENERGY STAR V. 4.1	DOE CCD			
Electric Consumption (kWh/y)	Residential Furnaces EERE 2011								
Average Life (y)									
Retail Equipment Cost (2022$)									
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Gas-Fired Boilers

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.0</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="7">Boilers EERE 2016</td><td colspan="8">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>AFUE (%)</td><td colspan="2">Boilers EERE 2022 Preliminary Analysis</td><td>DOE CCD</td><td>ENERGY STAR V. 3.0</td><td colspan="4">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Electric Consumption (kWh/y)</td><td colspan="8" rowspan="5">Boilers EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Oil-Fired Boilers

Final

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 3.0	High	Typical / High		
Typical Input Capacity (kBtu/h)	Boilers EERE 2016	Boilers EERE 2022 Preliminary Analysis					Guidehouse		
AFUE (%)		Boilers EERE 2022 Preliminary Analysis		DOE CCD	ENERGY STAR V. 3.0	Boilers EERE 2022 Preliminary Analysis			
Electric Consumption (kWh/y)		Boilers EERE 2022 Preliminary Analysis							
Average Life (y)									
Retail Equipment Cost (2022$)									
Total Installed Cost (2022$)									
Annual Maintenance Cost (2022$)									

Residential Electric Resistance Furnaces

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="3">Typical</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="4">Distributors</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>AFUE (%)</td><td colspan="4">DOE / ASHRAE</td></tr>
<tr><td>Average Life (y)</td><td colspan="4">Distributors</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">EIA Technology Forecast Updates (2018)</td><td colspan="3" rowspan="2">Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="4">Guidehouse</td></tr>
</table>

Residential Electric Resistance Unit Heaters

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SOURCES	2015	2020	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical		
Typical Capacity (kBtu/h)	Distributors		Utilities/Distributors	Guidehouse		
Efficiency (%)	DOE		DOE			
Average Life (y)	Guidehouse		Guidehouse			
Retail Equipment Cost (2022$)			Distributors			
Total Installed Cost (2022$)			Home Remodeling Service			
Annual Maintenance Cost (2022$)			Guidehouse			

Residential Central Air Conditioners – North (Not Hot-Dry or Hot-Humid)

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="3">2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 5.0</th><th>High</th><th>New Standard</th><th>ENERGY STAR V. 6.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="9">CAC and HP EERE 2016</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>SEER</td><td colspan="2">CAC and HP EERE 2016 / Guidehouse</td><td>CFR</td><td>DOE CCD</td><td>ENERGY STAR V. 5.0</td><td>CAC and HP EERE 2016</td><td colspan="2">RESNET</td><td>CAC and HP EERE 2016</td></tr>
<tr><td>SSER2</td><td colspan="6">RESNET</td><td>CAC and HP EERE 2016</td><td>ENERGY STAR V. 6.1</td><td>RESNET</td></tr>
<tr><td>Average Life (y)</td><td colspan="9" rowspan="2">CAC and HP EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="9">CAC and HP EERE 2016 / Less (2021)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="9">CAC and HP EERE 2016</td></tr>
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Residential Central Air Conditioners – South (Hot-Dry and Hot-Humid)

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="3">2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 5.0</th><th>High</th><th>New Standard</th><th>ENERGY STAR V. 6.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="9">CAC and HP EERE 2016</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>SEER</td><td colspan="2">CAC and HP EERE 2016 / Guidehouse</td><td>CFR</td><td>DOE CCD</td><td>ENERGY STAR V. 5.0</td><td>CAC and HP EERE 2016</td><td colspan="2">RESNET</td><td>CAC and HP EERE 2016</td></tr>
<tr><td>SSER2</td><td colspan="6">RESNET</td><td>CAC and HP EERE 2016</td><td>ENERGY STAR V. 6.1</td><td>RESNET</td></tr>
<tr><td>Average Life (y)</td><td colspan="9" rowspan="2">CAC and HP EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="9">CAC and HP EERE 2016 / Less (2021)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="9">CAC and HP EERE 2016</td></tr>
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Residential Room Air Conditioners

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.2</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="2">Distributors</td><td colspan="10">RAC EERE 2022 NOPR</td></tr>
<tr><td>CEER (Btu/Wh)</td><td colspan="2">Guidehouse</td><td>CFR</td><td>DOE CCD</td><td>ENERGY STAR V. 4.2</td><td>DOE CCD</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Average Life (y)</td><td rowspan="5">RAC EERE 2011</td><td colspan="5" rowspan="5">RAC EERE 2022 NOPR</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Portable Air Conditioners

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SOURCES	2015	2020	2022		2025		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	New Standard	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	PAC EERE 2020/Guidehouse						Guidehouse					
CEER												
Average Life (y)												
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Swamp Coolers

SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
CFM	Product Literature / Guidehouse				Guidehouse					
Power (Hp)										
Average Life (y)	TLC Plumbing / Guidehouse									
Retail Equipment Cost (2022$)	Product Literature / Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse									
Total Installed Cost (2022$)										
Annual Maintenance Cost (2022$)										

Residential Air-Source Heat Pumps

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 5.0</th><th>High</th><th>New Standard</th><th>ENERGY STAR V. 6.1</th><th>ENERGY STAR Cold Climate Criteria</th><th>High</th><th colspan="3">Typical/High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="13">CACs and HPs EERE 2016 Direct Final Rule</td></tr>
<tr><td>SEER (Cooling)</td><td colspan="2" rowspan="2">CACs and HPs EERE 2016 Direct Final Rule/ Guidehouse</td><td rowspan="2">CFR</td><td rowspan="2">DOE CCD/ Guidehouse</td><td rowspan="2">ENERGY STAR V. 5.0</td><td rowspan="2">CACs and HPs EERE 2016 Direct Final Rule</td><td rowspan="2">CACs and HPs EERE 2016 Direct Final Rule/ Guidehouse</td><td rowspan="2">ENERGY STAR V. 6.1</td><td rowspan="2">ENERGY STAR V. 6.1</td><td rowspan="2">CACs and HPs EERE 2016 Direct Final Rule</td><td colspan="3" rowspan="2">CACs and HPs EERE 2016 Direct Final Rule/Guidehouse</td></tr>
<tr><td>HSPF (Heating)</td></tr>
<tr><td>Average Life (y)</td><td colspan="10" rowspan="4">CACs and HPs EERE 2016 Direct Final Rule</td><td colspan="3" rowspan="4">Guidehouse</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Ductless Mini-Split Air-Source Heat Pumps

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SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	AHRI/Guidehouse				Guidehouse					
SEER										
EER										
HSPF										
Average Life (y)	CACs and HPs EERE 2016 Direct Final Rule									
Retail Equipment Cost (2022$)	Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse									
Total Installed Cost (2022$)										
Annual Maintenance Cost (2022$)	CACs and HPs EERE 2016 Direct Final Rule									

Residential Ground-Source Heat Pumps

<table>
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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.2</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="2">Water-Source Unitary Heat Pumps EERE 2015 Final Rule / DOE CCD</td><td colspan="10" rowspan="7">Guidehouse</td></tr>
<tr><td>COP (Heating)</td><td rowspan="2">AHRI Database</td><td rowspan="2">AHRI Database / DOE CCD</td></tr>
<tr><td>EER (Cooling)</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Natural Gas Heat Pumps

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SOURCES	2015	2020	2022	2030	2040	2050
	Installed Base		Typical			
Typical Capacity (kBtu/h)	Manufacturer		Guidehouse			
COP (Heating)	Product Literature					
COP (Cooling)						
Annual Electric Use (kWh/y)						
Average Life (y)	Guidehouse					
Retail Equipment Cost (2022$)	PERC					
Total Installed Cost (2022$)	Guidehouse					
Annual Maintenance Cost (2022$)						

Residential Cordwood Stoves

SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	Distributors / Product Literature				Guidehouse					
Efficiency (Non-Catalytic) (HHV)	Guidehouse / Literature	EPA Certified Wood Stove Database (Room Heaters)								
Efficiency (Catalytic) (HHV)										
Average Life (y)	Guidehouse									
Retail Equipment Cost (2022$)	Product Literature/Dealers									
Total Installed Cost (2022$)	Dealers	Dealers/Guidehouse								
Annual Maintenance Cost (2022$)	Dealers/Guidehouse									

Residential Wood Pellet Stoves

SOURCES	2015	2020	2022		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	Distributors / Product Literature				Guidehouse					
Efficiency (HHV)	EPA Default/ Literature/ Guidehouse	EPA Certified Wood Stove Database (Room Heaters)								
Average Life (y)	Guidehouse									
Retail Equipment Cost (2022$)	Product Literature/ Dealers									
Total Installed Cost (2022$)	Dealers/Guidehouse									
Annual Maintenance Cost (2022$)										

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Residential Water Heating

Residential Gas-Fired Storage Water Heaters

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>ENERGY STAR V. 5.0</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (gal)</td><td rowspan="2">Guidehouse</td><td>CWH EERE 2010 Final Rule /AHRI</td><td colspan="5">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>DOE CCD</td><td colspan="2">CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">CWH EERE 2010 Final Rule</td><td colspan="5" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td>Distributors</td><td>CWH EERE 2010 Final Rule</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td>EIA Technology Forecast Updates (2018)</td><td>CWH EERE 2010 Final Rule</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="2">CWH EERE 2010 Final Rule</td></tr>
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Residential Oil-Fired Water Heaters

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="3">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI</td><td>CWH EERE 2010 Final Rule/AHRI</td><td colspan="3" rowspan="6">CWH EERE 2022 Preliminary Analysis</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>Guidehouse</td><td>AHRI/DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">CWH EERE 2010 Final Rule</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Electric Resistance Storage Water Heaters

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SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	AHRI	CWH EERE 2010 Final Rule/AHRI	CWH EERE 2022 Preliminary Analysis			Guidehouse					
Uniform Energy Factor	Guidehouse	AHRI/ DOE CCD									
Average Life (y)	CWH EERE 2010 Final Rule										
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)											

Residential Heat Pump Water Heaters

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<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
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<tr><td>Typical Capacity (gal)</td><td rowspan="2">Guidehouse</td><td>AHRI</td><td colspan="3">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>DOE CCD</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Average Life (y)</td><td colspan="2">CWH EERE 2010 Final Rule</td><td colspan="3" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td>CWH EERE 2010 Final Rule</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="2" rowspan="2">CWH EERE 2010 Final Rule</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Solar Water Heaters

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	ENERGY STAR V. 4.0	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Guidehouse		ENERGY STAR		Guidehouse		
Solar Uniform Energy Factor (SUEF)			DOE				
Average Life (y)	DOE / Guidehouse						
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023				
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse		DOE				

Residential Gas-Fired Instantaneous Water Heaters

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<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>ENERGY STAR V. 5.0</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td>AHRI</td><td>CWH EERE 2010 Final Rule /AHRI</td><td colspan="5">CWH EERE 2022 Preliminary Analysis</td><td colspan="6" rowspan="6">Guidehouse</td></tr>
<tr><td>Uniform Energy Factor</td><td>Guidehouse</td><td>DOE CCD</td><td colspan="2">CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td><td>CWH EERE 2022 Preliminary Analysis</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">CWH EERE 2010 Final Rule</td><td colspan="5" rowspan="4">CWH EERE 2022 Preliminary Analysis</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
</table>

Residential Electric Instantaneous Water Heaters

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SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	Guidehouse		CWH EERE 2022 Preliminary Analysis			Guidehouse					
Uniform Energy Factor			CWH EERE 2022 Preliminary Analysis/DOE CCD								
Average Life (y)			Gordian's RSMeans Data – Building Construction Costs 2023								
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)			Guidehouse								

Residential Appliances

Residential Refrigerator-Freezers (Top)

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SOURCES	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	RF EERE 2011 / Guidehouse	RF EERE 2021 Preliminary Analysis / Guidehouse					Guidehouse					
Energy Consumption (kWh/y)		DOE CCD/ Guidehouse	CFR	DOE CCD	ENERGY STAR	DOE CCD						
Average Life (y)		RF EERE 2021 Preliminary Analysis / Guidehouse										
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Refrigerator-Freezers (Side)

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<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
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<tr><td>Typical Capacity (ft^3)</td><td rowspan="6">RF EERE 2011 / Guidehouse</td><td colspan="5">RF EERE 2021 Preliminary Analysis / Guidehouse</td><td rowspan="6" colspan="6">Guidehouse</td></tr>
<tr><td>Energy Consumption (kWh/y)</td><td>DOE CCD/ Guidehouse</td><td>CFR</td><td>DOE CCD</td><td>ENERGY STAR</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td rowspan="4" colspan="5">RF EERE 2021 Preliminary Analysis / Guidehouse</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Refrigerator-Freezers (Bottom)

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SOURCES	2015	2020	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 5.1	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	RF EERE 2011 / Guidehouse	RF EERE 2021 Preliminary Analysis / Guidehouse					Guidehouse					
Energy Consumption (kWh/y)		DOE CCD/ Guidehouse	CFR	DOE CCD	ENERGY STAR	DOE CCD						
Average Life (y)		RF EERE 2021 Preliminary Analysis / Guidehouse										
Retail Equipment Cost (2022$)												
Total Installed Cost (2022$)												
Annual Maintenance Cost (2022$)												

Residential Freezers (Chest)

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td colspan="2">RF EERE 2011 / Guidehouse</td><td colspan="3">RF EERE Preliminary Analysis 2021/DOE CCD</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>Energy Consumption (kWh/y)</td><td colspan="2">Guidehouse</td><td>RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021/DOE CCD</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">RF EERE 2011 / Guidehouse</td><td colspan="2" rowspan="4">RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="3">RF EERE Preliminary Analysis 2021/DOE CCD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Freezers (Upright)

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<tr><td>Typical Capacity (ft³)</td><td colspan="2">RF EERE 2011/ Guidehouse</td><td colspan="4">RF EERE Preliminary Analysis 2021/ DOE CCD</td><td colspan="3" rowspan="6">Guidehouse</td></tr>
<tr><td>Energy Consumption (kWh/y)</td><td colspan="2">Guidehouse</td><td>RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021/ DOE CCD</td><td>ENERGY STAR</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="2" rowspan="4">RF EERE 2011 / Guidehouse</td><td colspan="3" rowspan="4">RF EERE Preliminary Analysis 2021</td><td>RF EERE Preliminary Analysis 2021</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="3">RF EERE Preliminary Analysis 2021/ DOE CCD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
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Residential Natural Gas Cooktops

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Distributors / Product Literature				Guidehouse		
Integrated Annual Energy Consumption (kBtu/y)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						
Cooking Efficiency (%)	Guidehouse						
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD						
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2016 SNOPR / Consumer Cooking Products EERE 2020 NOPD						
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Natural Gas Ovens

SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (kBtu/h)	Consumer Cooking Products EERE 2016 SNOPR / Product Literature				Guidehouse		
Typical Cavity Volume (ft^3)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD					
Integrated Annual Energy Consumption (kBtu/y)							
Cooking Efficiency (%)	Guidehouse						
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD	Consumer Cooking Products EERE 2020 NOPD					
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2016 SNOPR						
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Natural Gas Ranges

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<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity of Cooktop Component (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="3" rowspan="8">Guidehouse</td></tr>
<tr><td>Typical Capacity of Oven Component (kBtu/h)</td><td colspan="4">Consumer Cooking Products EERE 2016 SNOPR / Product Literature</td></tr>
<tr><td>Typical Cavity Volume of Oven Component (ft³)</td><td>Consumer Cooking Products EERE 2020 NOPD</td><td colspan="3" rowspan="3">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Integrated Annual Energy Consumption (kBtu/y)</td><td>Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
<tr><td>Average Life (y)</td><td>Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="4" rowspan="2">Guidehouse / Distributors / Gordian's RSMeans Data – Building Construction Costs 2023</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="4">Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
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Residential Electric Cooktops

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (W)	Consumer Cooking Products EERE 2016 SNOPR / Distributors				Guidehouse		
Integrated Annual Energy Consumption (kWh/y)	Consumer Cooking Products EERE 2020 NOPD						
Average Life (y)							
Retail Equipment Cost (2022$)							
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Electric Ovens

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SOURCES	2015	2020	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High		
Typical Capacity (W)	Consumer Cooking Products EERE 2016 SNOPR / Distributors				Guidehouse		
Typical Cavity Volume (ft^3)	Consumer Cooking Products EERE 2016 SNOPR	Consumer Cooking Products EERE 2020 NOPD					
Integrated Annual Energy Consumption (kWh/y)							
Average Life (y)	Consumer Cooking Products EERE 2020 NOPD						
Retail Equipment Cost (2022$)	Consumer Cooking Products EERE 2020 NOPD						
Total Installed Cost (2022$)							
Annual Maintenance Cost (2022$)	Guidehouse / Consumer Cooking Products EERE 2016 SNOPR						

Residential Electric Ranges

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<tr><td>Typical Capacity of Cooktop Component (W)</td><td colspan="4" rowspan="2">Consumer Cooking Products EERE 2016 SNOPR / Distributors</td><td colspan="3" rowspan="8">Guidehouse</td></tr>
<tr><td>Typical Capacity of Oven Component (W)</td></tr>
<tr><td>Typical Cavity Volume of Oven Component (ft^3)</td><td rowspan="2">Consumer Cooking Products EERE 2016 SNOPR</td><td colspan="3" rowspan="5">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Integrated Annual Energy Consumption (kWh/y)</td></tr>
<tr><td>Average Life (y)</td><td>Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">Consumer Cooking Products EERE 2020 NOPD</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="4">Guidehouse / Consumer Cooking Products EERE 2016 SNOPR</td></tr>
</table>

Residential Electric Clothes Dryers

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<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 1.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td colspan="5">DOE CCD</td><td>Guidehouse / DOE CCD / ENERGY STAR</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>CEF, D1 (lb/kWh)</td><td rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse</td><td rowspan="2">DOE CCD</td><td rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR</td><td rowspan="2">DOE CCD</td><td rowspan="2">ENERGY STAR V. 1.1</td><td>DOE CCD</td></tr>
<tr><td>CEF, D2 (lb/kWh)</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">Consumer Clothes Dryers EERE 2022 NOPR</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6" rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6">Consumer Clothes Dryers EERE 2022 NOPR</td></tr>
</table>

Residential Natural Gas Clothes Dryers

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 1.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td colspan="6">DOE CCD</td><td colspan="3" rowspan="7">Guidehouse</td></tr>
<tr><td>CEF, D1 (lb/kWh)</td><td rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse</td><td rowspan="2">DOE CCD</td><td rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR</td><td rowspan="2">DOE CCD</td><td rowspan="2">ENERGY STAR V. 1.1</td><td rowspan="2">DOE CCD</td></tr>
<tr><td>CEF2, D2 (lb/kWh)</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">Consumer Clothes Dryers EERE 2022 NOPR</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6" rowspan="2">Consumer Clothes Dryers EERE 2022 NOPR / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6">Consumer Clothes Dryers EERE 2022 NOPR</td></tr>
</table>

Residential Clothes Washers (Front)

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SOURCES	2015	2020	2022				2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 8.1	High	Typical / High		
Typical Capacity (ft^3)	Guidehouse	DOE CCD / Guidehouse	DOE CCD	DOE CCD	DOE CCD	DOE CCD	Guidehouse		
Integrated Modified Energy Factor (ft^3/kWh/cycle)	AHAM / Guidehouse		RCW EERE 2021 Preliminary Analysis		ENERGY STAR V. 8.1				
Integrated Water Factor (gal/cycle/ft^3)									
Average Life (y)	RCW EERE 2021 Preliminary Analysis								
Water Consumption (gal/cycle)	Guidehouse / RCW EERE 2021 Preliminary Analysis								
Hot Water Energy (kWh/cycle)									
Machine Energy (kWh/cycle)									
Dryer Energy (kWh/cycle)									
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)	RCW EERE 2021 Preliminary Analysis/ Distributors							
Total Installed Cost (2022$)		RCW EERE 2021 Preliminary Analysis/ Guidehouse							
Annual Maintenance Cost (2022$)	RCW EERE 2021 Preliminary Analysis / Guidehouse								

Residential Clothes Washers (Top)

<table>
<tr><th rowspan="2">SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 8.1</th><th>High</th><th colspan="3">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td>Guidehouse</td><td>Guidehouse</td><td>DOE CCD</td><td rowspan="3">DOE CCD</td><td>DOE CCD</td><td>DOE CCD</td><td colspan="3" rowspan="10">Guidehouse</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Guidehouse</td><td colspan="2" rowspan="2">RCW EERE 2021 Preliminary Analysis</td><td rowspan="2">ENERGY STAR V. 8.1</td><td rowspan="2">DOE CCD</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">RCW EERE 2021 Preliminary Analysis</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6">RCW EERE 2021 Preliminary Analysis / Guidehouse</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td rowspan="3">Guidehouse</td><td colspan="5" rowspan="5">RCW EERE 2021 Preliminary Analysis / Guidehouse</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
<tr><td>Dryer Energy (kWh/cycle)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">EIA Technology Forecast Updates (2018)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6">RCW EERE 2021 Preliminary Analysis / Guidehouse</td></tr>
</table>

Residential Dishwashers

SOURCES	2015	2020	2022				2023	2030	2040	2050
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR V. 6.0**	**High**	**ENERGY STAR V. 7.0**	**Typical / High**		
Typical Annual Energy Use (kWh/y)	AHAM 2014 / DW EERE 2012 Final Rule	Guidehouse / DOE CCD / ENERGY STAR	CFR	Guidehouse / DOE CCD / ENERGY STAR	ENERGY STAR	DW EERE 2022 Preliminary Analysis	ENERGY STAR	Guidehouse		
Water Consumption (gal/cycle)										
Water Heating Energy Use (kWh/y)	AHAM 2014 / DW EERE 2012 Final Rule	DW EERE 2016 Direct Final Rule	DW EERE 2022 Preliminary Analysis							
Average Life (y)	DW EERE 2016 Direct Final Rule/Guidehouse									
Retail Equipment Cost (2022$)	DW EERE 2012 Final Rule	DW EERE 2016 Direct Final Rule								
Total Installed Cost (2022$)										

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Commercial Space Heating and Cooling

Commercial Gas-Fired Furnaces

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="3">2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th>New Standard</th><th>Typical</th><th>High</th><th colspan="3">Typical/High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="2">AHRI</td><td>CWAF EERE 2015</td><td colspan="4">DOE CCD</td><td colspan="5" rowspan="9">Guidehouse</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>DOE CCD</td><td>CFR</td><td colspan="2">DOE CCD</td><td>CFR</td></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td colspan="6">Guidehouse</td></tr>
<tr><td>Average Life (y)</td><td colspan="6" rowspan="6">CWAF EERE 2015</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Oil-Fired Furnaces

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SOURCES	2012	2018	2022			2023		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	Typical/High		
Typical Input Capacity (kBtu/h)	AHRI	DOE CCD	DOE CCD				Guidehouse			
Thermal Efficiency (%)			10 CFR 431.77	DOE CCD		10 CFR 431.77				
Typical Output Capacity (kBtu/h)	Guidehouse									
Average Life (y)	CWAF EERE 2015									
Retail Equipment Cost (2022$)										
Total Installed Cost (2022$)										
Total Installed Cost (2022$/kBtu/h)										
Annual Maintenance Cost (2022$)										
Annual Maintenance Cost (2022$/kBtu/h)										

Commercial Electric Resistance Heaters

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SOURCES	2012		2018		2022		2030		2040		2050	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBtu/h)	Distributors/Guidehouse						Guidehouse					
Efficiency (%)	Guidehouse/DOE											
Average Life (y)	Technology Cost and Performance File for Commercial Model for AEO2010											
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)				Gordian's RSMeans Data – Building Construction Costs 2023							
Total Installed Cost (2022$)												
Total Installed Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$)	Guidehouse											
Annual Maintenance Cost (2022$/kBtu/h)												

Commercial Electric Boilers

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical			
Typical Capacity (kW)	BSRIA		Guidehouse			
Efficiency (%)	EERE / Guidehouse					
Average Life (y)	ASHRAE 2007 HVAC Applications	ASHRAE 2015 HVAC Applications	ASHRAE 2019 HVAC Applications			
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse			
Total Installed Cost (2022$)			Gordian's RSMeans Data – Building Construction Costs 2023			
Total Installed Cost (2022$/kBtu/h)						
Annual Maintenance Cost (2022$)			EIA Technology Forecast Updates (2018)			
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Gas-Fired Boilers

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SOURCES	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	Guidehouse	Comm. Packaged Boilers EERE 2020												
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Guidehouse	Comm. Packaged Boilers EERE 2020 / Guidehouse	DOE CCD			Comm. Packaged Boilers EERE 2020/Guidehouse								
Average Life (y)	Comm. Heating, AC, WH EERE 2009	Comm. Packaged Boilers EERE 2020												
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)													
Total Installed Cost (2022$)														
Total Installed Cost (2022$/kBtu/h)														
Annual Maintenance Cost (2022$)	Comm. Heating, AC, WH EERE 2009													
Annual Maintenance Cost (2022$/kBtu/h)														

Commercial Oil-Fired Boilers

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SOURCES	2012	2018	2022			2023			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	New Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	Guidehouse	Comm. Packaged Boilers EERE 2020												
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Guidehouse	Comm. Packaged Boilers EERE 2020 / Guidehouse	DOE CCD			Comm. Packaged Boilers EERE 2020/Guidehouse								
Average Life (y)	Comm. Heating, AC, WH EERE 2009	Comm. Packaged Boilers EERE 2020												
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)													
Total Installed Cost (2022$)														
Total Installed Cost (2022$/kBtu/h)														
Annual Maintenance Cost (2022$)	Comm. Heating, AC, WH EERE 2009													
Annual Maintenance Cost (2022$/kBtu/h)														

Commercial Centrifugal Chillers (Water-Cooled)

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>ASHRAE 90.1-2019</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="5">IPCC/ARB/TEAP/Guidehouse</td><td colspan="6" rowspan="10">Guidehouse</td></tr>
<tr><td>Efficiency (kW/ton)</td><td rowspan="2">ASHRAE 90.1-2010/FEMP/eSource/Product Literature</td><td colspan="4" rowspan="2">ASHRAE 90.1-2019/Product Lit</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (y)</td><td>2007 ASHRAE Applications Handbook</td><td colspan="4">2015 ASHRAE Applications Handbook A37 Table 4</td></tr>
<tr><td>Retail Equipment Cost (2022$/ton)</td><td rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="4" rowspan="3">Gordian’s RSMeans Data – Building Construction Costs 2023</td></tr>
<tr><td>Total Installed Cost (2022$/ton)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/ton)</td><td colspan="5" rowspan="2">Guidehouse/Alabama Power</td></tr>
<tr><td>Annual Maitnenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Reciprocating Chillers (Air-Cooled Only)

<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>ASHRAE 90.1-2019</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="2">BSRIA/DEER</td><td colspan="3">Guidehouse</td><td colspan="6" rowspan="9">Guidehouse</td></tr>
<tr><td>Efficiency (kW/ton)</td><td>ASHRAE 90.1-2010/DEER/ FEMP/Product Literature</td><td>ASHRAE 90.1-2016 (>150 TR)</td><td colspan="2" rowspan="2">ASHRAE 90.1-2019</td><td rowspan="2">Product Lit</td></tr>
<tr><td>COP</td><td>ASHRAE 90.1-2010/DEER/ FEMP/Product Literature</td><td>ASHRAE 90.1-2016 (>150 TR)</td></tr>
<tr><td>Average Life (y)</td><td>Manufacturers</td><td colspan="4">2015 ASHRAE Applications Handbook A37 Table 4</td></tr>
<tr><td>Retail Equipment Cost (2022$/ton)</td><td colspan="2" rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="3" rowspan="3">Gordian’s RSMeans Data – Building Construction Costs 2023</td></tr>
<tr><td>Total Installed Cost (2022$/ton)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/ton)</td><td colspan="5" rowspan="2">Guidehouse/Alabama Power</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Screw Chillers (Air-Cooled Only)

<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>ASHRAE 90.1-2019</th><th>Typical</th><th>High</th><th colspan="3">Typical/High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="5">Guidehouse</td><td colspan="3" rowspan="9">Guidehouse</td></tr>
<tr><td>Efficiency (kW/ton)</td><td rowspan="2">Guidehouse</td><td rowspan="2">ASHRAE 90.1-2016 (>150 TR)</td><td rowspan="2">ASHRAE 90.1-2019 (>150 TR)</td><td rowspan="2">ASHRAE 90.1-2019 (>150 TR)/Product Lit</td><td rowspan="2">Product Lit</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (y)</td><td>Manufacturers</td><td colspan="4">FacilitiesNet</td></tr>
<tr><td>Retail Equipment Cost (2022$/ton)</td><td colspan="2" rowspan="3">EIA Technology Forecast Updates (2018)</td><td colspan="3" rowspan="3">Gordian’s RSMeans Data – Building Construction Costs 2023 / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/ton)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/ton)</td><td colspan="5" rowspan="2">Guidehouse/Alabama Power</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Scroll Chillers (Air-Cooled Only)

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SOURCE	2012	2018	2022			2030	2040	2050
	Installed Base	Installed Base	ASHRAE 90.1-2019	Typical	High	Typical / High		
Typical Capacity (tons)	Guidehouse/Manufacturers					Guidehouse		
Efficiency [full-load/IPLV] (kW/ton)	Guidehouse	Product Lit/ Guidehouse	ASHRAE 90.1-2019 (>150 TR)	Product Lit/ Guidehouse	Product Lit			
COP [full-load/IPLV]								
Average Life (y)	Manufacturers							
Retail Equipment Cost (2022$/ton)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse					
Total Installed Cost (2022$/ton)								
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$/ton)	Guidehouse/Alabama Power							
Annual Maintenance Cost (2022$/kBtu/h)								

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

SOURCES	2012		2018		2022				2030	2040	2050
	Installed Base: Absorption	Installed Base: Engine-Driven	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1-2019 Absorption	CA Title 24 – Engine-Driven	Absorption	Engine-Driven	Absorption/Engine-Driven		
Typical Capacity (tons)	BSRIA/Distributors								Guidehouse		
COP [full-load]	Product Literature/ Guidehouse		Product Lit		ASHRAE 90.1-2019 Direct-fired Double Effect	CA Title 24 Gas Engine Standard	Product Lit				
COP [IPLV]											
Average Life (y)	2007 ASHRAE Applications Handbook/ Distributors		2015 ASHRAE Applications Handbook A37 Table 4								
Retail Equipment Cost (2022$/ton)	EIA Technology Forecast Updates (2018)				Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse						
Total Installed Cost (2022$/ton)											
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$/ton)	Guidehouse/Alabama Power										
Annual Maintenance Cost (2022$/kBtu/h)											

Commercial Rooftop Air Conditioners

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th colspan="4">2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.1</th><th>High</th><th>New Standard</th><th>Typical</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td>AHRI / Guidehouse</td><td colspan="9">CUAC EERE 2016</td><td colspan="6" rowspan="3">CUAC EERE 2016 / Guidehouse</td></tr>
<tr><td>Part Load Efficiency (IEER)</td><td colspan="4">CUAC EERE 2016</td><td>ENERGY STAR</td><td colspan="3">CUAC EERE 2016</td><td>ENERGY STAR</td><td>CUAC EERE 2016</td></tr>
<tr><td>Efficiency (EER)</td><td colspan="10">CUAC EERE 2016 / Guidehouse</td></tr>
<tr><td>Efficiency Conversion</td><td colspan="16">Calculated</td></tr>
<tr><td>Average Life (y)</td><td colspan="16">CUAC EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td rowspan="2">Distributors / Guidehouse / DEER, 2008</td><td colspan="15" rowspan="2">CUAC EERE 2016</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td><td colspan="16">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="16">CUAC EERE 2016</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td><td colspan="16">Calculated</td></tr>
</table>

Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base		Typical			
Typical Capacity (tons)	EIA Technology Forecast Updates (2018)		Guidehouse			
Heating COP						
Cooling COP						
Average Life (y)						
Retail Equipment Cost ($/ton)			Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse			
Total Installed Cost ($/ton)						
Total Installed Cost ($/kBtu/h)						
Annual Maintenance Cost (2022$)						
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Rooftop Heat Pumps

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th colspan="3">2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 3.1</th><th>High</th><th>New Standard</th><th>ENERGY STAR V. 4.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="9">CUHP EERE 2016</td><td colspan="6" rowspan="3">CUHP EERE 2016 / Guidehouse</td></tr>
<tr><td>Part Load Efficiency (IEER)</td><td colspan="4" rowspan="2">CUHP EERE 2016 / Guidehouse</td><td rowspan="2">ENERGY STAR</td><td colspan="2" rowspan="2">CUHP EERE 2016</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">CUHP EERE 2016</td></tr>
<tr><td>COP (Heating)</td></tr>
<tr><td>Average Life (y)</td><td rowspan="6">EIA Technology Forecast Updates (2018)</td><td colspan="14" rowspan="6">CUHP EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Final

Commercial Ground-Source Heat Pumps

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	U.S. DOE/EIA	Water-Source Unitary Heat Pumps EERE 2015 Final Rule				Guidehouse					
COP (Heating)	Guidehouse	AHRI Database									
EER (Cooling)											
Average Life (y)	Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule										
Retail Equipment Cost (2022$)	Distributors/Guidehouse	Water-Source Unitary Heat Pumps 2015 EERE Final Rule / Guidehouse									
Total Installed Cost (2022$)	U.S. DOD/IGSHPA/MA DOER/CEFIA/ASHRAE										
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$)	Geothermal Heat Pump Consortium, Inc. (U.S. DOE Contract DE-FG07-95ID13347)										
Annual Maintenance Cost (2022$/kBtu/h)											

Packaged Terminal Air Conditioners

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SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	PTAC & PTHP EERE 2022 NOPD					PTAC & PTHP EERE 2022 NOPD / Guidehouse					
Efficiency (EER)											
Efficiency											
Average Life (y)											
Retail Equipment Cost (2022$)											
Total Installed Cost (2022$)											
Total Installed Cost (2022$/kBtu/h)											
Annual Maintenance Cost (2022$)											
Annual Maintenance Cost (2022$/kBtu/h)											

Packaged Terminal Heat Pumps

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<table>
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<tr><td>Typical Capacity (kBtu/h)</td><td colspan="5" rowspan="10">PTAC & PTHP EERE 2022 NOPD</td><td colspan="6" rowspan="10">PTAC & PTHP EERE 2022 NOPD / Guidehouse</td></tr>
<tr><td>Efficiency (EER)</td></tr>
<tr><td>Efficiency</td></tr>
<tr><td>COP (Heating)</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
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Commercial Water Heating

Commercial Gas-Fired Storage Water Heaters

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SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR V. 2.0	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	EIA Technology Forecast Updates (2018)	CWH EERE 2022 NOPR										
Typical Input Capacity (kBtu/h)												
Thermal Efficiency (%)		DOE CCD / Guidehouse	CFR	DOE CCD / Guidehouse	ENERGY STAR	DOE CCD	CWH EERE 2022 NOPR / Guidehouse					
Average Life (y)		CWH EERE 2022 NOPR										
Retail Equipment Cost (2022$)	CWH EERE 2022 NOPR											
Total Installed Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$)												
Annual Maintenance Cost (2022$/kBtu/h)												
Annual Maintenance Cost (2022$/kBtu/h)												

Commercial Electric Resistance Storage Water Heaters

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SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical		
Typical Storage Capacity (gal)	Product Literature / Guidehouse	CWH EERE 2016 NOPR			Guidehouse		
Typical Input Capacity (kW)	Product Literature						
Typical Input Capacity (kBtu/h)							
Thermal Efficiency (%)	Guidehouse						
Average Life (y)	CWH EERE 2016 NOPR						
Retail Equipment Cost (2022$)	CWH EERE 2016 NOPR / Guidehouse	CWH EERE 2016 NOPR					
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)							
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Heat Pump Water Heaters

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SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.0	Typical	Typical	Typical
Water Flow Rate (gal/min)	Distributors/Guidehouse		Guidehouse				
Typical Output Capacity (kW)							
Typical Output Capacity (kBtu/h)							
Coefficient of Performance (COP_h)							
Average Life (y)	EERE/Guidehouse						
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)						
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)	Guidehouse						
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Oil-Fired Storage Water Heaters

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SOURCES	2012	2018	2022			2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical/High		
Typical Storage Capacity (gal)	AHRI / Guidehouse	DOE CCD/Guidehouse				Guidehouse		
Typical Input Capacity (kBtu/h)								
Thermal Efficiency (%)	Guidehouse		CFR	DOE CCD				
Average Life (y)	Commercial Heating, Air Conditioning and Water Heating Equipment EERE 2001							
Retail Equipment Cost (2022$)	Distributors / Guidehouse							
Total Installed Cost (2022$)								
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$)								
Annual Maintenance Cost (2022$/kBtu/h)								

Commercial Electric Booster Water Heaters

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SOURCES	2012	2018	2022	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical
Typical Capacity (gal)	Product Literature / Guidehouse					
Typical Output Capacity (kBtu/h)						
Thermal Efficiency (%)						
Average Life (y)						
Retail Equipment Cost (2022$)						
Total Installed Cost (2022$)						
Total Installed Cost (2022$/kBtu/h)						
Annual Maintenance Cost (2022$)						
Annual Maintenance Cost (2022$/kBtu/h)						

Commercial Gas-Fired Booster Water Heaters

Return to Table of Contents

SOURCES	2012	2018	2022		2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	Typical	Typical	Typical
Typical Capacity (gal)	Product Literature / Guidehouse				Guidehouse		
Typical Output Capacity (kBtu/h)							
Thermal Efficiency (%)							
Average Life (y)							
Retail Equipment Cost (2022$)							
Total Installed Cost (2022$)							
Total Installed Cost (2022$/kBtu/h)							
Annual Maintenance Cost (2022$)							
Annual Maintenance Cost (2022$/kBtu/h)							

Commercial Gas-Fired Instantaneous Water Heaters

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR V. 2.0</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="6">DOE CCD</td><td colspan="6" rowspan="2">DOE CCD / Guidehouse</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="2">Guidehouse/DOE CCD</td><td colspan="2">DOE CCD</td><td>ENERGY STAR</td><td>DOE CCD</td></tr>
<tr><td>Average Life (y)</td><td colspan="12" rowspan="6">CWH EERE 2022 NOPR</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Solar Water Heaters

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SOURCES	2012	2018	2022		2023	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 4.0	ENERGY STAR V. 5.0	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Guidehouse					Guidehouse		
Typical Capacity (m^2)								
Typical Capacity (Input) (kBtu/h) - North								
Typical Capacity (Input) (kBtu/h) - South								
Solar Uniform Energy Factor (SUEF)	ENERGY STAR / Guidehouse							
Average Life (y)	SRCC / Guidehouse							
Retail Equipment Cost (2022$)	EIA Technology Forecast Updates (2018)		Gordian's RSMeans Data – Building Construction Costs 2023 / Guidehouse					
Total Installed Cost (2022$)								
Total Installed Cost (2022$/kBtu/h) - North	Guidehouse							
Total Installed Cost (2022$/kBtu/h) - South								
Annual Maintenance Cost (2022$)	DOE / Guidehouse							
Annual Maintenance Cost (2022$/kBtu/h) - North								
Annual Maintenance Cost (2022$/kBtu/h) - South								

Commercial Cooking Products

Commercial Natural Gas Range with Griddle and Oven

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SOURCES	2012	2018	2022			2023	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR V. 2.2	High	ENERGY STAR V. 3.0	Typical/High		
Griddle - Cooking Energy Efficiency (%)	Guidehouse	FSTC	ENERGY STAR / FSTC	ENERGY STAR	ENERGY STAR	NA	Guidehouse		
Oven - Cooking Energy Efficiency (%)						ENERGY STAR			
Range - Cooking Energy Efficiency (%)			FEMP / CEC	NA	FEMP / CEC	NA			
Combined Energy Efficiency (%)	Guidehouse / FSTC								
Griddle - Normalized Idle Energy Rate (Btu/h/ft^2)	Guidehouse	FSTC	ENERGY STAR / FSTC	ENERGY STAR	ENERGY STAR	NA			
Oven - Idle Energy Rate (Btu/h)	FEMP		ENERGY STAR			ENERGY STAR			
Range - Idle Energy Rate (Btu/h)	FSTC			NA	FSTC	NA			
Combined Idle Energy Rate (Btu/h)	Guidehouse / FSTC / Distributors								
Average Life (y)	FSTC								
Retail Equipment Cost (2022$)	Distributors								
Total Installed Cost (2022$)	FSTC / Guidehouse								
Total Installed Cost (2022$/kBtu/h)									
Annual Maintenance Cost (2022$)	FSTC								
Annual Maintenance Cost (2022$/kBtu/h)									

Commercial Electric Range with Griddle and Oven

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th>2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>ENERGY STAR V. 2.2</th><th>High</th><th>ENERGY STAR V. 3.0</th><th colspan="3">Typical/High</th></tr>
<tr><td>Griddle - Cooking Energy Efficiency (%)</td><td rowspan="3">Guidehouse</td><td rowspan="3">FSTC</td><td rowspan="3">FSTC / ENERGY STAR / Guidehouse</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td>NA</td><td colspan="3" rowspan="14">Guidehouse</td></tr>
<tr><td>Oven - Cooking Energy Efficiency (%)</td><td>ENERGY STAR</td></tr>
<tr><td>Range - Cooking Energy Efficiency (%)</td><td>NA</td><td>CEC</td><td>NA</td></tr>
<tr><td>Combined Energy Efficiency (%)</td><td colspan="6">Guidehouse / FSTC</td></tr>
<tr><td>Griddle - Normalized Idle Energy Rate (kW/ft^2)</td><td rowspan="2">Guidehouse</td><td rowspan="2">FSTC</td><td rowspan="2">FSTC / ENERGY STAR / Guidehouse</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td>NA</td></tr>
<tr><td>Oven - Idle Energy Rate (kW)</td><td>ENERGY STAR</td></tr>
<tr><td>Range - Idle Energy Rate (kW)</td><td colspan="6">NA</td></tr>
<tr><td>Combined Idle Energy Rate (kW)</td><td colspan="6">Guidehouse / FSTC / Distributors</td></tr>
<tr><td>Average Life (y)</td><td colspan="6">FSTC</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6">Distributors</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="6" rowspan="2">FSTC / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6" rowspan="2">FSTC</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
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Commercial Hot Food Holding Cabinets – Small

