Assumptions to the Annual Energy Outlook 2025: Transportation Demand Module

April 2025

Independent Statistics and Analysis
U.S. Energy Information Administration

www.eia.gov
U.S. Department of Energy
Washington, DC 20585

Table of Contents

Table of Figures

Table of Tables

Transportation Demand Module

The National Energy Modeling System's (NEMS) Transportation Demand Module (TDM) estimates transportation energy consumption across nine census divisions for seven fuel types. We model each fuel type according to fuel-specific and associated technology attributes by transportation mode. We report total transportation energy consumption as the sum of energy use in the following transport modes:

- Light-duty vehicles (LDVs) (cars, light trucks, and two- and three-wheeled vehicles)
- Commercial light trucks (8,501 pounds–10,000 pounds gross vehicle weight rating)
- Freight trucks (greater than 10,000 pounds gross vehicle weight)
- Buses (transit, school, and intercity)
- Freight and passenger aircraft
- Freight and passenger rail
- Maritime freight shipping
- Miscellaneous transport (such as recreational boating)

We further subdivide LDV fuel consumption into household usage and commercial fleet consumption.

Key assumptions

We make key assumptions for transportation travel demand, efficiency, and energy consumption for LDVs, commercial light trucks, freight transportation, and air travel by submodule and their components.

Light-duty vehicle submodule

The TDM uses an engineering-based model to determine future LDV attributes by manufacturer group, size class, and powertrain. Vehicles represented in manufacturer groups reflect similarities in vehicle attributes that are designed and targeted toward specific consumer groups represented in the consumer vehicle choice component. As a result, vehicles represented in the manufacturer groups align with consumer behavior reflected for the consumer groups purchasing those vehicles. For example, five manufacturer groups are represented for cars. Three of those car manufacturer groups reflect vehicle brands that compete in the mass market: those priced at the low end of the mass market, those priced at the middle of the mass market, and those priced at the high end of the mass market. The two remaining car manufacturer groups reflect: the luxury priced vehicles and vehicles with high luxury/exotic pricing. Light truck manufacturer groups are segmented primarily by vehicle brand (domestic, Asian, and European) but also include a manufacturer group that contains the luxury vehicle product offerings across those light truck vehicle brands.

The LDV Manufacturers Technology Choice Component (MTCC) includes advanced technology input assumptions, specific to cars and light trucks (as defined by 49 CFR 523.5), which include:

- Incremental fuel economy improvement
- Incremental cost
- Incremental weight change
- First year of introduction or commercial availability
- Fractional horsepower change

We developed input assumptions from multiple runs of the Volpe Corporate Average Fuel Economy (CAFE) Model.[1]

The LDV Regional Sales Component holds the share of vehicle sales across consumer groups within a census division constant at 2023 levels based on U.S. Environmental Protection Agency (EPA), National Highway Traffic Safety Administration (NHTSA) data, and S&P vehicle registration data.[2,3] We project the shares of sales by size-class based on income per capita, fuel prices, and the average predicted vehicle prices that are based on endogenous calculations within the MTCC.[4] Sales and vehicle attributes by census division, consumer group, and size class are contained in our LDV database, which merges data from U.S. Environmental Protection Agency (EPA), Wards Intelligence, and S&P vehicle registrations.

The MTCC determines market adoption of incremental technology improvements by manufacturer group and size class based on the cost effectiveness of each technology and an initial year of availability. In other words, the MTCC compares relative costs and outcomes (effects) of different courses of action. The component calculates a discounted stream of fuel savings (outcomes) for each technology, which is compared with the marginal cost to determine cost effectiveness and market penetration. The fuel economy calculations assume the following:

- Financial parameters to determine a technology's economic effectiveness based on the need to improve fuel economy to meet CAFE and EPA tailpipe greenhouse gas (GHG) program standards relative to consumer willingness to pay for fuel economy improvement beyond those minimum requirements.
- Future fuel economy and tailpipe GHG standards for LDVs correspond to current law through model year (MY) 2032, reflecting the attribute-based final CAFE standards, as issued in 2022 and 2024, as well as the attribute-based final EPA GHG standards, as issued in 2021 and 2024.[5,6,7,8] For MY2033 through MY2050, fuel economy and tailpipe GHG standards hold constant at MY2032 levels. Fuel economy improvements are still possible based on continued improvements in economic effectiveness.
- Expected future fuel prices are calculated based on an extrapolation of the growth rate between a five-year moving average of fuel prices that is three years before the present and a five-year moving average of fuel prices that is four years before the present. This calculation aligns with the assumption that manufacturers take three to four years to significantly modify vehicles offered.

We use the shortfall, expressed as degradation factors, to convert the new LDV as-tested, fuel economy values to on-road, fuel economy values.[9] Degradation factors are adjustments to tested fuel economy values to account for the difference between fuel economy performance realized in the CAFE two-cycle test procedure and fuel economy estimates based on EPA's five cycle test.[10] The degradation factor varies by powertrain, size class, and manufacturer group, and it is held constant from 2023 through 2050 based on the last available historical data (MY2023).

The LDV Vehicle Miles Traveled (VMT) Component projects personal travel demand using fuel prices, personal income, employment, number of vehicles per licensed driver, and population demographics. We break population demographic distribution assumptions from the U.S. Census Bureau into 5 categories (age) each with 2 subcategories (gender) for a total of 10 categories. We also use licensing rates from the U.S. Department of Transportation's Federal Highway Administration (FHWA) and divide those into the same five age categories. We then project licensing rates for each age category using the population estimates from the U.S. Census Bureau. We apply these licensing rate projections to the historical VMT per licensed driver taken from FHWA to project the VMT per licensed driver using the historical relationship of VMT to cost to drive, income, employment, and registered vehicles per licensed driver.

