Transportation Demand Module Assumptions

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Transportation Demand Module

The National Energy Modeling System's (NEMS) Transportation Demand Module (TDM) estimates transportation energy consumption across nine census divisions and for 10 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
Freight and passenger aircraft
Freight and passenger rail
Maritime freight shipping
Miscellaneous transport (such as recreational boating)

We further subdivide light-duty vehicle fuel consumption into household usage and commercial fleet consumption.

Key assumptions

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

Light-duty vehicle submodule

The LDV Manufacturers Technology Choice Component (MTCC) includes advanced technology input assumptions, specific to cars and light trucks, that 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[i] (Table 1 and Table 2).

The LDV Regional Sales Component holds the share of vehicle sales by manufacturers constant within a vehicle size class at 2020 levels based on U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) data.[ii, iii] We project the shares of sales by size-class based on income per capita, fuel prices, and average predicted vehicle prices that are based on endogenous calculations within the MTCC.[iv]

The MTCC uses the technologies listed in Table 1 and Table 2 for each manufacturer and size class to determine market adoption 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 program standards relative to consumer willingness to pay for fuel economy improvement beyond those minimum requirements.

Future fuel economy standards for LDVs correspond to current law through model year (MY) 2026, reflecting the attribute-based final CAFE standards, as issued in 2022.[v] For MY2027 through MY2050, fuel economy standards hold constant at MY2026 levels, and 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.

Table 1. Standard technology matrix for cars

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2018 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
Mass reduction, level 1 (5% reduction in glider weight)	1.5%	$0.0	$0.5	0.0	-2.5	2005	0.0%
Mass reduction, level 2 (7.5% reduction in glider weight)	3.5%	$0.0	$0.9	0.0	-3.8	2009	0.0%
Mass reduction, level 3 (10% reduction in glider weight)	5.8%	$0.0	$1.3	0.0	-5.0	2011	0.0%
Mass reduction, level 4 (15% reduction in glider weight)	8.2%	$0.0	$1.8	0.0	-7.5	2015	0.0%
Mass reduction, level 5 (20% reduction in glider weight)	9.9%	$0.0	$7.0	0.0	-10.0	2015	0.0%
Aero I-5% Cd reduction	0.9%	$57.2	$0.0	0.0	0.0	2000	0.0%
Aero II-10% Cd reduction	2.8%	$116.9	$0.0	0.0	0.0	2011	0.0%
Aero III-15% Cd reduction	3.9%	$165.2	$0.0	0.0	0.0	2015	0.0%
Aero IV-20% Cd reduction	4.4%	$292.2	$0.0	0.0	0.0	2015	0.0%
Tire rolling resistance I- 10% reduction	2.0%	$7.5	$0.0	0.0	0.0	2000	0.0%
Tire rolling resistance II- 20% reduction	4.1%	$56.8	$0.0	0.0	0.0	2010	0.0%
Low drag brakes	0.8%	$90.3	$0.0	0.0	0.0	2000	0.0%
Secondary axle disconnect	1.4%	$93.9	$0.0	0.0	0.0	2012	0.0%
Manual trans 5 spd (base only)	0.0%	$2.0	$0.0	0.0	0.0	1995	0.0%
Manual trans 6 spd	1.7%	$371.2	$0.0	0.0	0.0	1995	0.0%
Manual trans 7 spd	5.6%	$758.6	$0.0	0.0	0.0	2014	0.0%
Auto trans 5 (base only)	0.0%	$2.0	$0.0	0.0	0.0	1995	0.0%
Auto trans 6	4.7%	-$22.1	$0.0	0.0	0.0	2003	0.0%
Auto trans 6 level 2	8.1%	$276.7	$0.0	20.0	0.0	2012	0.0%
7-speed automatic transmission, level 2 (base only)	8.1%	$237.6	$0.0	0.0	0.0	2009	0.0%
CVT (base only)	11.4%	$253.1	$0.0	0.0	0.0	1998	0.0%
CVT level 2 (replacing CVT)	15.7%	$190.2	$0.0	-25.0	0.0	2015	0.0%
Auto trans 8	14.0%	$110.2	$0.0	50.0	0.0	2009	0.0%
Auto trans 8 level 2	15.2%	$397.7	$0.0	50.0	0.0	2014	0.0%
Auto trans 8 level 3	15.9%	$628.0	$0.0	50.0	0.0	2016	0.0%
9-speed automatic transmission, level 2 (base only)	12.8%	$513.2	$0.0	50.0	0.0	2016	0.0%
Auto trans 10 level 2	16.6%	$513.2	$0.0	50.0	0.0	2016	0.0%
Auto trans 10 level 3	17.8%	$744.2	$0.0	50.0	0.0	2023	0.0%