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SOURCES	2012	2018	2022				2030	2040
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical/High	
Interior Volume (ft^3)	FEMP / ENERGY STAR						Guidehouse	
Maximum Idle Energy Rate (W)	CEE / Guidehouse	FEMP	ASAP	ASAP / ENERGY STAR	ENERGY STAR V. 2.0	FEMP / ENERGY STAR	Guidehouse	
Annual Energy Use (kWh/y)	FEMP						Guidehouse	
Average Life (y)	FEMP						Guidehouse	
Retail Equipment Cost (2022$)	Distributors / ENERGY STAR Savings Calculator / Guidehouse						Guidehouse	
Total Installed Cost (2022$)	Guidehouse						Guidehouse	
Total Installed Cost (2022$/kBtu/h)	Guidehouse						Guidehouse	
Annual Maintenance Cost (2022$)	FSTC						Guidehouse	
Annual Maintenance Cost (2022$/kBtu/h)	FSTC						Guidehouse	

Commercial Hot Food Holding Cabinets – Medium

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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th>2030</th><th>2040</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>State Standards</th><th>Typical</th><th>ENERGY STAR V. 2.0</th><th>High</th><th colspan="2">Typical/High</th></tr>
<tr><td>Interior Volume (ft^3)</td><td colspan="6">FEMP / ENERGY STAR</td><td colspan="2" rowspan="9">Guidehouse</td></tr>
<tr><td>Maximum Idle Energy Rate (W)</td><td>CEE / Guidehouse</td><td>FEMP</td><td>ASAP</td><td>ASAP / ENERGY STAR</td><td>ENERGY STAR V. 2.0</td><td>FEMP / ENERGY STAR</td></tr>
<tr><td>Annual Energy Use (kWh/y)</td><td colspan="6" rowspan="2">FEMP</td></tr>
<tr><td>Average Life (y)</td></tr>
<tr><td>Retail Equipment Cost (2022$)</td><td colspan="6">Distributors / ENERGY STAR Savings Calculator / Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="6" rowspan="2">Guidehouse</td></tr>
<tr><td>Total Installed Cost (2022$/kBtu/h)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td><td colspan="6" rowspan="2">FSTC</td></tr>
<tr><td>Annual Maintenance Cost (2022$/kBtu/h)</td></tr>
</table>

Commercial Hot Food Holding Cabinets – Large

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SOURCES	2012	2018	2022				2030	2040
	Installed Base	Installed Base	State Standards	Typical	ENERGY STAR V. 2.0	High	Typical/High	
Interior Volume (ft^3)	FEMP / ENERGY STAR						Guidehouse	
Maximum Idle Energy Rate (W)	CEE / Guidehouse	FEMP	ASAP	ASAP / ENERGY STAR	ENERGY STAR V. 2.0	FEMP / ENERGY STAR		
Annual Energy Use (kWh/y)	FEMP							
Average Life (y)								
Retail Equipment Cost (2022$)	Distributors / ENERGY STAR Savings Calculator / Guidehouse							
Total Installed Cost (2022$)	Guidehouse							
Total Installed Cost (2022$/kBtu/h)								
Annual Maintenance Cost (2022$)	FSTC							
Annual Maintenance Cost (2022$/kBtu/h)								

Appendix B
References

Guidehouse
1676 International Drive
McLean, VA 22102

And

Leidos
11951 Freedom Drive
Reston, VA 20190

- AHRI. Air Conditioners Monthly Shipments, Retrieved August 2022 from: https://ahrinet.org/statistics
- AHRI. Furnaces Historical Data, Retrieved August 2022 from: https://ahrinet.org/statistics
- Alabama Power (n.d.). Chillers: Compare Maintenance Costs. Retrieved September 2017 from: http://www.alabamapower.com/business/ways-to-save/chillers-space-cooling-options/compare-maintenance-costs.html
- ASAP. Hot Food Holding Cabinets. Retrieved October 2022 from https://appliance-standards.org/product/hot-food-holding-cabinets
- ASHRAE. (2004). ASHRAE Standard 90.1-2004. ASHRAE, Inc.
- ASHRAE. (2007). ANSI/ASHRAE/IESNA Standard 90.1-2007. ASHRAE, Inc.
- ASHRAE. (2016). ANSI/ASHRAE/IESNA Standard 90.1-2016. ASHRAE, Inc.
- ASHRAE. (2019). ANSI/ASHRAE/IESNA Standard 90.1-2019. ASHRAE, Inc.
- ASHRAE. (2015). 2015 ASHRAE Handbook – HVAC Applications. ASHRAE Inc.
- Building Services Research and Information Association & Ducker Research Company. (1997, 1998). U.S. Market for Central Plant Air Conditioning; Market for Ducted Warm Air Central Heating; U.S. Market for Hydronic Heating and Burners; U.S. Water Heating Market; U.S. Unitary and Close Control Air Conditioning.
- California Energy Commission. (2019). Building Energy Efficiency Standards for Residential and Nonresidential Buildings.
- CEC. (n.d.). California Energy Commission Appliance Efficiency Database. Retrieved 2004, September 2010, June 2013, and October 2022 from: http://www.appliances.energy.ca.gov/AdvancedSearch.aspx

References

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- CEE. (2009). "Commercial Hot Food Holding Cabinets Program Guide." Consortium for Energy Efficiency. April 2009.
- CFR. (n.d.). National energy conservation standards authorized under the Energy Policy and Conservation Act of 1975 (EPCA) and codified in the Code of Federal Regulations (CFR).
- DOE. (n.d.). *Estimating the Cost and Energy Efficiency of a Solar Water Heater*. Retrieved October 2022 from https://energy.gov/energysaver/estimating-cost-and-energy-efficiency-solar-water-heater
- DOE. (n.d.). Solar Water Heaters. Retrieved October 2022 from https://energy.gov/energysaver/solar-water-heaters
- Distributors. (n.d.). Guidehouse online research and discussions with distributors (e.g., Grainger, Home Depot, Lowe's, Sears, and others).
- EERE. (2001). Energy Efficiency Program for Commercial and Industrial Equipment; Efficiency Standards for Commercial Heating, Air Conditioning and Water Heating Equipment; Final Rule.
- EERE. (2007). Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers; Final Rule.
- EERE. (2008). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule.
- EERE. (2009). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards and Test Procedures for Commercial Heating, Air-Conditioning, and Water-Heating Equipment; Final Rule.
- EERE. (2010). Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule.

References

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- EERE. (2011). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Dryers and Room Air Conditioners; Direct Final Rule.
- EERE. (2011). Energy Conservation Program: Energy Conservation Standards for Residential Furnaces and Residential Central Air Conditioners and Heat Pumps; Direct Final Rule.
- EERE. (2011). Energy Conservation Program: Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers; Final Rule.
- EERE. (2012). Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers; Direct Final Rule.
- EERE. (2014). Energy Conservation Standards for Residential/Consumer Clothes Dryers.
- EERE. (2014). Energy Conservation Standards for Residential Conventional Cooking Products (Ovens).
- EERE. (2014). Energy Conservation Standards for Residential Furnaces.
- EERE. (2015). Energy Efficiency Program For Consumer Products And Commercial And Industrial Equipment: Commercial Warm Air Furnaces.
- EERE. (2015). Final Rule Technical Support Document: Energy Efficiency Program for Small, Large, and Very Large Commercial Package Air Conditioners.
- EERE. (2016). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces; Direct final rule and Technical Support Document.
- EERE. (2016). Energy Conservation Program: Energy Conservation Standards for Residential Boilers.

- EERE. (2016). Final Rule Technical Support Document: Energy Efficiency Program for Residential Central Air Conditioners and Heat Pumps.
- EERE. (2016). Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Commercial Water Heating Equipment: Notice of Proposed Rulemaking.
- EERE. (2017). Energy Conservation Standards for Residential Clothes Washers.
- EERE. (2020). Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers; Final rule
- EERE. (2020). Energy Conservation Program: Energy Conservation Standards for Portable Air Conditioners.
- EERE. (2020). Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Portable Air Conditioners.
- EERE. (2021). Energy Conservation Program: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers, and Freezers.; Preliminary Analysis
- EERE. (2021). Energy Conservation Program: Product Classes for Residential Dishwashers, Residential Clothes Washers, and Consumer Clothes Dryers.
- EERE. (2022). Energy Conservation Program: Energy Conservation Standards for Residential Boilers; Preliminary Analysis.
- EERE. (2022). Energy Conservation Program: Energy Conservation Standards for Room Air Conditioners; Notice of Proposed Rulemaking.
- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps; Notice of Proposed Determination.

References

- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Consumer Water Heaters; Preliminary Analysis.
- EERE (2022). Energy Conservation Program: Energy Conservation Standards for Commercial Water Heating Equipment; Notice of Proposed Rulemaking.
- EIA – Technology Forecast Updates – Residential and Commercial Building Technologies. (2018). Retrieved August 2022 from: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf
- ENERGY STAR Savings Calculator (n.d.). "Savings Calculator for ENERGY STAR Qualified Commercial Kitchen Equipment." U.S. EPA and DOE. Retrieved June 2013 from http://www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing
- ENERGY STAR. (n.d.). Retrieved June 2013, September 2017, and October 2022, from ENERGY STAR Products: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
- EPA. USEPA Certified Wood Stove Database. Retrieved August 2022 from: https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.search
- FacilitiesNet. (2009). Properly Diagnosing Chiller Life Cycles. Retrieved September 2017 from: http://www.facilitiesnet.com/hvac/article/Properly-Diagnosing-Chiller-Life-Cycles--10645
- FEMP. (2012). "Federal Energy Management Program: Covered Product Category: Hot Food Holding Cabinets." Retrieved June 2013 from: http://www1.eere.energy.gov/femp/technologies/printable_versions/eep_hot_food.html
- FEMP. (2016, August). Purchasing Energy-Efficient Air-Cooled Chillers. Retrieved September 2017, from FEMP Technologies: https://www1.eere.energy.gov/femp/technologies/eep_ac_chillers.html

References

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- FEMP. (2016, August). Purchasing Energy-Efficient Water-Cooled Electric Chillers. Retrieved September 2017, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-water-cooled-electric-chillers
- FEMP. (2020, June). Purchasing Energy-Efficient Air-Cooled Electric Chillers. Retrieved September 2022, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-air-cooled-electric-chillers
- FEMP. (2020, June). Purchasing Energy-Efficient Water-Cooled Electric Chillers. Retrieved September 2022, from FEMP Technologies: https://energy.gov/eere/femp/purchasing-energy-efficient-water-cooled-electric-chillers
- FEMP. (2021, December). Purchasing Energy-Efficient Hot Food Holding Cabinets. Retrieved October 2022 from FEMP Technologies: https://www.energy.gov/eere/femp/purchasing-energy-efficient-hot-food-holding-cabinets
- FSTC. (n.d.). Appliance Reports, Rangetop Performance Reports. Retrieved December 2017, from: https://fishnick.com/publications/appliancereports/rangetops/
- FSTC. (n.d.). Appliance Reports, Griddle Performance Reports. Retrieved December 2017, from: https://fishnick.com/publications/appliancereports/griddles/
- Gordian's RSMeans Data – Building Construction Costs 2023. Copyright RSMeans and Gordian. 30 Patewood Dr. Suite 350, Greenville, SC, 29615; All rights reserved.
- Guidehouse. (n.d.). In-House Expertise.
- Less et. al. (2021). The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes. Retrieved February 2023 from: https://eta-publications.lbl.gov/sites/default/files/final_walker_-_the_cost_of_decarbonization_and_energy.pdf
- IGSPHA. (n.d.). International Ground-Source Heat Pump Association. Retrieved 2007 from www.igshpa.okstate.edu

References

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- International Ground-Source Heat Pump Association (IGSHPA) Conference Proceedings. (2012, October). Measuring the Costs & Benefits of Nationwide Geothermal Heat Pump (GHP) Deployment – A Progress Report. Retrieved June 2013, from IGSHPA: http://www.igshpa.okstate.edu/membership/members_only/proceedings/2012/10-3-2012-0130-Session-C-Measuring-the-Costs-&-Benefits-of-Nationwide-Geothermal-Heat-Pump-(GHP)-Deployment-A-Progress-Report.pdf
- Manufacturers. (n.d.). Guidehouse discussions with product manufacturers.
- Product Literature. (n.d.). Literature from manufacturers and experts on specific products.
- Propane Education and Research Council (PERC). (2007). Assessment of Propane Fired Gas Air Conditioning, Heat Pumping and Dehumidification Technologies, Products, Markets and Economics
- Residential Energy Services Network. Draft PDS-01, MINHERS Addendum 71, SEER2/HSPF2 Conversions. Retrieved February 2023 from: https://www.resnet.us/about/standards/minhers/draft-pds-01-minhers-addendum-71-seer2-hspf2-conversions/
- Solar Rating and Certification Corporation (SRCC). (n.d.) Solar Uniform Energy Factor Specification. Retrieved October 2022 from: https://solar-rating.org/resources/suef/
- Technology Cost and Performance File for Commercial Model for AEO2010. (2009). (E. Boedecker, Compiler)
- U.S. Department of Energy's Compliance Certification Database. Retrieved August 2022 to February 2023 from: http://www.regulations.doe.gov/certification-data/

APPENDIX C

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

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DISCLAIMER

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Objective

The objective of this study is to develop baseline and projected performance and cost characteristics for residential and commercial end-use equipment.

- Examine 2012 and 2018 (commercial) and 2015 and 2020 (residential) baselines, as well as this year's baseline (2022).
  - Review literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost and efficiency of a generic product.
- Forecast technology improvements that are projected to be available through 2050.
  - Review trends in standards, product enhancements, and research and development (R&D).
  - Project impact of product improvements and technology enhancement.

The performance and cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Methodology

Input from industry stakeholders, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments affect performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 and 2018 (for commercial products) and 2015 and 2020 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

— **Installed Stock Average**: the installed and *in use* equipment for that year. Represents the installed stock of equipment, but does *not* represent sales.

— **Current Standard**: the minimum efficiency (or maximum energy use) required (allowed) by current U.S. Department of Energy (DOE) standards, when applicable. For lighting, if no product exists at the standard efficiency level, a hypothetical wattage and lumen output is given for the standard's efficiency level.

— **ENERGY STAR®**: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR® criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications. For lighting, if no products exist at the ENERGY STAR efficiency level, a hypothetical wattage and lumen output is given for the ENERGY STAR efficiency level.

— **Low**: The minimum efficiency product or product mix available on the market. This rating typically reflects minimal compliance with DOE standards.

— **Typical**: the average, or typical, product being sold in the particular timeframe.

— **High**: the product with the highest efficiency available in the particular timeframe.

— **Lumens (lm):** the unit for luminous flux used in the SI unit system. This unit is used to indicate a light source's light output. All reported lumens are initial lumens. 1 kilolumen (klm) = 1,000 lumens.

— **Correlated Color Temperature (CCT)**: a specification of the color appearance of the light emitted by a lamp. Note: CCT is not a performance metric.

— **Color Rendering Index (CRI)**: a scale from 0 to 100 percent indicating how accurate a given light source is at rendering color when compared to a reference light source. The higher the CRI, the better the color rendering ability.

— **British thermal unit (Btu)**: a measure of the heat content of fuels or energy sources. It is the quantity of heat required to raise the temperature of one pound of liquid water by 1°F at the temperature that water has its greatest density (approximately 39 °F). 1 kBtu = 1,000 Btu.

— **Cubic Feet per Minute (CFM)**: a measure of airflow volume equal to the number of cubic feet of air flowing through a two-dimensional plane in one minute.

— **Not Available (N/A)**: data is not available where indicated.

Calculations

The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric

- **Lighting**
  - **System Wattage** = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
  - **System Lumens** = Lamp Lumens * Ballast Factor
  - **Lamp Efficacy** = Lamp Lumens / Lamp Wattage
  - **System Efficacy** = System Lumens / System Wattage
  - **Lamp Cost ($/klm)** = Lamp Cost / (Lamp Lumens / 1,000)
  - **Total Equipment Cost** = Lamp Cost + Fixture (including ballast) Cost
  - **System Cost ($/klm)** = Total Equipment Cost / (System Lumens / 1,000). l/b/f denotes that the cost includes the luminaire, the ballast, and the fixture.
  - **Total Installed Cost** = Total Equipment Cost + Labor Installation Cost
  - **Ballast Luminous Efficiency (BLE)** = A/(1+B*Avg Total Lamp Arc Power^(-C)) where A, B, and C are pre-defined constants by DOE Energy Conservation Standards for Fluorescent Lamp Ballasts.
- **Commercial Refrigeration**
  - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3,412)
  - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
  - **Total Installed Cost ($/kBtu/hour)** = Total Installed Cost*1,000 / (Cooling or Heat Rejection Capacity). h used as an abbreviation for hour throughout
  - **Annual Maintenance Cost ($/kBtu/h)** = Annual Maintenance Cost * 1,000 / (Cooling or Heat Rejection Capacity)
- **Ventilation**
  - **CFM out / Btu in / h** = System Airflow / (System Fan Power * 3,412)
  - **Total Installed Cost ($/1,000 CFM)** = Total Installed Cost * 1,000 / System Airflow
  - **Annual Maintenance Cost ($/1,000 CFM)** = Annual Maintenance Cost * 1,000 / System Fan Power

Market Transformation

The market for the reviewed products has changed since this analysis was performed in 2015. These changes are noted and reflected in the efficiency and cost characteristics.

- DOE issued federal minimum efficiency standards that have gone into effect for General Service Fluorescent Lamps (2012), Incandescent Reflector Lamps (2012), and Fluorescent Lamp Ballasts (2019).

- In April 2022, DOE codified into the Code of Federal Regulations the 45 lumens per watt (lm/W) backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act (10 CFR 430, 87 FR 27439). This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

- DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018. DOE also issued federal minimum efficiency standards that have or will soon go into effect for Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017), and Commercial Refrigeration Equipment (2017).

Residential Lighting

The residential general service lamps characterized in this report are a 60-watt and a 75-watt medium screw-based (E26) A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60-watt incandescent lamp produces approximately 800 – 850 lumens. A standard 75-watt incandescent lamp produces approximately 1,100 lumens.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60-watt general service lamps, effective in 2014, and 75-watt lamps, effective in 2013. These standards cannot be achieved by incandescent bulbs, but can be by halogen, CFL, and LED technologies.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent, halogen, and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022.
CFL	+0.5%	0%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps.

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	60.0	60.0	N/A	N/A	N/A	N/A	18.9	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	850	850	N/A	N/A	N/A	N/A	850	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.2	14.2	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	511	511	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$0.30	$0.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$0.34	$0.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$0.30	$0.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$0.15	$0.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$0.35	$0.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.18	$0.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Despite the phase out of incandescent lamps, these products remain in the installed stock.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with incandescent technologies.

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	75.0	75.0	N/A	N/A	N/A	N/A	26.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,170	1,170	N/A	N/A	N/A	N/A	1,170	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	15.6	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	0.8	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	511	511	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$0.44	$0.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$0.38	$0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$0.44	$0.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$0.30	$0.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$0.38	$0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.26	$0.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 75 watt incandescent lamps as of January 1, 2013. Despite the phase out of incandescent lamps, these products remain in the installed stock.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with incandescent technologies.

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	43.1	43.1	N/A	43.0	N/A	N/A	16.7	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	750	750	N/A	750	N/A	N/A	750	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	17.4	17.4	N/A	17.4	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	621	621	N/A	621	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$2.36	$4.90	N/A	$5.92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$3.15	$6.54	N/A	$7.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$2.36	$4.90	N/A	$5.92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.47	$3.04	N/A	$3.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$3.15	$6.54	N/A	$7.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.95	$4.06	N/A	$4.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, 60 watt incandescent lamps were replaced by halogen lamps.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with existing halogen lamp technologies.

Performance and Cost Characteristics » Residential General Service Halogen Lamps (75 W Incandescent Equivalent)

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	53.0	53.0	N/A	53.0	N/A	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,050	936	N/A	890	N/A	N/A	890	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.8	17.7	N/A	16.8	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,950	N/A	2,950	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	621	621	N/A	621	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$2.37	$3.58	N/A	$4.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$2.26	$3.82	N/A	$4.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$2.37	$3.58	N/A	$4.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.47	$2.22	N/A	$2.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$2.26	$3.82	N/A	$4.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.40	$2.37	N/A	$2.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with existing halogen lamp technologies.

Performance and Cost Characteristics » Residential General Service Compact Fluorescent Lamps (60 W Incandescent Equivalent)

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[4]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	13.0	13.1	14.0	13.0	13.0	13.8	20.0	12.5	12.5	11.9	11.9	11.3	11.3
Lamp Lumens	825	900	900	900	925	800	900	900	925	900	925	900	925
Lamp Efficacy (lm/W) [3]	63.5	68.5	64.3	69.2	71.2	80.0	45.0	72.0	74.1	75.7	77.8	79.6	81.8
CRI	82	82	82	82	82	80	N/A	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	10.0	10.0	10.0	10.0	12.0	10.0	N/A	10.0	12.0	10.0	12.0	10.0	12.0
Annual Operating Hours (h/y)	767	767	767	767	767	N/A	N/A	767	767	767	767	767	767
Lamp Price (2022$)	$2.55	$5.40	$1.50	$5.35	$4.63	N/A	N/A	$5.14	$4.45	$4.89	$4.23	$4.65	$4.02
Lamp Cost (2022$/klm)[3]	$3.10	$6.00	$1.67	$5.94	$5.01	N/A	N/A	$5.71	$4.81	$5.43	$4.57	$5.17	$4.35
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0	0	0	0	0	N/A	N/A	0	0	0	0	0	0
Total Installed Cost (2022$)	$2.55	$5.40	$1.50	$5.35	$4.63	N/A	N/A	$5.14	$4.45	$4.89	$4.23	$4.65	$4.02
Annual Maintenance Cost (2022$)	$0.20	$0.41	$0.12	$0.41	$0.30	N/A	N/A	$0.39	$0.28	$0.37	$0.27	$0.36	$0.26
Total Installed Cost (2022$/klm)	$3.09	$6.00	$1.67	$5.94	$5.01	N/A	N/A	$5.71	$4.81	$5.43	$4.57	$5.17	$4.35
Annual Maintenance Cost (2022$/klm)	$0.24	$0.46	$0.13	$0.46	$0.32	N/A	N/A	$0.44	$0.31	$0.42	$0.29	$0.40	$0.28

1. 2020 data back calculated based on 2022 data and the following assumptions: Efficacy +0.5%/y, Cost -0.5%/y (NCI, 2019)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards can be met with existing CFL products.
3. Year-to-year price and performance assumptions for incumbent technologies from 2022 to 2050: Efficacy +0.5%/y, Cost -0.5%/y (NCI, 2019)
4. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	8.7	9.2	10.0	8.9	8.0	10.0	17.8	7.3	6.6	5.8	5.2	5.0	4.5
Lamp Lumens	656	803	800	800	800	800	800	800	800	800	800	800	800
Lamp Efficacy (lm/W)	75.5	87.1	80.0	90.0	100.0	80.0	45.0	108.9	120.9	138.6	154.0	160.7	178.6
CRI	81	85	80	81	90	80	N/A	81	90	81	90	81	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	21	15	14	18	15.0	N/A	14	18	14	18	14	18
Annual Operating Hours (h/y)	657	657	657	657	657	657	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$13.53	$4.56	$6.20	$3.92	$5.32	$6.20	N/A	$3.23	$4.39	$2.84	$3.86	$2.46	$3.33
Lamp Cost (2022$/klm)	$20.63	$5.68	$7.75	$4.90	$6.65	$7.75	N/A	$4.04	$5.49	$3.56	$4.83	$3.07	$4.17
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$13.53	$4.56	$6.20	$3.92	$5.32	$6.20	N/A	$3.23	$4.39	$2.84	$3.86	$2.46	$3.33
Annual Maintenance Cost (2022$)	$0.35	$0.15	$0.27	$0.18	$0.19	$0.27	N/A	$0.15	$0.16	$0.13	$0.14	$0.11	$0.12
Total Installed Cost (2022$/klm)	$20.63	$5.68	$7.75	$4.90	$6.65	$7.75	N/A	$4.04	$5.49	$3.56	$4.83	$3.07	$4.17
Annual Maintenance Cost (2022$/klm)	$0.54	$0.18	$0.34	$0.22	$0.24	$0.34	N/A	$0.18	$0.20	$0.16	$0.17	$0.14	$0.15

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential General Service Filament-LED Lamps (60 W Incandescent Equivalent)

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	9.7	7.1	5.5	6.9	8.0	13.8	17.8	7.0	6.6	5.5	5.2	4.7	4.5
Lamp Lumens	457	650	450	650	800	800	800	800	800	800	800	800	800
Lamp Efficacy (lm/W)	47.1	91.7	81.8	94.8	100.0	80.0	45.0	114.6	120.9	146.0	154.0	169.3	178.6
CRI	82	84	90	84	80	80	N/A	81	90	81	90	81	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	23	21	15	15	15	15	N/A	15	15	15	15	15	15
Annual Operating Hours (h/y)	657	657	657	657	657	N/A	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$15.17	$6.88	$6.25	$5.91	$7.75	N/A	N/A	$4.87	$6.39	$4.29	$5.62	$3.70	$4.86
Lamp Cost (2022$/klm)	$33.20	$10.58	$13.89	$9.09	$9.69	N/A	N/A	$6.09	$7.99	$5.36	$7.03	$4.63	$6.07
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$15.17	$6.88	$6.25	$5.91	$7.75	N/A	N/A	$4.87	$6.39	$4.29	$5.62	$3.70	$4.86
Annual Maintenance Cost (2022$)	$0.43	$0.21	$0.27	$0.26	$0.34	N/A	N/A	$0.21	$0.28	$0.19	$0.25	$0.16	$0.21
Total Installed Cost (2022$/klm)	$33.20	$10.58	$13.89	$9.09	$9.69	N/A	N/A	$6.09	$7.99	$5.36	$7.03	$4.63	$6.07
Annual Maintenance Cost (2022$/klm)	$0.93	$0.33	$0.61	$0.40	$0.42	N/A	N/A	$0.27	$0.35	$0.23	$0.31	$0.20	$0.27

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential Reflector Lamps

The residential reflector lamps characterized in this report are directional lamps that emit approximately 550 – 850 lumens (except for LED PAR38s which have outputs up to 1,700 lumens). Multiple baseline reflector lamps were analyzed, including 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, and LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- EPAct92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPAct92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPAct92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market, was still exempted until 2022.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service, reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022.
CFL	+0.5%	0%	-0.5%	In addition to higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	65.0	65.0	N/A	65.0	N/A	N/A	13.3	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	637	637	N/A	602	N/A	N/A	600	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	9.8	9.8	N/A	9.3	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	2.0	2.0	N/A	2.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	621	621	N/A	621	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$4.00	$4.00	N/A	$3.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$6.28	$6.28	N/A	$6.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$4.00	$4.00	N/A	$3.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.24	$1.24	N/A	$1.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$6.28	$6.28	N/A	$6.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.95	$1.95	N/A	$1.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Incandescent BR30 lamps were previously exempted from DOE Incandescent Reflector Lamp standards and the EISA 2007 general service lamp definition until DOE's new final rule in 2022. The new definitions go into effect in 2023.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with incandescent technologies.

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	47.1	38.8	N/A	38.8	N/A	N/A	12.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	660	576	N/A	542	N/A	N/A	542	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.0	14.0	N/A	14.0	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.5	1.5	N/A	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	876	876	N/A	876	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$6.77	$8.13	N/A	$8.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$10.26	$14.12	N/A	$16.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$6.77	$8.13	N/A	$8.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$3.96	$4.75	N/A	$5.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$10.26	$14.12	N/A	$16.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$5.99	$8.25	N/A	$9.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Halogen PAR30 lamps were previously exempted from the EISA 2007 GSL definition until DOE's new final rule in 2022. The new definitions go into effect in 2023. Note: product offerings are very limited in 2022.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with halogen technologies.

Performance and Cost Characteristics » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR))

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	38.9	45.5	N/A	48.0	N/A	N/A	18.7	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	650	786	N/A	840	N/A	N/A	840	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.7	17.3	N/A	17.5	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	4.0	4.0	N/A	4.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	876	876	N/A	876	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$14.69	$25.62	N/A	$29.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$22.59	$32.60	N/A	$35.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$14.69	$25.62	N/A	$29.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$3.22	$5.61	N/A	$6.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$22.59	$32.60	N/A	$35.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$4.95	$7.14	N/A	$7.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Halogen PAR30 lamps were previously exempted from the EISA 2007 GSL definition until DOE's new final rule in 2022. The new definitions go into effect in 2023. Note: product offerings are very limited in 2022.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with halogen technologies.

Performance and Cost Characteristics » Residential Reflector Lamps (BR30 CFL)

DATA	2015[1]	2020[1]	2022[2]				2023[3]	2030[3]		2040[3]		2050[3]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[4]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	15.5	15.1	N/A	N/A	N/A	N/A	16.7	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	750	750	N/A	N/A	N/A	N/A	750	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	48.3	49.5	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	82	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	8.2	8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	913	913	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$6.76	$6.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$9.01	$8.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$6.76	$6.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$0.75	$0.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$9.01	$8.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.00	$0.95	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. 2015 and 2020 data calculated based on 2009 installed stock data and the following assumptions: Efficacy +0.5%/y, Cost -0.5%/y (NCI, 2019)
2. Virtually all manufacturers have discontinued manufacturing of CFL reflector lamps in favor of LEDs. Distributor offerings for CFL reflectors have been eliminated.
3. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. Although these standards can be met with CFL technology, manufacturers have discontinued manufacturing CFL reflector lamps in favor of LEDs.
4. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

DATA	2015	2020	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	14.2	10.9	11.0	8.8	7.2	10.7	14.4	7.1	6.2	6.2	5.4	5.5	4.8
Lamp Lumens	706	781	800	683	650	650	650	650	650	650	650	650	650
Lamp Efficacy (lm/W)	49.8	71.5	72.7	78.6	90.3	61.0	45.0	91.7	105.4	104.9	120.5	118.0	135.6
CRI	82	85	92	87	90	80	N/A	87	90	87	90	87	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	25	25	19	18	15	N/A	19	18	19	18	19	18
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$21.40	$15.36	$4.09	$5.01	$5.96	N/A	N/A	$4.11	$4.89	$3.62	$4.31	$3.14	$3.74
Lamp Cost (2022$/klm)	$30.31	$19.66	$5.11	$7.33	$9.17	N/A	N/A	$6.32	$7.53	$5.57	$6.64	$4.83	$5.75
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$21.40	$15.36	$4.09	$5.01	$5.96	N/A	N/A	$4.11	$4.89	$3.62	$4.31	$3.14	$3.74
Annual Maintenance Cost (2022$)	$0.63	$0.45	$0.12	$0.20	$0.24	N/A	N/A	$0.16	$0.19	$0.14	$0.17	$0.12	$0.15
Total Installed Cost (2022$/klm)	$30.31	$19.66	$5.11	$7.33	$9.17	N/A	N/A	$6.32	$7.53	$5.57	$6.64	$4.83	$5.75
Annual Maintenance Cost (2022$/klm)	$0.89	$0.57	$0.15	$0.29	$0.37	N/A	N/A	$0.25	$0.30	$0.22	$0.26	$0.19	$0.23

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential Reflector LED PAR38

DATA	2015	2020	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	19.2	15.5	17.0	16.4	17.0	22.0	29.9	14.0	14.6	12.3	12.7	10.9	11.3
Lamp Lumens	1,202	1,211	1,200	1,344	1,700	1,344	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	62.7	77.9	70.6	82.0	100.0	61.0	45.0	95.7	116.7	109.5	133.5	123.2	150.2
CRI	83	86	82	86	82	80	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	3,000	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	24	27	25	27	25	15	N/A	27	25	27	25	27	25
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Lamp Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Annual Maintenance Cost (2022$)	$1.07	$0.60	$0.69	$0.62	$0.46	N/A	N/A	$0.52	$0.38	$0.46	$0.34	$0.41	$0.31
Total Installed Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Annual Maintenance Cost (2022$/klm)	$0.89	$0.49	$0.58	$0.46	$0.27	N/A	N/A	$0.39	$0.23	$0.35	$0.20	$0.31	$0.18

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. All LED lighting products exceed the new minimum efficacy standards.

This section characterizes commercial linear fixtures that house two 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp or fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- Residential linear lamps often have a nominal CCT rating of 3,500K, but products with CCTs of 3,000K, 4,000K, and 4,100K (neutral white) are also common. 5,000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps, which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible because homeowners likely replace lamps themselves as they burn out. Therefore, annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for residential linear systems.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards required that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover linear lamps. (ENERGY STAR, 2020)

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited because the technology is mature.
T8	0%	0%	-0.5%	Limited because the technology is mature.
T5	0%	0%	-0.5%	Limited because the technology is mature.

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	40.0	40.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	2,860	2,860	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	72	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	70.0	82.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	3,890	5,148	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	56	62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	78%	87%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	4,100	4,100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	15	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	694	694	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$1.10	$1.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price (2022$)	$13.31	$13.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$34.67	$34.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$0.38	$0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (lamp, ballast, and fixture (l/b/f)) Cost (2022$/klm)	$12.90	$12.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hours)	0.5	0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$39.71	$39.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.84	$1.84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$10.21	$10.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.47	$0.47	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note: Assume no labor is associated with lamp replacement in the residential sector because residents likely replace the lamps themselves.
Assume real cost has not changed since 2009 because this product has been phased out.

Performance and Cost Characteristics » Residential Linear Fluorescent Lamp T8

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	30.8	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Lamp Lumens	2,770	2,855	2,450	2,855	3,100	2,855	3,100	2,855	3,100	2,855	3,100
Lamp Efficacy (lm/W)[1]	90	89	77	89	97	89	97	89	97	89	97
System Wattage	62.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1
System Lumens	4,875	5,082	4,361	5,082	5,518	5,082	5,518	5,082	5,518	5,082	5,518
System Efficacy (lm/W)	78	81	69	81	87	81	87	81	87	81	87
Ballast Efficiency (BLE)	87%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
CRI	85	87	90	87	85	87	85	87	85	87	85
Correlated Color Temperature (CCT)	4,100	4,100	5,000	4,100	3,500	4,100	3,500	4,100	3,500	4,100	3,500
Average Lamp Life (thousand hours)	21	31	23	31	40	31	40	31	40	31	40
Annual Operating Hours (h/y)	767	767	767	767	767	767	767	767	767	767	767
Lamp Price (2022$)	$6.54	$4.12	$3.36	$4.08	$4.32	$3.92	$4.15	$3.73	$3.95	$3.55	$3.75
Ballast Price (2022$)[2]	$19.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$29.23	$76.29	$75.53	$75.53	$75.53	$72.56	$72.56	$69.01	$69.01	$65.64	$65.64
Lamp Cost (2022$/klm)	$2.36	$1.44	$1.37	$1.43	$1.39	$1.37	$1.34	$1.31	$1.27	$1.24	$1.21
System (l/b/f) Cost (2022$/klm)	$12.59	$29.61	$33.57	$29.31	$27.15	$27.19	$25.18	$25.86	$23.95	$24.60	$22.78
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$100.01	$189.07	$179.41	$181.97	$182.82	$171.18	$171.97	$164.42	$165.18	$158.00	$158.71
Annual Maintenance Cost (2022$)	$0.48	$0.21	$0.22	$0.20	$0.17	$0.19	$0.16	$0.18	$0.15	$0.18	$0.14
Total Installed Cost (2022$/klm)	$20.51	$37.20	$41.14	$35.81	$33.13	$33.68	$31.17	$32.35	$29.93	$31.09	$28.76
Annual Maintenance Cost (2022$/klm)	$0.10	$0.04	$0.05	$0.04	$0.03	$0.04	$0.03	$0.04	$0.03	$0.03	$0.03

1. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future, and that the cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
2. From 2020 to 2050, fixture (and fixture price) includes ballast.

Note: Assume no labor is associated with lamp replacement in the residential sector because residents likely replace lamps themselves.

Performance and Cost Characteristics » Residential Linear Fluorescent Lamp T5

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	27.0	27.5	28.0	27.5	26.0	27.5	26.0	27.5	26.0	27.5	26.0
Lamp Lumens	2,697	2,732	2,530	2,732	2,900	2,732	2,900	2,732	2,900	2,732	2,900
Lamp Efficacy (lm/W)[1]	100	99	90	99	112	99	112	99	112	99	112
System Wattage	51.5	61.7	62.9	61.7	58.4	61.7	58.4	61.7	58.4	61.7	58.4
System Lumens	4,747	5,464	5,060	5,464	5,800	5,464	5,800	5,464	5,800	5,464	5,800
System Efficacy (lm/W)	92	89	81	89	99	89	99	89	99	89	99
Ballast Efficiency (BLE)	92%	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%
CRI	85	85	85	85	85	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4,100	4,100	5,000	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	30	29	36	29	30	29	30	29	30	29	30
Annual Operating Hours (h/y)	949	949	949	949	949	949	949	949	949	949	949
Lamp Price (2022$)	$7.05	$9.54	$13.76	$9.45	$21.28	$9.08	$20.44	$8.63	$19.44	$8.21	$18.49
Ballast Price (2022$)[2]	$31.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$109.93	$170.87	$170.87	$170.87	$170.87	$164.15	$164.15	$156.13	$156.13	$148.50	$148.50
Lamp Cost (2022$/klm)	$2.61	$3.49	$5.44	$3.46	$7.34	$3.32	$7.05	$3.16	$6.70	$3.01	$6.38
System (l/b/f) Cost (2022$/klm)	$32.69	$34.77	$39.21	$34.73	$36.80	$33.37	$35.35	$31.73	$33.62	$30.18	$31.98
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$193.80	$228.57	$231.39	$222.77	$246.43	$215.31	$238.04	$206.40	$228.02	$197.92	$218.48
Annual Maintenance Cost (2022$)	$0.45	$0.62	$0.73	$0.62	$1.35	$0.59	$1.29	$0.57	$1.23	$0.54	$1.17
Total Installed Cost (2022$/klm)	$40.83	$41.83	$45.73	$40.77	$42.49	$39.41	$41.04	$37.77	$39.31	$36.22	$37.67
Annual Maintenance Cost (2022$/klm)	$0.09	$0.11	$0.14	$0.11	$0.23	$0.11	$0.22	$0.10	$0.21	$0.10	$0.20

1. Year-to-year price and performance assumptions for incumbent technologies 2030–2050: Efficacy +0.5%/yr, Life +0.5%/yr, Cost -0.5%/yr (SSL Forecast 2018). 2020 data back calculated using the 2022 data and these assumptions
2. From 2020 to 2050, fixture (and fixture price) includes ballast.

Note: Assume no labor is associated with lamp replacement in the residential sector because residents likely replace lamps themselves.

Performance and Cost Characteristics » Residential Linear LED Replacement Lamp 2-Lamp System

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	18.5	16.3	16.0	13.7	11.0	11.6	9.3	10.0	8.0	8.8	7.2
Lamp Lumens	2,013	2,130	1,800	1,920	1,800	1,920	1,800	1,920	1,800	1,920	1,800
Lamp Efficacy (lm/W)	111.0	130.7	112.5	140.1	163.6	166.2	194.1	192.2	224.4	218.0	250.0
System Wattage	36.9	32.6	32.0	27.4	22.0	23.1	18.6	20.0	16.0	17.6	14.4
System Lumens	3,583	4,004	3,384	3,686	3,456	3,686	3,456	3,686	3,456	3,686	3,456
System Efficacy (lm/W)	97.0	122.8	105.8	134.5	157.1	159.6	186.3	184.5	215.4	209.3	240.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	82	82	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	4,100	3,500	4,100	4,100	5,000	4,100	5,000	4,100	5,000	4,100	5,000
Average Lamp Life (thousand hours)	55	50	50	54	50	54	50	54	50	54	50
Annual Operating Hours (h/y)	730	730	730	730	730	730	730	730	730	730	730
Lamp Price (2022$)	$27.00	$12.89	$14.63	$11.11	$4.28	$9.97	$3.84	$9.87	$3.80	$9.77	$3.77
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$13.41	$6.05	$8.13	$5.79	$2.38	$5.19	$2.13	$5.14	$2.11	$5.09	$2.09
System (l/b/f) Cost (2022$/klm)	N/A	$6.44	$8.65	$6.03	$2.48	$5.41	$2.22	$5.35	$2.20	$5.30	$2.18
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$54.00	$25.78	$29.26	$22.22	$8.56	$19.95	$7.68	$19.74	$7.60	$19.55	$7.53
Annual Maintenance Cost (2022$)	$0.72	$0.38	$0.43	$0.30	$0.12	$0.27	$0.11	$0.27	$0.11	$0.26	$0.11
Total Installed Cost (2022$/klm)	$15.07	$6.44	$8.65	$6.03	$2.48	$5.41	$2.22	$5.35	$2.20	$5.30	$2.18
Annual Maintenance Cost (2022$/klm)	$0.20	$0.09	$0.13	$0.08	$0.04	$0.07	$0.03	$0.07	$0.03	$0.07	$0.03

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

Note: Assume no labor is associated with lamp replacement in the residential sector because residents likely replace lamps themselves.