We determine initial LDV stocks by census division, vintage, and fuel type by analyzing S&P Global data. We also estimate regional vehicle scrappage rates using S&P Global data, accounting for vehicles scrapping out of the fleet and vehicles flowing across regions as they age.

Commercial light-duty fleet assumptions

The TDM separates commercial, light-duty fleets into four types:

- Business (rental)
- Government
- Commercial and utility
- Ride hailing and taxi service

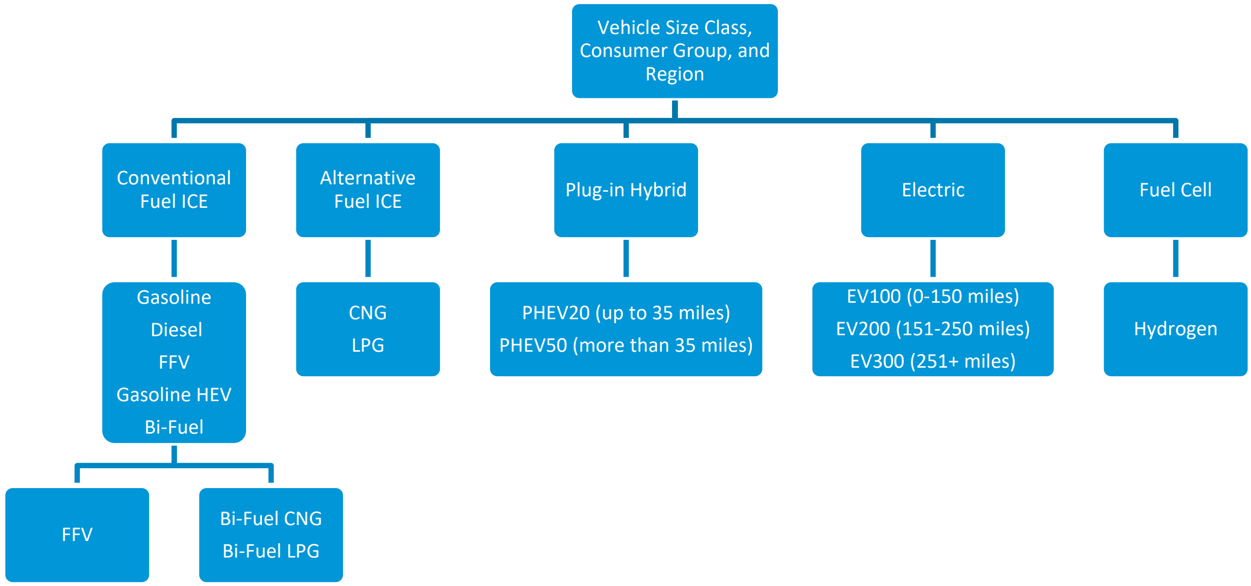
Based on these classifications, commercial, light-duty fleet vehicles vary in survival rates and duration of in-fleet use, reflected in VMT, before being sold for use as personal vehicles. Fleet vehicles are sold to households for personal use at different rates for passenger cars and light trucks, depending on the fleet type. Vehicles used for ride hailing or taxi service remain in fleet use for the life of the vehicle.

We assume ride-hailing and taxi service fleets comprise 5% of the commercial and utility fleet, as designated by S&P Global for cars and light trucks.[11] Annual VMT per vehicle by fleet type, within each group, class, and census division stays constant during the projection period based on S&P Global vehicle registration and odometer data.

Consumer vehicle choice assumptions

The Consumer Vehicle Choice Component (CVCC) uses a nested multinomial logit model that estimates powertrain sales shares within each region, size class, and consumer group based on relevant vehicle and fuel attributes. The nesting structure first predicts the probability of fuel choice for multi-fuel vehicles within a technology set. The second-level choice predicts penetration among similar technologies within a technology set (for example, 200-mile electric vehicles [EV] versus 300-mile EV). The third-level choice determines market share among the different technology sets (Figure 1).[12]

Figure 1. Nesting structure for National Energy Modeling System, Transportation Demand Module, Consumer Vehicle Choice Component



Source: U.S. Energy Information Administration
Note: EV=electric vehicles; ICE=internal combustion engine; CNG=compressed natural gas; LPG=liquid petroleum gas; FFV=flex-fuel vehicle; PHEV=plug-in hybrid electric vehicle; EV=electric vehicle; HEV=hybrid electric vehicle

The vehicle attributes considered in the choice algorithm include:

- Vehicle price
- Fuel cost (fuel price and fuel economy)
    - Captures multifuel capability
- Maintenance cost
- Range
- Home refueling capability
- Fuel availability
- Make/model availability
- Horsepower-to-weight ratio
- Luggage space

We determine vehicle attributes endogenously based on historical relationships to vehicle weight and size class, except for maintenance cost and luggage space.[13] Battery costs for plug-in hybrid electric vehicles (PHEVs) and all-electric vehicles are based on the historical relationship between cumulative production and pack price, described by a learning rate. Vehicle attributes vary by eight size classes for cars and eight size classes for light trucks, and fuel availability varies by census division based on exogenous public and private station build inputs through 2032 and electric vehicle on-road stock growth from 2033–2050. The nested multinomial logit model coefficients reflect consumer group purchase decisions for size classes, cars, and light trucks separately.

