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March 2023
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>5</td>
</tr>
<tr>
<td>Methodology</td>
<td>6</td>
</tr>
<tr>
<td>Definitions</td>
<td>7</td>
</tr>
<tr>
<td>Market Transformation</td>
<td>8</td>
</tr>
<tr>
<td>Residential Gas-Fired Furnaces (North)</td>
<td>10</td>
</tr>
<tr>
<td>Residential Gas-Fired Furnaces (Rest of Country)</td>
<td>11</td>
</tr>
<tr>
<td>Residential Oil-Fired Furnaces</td>
<td>14</td>
</tr>
<tr>
<td>Residential Gas-Fired Boilers</td>
<td>17</td>
</tr>
<tr>
<td>Residential Oil-Fired Boilers</td>
<td>20</td>
</tr>
<tr>
<td>Residential Electric Furnaces</td>
<td>23</td>
</tr>
<tr>
<td>Residential Electric Resistance Heaters</td>
<td>25</td>
</tr>
<tr>
<td>Residential Central Air Conditioners (North)</td>
<td>27</td>
</tr>
<tr>
<td>Residential Central Air Conditioners (South)</td>
<td>28</td>
</tr>
<tr>
<td>Residential Room Air Conditioners</td>
<td>31</td>
</tr>
<tr>
<td>Residential Portable Air Conditioners</td>
<td>34</td>
</tr>
<tr>
<td>Residential Swamp Coolers</td>
<td>37</td>
</tr>
<tr>
<td>Residential Air-Source Heat Pumps</td>
<td>39</td>
</tr>
<tr>
<td>Residential Ductless Mini-Split Air-Source Heat Pumps</td>
<td>43</td>
</tr>
<tr>
<td>Residential Ground-Source Heat Pumps</td>
<td>45</td>
</tr>
<tr>
<td>Residential Natural Gas Heat Pumps</td>
<td>47</td>
</tr>
<tr>
<td>Residential Cordwood Stoves</td>
<td>49</td>
</tr>
<tr>
<td>Residential Wood Pellet Stoves</td>
<td>52</td>
</tr>
<tr>
<td>Residential Gas-Fired Water Heater</td>
<td>56</td>
</tr>
<tr>
<td>Residential Oil-Fired Water Heater</td>
<td>59</td>
</tr>
<tr>
<td>Residential Electric Resistance Water Heater</td>
<td>62</td>
</tr>
<tr>
<td>Residential Electric Heat Pump Water Heater</td>
<td>65</td>
</tr>
<tr>
<td>Residential Solar Water Heater</td>
<td>68</td>
</tr>
<tr>
<td>Residential Gas-Fired Instantaneous Water Heater</td>
<td>72</td>
</tr>
<tr>
<td>Residential Electric Instantaneous Water Heater</td>
<td>74</td>
</tr>
<tr>
<td>Residential Refrigerator/Freezer (Top-Mount)</td>
<td>77</td>
</tr>
<tr>
<td>Residential Refrigerator/Freezer (Side-Mount)</td>
<td>78</td>
</tr>
<tr>
<td>Residential Refrigerator/Freezer (Bottom-Mount)</td>
<td>79</td>
</tr>
<tr>
<td>Residential Freezers (Chest)</td>
<td>83</td>
</tr>
<tr>
<td>Residential Freezers (Upright)</td>
<td>84</td>
</tr>
<tr>
<td>Residential Natural Gas Cooktops</td>
<td>87</td>
</tr>
<tr>
<td>Residential Natural Gas Ovens</td>
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</tr>
<tr>
<td>Residential Natural Gas Ranges</td>
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</tr>
<tr>
<td>Residential Electric Cooktops</td>
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<tr>
<td>Residential Electric Ovens</td>
<td>93</td>
</tr>
<tr>
<td>Residential Electric Ranges</td>
<td>94</td>
</tr>
<tr>
<td>Residential Clothes Dryers (Electric)</td>
<td>97</td>
</tr>
<tr>
<td>Residential Clothes Dryers (Gas)</td>
<td>98</td>
</tr>
<tr>
<td>Residential Clothes Washers (Front-Loading)</td>
<td>101</td>
</tr>
<tr>
<td>Residential Clothes Washers (Top-Loading)</td>
<td>102</td>
</tr>
<tr>
<td>Residential Dishwashers</td>
<td>105</td>
</tr>
</tbody>
</table>
# Table of Contents

- **Commercial Gas-Fired Furnaces** 109
- **Commercial Oil-Fired Furnaces** 112
- **Commercial Electric Resistance Heaters** 115
- **Commercial Electric Boilers** 117
- **Commercial Gas-Fired Boilers** 119
- **Commercial Oil-Fired Boilers** 122
- **Commercial Centrifugal Chillers** 125
- **Commercial Reciprocating Chillers** 127
- **Commercial Screw Chillers** 129
- **Commercial Scroll Chillers** 131
- **Commercial Gas Fired Chillers** 133
- **Commercial Rooftop Air Conditioners** 135
- **Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners** 137
- **Commercial Rooftop Heat Pumps** 139
- **Commercial Ground-Source Heat Pumps** 141
- **Packaged Terminal Air Conditioners** 143
- **Packaged Terminal Heat Pumps** 145
- **Commercial Gas-Fired Water Heater** 148
- **Commercial Electric Resistance Water Heater** 151
- **Commercial Heat Pump Water Heater** 154
- **Commercial Oil-Fired Water Heater** 156

- **Commercial Electric Booster Water Heater** 158
- **Commercial Gas-Fired Booster Water Heater** 159
- **Commercial Gas-Fired Instantaneous Water Heater** 161
- **Commercial Solar Water Heater** 164
- **Commercial Gas Range with Griddle and Oven** 167
- **Commercial Electric Range with Griddle and Oven** 168
- **Commercial Hot Food Holding Cabinet - Small** 172
- **Commercial Hot Food Holding Cabinet - Medium** 173
- **Commercial Hot Food Holding Cabinet - Large** 174

- **Data Sources** A-1
- **References** B-1
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.
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.
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. 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.
Residential Space Heating and Cooling
## Residential Gas-Fired Furnaces (North)

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<td>80</td>
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<td>1,300</td>
<td>1,080</td>
<td>1,200</td>
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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.
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.

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<tr>
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<td>80</td>
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<td>Annual Maintenance Cost (2022$)</td>
<td>40</td>
<td>120</td>
<td>130</td>
<td>130</td>
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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

- 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.
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)
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.

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<td>Typical Input Capacity (kBtu/h)</td>
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<td>105</td>
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<td>AFUE (%)</td>
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<td>83</td>
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<td>Retail Equipment Cost (2022$)</td>
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<td>6,820</td>
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<tr>
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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

- Current Federal standards:
  - $\text{AFUE} \geq 83\%$
  - $\leq 11$ watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR V. 4.1 criteria: $\text{AFUE} \geq 85\%$
- 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.
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.
### Residential Gas-Fired Boilers

<table>
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<td>AFUE (%)</td>
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<td>502</td>
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<tr>
<td>Average Life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>2,540</td>
<td>2,890</td>
<td>1,820</td>
<td>2,890</td>
<td>2,440</td>
<td>3,670</td>
</tr>
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<td>Total Installed Cost (2022$)</td>
<td>7,760</td>
<td>5,940</td>
<td>8,700</td>
<td>5,940</td>
<td>6,700</td>
<td>6,710</td>
</tr>
</tbody>
</table>

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

- 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. 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
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020¹</th>
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<th>2030²</th>
<th>2040²</th>
<th>2050²</th>
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<tbody>
<tr>
<td>Typical Input Capacity (kBtu/h)</td>
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<td>140</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>AFUE (%)</td>
<td>84</td>
<td>86</td>
<td>86</td>
<td>87</td>
<td>88</td>
<td>86</td>
</tr>
<tr>
<td>Electric Consumption (kWh/y)³</td>
<td>230</td>
<td>310</td>
<td>310</td>
<td>307</td>
<td>305</td>
<td>310</td>
</tr>
<tr>
<td>Average Life (y)⁴</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>4,850</td>
<td>3,590</td>
<td>3,590</td>
<td>3,680</td>
<td>3,770</td>
<td>3,590</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>9,800</td>
<td>5,510</td>
<td>5,510</td>
<td>5,600</td>
<td>5,690</td>
<td>5,510</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁴</td>
<td>160</td>
<td>170</td>
<td>170</td>
<td>170</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>

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.