Performance and Cost Characteristics » Residential Linear LED Luminaire

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	50.0	43.1	49.0	44.0	35.0	35.6	28.3	29.9	23.8	25.8	20.5
System Lumens	4,615	4,945	5,024	5,302	4,800	5,302	4,800	5,302	4,800	5,302	4,800
System Efficacy (lm/W)	92.3	114.7	102.5	120.5	137.1	148.8	169.3	177.2	201.7	205.5	233.9
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	82	80	79	80	79	80	79	80	79	80
Correlated Color Temperature (CCT)	3,838	3,000	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	56	58	54	53	50	53	50	53	50	53	50
Annual Operating Hours (h/y)	584	584	584	584	584	584	584	584	584	584	584
Lamp or Luminaire Price (2022$)	$181.60	$158.60	$144.85	$152.54	$207.80	$121.11	$164.98	$105.34	$143.50	$90.11	$122.76
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$78.70	$64.15	$57.66	$57.54	$86.58	$45.68	$68.74	$39.74	$59.79	$33.99	$51.15
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$401.81	$355.81	$322.70	$338.08	$448.60	$275.22	$362.97	$243.68	$320.01	$213.23	$278.52
Annual Maintenance Cost (2022$)	$2.30	$1.97	$1.92	$2.04	$2.81	$1.70	$2.31	$1.52	$2.06	$1.36	$1.82
Total Installed Cost (2022$/klm)	$87.07	$71.95	$64.23	$63.76	$93.46	$51.91	$75.62	$45.96	$66.67	$40.22	$58.03
Annual Maintenance Cost (2022$/klm)	$0.50	$0.40	$0.38	$0.39	$0.59	$0.32	$0.48	$0.29	$0.43	$0.26	$0.38

1. N/A because the lamp and fixture are both included in the luminaire.

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1,000 – 1,400 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application. This product is, as of 2022, expected to be eliminated by DOE's 45 lm/W backstop requirement.
- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours for residential reflector lamps.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **<u>This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.</u>** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90.
- For ENERGY STAR qualification, general service reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90.
- Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Incandescent Directional	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
CFL	+0.5%	0%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Residential Outdoor Lamps (Security: Incandescent BR30)

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	65.0	65.0	N/A	65.0	N/A	N/A	13.3	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	637	637	N/A	602	N/A	N/A	600	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	9.8	9.8	N/A	9.3	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	2.0	2.0	N/A	2.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	621	621	N/A	621	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$4.00	$4.00	N/A	$3.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$6.28	$6.28	N/A	$6.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$4.00	$4.00	N/A	$3.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.24	$1.24	N/A	$1.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$6.28	$6.28	N/A	$6.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.95	$1.95	N/A	$1.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Incandescent BR30 lamps were previously exempted from DOE Incandescent Reflector Lamp standards and the EISA 2007 general service lamp definition until DOE's new final rule in 2022. The new definitions go into effect in 2023.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with incandescent technologies.

Final

DATA	2015	2020	2022				2023[1]	2030[1]		2040[1]		2050[1]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	88.7	78.7	N/A	70.0	N/A	N/A	29.1	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,323	1,316	N/A	1,308	N/A	N/A	1,308	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.9	16.9	N/A	18.7	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,900	2,900	N/A	2,900	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	2.4	2.4	N/A	1.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	876	876	N/A	876	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$6.24	$9.15	N/A	$10.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$4.71	$6.96	N/A	$7.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$6.24	$9.15	N/A	$10.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$2.28	$3.34	N/A	$6.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$4.71	$6.96	N/A	$7.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.72	$2.54	N/A	$5.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with halogen technologies.

DATA	2015	2020	2022				2023[1]	2030[1]		2040[1]		2050[1]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	70.0	70.0	N/A	70.0	N/A	N/A	28.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,407	1,334	N/A	1,260	N/A	N/A	1,260	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	20.1	19.1	N/A	18.0	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,900	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	3.6	3.6	N/A	3.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	876	876	N/A	876	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$21.85	$27.31	N/A	$29.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$15.53	$20.48	N/A	$23.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$21.85	$27.31	N/A	$29.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$5.32	$6.64	N/A	$8.61	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$15.53	$20.48	N/A	$23.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$3.78	$4.98	N/A	$6.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with halogen technologies.

DATA	2015[1]	2020[1]	2022[2]				2023[3]	2030[3]		2040[3]		2050[3]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	23.0	22.4	N/A	N/A	N/A	N/A	28.9	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,300	1,300	N/A	N/A	N/A	N/A	1,300	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	56.5	57.9	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	82	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	10.0	10.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	913	913	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$8.52	$8.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$6.55	$6.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$8.52	$8.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$0.78	$0.74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$6.55	$6.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.60	$0.57	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. 2015 and 2020 data calculated based on 2009 installed stock data and the following assumptions: Efficacy +0.5%/y, Cost -0.5%/y (NCI, 2019)
2. Virtually all manufacturers have discontinued manufacturing of CFL reflector lamps in favor of LEDs. Distributor offerings for CFL reflectors have been eliminated.
3. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. Although these standards can be met with CFL technology, manufacturers have discontinued manufacturing CFL reflector lamps in favor of LEDs.

Performance and Cost Characteristics » Residential Outdoor Lamps (Security: LED PAR38)

DATA	2015	2020	2022				2023[1]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	19.2	15.5	17.0	16.4	17.0	22.0	29.9	14.0	14.6	12.3	12.7	10.9	11.3
Lamp Lumens	1,202	1,211	1,200	1,344	1,700	1,344	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	62.7	77.9	70.6	82.0	100.0	61.0	45.0	95.7	116.7	109.5	133.5	123.2	150.2
CRI	83	86	82	86	82	80	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	3,000	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	24	27	25	27	25	15	N/A	27	25	27	25	27	25
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Lamp Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Annual Maintenance Cost (2022$)	$1.07	$0.60	$0.69	$0.62	$0.46	N/A	N/A	$0.52	$0.38	$0.46	$0.34	$0.41	$0.31
Total Installed Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Annual Maintenance Cost (2022$/klm)	$0.89	$0.49	$0.58	$0.46	$0.27	N/A	N/A	$0.39	$0.23	$0.35	$0.20	$0.31	$0.18

1. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.
2. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

Performance and Cost Characteristics » Residential Outdoor Lamps (Porch: Incandescent A19)

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	75.0	75.0	N/A	N/A	N/A	N/A	26.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,170	1,170	N/A	N/A	N/A	N/A	1,170	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	15.6	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	0.8	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	511	511	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$0.44	$0.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$0.38	$0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hours)	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$0.44	$0.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$0.30	$0.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$0.38	$0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.26	$0.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 75 watt incandescent lamps as of January 1, 2013. Despite the phase out of incandescent lamps, these products remain in the installed stock.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with incandescent technologies.

Performance and Cost Characteristics » Residential Outdoor Lamps (Porch: Halogen A19)

DATA	2015[1]	2020[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	53.0	53.0	N/A	53.0	N/A	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1050	936	N/A	890	N/A	N/A	890	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.8	17.7	N/A	16.8	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,950	N/A	2,950	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	621	621	N/A	621	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$2.37	$3.58	N/A	$4.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$2.26	$3.82	N/A	$4.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$0.00	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Installation (hours)	0	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$2.37	$3.58	N/A	$4.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$1.47	$2.22	N/A	$2.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$2.26	$3.82	N/A	$4.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.40	$2.37	N/A	$2.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards cannot be met with existing halogen lamp technologies.

Performance and Cost Characteristics » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

DATA	2015	2020[1]	2022				2023[3]	2030[4]		2040[4]		2050[4]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	18.6	14.6	20.0	18.8	18.0	13.8	26.0	13.9	12.8	13.2	12.2	12.5	11.6
Lamp Lumens	1,216	900	1,100	1,171	1,250	800	1,171	900	925	900	925	900	925
Lamp Efficacy (lm/W)	65.4	61.8	55.0	62.4	69.4	80.0	45.0	65.0	72.3	68.3	76.0	71.8	79.9
CRI	82	82	85	83	82	80	N/A	83	82	83	82	83	82
Correlated Color Temperature (CCT)	2,700	2,700	5,000	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	10.0	10.0	12.0	10.4	10.0	10.0	N/A	10.4	10.0	10.4	10.0	10.4	10.0
Annual Operating Hours (h/y)	767	767	767	767	767	N/A	N/A	767	767	767	767	767	767
Lamp Price (2022$)	$3.82	$5.33	$9.00	$5.28	$5.91	N/A	N/A	$5.07	$5.67	$4.82	$5.40	$4.59	$5.13
Lamp Cost (2022$/klm)	$3.14	$5.92	$8.18	$4.51	$4.72	N/A	N/A	$5.63	$6.13	$5.36	$5.83	$5.10	$5.55
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0	0	0	0	0	N/A	N/A	0	0	0	0	0	0
Total Installed Cost (2022$)	$3.82	$5.33	$9.00	$5.28	$5.91	N/A	N/A	$5.07	$5.67	$4.82	$5.40	$4.59	$5.13
Annual Maintenance Cost (2022$)	$0.29	$0.41	$0.58	$0.39	$0.45	N/A	N/A	$0.37	$0.44	$0.36	$0.41	$0.34	$0.39
Total Installed Cost (2022$/klm)	$3.14	$5.92	$8.18	$4.51	$4.72	N/A	N/A	$5.63	$6.13	$5.36	$5.83	$5.10	$5.55
Annual Maintenance Cost (2022$/klm)	$0.24	$0.45	$0.52	$0.33	$0.36	N/A	N/A	$0.42	$0.47	$0.40	$0.45	$0.38	$0.43

1. 2020 data back calculated based on 2022 data and the following assumptions: Efficacy +0.5%/y, Cost -0.5%/y (NCI, 2019)
2. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
3. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. CFL products exceed the new minimum efficacy standards.
4. The market for 75W equivalent bare spiral CFLs is very limited because almost all product lines are discontinued. This trend is expected to continue until no products are offered at this level by 2030.

DATA	2015	2020	2022				2023[1]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	12.9	11.8	13.5	11.9	11.0	13.6	24.4	9.9	9.1	7.7	7.1	6.7	6.2
Lamp Lumens	1,073	1,102	1,100	1,089	1,100	1,089	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Lamp Efficacy (lm/W)	83.1	93.5	81.5	92.2	100.0	80	45.0	111.5	120.9	142.0	154.0	164.6	178.6
CRI	81	85	80	86	80	80	N/A	86	80	86	80	86	80
Correlated Color Temperature (CCT)	2,700	2,700	3,000	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	21	25	18	25	15	N/A	18	25	18	25	18	25
Annual Operating Hours (h/y)	657	657	657	657	657	N/A	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$18.13	$8.48	$4.39	$3.92	$5.29	N/A	N/A	$3.23	$4.36	$2.84	$3.84	$2.46	$3.31
Lamp Cost (2022$/klm)	$16.90	$7.70	$3.99	$3.60	$4.81	N/A	N/A	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$18.13	$8.48	$4.39	$3.92	$5.29	N/A	N/A	$3.23	$4.36	$2.84	$3.84	$2.46	$3.31
Annual Maintenance Cost (2022$)	$0.49	$0.27	$0.12	$0.14	$0.14	N/A	N/A	$0.12	$0.11	$0.10	$0.10	$0.09	$0.09
Total Installed Cost (2022$/klm)	$16.90	$7.70	$3.99	$3.60	$4.81	N/A	N/A	$2.94	$3.97	$2.59	$3.49	$2.23	$3.01
Annual Maintenance Cost (2022$/klm)	$0.45	$0.24	$0.10	$0.13	$0.13	N/A	N/A	$0.11	$0.10	$0.09	$0.09	$0.08	$0.08

1. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.
2. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

Commercial Lighting

Performance and Cost Characteristics » Commercial General Service Lamps in Recessed Can Fixtures

This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw-based general service lamps emitting approximately 1,600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures because light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of general service lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial general service lamps (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for high intensity discharge (HID) lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but they can be met by halogen, CFL, and LED technologies from 2012 to 2023.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022
CFL	+0.5%	0%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Commercial General Service 100W Incandescent Lamp in Recessed Can Fixture

DATA	2012[1]	2018[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	100.0	100.0	N/A	N/A	N/A	N/A	36.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,620	1,620	N/A	N/A	N/A	N/A	1,620	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.2	16.2	N/A	N/A	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	100.0	100.0	N/A	N/A	N/A	N/A	36.0	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens[3]	988	988	N/A	N/A	N/A	N/A	988	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	9.9	9.9	N/A	N/A	N/A	N/A	27.5	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,700	2,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	0.8	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	4,015	4,015	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$0.67	$0.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$23.72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$0.41	$0.41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$24.68	$24.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hours)	1.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$101.61	$101.61	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$24.25	$24.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$102.83	$102.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$24.54	$24.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 100 watt incandescent lamps as of January 1, 2012. Despite the phase out of incandescent lamps, these products remain in the installed stock.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. These standards cannot be met with incandescent technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. Note: the 45 lm/W backstop applies to the lamp, not the calculated fixture efficacy.
3. Based on a fixture efficiency of 61% for an omnidirectional lamp installed in a recessed can fixture.

Performance and Cost Characteristics » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

DATA	2012[1]	2018[1]	2022[2]				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	72.0	72.0	N/A	72.0	N/A	N/A	33.1	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,490	1,490	N/A	1,490	N/A	N/A	1,490	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	20.7	20.7	N/A	20.7	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	72.0	72.0	N/A	72.0	N/A	N/A	33.1	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens[3]	909	909	N/A	909	N/A	N/A	909	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	12.6	12.6	N/A	12.6	N/A	N/A	27.5	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	3,000	N/A	3,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	4,015	4,015	N/A	4,015	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$2.33	$5.16	N/A	$4.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	N/A	$22.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$1.57	$3.46	N/A	$2.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$28.67	$34.71	N/A	$28.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	N/A	$66.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.05	0.05	N/A	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$103.28	$108.77	N/A	$92.09	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$24.87	$36.23	N/A	$29.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$113.63	$119.67	N/A	$101.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$27.36	$39.86	N/A	$32.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 100 watt incandescent lamps as of January 1, 2012. Starting in 2012, 100 watt incandescent lamps were replaced by halogen lamps.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. These standards cannot be met with existing commercialized halogen lamp technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. Note: the 45 lm/W backstop applies to the lamp, not the calculated fixture efficacy.
3. Based on a fixture efficiency of 61% for an omnidirectional lamp installed in a recessed can fixture.

Additional note: No products are currently marketed specifically as 100W equivalent HIR general service lamps and no available data from manufacturers. It is assumed this market is the same as 100W equivalent halogen lamps.

Performance and Cost Characteristics » Commercial General Service 100W Equivalent CFL Bare Spiral in Recessed Can Fixture

DATA	2012	2018	2022				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	24.7	24.6	25.0	24.6	26.0	26.0	37.6	23.6	25.0	22.5	23.8	21.4	22.6
Lamp Lumens	1,680	1,680	1,600	1,694	1,835	1,600	1,694	1,694	1,835	1,694	1,835	1,694	1,835
Lamp Efficacy (lm/W)	68.1	68.2	64.0	68.9	70.6	80.0	45.0	71.7	73.4	75.3	77.2	79.2	81.2
System Wattage	24.7	24.6	25.0	24.6	26.0	26.0	37.6	23.6	25.0	22.5	23.8	21.4	22.6
System Lumens[3]	1,025	1,025	976	1,033	1,119	976	1,033	1,033	1,119	1,033	1,119	1,033	1,119
System Efficacy (lm/W)	41.6	41.6	39.0	42.0	43.1	37.5	27.5	43.7	44.8	46.0	47.1	48.3	49.5
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	82	82	82	82	82	82	N/A	82	82	82	82	82	82
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	5,000	3,000	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	10.0	10.0	10.0	10.0	10.0	10.0	N/A	10.0	10.0	10.0	10.0	10.0	10.0
Annual Operating Hours (h/y)	4,745	4,745	4,745	4,745	4,745	N/A	N/A	4,745	4,745	4,745	4,745	4,745	4,745
Lamp Price (2022$) [4]	$3.08	$6.40	$9.90	$8.62	$9.35	N/A	N/A	$8.28	$8.98	$7.87	$8.54	$7.49	$8.13
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$) [4]	$23.72	$26.38	$22.07	$22.07	$22.07	N/A	N/A	$21.20	$21.20	$20.17	$20.17	$19.18	$19.18
Disposal Cost (2022$)	$0.50	$0.50	$0.50	$0.50	$0.50	N/A	N/A	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50
Lamp Cost (2022$/klm)	$1.84	$3.81	$6.19	$5.09	$5.10	N/A	N/A	$4.89	$4.90	$4.65	$4.66	$4.42	$4.43
System (l/b/f) Cost (2022$/klm)	$26.15	$31.98	$32.76	$29.70	$28.07	N/A	N/A	$28.53	$26.97	$27.13	$25.65	$25.81	$24.39
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	N/A	N/A	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.0	1.0	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hours)	0.05	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost (2022$)	$104.03	$110.01	$97.97	$96.69	$97.42	N/A	N/A	$95.48	$96.18	$94.04	$94.71	$92.67	$93.31
Annual Maintenance Cost (2022$)	$3.53	$5.11	$6.50	$5.89	$6.24	N/A	N/A	$5.73	$6.07	$5.54	$5.86	$5.36	$5.66
Total Installed Cost (2022$/klm)	$101.48	$107.32	$100.38	$93.57	$87.03	N/A	N/A	$92.40	$85.93	$91.00	$84.61	$89.68	$83.36
Annual Maintenance Cost (2022$/klm)	$3.45	$4.98	$6.66	$5.70	$5.57	N/A	N/A	$5.55	$5.42	$5.36	$5.23	$5.18	$5.06

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. These standards can be met with existing CFL products. Note: the 45 lm/W backstop applies to the lamp, not the calculated fixture efficacy.
3. Based on a fixture efficiency of 61% for an omnidirectional lamp installed in a recessed can fixture.
4. Year-to-year price and performance assumptions 2022 – 2050: Efficacy +0.5%, Equipment Cost -0.5%

Performance and Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA	2012	2018	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	26.7	14.5	16.0	14.8	13.0	20.0	34.8	12.2	10.8	9.6	8.4	8.3	7.3
Lamp Lumens	1,600	1,528	1,600	1,567	1,600	1,600	1,567	1,567	1,600	1,567	1,600	1,567	1,600
Lamp Efficacy (lm/W)	60.0	105.1	100.0	106.0	123.1	80.0	45.0	128.2	148.8	163.3	189.5	189.3	219.8
System Wattage	26.7	14.5	16.0	14.8	13.0	20.0	34.8	12.2	10.8	9.6	8.4	8.3	7.3
System Lumens[3]	976	932	976	956	976	976	956	956	976	956	976	956	976
System Efficacy (lm/W)	36.6	64.1	61.0	64.7	75.1	48.8	27.5	78.2	90.8	99.6	115.6	115.5	134.1
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	80	80	90	84.8	84	80	N/A	84.8	84.8	84.8	84.8	84.8	84.8
Correlated Color Temperature (CCT)	3,000	3,000	2,700	2,700	5,000	N/A	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	22.0	17.9	25.0	16.9	25.0	15.0	N/A	16.9	25.0	16.9	25.0	16.9	25.0
Annual Operating Hours (h/y)	4,928	4,928	4,928	4,928	4,928	N/A	N/A	4,928	4,928	4,928	4,928	4,928	4,928
Lamp Price (2022$)	$47.45	$11.28	$5.62	$7.04	$3.39	N/A	N/A	$5.81	$2.80	$5.11	$2.46	$4.41	$2.12
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	$22.07	$22.07	$22.07	N/A	N/A	$21.20	$21.20	$20.17	$20.17	$19.18	$19.18
Lamp Cost (2022$/klm)	$25.00	$7.38	$3.51	$4.49	$2.12	N/A	N/A	$3.71	$1.75	$3.26	$1.54	$2.82	$1.33
System (l/b/f) Cost (2022$/klm)	$72.92	$40.40	$28.37	$30.46	$26.09	N/A	N/A	$28.26	$24.59	$26.45	$23.18	$24.68	$21.83
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	N/A	N/A	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.0	1.0	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hours)	0.05	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost (2022$)	$148.39	$114.88	$93.69	$95.11	$91.46	N/A	N/A	$93.01	$90.00	$91.27	$88.63	$89.59	$87.30
Annual Maintenance Cost (2022$)	$11.49	$4.16	$1.76	$3.02	$1.32	N/A	N/A	$2.66	$1.20	$2.45	$1.14	$2.25	$1.07
Total Installed Cost (2022$/klm)	$152.04	$123.25	$95.99	$99.52	$93.71	N/A	N/A	$97.32	$92.21	$95.51	$90.81	$93.75	$89.45
Annual Maintenance Cost (2022$/klm)	$11.77	$4.46	$1.80	$3.16	$1.35	N/A	N/A	$2.78	$1.23	$2.57	$1.16	$2.35	$1.10

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards. Note: the 45 lm/W backstop applies to the lamp, not the calculated fixture efficacy.
3. Based on a fixture efficiency of 61% for an omnidirectional lamp installed in a recessed can fixture.

Performance and Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

This section characterizes commercial halogen, halogen infrared reflector (HIR), and LED screw-based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- HIR lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This design increases the efficacy of the lamp, without reducing operating life.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of reflector lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial reflector lamps (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- EPAct92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPAct92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPAct92 minimum performance standards by January 1, 2008. In 2015, DOE issued a final rule that determined that amending the standards for incandescent reflector lamps could not be economically justified.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022
CFL	+0.5%	0%	-0.5%	In addition to higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Commercial Halogen Reflector Lamp (PAR38) in Recessed Can Fixture

DATA	2012	2018	2022				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	90.0	87.3	N/A	70.0	N/A	N/A	29.1	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,323	1,323	N/A	1,308	N/A	N/A	1,308	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.7	15.1	N/A	18.7	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	90.0	87.3	N/A	70.0	N/A	N/A	29.1	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens[1]	1,230	1,230	N/A	1,217	N/A	N/A	1,217	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	13.7	14.1	N/A	17.4	N/A	N/A	41.9	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	2.4	2.4	N/A	1.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	4,052	4,052	N/A	4,052	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$4.49	$7.99	N/A	$10.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	N/A	$22.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$3.39	$6.04	N/A	$7.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$22.93	$27.93	N/A	$26.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	N/A	$66.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.05	0.05	N/A	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$105.43	$111.59	N/A	$98.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$14.09	$20.00	N/A	$40.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$85.69	$90.70	N/A	$80.86	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$11.46	$16.26	N/A	$33.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Based on a fixture efficiency of 93% for an directional reflector lamp installed in a recessed can fixture.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with existing commercialized halogen lamp technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

Final

Performance and Cost Characteristics » Commercial Halogen Infrared Reflector Lamp (PAR38) in Recessed Can Fixture

DATA	2012	2018	2022				2023[2]	2030[2]		2040[2]		2050[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	70.0	70.0	N/A	70.0	N/A	N/A	28.0	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1,407	1,407	N/A	1,260	N/A	N/A	1,260	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	20.1	20.1	N/A	18.0	N/A	N/A	45.0	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	70.0	70.0	N/A	70.0	N/A	N/A	28.0	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens[1]	1,309	1,309	N/A	1,172	N/A	N/A	1,172	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	18.7	18.7	N/A	16.7	N/A	N/A	41.9	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2,850	2,850	N/A	2,850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (thousand hours)	3.6	3.6	N/A	3.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (h/y)	4,052	4,052	N/A	4,052	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price (2022$)	$18.58	$25.12	N/A	$29.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	N/A	$22.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$13.20	$17.86	N/A	$23.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$32.33	$39.36	N/A	$44.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	N/A	$66.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hours)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.05	0.05	N/A	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$119.52	$128.73	N/A	$117.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$25.25	$32.62	N/A	$44.28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$91.34	$98.38	N/A	$100.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$19.30	$24.93	N/A	$37.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. Based on a fixture efficiency of 93% for an directional reflector lamp installed in a recessed can fixture.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. These standards cannot be met with existing commercialized halogen lamp technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

Performance and Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

DATA	2012	2018	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[3]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	17.2	16.6	17.0	16.4	17.0	22.0	29.9	14.0	14.6	12.3	12.7	10.9	11.3
Lamp Lumens	1,045	1,210	1,200	1,344	1,700	1,344	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	60.9	73.0	70.6	82.0	100.0	61.0	45.0	95.7	116.7	109.5	133.5	123.2	150.2
System Wattage	17.2	16.6	17.0	16.4	17.0	22.0	29.9	14.0	14.6	12.3	12.7	10.9	11.3
System Lumens[1]	972	1,125	1,116	1,250	1,581	1,250	1,250	1,250	1,581	1,250	1,581	1,250	1,581
System Efficacy (lm/W)	56.6	67.9	65.6	76.1	93.0	56.7	41.9	89.0	108.6	101.9	124.2	114.6	139.7
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	83	82	86	82	80	N/A	86	82	86	82	86	82
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	3,000	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	22	15	25	28	25	25	N/A	28	25	28	25	28	25
Annual Operating Hours (h/y)	4,928	4,928	4,928	4,928	4,928	N/A	N/A	4,928	4,928	4,928	4,928	4,928	4,928
Lamp Price (2022$)	$61.98	$28.10	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	$22.07	$22.07	$22.07	N/A	N/A	$21.20	$21.20	$20.17	$20.17	$19.18	$19.18
Lamp Cost (2022$/klm)	$59.31	$23.23	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
System (l/b/f) Cost (2022$/klm)	$88.18	$48.42	$41.02	$36.13	$23.88	N/A	N/A	$32.48	$21.75	$30.02	$20.22	$27.64	$18.74
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	N/A	N/A	$91.40	$91.40	$91.40	$91.40	$91.40	$91.40
Labor System Installation (hours)	1.0	1.0	1.0	1.0	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hours)	0.05	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost (2022$)	$162.93	$131.71	$111.78	$111.16	$103.76	N/A	N/A	$132.00	$125.78	$128.92	$123.36	$125.95	$121.02
Annual Maintenance Cost (2022$)	$14.75	$10.50	$5.32	$4.64	$3.74	N/A	N/A	$4.22	$3.50	$3.86	$3.23	$3.51	$2.96
Total Installed Cost (2022$/klm)	$167.64	$117.04	$100.16	$88.92	$65.63	N/A	N/A	$105.59	$79.56	$103.13	$78.02	$100.75	$76.55
Annual Maintenance Cost (2022$/klm)	$15.17	$9.33	$4.77	$3.72	$2.37	N/A	N/A	$3.37	$2.21	$3.09	$2.04	$2.81	$1.87

1. Based on a fixture efficiency of 93% for an omnidirectional lamp installed in a recessed can fixture.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. All LED lighting products exceed the new minimum efficacy standards.
3. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

Performance and Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house two 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp or fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Linear lamps often have a nominal CCT rating of 3,500K, but products with CCTs of 3,000K, 4,000K, and 4,100K (neutral white) are also common. 5,000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps, which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours/year for commercial 4ft linear systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2020).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	0%	0%	-0.5%	Limited because the technology is mature.
T8 F32 High Efficiency/High Output	0%	0%	-0.5%	Limited because the technology is mature.
T5 F28	0%	0%	-0.5%	Limited because the technology is mature.

Performance and Cost Characteristics » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average[1]	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Lamp Lumens	2,725	2,855	2,450	2,855	3,100	2,855	3,100	2,855	3,100	2,855	3,100
Lamp Efficacy (lm/W)	85.2	89.0	76.6	89.2	96.9	89.2	96.9	89.2	96.9	89.2	96.9
System Wattage	61.8	62.5	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1
System Lumens	4,796	5,082	4,361	5,082	5,518	5,082	5,518	5,082	5,518	5,082	5,518
System Efficacy (lm/W)	77.7	81.4	69.1	80.6	87.5	80.6	87.5	80.6	87.5	80.6	87.5
Ballast Efficiency (BLE)	91%	91%	90%	90%	90%	90%	90%	90%	90%	90%	90%
CRI	83	87	90	87	85	87	85	87	85	87	85
Correlated Color Temperature (CCT)	4,100	4,100	5,000	4,100	3,500	4,100	3,500	4,100	3,500	4,100	3,500
Average Lamp Life (thousand hours)	24	31	23	31	40	31	40	31	40	31	40
Annual Operating Hours (h/y)	4,055	2,920	2,920	2,920	2,920	2,920	2,920	2,920	2,920	2,920	2,920
Lamp Price (2022$)	$7.81	$5.02	$3.36	$4.08	$4.32	$3.92	$4.15	$3.73	$3.95	$3.55	$3.75
Ballast Price (2022$)[2]	$19.56	$19.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$29.67	$77.61	$75.53	$75.53	$75.53	$72.56	$72.56	$69.01	$69.01	$65.64	$65.64
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$2.86	$1.76	$1.37	$1.43	$1.39	$1.37	$1.34	$1.31	$1.27	$1.24	$1.21
System (l/b/f) Cost (2022$/klm)	$13.52	$21.07	$33.57	$29.31	$27.15	$15.91	$14.65	$15.05	$13.94	$14.31	$13.26
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$103.45	$145.67	$179.41	$181.97	$182.82	$113.86	$113.86	$109.47	$109.91	$105.73	$106.15
Annual Maintenance Cost (2022$)	$7.89	$3.88	$4.24	$3.28	$2.58	$3.25	$2.55	$3.21	$2.52	$3.18	$2.49
Total Installed Cost (2022$/klm)	$21.57	$28.66	$41.14	$35.81	$33.13	$22.41	$20.63	$21.54	$19.92	$20.81	$19.24
Annual Maintenance Cost (2022$/klm)	$1.65	$0.76	$0.97	$0.65	$0.47	$0.64	$0.46	$0.63	$0.46	$0.63	$0.45

1. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future and that cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
2. From 2020 to 2050, fixture (and fixture price) includes ballast.

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average[2]	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	28.0	28.0	28.0	28.0	28.0	28.0
Lamp Lumens	2,560	2,682	2,682	2,682	2,682	2,682
Lamp Efficacy (lm/W)	91	96	96	96	96	96
System Wattage	55.4	55.4	55.4	55.4	55.4	55.4
System Lumens	4,557	4,774	4,774	4,774	4,774	4,774
System Efficacy (lm/W)	82	86	86	86	86	86
Ballast Efficiency (BLE)	90%	90%	90%	90%	90%	90%
CRI	85	84	84	84	84	84
Correlated Color Temperature (CCT)	4,100	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	24	48	48	48	48	48
Annual Operating Hours (h/y)	4,055	2,920	2,920	2,920	2,920	2,920
Lamp Price (2022$)	$11.17	$5.40	$5.29	$5.08	$4.84	$4.60
Ballast Price (2022$)[3]	$19.56	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$35.20	$77.05	$75.53	$72.56	$69.01	$65.64
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$4.36	$2.01	$1.97	$1.90	$1.80	$1.71
System (l/b/f) Cost (2022$/klm)	$30.12	$32.75	$32.11	$30.85	$29.34	$27.90
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$104.54	$121.06	$113.82	$110.64	$106.85	$103.24
Annual Maintenance Cost (2022$)	$9.03	$2.54	$2.26	$2.23	$2.20	$2.17
Total Installed Cost (2022$/klm)	$22.94	$25.36	$23.84	$23.18	$22.38	$21.63
Annual Maintenance Cost (2022$/klm)	$1.98	$0.53	$0.47	$0.47	$0.46	$0.46

1. Only a typical dataset because provided as these lamps all have similar efficacies.
2. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future and that cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
3. From 2018 to 2050, fixture (and fixture price) includes ballast.

Performance and Cost Characteristics » Commercial 4-ft T5 F28 in 2-Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	28.0	27.7	28.0	27.5	26.0	27.5	26.0	27.5	26.0	27.5	26.0
Lamp Lumens	2,697	2,732	2,530	2,732	2,900	2,732	2,900	2,732	2,900	2,732	2,900
Lamp Efficacy (lm/W)	96.3	98.5	90.4	99.3	111.5	99.3	111.5	99.3	111.5	99.3	111.5
System Wattage	62.9	62.3	62.9	61.7	58.4	61.7	58.4	61.7	58.4	61.7	58.4
System Lumens	5,394	5,464	5,060	5,464	5,800	5,464	5,800	5,464	5,800	5,464	5,800
System Efficacy (lm/W)	85.8	87.8	80.5	88.5	99.4	88.5	99.4	88.5	99.4	88.5	99.4
Ballast Efficiency (BLE)	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%
CRI	85	85	85	85	85	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4,100	3,500	5,000	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	30	29	36	29	30	29	30	29	30	29	30
Annual Operating Hours (h/y)	4,055	3,176	3,176	3,176	3,176	3,176	3,176	3,176	3,176	3,176	3,176
Lamp Price (2022$)[1]	$6.54	$6.96	$13.76	$9.45	$21.28	$9.08	$20.44	$8.63	$19.44	$8.21	$18.49
Ballast Price (2022$)[2]	$31.94	$22.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$111.59	$83.32	$170.87	$170.87	$170.87	$164.15	$164.15	$156.13	$156.13	$148.50	$148.50
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$2.42	$2.55	$5.44	$3.46	$7.34	$3.32	$7.05	$3.16	$6.70	$3.01	$6.38
System (l/b/f) Cost (2022$/klm)	$29.03	$21.97	$39.21	$34.73	$36.80	$37.53	$35.35	$31.73	$33.62	$30.18	$31.98
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$195.22	$158.68	$231.39	$222.77	$246.43	$238.04	$238.04	$206.40	$228.02	$197.92	$218.48
Annual Maintenance Cost (2022$)	$5.97	$4.93	$4.78	$4.99	$7.33	$4.91	$7.15	$4.81	$6.94	$4.72	$6.74
Total Installed Cost (2022$/klm)	$36.19	$29.04	$45.73	$40.77	$42.49	$43.57	$41.04	$37.77	$39.31	$36.22	$37.67
Annual Maintenance Cost (2022$/klm)	$1.11	$0.90	$0.94	$0.91	$1.26	$0.90	$1.23	$0.88	$1.20	$0.86	$1.16

1. Year-to-year price and performance assumptions for incumbent technologies 2030–2050: Efficacy +0%/y, Life +0%/y, Cost -0.5%/y (SSL Forecast 2018).
2. From 2020 to 2050, fixture (and fixture price) includes ballast.

Performance and Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	20.8	17.0	16.0	13.7	11.0	11.6	9.3	10.0	8.0	8.8	7.2
Lamp Lumens	2,091	2,003	1,800	1,920	1,800	1,920	1,800	1,920	1,800	1,920	1,800
Lamp Efficacy (lm/W)	100.5	117.8	112.5	140.1	163.6	166.2	194.1	192.2	224.4	218.0	250.0
System Wattage	41.6	34.0	32.0	27.4	22.0	23.1	18.6	20.0	16.0	17.6	14.4
System Lumens	3,555	3,565	3,456	3,686	3,456	3,686	3,456	3,686	3,456	3,686	3,456
System Efficacy (lm/W)	85.4	104.9	108.0	134.5	157.1	159.6	186.3	184.5	215.4	209.3	240.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	86	81	82	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	4,100	4,020	4,100	4,100	5,000	4,100	5,000	4,100	5,000	4,100	5,000
Average Lamp Life (thousand hours)	50	54	50	54	50	54	50	54	50	54	50
Annual Operating Hours (h/y)	4,055	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541
Lamp Price (2022$)	$278.36	$35.06	$14.63	$11.11	$4.28	$9.88	$3.81	$9.66	$3.72	$9.44	$3.64
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$133.10	$17.50	$8.13	$5.79	$2.38	$5.15	$2.11	$5.03	$2.07	$4.92	$2.02
System (l/b/f) Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$587.35	$70.12	$29.26	$22.22	$8.56	$19.76	$7.61	$19.31	$7.44	$18.89	$7.28
Annual Maintenance Cost (2022$)	$47.64	$6.61	$3.93	$3.17	$2.46	$3.01	$2.39	$2.98	$2.38	$2.95	$2.37
Total Installed Cost (2022$/klm)	$165.20	$19.67	$8.47	$6.03	$2.48	$5.36	$2.20	$5.24	$2.15	$5.12	$2.11
Annual Maintenance Cost (2022$/klm)	$13.40	$1.85	$1.14	$0.86	$0.71	$0.82	$0.69	$0.81	$0.69	$0.80	$0.69

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

Performance and Cost Characteristics » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	51.5	50.0	49.0	44.0	35.0	35.6	28.3	29.9	23.8	25.8	20.5
System Lumens	4,818	4,673	5,024	5,302	4,800	5,302	4,800	5,302	4,800	5,302	4,800
System Efficacy (lm/W)	93.6	93.5	102.5	120.5	137.1	148.8	169.3	177.2	201.7	205.5	233.9
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	84	79	80	79	80	79	80	79	80	79	80
Correlated Color Temperature (CCT)	3,500	3,650	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lifetime (thousand hours)	67	53	54	53	50	53	50	53	50	53	50
Annual Operating Hours (h/y)	4,055	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431
Lamp or Luminaire Price (2022$)	$723.96	$188.00	$144.85	$152.54	$207.80	$127.58	$173.80	$118.37	$161.25	$109.57	$149.27
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$150.25	$40.23	$57.66	$57.54	$86.58	$24.06	$36.21	$22.33	$33.59	$20.67	$31.10
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$762.57	$226.61	$322.70	$338.08	$448.60	$160.58	$206.80	$151.37	$194.25	$142.57	$182.27
Annual Maintenance Cost (2022$)	$46.16	$14.67	$11.30	$12.01	$16.52	$10.40	$14.19	$9.80	$13.33	$9.23	$12.51
Total Installed Cost (2022$/klm)	$158.27	$48.49	$64.23	$63.76	$93.46	$30.29	$43.08	$28.55	$40.47	$26.89	$37.97
Annual Maintenance Cost (2022$/klm)	$9.58	$3.14	$2.25	$2.27	$3.44	$1.96	$2.96	$1.85	$2.78	$1.74	$2.61

1. N/A because the lamp and fixture are both included in the luminaire.

Performance and Cost Characteristics » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Occupancy Sensor

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average[2]	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	28.0	28.0	28.0	28.0	28.0	28.0
Lamp Lumens	2,560	2,682	2,682	2,682	2,682	2,682
Lamp Efficacy (lm/W)	91	96	96	96	96	96
System Wattage	50.3	55.4	55.4	55.4	55.4	55.4
System Lumens	4,506	4,774	4,774	4,774	4,774	4,774
System Efficacy (lm/W)	90	86	86	86	86	86
Ballast Efficiency (BLE)	90%	90%	90%	90%	90%	90%
CRI	85	84	84	84	84	84
Correlated Color Temperature (CCT)	4,100	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	24	48	48	48	48	48
Annual Operating Hours (h/y)[3]	4,055	2,920	1,869	1,869	1,869	1,869
Lamp Price (2022$)	$11.17	$5.40	$5.29	$5.08	$4.84	$4.60
Ballast Price (2022$)	$19.56	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$35.20	$77.05	$75.53	$72.56	$69.01	$65.64
Occupancy Sensor Price (2022$)	N/A	N/A	$161.34	$161.34	$161.34	$161.34
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$4.36	$2.01	$1.97	$1.90	$1.80	$1.71
System (l/b/f) Cost (2022$/klm)	$30.12	$32.75	$92.26	$91.00	$89.49	$88.06
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$104.54	$121.06	$275.16	$271.98	$268.19	$264.58
Annual Maintenance Cost (2022$)	$9.03	$2.54	$1.44	$1.43	$1.41	$1.39
Total Installed Cost (2022$/klm)	$23.20	$25.36	$57.64	$56.97	$56.18	$55.42
Annual Maintenance Cost (2022$/klm)	$2.00	$0.53	$0.30	$0.30	$0.30	$0.29

1. Only a typical dataset is provided because these lamps all have similar efficacies.
2. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future and that cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
3. Assumes occupancy sensor reduces hours of use by 36% (NCI, 2019)

Performance and Cost Characteristics » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Specular Reflector

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average[2]	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	28.0	28.0	28.0	28.0	28.0	28.0
Lamp Lumens	2,560	2,682	2,682	2,682	2,682	2,682
Lamp Efficacy (lm/W)	91.4	95.8	95.8	95.8	95.8	95.8
System Wattage	55.4	55.4	55.4	55.4	55.4	55.4
System Lumens[3]	4,506	4,774	5,347	5,347	5,347	5,347
System Efficacy (lm/W)	81	86	97	97	97	97
Ballast Efficiency (BLE)	90%	90%	90%	90%	90%	90%
CRI	85	84	84	84	84	84
Correlated Color Temperature (CCT)	4,100	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	24	48	48	48	48	48
Annual Operating Hours (h/y)	2,920	4,055	4,055	4,055	4,055	4,055
Lamp Price (2022$)	$11.17	$5.40	$5.29	$5.08	$4.84	$4.60
Ballast Price (2022$)	$19.56	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$35.20	$77.05	$75.53	$72.56	$69.01	$65.64
Reflector Price (2022$)	N/A	N/A	$44.53	$44.53	$44.53	$44.53
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$4.36	$2.01	$1.97	$1.90	$1.80	$1.71
System (l/b/f) Cost (2022$/klm)	$30.12	$32.75	$48.71	$47.45	$45.94	$44.51
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$104.54	$121.06	$158.35	$155.17	$151.38	$147.77
Annual Maintenance Cost (2022$)	$6.50	$3.53	$3.13	$3.10	$3.06	$3.02
Total Installed Cost (2022$/klm)	$23.20	$25.36	$29.62	$29.02	$28.31	$27.64
Annual Maintenance Cost (2022$/klm)	$1.44	$0.74	$0.59	$0.58	$0.57	$0.56

1. Only a typical dataset is provided because these lamps all have similar efficacies.
2. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future and that cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
3. Specular reflector is expected to add 12% luminaire efficiency (LRC, 1992).