Where applicable, we calculate CVCC fuel-efficient technology attributes relative to conventional gasoline miles per gallon (mpg). Specifically, individual alternative-fuel technology improvements also depend on the CVCC technology type, cost, research and development, and availability over time. We estimated make and model availability exogenously according to current and future offerings announced by manufacturers, as well as endogenously according to sales growth by powertrain, manufacturer group, and size class.[14] We derived coefficients that summarized consumer valuation of vehicle attributes from assumed economic valuation compared with vehicle price elasticities. We establish historical vehicle sales by analyzing S&P Global and sales data from the EPA Engines and Vehicles Compliance Information System.[15,16] We calibrated CVCC vehicle sales in the first projection year (2024) to the 2024 sales data estimated by Ward's Intelligence.[17] We used a fuel-switching algorithm based on the relative fuel prices for alternative fuels compared with gasoline to determine the percentage of total fuel consumption represented by alternative fuels in flex-fuel ethanol vehicles.

Battery Cost Submodule

Lithium-ion battery costs (dollar per kilowatthour) are projected endogenously based on production learning and economies of scale, represented as a learning rate that couples production cost to cumulative battery production in kilowatthours. The model applies a two-stage learning curve, using different learning rates for the pack and the material inputs to ensure the total cost does not fall below the cost to mine and process the critical minerals, similar to that derived in Hseih, et al.[18] The learning rates applied are 16.5% for the pack and 3.5% for the material inputs.

Historical LDV battery costs were derived from Bloomberg New Energy Finance's Lithium-Ion Battery Cost Survey series, using an average of North American and European pack prices for battery electric vehicles (BEV) and a multiplier to account for the increased cost of PHEV batteries. Historical freight truck battery costs were derived from a study commissioned by EPA in support of its latest freight truck tailpipe GHG rulemaking (see more regulatory discussion in Legislation and Regulations section below).[19] These costs vary by size class according to the detail provided in the study and assume a 50/50 mix of lithium iron phosphate (LFP) and nickel manganese cobalt (NMC) pack chemistries. Each of these battery costs is marked up to a retail-price-equivalent based on factors developed for EPA: 1.5 for LDV and 1.42 for medium- and heavy-duty truck.[20]

Freight Transport Submodule

The Freight Transport Submodule includes the Freight Truck, Rail Freight, and Waterborne Freight components.

Freight Truck Component

The Freight Truck Component estimates vehicle stocks, travel, fuel efficiency, and energy use for three classes of trucks: light-medium (Class 3), medium (Classes 4–6), and heavy (Classes 7–8). The 3 size classes are comprised of 19 subclasses based on gross vehicle weight rating (GVWR) and usage to accurately assess technology and advanced powertrain adoption. These classes are aggregated into 14 subclasses to estimate NHTSA fuel economy and EPA tailpipe GHG compliance, and 3 groupings to estimate compliance with California's Advanced Clean Truck rule (ACT) as shown in Table 1. Class 2b-8 truck market segmentation in the National Energy Modeling System's Transportation Demand Module .

Table 1. Class 2b-8 truck market segmentation in the National Energy Modeling System's Transportation Demand Module

Vehicle category	Class	Type	Roof	EPA/NHTSA category	California Advanced Clean Trucks Grouping
1	2b	Pickup and van	-	1	1
2	2b	Vocational	-	2	1
3	3	Pickup and van	-	1	1
4	3	Vocational	-	2	1
5	4	Vocational	-	2	2
6	5	Vocational	-	2	2
7	6	Vocational	-	3	2
8	7	Tractor—day cab	Low	5	3
9	7	Tractor—day cab	Mid	6	3
10	7	Tractor—day cab	High	7	3
11	7	Vocational	-	3	2
12	8	Tractor—day cab	Low	8	3
13	8	Tractor—day cab	Mid	9	3
14	8	Tractor—day cab	High	10	3
15	8	Vocational	-	4	2
16	8	Tractor—sleeper cab	Low	11	3
17	8	Tractor—sleeper cab	Mid	12	3
18	8	Tractor—sleeper cab	High	13	3
19	8	Tractor—heavy haul	-	14	3

Data source: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2, U.S. Environmental Protection Agency (EPA) and U.S. Department of Transportation, Final Rules, *Federal Register*, Vol. 81, No. 206 (October 2016) and Advanced Clean Trucks Regulation, California Air Resources Board, March 15, 2021

Note: NHTSA=National Highway Traffic Safety Administration

Within the size classes, the stock model structure covers 34 vehicle vintages and estimates energy use by seven fuel types:

- Diesel
- Gasoline
- LPG
- Natural gas (compressed natural gas [CNG] and liquefied natural gas [LNG])
- Ethanol
- Electricity
- Hydrogen

Fuel consumption estimates are reported regionally (by census division) according to the distillate fuel shares from our State Energy Data System.[21] The technology input data are specific to the type of truck and include the year of introduction, incremental fuel efficiency improvement, and capital cost.