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2018 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
DCT 6	13.3%	$30.6	$0.0	-10.0	0.0	2004	0.0%
DCT 8 (includes 7)	15.5%	$569.0	$0.0	0.0	0.0	2012	0.0%
Improved engine friction reduction, 4cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
Improved engine friction reduction, 6cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
Improved engine friction reduction, 8cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
SOHC VVL 4cyl	3.2%	$209.8	$0.0	25.0	0.0	2000	2.5%
SOHC VVL 6cyl	3.2%	$314.8	$0.0	40.0	0.0	2000	2.5%
SOHC VVL 8cyl	3.2%	$419.7	$0.0	50.0	0.0	2000	2.5%
SOHC SGDI 4cyl	2.1%	$349.7	$0.0	20.0	0.0	2006	2.5%
SOHC SGDI 6cyl	2.1%	$524.6	$0.0	30.0	0.0	2006	2.5%
SOHC SGDI 8cyl	2.1%	$699.5	$0.0	40.0	0.0	2006	2.5%
SOHC DEAC 4cyl	6.4%	$180.2	$0.0	10.0	0.0	2016	0.0%
SOHC DEAC 6cyl	6.4%	$212.6	$0.0	10.0	0.0	2010	0.0%
SOHC DEAC 8cyl	6.4%	$239.7	$0.0	10.0	0.0	2004	0.0%
DOHC VVL 4cyl	3.2%	$316.2	$0.0	25.0	0.0	2000	2.5%
DOHC VVL 6cyl	3.2%	$474.2	$0.0	40.0	0.0	2000	2.5%
DOHC VVL 8cyl	3.2%	$632.3	$0.0	50.0	0.0	2000	2.5%
DOHC SGDI 4cyl	2.1%	$349.7	$0.0	20.0	0.0	2006	2.5%
DOHC SGDI 6cyl	2.1%	$524.6	$0.0	30.0	0.0	2006	2.5%
DOHC SGDI 8cyl	2.1%	$699.5	$0.0	40.0	0.0	2006	2.5%
DOHC DEAC 4cyl	6.4%	$180.2	$0.0	10.0	0.0	2016	0.0%
DOHC DEAC 6cyl	6.4%	$212.6	$0.0	10.0	0.0	2010	0.0%
DOHC DEAC 8cyl	6.4%	$239.7	$0.0	10.0	0.0	2004	0.0%
TURBO1 4cyl	14.4%	$554.7	$0.0	-100.0	0.0	2009	3.8%
TURBO1 6cyl	14.4%	$256.1	$0.0	-100.0	0.0	2009	3.8%
TURBO1 8cyl	14.4%	$640.2	$0.0	-100.0	0.0	2009	3.8%
TURBO2 4cyl	15.7%	$1,172.0	$0.0	-100.0	0.0	2016	3.8%
TURBO2 6cyl	15.7%	$875.0	$0.0	-100.0	0.0	2016	3.8%
TURBO2 8cyl	15.7%	$1,644.9	$0.0	-100.0	0.0	2016	3.8%
CEGR1 4cyl	15.9%	$1,599.0	$0.0	-80.0	0.0	2016	3.8%
CEGR1 6cyl	15.9%	$1,302.0	$0.0	-80.0	0.0	2016	3.8%
CEGR1 8cyl	15.9%	$2,071.9	$0.0	-80.0	0.0	2016	3.8%
High compression ratio 1- 4cyl	12.3%	$127.1	$0.0	0.0	0.0	2016	2.0%
High compression ratio 1- 6cyl	12.3%	$133.6	$0.0	0.0	0.0	2016	2.0%
High compression ratio 1- 8cyl	12.3%	$182.4	$0.0	0.0	0.0	2016	2.0%
High compression ratio 1 (Plus)- 4cyl	13.8%	$182.4	$0.0	0.0	0.0	2018	2.0%
High compression ratio 1 (Plus)- 6cyl	13.8%	$188.9	$0.0	0.0	0.0	2018	2.0%
High compression ratio 1 (Plus)- 8cyl	13.8%	$237.6	$0.0	0.0	0.0	2018	2.0%
High compression ratio 2 (HCR with DEAC & CEGR)- 4cyl	19.4%	$425.8	$0.0	0.0	0.0	2051	3.0%
High compression ratio 2 (HCR with DEAC & CEGR)- 6cyl	19.4%	$528.2	$0.0	0.0	0.0	2051	3.0%
High compression ratio 2 (HCR with DEAC & CEGR)- 8cyl	19.4%	$685.6	$0.0	0.0	0.0	2051	3.0%

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2018 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
Advanced DEAC 4cyl	14.8%	$376.2	$0.0	10.0	0.0	2020	0.0%
Advanced DEAC 6cyl	14.8%	$506.7	$0.0	10.0	0.0	2020	0.0%
Advanced DEAC 8cyl	14.8%	$631.8	$0.0	10.0	0.0	2018	0.0%
Turbocharging and downsizing with cylinder deactivation, 4cyl	17.5%	$734.9	$0.0	-100.0	0.0	2020	0.0%
Turbocharging and downsizing with cylinder deactivation, 6cyl	17.5%	$436.3	$0.0	-100.0	0.0	2020	0.0%
Turbocharging and downsizing with cylinder deactivation, 8cyl	17.5%	$852.9	$0.0	-100.0	0.0	2020	0.0%

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2018 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
Turbocharging and downsizing with advanced cylinder deactivation, 4cyl	19.9%	$1,332.7	$0.0	-100.0	0.0	2020	0.0%
Turbocharging and downsizing with advanced cylinder deactivation, 6cyl	19.9%	$1,034.1	$0.0	-100.0	0.0	2020	0.0%
Turbocharging and downsizing with advanced cylinder deactivation, 6cyl	19.9%	$1,749.6	$0.0	-100.0	0.0	2020	0.0%
Electric power steering	1.3%	$131.0	$0.0	0.0	0.0	2004	0.0%
Improved accessories (IACC)	2.0%	$55.2	$0.0	0.0	0.0	2005	0.0%