---

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.
Residential Oil-Fired Boilers

- 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.
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

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

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

- 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

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
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<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Capacity (kBtu/h)</strong></td>
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<td>3.5</td>
<td>5.1</td>
<td>5.1</td>
<td>5.1</td>
<td>5.1</td>
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<tr>
<td><strong>Efficiency (%)</strong></td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td><strong>Average Life (y)</strong></td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<td>15</td>
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<td></td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>90</td>
<td>90</td>
<td>85</td>
<td>85</td>
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<td><strong>Total Installed Cost (2022$)</strong></td>
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<td>390</td>
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<td>320</td>
<td>1,190</td>
<td>1,190</td>
<td>1,190</td>
<td>1,190</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

- 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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installed Base</strong></td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td><strong>Installed Base</strong></td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td><strong>Current Standard</strong></td>
<td>12.5</td>
<td>13.9</td>
<td>13.0</td>
<td>14.1</td>
<td>15.0</td>
<td>17.0</td>
<td>14.1</td>
</tr>
<tr>
<td><strong>ENERGY STAR V. 5.0</strong></td>
<td>13.4</td>
<td>NA</td>
<td>16.2</td>
<td>13.4</td>
<td>15.2</td>
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<tr>
<td><strong>SEER2</strong></td>
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<td>13.4</td>
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<tr>
<td><strong>SEER2</strong></td>
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<td>11</td>
<td>11</td>
<td>11</td>
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<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Average Life (y)</strong></td>
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<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>2,410</td>
<td>2,670</td>
<td>2,580</td>
<td>2,700</td>
<td>3,110</td>
<td>3,950</td>
<td>2,680</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>4,000</td>
<td>4,300</td>
<td>5,250</td>
<td>5,320</td>
<td>5,980</td>
<td>5,980</td>
<td>5,310</td>
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<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<td>20</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
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<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

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)

## DATA

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installed Base</strong></td>
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<tr>
<td><strong>Current Standard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Typical</strong></td>
<td>36</td>
<td>36</td>
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<tr>
<td><strong>ENERGY STAR V. 5.0</strong></td>
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<td>17.0</td>
<td>15.1</td>
<td>17.0</td>
</tr>
<tr>
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<td>NA</td>
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<tr>
<td><strong>High</strong></td>
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<td>16.2</td>
<td>14.3</td>
<td>16.2</td>
<td>14.3</td>
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<tr>
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<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>2,410</td>
<td>2,760</td>
<td>2,680</td>
<td>2,850</td>
<td>3,110</td>
<td>3,950</td>
<td>3,110</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>4,000</td>
<td>4,390</td>
<td>5,310</td>
<td>5,390</td>
<td>5,520</td>
<td>5,980</td>
<td>5,520</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

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:**

Ranges represent the span of typical values for a given parameter.
Residential Central Air Conditioners

- 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.
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.
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

- 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.
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022(^1)</th>
<th>2025</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>High(^5)</td>
<td>New Standard</td>
<td>High(^5)</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)(^1)</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
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<tr>
<td>CEER(^2)</td>
<td>5.6</td>
<td>5.6</td>
<td>5.5</td>
<td>7.6</td>
<td>6.7</td>
<td>7.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>810</td>
<td>760</td>
<td>810</td>
<td>760</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)(^3)</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>810</td>
<td>760</td>
<td>810</td>
<td>760</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)(^3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

• 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)

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

• 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.
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<tr>
<td></td>
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<td>High</td>
<td>Typical</td>
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<tr>
<td>Air Flow Rate (CFM)</td>
<td>3,800</td>
<td>3,800</td>
<td>3,800</td>
<td>4,700</td>
<td>3,800</td>
<td>4,700</td>
</tr>
<tr>
<td>Power (Hp)</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
<td>1/2</td>
<td>1/3</td>
<td>1/2</td>
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<tr>
<td>Average Life (y)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
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<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>960</td>
<td>960</td>
<td>960</td>
<td>1,100</td>
<td>960</td>
<td>1,100</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>1,360</td>
<td>1,360</td>
<td>1,360</td>
<td>1,540</td>
<td>1,360</td>
<td>1,540</td>
</tr>
</tbody>
</table>

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.
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 being 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).
## Residential Air-Source Heat Pumps

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 5.0</td>
<td>High</td>
<td>New Standard</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>SEER (Cooling)³</td>
<td>13.1</td>
<td>15.3</td>
<td>14.0</td>
<td>15.3</td>
<td>15.0</td>
<td>22.6</td>
<td>15.0</td>
</tr>
<tr>
<td>SEER²</td>
<td>12.4</td>
<td>14.5</td>
<td>NA</td>
<td>14.5</td>
<td>NA</td>
<td>21.5</td>
<td>14.3</td>
</tr>
<tr>
<td>HSPF (Heating)³</td>
<td>7.9</td>
<td>8.6</td>
<td>8.2</td>
<td>8.6</td>
<td>8.5</td>
<td>12.4</td>
<td>8.8</td>
</tr>
<tr>
<td>HSPF²</td>
<td>6.7</td>
<td>7.3</td>
<td>NA</td>
<td>7.3</td>
<td>NA</td>
<td>10.6</td>
<td>7.5</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)³</td>
<td>3,290</td>
<td>4,270</td>
<td>3,970</td>
<td>4,270</td>
<td>4,110</td>
<td>6,740</td>
<td>4,110</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)³</td>
<td>5,790</td>
<td>6,880</td>
<td>6,730</td>
<td>6,880</td>
<td>6,810</td>
<td>8,620</td>
<td>6,810</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

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).

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39
Residential Air-Source Heat Pumps

• 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 H42 test
  — Percent of Heating Capacity at 5 °F ≥ 70% of that at 47 °F, with the 5 °F capacity measured per Appendix M1 H42 test and the 47 °F capacity measured as the nominal heating capacity per Appendix M1 (i.e., from the Appendix M1 H1N 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 H12 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
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

- 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

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

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 (\(\alpha\)), shape (\(\beta\)), and delay (\(\theta\)) parameters: (15.88, 2, 1).
Residential Ductless Mini-Split Air-Source Heat Pumps

• 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 3.2</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>COP (Heating)(^1)</td>
<td>3.1</td>
<td>3.7</td>
<td>3.2</td>
<td>3.6</td>
<td>3.6</td>
<td>4.5</td>
</tr>
<tr>
<td>EER (Cooling)(^2)</td>
<td>13.3</td>
<td>17.3</td>
<td>14.1</td>
<td>17.3</td>
<td>17.1</td>
<td>22.0</td>
</tr>
<tr>
<td>Average Life (y)</td>
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<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>4,650</td>
<td>5,470</td>
<td>4,820</td>
<td>5,470</td>
<td>5,410</td>
<td>6,530</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>14,060</td>
<td>14,880</td>
<td>14,230</td>
<td>14,880</td>
<td>14,880</td>
<td>15,940</td>
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<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

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 ($\alpha$), shape ($\beta$), and delay parameters: (17.04, 1.64, 1).
Residential Ground-Source Heat Pumps

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Heating COP</th>
<th>Cooling EER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed Loop</td>
<td>3.6</td>
<td>17.1</td>
</tr>
<tr>
<td>Open Loop</td>
<td>4.1</td>
<td>21.1</td>
</tr>
<tr>
<td>Direct Expansion</td>
<td>3.6</td>
<td>16</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>COP (Heating)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>COP (Cooling)</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Annual Electric Use (kWh/y)</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
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</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>12,940</td>
<td>12,940</td>
<td>12,940</td>
<td>12,940</td>
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<td>14,350</td>
<td>14,350</td>
<td>14,350</td>
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</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>14,700</td>
<td>14,700</td>
<td>14,700</td>
<td>14,700</td>
<td>14,700</td>
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<tr>
<td></td>
<td>17,290</td>
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<td>17,290</td>
<td>17,290</td>
<td>17,290</td>
<td>17,290</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

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

- 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

### DATA

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

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

- 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.
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

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

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.
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).
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.
Residential Water Heating
# Residential Gas-Fired Storage Water Heaters

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

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

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

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

- 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).
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

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

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 (\(\alpha\)), shape (\(\beta\)), and delay (\(\theta\)) parameters: (16.2, 1.70, 1).
Residential Oil-Fired Water Heaters

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

<table>
<thead>
<tr>
<th>Volume Range</th>
<th>Draw Pattern</th>
<th>Federal standard$^1$</th>
<th>Federal minimum UEF for typical sizes</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 50 gal</td>
<td>Very Small</td>
<td>UEF=0.2509-(0.0012*Gal)</td>
<td>No models on the market</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>UEF=0.533-(0.0016*Gal)</td>
<td>No models on the market</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>UEF=0.6078-(0.0016*Gal)</td>
<td>No models on the market</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>UEF=0.6815-(0.0014*Gal)</td>
<td>0.64 for a 29-gallon water heater</td>
<td>NA</td>
</tr>
</tbody>
</table>

- 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).
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installed Base</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Current Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Typical</td>
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<td>36</td>
<td>36</td>
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</tr>
<tr>
<td>High</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
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<tr>
<td>Uniform Energy Factor(^1)</td>
<td>0.88</td>
<td>0.93</td>
<td>0.92</td>
<td>0.93</td>
<td>0.92</td>
<td>0.93</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>13</td>
<td>13</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>290</td>
<td>350</td>
<td>330</td>
<td>330</td>
<td>600</td>
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<td></td>
<td>530</td>
<td>650</td>
<td>760</td>
<td>760</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>590</td>
<td>710</td>
<td>500</td>
<td>500</td>
<td>550</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>940</td>
<td>1,290</td>
<td>1,310</td>
<td>1,310</td>
<td>1,430</td>
<td>1,310</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)(^2)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