The Freight Truck Component uses projections of industrial output—reported in NEMS using North American Industry Classification System (NAICS) codes—to estimate growth in Class 2b–8 freight truck travel. We determine regional freight-truck, ton-mile demand by commodity type by using a ton-mile per dollar of industrial output measure from the Freight Analysis Framework along with geographic information system data that we use to determine regional distances between origin or destination points.[22] VMT growth is derived from growth in ton-mile demand and is applied to historical freight truck VMT by region and commodity type.[23, 24] We then distribute projected VMT by size class and vintage based on annual VMT schedules from 2021 Vehicle Inventory and Use Survey (VIUS) odometer and reported annual mileage readings and, for Class 2b, Polk odometer readings.[25,26]

Fuel economy of new freight trucks depends on the market penetration of advanced technology components and advanced powertrains.[27] For the advanced technology components, we determine market penetration based on technology type, cost effectiveness, and introduction year. We calculate cost effectiveness based on fuel price, vehicle travel, fuel economy improvement, and incremental capital cost. We model market penetration of the following powertrains:

- Conventional diesel
- Conventional gasoline
- Propane
- Compressed natural gas
- Flex-fuel (E85)
- Battery electric
- Plug-in hybrid diesel
- Plug-in hybrid gasoline
- Hydrogen fuel cell
- Hydrogen fuel cell – battery-dominant
- Hybrid gasoline
- Hydrogen internal combustion engine

Market penetration is determined based on estimated payback, which accounts for upfront capital investment (incremental purchase price, sales and excise taxes, infrastructure installation, federal incentives and tax credits) and operational costs (fuel, maintenance and repair, insurance, value of time spent refueling). Payback period varies by size class, and the model ensures this fleet purchase decision is modeled for each of the 9 regions, 19 size classes, and 11 annual VMT bins. We assume that the availability of electric and hydrogen refueling infrastructure does not limit adoption of electric or hydrogen vehicles.

We determine initial freight truck stocks by vintage and fuel type by analyzing S&P Global data. We also estimate regional vehicle scrappage rates using S&P Global data, accounting for vehicles scrapping out of the fleet and vehicles flowing across regions as they age.

Light Commercial Truck Component

The Light Commercial Truck Component of the NEMS TDM—integrated into the Freight Truck Component—represents light trucks that have an 8,501-pound to 10,000-pound GVWR (Class 2b vehicles). We assume these vehicles are primarily commercial. This component implements a 34-year stock model that estimates vehicle stocks, travel, fuel economy, and energy use by vintage (age). We derived the vehicle distribution by vintage and vehicle scrappage rates by analyzing registration data from S&P Global.[28] We constructed annual vehicle travel schedules by vintage from the same registration data, along with the corresponding odometer reading data and VMT estimates from VIUS. The growth in light, commercial truck VMT is based on industrial gross output for agriculture, mining, construction, total manufacturing, utilities, and personal travel. The overall growth in VMT reflects a weighted average based on the distribution of total light, commercial truck VMT by sector. Fuel economy and market penetration of both advanced technology and advanced powertrains are estimated alongside Class 3-8 freight trucks, using the same cost effectiveness and payback methodologies.

Freight rail

The Freight Rail Component uses the industrial output by NAICS code, measured in real 2012 dollars, and a ton-mile per dollar output measure to project rail ton-miles by census division and commodity. We develop this projection using data from the Freight Analysis Framework and NEMS Macroeconomic Activity Module.[29] We use coal production from the NEMS Coal Market Module to adjust data for coal transported by rail. Historical freight rail ton-miles and efficiencies are from the Association of American Railroads, as compiled in the Transportation Energy Data Book.[30] The projected distribution of rail fuel consumption by fuel type is based on the cost-effectiveness of LNG compared with diesel, considering fuel costs and incremental locomotive costs.

Domestic and international waterborne freight

Similar to the Freight Rail Component, domestic freight shipping within the Waterborne Freight Component uses the industrial output by NAICS code, measured in real 2012 dollars, and a ton-mile per dollar output measure to project domestic marine ton-miles by census division and industrial commodity. We use those projections to develop rates of domestic marine travel.[31]

The Transportation Energy Data Book provides domestic shipping efficiencies, and the Department of the Army Corps of Engineers provides historical ton-miles.[32, 33] The energy consumption for international shipping within the Waterborne Freight Component is based on the total level of imports and exports. We base the distribution of domestic and international shipping fuel consumption by fuel type on historical data through 2016 and allow LNG as a marine fuel starting in 2013, based on fuel economics. Historical estimates of regional domestic shipping fuel shares are distributed according to regional shares in our State Energy Data System.[34]

Marine fuel choice for ocean-going vessels within Emission Control Areas (ECA)

North American ECAs generally extend 200 nautical miles (nm) from U.S. and Canadian ports (50 nm for the U.S. Caribbean ECA). Fuel-burn requirements that went into effect on January 1, 2015, require existing ships to either burn fuel containing a maximum of 0.1% sulfur or use scrubbers to remove the sulfur emissions. Outside of ECAs, starting on January 1, 2020 (under the International Maritime Organization's regulations, Annex VI of the International Convention for the Prevention of Pollution from Ships), sulfur emissions from ships are limited to 0.5% sulfur, down from the previous limit of 3.5% sulfur. New ships will be built with engines and controls to handle alternative fuels and meet the ECA limits.

Compliance options (modeled as a logit choice function based on marine fuel prices) associated with travel in the ECAs for new vessels include:

- Using exhaust controls (for example, scrubbers and selective catalytic reduction)
- Changing fuels to marine gas oil (MGO) or LNG
- Installing engine-based controls (for example, exhaust gas recirculation)

We use compliance options adopted for ECA operations to inform vessel compliance options for open-sea operations, as well as to address fuel availability and fueling infrastructure risks. Other technologies and fuels (for example, methanol and ammonia) are also under development by industry but have not yet reached wide-scale adoption.