Performance and Cost Characteristics » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Occupancy Sensor and Specular Reflector

DATA[1]	2012	2018	2022	2030	2040	2050
	Installed Stock Average	Installed Stock Average[2]	Typical	Typical	Typical	Typical
Lamp Wattage	28.0	28.0	28.0	28.0	28.0	28.0
Lamp Lumens	2,560	2,682	2,682	2,682	2,682	2,682
Lamp Efficacy (lm/W)	91.4	95.8	95.8	95.8	95.8	95.8
System Wattage	50.3	55.4	55.4	55.4	55.4	55.4
System Lumens[3]	4,506	4,774	5,347	5,347	5,347	5,347
System Efficacy (lm/W)	89.6	86.2	96.6	96.6	96.6	96.6
Ballast Efficiency (BLE)	90%	90%	90%	90%	90%	90%
CRI	85	84	84	84	84	84
Correlated Color Temperature (CCT)	4,100	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	24	48	48	48	48	48
Annual Operating Hours (h/y)[3]	4,055	2,920	1,869	1,869	1,869	1,869
Lamp Price (2022$)	$11.17	$5.40	$5.29	$5.08	$4.84	$4.60
Ballast Price (2022$)	$19.56	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$35.20	$77.05	$75.53	$72.56	$69.01	$65.64
Reflector Price (2022$)	N/A	N/A	$44.53	$44.53	$44.53	$44.53
Occupancy Sensor Price (2022$)	N/A	N/A	$161.34	$161.34	$161.34	$161.34
Disposal Costs (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$4.36	$2.01	$1.97	$1.90	$1.80	$1.71
System (l/b/f) Cost (2022$/klm)	$30.12	$32.75	$108.87	$107.61	$106.10	$104.66
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$104.54	$121.06	$319.69	$316.51	$312.72	$309.11
Annual Maintenance Cost (2022$)	$9.03	$2.54	$1.44	$1.43	$1.41	$1.39
Total Installed Cost (2022$/klm)	$23.20	$25.36	$59.79	$59.20	$58.49	$57.81
Annual Maintenance Cost (2022$/klm)	$2.00	$0.53	$0.27	$0.27	$0.26	$0.26

1. Only a typical dataset is provided because these lamps all have similar efficacies.
2. Data and assumptions taken from the 2018 SSL Forecast. The report states that efficacy improvements for T8 lamps are not expected in the future and that cost for all commercial fixtures is expected to decrease between 0.1%-0.6% per year. We use 0.5% per year here.
3. Assumes occupancy sensor reduces hours of use by 36% (NCI, 2019). Specular reflector is expected to add 12% luminaire efficiency (LRC, 1992).

Performance and Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house two 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp or fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Linear lamps often have a nominal CCT rating of 3,500K, but products with CCTs of 3,000K, 4,000K, and 4,100K (neutral white) are also common. 5,000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours/year for commercial 8ft linear systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2020).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume the manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	0%	0%	-0.5%	Limited because the technology is mature.
T8 F59 High Efficiency	0%	0%	-0.5%	Limited because the technology is mature.
T8 F96 High Output	0%	0%	-0.5%	Limited because the technology is mature.

Performance and Cost Characteristics » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0
Lamp Lumens	5,430	5,788	5,900	5,905	5,950	5,905	5,950	5,905	5,950	5,905	5,950
Lamp Efficacy (lm/W)	92.0	98.1	100.0	100.1	100.8	100.1	100.8	100.1	100.8	100.1	100.8
System Wattage	106.8	111.6	112.9	112.9	112.9	112.9	112.9	112.9	112.9	112.9	112.9
System Lumens	9,448	10,071	10,384	10,393	10,472	10,393	10,472	10,393	10,472	10,393	10,472
System Efficacy (lm/W)	88.5	90.3	92.0	92.1	92.8	92.1	92.8	92.1	92.8	92.1	92.8
Ballast Efficiency (BLE)	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	82	84	85	84	85	84	85	84	85	84	85
Correlated Color Temperature (CCT)	4,100	4,100	3,500	4,100	3,500	4,100	3,500	4,100	3,500	4,100	3,500
Average Lamp Life (thousand hours)	24	21	24	21	24	21	24	21	24	21	24
Annual Operating Hours (h/y)	4,147	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066
Lamp Price (2022$)	$14.70	$21.80	$23.58	$21.37	$22.84	$20.53	$21.94	$19.53	$20.87	$18.57	$19.85
Ballast Price (2022$)	$23.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	$27.20	$117.38	$115.06	$115.06	$115.06	$110.54	$110.54	$105.13	$105.13	$99.99	$99.99
Disposal Costs (2022$)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96
Lamp Cost (2022$/klm)	$2.28	$3.77	$4.00	$3.62	$3.84	$3.48	$3.69	$3.31	$3.51	$3.15	$3.34
System (l/b/f) Cost (2022$/klm)	$12.40	$15.99	$15.62	$15.18	$15.35	$14.59	$14.75	$13.87	$14.03	$13.20	$13.34
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Labor Lamp Change (hours)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost (2022$)	$114.60	$238.20	$247.36	$242.94	$245.88	$236.74	$239.56	$229.33	$232.01	$222.28	$224.83
Annual Maintenance Cost (2022$)	$8.98	$9.66	$8.51	$9.08	$8.32	$8.83	$8.09	$8.54	$7.82	$8.26	$7.55
Total Installed Cost (2022$/klm)	$12.13	$23.65	$23.82	$23.38	$23.48	$22.78	$22.88	$22.07	$22.16	$21.39	$21.47
Annual Maintenance Cost (2022$/klm)	$0.95	$0.96	$0.82	$0.87	$0.79	$0.85	$0.77	$0.82	$0.75	$0.79	$0.72

1. From 2018 to 2050, fixture (and fixture price) includes ballast.

Performance and Cost Characteristics » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0
Lamp Lumens	7600	8134	7710	8134	8200	8134	8200	8134	8200	8134	8200
Lamp Efficacy (lm/W)	88.4	94.6	89.7	94.6	95.3	94.6	95.3	94.6	95.3	94.6	95.3
System Wattage	148.4	183.6	183.6	183.6	183.6	183.6	183.6	183.6	183.6	183.6	183.6
System Lumens	12,026	15,455	14,649	15,455	15,580	15,455	15,580	15,455	15,580	15,455	15,580
System Efficacy (lm/W)	81.0	84.2	79.8	84.2	84.9	84.2	84.9	84.2	84.9	84.2	84.9
Ballast Efficiency (BLE)	92%	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%
CRI	78	85	85	85	85	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4,100	4,100	3,500	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100
Average Lamp Life (thousand hours)	18	22	18	22	30	22	30	22	30	22	30
Annual Operating Hours (h/y)	4,147	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066	3,066
Lamp Price (2022$)	$20.22	$30.62	$16.51	$30.02	$73.42	$28.84	$70.53	$27.43	$67.09	$26.09	$63.81
Ballast Price (2022$)	$18.55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	$27.20	$117.38	$115.06	$115.06	$115.06	$110.54	$110.54	$105.13	$105.13	$99.99	$99.99
Disposal Costs (2022$)	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96	$0.96
Lamp Cost (2022$/klm)	$2.24	$3.77	$2.14	$3.69	$8.95	$3.55	$8.60	$3.37	$8.18	$3.21	$7.78
System (l/b/f) Cost (2022$/klm)	$21.99	$11.56	$10.11	$11.33	$16.81	$10.88	$16.15	$10.35	$15.36	$9.85	$14.61
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Labor Lamp Change (hours)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost (2022$)	$143.19	$255.85	$233.22	$260.24	$347.04	$253.36	$336.75	$245.13	$324.44	$237.31	$312.74
Annual Maintenance Cost (2022$)	$13.48	$11.68	$8.94	$11.08	$16.99	$10.75	$16.40	$10.35	$15.70	$9.98	$15.03
Total Installed Cost (2022$/klm)	$17.89	$16.55	$15.92	$16.84	$22.27	$16.39	$21.61	$15.86	$20.82	$15.36	$20.07
Annual Maintenance Cost (2022$/klm)	$1.12	$0.76	$0.61	$0.72	$1.09	$0.70	$1.05	$0.67	$1.01	$0.65	$0.96

1. From 2018 to 2050, fixture (and fixture price) includes ballast.

Performance and Cost Characteristics » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	35.7	34.0	39.0	40.0	32.9	33.7	28.4	29.2	25.1	25.7
Lamp Lumens	N/A	3,975	4,200	4,960	5,500	4,960	5,500	4,960	5,500	4,960	5,500
Lamp Efficacy (lm/W)	N/A	111.2	123.5	127.2	137.5	150.8	163.1	174.4	188.6	197.9	213.9
System Wattage	N/A	71.5	68.0	78.0	80.0	65.8	67.5	56.9	58.3	50.1	51.4
System Lumens	N/A	7,473	8,064	9,523	10,560	9,523	10,560	9,523	10,560	9,523	10,560
System Efficacy (lm/W)	N/A	104.5	118.6	122.1	132.0	144.8	156.5	167.4	181.0	189.9	205.4
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	82	81	82	81	82	81	82	81	82
Correlated Color Temperature (CCT)	N/A	5,000	4,000	4,000	5,000	4,000	5,000	4,000	5,000	4,000	5,000
Average Lamp Life (thousand hours)	N/A	50	50	50	50	50	50	50	50	50	50
Annual Operating Hours (h/y)	N/A	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541
Lamp Price (2022$)	N/A	$89.59	$33.11	$37.22	$41.44	$32.35	$36.02	$31.71	$35.30	$31.11	$34.64
Ballast Price (2022$) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	N/A	$19.00	$7.88	$7.50	$7.53	$6.52	$6.55	$6.39	$6.42	$6.27	$6.30
System (l/b/f) Cost (2022$/klm)	N/A	$23.98	$8.21	$7.82	$7.85	$6.79	$6.82	$6.66	$6.69	$6.53	$6.56
Labor Cost (2022$/h)	N/A	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	N/A	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost (2022$)	N/A	$179.18	$66.22	$74.44	$82.88	$64.70	$72.04	$63.42	$70.61	$62.22	$69.28
Annual Maintenance Cost (2022$)	N/A	$14.22	$6.00	$6.58	$7.18	$5.89	$6.41	$5.80	$6.31	$5.71	$6.21
Total Installed Cost (2022$/klm)	N/A	$45.08	$8.21	$7.82	$7.85	$6.79	$6.82	$6.66	$6.69	$6.53	$6.56
Annual Maintenance Cost (2022$/klm)	N/A	$3.58	$0.74	$0.69	$0.68	$0.62	$0.61	$0.61	$0.60	$0.60	$0.59

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	73.0	90.0	78.0	72.0	64.6	59.6	55.2	50.9	48.1	44.4
System Lumens	N/A	8,000	8,200	9,465	10,400	9,465	10,400	9,465	10,400	9,465	10,400
System Efficacy (lm/W)	N/A	109.6	91.1	121.3	144.4	146.5	174.4	171.6	204.3	196.6	234.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	90	80	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	N/A	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Average Lifetime (thousand hours)	N/A	75	50	73	100	73	100	73	100	73	100
Annual Operating Hours (h/y)	N/A	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431
Lamp or Luminaire Price (2022$)	N/A	$759.16	$119.99	$142.48	$153.91	$109.90	$118.71	$96.00	$103.70	$82.68	$89.31
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	N/A	$80.00	$14.63	$15.05	$14.80	$11.61	$11.41	$10.14	$9.97	$8.73	$8.59
Labor Cost (2022$/h)	N/A	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	N/A	1.0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Labor Lamp Change (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	N/A	$708.20	$206.52	$229.01	$240.44	$196.42	$205.24	$182.53	$190.23	$169.20	$175.83
Annual Maintenance Cost (2022$)	N/A	$39.16	$22.40	$17.46	$13.53	$14.40	$11.11	$13.09	$10.08	$11.84	$9.10
Total Installed Cost (2022$/klm)	N/A	$88.53	$25.18	$24.20	$23.12	$20.75	$19.73	$19.28	$18.29	$17.88	$16.91
Annual Maintenance Cost (2022$/klm)	N/A	$4.89	$2.73	$1.84	$1.30	$1.52	$1.07	$1.38	$0.97	$1.25	$0.87

1. N/A because the lamp and fixture are both included in the luminaire.

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 10,000 system lumens. Low bay lighting is defined as "interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor"(IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Low bay conventional lighting technologies, such as metal halide and sodium vapor lamps, provide higher efficacy ranging from 80 lm/W to 100 lm/W. Older, mercury vapor lamps have much lower efficacy at approximately 40 lm/W.
- CCT and CRI values range broadly based on technology type for low bay products.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires, which are sold as one integrated system. Many factors influence the price of LED luminaires, including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical luminaire prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial low-bay systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

ENERGY STAR:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- (Navigant, 2019). Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	0%	0%	-0.5%	Limited because the technology is mature.
Metal Halide	0%	0%	-0.5%	Limited because the technology is mature.
Sodium Vapor	0%	0%	-0.5%	Limited because the technology is mature.

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030[2] Typical	2040[2] Typical	2050[2] Typical
Lamp Wattage	175.0	175.0	175.0	N/A	N/A	N/A
Lamp Lumens	7,400	7,400	7,400	N/A	N/A	N/A
Lamp Efficacy (lm/W)	42.3	42.3	44.0	N/A	N/A	N/A
System Wattage	205.9	205.9	205.9	N/A	N/A	N/A
System Lumens	7,400	7,400	7,400	N/A	N/A	N/A
System Efficacy (lm/W)	35.9	35.9	35.9	N/A	N/A	N/A
Ballast Efficiency	85%	85%	85%	N/A	N/A	N/A
CRI	33	33	33	N/A	N/A	N/A
Correlated Color Temperature (CCT)	3,700	3,700	3,700	N/A	N/A	N/A
Average Lamp Life (thousand hours)	24	24	24	N/A	N/A	N/A
Annual Operating Hours (h/y)	3,687	3,687	3,687	N/A	N/A	N/A
Lamp Price (2022$)	$13.96	$13.55	$13.80	N/A	N/A	N/A
Ballast Price (2022$)	$51.91	$50.37	$49.48	N/A	N/A	N/A
Fixture Price (2022$)	$38.73	$37.58	$36.83	N/A	N/A	N/A
Disposal Cost (2022$)	$1.50	$1.50	$1.50	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$1.89	$1.83	$1.86	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$14.13	$13.72	$13.53	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	N/A	N/A	N/A
Labor System Installation (hours)	1.5	1.5	1.5	N/A	N/A	N/A
Labor Lamp Change (hours)	0.5	0.5	0.5	N/A	N/A	N/A
Total Installed Cost (2022$)	$220.43	$217.33	$199.11	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$8.31	$8.24	$7.42	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$29.79	$29.37	$26.91	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$1.12	$1.11	$1.00	N/A	N/A	N/A

1. Only a typical dataset is provided because these lamps all have similar efficacies.
2. EPAct 2005 limited the sale and production of mercury vapor ballasts since 2008, and by 2030 there is no expected market for these products.

Performance and Cost Characteristics » Commercial Metal Halide Low-Bay

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	100.0	100.0	100.0	100.0	100.0	100.0
Lamp Lumens	8,084	8,331	8,500	8,500	8,500	8,500
Lamp Efficacy (lm/W)	80.8	83.3	85.0	85.0	85.0	85.0
System Wattage	113.6	113.6	113.6	113.6	113.6	113.6
System Lumens	7,400	7,400	7,400	7,400	7,400	7,400
System Efficacy (lm/W)	65.1	65.1	65.1	65.1	65.1	65.1
Ballast Efficiency	88%	88%	88%	88%	88%	88%
CRI	80	80	80	80	80	80
Correlated Color Temperature (CCT)	4,000	4,000	4,000	4,000	4,000	4,000
Average Lamp Life (thousand hours)	15	15	15	15	15	15
Annual Operating Hours (h/y)	3,760	3,760	3,760	3,760	3,760	3,760
Lamp Price (2022$)	$17.97	$17.44	$17.10	$16.43	$15.62	$14.86
Ballast Price (2022$)	$57.97	$56.26	$49.48	$47.54	$45.21	$43.00
Fixture Price (2022$)	$38.73	$37.58	$36.83	$35.39	$33.66	$32.01
Disposal Cost (2022$)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50
Lamp Cost (2022$/klm)	$2.22	$2.09	$2.01	$1.93	$1.84	$1.75
System (l/b/f) Cost (2022$/klm)	$15.50	$15.04	$13.97	$13.43	$12.77	$12.14
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Total Installed Cost (2022$)	$230.51	$227.11	$202.41	$198.35	$193.49	$188.87
Annual Maintenance Cost (2022$)	$14.56	$14.43	$12.93	$12.76	$12.56	$12.37
Total Installed Cost (2022$/klm)	$31.15	$30.69	$27.35	$26.80	$26.15	$25.52
Annual Maintenance Cost (2022$/klm)	$1.97	$1.95	$1.75	$1.72	$1.70	$1.67

1. Only a typical dataset is provided because these lamps all have similar efficacies.

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	100.0	100.0	100.0	100.0	100.0	100.0
Lamp Lumens	8,550	8,550	9,300	9,300	9,300	9,300
Lamp Efficacy (lm/W)	85.5	85.5	93.0	93.0	93.0	93.0
System Wattage	128.0	128.0	128.0	128.0	128.0	128.0
System Lumens	8,550	8,550	9,300	9,300	9,300	9,300
System Efficacy (lm/W)	66.8	66.8	72.6	72.6	72.6	72.6
Ballast Efficiency	78%	78%	78%	78%	78%	78%
CRI	22	22	22	22	22	22
Correlated Color Temperature (CCT)	2,100	2,100	2,100	2,100	2,100	2,100
Average Lamp Life (thousand hours)	24	24	24	24	24	24
Annual Operating Hours (h/y)	3,614	3,614	3,614	3,614	3,614	3,614
Lamp Price (2022$)	$54.04	$52.44	$13.14	$12.62	$12.01	$11.42
Ballast Price (2022$)	$56.14	$54.48	$43.26	$41.56	$39.53	$37.60
Fixture Price (2022$)	$128.14	$124.35	$121.88	$117.09	$111.36	$105.92
Disposal Cost (2022$)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50
Lamp Cost (2022$/klm)	$6.32	$6.13	$1.41	$1.36	$1.29	$1.23
System (l/b/f) Cost (2022$/klm)	$27.87	$27.05	$19.17	$18.42	$17.52	$16.66
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Total Installed Cost (2022$)	$354.16	$347.10	$277.28	$270.27	$261.90	$253.93
Annual Maintenance Cost (2022$)	$14.18	$13.93	$7.17	$7.10	$7.00	$6.91
Total Installed Cost (2022$/klm)	$41.42	$40.60	$29.81	$29.06	$28.16	$27.30
Annual Maintenance Cost (2022$/klm)	$1.66	$1.63	$0.77	$0.76	$0.75	$0.74

1. Only a typical dataset is provided because these lamps all have similar efficacies.

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	68.1	84.0	40.0	73.0	76.0	61.2	63.7	52.7	54.9	46.3	48.2
System Lumens	4,877	10,000	5,000	10,000	12,000	10,000	12,000	10,000	12,000	10,000	12,000
System Efficacy (lm/W)	71.6	119.0	125.0	137.0	157.9	163.4	188.4	189.7	218.7	216.0	248.9
Ballast Efficiency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	85	78	84	81	80	81	84	81	84	81	81
Correlated Color Temperature (CCT)	4,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Average Lifetime (thousand hours)	50	74	75	65	60	65	60	65	60	65	60
Annual Operating Hours (h/y)	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042
Lamp or Luminaire Price (2022$)	$903.82	$281.00	$63.99	$145.46	$285.89	$123.82	$243.37	$111.24	$218.63	$99.09	$194.75
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$185.31	$28.10	$12.80	$14.55	$23.82	$12.38	$20.28	$11.12	$18.22	$9.91	$16.23
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$865.44	$396.83	$162.99	$244.46	$384.89	$222.82	$342.37	$210.24	$317.63	$198.09	$293.75
Annual Maintenance Cost (2022$)	$69.95	$37.02	$12.23	$24.24	$45.18	$21.55	$39.45	$19.99	$36.12	$18.48	$32.90
Total Installed Cost (2022$/klm)	$177.44	$39.68	$32.60	$24.45	$32.07	$22.28	$28.53	$21.02	$26.47	$19.81	$24.48
Annual Maintenance Cost (2022$/klm)	$14.34	$3.70	$2.45	$2.42	$3.77	$2.16	$3.29	$2.00	$3.01	$1.85	$2.74

1. N/A because the lamp and fixture are both included in the luminaire.

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 system lumens. High-bay lighting is defined as "interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor" (IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- High bay conventional lighting technologies, such as metal halide and sodium vapor lamps, provide higher efficacy ranging from 80 lm/W to 100 lm/W. Older, mercury vapor lamps have much lower efficacy at approximately 40 lm/W.
- CCT and CRI values range broadly based on technology type for high bay products.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires, which are sold as one integrated system. Many factors influence the price of LED luminaires including, CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical luminaire prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial high bay systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

ENERGY STAR:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	0%	0%	-0.5%	Limited because the technology is mature.
Metal Halide	0%	0%	-0.5%	Limited because the technology is mature.
Sodium Vapor	0%	0%	-0.5%	Limited because the technology is mature.

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030[2] Typical	2040[2] Typical	2050[2] Typical
Lamp Wattage	400.0	400.0	400.0	N/A	N/A	N/A
Lamp Lumens	15,800	15,800	21,000	N/A	N/A	N/A
Lamp Efficacy (lm/W)	39.5	39.5	52.5	N/A	N/A	N/A
System Wattage	449.4	449.4	449.4	N/A	N/A	N/A
System Lumens	15,800	15,800	21,000	N/A	N/A	N/A
System Efficacy (lm/W)	35.2	35.2	46.7	N/A	N/A	N/A
Ballast Efficiency	89%	89%	89%	N/A	N/A	N/A
CRI	50	50	50	N/A	N/A	N/A
Correlated Color Temperature (CCT)	3,900	3,900	3,900	N/A	N/A	N/A
Average Lamp Life (thousand hours)	24	24	24	N/A	N/A	N/A
Annual Operating Hours (h/y)	3,687	3,687	3,687	N/A	N/A	N/A
Lamp Price (2022$)	$23.81	$23.10	$28.93	N/A	N/A	N/A
Ballast Price (2022$)	$55.39	$53.75	$64.35	N/A	N/A	N/A
Fixture Price (2022$)	$106.65	$103.49	$101.43	N/A	N/A	N/A
Disposal Cost (2022$)	$1.50	$1.50	$1.50	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$1.51	$1.46	$1.38	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$11.76	$11.41	$9.27	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	N/A	N/A	N/A
Labor System Installation (hours)	2.0	2.0	2.0	N/A	N/A	N/A
Labor Lamp Change (hours)	0.5	0.5	0.5	N/A	N/A	N/A
Total Installed Cost (2022$)	$340.29	$334.78	$326.71	N/A	N/A	N/A
Annual Maintenance Cost (2022$)	$9.82	$9.71	$9.74	N/A	N/A	N/A
Total Installed Cost (2022$/klm)	$21.54	$21.19	$15.56	N/A	N/A	N/A
Annual Maintenance Cost (2022$/klm)	$0.62	$0.61	$0.46	N/A	N/A	N/A

1. Only a typical dataset is provided because these lamps all have similar efficacies.

DATA[1]	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	400.0	400.0	400.0	400.0	400.0	400.0
Lamp Lumens	32,000	32,972	42,000	42,000	42,000	42,000
Lamp Efficacy (lm/W)	80.0	82.4	105.0	105.0	105.0	105.0
System Wattage	444.4	444.4	444.4	444.4	444.4	444.4
System Lumens	32,000	32,972	42,000	42,000	42,000	42,000
System Efficacy (lm/W)	72.0	74.2	94.5	94.5	94.5	94.5
Ballast Efficiency	90%	90%	90%	90%	90%	90%
CRI	80	80	80	80	80	80
Correlated Color Temperature (CCT)	4,000	4,000	4,000	4,000	4,000	4,000
Average Lamp Life (thousand hours)	20	20	20	20	20	20
Annual Operating Hours (h/y)	3,760	3,760	3,760	3,760	3,760	3,760
Lamp Price (2022$)	$34.95	$33.91	$42.15	$40.49	$38.51	$36.63
Ballast Price (2022$)	$55.39	$53.75	$64.35	$61.82	$58.80	$55.92
Fixture Price (2022$)	$248.32	$248.32	$248.32	$238.56	$226.90	$215.80
Disposal Cost (2022$)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50
Lamp Cost (2022$/klm)	$1.09	$1.03	$1.00	$0.96	$0.92	$0.87
System (l/b/f) Cost (2022$/klm)	$10.58	$10.19	$8.45	$8.12	$7.72	$7.34
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	2.0	2.0	2.0	2.0	2.0	2.0
Labor Lamp Change (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Total Installed Cost (2022$)	$493.10	$490.43	$486.82	$472.87	$456.21	$440.36
Annual Maintenance Cost (2022$)	$14.11	$13.91	$14.41	$14.10	$13.72	$13.37
Total Installed Cost (2022$/klm)	$15.41	$14.87	$11.59	$11.26	$10.86	$10.48
Annual Maintenance Cost (2022$/klm)	$0.44	$0.42	$0.34	$0.34	$0.33	$0.32

1. Only a typical dataset is provided because these lamps all have similar efficacies.

DATA[1]	2012	2018	2022	2030	2040	2050
	Installed Stock Average	Installed Stock Average	Typical	Typical	Typical	Typical
Lamp Wattage	250.0	250.0	250.0	250.0	250.0	250.0
Lamp Lumens	24,300	24,300	28,500	28,500	28,500	28,500
Lamp Efficacy (lm/W)	97.2	97.2	114.0	114.0	114.0	114.0
System Wattage	297.0	296.6	296.6	296.6	296.6	296.6
System Lumens	24,300	24,300	28,500	28,500	28,500	28,500
System Efficacy (lm/W)	81.8	81.9	96.1	96.1	96.1	96.1
Ballast Efficiency	84%	84%	84%	84%	84%	84%
CRI	22	22	22	22	22	22
Correlated Color Temperature (CCT)	2,100	2,100	2,100	2,100	2,100	2,100
Average Lamp Life (thousand hours)	24	24	24	24	24	24
Annual Operating Hours (h/y)	3,614	3,614	3,614	3,614	3,614	3,614
Lamp Price (2022$)	$53.71	$52.12	$20.37	$19.57	$18.61	$17.70
Ballast Price (2022$)	$90.16	$87.49	$90.09	$86.55	$82.32	$78.29
Fixture Price (2022$)	$280.71	$272.39	$266.98	$256.49	$243.95	$232.02
Disposal Cost (2022$)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50
Lamp Cost (2022$/klm)	$2.21	$2.14	$0.71	$0.69	$0.65	$0.62
System (l/b/f) Cost (2022$/klm)	$17.47	$16.95	$13.24	$12.72	$12.10	$11.51
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	2.0	2.0	2.0	2.0	2.0	2.0
Labor Lamp Change (hours)	0.5	0.5	0.5	0.5	0.5	0.5
Total Installed Cost (2022$)	$579.02	$566.44	$509.44	$494.61	$476.88	$460.02
Annual Maintenance Cost (2022$)	$14.13	$13.89	$8.26	$8.14	$8.00	$7.86
Total Installed Cost (2022$/klm)	$23.83	$23.31	$17.88	$17.35	$16.73	$16.14
Annual Maintenance Cost (2022$/klm)	$0.58	$0.57	$0.29	$0.29	$0.28	$0.28

1. Only a typical dataset is provided because these lamps all have similar efficacies.

Performance and Cost Characteristics » Commercial T5 4xF54 HO High-Bay

DATA[1]	2012	2018	2022		2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	54.0	54.0	54.0	54.0	54.0	54.0	54.0	54.0	54.0	54.0
Lamp Lumens	4,850	4,850	4,273	4,750	4,273	4,750	4,273	4,750	4,273	4,750
Lamp Efficacy (lm/W)	89.8	89.8	79.1	88.0	79.1	88.0	79.1	88.0	79.1	88.0
System Wattage	233.8	233.8	233.8	233.8	233.8	233.8	233.8	233.8	233.8	233.8
System Lumens	19,400	19,400	17,092	19,000	17,092	19,000	17,092	19,000	17,092	19,000
System Efficacy (lm/W)	83.0	83.0	73.1	81.3	73.1	81.3	73.1	81.3	73.1	81.3
Ballast Efficiency (BLE)	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	86	86	86	86	86	86	86	86	86	86
Correlated Color Temperature (CCT)	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100
Average Lamp Life (thousand hours)	24	24	25	25	25	25	25	25	25	25
Annual Operating Hours (h/y)	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042
Lamp Price (2022$)	$8.45	$8.20	$4.70	$13.65	$4.51	$13.11	$4.29	$12.47	$4.08	$11.86
Ballast Price (2022$)	$33.43	$32.44	$32.17	$32.17	$30.91	$30.91	$29.39	$29.39	$27.96	$27.96
Fixture Price (2022$)	$129.23	$125.40	$122.91	$122.91	$118.08	$118.08	$112.31	$112.31	$106.82	$106.82
Disposal Cost (2022$)	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
Lamp Cost (2022$/klm)	$1.74	$1.69	$1.10	$2.87	$1.06	$2.76	$1.00	$2.63	$0.96	$2.50
System (l/b/f) Cost (2022$/klm)	$10.13	$9.83	$10.17	$11.04	$9.77	$10.60	$9.30	$10.08	$8.84	$9.59
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Labor Lamp Change (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total Installed Cost (2022$)	$325.54	$320.47	$291.78	$300.73	$285.50	$294.10	$277.99	$286.17	$270.86	$278.63
Annual Maintenance Cost (2022$)	$12.51	$12.35	$8.68	$14.47	$8.56	$14.12	$8.42	$13.71	$8.29	$13.32
Total Installed Cost (2022$/klm)	$16.78	$16.52	$17.07	$15.83	$16.70	$15.48	$16.26	$15.06	$15.85	$14.66
Annual Maintenance Cost (2022$/klm)	$0.65	$0.64	$0.51	$0.76	$0.50	$0.74	$0.49	$0.72	$0.48	$0.70

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	212.2	167.0	150.0	137.8	130.0	115.5	109.0	99.4	93.9	87.4	82.5
System Lumens	18,915	18,797	18,500	18,500	18,900	18,500	18,900	18,500	18,900	18,500	18,900
System Efficacy (lm/W)	89.1	112.6	123.3	134.3	145.4	160.2	173.4	186.0	201.4	211.7	229.2
Ballast Efficiency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	74	78	80	80	80	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Average Lifetime (thousand hours)	70	67	100	100	100	100	100	100	100	100	100
Annual Operating Hours (h/y)	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042
Lamp or Luminaire Price (2022$)	$2,842.05	$448.43	$177.54	$195.81	$234.20	$162.12	$193.90	$148.87	$178.06	$136.20	$162.90
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$150.25	$23.86	$9.60	$10.58	$12.39	$8.76	$10.26	$8.05	$9.42	$7.36	$8.62
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$2,996.49	$602.87	$309.54	$327.81	$366.20	$294.12	$325.90	$280.87	$310.06	$268.20	$294.90
Annual Maintenance Cost (2022$)	$173.01	$36.40	$12.51	$13.25	$14.80	$11.89	$13.17	$11.35	$12.53	$10.84	$11.92
Total Installed Cost (2022$/klm)	$158.42	$32.07	$16.73	$17.72	$19.38	$15.90	$17.24	$15.18	$16.41	$14.50	$15.60
Annual Maintenance Cost (2022$/klm)	$9.15	$1.94	$0.68	$0.72	$0.78	$0.64	$0.70	$0.61	$0.66	$0.59	$0.63

1. N/A because the lamp and fixture are both included in the luminaire.

Refrigeration

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)[1]	1,200	1,200	1,200	1,190	930	N/A	1,190	930	1,190	930	1,190	930
Median Store Size (ft^2)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Power Input (kW)	162	155	162	160	125	N/A	160	125	160	125	160	125
Annual Energy Use (MMWh/y)[2]	1,497	1,497	1,305	1,232	1,160	N/A	1,232	1,160	1,232	1,160	1,232	1,160
Indexed Annual Efficiency[3]	1.00	1.00	1.15	1.21	1.29	N/A	1.21	1.29	1.21	1.29	1.21	1.29
Average Life (years)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost (2022$)	$630,000	$630,000	$488,000	$625,000	$630,000	N/A	$625,000	$630,000	$625,000	$630,000	$625,000	$630,000
Total Installed Cost (2022$/kBtu/h)	$525,000	$525,000	$406,667	$525,210	$677,419	N/A	$525,210	$677,419	$525,210	$677,419	$525,210	$677,419
Annual Maintenance Cost (2022$)[4]	$3,400	$3,400	$3,400	$3,400	$3,400	N/A	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400
Annual Maintenance Cost (2022$/kBtu/h)	$2,833	$2,833	$2,833	$2,857	$3,656	N/A	$2,857	$3,656	$2,857	$3,656	$2,857	$3,656

1. The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This refrigeration system usually includes two low temperature racks and two medium temperature racks. For 2018, a 1,200 MBtu/h total cooling capacity is based on a 200-ton estimate for total capacity–80 tons for the medium temperature racks and 20 tons for the low temperature racks.
2. Capacity and annual energy consumption for 2022 and beyond are based on market research and Guidehouse estimates.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks-approximately half a day per rack of labor for technician is assumed.

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-horsepower (hp) to 15-hp size range. Usually, each rack has three to five compressors serve a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range of 60% to 70%.
- Energy use and capacity for the Reference Case are projected to remain static over the coming decades because commercial compressor racks systems are a mature technology. The Reference Case assumes low R&D efforts because it is an established technology.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)[1]	1,680	1,520	1,440	1,440	1,440	N/A	1,440	1,440	1,440	1,440	1,440	1,440
Median Store Size (ft^2)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Power Input (kW)	25	25	18	18	18	N/A	18	18	18	18	18	18
Annual Energy Use (MMWh/y)	120	120	115	106	86	N/A	106	86	106	86	106	86
Indexed Annual Efficiency[2]	1.00	1.00	1.04	1.13	1.40	N/A	1.13	1.40	1.13	1.40	1.13	1.40
Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost (2022$)	$54,000	$60,000	$54,000	$60,000	$80,000	N/A	$60,000	$80,000	$60,000	$80,000	$60,000	$80,000
Total Installed Cost (2022$/kBtu/h)	$32,143	$39,474	$37,500	$41,667	$55,556	N/A	$41,667	$55,556	$41,667	$55,556	$41,667	$55,556
Annual Maintenance Cost (2022$)[3]	$954	$954	$954	$954	$954	N/A	$954	$954	$954	$954	$954	$954
Annual Maintenance Cost (2022$/kBtu/h)	$0.57	$0.63	$0.66	$0.66	$0.66	N/A	$0.66	$0.66	$0.66	$0.66	$0.66	$0.66

1. Total capacity is the total heat rejected (THR) by condensers comprised of two low temperature condensers (THRL = 240 MBtu/h each, suction temperature= -25°F, condensing temperature-110°F) and two medium temperature condensers (THRM = 520 MBtu/h each, suction temperature = 15°F, condensing temperature = 115°F); ambient temperature = 95°F. (NCI, 2009). For 2022 and beyond, capacity was estimated by Guidehouse.
2. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
3. Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks.

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50%-70%.
- Energy use is projected to remain static over the coming decades because commercial condensers are a mature technology.

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	17,623	11,850	11,850	11,850	11,850	N/A	11,850	11,850	11,850	11,850	11,850	11,850
Median Store Size (ft^2)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Case Length (ft)	12	12	12	12	12	N/A	12	12	12	12	12	12
Annual Energy Use (kWh/y)[1,2]	13,497	10,506	10,506	9,771	9,087	N/A	9,771	9,087	9,771	9,087	9,771	9,087
Annual Energy Use / Case Length (kWh/ft)	1,125	876	876	814	757	N/A	814	757	814	757	814	757
Indexed Annual Efficiency[3]	1.00	1.28	1.28	1.38	1.49	N/A	1.38	1.49	1.38	1.49	1.38	1.49
Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$8,510	$10,650	$7,265	$9,500	$10,680	N/A	$9,500	$10,680	$9,500	$10,680	$9,500	$10,680
Total Installed Cost (2022$)	$10,811	$12,650	$9,265	$11,500	$12,680	N/A	$11,500	$12,680	$11,500	$12,680	$11,500	$12,680
Total Installed Cost (2022$/kBtu/h)	613	1,068	782	970	1,070	N/A	970	1,070	970	1,070	970	1,070
Annual Maintenance Cost (2022$)[4]	$940	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost (2022$/kBtu/h)	$53.34	$79.32	$79.32	$79.32	$79.32	N/A	$79.32	$79.32	$79.32	$79.32	$79.32	$79.32

1. For 2022 and beyond, energy consumption and cost values were estimated using shipment-weighted averages reported in DOE's 2014 CRE Final Rule Technical Support Document (TSD) for equipment commonly used as display cases. DOE's updated conservation standard went into effect in 2017, so units sold in 2018 are assumed to comply with this standard.
2. For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance.

- DOE set federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. These standards set maximum daily energy consumption levels, in kilowatt-hours per day, for display cases manufactured sold in the United States on or after January 1, 2012.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014 for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA).

Equipment Description	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler (VOP.RC.M)	0.82xTDA+4.07	0.64xTDA+4.07
Semi-Vertical Open Cooler (SVO.RC.M)	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler (HZO.RC.M)	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler (VCT.RC.M)	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler (SOC.RC.M)	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer (VCT.RC.L)	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer (HZO.RC.L)	0.57xTDA+6.88	0.55xTDA+6.88

- According to CBECS 2018 microdata, the average building size for food sale building type is 31,997.
- Unit energy consumption for 2022 and beyond is estimated using a shipment-weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD with updated analysis from Guidehouse in 2016. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks.
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- The efficiency of supermarket display cases can be increased through the use of improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, and improved insulation.
- Energy use is projected to remain static over the coming decades because supermarket display cases are a mature technology.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	2,929	2,400	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349
Size (ft^3)	49	49	46	46	46	47	46	46	46	46	46	46
Annual Energy Use (kWh/y)	2,340	2,222	1,935	1,351	810	810	1,351	810	1,351	810	1,351	810
Annual Energy Use / Volume ($kWh/y/ft^3$)[1]	48	45	42	29	18	17	29	18	29	18	29	18
Indexed Annual Efficiency[3]	1.00	1.05	1.21	1.73	2.89	2.89	1.73	2.89	1.73	2.89	1.73	2.89
Average Life (years)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$2,624	$2,403	$2,728	$2,780	$3,021	$3,021	$2,780	$3,021	$2,780	$3,021	$2,780	$3,021
Total Installed Cost (2022$)[4]	$3,454	$3,282	$3,591	$3,643	$3,884	$3,884	$3,643	$3,884	$3,643	$3,884	$3,643	$3,884
Total Installed Cost (2022$/kBtu/h)	$1,179	$1,368	$1,529	$1,551	$1,654	$1,654	$1,551	$1,654	$1,551	$1,654	$1,551	$1,654
Annual Maintenance Cost (2022$)[5]	$185	$185	$185	$185	$185	$186	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost (2022$/kBtu/h)	$63	$77	$79	$79	$79	$79	$79	$79	$79	$79	$79	$79

1. EPACT 2005 energy standards went into effect in 2010. 2022 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipment-weighted averages solid- and transparent-doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards went into effect in 2017; therefore, compliance with this standard is assumed for 2022 and beyond.
2. The ENERGY STAR category is based on a shipment weighted average of solid- and transparent-doored units that are minimally compliant with ENERGY STAR v3, effective October 1, 2014. Units compliant with ENERGY STAR are found to be the most efficient reach-in refrigeration equipment on the market in 2022.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 is based on NCI 2009 report that assumes a cost of $863. Installation cost for 2022 and beyond is based DOE's 2014 CRE Final Rule and additional analysis by Guidehouse, which assumes an installation cost of $878 for self-contained equipment.
5. Maintenance costs after 2012 are based on DOE's CRE 2014 Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized.

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V) in ft^3.
- In 2014, DOE updated its energy conservation standards for reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its ENERGY STAR specifications for reach-in refrigerators, effective March 27, 2017. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.022xV+0.97	0.066xV+0.31	0.04xV+1.09	0.024xV+1.89
Glass Door (VCT.SC.M)	0.095xV+0.445	0.05xV+1.12	0.076xV+0.034	0.105xV-1.111

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD with updated analysis from Guidehouse in 2016. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, respectively.
- The efficiency of commercial reach-in refrigerators can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- For this referenced scenario, energy use is projected to remain static over the coming decades because reach-in refrigerators are a mature technology.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	4,341	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Annual Energy Use (kWh/y)[1]	6,023	5,585	5,585	4,847	4,110	4,110	4,847	4,110	4,847	4,110	4,847	4,110
Annual Energy Use / Volume (kWh/y/ft^3)	123	114	114	99	84	84	99	84	99	84	99	84
Indexed Annual Efficiency[3]	1.00	1.08	1.08	1.24	1.47	1.47	1.24	1.47	1.24	1.47	1.24	1.47
Average Life (years)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$2,886	$2,886	$2,886	$3,175	$3,493	$3,493	$3,175	$3,493	$3,175	$3,493	$3,175	$3,493
Total Installed Cost (2022$)[4]	$3,749	$3,749	$3,749	$4,125	$4,443	$4,443	$4,125	$4,443	$4,125	$4,443	$4,125	$4,443
Total Installed Cost (2022$/kBtu/h)	$864	$864	$864	$950	$1,024	$1,024	$950	$1,024	$950	$1,024	$950	$1,024
Annual Maintenance Cost (2022$)[5]	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost (2022$/kBtu/h)	$41.70	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71

1. A 49 ft^3 unit was characterized, because it was the representative size selected for DOE's rulemaking analysis.
2. The ENERGY STAR category was based on a solid-doored unit that is minimally compliant with ENERGY STAR v3, effective October 1, 2014.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and 2018 is based on DOE's on-going CRE rulemaking, which assumes a cost of $863 for self-contained equipment and $950 for 2022 and beyond based on analysis from Guidehouse.
5. Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the CRE TSD.