Data source: U.S. Energy Information Administration, AEO2023 National Energy Modeling System, run REF2023.020623A

Table 2. Standard technology matrix for light trucks

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2018 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
Mass reduction, level 1 (5% reduction in glider weight)	1.5%	$0.0	$0.3	0.0	-2.5	2005	0.0%
Mass Reduction, level 2 (7.5% reduction in glider weight)	3.8%	$0.0	$0.7	0.0	-3.8	2009	0.0%
Mass Reduction, level 3 (10% reduction in glider weight)	6.5%	$0.0	$1.3	0.0	-5.0	2011	0.0%
Mass Reduction, level 4 (15% reduction in glider weight)	9.0%	$0.0	$1.9	0.0	-7.5	2015	0.0%
Mass Reduction, level 5 (20% reduction in glider weight)	9.9%	$0.0	$9.0	0.0	-10.0	2015	0.0%
Aero I-5% Cd reduction	1.0%	$57.2	$0.0	0.0	0.0	2000	0.0%
Aero II-10% Cd reduction	2.2%	$116.9	$0.0	0.0	0.0	2011	0.0%
Aero III-15% Cd reduction	3.5%	$292.2	$0.0	0.0	0.0	2015	0.0%
Aero IV-20% Cd reduction	5.3%	$762.3	$0.0	0.0	0.0	2015	0.0%
Tire rolling resistance I- 10% reduction	2.0%	$7.5	$0.0	0.0	0.0	2000	0.0%
Tire rolling resistance II- 20% reduction	4.0%	$56.8	$0.0	0.0	0.0	2010	0.0%
Low drag brakes	0.8%	$90.3	$0.0	0.0	0.0	2000	0.0%
Secondary axle disconnect	1.3%	$93.9	$0.0	0.0	0.0	2012	0.0%
Manual trans 5 spd (base only)	0.0%	$2.0	$0.0	0.0	0.0	1995	0.0%
Manual trans 6 spd	2.2%	$371.2	$0.0	0.0	0.0	1995	0.0%
Manual trans 7 spd	2.2%	$758.6	$0.0	0.0	0.0	2014	0.0%
Auto trans 5 (base only)	0.0%	$2.0	$0.0	0.0	0.0	1995	0.0%
Auto trans 6	7.4%	-$22.1	$0.0	0.0	0.0	2003	0.0%
Auto trans 6 level 2	7.9%	$276.7	$0.0	20.0	0.0	2012	0.0%
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Improved engine friction reduction, 4cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
Improved engine friction reduction, 6cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
Improved engine friction reduction, 8cyl	1.4%	$99.9	$0.0	0.0	0.0	2003	1.3%
SOHC VVL 4cyl	2.8%	$209.8	$0.0	25.0	0.0	2000	1.6%
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DOHC DEAC 8cyl	4.2%	$239.7	$0.0	10.0	0.0	2004	1.6%
TURBO1 4cyl	14.7%	$554.7	$0.0	-100.0	0.0	2009	2.5%
TURBO1 6cyl	14.7%	$256.1	$0.0	-100.0	0.0	2009	2.5%
TURBO1 8cyl	14.7%	$640.2	$0.0	-100.0	0.0	2009	2.5%
TURBO2 4cyl	16.2%	$1,172.0	$0.0	-100.0	0.0	2016	2.5%
TURBO2 6cyl	16.2%	$875.0	$0.0	-100.0	0.0	2016	2.5%
TURBO2 8cyl	16.2%	$1,644.9	$0.0	-100.0	0.0	2016	3.8%
CEGR1 4cyl	16.1%	$1,599.0	$0.0	-80.0	0.0	2016	3.8%
CEGR1 6cyl	16.1%	$1,302.0	$0.0	-80.0	0.0	2016	3.8%
CEGR1 8cyl	16.1%	$2,071.9	$0.0	-80.0	0.0	2016	3.8%
High compression ratio 1- 4cyl	7.7%	$127.1	$0.0	0.0	0.0	0	3.8%
High compression ratio 1- 6cyl	12.3%	$133.6	$0.0	0.0	0.0	0	3.8%
High compression ratio 1- 8cyl	12.3%	$182.4	$0.0	0.0	0.0	0	3.8%
High compression ratio 1 (Plus)- 4cyl	9.8%	$182.4	$0.0	0.0	0.0	0	3.8%
High compression ratio 1 (Plus)- 6cyl	14.4%	$188.9	$0.0	0.0	0.0	0	3.8%
High compression ratio 1 (Plus)- 8cyl	14.4%	$237.6	$0.0	0.0	0.0	0	3.8%
High compression ratio 2 (HCR with DEAC & CEGR)- 4cyl	18.1%	$425.8	$0.0	0.0	0.0	0	3.8%
High compression ratio 2 (HCR with DEAC & CEGR)- 6cyl	18.1%	$528.2	$0.0	0.0	0.0	0	3.8%
High compression ratio 2 (HCR with DEAC & CEGR)- 8cyl	18.1%	$685.6	$0.0	0.0	0.0	0	3.8%
Advanced DEAC 4cyl	12.4%	$376.2	$0.0	10.0	0.0	2020	3.8%
Advanced DEAC 6cyl	12.4%	$506.7	$0.0	10.0	0.0	2020	3.8%
Advanced DEAC 8cyl	12.4%	$631.8	$0.0	10.0	0.0	2018	3.8%
Turbocharging and downsizing with cylinder deactivation, 4cyl	16.6%	$734.9	$0.0	-100.0	0.0	2020	3.8%
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Turbocharging and downsizing with advanced cylinder deactivation, 4cyl	19.1%	$1,332.7	$0.0	-100.0	0.0	2020	3.8%
Turbocharging and downsizing with advanced cylinder deactivation, 6cyl	19.1%	$1,034.1	$0.0	-100.0	0.0	2020	3.8%
Turbocharging and downsizing with advanced cylinder deactivation, 6cyl	19.1%	$1,749.6	$0.0	-100.0	0.0	2020	0.0%
Electric power steering	0.9%	$131.0	$0.0	0.0	0.0	2004	0.0%
Improved accessories (IACC)	2.3%	$55.2	$0.0	0.0	0.0	2005	0.0%
SS12V (start-stop - 12V micro-hybrid)	3.5%	$306.4	$0.0	45.0	0.0	2005	0.0%
BISG (belt driven starter/alternator - 48V mild hybrid)	7.4%	$792.4	$0.0	80.0	0.0	2012	-2.5%