Ship-efficiency improvements, shipping-demand changes, and fuel-price fluctuations will also drive future fuel-consumption projections within the North American and U.S. Caribbean ECAs. We outlined these assumptions for baseline fuel estimates and technology choice options in a 2015 report, which includes methodology and assumptions for projecting fuel demand within North American ECAs.[35]

Air Travel Submodule

The Air Travel Submodule is a 16-region world demand and supply model for passenger and cargo transport (Table 2). For each region, we compute demand for domestic (both takeoff and landing occur in the same region) and international (either takeoff or landing is in one region but not both) travel. Once we project the demand for aircraft, the Aircraft Fleet Efficiency Component adjusts passenger and cargo aircraft stocks—by parking, un-parking, converting, or purchasing aircraft—to satisfy the projected demand for air travel.

Table 2. Regions for the Air Travel Submodule, *Annual Energy Outlook 2025*

Region number	Region	Major countries in region
1	United States	United States
2	Canada	Canada
3	Mexico	Mexico, Chile
4	OECD Europe	France, Germany, United Kingdom
5	Japan	Japan
6	Australia and New Zealand	Australia, New Zealand
7	South Korea	South Korea
8	Russia	Russia
9	Other Europe and Eurasia	Romania, Ukraine
10	China	China
11	India	India
12	Other non-OECD Asia	Indonesia, Pakistan, Taiwan, Thailand
13	Middle East	Iran, Iraq, Saudia Arabia
14	Africa	Egypt, Nigeria, South Africa
15	Brazil	Brazil
16	Non-OECD Americas	Argentina, Peru, Venezuela

Data source: Jet Information Services, 2022 World Jet Inventory, data tables (2023)

Air Travel Demand Component

The Air Travel Demand Component projects domestic and international per capita revenue passenger miles (RPMs) and freight revenue ton-miles (RTMs) by region. RPM and RTM projections begin in 2023 and are based on historical relationships between population, gross domestic product (GDP), RPMs, and RTMs from 1995 to 2022.[36, 37] Freight RTMs are split between belly freight (carried in the cargo holds of passenger aircraft) and dedicated freighters.

Aircraft Fleet Efficiency Component

The Aircraft Fleet Efficiency Component consists of a world regional stock model of narrow-body, wide-body, and regional jets by vintage. We base total aircraft supply for a given year on the initial supply of aircraft for 2022, new passenger aircraft sales for 2022, and the survival rate by vintage (see input file *trnairx.xlsx*).[38]

The available seat miles per plane per year, which bounds the carrying capacity for each aircraft by body type, increase gradually over time. We apply load factors to domestic and international travel routes to determine demand for seat miles. Domestic and international seat-mile and freight ton-mile demand, organized by aircraft body type, move to the Aircraft Fleet Efficiency Component, which adjusts the initial aircraft stock to meet that demand. First, we adjust the dedicated freighter stock, starting with filling belly freight capacity on the current year passenger aircraft, and then we consider four sequential options to meet remaining demand:

1. Re-activate parked freighters
2. Convert parked passenger aircraft
3. Convert older active passenger aircraft
4. Purchase new dedicated freighters

Passenger stock undergoes similar but more limited options:

- Re-activate parked passenger aircraft
- Purchase new passenger aircraft

We assume technological availability, economic viability, and efficiency characteristics of new jet aircraft grow at a fixed rate, specifically, that fuel consumption per ton-mile decreases at 1.0% per year through 2050. Fuel efficiency of new aircraft acquisitions represents an improvement over the stock efficiency of surviving airplanes. Efficiency of passenger aircraft includes belly freight that is converted to revenue passenger-miles using an average passenger and luggage weight of 200 pounds. We account for further operational efficiency improvements by using annual reductions in an air management penalty factor derived from International Civil Aviation Organization (ICAO) data, based on distance between airports versus actual distance traveled.

Legislation and regulations

National Highway Traffic Safety Administration (NHTSA) CAFE and EPA tailpipe GHG standards for light-duty vehicles

The AEO2025 Reference case enforces the attribute-based final CAFE standards, as issued in 2022 and 2024, as well as the attribute-based final EPA GHG standards, as issued in 2021 and 2024.[5,6,7,8] The standards increase in stringency between 2023 and 2032. The model holds both sets of standards constant in subsequent model years (2033 through 2050), although fuel economy improvements are still possible based on continued improvements in economic effectiveness.

Both CAFE and GHG standards are applied to the light-duty vehicle sales projection. The model attempts to meet these standards within each individual manufacturer group, based on the group's unique size class distribution and the corresponding vehicle footprints, through incremental technology adoption. Off-cycle and air conditioning (A/C) efficiency and leakage credits are applied based on the maximum allowed, including the phase-out of off-cycle credits through 2033, the phase-out of maximum A/C leakage credits through 2031, and the ineligibility of BEVs to earn off-cycle and A/C efficiency credits starting in MY2027. We account for the U.S. Department of Energy's (DOE) changes to the Petroleum Equivalency Factor (PEF) in March 2024, and its impact on calculation of CAFE compliance fuel economy for BEVs and PHEVs in MY2027+.[39]

In cases where the model is unable to meet either standard, advanced powertrain (hybrid, plug-in hybrid, and battery electric) sales are increased until the entire aggregate market is in compliance with both standards. We base advanced powertrain selection in this process on cost effectiveness (fuel savings versus purchase price). We ensure that no more than 2.0 mpg of credits are transferred between the car and light truck fleets in a given year.