- EPACT 2005 set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V) in ft^3.
- In March of 2017, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its ENERGY STAR specifications for reach-in freezers, effective March 27, 2017. These standards are also based on the refrigerated volume of the unit.

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.L)	0.21xV+0.9	0.12xV+2.248	0.285xV-2.703	0.142xV+4.445
Glass Door (VCT.SC.L)	0.232xV+2.36	0.232xV+2.36	0.232xV+2.36	0.232xV+2.36

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE’s 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size of 4,341 Btu/h.
- The efficiency of commercial reach-in freezers can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- For this referenced scenario, energy use is projected to remain static over the coming decades because reach-in freezers are a mature technology.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)[1]	37,820	39,422	41,024	41,024	41,024	N/A	41,024	41,024	41,024	41,024	41,024	41,024
Size (ft^2)	305	240	240	240	240	N/A	240	240	240	240	240	240
Annual Energy Use (kWh/y)[2]	30,689	20,040	17,600	16,200	14,800	N/A	16,200	14,800	16,200	14,800	16,200	14,800
Annual Energy Use / Area (kWh/ft^2/y)	101	84	73	68	62	N/A	68	62	68	62	68	62
Indexed Annual Efficiency[3]	1.00	1.53	1.74	1.89	2.07	N/A	1.89	2.07	1.89	2.07	1.89	2.07
Insulated Box Average Life (years)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$23,598	$19,847	$16,050	$19,847	$23,644	N/A	$16,050	$23,644	$16,050	$23,644	$16,050	$23,644
Total Installed Cost (2022$)[4]	$27,012	$23,897	$20,100	$23,897	$27,694	N/A	$20,100	$27,694	$20,100	$27,694	$20,100	$27,694
Total Installed Cost (2022$/kBtu/h)	$714	$606	$490	$583	$675	N/A	$490	$675	$490	$675	$490	$675
Annual Maintenance Cost (2022$)[5]	$716	$740	$740	$740	$740	N/A	$740	$740	$740	$740	$740	$740
Annual Maintenance Cost (2022$/kBtu/h)	$18.93	$18.77	$18.04	$18.04	$18.04	N/A	$18.04	$18.04	$18.04	$18.04	$18.04	$18.04

1. Assumes medium temperature units are refrigerators.
2. Average unit energy consumption was adapted from the DOE CRE 2016 report by assuming electronically commutated motor (ECM) evaporator fan motors are required for Energy Policy & Conservation Act (EPCA) compliance, as well as ECM condenser fan motors.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and beyond is based on DOE's Walk-In TSD.
5. Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

- For 2012 and beyond, the unit characterized was a walk-in storage cooler, based on DOE's WICF TSD.
- A typical walk-in refrigerator includes:
  - insulated floor and wall panels
  - merchandising doors, shelving, and lighting (not included in cost estimate)
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with the AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in the analysis for all units for 2012 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009, must:

- For 2012 and beyond
- have automatic door closers
- have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
- contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
- use electronically commutated motors or three-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
- use electronically commutated motors, permanent split capacitor-type motors, or three-phase motors (for condenser fan motors of under 1 horsepower)
- use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEF (Annual Walk-In Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-In Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.M.I, ≥9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.M.O, ≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	5.93 · 10¥5 · Q + 2.33
Dedicated Condensing, Low Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	2.30 · 10¥4 · Q + 2.73
Dedicated Condensing, Low Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	22,114	23,500	23,500	23,500	23,500	N/A	23,500	23,500	23,500	23,500	23,500	23,500
Size (ft^2) [1]	172	161	161	161	161	N/A	161	161	161	161	161	161
Annual Energy Use (kWh/y)[2]	22,862	22,000	22,000	20,460	19,028	N/A	20,460	19,028	20,460	19,028	20,460	19,028
Annual Energy Use / Area (kWh/ft^2/y)	133	124	124	115	107	N/A	115	107	115	107	115	107
Indexed Annual Efficiency[3]	1.00	1.04	1.04	1.12	1.20	N/A	1.12	1.20	1.12	1.20	1.12	1.20
Insulated Box Average Life (years)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$22,008	$21,950	$21,950	$22,850	$23,750	N/A	$22,850	$23,750	$22,850	$23,750	$22,850	$23,750
Total Installed Cost (2022$)[4]	$24,058	$23,950	$23,950	$24,850	$25,750	N/A	$24,850	$25,750	$24,850	$25,750	$24,850	$25,750
Total Installed Cost (2022$/kBtu/h)	$1,088	$1,019	$1,019	$1,057	$1,096	N/A	$1,057	$1,096	$1,057	$1,096	$1,057	$1,096
Annual Maintenance Cost (2022$)[5]	$741	$741	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost (2022$/kBtu/h)	$33.51	$31.53	$31.53	$31.53	$31.53	N/A	$31.53	$31.53	$31.53	$31.53	$31.53	$31.53

1. Based on DOE's 2014 WICF Final Rule TSD and additional analysis by Guidehouse, the average floor area for a walk-in storage freezer as 161 ft^2.
2. EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2022 and beyond are characterized using data from DOE's 2014 WICF rulemaking. All units for 2022 and beyond are assumed to comply with this standard.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and beyond is based on DOE's WICF TSD and additional analysis by Guidehouse.
5. Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

- The commercial walk-in freezer characterized in this report is a walk-in storage freezer with an area of 161 ft^2.
- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with the AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009, must:

- have automatic door closers
- have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
- contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
- contain floor insulation of at least R–28
- use electronically commutated motors or three-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
- use electronically commutated motors, permanent split capacitor-type motors, or three-phase motors (for condenser fan motors of under 1 horsepower)
- use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEF (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.M.I, ≥9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

DATA	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR[6]	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Output (pounds [lbs] per day)[1]	300	641	700	700	700	700	700	700	700	700	700	700
Cooling Capacity (Btu/h)[2]	1963	4194	4580	4580	4580	4580	4580	4580	4580	4580	4580	4580
Water Use per Hundred Pounds (gal/hundred lbs)[3]	20	25	25	20	15	15	20	15	20	15	20	15
Energy Use per Hundred Pounds (kWh/hundred lbs)	7.7	7.5	7.1	5.8	4.8	4.8	5.8	4.8	5.8	4.8	5.8	4.8
Annual Energy Use (kWh/y)[4]	3,185	2,502	1,675	1,478	1,190	1,190	1,478	1,190	1,478	1,190	1,478	1,190
Indexed Annual Efficiency[5]	1.00	1.27	1.90	2.15	2.68	2.68	2.15	2.68	2.15	2.68	2.15	2.68
Average Life (years)	8.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Retail Equipment Cost (2022$)	$2,146	$2,616	$2,946	$3,020	$3,368	$3,368	$3,020	$3,368	$3,020	$3,368	$3,020	$3,368
Total Installed Cost (with Bin)	$2,441	$3,626	$3,276	$3,350	$3,737	$3,737	$3,350	$3,737	$3,350	$3,737	$3,350	$3,737
Total Installed Cost (2022$/kBtu/h)	$1,244	$865	$715	$732	$816	$816	$732	$816	$732	$816	$732	$816
Annual Maintenance Cost (2022$)[7]	$826	$826	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800
Annual Maintenance Cost (2022$/kBtu/h)	$421	$197	$175	$175	$175	$175	$175	$175	$175	$175	$175	$175

1. Based on the average output from the Compliance Certification Database and values within 2022 Automatic Commercial Ice Maker (ACIM) TSD.
2. Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice.
3. Water use refers to potable water.
4. EPACT 2005 energy standards went into effect in 2010. The 2015 low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond uses data from this rulemaking. All units for 2020 and beyond are assumed to comply with the updated standard.
5. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
6. The ENERGY STAR category is based on minimum compliance with the ENERGY STAR v3.0 standard, which went into effect on January 28, 2018. According to this analysis, ENERGY STAR certification is typical for the small air-cooled ice-making head (IMH) unit characterized.
7. Maintenance cost is based on the average cost of equipment within the 700 lb/day output range and includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

- Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin. Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- ENERGY STAR® updated its maximum energy consumption levels, in kilowatt-hours per 100 pounds of ice, for air-cooled ice machines that went into effect on January 28, 2018. These efficiency levels are based on the harvest rate, in pounds per 24 hours. (H). Water-cooled ice machines are not eligible for ENERGY STAR certification.

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers

Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/hundred lbs ice)
IMH	$200 \leq H \leq 1600$	$\leq 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \leq H \leq 1600$	$\leq 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \leq H \leq 4000$	$\leq -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \leq H \leq 450$	$\leq 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers

Equipment Type	Energy Consumption Rate (kWh/hundred lbs ice)	Potable Water Use (gal/hundred lbs ice)
IMH	$\leq 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\leq 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\leq 59.45 * H^{-0.349} + 0.08$	≤ 15.0

EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 pounds and 2500 pounds per 24-hour period that are manufactured or sold in the United States on or after January 1, 2010. The energy consumption is based on the harvest rate in pounds per 24 hours (H). In 2015, DOE finalized new standards for ACIMs extending coverage to flake, nugget, and tube-type machines and to capacities up to 4,000 pounds per 24 hours.

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/hundred lbs ice)	Maximum Condenser Water Use (gal/hundred lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1,436	5.58-0.0011 H	200-0.022 H
		≥1,436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1,000	8.85-0.0038 H	Not Applicable
		≥1,000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Water use is for the condenser only and does not include potable water used to make ice.

2014 DOE Standards

Energy Conservation Standards for Batch-Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous-Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

DATA	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR[2]	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Cooling Capacity (Btu/h)	4,689	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Annual Energy Use (kWh/y)	1,829	1,635	1,380	1,141	902	902	1,141	902	1,141	902	1,141	902
Annual Energy Use / Volume ($kWh/ft^3/y$)[1]	68	73	55	35	26	26	35	26	35	26	35	26
Indexed Annual Efficiency[3]	1.00	1.12	1.33	1.60	2.03	2.03	1.60	2.03	1.60	2.03	1.60	2.03
Average Life (years)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost (2022$)	$2,382	$2,051	$1,710	$2,762	$3,332	$3,332	$2,762	$3,332	$2,762	$3,332	$2,762	$3,332
Total Installed Cost (2022$)[4]	$2,382	$2,051	$1,710	$2,762	$3,332	$3,332	$2,762	$3,332	$2,762	$3,332	$2,762	$3,332
Total Installed Cost (2022$/kBtu/h)	$508	$436	$364	$588	$709	$709	$588	$709	$588	$709	$588	$709
Annual Maintenance Cost (2022$)	$108	$108	$95	$95	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost (2022$/kBtu/h)	$23.03	$22.98	$20.21	$20.21	$20.11	$20.11	$20.21	$20.11	$20.21	$20.11	$20.21	$20.11

1. EPACT 2005 energy conservation standards went into effect in 2010. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2018 and beyond use data reported in this rulemaking's TSD. Units sold in 2022 and beyond are assumed to comply with this updated standard.
2. The ENERGY STAR category characterizes a unit that is compliant with ENERGY STAR v4, effective March 2017. This standard does not separately define units with pull-down capability.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible.

- EPACT 2005 sets maximum daily energy consumption levels, in kilowatt-hours per day, for commercial refrigerators with transparent doors and self-contained condensing unit designed for pull-down temperature applications (i.e., beverage merchandisers) and went into effect on January 1, 2010.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its ENERGY STAR specifications for glass-doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that ENERGY STAR does not have a separate equipment class for units with pull-down capability.

Beverage Merchandiser Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Glass Door	0.118*V + 1.382	≤ 0.140*V + 1.050	≤ 0.088*V + 2.625	≤ 0.110*V + 1.500

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking and additional analysis by Guidehouse, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,700 Btu/h.
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, LED lighting, and improved insulation.
- For the Reference Case, beverage merchandisers are assumed to be mature technologies with few technology advancements in the coming years that would dramatically improve the efficiency.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	1,810	1,707	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	470	500	500	500	500	500	500	500	500	500	500	500
Size (ft^3)	26	35	35	35	35	35	35	35	35	35	35	35
Annual Energy Use (kWh/y)[1]	1,632	1,550	1,550	1,531	1,443	1,443	1,531	1,443	1,531	1,443	1,531	1,443
Annual Energy Use / Volume ($kWh/ft^3/y$)	63	44	44	44	41	41	44	41	44	41	44	41
Indexed Annual Efficiency[3]	1.00	1.05	1.05	1.07	1.13	1.13	1.07	1.13	1.07	1.13	1.07	1.13
Average Life (years)	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost (2022$)	$3,209	$2,553	$3,059	$3,272	$3,520	$3,520	$3,272	$3,520	$3,272	$3,520	$3,272	$3,520
Total Installed Cost (2022$)	$3,320	$2,705	$3,276	$3,489	$3,737	$3,737	$3,489	$3,737	$3,489	$3,737	$3,489	$3,737
Total Installed Cost (2022$/kBtu/h)	$1,834	$1,585	$1,810	$1,928	$2,065	$2,065	$1,928	$2,065	$1,928	$2,065	$1,928	$2,065
Annual Maintenance Cost (2022$)[4]	$270	$270	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
Annual Maintenance Cost (2022$/kBtu/h)	$149	$149	$184	$184	$184	$184	$184	$184	$184	$184	$184	$184

1. Energy use for 2018 and beyond is estimated based on DOE's 2020 BVM Final Rule and the 2022 Compliance Certification Database.
2. The ENERGY STAR category assumes units are compliant with the ENERGY STAR v4 standard because combination units are currently not separately defined by ENERGY STAR. This standard went into effect on April 29, 2020. Our analysis finds ENERGY STAR certified equipment to be the most efficient currently available on the market.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils, and an annualized cost for refurbishments/remanufacturing.

- DOE set federal energy efficiency standards for refrigerated vending machines. These standards set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial refrigerated vending machines manufactured or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
- In December 2015, DOE updated its energy conservation standards for beverage vending machines and defined two new product classes for combination vending machines. The energy conservation standard remains the same in the updated 2022 technical support document for vending machines. Compliance with these standards was required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2022 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Type	Maximum Daily Energy Consumption
Class A (Transparent-Front)	MDEC= 0.052 × V + 2.43
Class B (Solid-Front)	MDEC = 0.052 × V + 2.20
Combination A	MDEC = 0.086 × V + 2.66
Combination B	MDEC = 0.111 × V + 2.04

ENERGY STAR® updated its maximum daily energy consumption efficiency levels, also in kilowatt-hours per day, for refrigerated vending machines that went into effect on April 29, 2020. These efficiency levels are based on refrigerated volume.

Equipment Class	Maximum daily energy consumption (kilowatt-hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25% or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.04836 x V + 2.2599
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.04576 x V+1.936
Combination A – a combination vending machine where 25% or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.07998 x V + 2.4738
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.09768 x V + 1.7952

Commercial Ventilation

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	High[4,7]	ENERGY STAR	Typical[4,6]	High[4,7]	Typical[4,6]	High[4,7]	Typical[4,6]	High[4,7]
System Airflow (CFM)	15,000	16,300	16,300	16,300	16,300	N/A	16,300	16,300	16,300	16,300	16,300	16,300
System Fan Power (kW)	11.56	11.56	11.56	10.98	10.78	N/A	10.98	10.78	10.98	10.78	10.98	10.78
Specific Fan Power (W/CFM)	0.771	0.709	0.709	0.674	0.661	N/A	0.674	0.661	0.674	0.661	0.674	0.661
Annual Fan Energy Use (kWh/y)[1]	43,924	23,038	23,038	21,886	20,792	N/A	21,886	20,792	21,886	20,792	21,886	20,792
Average Life (years)	35	35	35	35	35	N/A	35	35	35	35	35	35
Total Installed Cost (2022$)[2]	$80,288	$83,083	$83,083	$86,901	$90,651	N/A	$86,901	$90,651	$86,901	$90,651	$86,901	$90,651
Annual Maintenance Cost (2022$)	$1,054	$1,054	$1,054	$1,054	$1,054	N/A	$1,054	$1,054	$1,054	$1,054	$1,054	$1,054
Total Installed Cost (2022$/thousand cubic feet per minute [CFM])	$5,353	$5,097	$5,097	$5,331	$5,561	N/A	$5,331	$5,561	$5,331	$5,561	$5,331	$5,561
Annual Maintenance Cost (2022$/thousand CFM)	$70	$65	$65	$65	$65	N/A	$65	$65	$65	$65	$65	$65

1. Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 16,300 CFM constant air volume (CAV) air handling unit (AHU) and hypothetical supply ductwork layout
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. ASHRAE 90.1-2016 and 2019 Section 6.5.3.2 require minimum two-speed fan control (no longer always constant volume).
5. Two-speed variable frequency drive (VFD)
6. Modulating VFD
7. Modulating custom engineered VFD

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, these systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain the space temperature setpoint. Beginning with ASHRAE 90.1-2013 and continued in ASHRAE 90.1-2019, new CAV ventilation systems were mandated to have at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. Systems with variable speed fans are increasingly popular, making the term “constant air volume” somewhat of a misnomer for this system type. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- The unit characterized in this report is a 16,300 CFM CAV system. The average commercial building is approximately 16,300 square feet (CBECS 2018). Assuming 1 CFM is needed per square foot of floor area results in a 16,300 CFM air handling unit.
- A 16,300 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $71,829 (RS Means 2022). Ductwork would cost approximately $9,272 additional ($81,101 total). A two-speed motor (estimated $500 incremental cost) and variable frequency drive (estimated $5,800) add cost. Custom engineered variable frequency drives (estimated $9,550) and premium efficiency motors (estimated additional $1,500) add an additional cost to the system.
- Annual maintenance cost assumes 8 hours worth of labor by a technician to perform the necessary tasks (e.g., filter replacement, draining condenser water, etc.)
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, motor efficiency, and speed and flow control.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	High[6]	ENERGY STAR	Typical[6]	High[6,7]	Typical[6,7]	High[6,7]	Typical[6,7]	High[6,7]
System Airflow (CFM)	15,000	16,300	16,300	16,300	16,300	N/A	16,300	16,300	16,300	16,300	16,300	16,300
System Fan Power (kW)	15.99	15.99	15.99	15.99	15.99	N/A	15.99	15.19	15.99	15.19	15.99	15.19
Specific Fan Power (W/CFM)	1.066	1.066	0.981	0.981	0.981	N/A	0.981	0.932	0.981	0.932	0.981	0.932
Annual Fan Energy Use (kWh/y)[1]	24,699	24,082	24,082	22,878	21,734	N/A	22,878	21,734	22,878	21,734	22,878	21,734
Average Life (years)	28	28	28	28	28	N/A	28	28	28	28	28	28
Total Installed Cost (2022$)[2]	$103,327	$110,414	$118,814	$124,495	$124,995	N/A	$124,495	$124,995	$124,495	$124,995	$124,495	$124,995
Annual Maintenance Cost (2022$)	$1,054	$1,054	$1,054	$1,054	$1,054	N/A	$1,054	$1,054	$1,054	$1,054	$1,054	$1,054
Total Installed Cost (2022$/thousand CFM)	$6,888	$6,774	$7,289	$7,638	$7,668	N/A	$7,638	$7,668	$7,638	$7,668	$7,638	$7,668
Annual Maintenance Cost (2022$/thousand CFM)	$70	$65	$65	$65	$65	N/A	$65	$65	$65	$65	$65	$65

1. Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 16,300 CFM VAV AHU, VFD, (10) VAV boxes, (10) VAV controllers with associated space temperature sensor, and hypothetical supply ductwork layout
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. ASHRAE 90.1-2016 and 2019 Section 6.5.3.2 minimum power-flow requirement
5. ASHRAE 90.1-2019 fan power limit and typical VAV power-flow relationship for 40%-100% flow
6. ASHRAE 90.1-2019 fan power limit and typical VAV power-flow relationship for 30%-100% flow
7. High aerodynamic efficiency fan

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating, then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet the space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speed and flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 16,300 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 16,300 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $82,023 (RS Means 2022). Ductwork and (10) VAV boxes with reheat would cost approximately an additional $28,272. (10) VAV controllers and the associated space temperature sensor would cost approximately $8,400 ($118,695 total). A 15 hp variable frequency drive (estimated $5,800) is an additional cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Annual maintenance cost assumes 8 hours worth of labor by a technician to perform the necessary tasks (e.g., filter replacement, draining condenser water, etc.)
- Fan energy is affected by several factors, including fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[5]	High[6]	ENERGY STAR	Typical[4,6]	High[4,7]	Typical[4,7]	High[4,8]	Typical[4,8]	High[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.241	0.241	0.241	0.148	0.148	N/A	0.141	0.134	0.134	0.136	0.136	0.129
Specific Fan Power (W/CFM)	0.302	0.302	0.301	0.185	0.185	N/A	0.176	0.167	0.167	0.170	0.170	0.162
Annual Fan Energy Use (kWh/y)[1]	543	542	542	333	333	N/A	316	301	301	306	306	291
Average Life (years)	37	37	37	37	37	N/A	37	37	37	37	37	37
Total Installed Cost (2022$)[2]	$2,845	$2,688	$3,038	$3,521	$3,961	N/A	$3,961	$4,161	$3,961	$4,161	$3,961	$4,161
Annual Maintenance Cost (2022$)	$117	$117	$117	$117	$117	N/A	$117	$117	$117	$117	$117	$117
Total Installed Cost (2022$/thousand CFM)	$3,557	$3,360	$3,798	$4,401	$4,951	N/A	$4,951	$5,201	$4,951	$5,201	$4,951	$5,201
Annual Maintenance Cost (2022$/thousand CFM)	$146	$146	$146	$146	$146	N/A	$146	$146	$146	$146	$146	$146

1. Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 2-ton horizontal two-pipe fan coil unit, housing, and controls
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. Based on ASHRAE 90.1-2016 and 2019 Section 6.5.3.6 requirement of electronically commutated or 70+% efficient fan motor
5. Permanent split capacitor fan motor
6. Electronically commutated fan motor (single speed)
7. Electronically commutated fan motor (two-speed)
8. Electronically commutated fan motor (variable speed)
9. High aerodynamic efficiency fan

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but they do not include the source of cooling or heating. The unit characterized in this report is a cooling only (two-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- Fan coil unit fan motors can be shaded pole, a single-phase AC motor with offset start winding and no capacitor; PSC, a single-phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but manufacturers also offer single speed, two speed, and ECM motors as an option. ASHRAE 90.1-2019 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit, the filters must be changed, and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including fan type configuration, filter and coil pressure drops, motor efficiency, and fan speed control.

Appendix A
Data Sources

Guidehouse
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

Residential Lighting

Data Sources » Residential General Service Incandescent Lamps (60 watt)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="4">2016 EIA Ref. Case</td><td rowspan="15">Assume Unchanged</td><td rowspan="15" colspan="11">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2008</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td>2016 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td>DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="2">2016 EIA Ref. Case</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential General Service Incandescent Lamps (75 watt)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Assume Unchanged	N/A										
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2008												
Average Lamp Life (thousand hours)	2016 EIA Ref. Case												
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	2016 EIA Ref. Case												
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential General Service Halogen Lamps (60 watt Incandescent Equivalent)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Assume Unchanged	N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2008			DOE, 2008									
Average Lamp Life (thousand hours)	2016 EIA Ref. Case	Assume Unchanged		Distributor Websites									
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated		Distributor Websites									
Lamp Cost (2022$/klm)	Calculated			Calculated									
Labor Cost (2022$/h)	N/A			N/A									
Labor Installation (hours)													
Total Installed Cost (2022$)	Calculated			Calculated									
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources» Residential General Service Halogen Lamps (75 watt Incandescent Equivalent)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Calculated	N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2008			DOE, 2008									
Average Lamp Life (thousand hours)	2016 EIA Ref. Case	Distributor Websites or Product Catalogs		Distributor Websites									
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated		Distributor Websites									
Lamp Cost (2022$/klm)	Calculated			Calculated									
Labor Cost (2022$/h)	N/A			N/A									
Labor Installation (hours)													
Total Installed Cost (2022$)	Calculated			Calculated									
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Final

Data Sources » Residential General Service Compact Fluorescent Lamps (60 watt Incandescent Equivalent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
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<tr><td>Lamp Wattage</td><td rowspan="4">2016 EIA Ref. Case</td><td rowspan="3">Calculated</td><td colspan="3" rowspan="2">Distributor Websites or Product Catalogs</td><td rowspan="6">ENERGY STAR, 2020</td><td rowspan="3">DOE, 2022</td><td colspan="6" rowspan="6">NCI, 2019</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>CRI</td><td rowspan="3">Assume Unchanged</td><td colspan="3" rowspan="3">Distributor Websites or Product Catalogs</td><td rowspan="3">N/A</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>Product Catalogs</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td>2016 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="13">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="2">2016 EIA Ref. Case</td><td rowspan="2">Calculated</td><td colspan="3">Distributor Websites or Product Catalogs</td><td rowspan="8">N/A</td><td rowspan="2">N/A</td><td colspan="6" rowspan="2">NCI, 2019</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="5" rowspan="2">N/A</td><td colspan="7" rowspan="2">N/A</td></tr>
<tr><td>Labor Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td><td colspan="5" rowspan="4">Calculated</td><td rowspan="4">N/A</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th></th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="6">Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td><td rowspan="6">2020 DOE LED Pricing Analysis</td><td colspan="3" rowspan="2">Distributor Websites or Product Catalogs</td><td rowspan="6">ENERGY STAR, 2020</td><td rowspan="3">DOE, 2022</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Assume Unchanged</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="3">Distributor Websites or Product Catalogs</td><td rowspan="3">N/A</td><td colspan="6" rowspan="2">Assume Unchanged</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="13">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td>Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td><td>2020 DOE LED Pricing Analysis</td><td colspan="3">Distributor Websites or Product Catalogs</td><td colspan="2">N/A</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td colspan="13">Calculated</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="13" rowspan="2">N/A</td></tr>
<tr><td>Labor Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td><td colspan="6" rowspan="4">Calculated</td><td rowspan="4">N/A</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential General Service Filament-LED Lamps (60 Watt Equivalent)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average		Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Assume Unchanged					
Lamp Efficacy (lm/W)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Calculated			ENERGY STAR, 2020	DOE, 2022	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Assume Unchanged					
Correlated Color Temperature (CCT)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Assume Unchanged					
Average Lamp Life (thousand hours)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)	N/A												
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)	Calculated						N/A	Calculated					
Total Installed Cost (2022$/klm)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$/klm)	Calculated						N/A	Calculated					

Data Sources » Residential Reflector Lamps (65W BR30 Incandescent)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Assume Unchanged	N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2012(1)												
Average Lamp Life (thousand hours)	2016 EIA Ref. Case												
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case			Distributor Websites or Product Catalogs									
Lamp Cost (2022$/klm)				Calculated									
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Reflector Lamps (PAR30 Halogen)

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023 Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage		Assume Unchanged											
Lamp Lumens	2016 EIA Ref. Case	Calculated											
Lamp Efficacy (lm/W)													
CRI				Distributor Websites or Product Catalogs									
Correlated Color Temperature (CCT)	DOE, 2012(1)	Assume Unchanged											
Average Lamp Life (thousand hours)	2016 EIA Ref. Case		N/A		N/A								
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated		Distributor Websites or Product Catalogs									
Lamp Cost (2022$/klm)				Calculated									
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR)

DATA SOURCES	2009	2020	2015				2023	2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Calculated	N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI		Assume Unchanged											
Correlated Color Temperature (CCT)	DOE, 2012(1)												
Average Lamp Life (thousand hours)	2016 EIA Ref. Case												
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated		Distributor Websites or Product Catalogs									
Lamp Cost (2022$/klm)				Calculated									
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Reflector Lamps (BR30 CFL)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td colspan="2" rowspan="4">2016 EIA Ref. Case / Calculated</td><td colspan="11" rowspan="16">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td colspan="2">DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td colspan="2">2016 EIA Ref. Case / Calculated</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="2">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td colspan="2" rowspan="2">2016 EIA Ref. Case / Calculated</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="2" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="2" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential Reflector LED BR30

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023 Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Reflector LED PAR38

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	2016 EIA Ref. Case	Assume Unchanged	N/A								
Lamp Lumens											
Lamp Efficacy (lm/W)	Calculated										
System Wattage											
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)	2016 EIA Ref. Case	Chapter 5; Table 5.8.16 of GSFL Ballast Final Rule TSD (DOE, 2020)									
CRI	2016 EIA Ref. Case	Assume Unchanged									
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)	DOE, 2017										
Lamp Price (2022$)	2016 EIA Ref. Case										
Ballast Price (2022$)											
Fixture Price (2022$)											
Lamp Cost (2022$/klm)	Calculated										
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)	2016 EIA Ref. Case										
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Linear Fluorescent Lamp T8

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	Calculated	Distributor Websites				Calculated					
Lamp Lumens	2016 EIA Ref. Case										
Lamp Efficacy (lm/W)	2015 GSFL TSD, Figure 11.5.4	Calculated									
System Wattage	Calculated										
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)	2016 EIA Ref. Case	Chapter 5; Table 5.8.15 of GSFL Ballast Final Rule TSD (DOE, 2020)									
CRI	2016 EIA Ref. Case	Distributor Websites				Distributor Websites					
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)						Calculated					
Annual Operating Hours (h/y)	DOE, 2017										
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Ballast Price (2022$)		N/A									
Fixture Price (2022$)		Calculated									
Lamp Cost (2022$/klm)	Calculated										
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)	2016 EIA Ref. Case	Assume unchanged	2022 RS Means Online								
Labor System Installation (hours)											
Labor Lamp Change (hours)			N/A								
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Linear Fluorescent Lamp T5

DATA SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	Distributor Websites				Assume unchanged					
Lamp Lumens	2016 EIA Ref. Case	Distributor Websites				Assume unchanged					
Lamp Efficacy (lm/W)	2015 GSFL TSD, Figure 11.5.4	Calculated				Assume unchanged					
System Wattage	Calculated										
System Lumens	Calculated										
System Efficacy (lm/W)	Calculated										
Ballast Efficiency (BLE)	Chapter 5; Table 5.3.32 of GSFL IRL Final Rule TSD (DOE, 2015)	Chapter 5; Table 5.8.6 of GSFL Ballast Final Rule TSD (DOE, 2020)									
CRI	2016 EIA Ref. Case	Distributor Websites									
Correlated Color Temperature (CCT)	2016 EIA Ref. Case	Distributor Websites									
Average Lamp Life (thousand hours)	2016 EIA Ref. Case	Distributor Websites									
Annual Operating Hours (h/y)	DOE, 2017										
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Ballast Price (2022$)	2016 EIA Ref. Case	N/A	Distributor Websites			Calculated					
Fixture Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Lamp Cost (2022$/klm)	Calculated										
System (l/b/f) Cost (2022$/klm)	Calculated										
Labor Cost (2022$/h)	2016 EIA Ref. Case		2022 RS Means Online								
Labor System Installation (hours)	2016 EIA Ref. Case		2022 RS Means Online								
Labor Lamp Change (hours)	2016 EIA Ref. Case		N/A								
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)	Calculated										
Total Installed Cost (2022$/klm)	Calculated										
Annual Maintenance Cost (2022$/klm)	Calculated										

Data Sources » Residential Linear LED Replacement Lamp 2-Lamp System

DATA SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	LED Webscrape Database	DOE Web Scrape Database	Distributor websites			Calculated					
Lamp Lumens						Assume same as 2022 Typical and High					
Lamp Efficacy (lm/W)						Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage	Calculated										
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)	N/A										
CRI	2016 EIA Ref. Case	2016 EIA Ref. Case	Distributor Websites			Distributor Websites					
Correlated Color Temperature (CCT)	2016 EIA Ref. Case	Distributor Websites									
Average Lamp Life (thousand hours)	LED Webscrape Database	DOE Web Scrape Database									
Annual Operating Hours (h/y)	DOE, 2017										
Lamp Price (2022$)	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A				N/A					
Fixture Price (2022$)		N/A									
Lamp Cost (2022$/klm)	Calculated										
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)	N/A										
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Linear LED Luminaire

DATA SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	N/A										
Lamp Efficacy (lm/W)											
System Wattage						Calculated					
System Lumens	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Assume same as 2022 Typical and High					
System Efficacy (lm/W)						Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Efficiency (BLE)	N/A										
CRI											
Correlated Color Temperature (CCT)	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Distributor Websites					
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)	DOE, 2017										
Lamp or Luminaire Price (2022$)	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)											
Fixture Price (2022$)											
Lamp Cost (2022$/klm)	N/A										
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)			2022 RS Means Online								
Labor System Installation (hours)	2016 EIA Ref. Case										
Labor Lamp Change (hours)			N/A								
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)	Calculated										
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Outdoor Lamps (Security: BR30 Incandescent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th>2020</th><th colspan="4">2015</th><th>2023</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td colspan="13" rowspan="15">Same as indoor Residential Incandescent Reflector</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td></tr>
<tr><td>Lamp Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td></tr>
<tr><td>Labor Lamp Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential Outdoor Lamps (Security: PAR38 Halogen)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Interpolation Based on Commercial PAR38		Same as Commercial PAR38 Halogen										
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Security: PAR38 HIR)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Interpolated from Commercial PAR38 HIR		Same as Commercial PAR38 HIR										
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Security: CFL PAR38)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case / Calculated		N/A										
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2012(1)												
Average Lamp Life (thousand hours)	2016 EIA Ref. Case / Calculated												
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	2016 EIA Ref. Case / Calculated												
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Security: LED PAR38)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential LED PAR38												
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Porch: A19 Incandescent)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Incandescent												
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Porch: Halogen A-Type)

DATA SOURCES	2015	2020	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Equivalent Halogen												
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2015</th><th>2020</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="4">2016 EIA Ref. Case</td><td rowspan="3">Calculated</td><td colspan="3" rowspan="2">Distributor Websites or Product Catalogs</td><td rowspan="6">ENERGY STAR, 2020</td><td rowspan="3">DOE, 2022</td><td colspan="6" rowspan="6">NCI, 2019</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>CRI</td><td rowspan="3">Assume Unchanged</td><td colspan="3" rowspan="3">Distributor Websites or Product Catalogs</td><td rowspan="3">N/A</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>Product Catalogs</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td>2016 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="13">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="2">2016 EIA Ref. Case</td><td rowspan="2">Calculated</td><td colspan="3">Distributor Websites or Product Catalogs</td><td rowspan="8">N/A</td><td rowspan="2">N/A</td><td colspan="6" rowspan="2">NCI, 2019</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="5" rowspan="2">N/A</td><td colspan="7" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="5" rowspan="4">Calculated</td><td rowspan="4">N/A</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Residential Outdoor Lamps (Porch: LED A-Type)

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023 Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Commercial Lighting

Data Sources » Commercial General Service 100W Incandescent Lamp in Recessed Can Fixture

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage													
Lamp Lumens													
Lamp Efficacy (lm/W)													
System Wattage	2016 EIA Reference Case												
System Lumens													
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI													
Correlated Color Temperature (CCT)	DOE, 2008												
Average Lamp Life (thousand hours)	2016 EIA Reference Case												
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)							N/A						
Ballast Price (2022$)													
Fixture Price (2022$)	2016 EIA Reference Case; Calculated												
Lamp Cost (2022$/klm)													
System (l/b/f) Cost (2022$/klm)													
Labor Cost (2022$/h)													
Labor System Installation (hours)	2016 EIA Reference Case												
Labor Lamp Change (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)	Calculated												
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="4">2022</th><th>2023</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>ENERGY STAR</th><th>Standard</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="8">2016 EIA Reference Case</td><td rowspan="8">Assume Unchanged</td><td rowspan="23">N/A</td><td rowspan="10">Product Catalogs</td><td rowspan="23" colspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td colspan="2">DOE, 2008</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td><td>2016 EIA Reference Case</td><td>Assume Unchanged</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="2">DOE, 2017</td><td>DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="5">2016 EIA Reference Case</td><td rowspan="5">DOE, 2019</td><td rowspan="3">Distributor Websites</td></tr>
<tr><td>Ballast Price (2022$)</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="2" rowspan="3">2016 EIA Reference Case</td><td rowspan="3">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="2" rowspan="4">Calculated</td><td rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial General Service 100W Equivalent CFL Bare Spiral in Recessed Can Fixture

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Reference Case	Calculated / Guidehouse	Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)								NCI, 2019					
System Wattage							Same as lamp wattage						
System Lumens							Calculated						
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI							N/A	Assume Unchanged					
Correlated Color Temperature (CCT)	2016 EIA Reference Case												
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)	DOE, 2017					N/A	DOE, 2017						
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites				N/A	NCI, 2019					
Ballast Price (2022$)													
Fixture Price (2022$)			NCI, 2019										
Disposal Cost (2022$)	EPA, 2022							EPA, 2022					
Lamp Cost (2022$/klm)	Calculated							NCI, 2019					
System (l/b/f) Cost (2022$/klm)													
Labor Cost (2022$/h)	2016 EIA Reference Case		2022 RS Means Online					2022 RS Means Online					
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)	Calculated							Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Reference Case	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)								Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage		Calculated											
System Lumens													
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Assume Unchanged					
Correlated Color Temperature (CCT)						N/A							
Average Lamp Life (thousand hours)						ENERGY STAR, 2020		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)				Assume Unchanged	
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	2016 EIA Reference Case	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A						N/A					
Fixture Price (2022$)													
Lamp Cost (2022$/klm)		Calculated						Calculated					
System (l/b/f) Cost (2022$/klm)		N/A						N/A					
Labor Cost (2022$/h)		2016 EIA Reference Case	2022 RS Means Online					2022 RS Means Online					
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)		Calculated						Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial Halogen Reflector Lamp (PAR38) in Recessed Can Fixture

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023 Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	2016 EIA Reference Case	2016 EIA Reference Case / Calculated, NCI, 2019	N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
System Wattage													
System Lumens													
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Reference Case; Calculated			Distributor Websites or Product Catalogs									
Ballast Price (2022$)													
Fixture Price (2022$)													
Lamp Cost (2022$/klm)				Calculated									
System (l/b/f) Cost (2022$/klm)													
Labor Cost (2022$/h)	2016 EIA Reference Case			2022 RS Means Online									
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)	Calculated			Calculated									
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial Halogen Infrared Reflector Lamp (PAR38) in Recessed Can Fixture

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Reference Case		N/A	Distributor Websites or Product Catalogs	N/A								
Lamp Lumens													
Lamp Efficacy (lm/W)													
System Wattage													
System Lumens													
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)													
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017									
Lamp Price (2022$)	2016 EIA Reference Case; Calculated			Distributor Websites or Product Catalogs									
Ballast Price (2022$)													
Fixture Price (2022$)													
Lamp Cost (2022$/klm)				Calculated									
System (l/b/f) Cost (2022$/klm)													
Labor Cost (2022$/h)	2016 EIA Reference Case			2022 RS Means Online									
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)	Calculated			Calculated									
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial LED Reflector Lighting (PAR38)