Data source: U.S. Energy Information Administration, AEO2023 National Energy Modeling System, run REF2023.020623A

We use the shortfall, expressed as degradation factors, to convert the new LDV as-tested, fuel-economy values to on-road fuel economy values.[vi] Degradation factors are adjustments to tested fuel economy values to account for the difference between fuel economy performance realized in the CAFE test procedure and fuel economy realized under normal driving conditions. The degradation factor is 0.817 for cars and 0.815 for light trucks from 2022 through 2050.

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 VMT coefficients below (Table 3).

Table 3. Vehicle miles traveled equation coefficients, by age and gender cohorts

Cohort	Age				
	15–19	**20–34**	**35–54**	**55–64**	**65 or more**
BETACOST					
Male	0.0398	0.0583	0.0423	0.0026	0.0327
Female	0.0404	0.0107	-0.0397	0.0491	-0.0368
ALPHA					
Male	3.5977	1.1284	1.7897	0.4314	-0.2296
Female	5.7351	0.3715	0.3798	-4.6139	-0.8011
BETAVMT					
Male	0.6303	0.7284	0.4847	0.3149	0.4809
Female	0.3542	0.3030	0.7739	0.3442	0.8714
BETAINC					
Male	-0.2389	0.0000	0.0000	0.1821	0.1490
Female	-0.4307	0.1603	0.0076	0.5858	0.0797
BETAVPLD					
Male	0.0000	-0.3556	0.0287	0.1185	0.1433
Female	0.3360	0.1714	0.5553	0.1247	0.5340
BETAEMP					
Male	0.8298	0.8384	0.7342	0.8702	0.3950
Female	0.3910	0.7022	-0.2556	0.3825	-0.4220

Data source: U.S. Energy Information Administration, AEO2023 National Energy Modeling System, run REF2023.020623A

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. Of total passenger car sales to fleets in 2021:

68% were used in business (rental) fleets
29% were used in commercial and utility fleets
2% were used in government fleets
1% were used in ride-hailing or taxi fleets

Of total light-truck sales to fleets in 2021:

34% were used in business (rental) fleets
58% were used in commercial and utility fleets
5% were used in government fleets
3% were used in ride-hailing or taxi fleets

We assume ride-hailing and taxi service fleets are 5% of the commercial and utility fleet, as designated by S&P Global R.L. Polk for cars and light trucks.[vii] Car and light-truck shares by fleet type hold constant from 2021 through 2050. In 2021, 16% of all passenger cars and 14% of all light trucks sold were for fleet use. After 2021, the fleets' shares of total passenger car and light-truck sales change as the sales distribution across census divisions vary.

Shares of vehicle sales by size class and fleet type remain the same as in 2016 in the projection (Table 4). We assume that after 2021, the shares of new vehicles purchased by powertrain type within each fleet type change depending on the usage and regulations for a given fleet (Table 5). Annual VMT per vehicle by fleet type stays constant during the projection period based on S&P Global R.L. Polk vehicle registration and odometer data.

Table 4. Share of new vehicle sales by fleet type and size class, 2016

	Fleet type			
Size class	**Business**	**Government**	**Commercial and utility**	**Ride-hailing and taxi service**
Car				
Mini	0.0%	0.0%	0.3%	2.0%
Subcompact	3.1%	0.7%	4.7%	4.0%
Compact	21.1%	8.3%	17.5%	17.0%
Midsize	41.2%	24.6%	44.2%	46.0%
Large	17.0%	59.2%	10.2%	30.0%
Two-seater	0.1%	0.2%	1.2%	1.0%
Small crossover utility vehicle	12.6%	4.6%	13.4%	0.0%
Large crossover utility vehicle	4.7%	2.4%	8.6%	0.0%
Light truck				
Small pickup	3.5%	4.1%	7.3%	0.5%
Large pickup	13.0%	27.8%	27.4%	0.5%
Small van	1.8%	2.7%	4.8%	10.0%
Large van	21.3%	8.8%	10.8%	34.0%
Small utility	2.6%	0.2%	2.2%	35.0%
Large utility	9.2%	11.8%	8.0%	20.0%
Small crossover utility vehicle	21.0%	4.6%	13.6%	0.0%