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

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

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).
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>ENERGY STAR V. 4.0</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (gal)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Uniform Energy Factor¹</td>
<td>2.05</td>
<td>3.28</td>
<td>3.33</td>
<td>3.30</td>
<td>3.73</td>
<td>3.33</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>13</td>
<td>13</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)²</td>
<td>1,290</td>
<td>1,410</td>
<td>630</td>
<td>630</td>
<td>670</td>
<td>630</td>
</tr>
<tr>
<td></td>
<td>1,650</td>
<td>1,760</td>
<td>1,440</td>
<td>1,440</td>
<td>1,670</td>
<td>1,370</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)²</td>
<td>1,710</td>
<td>1,880</td>
<td>870</td>
<td>870</td>
<td>980</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td>2,940</td>
<td>3,000</td>
<td>2,230</td>
<td>2,230</td>
<td>2,450</td>
<td>2,120</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

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.
• 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”).
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

### DATA

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>ENERGY STAR V. 4.0</td>
<td>Typical</td>
<td>Typical</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity ( (ft^2) )</td>
<td>42</td>
<td>42</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Solar Uniform Energy Factor (SUEF)</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>99.0</td>
<td>99.0</td>
<td>99.0</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>7,710</td>
<td>7,710</td>
<td>6,430</td>
<td>6,430</td>
<td>6,430</td>
<td>6,430</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>10,650</td>
<td>10,650</td>
<td>8,060</td>
<td>8,060</td>
<td>8,060</td>
<td>8,060</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Applicable Products</th>
<th>Backup Fuel</th>
<th>ENERGY STAR Requirement</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electric</td>
<td>SEF ≥ 1.8</td>
<td></td>
</tr>
</tbody>
</table>

- 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-thirds of the current solar water heater market is in the southern or western U.S. (including Hawaii). A collector area of 42 square feet (ft²) would be typical for these areas. Colder areas of the U.S. would require a larger collector (e.g., 65 ft²).

- 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

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.

Shipments of ENERGY STAR-Certified Residential Solar Water Heaters

Source: ENERGY STAR
## Residential Gas-Fired Instantaneous Water Heaters

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 4.0</td>
<td>High</td>
<td>ENERGY STAR V. 5.0</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
</tr>
<tr>
<td>Uniform Energy Factor (UEF)(^1)</td>
<td>0.81</td>
<td>0.89</td>
<td>0.81</td>
<td>0.92</td>
<td>0.87</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>1,410</td>
<td>1,180</td>
<td>430</td>
<td>580</td>
<td>580</td>
<td>610</td>
<td>610</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>2,590</td>
<td>1,760</td>
<td>920</td>
<td>1,070</td>
<td>950</td>
<td>1,090</td>
<td>1,090</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)(^2)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

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 (\(\alpha\)), shape (\(\beta\)), and delay (\(\theta\)) parameters: (21.3, 1.76, 1).
The equations for Federal Standards and the voluntary ENERGY STAR requirements, if applicable, are:

<table>
<thead>
<tr>
<th>Volume Range</th>
<th>Draw Pattern</th>
<th>Federal standard</th>
<th>Federal minimum UEF for typical sizes</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2 gal and &gt;50,000 Btu/h</td>
<td>Very Small</td>
<td>UEF=0.80</td>
<td>No models on the market</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>UEF=0.81</td>
<td>No models on the market</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>UEF=0.81</td>
<td>0.81</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>UEF=0.81</td>
<td>0.81</td>
<td>0.87</td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representitive Input Rate (kW)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Uniform Energy Factor (UEF)¹</td>
<td>0.96</td>
<td>0.96</td>
<td>0.91</td>
<td>0.96</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>260</td>
<td>260</td>
<td>260</td>
<td>260</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>520</td>
<td>520</td>
<td>520</td>
<td>520</td>
<td>520</td>
<td>520</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)²</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

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

- The Federal standards are:

<table>
<thead>
<tr>
<th>Volume Range</th>
<th>Draw Pattern</th>
<th>Federal standard</th>
<th>Federal minimum UEF for typical sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2 gal</td>
<td>Very Small</td>
<td>UEF=0.91</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>UEF=0.91</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>UEF=0.91</td>
<td>No models on the market</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>UEF=0.92</td>
<td>No models on the market</td>
</tr>
</tbody>
</table>

- 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.
Residential Appliances
## Residential Refrigerator-Freezers (Top)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 5.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (ft³)²</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Energy Consumption (kWh/y)³</td>
<td>512</td>
<td>401</td>
<td>411</td>
<td>401</td>
<td>370</td>
<td>358</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>670</td>
<td>750</td>
<td>740</td>
<td>750</td>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>670</td>
<td>750</td>
<td>740</td>
<td>750</td>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁴</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

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 (ft³). Energy consumption values for the 2020 installed base and 2022 and beyond are based on an adjusted volume of 22 ft³, 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)

<table>
<thead>
<tr>
<th>DATA¹</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 5.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (ft³)²</td>
<td>26</td>
<td>26</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Energy Consumption (kWh/y)³</td>
<td>893</td>
<td>693</td>
<td>705</td>
<td>693</td>
<td>635</td>
<td>610</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>1,400</td>
<td>1,130</td>
<td>1,130</td>
<td>1,130</td>
<td>1,160</td>
<td>1,470</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>1,400</td>
<td>1,130</td>
<td>1,130</td>
<td>1,130</td>
<td>1,160</td>
<td>1,470</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁴</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

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 ft³ 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)

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

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

- 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 \times (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-mountain 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.
<table>
<thead>
<tr>
<th>DATA¹</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (ft³)²</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Energy Consumption (kWh/y)³</td>
<td>360</td>
<td>297</td>
<td>297</td>
<td>297</td>
<td>287</td>
<td>287</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>510</td>
<td>590</td>
<td>680</td>
<td>680</td>
<td>690</td>
<td>680</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>510</td>
<td>590</td>
<td>680</td>
<td>680</td>
<td>690</td>
<td>680</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁴</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

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 ft³, which is the average adjusted volume for units with a rounded total refrigerated volume of 15 ft³ 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)

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

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>9</td>
<td>23</td>
<td>9</td>
<td>23</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Integrated Annual Energy Consumption (kBtu/y)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1,061</td>
<td>914</td>
<td>914</td>
<td>730</td>
<td>914</td>
<td>730</td>
</tr>
<tr>
<td>Cooking Efficiency (%)</td>
<td>40</td>
<td>45</td>
<td>45</td>
<td>52</td>
<td>45</td>
<td>52</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>290</td>
<td>310</td>
<td>310</td>
<td>330</td>
<td>310</td>
<td>330</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>420</td>
<td>460</td>
<td>460</td>
<td>480</td>
<td>460</td>
<td>480</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Typical Cavity Volume (ft³)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Integrated Annual Energy Consumption (kBtu/y)¹</td>
<td>2,038</td>
<td>1,960</td>
<td>1,960</td>
<td>1,831</td>
<td>1,960</td>
<td>1,831</td>
</tr>
<tr>
<td>Cooking Efficiency (%)</td>
<td>6.6</td>
<td>6.9</td>
<td>6.9</td>
<td>7.3</td>
<td>6.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)²</td>
<td>740</td>
<td>770</td>
<td>770</td>
<td>810</td>
<td>770</td>
<td>810</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)²</td>
<td>870</td>
<td>920</td>
<td>920</td>
<td>950</td>
<td>920</td>
<td>950</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
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<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Capacity of Cooktop Component (kBtu/h)</strong></td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Installed Base</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td><strong>Typical Capacity of Oven Component (kBtu/h)</strong></td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Installed Base</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td><strong>Typical Cavity Volume of Oven Component (ft³)</strong></td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Integrated Annual Energy Consumption (kBtu/y)</strong></td>
<td>3,099</td>
<td>2,874</td>
<td>2,874</td>
<td>2,561</td>
<td>2,874</td>
<td>2,561</td>
</tr>
<tr>
<td><strong>Average Life (y)</strong></td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>750</td>
<td>770</td>
<td>850</td>
<td>850</td>
<td>870</td>
<td>850</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>900</td>
<td>920</td>
<td>1,000</td>
<td>1,000</td>
<td>920</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

- 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Base</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
</tr>
<tr>
<td>Typical Capacity (W)</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
</tr>
<tr>
<td>Integrated Annual Energy Consumption (kWh/y)(^1)</td>
<td>155</td>
<td>155</td>
<td>155</td>
<td>119</td>
<td>155</td>
<td>119</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)(^2)</td>
<td>470</td>
<td>470</td>
<td>470</td>
<td>810</td>
<td>470</td>
<td>810</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)(^2)</td>
<td>620</td>
<td>620</td>
<td>620</td>
<td>1,230</td>
<td>620</td>
<td>1,230</td>
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<tr>
<td>Annual Maintenance Cost (2022$)(^3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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 (\(\alpha\)) and shape (\(\beta\)) parameters: (16.88, 6.99).
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).