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Reference Case	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)								Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage		Calculated											
System Lumens													
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Assume Unchanged					
Correlated Color Temperature (CCT)						N/A							
Average Lamp Life (thousand hours)						ENERGY STAR, 2020		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)				Assume Unchanged	
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	2016 EIA Reference Case	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			N/A		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A						N/A					
Fixture Price (2022$)													
Lamp Cost (2022$/klm)		Calculated						Calculated					
System (l/b/f) Cost (2022$/klm)		N/A						N/A					
Labor Cost (2022$/h)		2016 EIA Reference Case	2022 RS Means Online					2022 RS Means Online					
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)		Calculated						Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	2016 EIA Ref. Case	Calculated	Assume same as residential T8								
Lamp Lumens		Assume same as residential T8									
Lamp Efficacy (lm/W)		SSL Forecast for 2018									
System Wattage		Calculated									
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)		Assume unchanged	Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)								
CRI		Assume same as residential T8									
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp Price (2022$)		SSL Forecast for 2018	Assume same as residential T8			Calculated					
Ballast Price (2022$)											
Fixture Price (2022$)											
Disposal Costs (2022$)	EPA, 2022										
Lamp Cost (2022$/klm)	2016 EIA Ref. Case	Calculated									
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)		2016 EIA Ref. Case	2022 RS Means Online								
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)		Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Ref. Case	Distributor Websites				
Lamp Lumens						
Lamp Efficacy (lm/W)						
System Wattage	Calculated					
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency (BLE)	Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)					
CRI	2016 EIA Ref. Case	Distributor Websites				
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)						
Annual Operating Hours (h/y)		DOE, 2017				
Lamp Price (2022$)		Calculated	Distributor Websites	Calculated		
Ballast Price (2022$)						
Fixture Price (2022$)						
Disposal Costs (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	Calculated					
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Ref. Case		2022 RS Means Online			
Labor System Installation (hours)						
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated					
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial 4-ft T5 F28 in 2-Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="3">2016 EIA Ref. Case</td><td>Calculated</td><td colspan="9" rowspan="3">Assume same as residential T5</td></tr>
<tr><td>Lamp Lumens</td><td>Assume same as residential T5, 2022</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td>SSL Forecast for 2018</td></tr>
<tr><td>System Wattage</td><td colspan="11" rowspan="3">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="11">Chapter 5; Table 5.8.6 of GSFL Ballast Final Rule TSD (DOE, 2020)</td></tr>
<tr><td>CRI</td><td rowspan="7">2016 EIA Ref. Case</td><td colspan="10" rowspan="3">Assume same as residential T5</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="10">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="3">SSL Forecast for 2018</td><td colspan="3" rowspan="3">Assume same as residential T5</td><td colspan="6" rowspan="3">Calculated</td></tr>
<tr><td>Ballast Price (2022$)</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Disposal Costs (2022$)</td><td colspan="11">EPA, 2022</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td rowspan="9">2016 EIA Ref. Case</td><td colspan="10" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="3">2016 EIA Ref. Case</td><td colspan="9" rowspan="3">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="10" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	LED Webscrape Database	Distributor websites			Calculated					
Lamp Lumens						Assume same as 2022 Typical and High					
Lamp Efficacy (lm/W)						Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage		Calculated				Calculated					
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)		N/A				N/A					
CRI		Distributor websites									
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp Price (2022$)		LED Webscrape Database	Distributor Websites			Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A				N/A					
Fixture Price (2022$)											
Lamp Cost (2022$/klm)		Calculated									
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)		Assume unchanged	2022 RS Means Online								
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)		Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="23">2016 EIA Ref. Case</td><td colspan="4" rowspan="3">N/A</td><td colspan="6" rowspan="3">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">LED Webscrape Database</td><td colspan="3" rowspan="3">Distributor websites</td><td colspan="6">Calculated</td></tr>
<tr><td>System Lumens</td><td colspan="6">Assume same as 2022 Typical and High</td></tr>
<tr><td>System Efficacy (lm/W)</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="4">N/A</td><td colspan="6">N/A</td></tr>
<tr><td>CRI</td><td colspan="10" rowspan="3">Distributor websites</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lifetime (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="10">DOE, 2017</td></tr>
<tr><td>Lamp or Luminaire Price (2022$)</td><td>LED Webscrape Database</td><td colspan="3">Distributor Websites</td><td colspan="6">Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>Ballast Price (2022$)</td><td colspan="10" rowspan="3">N/A</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td><td colspan="10">Calculated</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="3">Assume unchanged</td><td colspan="9" rowspan="3">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="10" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Occupancy Sensor

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Ref. Case	Distributor Websites				
Lamp Lumens						
Lamp Efficacy (lm/W)						
System Wattage		Calculated				
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency (BLE)		Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)				
CRI		Distributor Websites				
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)						
Annual Operating Hours (h/y)		DOE, 2017				
Lamp Price (2022$)		Calculated	Distributor Websites	Calculated		
Ballast Price (2022$)		N/A				
Fixture Price (2022$)		Calculated	Distributor Websites	Calculated		
Occupancy Sensor Price (2022$)	N/A			Distributor Websites		
Disposal Costs (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Ref. Case	Calculated				
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)		Assume unchanged	2022 RS Means Online			
Labor System Installation (hours)						
Labor Lamp Change (hours)						
Total Installed Cost (2022$)		Calculated				
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Specular Reflector

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th>2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="14">2016 EIA Ref. Case</td><td colspan="5" rowspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td><td colspan="5" rowspan="3">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="5">Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)</td></tr>
<tr><td>CRI</td><td colspan="5" rowspan="3">Distributor Websites</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="5">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td>Calculated</td><td>Distributor Websites</td><td colspan="3">Calculated</td></tr>
<tr><td>Ballast Price (2022$)</td><td colspan="5">N/A</td></tr>
<tr><td>Fixture Price (2022$)</td><td>Calculated</td><td rowspan="2">Distributor Websites</td><td colspan="3">Calculated</td></tr>
<tr><td>Reflector Price (2022$)</td><td colspan="2">N/A</td><td colspan="3">Distributor Websites</td></tr>
<tr><td>Disposal Costs (2022$)</td><td colspan="6">EPA, 2022</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td rowspan="9">2016 EIA Ref. Case</td><td colspan="5" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="3">Assume unchanged</td><td colspan="4" rowspan="3">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="5" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 4-ft T8 F28 High-efficiency and High-output in 2-Lamp System with Occupancy Sensor and Specular Reflector

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th>2022</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Typical</th><th>Typical</th><th>Typical</th><th>Typical</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="16">2016 EIA Ref. Case</td><td>Calculated</td><td rowspan="3">Distributor Websites</td><td rowspan="3">Distributor Websites</td><td rowspan="3">Distributor Websites</td><td rowspan="3">Distributor Websites</td></tr>
<tr><td>Lamp Lumens</td><td rowspan="2">Distributor Websites</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td><td colspan="5" rowspan="3">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="5">Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)</td></tr>
<tr><td>CRI</td><td colspan="5" rowspan="3">Distributor Websites</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="5">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="3">Calculated</td><td rowspan="5">Distributor Websites</td><td rowspan="3">Calculated</td><td rowspan="3">Calculated</td><td rowspan="3">Calculated</td></tr>
<tr><td>Ballast Price (2022$)</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Reflector Price (2022$)</td><td rowspan="2">N/A</td><td colspan="3" rowspan="2">Distributor Websites</td></tr>
<tr><td>Occupancy Sensor Price (2022$)</td></tr>
<tr><td>Disposal Costs (2022$)</td><td colspan="6">EPA, 2022</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td rowspan="9">2016 EIA Ref. Case</td><td colspan="5" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="3">Assume unchanged</td><td colspan="4" rowspan="3">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="5" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	Calculated	Distributor Websites			Assume same as 2022					
Lamp Lumens											
Lamp Efficacy (lm/W)			Calculated								
System Wattage		Calculated				Calculated					
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)		Assume unchanged	Chapter 5; Table 5.8.1 of GSFL Ballast Final Rule TSD (DOE, 2020)								
CRI	2016 EIA Ref. Case	Distributor Websites				Assume same as 2022					
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp Price (2022$)		Calculated	Distributor Websites			Calculated					
Ballast Price (2022$)											
Fixture Price (2022$)											
Disposal Costs (2022$)	EPA, 2022										
Lamp Cost (2022$/klm)	2016 EIA Ref. Case	Calculated									
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)		Assume unchanged	2022 RS Means Online								
Labor System Installation (hours)	Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)										
Labor Lamp Change (hours)	Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)										
Total Installed Cost (2022$)	2016 EIA Ref. Case	Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	2016 EIA Ref. Case	Assume same as 2022 typical	Distributor Websites			Assume same as 2022					
Lamp Lumens	2016 EIA Ref. Case	Assume same as 2022 typical	Distributor Websites			Assume same as 2022					
Lamp Efficacy (lm/W)	2016 EIA Ref. Case	Assume same as 2022 typical	Distributor Websites			Assume same as 2022					
System Wattage	2016 EIA Ref. Case	Calculated									
System Lumens	2016 EIA Ref. Case	Calculated									
System Efficacy (lm/W)	2016 EIA Ref. Case	Calculated									
Ballast Efficiency (BLE)	2016 EIA Ref. Case	Chapter 5; Table 5.3.26 GSFL IRL Final Rule TSD (DOE, 2014)									
CRI	2016 EIA Ref. Case	Distributor Websites									
Correlated Color Temperature (CCT)	2016 EIA Ref. Case	Distributor Websites									
Average Lamp Life (thousand hours)	2016 EIA Ref. Case	Distributor Websites									
Annual Operating Hours (h/y)	2016 EIA Ref. Case	DOE, 2017									
Lamp Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Ballast Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Fixture Price (2022$)	2016 EIA Ref. Case	Calculated	Distributor Websites			Calculated					
Disposal Costs (2022$)	EPA, 2022										
Lamp Cost (2022$/klm)	2016 EIA Ref. Case	Calculated	Calculated								
System (l/b/f) Cost (2022$/klm)	2016 EIA Ref. Case	Calculated	Calculated								
Labor Cost (2022$/h)	2016 EIA Ref. Case	2016 EIA Ref. Case	2022 RS Means Online								
Labor System Installation (hours)	Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)		2022 RS Means Online								
Labor Lamp Change (hours)	Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)										
Total Installed Cost (2022$)	2016 EIA Ref. Case	Calculated				Calculated					
Annual Maintenance Cost (2022$)	2016 EIA Ref. Case	Calculated				Calculated					
Total Installed Cost (2022$/klm)	2016 EIA Ref. Case	Calculated				Calculated					
Annual Maintenance Cost (2022$/klm)	2016 EIA Ref. Case	Calculated				Calculated					

Data Sources » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="25">N/A</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td colspan="3" rowspan="2">Distributor Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Assume same as 2022 Typical and High</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3" rowspan="4">Calculated</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">Calculated</td><td colspan="6" rowspan="3">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="10">N/A</td></tr>
<tr><td>CRI</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td colspan="3" rowspan="3">Distributor Websites</td><td colspan="6" rowspan="3">Assume same as 2022</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="10">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="5">2016 EIA Ref. Case, 2015 typical</td><td colspan="3">Distributor Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>Ballast Price (2022$)</td><td colspan="9" rowspan="2">N/A</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td colspan="9" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td>2016 EIA Ref. Case</td><td colspan="9">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td><td colspan="10">N/A</td></tr>
<tr><td>Labor Lamp Change (hours)</td><td colspan="10">Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td colspan="4" rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 8-ft Linear LED Luminaire Replacement for a 2-Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="22">N/A</td><td colspan="10" rowspan="3">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td colspan="3" rowspan="3">Distributor Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>System Lumens</td><td colspan="6">Assume same as 2022 Typical and High</td></tr>
<tr><td>System Efficacy (lm/W)</td><td colspan="6">Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="10">N/A</td></tr>
<tr><td>CRI</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td colspan="9" rowspan="3">Distributor Websites</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lifetime (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="10">DOE, 2017</td></tr>
<tr><td>Lamp or Luminaire Price (2022$)</td><td rowspan="5">2016 EIA Ref. Case, 2015 typical</td><td colspan="9">Distributor Websites</td></tr>
<tr><td>Ballast Price (2022$)</td><td colspan="9" rowspan="3">N/A</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td><td colspan="9">Calculated</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td rowspan="2">2016 EIA Ref. Case</td><td colspan="9" rowspan="2">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td></tr>
<tr><td>Labor Lamp Change (hours)</td><td colspan="10">N/A</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td rowspan="4">2016 EIA Ref. Case</td><td colspan="9" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial Mercury Vapor Low-bay

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs	N/A		
Lamp Lumens						
Lamp Efficacy (lm/W)						
System Wattage						
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)			
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)			
Annual Operating Hours (h/y)	DOE, 2017					
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)						
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	Calculated					
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated		Calculated			
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial Metal Halide Low-bay

DATA SOURCES	2012	2018	2022	2030	2040	2050
	Installed Stock Average	Installed Stock Average	Typical	Typical	Typical	Typical
Lamp Wattage	Assume Unchanged		Distributor Websites or Product Catalogs	Calculated		
Lamp Lumens	Distributor Websites or Product Catalogs; Calculated			Assume Unchanged		
Lamp Efficacy (lm/W)				Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System Wattage	2016 EIA Reference Case	Assume Unchanged				
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)	Assume Unchanged		
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017			
Lamp Price (2022$)	Distributor Websites or Product Catalogs ; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)	2016 EIA Reference Case; Calculated					
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated			
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated					
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial Sodium Vapor Low-bay

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs	Calculated		
Lamp Lumens				Assume Unchanged		
Lamp Efficacy (lm/W)				Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System Wattage						
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)	Assume Unchanged		
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017			
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)						
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated					
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial LED Low-bay Luminaire

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A										
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	N/A	Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency		N/A		N/A		N/A					
CRI		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017							
Lamp or Luminaire Price (2022$)	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A		N/A							
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated		Calculated		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Labor Cost (2022$/h)		2016 EIA Reference Case		2022 RS Means Online							
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated			Calculated							
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial Mercury Vapor High-Bay

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs		N/A	
Lamp Lumens						
Lamp Efficacy (lm/W)						
System Wattage						
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)			
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)			
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017			
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)						
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated			
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated		Calculated			
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial Metal Halide High-Bay

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs	Calculated		
Lamp Lumens		2016 EIA Reference Case; Calculated		Assume Unchanged		
Lamp Efficacy (lm/W)				Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System Wattage		Assume Unchanged				
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)	Assume Unchanged		
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017			
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)						
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated					
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial Sodium Vapor High-Bay

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Typical	2030 Typical	2040 Typical	2050 Typical
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs	Calculated		
Lamp Lumens				Assume Unchanged		
Lamp Efficacy (lm/W)				Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System Wattage						
System Lumens						
System Efficacy (lm/W)						
Ballast Efficiency			Chapter 5; Table 5.7.24 of HID Final Determination TSD (DOE, 2015)	Assume Unchanged		
CRI			Distributor Websites or Product Catalogs			
Correlated Color Temperature (CCT)						
Average Lamp Life (thousand hours)			Chapter 3; Section 3.4.2 of HID Final Determination TSD (DOE, 2015)	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017			
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs			
Ballast Price (2022$)						
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated			
Disposal Cost (2022$)	EPA, 2022					
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		
System (l/b/f) Cost (2022$/klm)						
Labor Cost (2022$/h)	2016 EIA Reference Case		Chapter 9; Section 9.2.2.1 of HID Final Determination TSD (DOE, 2015)			
Labor System Installation (hours)			2022 RS Means Online			
Labor Lamp Change (hours)						
Total Installed Cost (2022$)	Calculated					
Annual Maintenance Cost (2022$)						
Total Installed Cost (2022$/klm)						
Annual Maintenance Cost (2022$/klm)						

Data Sources » Commercial T5 4xF54 HO High-bay

DATA SOURCES	2012	2018	2022		2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Reference Case	Assume Unchanged	Distributor Websites or Product Catalogs		Calculated					
Lamp Lumens					Assume Unchanged					
Lamp Efficacy (lm/W)					Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage										
System Lumens										
System Efficacy (lm/W)										
Ballast Efficiency (BLE)			GSFL Ballast Final Rule TSD (DOE, 2020)		Assume Unchanged					
CRI			Distributor Websites or Product Catalogs							
Correlated Color Temperature (CCT)										
Average Lamp Life (thousand hours)			Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017		DOE, 2017							
Lamp Price (2022$)	2016 EIA Reference Case; Calculated		Distributor Websites or Product Catalogs							
Ballast Price (2022$)										
Fixture Price (2022$)			Chapter 7 & Appendix 6A; Table 6A.3.4 of HID Final Determination TSD (DOE, 2015), Calculated							
Disposal Cost (2022$)	EPA, 2022									
Lamp Cost (2022$/klm)	2016 EIA Reference Case; Calculated		Calculated		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System (l/b/f) Cost (2022$/klm)										
Labor Cost (2022$/h)	2016 EIA Reference Case		2022 RS Means Online							
Labor System Installation (hours)										
Labor Lamp Change (hours)										
Total Installed Cost (2022$)	Calculated									
Annual Maintenance Cost (2022$)										
Total Installed Cost (2022$/klm)										
Annual Maintenance Cost (2022$/klm)										

Data Sources » Commercial LED High-bay Luminaire

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	N/A										
Lamp Efficacy (lm/W)											
System Wattage											
System Lumens											
System Efficacy (lm/W)		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Efficiency	2016 EIA Reference Case	N/A		N/A							
CRI						Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017							
Lamp or Luminaire Price (2022$)		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	N/A	Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)	2016 EIA Reference Case										
Fixture Price (2022$)		N/A		N/A							
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated		Calculated							
Labor Cost (2022$/h)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Labor System Installation (hours)		2016 EIA Reference Case		2022 RS Means Online							
Labor Lamp Change (hours)											
Total Installed Cost (2022$)											
Annual Maintenance Cost (2022$)	Calculated			Calculated							
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Refrigeration

Data Sources » Commercial Compressor Rack Systems

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Total Capacity (kBtu/h)	ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Power Input (kW)	Copeland, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (MMWh/y)	ADL, 1996 / NCI Analysis, 2015	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Indexed Annual Efficiency	Calculated											
Average Life (years)	Kysor-Warren, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	NCI, 2009 / NCI Analysis, 2012	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Condensers

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (MMWh/y)	NCI Analysis, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft²)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Case Length (ft)	DOE, 2016: CRE Report / Guidehouse Analysis 2022											
Annual Energy Use (kWh/y)[1,2]	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use / Case Length (kWh/ft)	Calculated											
Indexed Annual Efficiency[3]	Calculated											
Average Life (years)	DOE, 2007 / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / The Restaurant Store										
Total Installed Cost (2022$)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)[4]	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Reach-In Refrigerators

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022										
Annual Energy Use / Volume (kWh/y/ft^3)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (years)	Calculated											
Retail Equipment Cost (2022$)	ACEEE, 2002	DOE, 2014: CRE TSD										
Total Installed Cost (2022$)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022 / The Restaurant Store										
Total Installed Cost (2022$/kBtu/h)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$)	Calculated											
Annual Maintenance Cost (2022$/kBtu/h)	NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Reach-In Freezers

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE, 2016: CRE Report										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2016: CRE Report										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use / Volume ($kWh/y/ft^3$)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ACEEE, 2002	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022 / The Restaurant Store										
Total Installed Cost (2022$)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE CRE Report 2016 / CCMS 2022 / Guidehouse Analysis 2022											
Size (ft^2)	DOE 2014 WICF TSD / Guidehouse Analysis 2022											
Annual Energy Use (kWh/y)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Annual Energy Use / Area (kWh/ft^2/y)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Compressor Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2023										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE CRE Report 2016 / CCMS 2022 / Guidehouse Analysis 2022										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	Guidehouse Analysis 2022										
Annual Energy Use (kWh/y)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	Guidehouse CRE Report 2016										
Annual Energy Use / Area (kWh/ft^2/y)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Compressor Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2023										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE CRE Report 2016 / Guidehouse Analysis 2022											
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Output (pounds [lbs] per day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / CCMS Database 2022										
Water Use per Hundred Pounds (gal/hundred lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / CCMS Database 2022										
Energy Use per Hundred Pounds (kWh/hundred lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Annual Energy Use (kWh/y)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / ENERGY STAR										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Retail Equipment Cost (2022$)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Size (ft³)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022										
Annual Energy Use / Volume (kWh/ft³/y)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (years)	ACEEE, 2002	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / KaTom Restaurant Supply										
Total Installed Cost (2022$)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Cooling Capacity (Btu/h)	DOE, 2015: BVM TSD / Guidehouse Analysis, 2015	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022										
Can Capacity	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Size (ft^3)	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022											
Annual Energy Use (kWh/y)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Annual Energy Use / Volume ($kWh/ft^3/y$)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (years)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Retail Equipment Cost (2022$)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Total Installed Cost (2022$)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE, 2015: BVM TSD / Guidehouse Analysis, 2015	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022										
Annual Maintenance Cost (2022$/kBtu/h)	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022											

Commercial Ventilation

Data Sources » Commercial Constant Air Volume Ventilation

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	CBECS 2003 & BED 2007	CBECS 2018										
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	CBECS 2003 & BED 2007	CBECS 2018										
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

Data Sources » Commercial Fan Coil Unit

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

Appendix B
References

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References

- ASHRAE Service Life and Maintenance Cost Database. (n.d.).
- ASHRAE 90.1-2010, 2016, 2019. *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- Appliance Magazine. (2005). Portrait of the U.S. Appliance Industry. Appliance Magazine.
- Arthur D. Little. (1996). Energy Savings Potential for Commercial Refrigeration Equipment.
- DOE SSL Program. (2012a). *2010 U.S. Lighting Market Characterization*
- DOE SSL Program. (2012b). *Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates*
- DOE SSL Program. (2017). *2015 U.S. Lighting Market Characterization*
- DOE Appliance and Equipment Standards Program. (2022). *The Compliance Certification Database*.
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Automatic Commercial Ice Makers*
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Commercial Refrigeration Equipment.*
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Refrigerated Beverage Vending Machines*
- EERE. (2015). *Energy Conservation Program for Appliance Standards: Walk-in Coolers and Freezers.*
- ENERGY STAR. (n.d.). Retrieved November 2015, from ENERGY STAR Products: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
- ENERGY STAR. (2020) from ENERGY STAR Lamps Specification Version 2.1: https://www.energystar.gov/sites/default/files/Lamps%20V2.1%20Final%20Specification%20%28Revised%20June%202020%29_0.pdf

- ENERGY STAR. (2014) *ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.1*
- ENERGY STAR. (2012) *ENERGY STAR® Program Requirements Product Specification for Luminaires (Light Fixtures) Eligibility Criteria Version 1.1*
- Environmental Protection Agency. (2022). *Establishing a Recycling Program for Mercury-Containing Light Bulbs*. From: https://www.epa.gov/hw/establishing-recycling-program-mercury-containing-light-bulbs
- Federal Standard. (1975). National energy conservation standards authorized under the Energy and Policy Conservation Act of 2007 (EPCA 1975).
- Federal Standard. (2005). National energy conservation standards authorized under the Energy Policy Act of 2005 (EPACT 2005).
- Federal Standard. (2007). National energy conservation standards authorized under the Energy Independence and Security Act of 2007 (EISA 2007).
- Food Marketing Institute. (n.d.). Retrieved May 2022, from FMI Supermarket Facts: https://www.fmi.org/our-research/supermarket-facts/average-total-store-size-square-feetLighting Research Institute. (1992). Specifier Reports, Specular Reflectors.
- KaTom. (n.d.) Retrieved May 2022, From: https://www.katom.com/
- Navigant Consulting, Inc. (2009). Energy Savings Potential and R&D Opportunities for Commercial Refrigeration.
- Navigant Consulting, Inc. (n.d.). In House Expertise.

References

- Navigant Consulting, Inc. (2019). Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Model. https://www.energy.gov/eere/ssl/downloads/2019-ssl-forecast-report
- Product Literature. (n.d.). Literature from manufacturers and experts on specific products
- The Restaurant Store. (n.d.). Retrieved May 2022, From: https://www.therestaurantstore.com/
- *RS Means Online.* (2022). Retrieved June 2022, From: https://www.rsmeansonline.com/
- Webstaurant. (n.d.) Retrieved May 2022, From: https://www.webstaurantstore.com/

APPENDIX D

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

Presented to:

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October 14, 2022

DISCLAIMER

October 2022

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Final

Objective

The objective of this study is to develop baseline and projected performance and cost characteristics for residential and commercial end-use equipment in an Advanced Case that assumes accelerated adoption of energy-saving technologies due to increased R&D funding and market incentives.

- Examine 2012 and 2018 (commercial) and 2015 and 2020 (residential) baselines, as well as this year's baseline (2022).
  - Review literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost and efficiency of a generic product.
- Forecast technology improvements that are projected to be available through 2050.
  - Review trends in standards, product enhancements, and research and development (R&D).
  - Project impact of product improvements and technology enhancement.

The performance and cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Methodology

Input from industry stakeholders, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments affect performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 and 2018 (for commercial products) and 2015 and 2020 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- **Installed Stock Average**: the installed and *in use* equipment for that year. Represents the installed stock of equipment, but does *not* represent sales.
- **Current Standard**: the minimum efficiency (or maximum energy use) required (allowed) by current U.S. Department of Energy (DOE) standards, when applicable. For lighting, if no product exists at the standard efficiency level, a hypothetical wattage and lumen output is given for the standard's efficiency level.
- **ENERGY STAR®**: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR® criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications. For lighting, if no products exist at the ENERGY STAR efficiency level, a hypothetical wattage and lumen output is given for the ENERGY STAR efficiency level.
- **Low**: The minimum efficiency product or product mix available on the market. This rating typically reflects minimal compliance with DOE standards.
- **Typical**: the average, or typical, product being sold in the particular timeframe.
- **High**: the product with the highest efficiency available in the particular timeframe.
- **Lumens (lm):** the unit for luminous flux used in the SI unit system. This unit is used to indicate a light source's light output. All reported lumens are initial lumens. 1 kilolumen (klm) = 1,000 lumens.
- **Correlated Color Temperature (CCT)**: a specification of the color appearance of the light emitted by a lamp. Note: CCT is not a performance metric.
- **Color Rendering Index (CRI)**: a scale from 0 to 100 percent indicating how accurate a given light source is at rendering color when compared to a reference light source. The higher the CRI, the better the color rendering ability.
- **British thermal unit (Btu)**: a measure of the heat content of fuels or energy sources. It is the quantity of heat required to raise the temperature of one pound of liquid water by 1°F at the temperature that water has its greatest density (approximately 39 °F). 1 kBtu = 1,000 Btu.
- **Cubic Feet per Minute (CFM)**: a measure of airflow volume equal to the number of cubic feet of air flowing through a two-dimensional plane in one minute.
- **Not Available (N/A)**: data is not available where indicated.

Calculations

The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric

- **Lighting**
  - **System Wattage** = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
  - **System Lumens** = Lamp Lumens * Ballast Factor
  - **Lamp Efficacy** = Lamp Lumens / Lamp Wattage
  - **System Efficacy** = System Lumens / System Wattage
  - **Lamp Cost ($/klm)** = Lamp Cost / (Lamp Lumens / 1,000)
  - **Total Equipment Cost** = Lamp Cost + Fixture (including ballast) Cost
  - **System Cost ($/klm)** = Total Equipment Cost / (System Lumens / 1,000). l/b/f denotes that the cost includes the luminaire, the ballast, and the fixture.
  - **Total Installed Cost** = Total Equipment Cost + Labor Installation Cost
  - **Ballast Luminous Efficiency (BLE)** = A/(1+B*Avg Total Lamp Arc Power^(-C)) where A, B, and C are pre-defined constants by DOE Energy Conservation Standards for Fluorescent Lamp Ballasts.
- **Commercial Refrigeration**
  - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3,412)
  - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
  - **Total Installed Cost ($/kBtu/hour)** = Total Installed Cost*1,000 / (Cooling or Heat Rejection Capacity). h used as an abbreviation for hour throughout
  - **Annual Maintenance Cost ($/kBtu/h)** = Annual Maintenance Cost * 1,000 / (Cooling or Heat Rejection Capacity)
- **Ventilation**
  - **CFM out / Btu in / h** = System Airflow / (System Fan Power * 3,412)
  - **Total Installed Cost ($/1,000 CFM)** = Total Installed Cost * 1,000 / System Airflow
  - **Annual Maintenance Cost ($/1,000 CFM)** = Annual Maintenance Cost * 1,000 / System Fan Power

Market Transformation

The market for the reviewed products has changed since this analysis was performed in 2015. These changes are noted and reflected in the efficiency and cost characteristics.

- DOE issued federal minimum efficiency standards that have gone into effect for General Service Fluorescent Lamps (2012), Incandescent Reflector Lamps (2012), and Fluorescent Lamp Ballasts (2019).

- In April 2022, DOE codified into the Code of Federal Regulations the 45 lumens per watt (lm/W) backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act (10 CFR 430, 87 FR 27439). This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

- DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018. DOE also issued federal minimum efficiency standards that have or will soon go into effect for Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017), and Commercial Refrigeration Equipment (2017).

Residential Lighting

Note: More R&D investment and effort in the lighting industry only changes projections of LED technologies because additional funding and effort will likely not be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are not included in this report.

The residential general service lamps characterized in this report are a 60-watt and a 75-watt medium screw-based (E26) A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60-watt incandescent lamp produces approximately 800 – 850 lumens. A standard 75-watt incandescent lamp produces approximately 1,100 lumens.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60-watt general service lamps, effective in 2014, and 75-watt lamps, effective in 2013. These standards cannot be achieved by incandescent bulbs, but can be by halogen, CFL, and LED technologies.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent, halogen, and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022.
CFL	+0.5%	0%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps.

Performance and Cost Characteristics » Residential General Service LED Lamps (60 W Incandescent Equivalent)

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	8.7	9.2	10.0	8.9	8.0	13.8	17.8	5.7	5.1	4.4	4.0	3.8	3.4
Lamp Lumens	656	803	800	800	800	800	800	800	800	800	800	800	800
Lamp Efficacy (lm/W)	75.5	87.1	80.0	90.0	100.0	80.0	45.0	141.5	157.2	180.2	200.2	209.0	232.1
CRI	81	85	80	81	90	80	N/A	81	90	81	90	81	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	21	15	14	18	15	N/A	14	18	14	18	14	18
Annual Operating Hours (h/y)	657	657	657	657	657	657	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$13.53	$4.56	$6.20	$3.92	$5.32	$6.20	N/A	$3.23	$4.39	$2.84	$3.86	$2.46	$3.33
Lamp Cost (2022$/klm)	$20.63	$5.68	$7.75	$4.90	$6.65	$7.75	N/A	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$13.53	$4.56	$6.20	$3.92	$5.32	$6.20	N/A	$3.23	$4.39	$2.84	$3.86	$2.46	$3.33
Annual Maintenance Cost (2022$)	$0.35	$0.15	$0.27	$0.18	$0.19	$0.27	N/A	$0.15	$0.16	$0.13	$0.14	$0.11	$0.12
Total Installed Cost (2022$/klm)	$20.63	$5.68	$7.75	$4.90	$6.65	$7.75	N/A	$4.04	$5.49	$3.56	$4.83	$3.07	$4.17
Annual Maintenance Cost (2022$/klm)	$0.54	$0.18	$0.34	$0.22	$0.24	$0.34	N/A	$0.18	$0.20	$0.16	$0.17	$0.14	$0.15

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential General Service Filament- LED Lamps (60 W Incandescent Equivalent)

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	9.7	7.1	5.5	6.9	8.0	13.8	17.8	5.4	5.1	4.2	4.0	3.6	3.4
Lamp Lumens	457	650	450	650	800	800	800	800	800	800	800	800	800
Lamp Efficacy (lm/W)	47.1	91.7	81.8	94.8	100.0	80.0	45.0	149.0	157.2	189.8	200.2	220.0	232.1
CRI	82	84	90	84	80	80	N/A	81	90	81	90	81	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	23	21	15	15	15	15	N/A	15	15	15	15	15	15
Annual Operating Hours (h/y)	657	657	657	657	657	N/A	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$15.17	$6.88	$6.25	$5.91	$7.75	N/A	N/A	$4.87	$6.39	$4.29	$5.62	$3.70	$4.86
Lamp Cost (2022$/klm)	$33.20	$10.58	$13.89	$9.09	$9.69	N/A	N/A	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$15.17	$6.88	$6.25	$5.91	$7.75	N/A	N/A	$4.87	$6.39	$4.29	$5.62	$3.70	$4.86
Annual Maintenance Cost (2022$)	$0.43	$0.21	$0.27	$0.26	$0.34	N/A	N/A	$0.21	$0.28	$0.19	$0.25	$0.16	$0.21
Total Installed Cost (2022$/klm)	$33.20	$10.58	$13.89	$9.09	$9.69	N/A	N/A	$6.09	$7.99	$5.36	$7.03	$4.63	$6.07
Annual Maintenance Cost (2022$/klm)	$0.93	$0.33	$0.61	$0.40	$0.42	N/A	N/A	$0.27	$0.35	$0.23	$0.31	$0.20	$0.27

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential Reflector Lamps

The residential reflector lamps characterized in this report are directional lamps that emit approximately 550 – 850 lumens (except for LED PAR38s which have outputs up to 1,700 lumens). Multiple baseline reflector lamps were analyzed, including 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, and LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- EPAct92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPAct92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPAct92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market, was still exempted until 2022.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service, reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022.
CFL	+0.5%	0%	-0.5%	In addition to higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Residential Reflector LED BR30

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	14.2	10.9	11.0	8.8	7.2	10.7	14.4	5.5	4.7	4.8	4.1	4.2	3.7
Lamp Lumens	706	781	800	683	650	650	650	650	650	650	650	650	650
Lamp Efficacy (lm/W)	49.8	71.5	72.7	78.6	90.3	61.0	45.0	119.2	137.0	136.3	156.7	153.4	176.3
CRI	82	85	92	87	90	80	N/A	87	90	87	90	87	90
Correlated Color Temperature (CCT)	2,700	2,700	2,700	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	25	25	19	18	15	N/A	19	18	19	18	19	18
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$21.40	$15.36	$4.09	$5.01	$5.96	N/A	N/A	$4.11	$4.89	$3.62	$4.31	$3.14	$3.74
Lamp Cost (2022$/klm)	$30.31	$19.66	$5.11	$7.33	$9.17	N/A	N/A	$6.32	$7.53	$5.57	$6.64	$4.83	$5.75
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$21.40	$15.36	$4.09	$5.01	$5.96	N/A	N/A	$4.11	$4.89	$3.62	$4.31	$3.14	$3.74
Annual Maintenance Cost (2022$)	$0.63	$0.45	$0.12	$0.20	$0.24	N/A	N/A	$0.16	$0.19	$0.14	$0.17	$0.12	$0.15
Total Installed Cost (2022$/klm)	$30.31	$19.66	$5.11	$7.33	$9.17	N/A	N/A	$6.32	$7.53	$5.57	$6.64	$4.83	$5.75
Annual Maintenance Cost (2022$/klm)	$0.89	$0.57	$0.15	$0.29	$0.37	N/A	N/A	$0.25	$0.30	$0.22	$0.26	$0.19	$0.23

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Final

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	19.2	15.5	17.0	16.4	17.0	10.7	29.9	10.8	11.2	9.4	9.8	8.4	8.7
Lamp Lumens	1,202	1,211	1,200	1,344	1,700	650	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	62.7	77.9	70.6	82.0	100.0	61.0	45.0	124.5	151.7	142.4	173.6	160.2	195.3
CRI	83	86	82	86	82	80	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	2,700	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	24	27	25	27	25	15	N/A	27	25	27	25	27	25
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Lamp Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Annual Maintenance Cost (2022$)	$1.07	$0.60	$0.69	$0.62	$0.46	N/A	N/A	$0.52	$0.38	$0.46	$0.34	$0.41	$0.31
Total Installed Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Annual Maintenance Cost (2022$/klm)	$0.89	$0.49	$0.58	$0.46	$0.27	N/A	N/A	$0.39	$0.23	$0.35	$0.20	$0.31	$0.18

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress presed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023, and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

This section characterizes commercial linear fixtures that house two 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp and fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- Residential linear lamps often have a nominal CCT rating of 3500K, but products with CCTs of 3000K, 4000K, and 4100K (neutral white) are also common. 5000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps, including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps. which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible because homeowners likely replace lamps themselves as they burn out. Therefore, annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for residential linear systems.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards required that the characterized residential ballasts have a minimum BLE= 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover linear lamps. (ENERGY STAR, 2020)

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume that manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited because the technology is mature.
T8	0%	0%	-0.5%	Limited because the technology is mature.
T5	0%	0%	-0.5%	Limited because the technology is mature.

Higher efficacy compared with Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	18.5	16.3	16.0	13.7	11.0	8.9	7.2	7.7	7.2	7.7	7.2
Lamp Lumens	2,013	2,130	1,800	1,920	1,800	1,920	1,800	1,920	1,800	1,920	1,800
Lamp Efficacy (lm/W)	111.0	130.7	112.5	140.1	163.6	216.1	250.0	250.0	250.0	250.0	250.0
System Wattage	36.9	32.6	32.0	27.4	22.0	17.8	14.4	15.4	14.4	15.4	14.4
System Lumens	3,583	4,004	3,456	3,686	3,456	3,686	3,456	3,686	3,456	3,686	3,456
System Efficacy (lm/W)	97.0	122.8	108.0	134.5	157.1	207.4	240.0	240.0	240.0	240.0	240.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	81	82	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	4,100	3,500	4,100	4,100	5,000	4,100	5,000	4,100	5,000	4,100	5,000
Average Lamp Life (thousand hours)	55	50	50	54	50	54	50	54	50	54	50
Annual Operating Hours (h/y)	584	584	584	584	584	584	584	584	584	584	584
Lamp Price (2022$)	$27.00	$12.89	$14.63	$11.11	$4.28	$9.97	$3.84	$9.87	$3.80	$9.77	$3.77
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$13.41	$6.05	$8.13	$5.79	$2.38	$5.19	$2.13	$5.14	$2.11	$5.09	$2.09
System (l/b/f) Cost (2022$/klm)	$15.07	$6.44	$8.47	$6.03	$2.48	$5.41	$2.22	$5.35	$2.20	$5.30	$2.18
Labor Cost (2022$/h)[2]	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$54.00	$25.78	$29.26	$22.22	$8.56	$19.95	$7.68	$19.74	$7.60	$19.55	$7.53
Annual Maintenance Cost (2022$)	$0.57	$0.30	$0.34	$0.24	$0.10	$0.22	$0.09	$0.21	$0.09	$0.21	$0.09
Total Installed Cost (2022$/klm)	$15.07	$6.44	$8.47	$6.03	$2.48	$5.41	$2.22	$5.35	$2.20	$5.30	$2.18
Annual Maintenance Cost (2022$/klm)	$0.16	$0.08	$0.10	$0.07	$0.03	$0.06	$0.03	$0.06	$0.03	$0.06	$0.03

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

Assume no labor is associated with lamp replacement in the residential sector because residents likely replace the lamps themselves.

Performance and Cost Characteristics » Residential Linear LED Luminaire

Higher efficacy compared with Reference Case

DATA	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	50.0	43.1	49.0	44.0	35.0	27.4	21.8	23.0	19.2	21.2	19.2
System Lumens	4,615	4,945	5,024	5,302	4,800	5,302	4,800	5,302	4,800	5,302	4,800
System Efficacy (lm/W)	92.3	114.7	102.5	120.5	137.1	193.4	220.1	230.4	250.0	250.0	250.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	82	80	79	80	79	80	79	80	79	80
Correlated Color Temperature (CCT)	3,838	3,000	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lamp Life (thousand hours)	56	58	54	53	50	53	50	53	50	53	50
Annual Operating Hours (h/y)	730	730	730	730	730	730	730	730	730	730	730
Lamp or Luminaire Price (2022$)	$181.60	$158.60	$144.85	$152.54	$207.80	$121.11	$164.98	$105.34	$143.50	$90.11	$122.76
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$78.70	$64.15	$57.66	$57.54	$86.58	$45.68	$68.74	$39.74	$59.79	$33.99	$51.15
Labor Cost (2022$/h)	$80.90	$80.90	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$403.65	$357.65	$322.70	$338.08	$448.60	$275.22	$362.97	$243.68	$320.01	$213.23	$278.52
Annual Maintenance Cost (2022$)	$2.89	$2.49	$2.40	$2.56	$3.52	$2.12	$2.89	$1.91	$2.58	$1.70	$2.27
Total Installed Cost (2022$/klm)	$87.46	$72.33	$64.23	$63.76	$93.46	$51.91	$75.62	$45.96	$66.67	$40.22	$58.03
Annual Maintenance Cost (2022$/klm)	$0.63	$0.50	$0.48	$0.48	$0.73	$0.40	$0.60	$0.36	$0.54	$0.32	$0.47

1. N/A because the lamp and fixture are both included in the luminaire.

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1,000 – 1,400 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application. This product is, as of 2022, expected to be eliminated by DOE's 45 lm/W backstop requirement.
- A majority of residential lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible because homeowners likely replaces lamps themselves as they burn out. Therefore, total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours for residential reflector lamps.
- Disposal costs are not characterized for residential lighting in this analysis. In residential cases, disposal is done by the occupant. Lamp and product burnout are assumed to result in no "added" cost aside from the work performed to install the replacement.

Legislation:

- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90.
- For ENERGY STAR qualification, general service reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90.
- Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Incandescent Directional	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
CFL	+0.5%	0%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Residential Outdoor Lamps (Security: LED Reflector)

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	19.2	15.5	17.0	16.4	17.0	10.7	29.9	10.8	11.2	9.4	9.8	8.4	8.7
Lamp Lumens	1,202	1,211	1,200	1,344	1,700	650	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	62.7	77.9	70.6	82.0	100.0	61.0	45.0	124.5	151.7	142.4	173.6	160.2	195.3
CRI	83	86	82	86	82	80	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	2,700	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	24	27	25	27	25	15	N/A	27	25	27	25	27	25
Annual Operating Hours (h/y)	730	730	730	730	730	N/A	N/A	730	730	730	730	730	730
Lamp Price (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Lamp Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$35.23	$22.44	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Annual Maintenance Cost (2022$)	$1.07	$0.60	$0.69	$0.62	$0.46	N/A	N/A	$0.52	$0.38	$0.46	$0.34	$0.41	$0.31
Total Installed Cost (2022$/klm)	$29.31	$18.54	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
Annual Maintenance Cost (2022$/klm)	$0.89	$0.49	$0.58	$0.46	$0.27	N/A	N/A	$0.39	$0.23	$0.35	$0.20	$0.31	$0.18

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress presed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Performance and Cost Characteristics » Residential Outdoor Lamps (Porch: LED A-Type)

Higher efficacy compared with Reference Case

DATA	2015	2020	2022				2023[1]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	12.9	11.8	13.5	11.9	11.0	13.6	24.4	7.6	7.0	6.0	5.5	5.1	4.7
Lamp Lumens	1,073	1,102	1,100	1,089	1,100	1,089	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Lamp Efficacy (lm/W)	83.1	93.5	81.5	92.2	100.0	80	45.0	144.9	157.2	184.6	200.2	214.0	232.1
CRI	81	85	80	86	80	80	N/A	86	80	86	80	86	80
Correlated Color Temperature (CCT)	2,700	2,700	3,000	2,700	2,700	2,700	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	25	21	25	18	25	N/A	N/A	18	25	18	25	18	25
Annual Operating Hours (h/y)	657	657	657	657	657	N/A	N/A	657	657	657	657	657	657
Lamp Price (2022$)	$18.13	$8.48	$4.39	$3.92	$5.29	N/A	N/A	$3.23	$4.36	$2.84	$3.84	$2.46	$3.31
Lamp Cost (2022$/klm)	$16.90	$7.70	$3.99	$3.60	$4.81	N/A	N/A	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost (2022$/h)	$0.00	$0.00	$0.00	$0.00	$0.00	N/A	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hours)	0.0	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost (2022$)	$18.13	$8.48	$4.39	$3.92	$5.29	N/A	N/A	$3.23	$4.36	$2.84	$3.84	$2.46	$3.31
Annual Maintenance Cost (2022$)	$0.49	$0.27	$0.12	$0.14	$0.14	N/A	N/A	$0.12	$0.11	$0.10	$0.10	$0.09	$0.09
Total Installed Cost (2022$/klm)	$16.90	$7.70	$3.99	$3.60	$4.81	N/A	N/A	$2.94	$3.97	$2.59	$3.49	$2.23	$3.01
Annual Maintenance Cost (2022$/klm)	$0.45	$0.24	$0.10	$0.13	$0.13	N/A	N/A	$0.11	$0.10	$0.09	$0.09	$0.08	$0.08

1. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress presed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.