GHG standards and fuel efficiency standards for medium- and heavy-duty engines and vehicles

On August 16, 2016, EPA and NHTSA jointly adopted a second round of standards for medium- and heavy-duty vehicles. This second round of standards (following the Phase 1 standards issued in September 2011) begins with MY2021 vehicles and increases in stringency through MY2027.[40] On March 29, 2024, EPA adopted a third phase of standards, which begins with MY2027 and increases in stringency through MY2032. The freight transport submodule incorporates the Phase 2 and Phase 3 standards for heavy-duty vehicles (HDVs) with a GVWR of more than 8,500 pounds (Classes 2b-8). Standard compliance is modeled among 14 HDV regulatory classifications that represent the discrete vehicle categories set forth in the rule (Table 1). The standards are held constant in subsequent model years.

The model attempts to meet these standards, within each size class and annual vehicle miles traveled (VMT) bin, through incremental technology adoption. In cases where the model is unable to meet either standard, battery electric, hydrogen fuel cell, and/or hydrogen internal combustion engine sales are increased until the entire aggregate market follows both standards. ZEV powertrain selection in this process is based on which powertrain results in the lowest compliance cost over years of operation within a given size class and annual VMT bin, constrained by maximum lifetime mileage for each size class.

The fuel economy and tailpipe GHG standards for Class 2b pickups and vans were included in the Phase 2 medium- and heavy-duty truck regulation but were not included in the subsequent Phase 3 heavy-duty truck regulation. They are covered under NHTSA and EPA’s MY2027+ light-duty vehicle standards and are modeled as such in NEMS TDM.

NEMS TDM does not include a full stock-flow and powertrain choice model for buses. School and transit buses are assumed to achieve EPA’s estimated BEV sales share from the Phase 3 GHG regulation. Stock flow was modeled offline to generate exogenous school and transit bus VMT shares that align with the EPA sales pathway.

California Advanced Clean Trucks Rule (ACT)

The ACT, approved by the California Air Resources Board (CARB) on March 15, 2021, and for which EPA issued a waiver on April 6, 2023 (required for enforcement), requires truck manufacturers to meet ZEV sales share targets that increase over time.[41,42] The targets are specified across three regulatory groupings: Class 2b-3, Class 4-8 Vocational, and Class 7&8 Tractor (see Table 1 for how NEMS’ 19 freight truck size classes map to these groupings). The rule applies to California and 10 other Section 177 states (Colorado, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, and Washington) that have adopted the ACT.

In cases where the model does not adopt sufficient ZEVs to meet the ACT requirements, battery-electric and/or hydrogen fuel cell sales are increased. ZEV powertrain selection in this process is based on which powertrain results in the lowest compliance cost over seven years of operation within a given size class and annual VMT bin, constrained by maximum lifetime mileage for each size class.

EPA Control of Air Pollution From New Motor Vehicles

On January 24, 2023, EPA finalized a regulation to lower criteria pollutant emissions from heavy-duty trucks. AEO2025 accounts for the cost impact of the more stringent standards starting in MY2027. The incremental compliance costs, taken from the regulation, are applied to up-front diesel, gasoline, CNG, and hydrogen ICE truck purchase prices in the Freight Truck Component.[43]

Energy Independence and Security Act of 2007 (EISA2007)

A fuel economy credit trading program is established based on EISA2007. Currently, manufacturers can bank CAFE credits for up to three years, and they can only apply then to the fleet (car or light truck) they earned the credit for. Starting in MY2011, the credit trading program allows manufacturers whose automobiles exceed the minimum fuel economy standards to earn credits that they can sell to other manufacturers whose automobiles did not achieve the prescribed standards. The credit trading program is designed to ensure that the total fuel savings associated with manufacturers that exceed the prescribed standards are preserved when credits are sold to manufacturers that did not achieve them.

Although the credit trading program began in 2011, EISA2007 allows manufacturers to apply credits they earned to any of the three model years before the model year they earned the credits in and to any of the five model years after they earned the credits. Transferring credits within a manufacturer’s fleet is limited to specific maximums:

For MY2011 through MY2013, the maximum transfer is 1.0 mpg.
For MY2014 through MY2017, the maximum transfer is 1.5 mpg.
For MY2018 and later, the maximum credit transfer is 2.0 mpg.

NEMS allows sensitivity analysis of manufacturers’ CAFE-credit banking, but it does not model credit trading across manufacturers. The projections do not consider credit trading because to do so would require significant modifications to NEMS and detailed technology cost and efficiency data by manufacturer, which are not readily available.

Bipartisan Infrastructure Law (BIL)

The 2021 BIL authorizes $1.2 trillion for transportation and infrastructure spending with $550 billion designated towards new investments and programs. The law allocates $7.5 billion over a five-year period to expand electric vehicle (EV) charging infrastructure across the United States with a goal of creating 500,000 chargers by 2030 to accelerate EV adoption, support domestic manufacturing and enhance the nation’s clean energy infrastructure. Two main programs provide funding:

- National Electric Vehicle Infrastructure (NEVI) Formula Program: Allocates $5 billion of funding to states to build fast charging stations to ensure reliable charging every 50 miles along major highways. Each station must include at least four DC fast chargers and at least 55% of the components must be made in America, with final assembly in the United States.
- Charging and Fueling Infrastructure (CFI) Discretionary Grant Program: Allocates $2.5 billion of funding to support community-based charging in rural underserved areas.

The NEMS charging infrastructure model takes into consideration funding allocations, deployment requirements, and expected charging infrastructure growth from both private and public investments to project the gradual deployment of EV charging infrastructure across the United States.