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
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<tbody>
<tr>
<td><strong>Installed Base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Capacity (W)</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
</tr>
<tr>
<td><strong>Typical Cavity Volume (ft³)</strong></td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Integrated Annual Energy Consumption (kWh/y)</strong></td>
<td>355</td>
<td>355</td>
<td>355</td>
<td>278</td>
<td>355</td>
<td>278</td>
</tr>
<tr>
<td><strong>Average Life (y)</strong></td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>730</td>
<td>630</td>
<td>730</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>770</td>
<td>770</td>
<td>770</td>
<td>870</td>
<td>770</td>
<td>870</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity of Cooktop Component (W)</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
<td>3,700</td>
</tr>
<tr>
<td>Typical Capacity of Oven Component (W)</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
<td>3,400</td>
</tr>
<tr>
<td>Typical Cavity Volume of Oven Component (ft³)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
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<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Integrated Annual Energy Consumption (kWh/y)³</td>
<td>510</td>
<td>510</td>
<td>510</td>
<td>397</td>
<td>510</td>
<td>397</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)²</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>900</td>
<td>630</td>
<td>900</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)²</td>
<td>770</td>
<td>770</td>
<td>770</td>
<td>1,050</td>
<td>770</td>
<td>1,050</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
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. 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.

On February 2, 2023, DOE proposed new and amended energy conservation standards for consumer conventional cooking products.

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.
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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 1.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (ft³)</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Combined Energy Factor, D1 (lb/kWh)²</td>
<td>3.59</td>
<td>3.73</td>
<td>3.73</td>
<td>3.73</td>
<td>NA</td>
<td>3.93</td>
</tr>
<tr>
<td>Combined Energy Factor, D2 (lb/kWh)²</td>
<td>3.59</td>
<td>3.93</td>
<td>3.73</td>
<td>3.93</td>
<td>3.93</td>
<td>11.00</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>580</td>
<td>980</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>710</td>
<td>710</td>
<td>710</td>
<td>710</td>
<td>1,110</td>
<td>710</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 1.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (ft³)</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Combined Energy Factor, D1 (lb/kWh)²</td>
<td>3.18</td>
<td>3.30</td>
<td>3.30</td>
<td>3.30</td>
<td>NA</td>
<td>3.48</td>
</tr>
<tr>
<td>Combined Energy Factor, D2 (lb/kWh)²</td>
<td>3.18</td>
<td>3.48</td>
<td>3.30</td>
<td>3.48</td>
<td>3.48</td>
<td>3.50</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
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</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>660</td>
<td>670</td>
<td>660</td>
<td>670</td>
<td>670</td>
<td>670</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>860</td>
<td>870</td>
<td>870</td>
<td>870</td>
<td>870</td>
<td>870</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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)

### Notes:
- 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

- 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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installed Base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
<td>3.7</td>
<td>4.1</td>
<td>3.4</td>
<td>4.5</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td><em>High</em></td>
<td>4.5</td>
<td>5.0</td>
<td>4.5</td>
<td>5.0</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Current Standard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
<td>3.4</td>
<td>4.1</td>
<td>4.5</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td><em>High</em></td>
<td>4.5</td>
<td>5.0</td>
<td>4.5</td>
<td>5.0</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>ENERGY STAR V. 8.1</strong></td>
<td></td>
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<tr>
<td><em>Typical</em></td>
<td>3.10</td>
<td>2.76</td>
<td>2.76</td>
<td>2.76</td>
<td>2.76</td>
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</tr>
<tr>
<td><em>High</em></td>
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<td>2.76</td>
<td>2.76</td>
<td>2.76</td>
<td>2.76</td>
<td>2.76</td>
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<tr>
<td><strong>Integrated Modified Energy Factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ft³/kWh/cycle)</td>
<td>2.16</td>
<td>2.76</td>
<td>1.84</td>
<td>2.76</td>
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<tr>
<td><strong>Integrated Water Factor</strong></td>
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</tr>
<tr>
<td>(gal/cycle/ft³)</td>
<td>4.7</td>
<td>3.2</td>
<td>4.7</td>
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<td><strong>Average Life (y)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
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<td>6</td>
<td>6</td>
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<td>6</td>
</tr>
<tr>
<td><em>High</em></td>
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<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td><strong>Water Consumption (gal/cycle)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
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<td><em>High</em></td>
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<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
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<tr>
<td><strong>Hot Water Energy (kWh/cycle)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
<td>0.21</td>
<td>0.17</td>
<td>0.36</td>
<td>0.12</td>
<td>0.12</td>
<td>0.13</td>
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<tr>
<td><em>High</em></td>
<td>0.12</td>
<td>0.13</td>
<td>0.12</td>
<td>0.13</td>
<td>0.12</td>
<td>0.13</td>
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<tr>
<td><strong>Machine Energy (kWh/cycle)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
<td>0.17</td>
<td>0.14</td>
<td>0.15</td>
<td>0.12</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td><em>High</em></td>
<td>0.12</td>
<td>0.17</td>
<td>0.12</td>
<td>0.17</td>
<td>0.12</td>
<td>0.17</td>
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<tr>
<td><strong>Dryer Energy (kWh/cycle)</strong></td>
<td></td>
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<td><em>Typical</em></td>
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<td>1.56</td>
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<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td></td>
<td></td>
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<tr>
<td><em>Typical</em></td>
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<td>1,000</td>
<td>705</td>
<td>930</td>
<td>930</td>
<td>950</td>
</tr>
<tr>
<td><em>High</em></td>
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<td>930</td>
<td>930</td>
<td>930</td>
<td>930</td>
<td>930</td>
</tr>
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<td><strong>Total Installed Cost (2022$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>Typical</em></td>
<td>915</td>
<td>1,175</td>
<td>880</td>
<td>1,130</td>
<td>1,130</td>
<td>1,150</td>
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<tr>
<td><em>High</em></td>
<td>1,130</td>
<td>1,150</td>
<td>1,130</td>
<td>1,150</td>
<td>1,130</td>
<td>1,150</td>
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<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Typical</em></td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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</tr>
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</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 8.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Capacity (ft³)</td>
<td>3.3</td>
<td>3.4</td>
<td>3.5</td>
<td>3.5</td>
<td>4.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Integrated Modified Energy Factor (ft³/kWh/cycle)</td>
<td>1.14</td>
<td>1.57</td>
<td>1.57</td>
<td>1.57</td>
<td>2.06</td>
<td>2.76</td>
</tr>
<tr>
<td>Integrated Water Factor (gal/cycle/ft³)</td>
<td>9.2</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
<td>4.3</td>
<td>3.2</td>
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<tr>
<td>Average Life (y)</td>
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<td></td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Water Consumption (gal/cycle)</td>
<td>30</td>
<td>22</td>
<td>23</td>
<td>23</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Hot Water Energy (kWh/cycle)</td>
<td>0.90</td>
<td>0.39</td>
<td>0.41</td>
<td>0.41</td>
<td>0.38</td>
<td>0.24</td>
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<tr>
<td>Machine Energy (kWh/cycle)</td>
<td>0.25</td>
<td>0.13</td>
<td>0.14</td>
<td>0.14</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Dryer Energy (kWh/cycle)</td>
<td>1.73</td>
<td>1.63</td>
<td>1.68</td>
<td>1.68</td>
<td>1.64</td>
<td>1.61</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>590</td>
<td>590</td>
<td>520</td>
<td>520</td>
<td>640</td>
<td>725</td>
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<tr>
<td>Total Installed Cost (2022$)</td>
<td>765</td>
<td>765</td>
<td>715</td>
<td>715</td>
<td>840</td>
<td>920</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<td>15</td>
</tr>
</tbody>
</table>

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

• 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\(^3\)):

<table>
<thead>
<tr>
<th></th>
<th>Integrated Modified Energy Factor</th>
<th>Integrated Water Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top-Loading</td>
<td>Front-Loading</td>
</tr>
<tr>
<td>Current DOE Standard</td>
<td>≥ 1.57</td>
<td>≥ 1.84</td>
</tr>
<tr>
<td>(effective 1/1/2018)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current ENERGY STAR V. 8.1</td>
<td>≥ 2.06</td>
<td>≥ 2.76</td>
</tr>
<tr>
<td>(effective 4/22/2021)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• 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

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

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

- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year):
  - Federal Standards:
  - 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
Commercial Space Heating and Cooling
## Commercial Gas-Fired Furnaces