Commercial Lighting

Note: More R&D investment and effort in the lighting industry will only change future projections of LED technologies because additional funding and effort will likely not be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are therefore not included in this report.
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This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw-based general service lamps emitting approximately 1,600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures because light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of general service lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial general service lamps (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for high intensity discharge (HID) lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but they can be met by halogen, CFL, and LED technologies from 2012 to 2023.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service omnidirectional lamps must have a minimum lamp efficacy of 70 lm/W for products with CRI ≥ 90 and 80 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022
CFL	+0.5%	0%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Final

Performance and Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

Higher efficacy compared with Reference Case

DATA	2012	2018	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[1]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	26.7	14.5	16.0	14.8	13.0	20.0	34.8	9.4	8.3	7.4	6.5	6.4	6.4
Lamp Lumens	1,600	1,528	1,600	1,567	1,600	1,600	1,567	1,567	1,600	1,567	1,600	1,567	1,600
Lamp Efficacy (lm/W)	60.0	105.1	100.0	106.0	123.1	80.0	45.0	166.7	193.5	212.2	246.4	246.1	250.0
System Wattage	26.7	14.5	16.0	14.8	13.0	20.0	34.8	9.4	8.3	7.4	6.5	6.4	6.4
System Lumens[3]	976	932	976	956	976	976	956	956	976	956	976	956	976
System Efficacy (lm/W)	36.6	64.1	61.0	64.7	75.1	48.8	27.5	101.7	118.0	129.5	150.3	150.1	152.5
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	80	80	90	84.8	84	80	N/A	84.8	84.8	84.8	84.8	84.8	84.8
Correlated Color Temperature (CCT)	3,000	3,000	2,700	2,700	5,000	N/A	N/A	2,700	2,700	2,700	2,700	2,700	2,700
Average Lamp Life (thousand hours)	22.0	17.9	25.0	16.9	25.0	15.0	N/A	16.9	25.0	16.9	25.0	16.9	25.0
Annual Operating Hours (h/y)	4,928	4,928	4,928	4,928	4,928	N/A	N/A	4,928	4,928	4,928	4,928	4,928	4,928
Lamp Price (2022$)	$47.45	$11.28	$5.62	$7.04	$3.39	N/A	N/A	$5.81	$2.80	$5.11	$2.46	$4.41	$2.12
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	$22.07	$22.07	$22.07	N/A	N/A	$21.20	$21.20	$20.17	$20.17	$19.18	$19.18
Lamp Cost (2022$/klm)	$25.00	$7.38	$3.51	$4.49	$2.12	N/A	N/A	$3.71	$1.75	$3.26	$1.54	$2.82	$1.33
System (l/b/f) Cost (2022$/klm)	$72.92	$40.40	$28.37	$30.46	$26.09	N/A	N/A	$28.26	$24.59	$26.45	$23.18	$24.68	$21.83
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	N/A	N/A	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.0	1.0	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hours)	0.05	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost (2022$)	$148.39	$114.88	$93.69	$95.11	$91.46	N/A	N/A	$93.01	$90.00	$91.27	$88.63	$89.59	$87.30
Annual Maintenance Cost (2022$)	$11.49	$4.16	$1.76	$3.02	$1.32	N/A	N/A	$2.66	$1.20	$2.45	$1.14	$2.25	$1.07
Total Installed Cost (2022$/klm)	$152.04	$123.25	$95.99	$99.52	$93.71	N/A	N/A	$97.32	$92.21	$95.51	$90.81	$93.75	$89.45
Annual Maintenance Cost (2022$/klm)	$11.77	$4.46	$1.80	$3.16	$1.35	N/A	N/A	$2.78	$1.23	$2.57	$1.16	$2.35	$1.10

1. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress presed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. All LED lighting products exceed the new minimum efficacy standards.
3. Based on a fixture efficiency of 61% for an omnidirectional lamp installed in a recessed can fixture.

Performance and Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

This section characterizes commercial halogen, halogen infrared reflector (HIR), and LED screw-based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- HIR lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This design increases the efficacy of the lamp, without reducing operating life.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of reflector lamps have a nominal CCT rating of 2,700K and give off a warm, yellowish white color, but products with CCTs of 3,000K, 3,500K, 4,100K (neutral white), 5,000K (daylight), and 6,500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2,700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100. However, CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination. High CRI products are preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial reflector lamps (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- EPAct92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPAct92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPAct92 minimum performance standards by January 1, 2008. In 2015, DOE issued a final rule that determined that amending the standards for incandescent reflector lamps could not be economically justified.
- In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress prescribed in the Energy Policy and Conservation Act. **This action also amended the definition of general service lamps to include previously exempted product classes, such as reflector lamps.** These standards can not be achieved by traditional incandescent or halogen technologies currently on the market, and given current and projected trends in industry, they will likely not be met. It is currently assumed that industry will increase its investment in LED technology at the expense of incandescent, halogen, and CFL technologies. The rule will go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023.

ENERGY STAR:

- For ENERGY STAR qualification, general service reflector lamps must have a minimum lamp efficacy of 61 lm/W for products with CRI ≥ 90 and 70 lm/W for lamps with CRI < 90. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2,700, 3,000, 3,500, 4,000/4,100, 5,000, or 6,000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements.
Halogen	0%	0%	-0.5%	Limited because the technology is mature and the technology cannot meet legislative requirements as of 2022
CFL	+0.5%	0%	-0.5%	In addition to higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance and Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

Higher efficacy compared with Reference Case

DATA	2012	2018	2022				2023[2]	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[3]	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	17.2	16.6	17.0	16.4	17.0	22.0	29.9	14.0	11.2	9.4	9.8	8.4	8.7
Lamp Lumens	1,045	1,210	1,200	1,344	1,700	1,344	1,344	1,344	1,700	1,344	1,700	1,344	1,700
Lamp Efficacy (lm/W)	60.9	73.0	70.6	82.0	100.0	61.0	45.0	95.7	151.7	142.4	173.6	160.2	195.3
System Wattage	17.2	16.6	17.0	16.4	17.0	22.0	29.9	14.0	11.2	9.4	9.8	8.4	8.7
System Lumens[1]	972	1,125	1,116	1,250	1,581	1,250	1,250	1,250	1,581	1,250	1,581	1,250	1,581
System Efficacy (lm/W)	56.6	67.9	65.6	76.1	93.0	56.7	41.9	89.0	141.1	132.4	161.4	149.0	181.6
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	83	83	82	86	82	80	N/A	86	82	86	82	86	82
Correlated Color Temperature (CCT)	3,000	3,000	2,700	3,000	3,000	3,000	N/A	3,000	3,000	3,000	3,000	3,000	3,000
Average Lamp Life (thousand hours)	22	15	25	28	25	25	N/A	28	25	28	25	28	25
Annual Operating Hours (h/y)	4,928	4,928	4,928	4,928	4,928	N/A	N/A	4,928	4,928	4,928	4,928	4,928	4,928
Lamp Price (2022$)	$61.98	$28.10	$23.71	$23.09	$15.69	N/A	N/A	$19.40	$13.18	$17.36	$11.79	$15.37	$10.45
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	$23.72	$26.38	$22.07	$22.07	$22.07	N/A	N/A	$21.20	$21.20	$20.17	$20.17	$19.18	$19.18
Lamp Cost (2022$/klm)	$59.31	$23.23	$19.76	$17.18	$9.23	N/A	N/A	$14.43	$7.75	$12.91	$6.94	$11.44	$6.14
System (l/b/f) Cost (2022$/klm)	$88.18	$48.42	$41.02	$36.13	$23.88	N/A	N/A	$32.48	$21.75	$30.02	$20.22	$27.64	$18.74
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	N/A	N/A	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.0	1.0	1.0	1.0	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hours)	0.05	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost (2022$)	$162.93	$131.71	$111.78	$111.16	$103.76	N/A	N/A	$106.60	$100.38	$103.52	$97.96	$100.55	$95.63
Annual Maintenance Cost (2022$)	$14.75	$10.50	$5.32	$4.64	$3.74	N/A	N/A	$3.99	$3.25	$3.64	$2.98	$3.29	$2.71
Total Installed Cost (2022$/klm)	$167.64	$117.04	$100.16	$88.92	$65.63	N/A	N/A	$85.28	$63.49	$82.81	$61.96	$80.44	$60.48
Annual Maintenance Cost (2022$/klm)	$15.17	$9.33	$4.77	$3.72	$2.37	N/A	N/A	$3.20	$2.05	$2.91	$1.88	$2.63	$1.71

1. Based on a fixture efficiency of 93% for an omnidirectional lamp installed in a recessed can fixture.
2. In April 2022, DOE codified into the Code of Federal Regulations the 45 lm/W backstop requirement for general service lamps that Congress presed in the Energy Policy and Conservation Act. The new minimum efficacy requirements go into effect for manufacture and import in January 2023 and for retail and distribution in July 2023. This Final Rule also amended the definition of GSLs to include previously exempted product classes, including reflector lamps. All LED lighting products exceed the new minimum efficacy standards.
3. Criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 2.1 (Published June, 2017, Revised June 2020)

Performance and Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house two 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp and fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Linear lamps often have a nominal CCT rating of 3,500K, but products with CCTs of 3,000K, 4,000K, and 4,100K (neutral white) are also common. 5,000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of two lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamp, which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps, including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022, reflecting a mix of lamp characteristics and features, were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours per year for commercial 4ft linear systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2020).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume that manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	0%	0%	-0.5%	Limited because the technology is mature.
T8 F32 High Efficiency/High Output	0%	0%	-0.5%	Limited because the technology is mature.
T5 F28	0%	0%	-0.5%	Limited because the technology is mature.

Performance and Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	20.8	17.0	16.0	13.7	11.0	8.9	7.2	7.7	7.2	7.7	7.2
Lamp Lumens	2,091	2,003	1,800	1,920	1,800	1,920	1,800	1,920	1,800	1,920	1,800
Lamp Efficacy (lm/W)	100.5	117.8	112.5	140.1	163.6	216.1	250.0	250.0	250.0	250.0	250.0
System Wattage	41.6	34.0	32.0	27.4	22.0	17.8	14.4	15.4	14.4	15.4	14.4
System Lumens	3,555	3,565	3,456	3,686	3,456	3,686	3,456	3,686	3,456	3,686	3,456
System Efficacy (lm/W)	85.4	104.9	108.0	134.5	157.1	207.4	240.0	240.0	240.0	240.0	240.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	86	81	82	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	4,100	4,020	4,100	3,500	5,000	3,500	5,000	3,500	5,000	3,500	5,000
Average Lamp Life (thousand hours)	50	54	50	54	50	54	50	54	50	54	50
Annual Operating Hours (h/y)	4,055	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541	3,541
Lamp Price (2022$)	$278.36	$35.06	$14.63	$11.11	$4.28	$9.88	$3.81	$9.66	$3.72	$9.44	$3.64
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	$133.10	$17.50	$8.13	$5.79	$2.38	$5.15	$2.11	$5.03	$2.07	$4.92	$2.02
System (l/b/f) Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost (2022$)	$587.35	$70.12	$29.26	$22.22	$8.56	$19.76	$7.61	$19.31	$7.44	$18.89	$7.28
Annual Maintenance Cost (2022$)	$47.63	$6.61	$3.93	$3.17	$2.46	$3.01	$2.39	$2.98	$2.38	$2.95	$2.37
Total Installed Cost (2022$/klm)	$165.20	$19.67	$8.47	$6.03	$2.48	$5.36	$2.20	$5.24	$2.15	$5.12	$2.11
Annual Maintenance Cost (2022$/klm)	$13.40	$1.85	$1.14	$0.86	$0.71	$0.82	$0.69	$0.81	$0.69	$0.80	$0.69

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

Performance and Cost Characteristics » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	51.5	50.0	49.0	44.0	35.0	27.4	21.8	23.0	19.2	21.2	19.2
System Lumens	4,818	4,673	5,024	5,302	4,800	5,302	4,800	5,302	4,800	5,302	4,800
System Efficacy (lm/W)	93.6	93.5	102.5	120.5	137.1	193.4	220.1	230.4	250.0	250.0	250.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	84	79	80	79	80	79	80	79	80	79	80
Correlated Color Temperature (CCT)	3,500	3,650	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Average Lifetime (thousand hours)	67	53	54	53	50	53	50	53	50	53	50
Annual Operating Hours (h/y)	4,055	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431
Lamp or Luminaire Price (2022$)	$723.96	$188.00	$144.85	$152.54	$207.80	$127.58	$173.80	$118.37	$161.25	$109.57	$149.27
Ballast Price (2022$) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$150.25	$40.23	$57.66	$57.54	$86.58	$24.06	$36.21	$22.33	$33.59	$20.67	$31.10
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$762.57	$226.61	$322.70	$338.08	$448.60	$160.58	$206.80	$151.37	$194.25	$142.57	$182.27
Annual Maintenance Cost (2022$)	$46.16	$14.67	$11.30	$12.01	$16.52	$10.40	$14.19	$9.80	$13.33	$9.23	$12.51
Total Installed Cost (2022$/klm)	$158.27	$48.49	$64.23	$63.76	$93.46	$30.29	$43.08	$28.55	$40.47	$26.89	$37.97
Annual Maintenance Cost (2022$/klm)	$9.58	$3.14	$2.25	$2.27	$3.44	$1.96	$2.96	$1.85	$2.78	$1.74	$2.61

1. N/A because the lamp and fixture are both included in the luminaire.

This section characterizes commercial linear fixtures that house two 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This narrowness allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that can fit directly into an existing fixture and fully integrated luminaires that can be used to replace existing fixtures. LED replacement lamps are also known as TLEDs. Type A TLEDs can be installed with existing ballasts and Type B and C TLEDs require the ballast to be disconnected. Replacement lamps are only sold to go into existing fixtures. If a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp and fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Linear lamps often have a nominal CCT rating of 3,500K, but products with CCTs of 3,000K, 4,000K, and 4,100K (neutral white) are also common. 5,000K (daylight) lamps are available as well. When replacing a light bulb, it is important to choose a product with a similar CCT value to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of two lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps, which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps, including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical lamp prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours per year for commercial 8ft linear systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014, for T8 700-series phosphor lamps), DOE fluorescent lamp standards required a minimum efficacy of 89 lm/W. Although the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).

ENERGY STAR:

- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2020).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume that manufacturers will focus on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	0%	0%	-0.5%	Limited because the technology is mature.
T8 F59 High Efficiency	0%	0%	-0.5%	Limited because the technology is mature.
T8 F96 High Output	0%	0%	-0.5%	Limited because the technology is mature.

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	35.7	34.0	39.0	40.0	25.3	25.9	21.9	22.4	19.8	22.0
Lamp Lumens	N/A	3,975	4,200	4,960	5,500	4,960	5,500	4,960	5,500	4,960	5,500
Lamp Efficacy (lm/W)	N/A	111.2	123.5	127.2	137.5	196.1	212.0	226.7	245.1	250.0	250.0
System Wattage	N/A	71.5	68.0	78.0	80.0	50.6	51.9	43.8	44.9	39.7	44.0
System Lumens	N/A	7,473	8,064	9,523	10,560	9,523	10,560	9,523	10,560	9,523	10,560
System Efficacy (lm/W)	N/A	104.5	118.6	122.1	132.0	188.2	203.5	217.7	235.3	240.0	240.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	82	81	82	81	82	81	82	81	82
Correlated Color Temperature (CCT)	N/A	5,000	4,000	4,000	5,000	4,000	5,000	4,000	5,000	4,000	5,000
Average Lamp Life (thousand hours)	N/A	50	50	50	50	50	50	50	50	50	50
Annual Operating Hours (h/y)	N/A	4,147	4,147	4,147	4,147	4,147	4,147	4,147	4,147	4,147	4,147
Lamp Price (2022$)	N/A	$89.59	$33.11	$37.22	$41.44	$32.35	$36.02	$31.71	$35.30	$31.11	$34.64
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	N/A	$19.00	$7.88	$7.50	$7.53	$6.52	$6.55	$6.39	$6.42	$6.27	$6.30
System (l/b/f) Cost (2022$/klm)[1]	N/A	$23.98	$8.21	$7.82	$7.85	$6.79	$6.82	$6.66	$6.69	$6.53	$6.56
Labor Cost (2022$/h)	N/A	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hours)	N/A	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost (2022$)	N/A	$200.80	$84.70	$92.92	$101.36	$83.18	$90.52	$81.90	$89.09	$80.70	$87.76
Annual Maintenance Cost (2022$)	N/A	$16.65	$7.02	$7.71	$8.41	$6.90	$7.51	$6.79	$7.39	$6.69	$7.28
Total Installed Cost (2022$/klm)	N/A	$50.51	$10.50	$9.76	$9.60	$8.73	$8.57	$8.60	$8.44	$8.47	$8.31
Annual Maintenance Cost (2022$/klm)	N/A	$4.19	$0.87	$0.81	$0.80	$0.72	$0.71	$0.71	$0.70	$0.70	$0.69

1. N/A because a fixture and an LED replacement lamp would not be purchased separately for a new installation or retrofit when there are integrated LED luminaires that are more efficient and cost effective. These lamps are sold only as replacements to go into existing fixtures.

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	73.0	90.0	78.0	72.0	49.7	45.9	42.4	41.6	37.9	41.6
System Lumens	N/A	8,000	8,200	9,465	10,400	9,465	10,400	9,465	10,400	9,465	10,400
System Efficacy (lm/W)	N/A	109.6	91.1	121.3	144.4	190.4	226.7	223.1	250.0	250.0	250.0
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	90	80	81	80	81	80	81	80	81	80
Correlated Color Temperature (CCT)	N/A	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Average Lifetime (thousand hours)	N/A	75	50	73	100	73	100	73	100	73	100
Annual Operating Hours (h/y)	N/A	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431	3,431
Lamp or Luminaire Price (2022$)	N/A	$759.16	$119.99	$142.48	$153.91	$109.90	$118.71	$96.00	$103.70	$82.68	$89.31
Ballast Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	N/A	$80.00	$14.63	$15.05	$14.80	$11.61	$11.41	$10.14	$9.97	$8.73	$8.59
Labor Cost (2022$/h)	N/A	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	N/A	1.0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	N/A	$708.20	$206.52	$229.01	$240.44	$196.42	$205.24	$182.53	$190.23	$169.20	$175.83
Annual Maintenance Cost (2022$)	N/A	$39.16	$22.40	$17.46	$13.53	$14.40	$11.11	$13.09	$10.08	$11.84	$9.10
Total Installed Cost (2022$/klm)	N/A	$88.53	$25.18	$24.20	$23.12	$20.75	$19.73	$19.28	$18.29	$17.88	$16.91
Annual Maintenance Cost (2022$/klm)	N/A	$4.89	$2.73	$1.84	$1.30	$1.52	$1.07	$1.38	$0.97	$1.25	$0.87

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 10,000 system lumens. Low bay lighting is defined as “interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor”(IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- Low bay conventional lighting technologies, such as metal halide and sodium vapor lamps, provide higher efficacy ranging from 80 lm/W to 100 lm/W. Older, mercury vapor lamps have much lower efficacy at approximately 40 lm/W.
- CCT and CRI values range broadly based on technology type for low bay products.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires, which are sold as one integrated system. Many factors influence the price of LED luminaires, including CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical luminaire prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial low-bay systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

ENERGY STAR:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime, and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	0%	0%	-0.5%	Limited because the technology is mature.
Metal Halide	0%	0%	-0.5%	Limited because the technology is mature.
Sodium Vapor	0%	0%	-0.5%	Limited because the technology is mature.

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	68.1	84.0	40.0	73.0	76.0	47.1	49.0	40.5	48.0	40.0	48.0
System Lumens	4,877	10,000	5,000	10,000	12,000	10,000	12,000	10,000	12,000	10,000	12,000
System Efficacy (lm/W)	71.6	119.0	125.0	137.0	157.9	212.5	244.9	246.7	250.0	250.0	250.0
Ballast Efficiency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	85	78	84	81	80	81	84	81	84	81	81
Correlated Color Temperature (CCT)	4,000	4,806	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	4,000
Average Lifetime (thousand hours)	50	74	75	65	60	65	60	65	60	65	60
Annual Operating Hours (h/y)	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042
Lamp or Luminaire Price (2022$)	$903.82	$281.00	$63.99	$145.46	$285.89	$123.82	$243.37	$111.24	$218.63	$99.09	$194.75
Ballast Price (2022$) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$) [1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$185.31	$28.10	$12.80	$14.55	$23.82	$12.38	$20.28	$11.12	$18.22	$9.91	$16.23
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$865.44	$396.83	$162.99	$244.46	$384.89	$222.82	$342.37	$210.24	$317.63	$198.09	$293.75
Annual Maintenance Cost (2022$)	$69.95	$37.02	$12.23	$24.24	$45.18	$21.55	$39.45	$19.99	$36.12	$18.48	$32.90
Total Installed Cost (2022$/klm)	$177.44	$39.68	$32.60	$24.45	$32.07	$22.28	$28.53	$21.02	$26.47	$19.81	$24.48
Annual Maintenance Cost (2022$/klm)	$14.34	$3.70	$2.45	$2.42	$3.77	$2.16	$3.29	$2.00	$3.01	$1.85	$2.74

1. N/A because the lamp and fixture are both included in the luminaire.

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 system lumens. High-bay lighting is defined as "interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor" (IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- High bay conventional lighting technologies, such as metal halide and sodium vapor lamps, provide higher efficacy ranging from 80 lm/W to 100 lm/W. Older, mercury vapor lamps have much lower efficacy at approximately 40 lm/W.
- CCT and CRI values range broadly based on technology type for high bay products.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires, which are sold as one integrated system. Many factors influence the price of LED luminaires including, CRI, lifetime, dimming capabilities, and efficacy. Therefore, typical luminaire prices in 2022 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours for commercial high bay systems (DOE SSL Program, 2012a).
- Commercial lighting disposal costs are estimated to be $0.12 per linear foot of fluorescent lamps, $1.50 per lamp for HID lamps, and $0.50 for CFLs (EPA, 2022).

ENERGY STAR:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2030, 2040, and 2050. We assume manufacturers will focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors (Navigant, 2019).
- For LED technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019). For traditional technologies, the following future improvements were assumed to occur year over year through 2050.

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	0%	0%	-0.5%	Limited because the technology is mature.
Metal Halide	0%	0%	-0.5%	Limited because the technology is mature.
Sodium Vapor	0%	0%	-0.5%	Limited because the technology is mature.

Higher efficacy compared with Reference Case

DATA	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	212	167	150	138	130	89	84	76	76	74	76
System Lumens	18,915	18,797	18,500	18,500	18,900	18,500	18,900	18,500	18,900	18,500	18,900
System Efficacy (lm/W)	89	113	123	134	145	208	225	242	250	250	250
Ballast Efficiency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	74	78	80	80	80	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Average Lifetime (thousand hours)	70	67	100	100	100	100	100	100	100	100	100
Annual Operating Hours (h/y)	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042	4,042
Lamp or Luminaire Price (2022$)	$2,842.05	$448.43	$177.54	$195.81	$234.20	$162.12	$193.90	$148.87	$178.06	$136.20	$162.90
Ballast Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price (2022$)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost (2022$/klm)[1]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost (2022$/klm)	$150.25	$23.86	$9.60	$10.58	$12.39	$8.76	$10.26	$8.05	$9.42	$7.36	$8.62
Labor Cost (2022$/h)	$77.22	$77.22	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00	$66.00
Labor System Installation (hours)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost (2022$)	$2,957.88	$564.26	$276.54	$294.81	$333.20	$261.12	$292.90	$247.87	$277.06	$235.20	$261.90
Annual Maintenance Cost (2022$)	$170.78	$34.07	$11.18	$11.91	$13.47	$10.55	$11.84	$10.02	$11.20	$9.51	$10.58
Total Installed Cost (2022$/klm)	$156.38	$30.02	$14.95	$15.94	$17.63	$14.11	$15.50	$13.40	$14.66	$12.71	$13.86
Annual Maintenance Cost (2022$/klm)	$9.03	$1.81	$0.60	$0.64	$0.71	$0.57	$0.63	$0.54	$0.59	$0.51	$0.56

1. N/A because the lamp and fixture are both included in the luminaire.

Refrigeration

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)[1]	1,200	1,200	1,200	1,190	930	N/A	1,190	930	1,190	930	1,190	930
Median Store Size (ft^2)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Power Input (kW)	162	155	162	160	125	N/A	160	125	160	125	160	125
Annual Energy Use (MMWh/y)[2]	1,497	1,497	1,305	1,232	1,160	N/A	1,109	1,044	998	939	898	845
Indexed Annual Efficiency[3]	1.00	1.00	1.15	1.21	1.29	N/A	1.35	1.43	1.50	1.59	1.67	1.77
Average Life (years)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost (2022$)	$630,000	$630,000	$488,000	$625,000	$630,000	N/A	$625,000	$630,000	$625,000	$630,000	$625,000	$630,000
Total Installed Cost (2022$/kBtu/h)	$525,000	$525,000	$406,667	$525,210	$677,419	N/A	$525,210	$677,419	$525,210	$677,419	$525,210	$677,419
Annual Maintenance Cost (2022$)[4]	$3,400	$3,400	$3,400	$3,400	$3,400	N/A	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400
Annual Maintenance Cost (2022$/kBtu/h)	$2,833	$2,833	$2,833	$2,857	$3,656	N/A	$2,857	$3,656	$2,857	$3,656	$2,857	$3,656

1. The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This refrigeration system usually includes two low temperature racks and two medium temperature racks. For 2018, a 1,200 MBtu/h total cooling capacity is based on a 200-ton estimate for total capacity–80 tons for the medium temperature racks and 20 tons for the low temperature racks.
2. Capacity and annual energy consumption for 2022 and beyond are based on market research and Guidehouse estimates.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks-approximately half a day per rack of labor for technician is assumed.

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-horsepower (hp) to 15-hp size range. Usually, each rack has three to five compressors serve a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range of 60% to 70%.
- Energy use and capacity for the Reference Case are projected to remain static over the coming decades because commercial compressor racks systems are a mature technology. The Reference Case assumes low R&D efforts because it is an established technology.
- **For this Advanced Case, a 10% reduction in energy consumption is assumed to occur over the Reference Case for 2022 and beyond due to vacuum insulated panel (VIP) adoption by display cases and a relaxation in charge size limits for more efficient, low global warming potential (GWP) refrigerants. Also, increased adoption of toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)[1]	1,680	1,520	1,440	1,440	1,440	N/A	1,440	1,368	1,300	1,300	1,235	1,235
Median Store Size (ft²)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Power Input (kW)	25	25	18	18	18	N/A	18	18	18	18	18	18
Annual Energy Use (MMWh/y)	120	120	115	106	86	N/A	95	77	86	70	77	63
Indexed Annual Efficiency[2]	1.00	1.00	1.04	1.13	1.40	N/A	1.26	1.55	1.40	1.72	1.55	1.91
Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost (2022$)	$54,000	$60,000	$54,000	$60,000	$80,000	N/A	$60,000	$80,000	$60,000	$80,000	$60,000	$80,000
Total Installed Cost (2022$/kBtu/h)	$32,143	$39,474	$37,500	$41,667	$55,556	N/A	$41,667	$58,480	$46,168	$61,538	$48,598	$64,777
Annual Maintenance Cost (2022$)[3]	$954	$954	$954	$954	$954	N/A	$954	$954	$954	$954	$954	$954
Annual Maintenance Cost (2022$/kBtu/h)	$0.57	$0.63	$0.66	$0.66	$0.66	N/A	$0.66	$0.70	$0.73	$0.73	$0.77	$0.77

1. Total capacity is the total heat rejected (THR) by condensers comprised of two low temperature condensers (THRL = 240 MBtu/h each, suction temperature = -25°F, condensing temperature-110°F) and two medium temperature condensers (THRM = 520 MBtu/h each, suction temperature = 15°F, condensing temperature = 115°F); ambient temperature = 95°F. (NCI, 2009). For 2022 and beyond, capacity was estimated by Guidehouse.
2. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
3. Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks.

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50%-70%.
- **For this Advanced Case, a 10% reduction in energy consumption and a 5% reduction in required capacity is assumed to occur over the Reference Case for 2020 and beyond due to VIP adoption by display cases and a relaxation in charge size limits for more efficient, low GWP. Also, increased adoption of toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Lower annual energy use, increased installed cost compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	17,623	11,850	11,850	11,850	11,850	N/A	11,850	11,850	11,850	11,850	11,850	11,850
Median Store Size (ft^2)	46,500	31,997	35,197	35,197	35,197	N/A	35,197	35,197	35,197	35,197	35,197	35,197
Case Length (ft)	12	12	12	12	12	N/A	12	12	12	12	12	12
Annual Energy Use (kWh/y)[1,2]	13,497	10,506	10,506	9,771	9,087	N/A	9,282	8,632	8,818	8,201	8,377	7,791
Annual Energy Use / Case Length (kWh/ft)	1,125	876	876	814	757	N/A	774	719	735	683	698	649
Indexed Annual Efficiency[3]	1.00	1.28	1.28	1.38	1.49	N/A	1.45	1.56	1.53	1.65	1.61	1.73
Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$8,510	$10,650	$7,265	$9,500	$10,680	N/A	$9,500	$10,680	$9,500	$10,680	$9,500	$10,680
Total Installed Cost (2022$)	$10,811	$12,650	$9,265	$11,500	$12,680	N/A	$11,500	$12,680	$11,500	$12,680	$11,500	$12,680
Total Installed Cost (2022$/kBtu/h)	613	1,068	782	970	1,070	N/A	970	1,070	970	1,070	970	1,070
Annual Maintenance Cost (2022$)[4]	$940	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost (2022$/kBtu/h)	$53.34	$79.32	$79.32	$79.32	$79.32	N/A	$79.32	$79.32	$79.32	$79.32	$79.32	$79.32

1. For 2022 and beyond, energy consumption and cost values were estimated using shipment-weighted averages reported in DOE's 2014 CRE Final Rule Technical Support Document (TSD) for equipment commonly used as display cases. DOE's updated conservation standard went into effect in 2017, so units sold in 2018 are assumed to comply with this standard.
2. For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance.

- DOE set federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. These standards set maximum daily energy consumption levels, in kilowatt-hours per day, for display cases manufactured sold in the United States on or after January 1, 2012.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014 for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA).

Equipment Description	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler (VOP.RC.M)	0.82xTDA+4.07	0.64xTDA+4.07
Semi-Vertical Open Cooler (SVO.RC.M)	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler (HZO.RC.M)	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler (VCT.RC.M)	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler (SOC.RC.M)	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer (VCT.RC.L)	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer (HZO.RC.L)	0.57xTDA+6.88	0.55xTDA+6.88

- According to CBECS 2018 microdata, the average building size for food sale building type is 31,997.
- Unit energy consumption for 2022 and beyond is estimated using a shipment-weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD with updated analysis from Guidehouse in 2016. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks.
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- The efficiency of supermarket display cases can be increased through the use of improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, and improved insulation.
- **For 2020 and beyond, accelerated adoption of energy savings technologies is assumed to take place more than in the Reference Case, including accelerated shipments migration to doored over open units, where applicable, as well as vacuum insulated panels.**
- **The incremental cost of VIPs is assumed to decrease from its present value due to increased R&D funding.**
- **Projected installed costs for this Advanced Case are higher than the Reference Case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This Advanced Case assumes a transition from Hydrofluorocarbons (HFC) to more efficient propane and ammonia refrigerants by 2040.**
- **Advanced Case assumes a 5% reduction in energy use per decade based on technology and efficiency improvements.**

Lower annual energy use, increased installed cost compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	2,929	2,400	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349	2,349
Size (ft^3)	49	49	46	46	46	47	46	46	46	46	46	46
Annual Energy Use (kWh/y)	2,340	2,222	1,935	1,351	810	810	1,283	770	1,283	770	1,283	770
Annual Energy Use / Volume ($kWh/y/ft^3$)[1]	48	45	42	29	18	17	28	17	28	17	28	17
Indexed Annual Efficiency[3]	1.00	1.05	1.21	1.73	2.89	2.89	1.82	3.04	1.82	3.04	1.82	3.04
Average Life (years)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$2,624	$2,403	$2,728	$2,780	$3,021	$3,021	$3,058	$3,323	$3,323	$3,364	$3,655	$3,655
Total Installed Cost (2022$)[4]	$3,454	$3,282	$3,591	$3,643	$3,884	$3,884	$3,932	$4,197	$4,197	$4,238	$4,529	$4,529
Total Installed Cost (2022$/kBtu/h)	$1,179	$1,368	$1,529	$1,551	$1,654	$1,654	$1,885	$2,568	$1,885	$2,568	$1,885	$2,568
Annual Maintenance Cost (2022$)[5]	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost (2022$/kBtu/h)	$63	$77	$79	$79	$79	$79	$79	$79	$79	$79	$79	$79

1. EPACT 2005 energy standards went into effect in 2010. 2022 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipment-weighted averages solid- and transparent-doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards went into effect in 2017; therefore, compliance with this standard is assumed for 2022 and beyond.
2. The ENERGY STAR category is based on a shipment weighted average of solid- and transparent-doored units that are minimally compliant with ENERGY STAR v3, effective October 1, 2014. Units compliant with ENERGY STAR are found to be the most efficient reach-in refrigeration equipment on the market in 2022.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 is based on NCI 2009 report that assumes a cost of $863. Installation cost for 2022 and beyond is based DOE's 2014 CRE Final Rule and additional analysis by Guidehouse, which assumes an installation cost of $878 for self-contained equipment.
5. Maintenance costs after 2012 are based on DOE's CRE 2014 Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized.

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V) in ft^3.
- In 2014, DOE updated its energy conservation standards for reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its ENERGY STAR specifications for reach-in refrigerators, effective March 27, 2017. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.022xV+0.97	0.066xV+0.31	0.04xV+1.09	0.024xV+1.89
Glass Door (VCT.SC.M)	0.095xV+0.445	0.05xV+1.12	0.076xV+0.034	0.105xV-1.111

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft^3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD with updated analysis from Guidehouse in 2016. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, respectively.
- The efficiency of commercial reach-in refrigerators can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- After 2022, the high efficiency cases are based on solid-doored units rather than shipment-weighted averages due to the assumption that stakeholders will increasingly value energy conservation.
- **Unit energy consumption is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to compliance with EPA Significant New Alternatives Policy (SNAP).**
- **For this Advanced Case, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration.**
- **A shipments migration from transparent- to solid-doored units is assumed for the Advanced Case.**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding.**
- **Projected installed costs for this Advanced Case are higher than the Reference Case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy-efficient technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Lower annual energy use, increased installed cost compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	4,341	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340	4,340
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Annual Energy Use (kWh/y)[1]	6,023	5,585	5,585	4,847	4,110	4,110	4,362	3,699	3,926	3,329	3,533	2,996
Annual Energy Use / Volume (kWh/y/ft^3)	123	114	114	99	84	84	89	75	80	68	72	61
Indexed Annual Efficiency[3]	1.00	1.08	1.08	1.24	1.47	1.47	1.38	1.63	1.53	1.81	1.70	2.01
Average Life (years)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$2,886	$2,886	$2,886	$3,175	$3,493	$3,493	$3,493	$3,842	$3,842	$4,226	$4,226	$4,649
Total Installed Cost (2022$)[4]	$3,749	$3,749	$3,749	$4,125	$4,443	$4,443	$4,443	$4,792	$4,792	$5,176	$5,176	$5,599
Total Installed Cost (2022$/kBtu/h)	$864	$864	$864	$950	$1,024	$1,024	$1,024	$1,104	$1,104	$1,193	$1,193	$1,290
Annual Maintenance Cost (2022$)[5]	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost (2022$/kBtu/h)	$41.70	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71	$41.71

1. A 49 ft^3 unit was characterized, because it was the representative size selected for DOE's rulemaking analysis.
2. The ENERGY STAR category was based on a solid-doored unit that is minimally compliant with ENERGY STAR v3, effective October 1, 2014.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and 2018 is based on DOE's on-going CRE rulemaking, which assumes a cost of $863 for self-contained equipment and $950 for 2022 and beyond based on analysis from Guidehouse.
5. Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the CRE TSD.

- EPACT 2005 set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V) in ft^3.
- In March of 2017, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its ENERGY STAR specifications for reach-in freezers, effective March 27, 2017. These standards are also based on the refrigerated volume of the unit.