Inflation Reduction Act of 2022 (IRA)

The 2022 IRA replaced the previous qualified plug-in, electric-drive motor vehicle tax credit (American Recovery and Reinvestment Act of 2009 and Energy Improvement and Extension Act of 2008) with a clean-vehicle credit. This credit, often referred to as the Section 30D credit, offers up to $7,500 to purchasers of eligible electric and hydrogen fuel-cell vehicles.[44] This new credit removes the previous cumulative sales-based phaseout by manufacturer and adds several additional requirements for eligibility. These requirements include:

- Final assembly occurs in North America
- Vehicle battery capacity is greater than or equal to 7 kilowatthours
- Vehicle manufacturer's suggested retail price is less than $55,000 for cars and $80,000 for light trucks (using EPA classifications)
- Purchaser's modified adjusted gross income is less than $300,000 for a joint return or surviving spouse, $225,000 for a head of household, or $150,000 otherwise

If a buyer meets the initial constraints, the vehicle could be eligible for two $3,750 credits (total of $7,500 possible). If a vehicle meets one of the following, it could be eligible for a $3,750 credit, and if it meets both, it could be eligible for the maximum $7,500 credit:

- Specified (increasing to 100% by 2029) share of battery components must be manufactured or assembled in North America
- Specified (increasing to 80% by 2027) share of critical minerals used in the battery must be extracted, processed, or recycled in the United States or any country with which the United States has a free trade agreement

The NEMS Light-Duty Vehicle Submodule does not incorporate country of vehicle assembly, nameplate manufacturer's suggested retail price (MSRP), consumer income, battery component sourcing, or critical mineral supply chain design. We estimate historical credit eligibility (2023 and 2024) based on published eligibility and model-year sales from EPA.[45,2] Projected eligibility in the Reference case is based on the growth in eligibility estimated by EPA used in compliance calculations for the MY2027–MY2032 tailpipe GHG standards.

The IRA also provides a production tax credit of $35 per kilowatthour to U.S. battery manufacturers for domestically produced batteries (Section 45X). We did not include this credit in the projection due to the uncertainty around the potential impact it could have on battery costs and EV pricing. The degree that this credit increases domestic battery production and the extent to which credits received are passed through to vehicle manufacturers and ultimately reflected in new EV pricing is uncertain at this time. In addition, EV pricing will also be influenced, in part, by the cost of batteries manufactured elsewhere and imported to the United States, as well as the profit margins and pricing flexibility associated with electric vehicles.

Additionally, we do not account for the LDV leasing provision in the Commercial Clean Vehicle credit (Section 45W), given uncertainty surrounding the extent to which credits received are passed through to consumers.[46]

With respect to the impacts of IRA tax credits on commercial light and freight trucks, we account for the Section 45W Commercial Clean Vehicle credit as well as the Section 30C Alternative Fuel Vehicle Refueling Property Credit.[47]

International Convention for the Prevention of Pollution from Ships (MARPOL)

In March 2010, the International Maritime Organization (IMO) amended the International Convention for the Prevention of Pollution from Ships (MARPOL) to designate specific portions of U.S., French, and Canadian waters as Emission Control Areas.[48] The area of the North American ECA includes waters adjacent to the Pacific Coast, the Atlantic Coast, the Gulf Coast, and the eight main Hawaiian Islands. The ECAs extend up to 200 nautical miles from the coasts of the United States, Canada, and the French territories, but they do not extend into marine areas subject to the sovereignty or jurisdiction of other countries. Compliance with the North American ECA became enforceable in August 2012.[49, 50] In October 2016, IMO members agreed to the 2008 MARPOL amendments that implement a new global limit in 2020 for sulfur emissions from ships. The ships have to use *fuel oil on board* with a sulfur content of no more than 0.50% mass by mass. IMO's interpretation of *fuel oil used on board* includes use in main and auxiliary engines and boilers.

California Global Warming Solutions Act of 2006: emissions limit (Assembly Bill 32)

The California Global Warming Solutions Act of 2006 set a statewide requirement to reduce GHG emissions to 1990-equivalent levels by 2020. On September 8, 2016, California added Section 38566 to the Health and Safety Code, relating to GHG (Senate Bill 32). Senate Bill 32 codifies a 2030 GHG emissions reduction target of 40% lower than in 1990. Senate Bill 32 and Assembly Bill 32 provisions direct state policies that affect transportation sector model assumptions to target increased adoption of ZEVs and other alternative powertrains and to decrease travel.