Large crossover utility vehicle	27.5%	40.0%	25.9%	0.0%

Data source: S&P Global Inc., copyright © R.L. Polk Co. or its third-party provider, various years, all rights reserved

Table 5. Share of new vehicle purchases by fleet type and powertrain, 2021

		Fleet type		
	Business	**Government**	**Commercial and utility**	**Ride-hailing and taxi service**
Car				
Gasoline	93.0%	63.8%	86.5%	92.7%
Diesel	0.0%	0.0%	0.0%	0.0%
Ethanol flex	4.5%	6.8%	0.5%	0.7%
Electric	0.0%	9.8%	6.1%	0.0%
Plug-in hybrid electric	0.0%	5.2%	0.8%	0.0%
Hybrid electric	2.4%	14.4%	6.1%	6.6%
Natural gas	0.0%	0.0%	0.0%	0.0%
LPG	0.0%	0.0%	0.0%	0.0%
Light Truck				
Gasoline	79.6%	80.9%	95.0%	95.5%
Diesel	0.0%	0.0%	0.0%	0.0%
Ethanol flex	20.3%	6.0%	0.5%	0.7%
Electric	0.0%	0.0%	0.2%	0.0%
Plug-in hybrid electric	0.0%	0.3%	0.6%	0.0%
Hybrid electric	0.1%	12.7%	3.7%	3.8%
Natural gas	0.0%	0.0%	0.0%	0.0%
LPG	0.0%	0.0%	0.0%	0.0%

Source data: S&P Global Inc., copyright © R.L. Polk Co. or its third-party provider, various years, all rights reserved

Note: LPG = liquefied petroleum gas

We assume highly automated vehicles (HAVs), including SAE International automation Levels 4 and 5,[viii] enter the ride-hailing or taxi service fleet in 2025, and a fleet-operator monthly return on investment calculation with assumed adoption rate limitations will determine their adoption. We further divide HAVs into three system configurations based on operational domain capabilities:

Level 4a: Low-speed operations in limited geo-fenced areas

Level 4b: Full-speed autonomous operations in limited geo-fenced areas that include any (legal) speed roads in a controlled environment (for example, limited-access highways). Highway speed operation requires a more sophisticated, higher-resolution and a more expensive HAV system to accurately sense and react to its environment within a shorter response time.

Level 5: Autonomous operations on all roads and road types, at all (legal) road speed limits, not limited to operational domains. The Level 5 HAV system is marginally more expensive than the Level 4b system because it needs a more capable and expensive processor and controller.

We assume HAVs are available for adoption in ride-hail and taxi service fleets and rely on similar operational assumptions as a human-driven taxi fleet (Table 6). HAVs are only offered in gasoline-powered vehicles because high-power HAV computation systems limit an electric vehicle's range and would, therefore, require longer refueling times, reducing daily revenue potential.

We assume fleet fuel economy for both conventional and alternative-fuel vehicles is the same as the personal new-vehicle fuel economy, and we subdivide fleet fuel economy into eight size classes for cars and eight for light trucks. HAVs are the only exception; we capture the additional power draw of the autonomous system with a degradation factor that improves during the projection period.

Table 6. Key assumptions for highly automated taxi fleet choice model

Parameter	Non-HAV	Level 4a	Level 4b	Level 5
First year available	-	2025	2030	2035
Annual VMT / vehicle	65,000	65,000	65,000	65,000
Lifetime mileage	450,000	450,000	450,000	450,000
Driver shifts per taxi, per day	2	0	0	0
Revenue per mile	$5.5	$5.5	$5.5	$5.5
Time-base monthly maintenance cost	$175	$300	$300	$300
Maintenance cost per mile	$0.10	$0.10	$0.10	$0.10
HAV incremental cost in 2018	-	$43,366	$48,630	$56,526
HAV incremental weight in 2018, pounds	-	28	48	51

Data source: Z FEDERAL, *Transportation Module/Autonomous Vehicle Model Development in NEMS – Deliverable 6.1.2 – Develop model design, algorithms, and structure*, April 2018

Note: Taxi operational parameters, including annual vehicle miles traveled (VMT), daily driver shifts, and revenue per mile, were primarily derived from analysis of New York City taxi trip record data and were adjusted based on analysis of taxi trip record data from Chicago, San Francisco, and Washington, DC. Costs are in 2018 U.S. dollars. HAV incremental cost and weight do not include LiDAR sensors or batteries.

Light Commercial Truck Component

The Light Commercial Truck Component of the NEMS TDM represents light trucks that have an 8,501-pound to 10,000-pound gross vehicle weight rating (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 Inc's registration data.[ix] We constructed annual vehicle travel schedules by vintage from the same registration data, along with the corresponding odometer reading data. As defined in NEMS, light, commercial trucks are a subset of Class 2 vehicles (vehicles with 6,001-pound to 10,000-pound GVWR) and are often referred to as Class 2b vehicles (8,501-pound to 10,000-pound GVWR). Class 2a vehicles (6,001-pound to 8,500-pound GVWR) are addressed in the Light-Duty Vehicle Submodule. 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. The fuel economy of new Class 2b trucks depends on the market penetration of advanced technology components.[x] For the advanced technology components, we determine market penetration based on technology type, cost effectiveness, and year of expected introduction. We base cost effectiveness on fuel price, vehicle travel, fuel economy improvement, and incremental capital cost.