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.L)	0.21xV+0.9	0.12xV+2.248	0.285xV-2.703	0.142xV+4.445
Glass Door (VCT.SC.L)	0.232xV+2.36	0.232xV+2.36	0.232xV+2.36	0.232xV+2.36

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size of 4,341 Btu/h.
- The efficiency of commercial reach-in freezers can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- **Unit energy consumption for reach-in freezers is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to EPA SNAP compliance.**
- **The typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration.**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding.**
- **Projected installed costs for this Advanced Case are higher than the Reference Case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs.**
- **This analysis finds that with increased R&D and market incentives for energy-efficient technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)[1]	37,820	39,422	41,024	41,024	41,024	N/A	41,024	41,024	41,024	41,024	41,024	41,024
Size (ft^2)	305	240	240	240	240	N/A	240	240	240	240	240	240
Annual Energy Use (kWh/yr)[2]	30,689	20,040	17,600	16,200	14,800	N/A	14,580	13,320	13,122	11,988	11,810	10,789
Annual Energy Use / Area (kWh/ft^2/yr)	101	84	73	68	62	N/A	61	56	55	50	49	45
Indexed Annual Efficiency[3]	1.00	1.53	1.74	1.89	2.07	N/A	2.10	2.30	2.34	2.56	2.60	2.84
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$23,598	$19,847	$16,050	$19,847	$23,644	N/A	$16,050	$23,644	$16,050	$23,644	$16,050	$23,644
Total Installed Cost (2022$)[4]	$27,012	$23,897	$20,100	$23,897	$27,694	N/A	$20,100	$27,694	$20,100	$27,694	$20,100	$27,694
Total Installed Cost (2022$/kBtu/hr)	$714	$606	$490	$583	$675	N/A	$490	$675	$490	$675	$490	$675
Annual Maintenance Cost (2022$)[5]	$716	$740	$740	$740	$740	N/A	$740	$740	$740	$740	$740	$740
Annual Maintenance Cost (2022$/kBtu/hr)	$18.93	$18.77	$18.04	$18.04	$18.04	N/A	$18.04	$18.04	$18.04	$18.04	$18.04	$18.04

1. Assumes medium temperature units are refrigerators.
2. Average unit energy consumption was adapted from the DOE CRE 2016 report by assuming electronically commutated motor (ECM) evaporator fan motors are required for Energy Policy & Conservation Act (EPCA) compliance, as well as ECM condenser fan motors.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and beyond is based on DOE's Walk-In Technical Support Document (TSD).
5. Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

- For 2012 and beyond, the unit characterized was a walk-in storage cooler, based on DOE's WICF TSD.
- A typical walk-in refrigerator includes:
  - insulated floor and wall panels
  - merchandising doors, shelving, and lighting (not included in cost estimate)
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with the AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This Advanced Case assumes a projected 10% decrease in energy consumption over the Reference Case due to adoption of more efficient refrigerants.**

The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in the analysis for all units for 2012 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009, must:

- For 2012 and beyond
- have automatic door closers
- have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
- contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
- use electronically commutated motors or three-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
- use electronically commutated motors, permanent split capacitor-type motors, or three-phase motors (for condenser fan motors of under 1 horsepower)
- use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEF (Annual Walk-In Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-In Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.M.I, ≥9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{¥5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{¥4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	22,114	23,500	23,500	23,500	23,500	N/A	23,500	23,500	23,500	23,500	23,500	23,500
Size (ft^2) [1]	172	161	161	161	161	N/A	161	161	161	161	161	161
Annual Energy Use (kWh/y)[2]	22,862	17,600	21,400	21,400	21,400	N/A	19,260	19,260	17,334	17,334	15,601	15,601
Annual Energy Use / Area (kWh/ft^2/y)	133	109	133	133	133	N/A	120	120	108	108	97	97
Indexed Annual Efficiency[3]	1.00	1.30	1.07	1.07	1.07	N/A	1.19	1.19	1.32	1.32	1.47	1.47
Insulated Box Average Life (years)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (years)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost (2022$)	$22,008	$21,950	$21,950	$22,850	$23,750	N/A	$22,850	$23,750	$22,850	$23,750	$22,850	$23,750
Total Installed Cost (2022$)[4]	$24,058	$23,950	$23,950	$24,850	$25,750	N/A	$24,850	$25,750	$24,850	$25,750	$24,850	$25,750
Total Installed Cost (2022$/kBtu/h)	$1,088	$1,019	$1,019	$1,057	$1,096	N/A	$1,057	$1,096	$1,057	$1,096	$1,057	$1,096
Annual Maintenance Cost (2022$)[5]	$741	$741	$741	$740	$741	N/A	$740	$741	$740	$741	$740	$741
Annual Maintenance Cost (2022$/kBtu/h)	$33.51	$31.53	$31.53	$31.49	$31.53	N/A	$31.49	$31.53	$31.49	$31.53	$31.49	$31.53

1. Based on DOE's 2014 WICF Final Rule TSD and additional analysis by Guidehouse, the average floor area for a walk-in storage freezer as 161 ft^2.
2. EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2022 and beyond are characterized using data from DOE's 2014 WICF rulemaking. All units for 2022 and beyond are assumed to comply with this standard.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Installation cost for 2012 and beyond is based on DOE's WICF TSD and additional analysis by Guidehouse.
5. Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

- The commercial walk-in freezer characterized in this report is a walk-in storage freezer with an area of 161 ft^2.
- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with the AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This Advanced Case assumes a projected 10% decrease in energy consumption over the Reference Case due to adoption of more efficient refrigerants.**

EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009, must:

- have automatic door closers
- have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
- contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
- contain floor insulation of at least R–28
- use electronically commutated motors or three-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
- use electronically commutated motors, permanent split capacitor-type motors, or three-phase motors (for condenser fan motors of under 1 horsepower)
- use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEF (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.M.I, ≥9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	5.93 · 10¥5 · Q + 2.33
Dedicated Condensing, Low Temperature, Indoor System, ≥9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	2.30 · 10¥4 · Q + 2.73
Dedicated Condensing, Low Temperature, Outdoor System, ≥9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[6]	Typical	High	Typical	High	Typical	High
Output (pounds [lbs] per day)[1]	300	641	700	700	700	700	700	700	700	700	700	700
Cooling Capacity (Btu/h)[2]	1963	4194	4580	4580	4580	4580	4580	4580	4580	4580	4580	4580
Water Use per Hundred Pounds (gal/hundred lbs)[3]	20	25	25	20	15	15	20	15	20	15	20	15
Energy Use per Hundred Pounds (kWh/hundred lbs)	7.7	7.5	7.1	5.8	4.8	4.8	5.8	4.8	5.8	4.8	5.8	4.8
Annual Energy Use (kWh/y)[4]	3,185	2,502	1,675	1,478	1,190	1,190	1,330	1,071	1,197	964	1,077	868
Indexed Annual Efficiency[5]	1.00	1.27	1.90	2.15	2.68	2.68	2.39	2.97	2.66	3.30	2.96	3.67
Average Life (years)	8.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Retail Equipment Cost (2022$)	$2,146	$2,616	$2,946	$3,020	$3,368	$3,368	$3,020	$3,368	$3,020	$3,368	$3,020	$3,368
Total Installed Cost (with Bin)	$2,441	$3,626	$3,276	$3,350	$3,737	$3,737	$3,350	$3,737	$3,350	$3,737	$3,350	$3,737
Total Installed Cost (2022$/kBtu/h)	$1,244	$865	$715	$732	$816	$816	$732	$816	$732	$816	$732	$816
Annual Maintenance Cost (2022$)[7]	$826	$826	$800	$800	$800	$800	$800	$800	$800	$800	$800	$800
Annual Maintenance Cost (2022$/kBtu/h)	$421	$197	$175	$175	$175	$175	$175	$175	$175	$175	$175	$175

1. Based on the average output from the Compliance Certification Database and values within 2022 Automatic Commercial Ice Maker (ACIM) TSD.
2. Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice.
3. Water use refers to potable water.
4. EPACT 2005 energy standards went into effect in 2010. The 2015 low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond uses data from this rulemaking. All units for 2020 and beyond are assumed to comply with the updated standard.
5. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
6. The ENERGY STAR category is based on minimum compliance with the ENERGY STAR v3.0 standard, which went into effect on January 28, 2018. According to this analysis, ENERGY STAR certification is typical for the small air-cooled ice-making head (IMH) unit characterized.
7. Maintenance cost is based on the average cost of equipment within the 700 lb/day output range and includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

- Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin. Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- ENERGY STAR® updated its maximum energy consumption levels, in kilowatt-hours per 100 pounds of ice, for air-cooled ice machines that went into effect on January 28, 2018. These efficiency levels are based on the harvest rate, in pounds per 24 hours. (H). Water-cooled ice machines are not eligible for ENERGY STAR certification.
- **For this Advanced Case, a 10% reduction in energy consumption is projected over the Reference Case due to the adoption of more efficient refrigerants such as propane, which, while not currently required by EPA SNAP, are a source of possible efficiency improvements.**

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers

Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/hundred lbs ice)
IMH	$200 \leq H \leq 1600$	$\leq 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \leq H \leq 1600$	$\leq 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \leq H \leq 4000$	$\leq -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \leq H \leq 450$	$\leq 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers

Equipment Type	Energy Consumption Rate (kWh/hundred lbs ice)	Potable Water Use (gal/hundred lbs ice)
IMH	$\leq 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\leq 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\leq 59.45 * H^{-0.349} + 0.08$	≤ 15.0

EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 pounds and 2500 pounds per 24-hour period that are manufactured or sold in the United States on or after January 1, 2010. The energy consumption is based on the harvest rate in pounds per 24 hours (H). In 2015, DOE finalized new standards for ACIMs extending coverage to flake, nugget, and tube-type machines and to capacities up to 4,000 pounds per 24 hours.

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/hundred lbs ice)	Maximum Condenser Water Use (gal/hundred lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1,436	5.58-0.0011 H	200-0.022 H
		≥1,436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1,000	8.85-0.0038 H	Not Applicable
		≥1,000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Water use is for the condenser only and does not include potable water used to make ice.

2014 DOE Standards

Energy Conservation Standards for Batch-Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous-Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	4,689	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Annual Energy Use (kWh/y)	1,829	1,635	1,380	1,141	902	902	1,141	902	1,084	857	1,030	814
Annual Energy Use / Volume ($kWh/ft^3/y$)[1]	68	73	55	35	26	26	35	26	35	26	35	26
Indexed Annual Efficiency[3]	1.00	1.12	1.33	1.60	2.03	2.03	1.60	2.03	1.69	2.13	1.78	2.25
Average Life (years)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost (2022$)	$2,382	$2,051	$1,710	$2,762	$3,332	$3,332	$2,762	$3,332	$2,762	$3,332	$2,762	$3,332
Total Installed Cost (2022$)[4]	$2,382	$2,051	$1,710	$2,762	$3,332	$3,332	$2,762	$3,332	$2,762	$3,332	$2,762	$3,332
Total Installed Cost (2022$/kBtu/h)	$508	$436	$364	$588	$709	$709	$588	$709	$588	$709	$588	$709
Annual Maintenance Cost (2022$)	$108	$108	$95	$95	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost (2022$/kBtu/h)	$23.03	$22.98	$20.21	$20.21	$20.11	$20.11	$20.21	$20.11	$20.21	$20.11	$20.21	$20.11

1. EPACT 2005 energy conservation standards went into effect in 2010. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2018 and beyond use data reported in this rulemaking's TSD. Units sold in 2022 and beyond are assumed to comply with this updated standard.
2. The ENERGY STAR category characterizes a unit that is compliant with ENERGY STAR v4, effective March 2017. This standard does not separately define units with pull-down capability.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible.

- EPACT 2005 sets maximum daily energy consumption levels, in kilowatt-hours per day, for commercial refrigerators with transparent doors and self-contained condensing unit designed for pull-down temperature applications (i.e., beverage merchandisers) and went into effect on January 1, 2010.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its ENERGY STAR specifications for glass-doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that ENERGY STAR does not have a separate equipment class for units with pull-down capability.

Beverage Merchandiser Size	$0 < V < 15$	$15 \le V < 30$	$30 \le V < 50$	$50 \le V$
Glass Door	0.118*V + 1.382	≤ 0.140*V + 1.050	≤ 0.088*V + 2.625	≤ 0.110*V + 1.500

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking and additional analysis by Guidehouse, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,700 Btu/h.
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, LED lighting, and improved insulation.
- For the Reference Case, beverage merchandisers are assumed to be mature technologies with few technology advancements in the coming years that would dramatically improve the efficiency.
- **For this Advanced Case, the typical unit in 2030 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Beverage merchandisers may transition from HFC to more efficient propane.**
- **Projected installed costs for this Advanced Case are the same as the Reference Case, assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040 and a 5% decrease in energy use from 2030 to 2040.**

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	1,810	1,707	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	470	500	500	500	500	500	500	500	500	500	500	500
Size (ft^3)	26	35	35	35	35	35	35	35	35	35	35	35
Annual Energy Use (kWh/y)[1]	1,632	1,550	1,550	1,531	1,443	1,443	1,455	1,371	1,382	1,302	1,313	1,237
Annual Energy Use / Volume (kWh/ft^3/y)	63	44	44	44	41	41	42	39	39	37	38	35
Indexed Annual Efficiency[3]	1.00	1.05	1.05	1.07	1.13	1.13	1.12	1.19	1.18	1.25	1.24	1.32
Average Life (years)	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost (2022$)	$3,209	$2,553	$3,059	$3,272	$3,520	$3,520	$3,272	$3,520	$3,272	$3,520	$3,272	$3,520
Total Installed Cost (2022$)	$3,320	$2,705	$3,276	$3,489	$3,737	$3,737	$3,489	$3,737	$3,489	$3,737	$3,489	$3,737
Total Installed Cost (2022$/kBtu/h)	$1,834	$1,585	$1,810	$1,928	$2,065	$2,065	$1,928	$2,065	$1,928	$2,065	$1,928	$2,065
Annual Maintenance Cost (2022$)[4]	$270	$270	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
Annual Maintenance Cost (2022$/kBtu/h)	$149	$149	$184	$184	$184	$184	$184	$184	$184	$184	$184	$184

1. Energy use for 2018 and beyond is estimated based on DOE's 2020 BVM Final Rule and the 2022 Compliance Certification Database.
2. The ENERGY STAR category assumes units are compliant with the ENERGY STAR v4 standard because combination units are currently not separately defined by ENERGY STAR. This standard went into effect on April 29, 2020. Our analysis finds ENERGY STAR certified equipment to be the most efficient currently available on the market.
3. Annual efficiency normalized to the efficiency of the 2012 installed base. Indexed Annual Efficiency = (2012 Energy Use) / (Energy Use).
4. Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils, and an annualized cost for refurbishments/remanufacturing.

- DOE set federal energy efficiency standards for refrigerated vending machines. These standards set maximum daily energy consumption levels, in kilowatt-hours per day, for commercial refrigerated vending machines manufactured or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
- In December 2015, DOE updated its energy conservation standards for beverage vending machines and defined two new product classes for combination vending machines. The energy conservation standard remains the same in the updated 2022 technical support document for vending machines. Compliance with these standards was required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2022 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Type	Maximum Daily Energy Consumption
Class A (Transparent-Front)	$MDEC = 0.052 \times V + 2.43$
Class B (Solid-Front)	$MDEC = 0.052 \times V + 2.20$
Combination A	$MDEC = 0.086 \times V + 2.66$
Combination B	$MDEC = 0.111 \times V + 2.04$

ENERGY STAR® updated its maximum daily energy consumption efficiency levels, also in kilowatt-hours per day, for refrigerated vending machines that went into effect on April 29, 2020. These efficiency levels are based on refrigerated volume.

Equipment Class	Maximum daily energy consumption (kilowatt-hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25% or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.04836 x V + 2.2599
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.04576 x V+1.936
Combination A – a combination vending machine where 25% or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.07998 x V + 2.4738
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.09768 x V + 1.7952

- DOE set federal energy efficiency standards for refrigerated vending machines in 2009. These standards set maximum daily energy consumption levels, in kWh/day, for commercial refrigerated vending machines manufactured and/or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerated Vending Machines that are fully-cooled (Type A) ≤ 0.055*V + 2.56
  - Refrigerated Vending Machines that are zone-cooled (Type B) ≤ 0.073*V + 3.16
- ENERGY STAR® updated its maximum daily energy consumption efficiency levels, also in kWh/day, for refrigerated vending machines, which went into effect on March 1, 2013. These efficiency levels are based on refrigerated volume.

Equipment Type	Maximum Daily Energy Consumption	Low Power Mode Requirement
Class A (Transparent-Front)	MDEC= 0.0523 x V + 2.432	Hard-wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source
Class B (Solid-Front)	MDEC = 0.0657 x V + 2.844	

- **Currently, stakeholders such as Coca Cola have indicated a preference for CO_2 refrigerant, which is less efficient. However, this Advanced Case scenario assumes a shift to more efficient propane for cost and energy consumption projections due to the superior efficiency of propane refrigerant.**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this Advanced Case are higher than the Reference Case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

In December 2015, DOE updated its energy conservation standards for beverage vending machines, and defined two new product classes for combination vending machines Compliance with these standards is required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2020 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.052 x V + 2.43
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.052 x V + 2.20
Combination A – a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.086 x V + 2.66
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.111 x V + 2.04

Commercial Ventilation

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	High[4,7]	ENERGY STAR	Typical[4,6]	High[4,7]	Typical[4,6]	High[4,7]	Typical[4,6]	High[4,7]
System Airflow (CFM)	15,000	16,300	16,300	16,300	16,300	N/A	16,300	16,300	16,300	16,300	16,300	16,300
System Fan Power (kW)	11.56	11.56	11.56	10.98	10.78	N/A	10.98	10.78	10.98	10.78	10.98	10.78
Specific Fan Power (W/CFM)	0.771	0.709	0.709	0.674	0.661	N/A	0.674	0.661	0.674	0.661	0.674	0.661
Annual Fan Energy Use (kWh/y)[1]	43,924	23,038	23,038	21,886	20,792	N/A	20,792	19,752	19,752	18,765	18,765	17,826
Average Life (years)	35	35	35	35	35	N/A	35	35	35	35	35	35
Total Installed Cost (2022$)[2]	$80,288	$83,083	$83,083	$86,901	$90,651	N/A	$86,901	$90,651	$86,901	$90,651	$86,901	$90,651
Annual Maintenance Cost (2022$)	$1,054	$1,054	$1,054	$1,054	$1,054	N/A	$1,054	$1,054	$1,054	$1,054	$1,054	$1,054
Total Installed Cost (2022$/thousand CFM)	$5,353	$5,097	$5,097	$5,331	$5,561	N/A	$5,331	$5,561	$5,331	$5,561	$5,331	$5,561
Annual Maintenance Cost (2022$/thousand CFM)	$70	$65	$65	$65	$65	N/A	$65	$65	$65	$65	$65	$65

1. Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 16,300 CFM constant air volume (CAV) air handling unit (AHU) and hypothetical supply ductwork layout
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. ASHRAE 90.1-2016 and 2019 Section 6.5.3.2 require minimum two-speed fan control (no longer always constant volume).
5. Two-speed variable frequency drive (VFD)
6. Modulating VFD
7. Modulating custom engineered VFD

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, these systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain the space temperature setpoint. Beginning with ASHRAE 90.1-2013 and continued in ASHRAE 90.1-2019, new CAV ventilation systems were mandated to have at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. Systems with variable speed fans are increasingly popular, making the term “constant air volume” somewhat of a misnomer for this system type. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- The unit characterized in this report is a 16,300 CFM CAV system. The average commercial building is approximately 16,300 square feet (CBECS 2018). Assuming 1 CFM is needed per square foot of floor area results in a 16,300 CFM air handling unit.
- A 16,300 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $71,829 (RS Means 2022). Ductwork would cost approximately $9,272 additional ($81,101 total). A two-speed motor (estimated $500 incremental cost) and variable frequency drive (estimated $5,800) add cost. Custom engineered variable frequency drives (estimated $9,550) and premium efficiency motors (estimated additional $1,500) add an additional cost to the system.
- Annual maintenance cost assumes 8 hours worth of labor by a technician to perform the necessary tasks (e.g., filter replacement, draining condenser water, etc.)
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, motor efficiency, and speed and flow control.
- **For this Advanced Case, the projections from 2030 to 2050 for system fan power and annual fan energy use assume a 5% improvement per decade based on the assumption that use of variable frequency drives and incremental improvements in technology will increase.**

Lower annual energy use compared with Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	High[6]	ENERGY STAR	Typical[6]	High[6,7]	Typical[6,7]	High[6,7]	Typical[6,7]	High[6,7]
System Airflow (CFM)	15,000	16,300	16,300	16,300	16,300	N/A	16,300	16,300	16,300	16,300	16,300	16,300
System Fan Power (kW)	15.99	15.99	15.99	15.99	15.99	N/A	15.99	15.19	15.99	15.19	15.99	15.19
Specific Fan Power (W/CFM)	1.066	1.066	0.981	0.981	0.981	N/A	0.981	0.932	0.981	0.932	0.981	0.932
Annual Fan Energy Use (kWh/yr)[1]	24,699	24,082	24,082	22,878	21,734	N/A	21,734	20,647	20,647	19,615	19,615	18,634
Average Life (yrs)	28	28	28	28	28	N/A	28	28	28	28	28	28
Total Installed Cost (2022$)[2]	$103,327	$110,414	$118,814	$124,495	$124,995	N/A	$124,495	$124,995	$124,495	$124,995	$124,495	$124,995
Annual Maintenance Cost (2022$)	$1,054	$1,054	$1,054	$1,054	$1,054	N/A	$1,054	$1,054	$1,054	$1,054	$1,054	$1,054
Total Installed Cost (2022$/1000 CFM)	$6,888	$6,774	$7,289	$7,638	$7,668	N/A	$7,638	$7,668	$7,638	$7,668	$7,638	$7,668
Annual Maintenance Cost (2022$/1000 CFM)	$70	$65	$65	$65	$65	N/A	$65	$65	$65	$65	$65	$65

1. Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 16,300 CFM VAV AHU, VFD, (10) VAV boxes, (10) VAV controllers with associated space temperature sensor, and hypothetical supply ductwork layout
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. ASHRAE 90.1-2016 and 2019 Section 6.5.3.2 minimum power-flow requirement
5. ASHRAE 90.1-2019 fan power limit and typical VAV power-flow relationship for 40%-100% flow
6. ASHRAE 90.1-2019 fan power limit and typical VAV power-flow relationship for 30%-100% flow
7. High aerodynamic efficiency fan

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating, then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet the space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speed and flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 16,300 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 16,300 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $82,023 (RS Means 2022). Ductwork and (10) VAV boxes with reheat would cost approximately an additional $28,272. (10) VAV controllers and the associated space temperature sensor would cost approximately $8,400 ($118,695 total). A 15 hp variable frequency drive (estimated $5,800) is an additional cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Annual maintenance cost assumes 8 hours worth of labor by a technician to perform the necessary tasks (e.g., filter replacement, draining condenser water, etc.)
- Fan energy is affected by several factors, including fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.
- **For this Advanced Case, the projections from 2030 to 2050 for system fan power and annual fan energy use assume a 5% improvement per decade based on the assumption use of variable frequency drives and incremental improvements in technology will increase.**

Same as Reference Case

DATA	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[5]	High[6]	ENERGY STAR	Typical[4,6]	High[4,7]	Typical[4,7]	High[4,8]	Typical[4,8]	High[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.241	0.241	0.241	0.148	0.148	N/A	0.141	0.134	0.134	0.136	0.136	0.129
Specific Fan Power (W/CFM)	0.302	0.302	0.301	0.185	0.185	N/A	0.176	0.167	0.167	0.170	0.170	0.162
Annual Fan Energy Use (kWh/y)[1]	543	542	542	333	333	N/A	316	301	301	306	306	291
Average Life (years)	37	37	37	37	37	N/A	37	37	37	37	37	37
Total Installed Cost (2022$)[2]	$2,845	$2,688	$3,038	$3,521	$3,961	N/A	$3,961	$4,161	$3,961	$4,161	$3,961	$4,161
Annual Maintenance Cost (2022$)	$117	$117	$117	$117	$117	N/A	$117	$117	$117	$117	$117	$117
Total Installed Cost (2022$/thousand CFM)	$3,557	$3,360	$3,798	$4,401	$4,951	N/A	$4,951	$5,201	$4,951	$5,201	$4,951	$5,201
Annual Maintenance Cost (2022$/thousand CFM)	$146	$146	$146	$146	$146	N/A	$146	$146	$146	$146	$146	$146

1. Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012)
2. Total installed cost of 2-ton horizontal two-pipe fan coil unit, housing, and controls
3. Based on ASHRAE 90.1-2016 and 2019 fan power limit (Table 6.5.3.1.1-1) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency
4. Based on ASHRAE 90.1-2016 and 2019 Section 6.5.3.6 requirement of electronically commutated or 70+% efficient fan motor
5. Permanent split capacitor fan motor
6. Electronically commutated fan motor (single speed)
7. Electronically commutated fan motor (two-speed)
8. Electronically commutated fan motor (variable speed)
9. High aerodynamic efficiency fan

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but they do not include the source of cooling or heating. The unit characterized in this report is a cooling only (two-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- Fan coil unit fan motors can be shaded pole, a single-phase AC motor with offset start winding and no capacitor; PSC, a single-phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but manufacturers also offer single speed, two speed, and ECM motors as an option. ASHRAE 90.1-2019 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2019 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit, the filters must be changed, and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2016 version of Standard 90.1 was used to represent the 2018 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including fan type configuration, filter and coil pressure drops, motor efficiency, and fan speed control.

Appendix A
Data Sources

Guidehouse
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

Leidos
8301 Greensboro Drive
McLean, VA 22102

Residential Lighting

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

DATA SOURCES	2015	2020	2022				2023**	2030		2040		2050	
	Installed Stock Average		Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential General Service Filament-LED Lamps (60 Watt Equivalent)

DATA SOURCES	2015	2020	2022				2023**	2030		2040		2050	
	Installed Stock Average		Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Reflector LED BR30

DATA SOURCES	2015 Installed Stock Average	2020	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023** Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023** Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs			N/A		Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated						N/A	Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Linear LED Replacement Lamp 2-Lamp System

DATA SOURCES	2015	2020	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	LED Webscrape Database	DOE Webscrape Database	Distributor Websites			Calculated					
Lamp Lumens						Assume Same as 2022 Typical and High					
Lamp Efficacy (lm/W)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage	Calculated										
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)	N/A										
CRI	2016 EIA Ref. Case	Distributor Websites	Distributor Websites								
Correlated Color Temperature (CCT)	2016 EIA Ref. Case										
Average Lamp Life (thousand hours)	LED Webscrape Database	DOE Web Scrape Database									
Annual Operating Hours (h/y)	DOE, 2017										
Lamp Price (2022$)	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Calculated					
Ballast Price (2022$)		N/A									
Fixture Price (2022$)											
Lamp Cost (2022$/klm)	Calculated										
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)	N/A										
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Linear LED Luminaire

DATA SOURCES	2015 Installed Stock Average	2020 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	N/A										
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Calculated					
System Lumens						Assume Same as 2022 Typical and High					
System Efficacy (lm/W)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Efficiency (BLE)	N/A										
CRI	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Distributor Websites					
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)	DOE, 2017										
Lamp or Luminaire Price (2022$)	LED Webscrape Database	DOE Web Scrape Database	Distributor Websites			Calculated					
Ballast Price (2022$)	N/A										
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)	2016 EIA Ref. Case		2022 RS Means Online								
Labor System Installation (hours)											
Labor Lamp Change (hours)			N/A								
Total Installed Cost (2022$)	Calculated										
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Residential Outdoor Lamps (Security: LED PAR38)

DATA SOURCES	2015	2020	2022				2023*	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential LED PAR38												
Lamp Lumens													
Lamp Efficacy (lm/W)													
CRI													
Correlated Color Temperature (CCT)													
Average Lamp Life (1000 hrs)													
Annual Operating Hours (hrs/yr)													
Lamp Price (2022$)													
Lamp Cost (2022$/klm)													
Labor Cost (2022$/hr)													
Labor Lamp Installation (hr)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Residential Outdoor Lamps (Porch: LED A-Type)

DATA SOURCES	2015	2020	2022				2023*	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR*	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)			Calculated					Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
CRI			Distributor Websites or Product Catalogs				N/A	Assume Unchanged					
Correlated Color Temperature (CCT)													
Average Lamp Life (thousand hours)								Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	2020 DOE LED Pricing Analysis	Distributor Websites or Product Catalogs			N/A		Model DOE Goals Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Lamp Cost (2022$/klm)	Calculated												
Labor Cost (2022$/h)	N/A												
Labor Lamp Installation (hours)													
Total Installed Cost (2022$)	Calculated												
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Commercial Lighting

Final

Data Sources » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2023 Standard	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage								Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage													
System Lumens*	2016 EIA Reference Case	Calculated											
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI						ENERGY STAR, 2020		Assume Unchanged					
Correlated Color Temperature (CCT)						N/A							
Average Lamp Life (thousand hours)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)				Assume Unchanged	
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs					Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)	2016 EIA Reference Case	N/A				N/A		N/A					
Fixture Price (2022$)*													
Lamp Cost (2022$/klm)		Calculated						Calculated					
System (l/b/f) Cost (2022$/klm)		N/A						N/A					
Labor Cost (2022$/h)													
Labor System Installation (hours)		2016 EIA Reference Case	2022 RS Means Online					2022 RS Means Online					
Labor Lamp Change (hours)													
Total Installed Cost (2022$)													
Annual Maintenance Cost (2022$)		Calculated						Calculated					
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial LED Reflector Lighting (PAR38)

DATA SOURCES	2012	2018	2022				2023	2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Standard	Typical	High	Typical	High	Typical	High
Lamp Wattage								Calculated					
Lamp Lumens								Assume Unchanged					
Lamp Efficacy (lm/W)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	DOE, 2022	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage													
System Lumens*	2016 EIA Reference Case	Calculated											
System Efficacy (lm/W)													
Ballast Efficiency (BLE)													
CRI						ENERGY STAR, 2020		Assume Unchanged					
Correlated Color Temperature (CCT)						N/A							
Average Lamp Life (thousand hours)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs			ENERGY STAR, 2020	N/A	Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)				Assume Unchanged	
Annual Operating Hours (h/y)	DOE, 2017												
Lamp Price (2022$)		Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	Distributor Websites or Product Catalogs					Model Reference Scenario, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)	2016 EIA Reference Case	N/A				N/A		N/A					
Fixture Price (2022$)													
Lamp Cost (2022$/klm)		Calculated						Calculated					
System (l/b/f) Cost (2022$/klm)		N/A						N/A					
Labor Cost (2022$/h)		2016 EIA Reference Case	2022 RS Means Online					2022 RS Means Online					
Labor System Installation (hours)													
Labor Lamp Change (hours)													
Total Installed Cost (2022$)		Calculated						Calculated					
Annual Maintenance Cost (2022$)													
Total Installed Cost (2022$/klm)													
Annual Maintenance Cost (2022$/klm)													

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	LED Webscrape Database	Distributor Websites			Calculated					
Lamp Lumens						Assume Same as 2022 Typical and High					
Lamp Efficacy (lm/W)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Wattage		Calculated									
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)		N/A									
CRI		Distributor Websites									
Correlated Color Temperature (CCT)											
Average Lamp Life (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp Price (2022$)		LED Webscrape Database	Distributor Websites			Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A									
Fixture Price (2022$)											
Lamp Cost (2022$/klm)		Calculated									
System (l/b/f) Cost (2022$/klm)											
Labor Cost (2022$/h)		2016 EIA Ref. Case	2022 RS Means Online								
Labor System Installation (hours)		N/A									
Labor Lamp Change (hours)		Assume unchanged									
Total Installed Cost (2022$)		Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	2016 EIA Ref. Case	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage		LED Webscrape Database	Distributor Websites			Calculated					
System Lumens						Assume Same as 2022 Typical and High					
System Efficacy (lm/W)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Efficiency (BLE)		N/A				N/A					
CRI		Distributor Websites									
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp or Luminaire Price (2022$)		LED Webscrape Database	Distributor Websites			Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A									
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated									
Labor Cost (2022$/h)		2016 EIA Ref. Case	2022 RS Means Online								
Labor System Installation (hours)		2022 RS Means Online									
Labor Lamp Change (hours)		N/A									
Total Installed Cost (2022$)		Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial 8-ft Linear LED Replacement Lamp for a 2-Lamp System

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2012</th><th>2018</th><th colspan="3">2022</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="23">N/A</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td rowspan="2" colspan="3">Distributor Websites</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Assume Same as 2022 Typical and High</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td rowspan="4" colspan="3">Calculated</td><td colspan="6">Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">Calculated</td><td rowspan="3" colspan="6">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td colspan="10">N/A</td></tr>
<tr><td>CRI</td><td rowspan="3">2016 EIA Ref. Case, 2015 typical</td><td rowspan="3" colspan="9">Distributor Websites</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (thousand hours)</td></tr>
<tr><td>Annual Operating Hours (h/y)</td><td colspan="10">DOE, 2017</td></tr>
<tr><td>Lamp Price (2022$)</td><td rowspan="6">2016 EIA Ref. Case, 2015 typical</td><td colspan="3">Distributor Websites</td><td rowspan="5" colspan="6">Calculated</td></tr>
<tr><td>Ballast Price (2022$)</td><td rowspan="2" colspan="3">N/A</td></tr>
<tr><td>Fixture Price (2022$)</td></tr>
<tr><td>Lamp Cost (2022$/klm)</td><td rowspan="2" colspan="3">Calculated</td></tr>
<tr><td>System (l/b/f) Cost (2022$/klm)</td></tr>
<tr><td>Labor Cost (2022$/h)</td><td colspan="9">2022 RS Means Online</td></tr>
<tr><td>Labor System Installation (hours)</td><td colspan="10">N/A</td></tr>
<tr><td>Labor Lamp Change (hours)</td><td colspan="10">Chapter 8; Table 8.2.4 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)</td></tr>
<tr><td>Total Installed Cost (2022$)</td><td rowspan="4" colspan="10">Calculated</td></tr>
<tr><td>Annual Maintenance Cost (2022$)</td></tr>
<tr><td>Total Installed Cost (2022$/klm)</td></tr>
<tr><td>Annual Maintenance Cost (2022$/klm)</td></tr>
</table>

Data Sources » Commercial 8-ft Linear LED Luminaire Replacement for a 2-Lamp System

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Lamp Wattage	N/A	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage		2016 EIA Ref. Case, 2015 typical	Distributor Websites			Calculated					
System Lumens						Assume Same as 2022 Typical and High					
System Efficacy (lm/W)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Efficiency (BLE)		N/A									
CRI		2016 EIA Ref. Case, 2015 typical	Distributor Websites								
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)											
Annual Operating Hours (h/y)		DOE, 2017									
Lamp or Luminaire Price (2022$)		2016 EIA Ref. Case, 2015 typical	Distributor Websites								
Ballast Price (2022$)		N/A									
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated									
Labor Cost (2022$/h)		2016 EIA Ref. Case, 2015 typical	2022 RS Means Online								
Labor System Installation (hours)											
Labor Lamp Change (hours)		N/A									
Total Installed Cost (2022$)		Calculated									
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial LED Low-Bay Luminaire

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A										
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	N/A	Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency		N/A		N/A		N/A					
CRI		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017							
Lamp or Luminaire Price (2022$)	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A		N/A		N/A					
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated		Calculated		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Labor Cost (2022$/h)		2016 EIA Reference Case		2022 RS Means Online							
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated			Calculated		Calculated					
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Data Sources » Commercial LED High-Bay Luminaire

DATA SOURCES	2012	2018	2022			2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A										
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)	N/A	Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
System Lumens											
System Efficacy (lm/W)											
Ballast Efficiency (BLE)		N/A		N/A		N/A					
CRI		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (thousand hours)						Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Annual Operating Hours (h/y)	DOE, 2017			DOE, 2017		DOE, 2017					
Lamp or Luminaire Price (2022$)	2016 EIA Reference Case	Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)		Distributor Websites or Product Catalogs		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Ballast Price (2022$)		N/A		N/A		N/A					
Fixture Price (2022$)											
Lamp Cost (2022$/klm)											
System (l/b/f) Cost (2022$/klm)		Calculated		Calculated		Model, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2019)					
Labor Cost (2022$/h)		2016 EIA Reference Case		2022 RS Means Online							
Labor System Installation (hours)											
Labor Lamp Change (hours)											
Total Installed Cost (2022$)	Calculated			Calculated		Calculated					
Annual Maintenance Cost (2022$)											
Total Installed Cost (2022$/klm)											
Annual Maintenance Cost (2022$/klm)											

Refrigeration

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)	ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Power Input (kW)	Copeland, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (MMWh/y)	ADL, 1996 / NCI Analysis, 2015	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Indexed Annual Efficiency	Calculated											
Average Life (years)	Kysor-Warren, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	NCI, 2009 / NCI Analysis, 2012	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/h)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (MMWh/y)	NCI Analysis, 2008 / ADL, 1996	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Median Store Size (ft²)	Food Marketing Institute (FMI), 2012	CBECS 2018										
Case Length (ft)	DOE, 2016: CRE Report / Guidehouse Analysis 2022											
Annual Energy Use (kWh/y)[1,2]	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use / Case Length (kWh/ft)	Calculated											
Indexed Annual Efficiency[3]	Calculated											
Average Life (years)	DOE, 2007 / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / The Restaurant Store										
Total Installed Cost (2022$)	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)[4]	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Reach-In Refrigerators

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022										
Annual Energy Use / Volume (kWh/y/ft^3)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (years)	Calculated											
Retail Equipment Cost (2022$)	ACEEE, 2002	DOE, 2014: CRE TSD										
Total Installed Cost (2022$)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022 / The Restaurant Store										
Total Installed Cost (2022$/kBtu/h)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$)	Calculated											
Annual Maintenance Cost (2022$/kBtu/h)	NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE, 2016: CRE Report										
Size (ft³)	ADL, 1996 / Distributor Web Sites	DOE, 2016: CRE Report										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use / Volume (kWh/y/ft³)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ACEEE, 2002	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022 / The Restaurant Store										
Total Installed Cost (2022$)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	NCI Analysis, 2008	DOE, 2016: CRE Report / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE CRE Report 2016 / CCMS 2022 / Guidehouse Analysis 2022											
Size (ft^2)	DOE 2014 WICF TSD / Guidehouse Analysis 2022											
Annual Energy Use (kWh/y)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Annual Energy Use / Area (kWh/ft^2/y)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Compressor Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2023										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Cooling Capacity (Btu/h)	ADL, 1996 / NCI Analysis, 2008	DOE CRE Report 2016 / CCMS 2022 / Guidehouse Analysis 2022										
Size (ft²)	ADL, 1996 / NCI Analysis, 2008	Guidehouse Analysis 2022										
Annual Energy Use (kWh/y)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	Guidehouse CRE Report 2016										
Annual Energy Use / Area (kWh/ft²/y)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Compressor Average Life (years)	ADL, 1996 / PG&E, 2004	DOE CRE Report 2016 / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2022										
Total Installed Cost (2022$)	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE CRE Report 2016 / Webstaurant 2022 / Guidehouse Analysis 2023										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE CRE Report 2016 / Guidehouse Analysis 2022											
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012 Installed Stock Average	2018 Installed Stock Average	2022 Low	2022 Typical	2022 High	2022 ENERGY STAR	2030 Typical	2030 High	2040 Typical	2040 High	2050 Typical	2050 High
Output (pounds [lbs] per day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / CCMS Database 2022										
Water Use per Hundred Pounds (gal/hundred lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / CCMS Database 2022										
Energy Use per Hundred Pounds (kWh/hundred lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Annual Energy Use (kWh/y)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022 / ENERGY STAR										
Indexed Annual Efficiency	Calculated											
Average Life (years)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Retail Equipment Cost (2022$)	Distributor Web Sites / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	ADL, 1996 / NCI Analysis, 2008	DOE, 2022: ACIM TSD / Guidehouse Analysis, 2022										
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

Data Sources » Commercial Beverage Merchandisers

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Annual Energy Use (kWh/y)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / ENERGY STAR 2022										
Annual Energy Use / Volume ($kWh/ft^3/y$)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (years)	ACEEE, 2002	DOE, 2014: CRE Report / Guidehouse Analysis 2022										
Retail Equipment Cost (2022$)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE Report / Guidehouse Analysis 2022 / KaTom Restaurant Supply										
Total Installed Cost (2022$)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE, 2014: CRE Report / Guidehouse Analysis 2022											
Annual Maintenance Cost (2022$/kBtu/h)	Calculated											

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/h)	DOE, 2015: BVM TSD / Guidehouse Analysis, 2015	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022										
Can Capacity	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Size (ft^3)	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022											
Annual Energy Use (kWh/y)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Annual Energy Use / Volume ($kWh/ft^3/y$)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (years)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Retail Equipment Cost (2022$)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Total Installed Cost (2022$)	DOE, 2015: BVM TSD	DOE, 2022: BVM TSD										
Total Installed Cost (2022$/kBtu/h)	Calculated											
Annual Maintenance Cost (2022$)	DOE, 2015: BVM TSD / Guidehouse Analysis, 2015	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022										
Annual Maintenance Cost (2022$/kBtu/h)	DOE, 2022: BVM TSD / Guidehouse Analysis, 2022											

Commercial Ventilation

Data Sources » Commercial Constant Air Volume Ventilation

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	CBECS 2003 & BED 2007	CBECS 2018										
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

Data Sources » Commercial Variable Air Volume Ventilation

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	CBECS 2003 & BED 2007	CBECS 2018										
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

Data Sources » Commercial Fan Coil Unit

DATA SOURCES	2012	2018	2022				2030		2040		2050	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	ENERGY STAR	Typical	High	Typical	High	Typical	High
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	ASHRAE 90.1-2007	ASHRAE 90.1-2016	ASHRAE 90.1-2019	ASHRAE 90.1 2019 / Guidehouse Analysis 2022								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/y)												
Average Life (years)	ASHRAE: Service Life Database											
Total Installed Cost (2022$)	2022 RS Means Online											
Annual Maintenance Cost (2022$)	2022 RS Means Online / Guidehouse											
Total Installed Cost (2022$/thousand CFM)	Calculated											
Annual Maintenance Cost (2022$/thousand CFM)	Calculated											

Appendix B
References

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1200 19th Street, NW, Suite 700
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And

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References

- ASHRAE Service Life and Maintenance Cost Database. (n.d.).
- ASHRAE 90.1-2010, 2016, 2019. *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- Appliance Magazine. (2005). Portrait of the U.S. Appliance Industry. Appliance Magazine.
- Arthur D. Little. (1996). Energy Savings Potential for Commercial Refrigeration Equipment.
- DOE SSL Program. (2012a). *2010 U.S. Lighting Market Characterization*
- DOE SSL Program. (2012b). *Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates*
- DOE SSL Program. (2017). *2015 U.S. Lighting Market Characterization*
- DOE Appliance and Equipment Standards Program. (2022). *The Compliance Certification Database*.
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Automatic Commercial Ice Makers*
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Commercial Refrigeration Equipment*.
- EERE. (2014). *Energy Conservation Program for Appliance Standards: Refrigerated Beverage Vending Machines*
- EERE. (2015). *Energy Conservation Program for Appliance Standards: Walk-in Coolers and Freezers*.
- ENERGY STAR. (n.d.). Retrieved November 2015, from ENERGY STAR Products: http://www.energystar.gov/index.cfm?c=products.pr_find_es_products
- ENERGY STAR. (2020) from ENERGY STAR Lamps Specification Version 2.1: https://www.energystar.gov/sites/default/files/Lamps%20V2.1%20Final%20Specification%20%28Revised%20June%202020%29_0.pdf

References

- ENERGY STAR. (2014) *ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.1*
- ENERGY STAR. (2012) *ENERGY STAR® Program Requirements Product Specification for Luminaires (Light Fixtures) Eligibility Criteria Version 1.1*
- Environmental Protection Agency. (2022). *Establishing a Recycling Program for Mercury-Containing Light Bulbs*. From: https://www.epa.gov/hw/establishing-recycling-program-mercury-containing-light-bulbs
- Federal Standard. (1975). National energy conservation standards authorized under the Energy and Policy Conservation Act of 2007 (EPCA 1975).
- Federal Standard. (2005). National energy conservation standards authorized under the Energy Policy Act of 2005 (EPACT 2005).
- Federal Standard. (2007). National energy conservation standards authorized under the Energy Independence and Security Act of 2007 (EISA 2007).
- Food Marketing Institute. (n.d.). Retrieved May 2022, from FMI Supermarket Facts: https://www.fmi.org/our-research/supermarket-facts/average-total-store-size-square-feetLighting Research Institute. (1992). Specifier Reports, Specular Reflectors.
- KaTom. (n.d.) Retrieved May 2022, From: https://www.katom.com/
- Navigant Consulting, Inc. (2009). Energy Savings Potential and R&D Opportunities for Commercial Refrigeration.
- Navigant Consulting, Inc. (n.d.). In House Expertise.

References

- Navigant Consulting, Inc. (2019). Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Model. https://www.energy.gov/eere/ssl/downloads/2019-ssl-forecast-report
- Product Literature. (n.d.). Literature from manufacturers and experts on specific products
- The Restaurant Store. (n.d.). Retrieved May 2022, From: https://www.therestaurantstore.com/
- *RS Means Online*. (2022). Retrieved June 2022, From: https://www.rsmeansonline.com/
- Webstaurant. (n.d.) Retrieved May 2022, From: https://www.webstaurantstore.com/