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2023&lt;sup&gt;3&lt;/sup&gt;</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>High</td>
<td>New Standard</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Input Capacity (kBtu/h)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>400</td>
<td>400</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Thermal Efficiency (%)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>Typical Output Capacity (kBtu/h)</td>
<td>320</td>
<td>320</td>
<td>200</td>
<td>203</td>
<td>203</td>
<td>203</td>
<td>203</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
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<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>1,230</td>
<td>1,230</td>
<td>1,230</td>
<td>1,260</td>
<td>1,260</td>
<td>1,260</td>
<td>1,260</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>2,540</td>
<td>2,540</td>
<td>2,540</td>
<td>2,580</td>
<td>2,580</td>
<td>2,580</td>
<td>2,580</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
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<td>8</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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

• 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.
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2023(^1)</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>High</td>
<td>New Standard</td>
<td>Typical</td>
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<tr>
<td>Typical Input Capacity (kBtu/h)</td>
<td>400</td>
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<td>250</td>
<td>250</td>
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<td>250</td>
</tr>
<tr>
<td>Thermal Efficiency (%)(^2)</td>
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<td>81</td>
<td>82</td>
<td>85</td>
<td>82</td>
<td>85</td>
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<tr>
<td>Typical Output Capacity (kBtu/h)</td>
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<td>Average Life (y)</td>
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<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
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<td>5,560</td>
<td>5,500</td>
<td>6,020</td>
<td>5,560</td>
<td>5,560</td>
<td>6,020</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>7,740</td>
<td>7,810</td>
<td>7,740</td>
<td>8,380</td>
<td>7,810</td>
<td>7,810</td>
<td>8,380</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>24</td>
<td>24</td>
<td>38</td>
<td>39</td>
<td>38</td>
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<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>370</td>
<td>360</td>
<td>360</td>
<td>370</td>
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<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<td>2</td>
</tr>
</tbody>
</table>

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:**
Commercial Oil-Fired Furnaces

- 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.
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

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

1. Capacity is output.
2. Annual Maintenance Cost is negligible.
Commercial Electric Resistance Heaters

- 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>Typical</td>
<td>Typical</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (kW)(^1)</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)(^2)</td>
<td>11,620</td>
<td>11,590</td>
<td>9,790</td>
<td>9,790</td>
<td>9,790</td>
<td>9,790</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)(^2)</td>
<td>17,500</td>
<td>13,820</td>
<td>11,950</td>
<td>11,950</td>
<td>11,950</td>
<td>11,950</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>31</td>
<td>25</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)(^2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1. Capacity is output.
2. Retail and installed costs for 2022 and forecasts for 2030 and beyond are based on Gordan’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

- 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>High</td>
<td>New Standard</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Input Capacity (kBtu/h)</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Thermal Efficiency (%)</td>
<td>77</td>
<td>85</td>
<td>80</td>
<td>85</td>
<td>99</td>
<td>84</td>
<td>85</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>40</td>
<td>56</td>
<td>48</td>
<td>56</td>
<td>70</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>1,710</td>
<td>2,100</td>
<td>2,100</td>
<td>2,100</td>
<td>2,140</td>
<td>2,100</td>
<td>2,100</td>
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<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

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 use 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.

Commercial Gas-Fired Boilers

- 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.

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

### DATA

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

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 use 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:**
Commercial Oil-Fired Boilers

- 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.
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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012 Installed Base</th>
<th>2018 Installed Base</th>
<th>ASHRAE 90.1-2019 Typical</th>
<th>2022(^2) Typical</th>
<th>2030 High</th>
<th>2040 High</th>
<th>2050 High</th>
<th>2030 High</th>
<th>2040 High</th>
<th>2050 High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Capacity (tons)(^1)</td>
<td>400</td>
<td>400</td>
<td>400</td>
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<td>600</td>
<td>600</td>
<td>600</td>
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</tr>
<tr>
<td>Efficiency [full-load] (kW/ton)</td>
<td>0.66</td>
<td>0.53</td>
<td>0.56</td>
<td>0.52</td>
<td>0.45</td>
<td>0.49</td>
<td>0.42</td>
<td>0.46</td>
<td>0.41</td>
<td>0.45</td>
</tr>
<tr>
<td>Efficiency [IPLV] (kW/ton)</td>
<td>0.61</td>
<td>0.37</td>
<td>0.50</td>
<td>0.31</td>
<td>0.30</td>
<td>0.30</td>
<td>0.28</td>
<td>0.29</td>
<td>0.26</td>
<td>0.28</td>
</tr>
<tr>
<td>COP [full-load]</td>
<td>5.4</td>
<td>6.6</td>
<td>6.3</td>
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<td>7.8</td>
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<td>8.4</td>
<td>7.6</td>
<td>8.6</td>
<td>7.8</td>
</tr>
<tr>
<td>COP [IPLV]</td>
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<td>7.0</td>
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<tr>
<td>Retail Equipment Cost (2022$/ton)</td>
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<td>680</td>
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<td>Total Installed Cost (2022$/kBtu/h)</td>
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<td>69</td>
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<td>Annual Maintenance Cost (2022$/ton)</td>
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<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
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<td>3</td>
<td>3</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

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)

- 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


- 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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>ASHRAE 90.1-2019</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (tons)(^1)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Efficiency [full-load] (kW/ton)</td>
<td>1.26</td>
<td>1.19</td>
<td>1.19</td>
<td>1.15</td>
<td>1.00</td>
<td>1.15</td>
</tr>
<tr>
<td>Efficiency [IPLV] (kW/ton)</td>
<td>1.13</td>
<td>0.86</td>
<td>0.86</td>
<td>0.80</td>
<td>0.79</td>
<td>0.80</td>
</tr>
<tr>
<td>COP [full-load]</td>
<td>2.8</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.1</td>
</tr>
<tr>
<td>COP [IPLV]</td>
<td>3.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$/ton)</td>
<td>725</td>
<td>820</td>
<td>820</td>
<td>820</td>
<td>1,030</td>
<td>820</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/ton)</td>
<td>800</td>
<td>880</td>
<td>880</td>
<td>880</td>
<td>1,180</td>
<td>880</td>
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<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>63</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>95</td>
<td>68</td>
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<tr>
<td>Annual Maintenance Cost (2022$/ton)</td>
<td>45</td>
<td>45</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

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.
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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>ASHRAE 90.1-2019</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (tons)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Efficiency [full-load] (kW/ton)</td>
<td>1.26</td>
<td>1.18</td>
<td>1.19</td>
<td>1.15</td>
<td>0.92</td>
<td>1.13</td>
</tr>
<tr>
<td>Efficiency [IPLV] (kW/ton)</td>
<td>1.13</td>
<td>0.84</td>
<td>0.86</td>
<td>0.81</td>
<td>0.55</td>
<td>0.79</td>
</tr>
<tr>
<td>COP [full-load]</td>
<td>2.8</td>
<td>3.0</td>
<td>3.0</td>
<td>3.1</td>
<td>3.8</td>
<td>3.1</td>
</tr>
<tr>
<td>COP [IPLV]</td>
<td>3.1</td>
<td>4.2</td>
<td>4.1</td>
<td>4.4</td>
<td>6.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$/ton)</td>
<td>760</td>
<td>970</td>
<td>1,130</td>
<td>1,130</td>
<td>1,230</td>
<td>1,140</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/ton)</td>
<td>820</td>
<td>850</td>
<td>770</td>
<td>770</td>
<td>870</td>
<td>780</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>73</td>
<td>87</td>
<td>86</td>
<td>86</td>
<td>95</td>
<td>87</td>
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<tr>
<td>Annual Maintenance Cost (2022$/ton)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

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)

- 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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>ASHRAE 90.1-2019</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (tons)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Efficiency [full-load] (kW/ton)</td>
<td>1.23</td>
<td>1.16</td>
<td>1.19</td>
<td>1.15</td>
<td>1.07</td>
<td>1.11</td>
</tr>
<tr>
<td>Efficiency [IPLV] (kW/ton)</td>
<td>0.99</td>
<td>0.77</td>
<td>0.88</td>
<td>0.77</td>
<td>0.70</td>
<td>0.73</td>
</tr>
<tr>
<td>COP [full-load]</td>
<td>2.9</td>
<td>3.0</td>
<td>3.0</td>
<td>3.1</td>
<td>3.3</td>
<td>3.2</td>
</tr>
<tr>
<td>COP [IPLV]</td>
<td>3.7</td>
<td>4.6</td>
<td>4.0</td>
<td>4.6</td>
<td>5.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$/ton)</td>
<td>680</td>
<td>1,000</td>
<td>1,060</td>
<td>1,060</td>
<td>1,160</td>
<td>1,120</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/ton)</td>
<td>970</td>
<td>1,210</td>
<td>1,170</td>
<td>1,170</td>
<td>1,270</td>
<td>1,230</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>76</td>
<td>91</td>
<td>85</td>
<td>85</td>
<td>93</td>
<td>90</td>
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<tr>
<td>Annual Maintenance Cost (2022$/ton)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>4</td>
</tr>
</tbody>
</table>