Consumer vehicle choice assumptions

The Consumer Vehicle Choice Component (CVCC) uses a nested multinomial logit model that predicts sales shares 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, gasoline hybrid versus diesel hybrid). The third-level choice determines market share among the different technology sets.[xi] The technology sets include:

- Conventional fuel capable
    - Gasoline
    - Diesel
    - Flex fuel
    - Bi-fuel compressed natural gas (CNG)
    - Bi-fuel liquefied petroleum gas (LPG)
- Hybrid
    - Gasoline and diesel hybrid-electric vehicles (HEVs)
    - Gasoline plug-in hybrid electric vehicles (PHEVs) with less than 35 miles of all-electric range (PHEV20)
    - PHEVs with 35 miles or higher all-electric range (PHEV50)
- Dedicated alternative fuel
    - CNG
    - LPG
- Fuel cell
    - Hydrogen
    - Methanol
- Electric battery powered
    - 100-mile range (0–149 miles)
    - 200-mile range (150–250 miles)
    - 300-mile range (250+ miles)

The vehicle attributes considered in the choice algorithm include:

- Vehicle price
- Maintenance cost
- Battery replacement cost
- Range
- Multi-fuel capability
- Home refueling capability
- Fuel economy
- Acceleration
- Luggage space

Vehicle attributes are determined endogenously, except for maintenance cost, battery replacement cost, and luggage space.[xii] Battery costs for PHEVs and all-electric vehicles are based on the historical relationship between cumulative production and pack price, described by a learning rate. The fuel attributes used in market share estimation include availability and price. Vehicle attributes vary by eight size classes for cars and eight for light trucks, and fuel availability varies by census division. The nested multinomial logit model coefficients reflect 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). We assume many fuel efficiency improvements in conventional vehicles transfer to alternative-fuel vehicles. Specific, individual alternative-fuel technology improvements also depend on the CVCC technology type, cost, research and development, and availability over time. We assume make and model availability estimates according to a logistic curve based on the initial technology introduction date and current offerings. 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 IHS Markit Polk and sales data from the EPA Engines and Vehicles Compliance Information System.[xiii, xiv] We calibrated CVCC vehicle sales in the first projection year (2022) to the October 2022 year-to-date sales data from Ward's Intelligence.[xv] 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 bi-fuel and flex-fuel ethanol vehicles.

Battery Cost Submodule

Lithium-ion battery costs (dollar per kilowatthour) are calculated 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 critical mineral 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.[xvi]

In 2022, critical mineral prices increased significantly, likely due to a mismatch in supply and demand. This mismatch led to what is estimated to have been the first year-over-year increase in electric-vehicle battery prices since electric vehicles entered the mass market in the early 2010s. To account for this, we implemented a price increase starting in 2022 that phases out over the next decade, under the assumption that supply and demand—particularly for lithium, nickel, and cobalt—will reach equilibrium over that timeframe. In addition, we reduced the learning rate used in the materials stage of the battery cost model from 3.5% to 0%.

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 three size classes are further divided into 14 subclasses for fuel economy classification (Table 7). These subclasses include 2 breakouts for the light-medium size class (pickup/van and vocational), 1 breakout for medium (vocational), and 10 breakouts for heavy. The 10 subclasses divide the heavy size class into Class 7 or Class 8; day cab or sleeper cab; and low, mid, or high roof. 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 (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.[xvii] The technology input data are specific to the type of truck and include the year of introduction, incremental fuel efficiency improvement, and capital cost (Table 8).

Table 7. Vehicle technology category for technology matrix for freight trucks

Vehicle category	Class	Type	Roof[a]
1	2b–3	Pickup and van	-
2	2b–5	Vocational	-
3	6–7	Vocational	-
4	8	Vocational	-
5	7	Tractor—day cab	Low
6	7	Tractor—day cab	Mid
7	7	Tractor—day cab	High
8	8	Tractor—day cab	Low
9	8	Tractor—day cab	Mid
10	8	Tractor—day cab	High
11	8	Tractor—sleeper cab	Low
12	8	Tractor—sleeper cab	Mid
13	8	Tractor—sleeper cab	High
14	8	Tractor—heavy haul	-

Data source: Greenhouse Gas Emissions 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 Rules, *Federal Register*, Vol. 81, No. 206 (October 2016)

[a] Applies to Class 7 and 8 day and sleeper cabs only.