Notes and sources

[1] U.S. Department of Transportation, National Highway Traffic Safety Administration, "CAFE Model Documentation" (Washington, DC, June 2024).
[2] U.S. Environmental Protection Agency, Engines and Vehicles Compliance Information System.
[3] U.S. Department of Transportation, National Highway Traffic Safety Administration, Volpe CAFE Model.
[4] Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry," Econometrica, Vol. 63, No.4 (July 1995), 891–951.
[5] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks, U.S. Department of Transportation, National Highway Traffic Safety Administration; Federal Register Vol. 87, No. 84, Monday, May 2, 2022.
[6] CAFE Standards for MYs 2027–2031 Passenger Cars and Light Trucks, U.S. Department of Transportation, National Highway Traffic Safety Administration; Federal Register Vol. 89, No. 121, Monday, June 24, 2024.
[7] Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards, Environmental Protection Agency; Federal Register Vol. 86, No. 248, Thursday, December 30, 2021.
[8] Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles, U.S. Environmental Protection Agency; Federal Register Vol. 89, No. 76, Thursday, April 18, 2024.
[9] U.S. Environmental Protection Agency, "Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates—Final Technical Support Document," EPA420-R-06-017, December 2006.
[10] U.S. Environmental Protection Agency, "Fuel Economy and EV Range Testing". https://www.epa.gov/greenvehicles/fuel-economy-and-ev-range-testing.
[11] S&P Global Inc.; Copyright © R.L. Polk Co. or its third-party provider, various years, all rights reserved.
[12] Greene, David L. and S.M. Chin, "Alternative Fuels and Vehicles (AFV) Model Changes," Center for Transportation Analysis, Oak Ridge National Laboratory, (Oak Ridge, TN, November 14, 2000).
[13] Energy and Environmental Analysis, Inc., Updates to the Fuel Economy Model (FEM) and Advanced Technology Vehicle (ATV) Module of the National Energy Modeling System (NEMS) Transportation Model, Prepared for the Energy Information Administration (EIA), (Arlington, VA, October 23, 2000).
[14] Wards Intelligence North America Product Cycle Chart, January 5, 2024.
[15] S&P Global R.L. Polk, op. cit., Note 11.
[16] U.S. Environmental Protection Agency, op. cit., Note 2.
[17] Ward's Intelligence, various years
[18] Hsieh, I-Yun Lisa, Sam Pan Menghsuan, Yet-Ming Chiang, and William Green. "Learning Only Buys You so Much Practical Limits on Battery Price Reduction," Applied Energy, 2019, 7.
[19] FEV Consulting. "Heavy Duty Commercial Vehicles Class 4 to 8: Technology and Cost Evaluation for Electrified Powertrains—Final Report," May 2024. https://www.regulations.gov/document/EPA-HQ-OAR-2022-0985-4138
[20] U.S. Environmental Protection Agency, Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3 Regulatory Impact Analysis, Table 3.3. EPA-420-R-24-006. March 2024.
[21] U.S. Energy Information Administration, State Energy Data System 2021.
[22] U.S. Department of Transportation, Freight Analysis Framework 5 (2021). https://faf.ornl.gov/
[23] IHS Global, Inc., "NEMS Freight Transportation Module Improvement Study," final report prepared for the U.S. Department of Energy, U.S. Energy Information Administration, Office of Energy Analysis (Lexington, MA, June 2014).
[24] U.S. Department of Transportation, Federal Highway Administration, Highway Statistics (1995–2020), Table VM-1.
[25] U.S. Bureau of Transportation Statistics, "Vehicle Inventory and Use Survey (VIUS)," June 13, 2024. https://www.bts.gov/vius
[26] S&P Global R.L. Polk, op. cit., Note 11.
[27] U.S. Environmental Protection Agency and U.S. Department of Transportation, op. cit., Note **Error! Bookmark not defined.**.
[28] S&P Global R.L. Polk, op. cit., Note 11.
[29] U.S. Department of Transportation, op. cit., Note 22.
[30] Oak Ridge National Laboratory, Transportation Energy Data Book: 40th Edition (Oak Ridge, TN, 2022), page 269.
[31] U.S. Department of Transportation, op. cit., Note 22.
[32] Oak Ridge National Laboratory, op. cit., Note 30.
[33] Department of the Army Corps of Engineers, Waterborne Commerce of the United States, various years. https://publibrary.planusace.us/#/series/Waterborne%20Commerce%20of%20the%20United%20States
[34] U.S. Energy Information Administration, op. cit., Note 21.

[35] Leidos Corporation, "Marine Fuel Choice for Ocean Going Vessels within Emission Control Areas," final report prepared for U.S. Department of Energy, U.S. Energy Information Administration (June 2015).
[36] U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, Air Carrier Summary Data (Form 41, Schedules T-1 and T-2), (2019); including Air Carrier Summary Data (Form 41 and 298C Summary Data).
[37] International Civil Aviation Organization, Traffic by Flight Stage, various years
[38] Jet Information Services Inc., World Jet Inventory: Year-End 2020 (2021).
[39] U.S. 10 CFR Part 474, Petroleum-Equivalent Fuel Economy Calculation, March 29, 2024.
[40] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2, U.S. Environmental Protection Agency and U.S. Department of Transportation, Final Rule, *Federal Register*, Vol. 81, No. 206 (October 2016).
[41] California Air Resources Board, Final Regulation Order Advanced Clean Trucks Regulation, March 2021. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf
[42] U.S. Environmental Protection Agency, California State Motor Vehicle and Engine Pollution Control Standards; Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions; Advanced Clean Trucks; Zero Emission Airport Shuttle; Zero- Emission Power Train Certification; Waiver of Preemption; Notice of Decision. April 2023.
[43] U.S. Environmental Protection Agency, Control of Air Pollution From New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards. Table V-2.
[44] Pub L. 117-169, Inflation Reduction Act of 2022. https://www.congress.gov/bill/117th-congress/house-bill/5376/text
[45] Federal Tax Credits for New Plug-in Electric and Fuel Cell Electric Vehicles Purchased in 2023 or After, U.S. Department of Energy and U.S. Environmental Protection Agency. https://fueleconomy.gov/feg/tax2023.shtml
[46] U.S. Internal Revenue Service, Commercial Clean Vehicle Credit. https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit
[47] U.S. Internal Revenue Service, Alternative Fuel Vehicle Refueling Property Credit. https://www.irs.gov/credits-deductions/alternative-fuel-vehicle-refueling-property-credit
[48] U.S. Environmental Protection Agency, "MARPOL Annex VI" (Washington, DC, January 14, 2015).
[49] U.S. Environmental Protection Agency, op. cit., Note 40.
[50] U.S. Energy Information Administration, "Impacts on marine fuel choice from enforcement of Emissions Control Areas in North America and U.S. Caribbean Sea waters under the International Convention for the Prevention of Pollution from Ships (MARPOL)," (September 15, 2016), page LR8.