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.
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)

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Capacity (tons)1</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>COP [full-load]</td>
<td>1.1</td>
<td>1.7</td>
<td>1.7</td>
<td>1.0</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>COP [IPLV]</td>
<td>NA</td>
<td>NA</td>
<td>1.6</td>
<td>2.6</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$/ton)</td>
<td>1,060</td>
<td>1,000</td>
<td>1,060</td>
<td>1,000</td>
<td>1,200</td>
<td>1,000</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/ton)</td>
<td>1,290</td>
<td>1,240</td>
<td>1,180</td>
<td>1,240</td>
<td>1,110</td>
<td>1,240</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>95</td>
<td>93</td>
<td>91</td>
<td>93</td>
<td>82</td>
<td>93</td>
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<tr>
<td>Annual Maintenance Cost (2022$/ton)</td>
<td>40</td>
<td>60</td>
<td>40</td>
<td>60</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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)

- 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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Output Capacity (kBtu/h)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Part Load Efficiency (IEER)</td>
<td>12.4</td>
<td>12.9</td>
<td>12.9</td>
<td>14.0</td>
<td>23.3</td>
<td>14.8</td>
<td>14.8</td>
</tr>
<tr>
<td>Efficiency (EER)</td>
<td>10.6</td>
<td>11.5</td>
<td>11.5</td>
<td>12.2</td>
<td>12.8</td>
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<td>12.8</td>
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<tr>
<td>Efficiency Conversion</td>
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<td>3.8</td>
<td>4.1</td>
<td>6.8</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>7,760</td>
<td>8,280</td>
<td>8,280</td>
<td>9,090</td>
<td>12,210</td>
<td>9,490</td>
<td>10,340</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>10,350</td>
<td>11,870</td>
<td>11,870</td>
<td>13,020</td>
<td>17,600</td>
<td>13,560</td>
<td>14,970</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>115</td>
<td>132</td>
<td>132</td>
<td>145</td>
<td>196</td>
<td>151</td>
<td>166</td>
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<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>370</td>
<td>370</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

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.
• Air-Cooled Commercial Packaged Air Conditioners

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

• 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

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

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.
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR V. 3.1</td>
<td>High</td>
<td>New Standard</td>
</tr>
<tr>
<td>Typical Capacity (kBtu/h)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Part Load Efficiency (IEER)</td>
<td>12.0</td>
<td>11.3</td>
<td>12.2</td>
<td>14.3</td>
<td>12.8</td>
<td>20.3</td>
<td>14.1</td>
</tr>
<tr>
<td>EER</td>
<td>10.2</td>
<td>11.2</td>
<td>11.3</td>
<td>11.5</td>
<td>11.8</td>
<td>13.0</td>
<td>12.0</td>
</tr>
<tr>
<td>COP (Heating)</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
<td>3.4</td>
<td>3.4</td>
<td>3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td>7,490</td>
<td>7,490</td>
<td>9,000</td>
<td>10,250</td>
<td>9,380</td>
<td>12,920</td>
<td>10,160</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>9,350</td>
<td>9,350</td>
<td>12,900</td>
<td>14,940</td>
<td>13,530</td>
<td>18,860</td>
<td>14,810</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>104</td>
<td>104</td>
<td>143</td>
<td>166</td>
<td>150</td>
<td>210</td>
<td>165</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

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

- Air-Cooled Commercial Packaged Heat Pumps

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

- 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

### DATA

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installed Base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Installed Base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Standard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Typical Capacity (kBtu/h)</strong></td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td><strong>COP (Heating)</strong></td>
<td>3.1</td>
<td>3.7</td>
<td>3.2</td>
<td>3.5</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>EER (Cooling)</strong></td>
<td>12.7</td>
<td>17.4</td>
<td>14.1</td>
<td>17.0</td>
<td>21.6</td>
<td>17.0</td>
</tr>
<tr>
<td><strong>Average Life (y)</strong></td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>10,470</td>
<td>6,470</td>
<td>5,590</td>
<td>6,470</td>
<td>7,880</td>
<td>6,470</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>19,760</td>
<td>18,230</td>
<td>17,350</td>
<td>18,230</td>
<td>19,650</td>
<td>18,230</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$/kBtu/h)</strong></td>
<td>673</td>
<td>466</td>
<td>447</td>
<td>466</td>
<td>495</td>
<td>466</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$/kBtu/h)</strong></td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

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.
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

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

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

- 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.

<table>
<thead>
<tr>
<th>Cooling Capacity (kBtu/h)</th>
<th>Equipment Size</th>
<th>Equipment Class</th>
<th>Federal Standard EER</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTAC</td>
<td>Standard</td>
<td>&lt; 7000</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥7000 Btu/h and ≤15,000 Btu/h</td>
<td>14.0 – (0.3 x Cap)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 15,000 Btu/h</td>
<td>9.5</td>
</tr>
</tbody>
</table>
## Packaged Terminal Heat Pumps

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

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.

<table>
<thead>
<tr>
<th>Cooling Capacity (kBtu/h)</th>
<th>Equipment Size</th>
<th>Equipment Class</th>
<th>Federal Standard EER</th>
<th>Federal Standard COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTHP</td>
<td>Standard</td>
<td>&lt; 7000</td>
<td>11.9</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥7,000 Btu/h and ≤15,000 Btu/h</td>
<td>14.0 – (0.3 x Cap)</td>
<td>3.7 – (0.052 x Cap)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 15,000 Btu/h</td>
<td>9.5</td>
<td>2.9</td>
</tr>
<tr>
<td>PTHP</td>
<td>Non-Standard</td>
<td>&lt; 7000</td>
<td>9.3</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥7,000 Btu/h and ≤15,000 Btu/h</td>
<td>10.8 – (0.213 x Cap)</td>
<td>2.9 – (0.026 x Cap)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 15,000 Btu/h</td>
<td>7.6</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Commercial Water Heating
## Final Commercial Gas-Fired Storage Water Heaters

### DATA

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
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<tbody>
<tr>
<td><strong>Installed Base</strong></td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Typical</strong></td>
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<td>100</td>
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<tr>
<td><strong>ENERGY STAR V. 2.0</strong></td>
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<tr>
<td><strong>Typical</strong></td>
<td>81</td>
<td>82</td>
<td>80</td>
<td>94</td>
<td>99</td>
<td>95</td>
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<tr>
<td><strong>High</strong></td>
<td>99</td>
<td>99</td>
<td>95</td>
<td>99</td>
<td>95</td>
<td>99</td>
</tr>
<tr>
<td><strong>Typical Storage Capacity (gal)</strong></td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Typical Input Capacity (kBtu/h)</strong></td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>199</td>
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<tr>
<td><strong>Thermal Efficiency (%)</strong></td>
<td>81</td>
<td>82</td>
<td>80</td>
<td>94</td>
<td>99</td>
<td>95</td>
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<tr>
<td><strong>Average Life (y)</strong></td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Retail Equipment Cost (2022$)</strong></td>
<td>3,870</td>
<td>3,890</td>
<td>3,850</td>
<td>4,180</td>
<td>4,290</td>
<td>4,200</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>5,170</td>
<td>5,200</td>
<td>5,140</td>
<td>5,530</td>
<td>5,650</td>
<td>5,550</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$/kBtu/h)</strong></td>
<td>42</td>
<td>42</td>
<td>43</td>
<td>42</td>
<td>41</td>
<td>39</td>
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<tr>
<td><strong>Annual Maintenance Cost (2022$/kBtu/h)</strong></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

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

- Input capacity > 155 kBtu/h and storage capacity ≤ 140 gal
- Federal standard:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): \(\text{Input Rate}/800 + 110 \times (\text{Rated Volume})^{1/2}\)
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss (Btu/h): \(0.84 \times [(\text{Input Rate}/800) + 110 \times (\text{Rated Volume})^{1/2}]\)
- 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

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

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

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

- 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.
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