Table 8. Standard technology matrix for freight trucks

Technology	Vehicle category	Introduction year	Capital costs (2015 dollars)	Engine type	Incremental fuel economy improvement (percentage)
Lower rolling resistance tires 1	1	2010	$10	All	1.1%[1]
	2–3,5–7	2010	$145	All	0.1%–1.7%[1]
	4,8–13	2010	$241	All	0.2%–1.3%[1]
Lower rolling resistance tires 2	1	2010	$82	All	2.2%[1]
	2–3,5–7	2010	$145	All	0.7%–1.7%[1]
	4,8–13	2010	$241	All	0.0%–1.3%[1]
Lower rolling resistance tires 3	2–3,5–7	2018	$177	All	1.6%–2.7%[1]
	4,8–13	2018	$295	All	2.3%–3.5%[1]
Lower rolling resistance tires 4	5–7	2021	$191	All	4.3%–4.6%[1]
	8–13	2021	$319	All	5.1%–5.9%[1]
Tire pressure monitoring system	2–4	2018	$342	All	0.9%
	5–7	2018	$421	All	1.0%
	8–14	2018	$648	All	1.0%
Automated tire inflation system	2–3	2018	$713	All	1.1%
	4	2018	$1,019	All	1.1%
	5–14	2018	$1,019	All	1.2%
Aerodynamics bin 1	1	2015	$53	All	0.8%
Aerodynamics bin 2	1	2015	$240	All	1.5%
	5–6,8–9,11–12	2010	$1,236	All	0.1%[1]
Aerodynamics bin 3	5–6,8–9	2014	$2,250	All	1.2%–1.7%[1]
	7,10	2014	$1,144	All	0.7%–0.8%[1]
	11–12	2014	$2,574	All	1.9%[1]
Aerodynamics bin 4	5–6,8–9	2014	$2,198	All	3.3%–4.4%[1]
	7,10	2014	$1,746	All	3.9%–4.1%[1]
	11–12	2014	$2,514	All	4.5%–4.7%[1]
Aerodynamics bin 5	7,10	2014	$2,529	All	6.4%–7.1%[1]
	13	2014	$2,937	All	7.1%[1]
Aerodynamics bin 6	7,10	2014	$3,074	All	9.0%–10.1%[1]
	13	2014	$3,570	All	10.5%[1]
Aerodynamics bin 7	7,10	2014	$3,619	All	11.6%–13.2%[1]
	13	2014	$4,204	All	13.9%[1]
Weight reduction (via single wide tires and/or aluminum wheels)	4	2014	$2,702	All	0.9%[1]
Weight reduction via material changes (assuming 10% on a 6,500 pound vehicle), 5% for 2b–3	1	2016	$84	All	1.5%
Weight reduction via material changes, 200 pounds for LH/MH vocational, additional 5% for 2b–3	1	2014	$249	All	1.5%
	2–3	2014	$772	All	0.8%–1.4%*
Low drag brakes	1	2014	$114	All	0.4%
Electric power steering	1	2015	$158	SI,CI	0.9%
Driveline friction reduction	1	2015	$145	All	0.5%
Improved accessories IACC1 (electrification)	1	2015	$86	SI,CI	0.9%
Improved accessories IACC2 (electrification)	1	2021	$138	SI,CI	0.9%
Improved accessories (42-volt electrical system, power steering, and electric AC)	2	2018	$472	SI,CI	2.0%
	3	2018	$892	All	2.0%
	4	2018	$1,783	All	1.5%
	5–14	2018	$312	All	1.0%
Air-conditioning efficiency	2–3	2018	$24	All	1.0%
	4	2018	$24	All	0.5%
	5–14	2018	$193	All	0.5%
Right-sized diesel engine	1	2014	$10	CI	5.0%

	5–13	2014	$10	CI	0.3%

Technology	Vehicle category	Introduction year	Capital costs (2015 dollars)	Engine type	Incremental fuel economy improvement (percentage)
Aftertreatment improvements 1 (diesel I Phase 1)	1	2010	$131	CI	4.0%
	2	2010	$129	CI	1.0%
Aftertreatment improvements 2 (Phase 2)	2–14	2014	$17	CI	0.6%
Low-friction lubrications—(diesel II Phase 1)	1–14	2005	$4	CI	0.5%
Engine friction reduction (diesel IV Phase 1)	1–2	2010	$128	CI	1.0%
	3–14	2010	$275	CI	1.0%
Improved water, oil, and fuel pump, pistons; valve train friction (VTF pickup, LH, MH vocational only) (diesel VI Phase 1)	1–2	2010	$234	CI	1.3%
	3,5–8	2010	$205	CI	1.3%
	4,9–13	2010	$165	CI	1.3%
Parasitic/friction (cylinder Kits, pumps, FIE), lubrication—phase 2 Package	5–13	2021	$239	CI	1.4%
Valve actuation (diesel III Phase 1)	2–13	2005	$231	CI	1.0%
Turbo efficiency improvements 1 (diesel V Phase 1—except pickups)	1	2021	$17	CI	2.5%
	2–14	2010	$20	CI	1.5%
Low temperature EGR, improved turbochargers (diesel IX Phase 1)	1	2010	$202	CI	5.0%
Sequential downsizing/turbocharging—(diesel X Phase 1)	5–13	2010	$1,320	CI	2.5%
Cylinder head, fuel rail and injector, EGR Cooler improvements 1 (diesel VII Phase 1)	1–2	2010	$46	CI	4.7%
	3–14	2010	$34	CI	4.7%
EGR/intake and exhaust manifolds/turbo/VVT/ports phase 2 package	5–13	2021	$255	CI	1.1%
Turbo compounding 1—mechanical (diesel VIII Phase 1)	5–13	2017	$1,100	CI	3.9%
Turbo compound with clutch—diesel phase 2 package	5–13	2021	$1,127	CI	1.8%
Waste heat recovery (same as diesel engine XI Phase 1)	4–13	2021	$11,377	CI	8.0%
Model based control	2–4	2021	$129	CI	2.0%
Combustion/FI/Control—phase 2 package	5–13	2021	$154	CI	1.1%
Downspeed—phase 2 package	5–13	2021	$0	SI,CI	0.1%
Low friction lubricants (gas I phase 1)	1–14	2010	$4	SI	0.5%
Engine friction reduction 1—(gas III Phase 1)	1–2	2010	$128	SI	2.0%
	3–4		$104	SI	2.0%
Engine changes to accommodate low friction lubes—required for engine friction reduction 2	1	2014	$6	SI	0.5%
Engine friction reduction 2	1	2014	$266	SI	2.0%
Stoichiometric gasoline direct injection (SGDI) (gas IV Phase 1)	1	2006	$471	SI	1.5%
	2	2010	$471	SI	1.5%
	3–4	2014	$471	SI	1.5%
Coupled cam phasing—SOHC & OHV only (gas II Phase 1—except pickups)	1	2015	$45	SI	2.0%
	2–4	2010	$51	SI	2.6%
Intake cam phasing VVT—DOHC gas	1	2015	$91	SI	1.5%
Dual cam phasing VVT—DOHC gas	1	2015	$193	SI	2.0%
Discrete variable valve lift (DVVL)—gasoline	1	2015	$310	SI	2.0%
Continuously variable valve lift (CVVL)—gasoline	1	2015	$519	SI	5.1%
Cylinder deactivation—gasoline	1	2021	$205	SI	3.9%
Turbocharge and downsize SGDI V8 to V6 (gas V Phase 1)	1–4	2018	$1,917	SI	2.1%
Cooled EGR—gasoline	1	2010	$390	SI	4.0%
6x2 axle	8–13	2018	$223	All	1.7%–2.2%[1]
Axle disconnect	4	2014	$124	All	1.6%[1]
Axle downspeed	5–13	2018	$61	All	1.2%–3.5%[1]
High efficiency axle	2–3	2018	$148	All	2.0%
	4–14	2018	$223	All	2.0%