<table>
<thead>
<tr>
<th>Data</th>
<th>2012 Installed Base</th>
<th>2018 Installed Base</th>
<th>2022 Typical</th>
<th>2022 ENERGY STAR V. 2.0 Typical</th>
<th>2030 Typical</th>
<th>2040 Typical</th>
<th>2050 Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Flow Rate (gal/min)</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
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<tr>
<td>Typical Output Capacity (kW)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Typical Output Capacity (kBtu/h)</td>
<td>171</td>
<td>171</td>
<td>171</td>
<td>171</td>
<td>171</td>
<td>171</td>
<td>171</td>
</tr>
<tr>
<td>Coefficient of Performance (COPₜ)</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>3.0</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<tr>
<td>Total Installed Cost (2022$)</td>
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<td>59,940</td>
<td>59,940</td>
<td>59,940</td>
<td>59,940</td>
<td>59,940</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>351</td>
<td>351</td>
<td>351</td>
<td>351</td>
<td>351</td>
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<tr>
<td>Annual Maintenance Cost (2022$)</td>
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<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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.
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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>High</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Storage Capacity (gal)</td>
<td>70</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Typical Input Capacity (kBtu/h)</td>
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<td>300</td>
<td>300</td>
<td>300</td>
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<td>300</td>
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<tr>
<td>Thermal Efficiency (%)</td>
<td>79</td>
<td>81</td>
<td>80</td>
<td>81</td>
<td>82</td>
<td>81</td>
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<tr>
<td>Average Life (y)</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
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<td>5,470</td>
<td>5,470</td>
<td>5,470</td>
<td>5,470</td>
<td>5,470</td>
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<tr>
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<td>6,120</td>
<td>6,120</td>
<td>6,120</td>
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<tr>
<td>Annual Maintenance Cost (2022$)</td>
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<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
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<tr>
<td>Annual Maintenance Cost (2022$/kBtu)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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

- 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

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

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>Typical</td>
<td>Typical</td>
</tr>
<tr>
<td>Typical Capacity (gal)</td>
<td>3</td>
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<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Typical Output Capacity (kBtu/h)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Thermal Efficiency (%)</td>
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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

- 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

#### DATA

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</table>

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

- 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.
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
### DATA

<table>
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<tr>
<th></th>
<th>2012</th>
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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.

**Notes:**
- 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

- 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

### DATA

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</tbody>
</table>

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

**DATA**

<table>
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<th>2022</th>
<th>2023</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Typical</td>
<td>ENERGY STAR V. 2.2</td>
<td>High</td>
<td>ENERGY STAR V. 3.0</td>
<td>Typical</td>
</tr>
<tr>
<td><strong>Griddle - Cooking Energy Efficiency (%)</strong></td>
<td>65</td>
<td>70</td>
<td>72</td>
<td>70</td>
<td>91</td>
<td>NA</td>
<td>72</td>
</tr>
<tr>
<td><strong>Oven - Cooking Energy Efficiency (%)</strong></td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>71</td>
<td>86</td>
<td>76</td>
<td>65</td>
</tr>
<tr>
<td><strong>Range - Cooking Energy Efficiency (%)</strong></td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>NA</td>
<td>87</td>
<td>NA</td>
<td>75</td>
</tr>
<tr>
<td><strong>Combined Energy Efficiency (%)</strong></td>
<td>69</td>
<td>71</td>
<td>71</td>
<td>NA</td>
<td>88</td>
<td>NA</td>
<td>71</td>
</tr>
<tr>
<td><strong>Griddle - Normalized Idle Energy Rate (kW/ft²)</strong></td>
<td>0.44</td>
<td>0.34</td>
<td>0.30</td>
<td>0.32</td>
<td>0.21</td>
<td>NA</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>Oven - Idle Energy Rate (kW)</strong></td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.6</td>
<td>0.6</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Range - Idle Energy Rate (kW)</strong></td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Combined Idle Energy Rate (kW)</strong></td>
<td>1.7</td>
<td>1.4</td>
<td>1.3</td>
<td>1.4</td>
<td>0.8</td>
<td>NA</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Average Life (y)</strong></td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$)</strong></td>
<td>11,410</td>
<td>11,410</td>
<td>11,410</td>
<td>11,410</td>
<td>11,410</td>
<td>11,410</td>
<td>11,410</td>
</tr>
<tr>
<td><strong>Total Installed Cost (2022$/kBtu/h)</strong></td>
<td>2,019</td>
<td>2,362</td>
<td>2,533</td>
<td>2,375</td>
<td>4,423</td>
<td>NA</td>
<td>2,533</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$)</strong></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Annual Maintenance Cost (2022$/kBtu/h)</strong></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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.
• 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.

<table>
<thead>
<tr>
<th>Product</th>
<th>ENERGY STAR V. 2.2 Requirements</th>
<th>Gas</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Griddle</td>
<td>Cooking Energy Efficiency</td>
<td>≥ 38%</td>
<td>≥ 70%</td>
</tr>
<tr>
<td></td>
<td>Normalized Idle Energy Rate</td>
<td>≤ 2,650 Btu/h per ft²</td>
<td>≤ 0.320 kW per ft²</td>
</tr>
<tr>
<td>Oven</td>
<td>Cooking Energy Efficiency</td>
<td>≥ 46%</td>
<td>≥ 71%</td>
</tr>
</tbody>
</table>
|         | 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

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

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>State Standards</td>
<td>Typical</td>
<td>ENERGY STAR V. 2.0</td>
<td>High</td>
</tr>
<tr>
<td>Interior Volume (ft$^3$)$^1$</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Maximum Idle Energy Rate (W)$^2$</td>
<td>312</td>
<td>312</td>
<td>312</td>
<td>312</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>Annual Energy Use (kWh/y)$^3$</td>
<td>1,025</td>
<td>1,025</td>
<td>1,025</td>
<td>1,025</td>
<td>552</td>
<td>552</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)$</td>
<td>8,016</td>
<td>8,016</td>
<td>8,016</td>
<td>8,016</td>
<td>17,677</td>
<td>17,677</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>2012</th>
<th>2018</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior Volume (ft³)¹</td>
<td>21.4</td>
<td>21.4</td>
<td>22.4</td>
<td>22.4</td>
<td>22.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Maximum Idle Energy Rate (W)²</td>
<td>900</td>
<td>856</td>
<td>896</td>
<td>299</td>
<td>298</td>
<td>298</td>
</tr>
<tr>
<td>Annual Energy Use (kWh/y)³</td>
<td>2,957</td>
<td>2,812</td>
<td>2,943</td>
<td>982</td>
<td>979</td>
<td>979</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)⁴</td>
<td>2,940</td>
<td>4,530</td>
<td>4,600</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)⁵</td>
<td>2,940</td>
<td>4,530</td>
<td>4,600</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>2,553</td>
<td>4,136</td>
<td>4,012</td>
<td>13,078</td>
<td>13,113</td>
<td>4,012</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁶</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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 ft³ to 28 ft³. For the medium size class, the interior volume increase from 21.4 ft³ to 22.4 ft³ 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 ft³ 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 ft³ 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, and Vermont) 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

<table>
<thead>
<tr>
<th>DATA</th>
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<th>2022</th>
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<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>State Standards</td>
<td>Typical</td>
<td>ENERGY STAR V. 2.0</td>
<td>High</td>
</tr>
<tr>
<td>Interior Volume (ft³)¹</td>
<td>44.0</td>
<td>44.0</td>
<td>44.0</td>
<td>44.0</td>
<td>44.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Maximum Idle Energy Rate (W)²</td>
<td>1,333</td>
<td>1,333</td>
<td>1,760</td>
<td>1,333</td>
<td>400</td>
<td>310</td>
</tr>
<tr>
<td>Annual Energy Use (kWh/y)³</td>
<td>4,380</td>
<td>4,380</td>
<td>5,782</td>
<td>4,380</td>
<td>1,314</td>
<td>1,018</td>
</tr>
<tr>
<td>Average Life (y)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)⁴</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Total Installed Cost (2022$)⁵</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Total Installed Cost (2022$/kBtu/h)</td>
<td>3,224</td>
<td>3,224</td>
<td>2,442</td>
<td>3,224</td>
<td>11,723</td>
<td>15,126</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)⁶</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$/kBtu/h)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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 ft³. 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 ft³ 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

- 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.
- 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 ≤ \(V\) < 28:
  - State standards: ≤ 40 \(\times V\) (baseline)
  - ENERGY STAR V. 2.0: ≤ 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 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
Residential Space Heating and Cooling
## Residential Gas-Fired Furnaces (North)

<table>
<thead>
<tr>
<th>SOURCES</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR (North) V. 4.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Input Capacity (kBtu/h)</td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFUE (%)</td>
<td>CFR</td>
<td>DOE CCD</td>
<td>ENERGY STAR V. 4.1</td>
<td>DOE CCD</td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
</tr>
<tr>
<td>Electric Consumption (kWh/y)</td>
<td>Residential Furnaces EERE 2016</td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Life (y)</td>
<td></td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail Equipment Cost (2022$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Installed Cost (2022$)</td>
<td>Residential Furnaces EERE 2016</td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Maintenance Cost (2022$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Residential Gas-Fired Furnaces (Rest of Country)

<table>
<thead>
<tr>
<th>SOURCES</th>
<th>2015</th>
<th>2020</th>
<th>2022</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Installed Base</td>
<td>Installed Base</td>
<td>Current Standard</td>
<td>Typical</td>
<td>ENERGY STAR (ROC) V. 4.1</td>
<td>High</td>
</tr>
<tr>
<td>Typical Input Capacity (kBtu/h)</td>
<td></td>
<td></td>
<td></td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFUE (%)</td>
<td>CFR</td>
<td>DOE CCD</td>
<td>ENERGY STAR V. 4.1</td>
<td>DOE CCD</td>
<td>Residential Furnaces EERE 2022 NOPR</td>
<td></td>
</tr>
<tr>
<td>Electric Consumption (kWh/y)</td>
<td>Residential Furnaces EERE 2016</td>
<td></td>
<td>Residential Furnaces EERE 2022 NOPR</td>
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## Residential Electric Resistance Furnaces

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### Typical Capacity (kBtu/h)
- Distributors
- RAC EERE 2022 NOPR

### CEER (Btu/Wh)
- Guidehouse
- CFR
- DOE CCD
- ENERGY STAR V. 4.2
- DOE CCD
- RAC EERE 2022 NOPR
- DOE CCD
- RAC EERE 2022 NOPR
- DOE CCD
- RAC EERE 2022 NOPR
- DOE CCD

### Average Life (y)

### Retail Equipment Cost (2022$)
- RAC EERE 2011
- RAC EERE 2022 NOPR

### Total Installed Cost (2022$)

### Annual Maintenance Cost (2022$)
## Residential Portable Air Conditioners

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### Typical Capacity (kBtu/h)

- **CEER**

### Average Life (y)

### Retail Equipment Cost (2022$)

### Total Installed Cost (2022$)

### Annual Maintenance Cost (2022$)

PAC EERE 2020/Guidehouse
## Residential Swamp Coolers

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## Residential Air-Source Heat Pumps

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Guidehouse
## Residential Ductless Mini-Split Air-Source Heat Pumps

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- **AHRI/Guidehouse**
- **Guidehouse**
- **CACs and HPs EERE 2016 Direct Final Rule**
- **Gordian’s RSMeans Data – Building Construction Costs 2023 / Guidehouse**
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- Product Literature

**Guidehouse**
- COP (Cooling)
- Annual Electric Use (kWh/y)
- Average Life (y)
- Retail Equipment Cost (2022$)
- Total Installed Cost (2022$)
- Annual Maintenance Cost (2022$)

**PERC**
- Retail Equipment Cost (2022$)
## Residential Cordwood Stoves

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# Residential Wood Pellet Stoves

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Residential Water Heating
## Residential Gas-Fired Storage Water Heaters

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# Residential Solar Water Heaters

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- **Typical Capacity (sq. ft.)**
  - SRCC / Guidehouse
  - ENERGY STAR

- **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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## Residential Electric Instantaneous Water Heaters

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- **Typical Capacity (kBtu/h)**: CWH EERE 2022 Preliminary Analysis
- **Uniform Energy Factor**: CWH EERE 2022 Preliminary Analysis/DOE CCD
- **Average Life (y)**: Guidehouse
- **Retail Equipment Cost (2022$)**: Gordian’s RSMeans Data – Building Construction Costs 2023
- **Total Installed Cost (2022$)**
- **Annual Maintenance Cost (2022$)**: Guidehouse
Residential Appliances
# Residential Refrigerator-Freezers (Top)

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- Typical Capacity (ft³)
  - RF EERE 2021 Preliminary Analysis / Guidehouse

- Energy Consumption (kWh/y)
  - DOE CCD/ Guidehouse
  - CFR
  - DOE CCD
  - ENERGY STAR
  - DOE CCD

- Average Life (y)
- Retail Equipment Cost (2022$)
- Total Installed Cost (2022$)
- Annual Maintenance Cost (2022$)

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### Typical Capacity (ft³)

- 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 2011 / Guidehouse

### Retail Equipment Cost (2022$)

### Total Installed Cost (2022$)

### Annual Maintenance Cost (2022$)
# Residential Freezers (Chest)

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**Return to Table of Contents**
# Residential Natural Gas Cooktops

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**Sources:**
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- Guidehouse / Consumer Cooking Products EERE 2020 NOPD
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# Residential Electric Cooktops

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| **Retail Equipment Cost (2022$)**            | Guidehouse / Consumer Cooking Products EERE 2016 SNOPR |
| **Total Installed Cost (2022$)**             | Guidehouse / Consumer Cooking Products EERE 2016 SNOPR |
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- Guidehouse

**Retail Equipment Cost (2022$)**
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**Annual Maintenance Cost (2022$)**
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Commercial Space Heating and Cooling
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## Commercial Oil-Fired Furnaces

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- **Typical Input Capacity (kBtu/h)**: Guidehouse
- **Thermal Efficiency (%)**: ASHRAE Standard 90.1-2004 / Guidehouse
- **Average Life (y)**: Comm. Heating, AC, WH EERE 2009
- **Retail Equipment Cost (2022$)**: EIA Technology Forecast Updates (2018)
- **Total Installed Cost (2022$)**: Comm. Packaged Boilers EERE 2020
- **Total Installed Cost (2022$/kBtu/h)**: Comm. Packaged Boilers EERE 2020
- **Annual Maintenance Cost (2022$)**: Comm. Heating, AC, WH EERE 2009
- **Annual Maintenance Cost (2022$/kBtu/h)**: Comm. Packaged Boilers EERE 2020
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# Commercial Centrifugal Chillers (Water-Cooled)

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- **AHRI / Guidehouse**
- **CUAC EERE 2016**
- **CUAC EERE 2016 / Guidehouse**

*Calculated*
# Commercial Gas-Fired Engine-Drive Rooftop Air Conditioners

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Guideline data sources and notes:
- **Guidehouse**
- **Gordian’s RSMeans Data – Building Construction Costs 2023**
## Commercial Rooftop Heat Pumps

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**Note:** The table above provides a summary of the energy efficiency standards and cost data for commercial rooftop heat pumps. The data includes the installed base, current standard, typical capacity, part load efficiency, COP, average life, and annual maintenance costs for different years and energy star versions.
## Commercial Ground-Source Heat Pumps

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### SOLAR THERMAL HEAT PUMPS

- **Typical Capacity (kBtu/h)**: Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule
- **COP (Heating)**: Guidehouse / AHRI Database
- **EER (Cooling)**: Guidehouse / Water-Source Unitary Heat Pumps EERE 2015 Final Rule
- **Average Life (y)**: Guidehouse
- **Retail Equipment Cost (2022$)**: U.S. DOE /IGSHPA /MA DOER/CEFIA/ASHRAE
- **Total Installed Cost (2022$)**: Guidehouse
- **Total Installed Cost (2022$/kBtu)**: Guidehouse
- **Annual Maintenance Cost (2022$/kBtu)**: Guidehouse

#### SOURCES

- U.S. DOE/EIA
- Water-Source Unitary Heat Pumps EERE 2015 Final Rule
- Guidehouse
- AHRI Database
- Water-Source Unitary Heat Pumps EERE 2015 Final Rule
- Distributors/Guidehouse
- U.S. DOE /IGSHPA /MA DOER/CEFIA/ASHRAE
- Geothermal Heat Pump Consortium, Inc. (U.S. DOE Contract DE-FG07-95ID13347)
# Packaged Terminal Air Conditioners

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## Packaged Terminal Heat Pumps

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Commercial Water Heating
## Commercial Gas-Fired Storage Water Heaters

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## Commercial Electric Resistance Storage Water Heaters

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**SOURCES**
- Product Literature / Guidehouse
- Guidehouse
- CWH EERE 2016 NOPR
# Commercial Heat Pump Water Heaters

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Product Literature / Guidehouse
# Commercial Gas-Fired Booster Water Heaters

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### SOURCES

- **Installed Base**: SRCC / Guidehouse
- **Typical Capacity (sq. ft.)**: SRCC / Guidehouse
- **Typical Capacity (m²)**: SRCC / Guidehouse
- **Typical Capacity (Input) (kBtu/h) - North**: EIA Technology Forecast Updates (2018)
- **Typical Capacity (Input) (kBtu/h) - South**: Gordinian’s RSMeans Data – Building Construction Costs 2023 / Guidehouse
- **Solar Uniform Energy Factor (SUEF)**: ENERGY STAR / Guidehouse
- **Average Life (y)**: SRCC / Guidehouse
- **Retail Equipment Cost (2022$)**: EIA Technology Forecast Updates (2018)
- **Total Installed Cost (2022$)**: Gordinian’s RSMeans Data – Building Construction Costs 2023 / Guidehouse
- **Total Installed Cost (2022$/kBtu/h) - North**: Guidehouse
- **Total Installed Cost (2022$/kBtu/h) - South**: Guidehouse
- **Annual Maintenance Cost (2022$)**: DOE / Guidehouse
- **Annual Maintenance Cost (2022$/kBtu/h) - North**: DOE / Guidehouse
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A-72
Commercial Cooking Products
## Commercial Natural Gas Range with Griddle and Oven

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## Commercial Electric Range with Griddle and Oven

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Appendix B
References

Guidehouse
1676 International Drive
McLean, VA 22102
And
Leidos
11951 Freedom Drive
Reston, VA 20190
References

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