Technology	Vehicle category	Introduction year	Capital costs (2015 dollars)	Engine type	Incremental fuel economy improvement (percentage)
8-speed transmission (two gears+HEG+ASL1 for pickups, not for vocational)	1	2018	$478	SI,CI	2.7%
	2–4	2018	$583	SI,CI	1.2%
Automated and automated manual transmission (AMT)	4–14	2018	$5,025	SI,CI	2.0%
High efficiency gearbox (HEG)	2–4	2021	$351	SI,CI	8.2%
	5–13	2021	$351	SI,CI	1.0%
Advanced shift strategy	2–4	2021	$97	SI,CI	4.5%
Early torque converter lockup (TORQ)	2–4	2015	$34	SI,CI	1.6%
Auto transmission, power-shift	5–13	2018	$15,922	SI,CI	2.0%
Dual clutch transmission (DCT)	5–14	2021	$17,241	SI,CI	2.0%
Neutral coast—requires automatic	5–13	2014	$0	SI,CI	1.0%
Advanced cruise control—requires automatic	5–13	2018	$980	All	2.0%
Stop-start (no regeneration for pickups, with enhancements for vocational)	1	2015	$563	SI,CI	1.1%[a]
	2	2021	$965	SI,CI	11.4%[a]
	3	2021	$1,015	SI,CI	9.7%[a]
	4	2021	$1,865	SI,CI	7.9%[a]
Neutral idle	2–4	2018	$121	SI,CI	4.1%–6.0%[a]
Tamper-proof AESS (automatic engine start/stop)	2–3	2018	$33	SI,CI	4.8%–5.7%[a]
	4	2014	$33	SI,CI	4.1%[a]
	5–13	2014	$33	SI,CI	4.1%
Adjustable AESS programmed to five minutes	11–13	2014	$33	SI,CI	1.0%
Tamper-proof AESS with diesel APU (auxiliary power unit)	11–13	2014	$6,461	SI,CI	4.1%
Adjustable AESS with diesel APU	11–13	2014	$6,461	SI,CI	3.3%
Tamper-proof AESS with battery APU	11–13	2015	$5,574	SI,CI	6.4%
Adjustable AESS with battery APU	11–13	2014	$5,574	SI,CI	5.1%
Tamper-proof AESS with auto stop-start	11–13	2015	$8,690	SI,CI	3.3%
Adjustable AESS with auto stop-start	11–13	2015	$8,690	SI,CI	2.6%
Tamper-proof AESS with FOH cold, main engine warm	11–13	2014	$997	SI,CI	2.8%
Adjustable AESS with FOH cold, main engine warm	11–13	2021	$997	SI,CI	2.2%
Mild hybrid (HEV)	1	2017	$2,854	SI,CI	3.2%
	2	2018	$6,960	SI,CI	12.0%
	3	2018	$10,939	SI,CI	12.0%
	4	2018	$18,269	SI,CI	12.0%
Strong hybrid (without stop-start for vocational)	1	2021	$7,087	SI,CI	17.2%
	2–4	2021	$13,044	SI,CI	8.0%

Data source: Greenhouse Gas Emissions 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 Rules, *Federal Register*, Vol. 81, No. 206 (October 2016); Final Rulemaking to Establish Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2, Regulatory Impact Analysis, U.S. Environmental Protection Agency and U.S. Department of Transportation, (August 2016); Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study—Report #1, National Highway Traffic Safety Administration (June 2015, Revised October 2015); Greenhouse Gas Emissions Model (GEM) for Medium- and Heavy-Duty Vehicle Compliance, U.S. Environmental Protection Agency (July 2016)

[a] Estimated with Greenhouse Gas Emissions Model (GEM)

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 3–8 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.[xviii] VMT growth is derived from growth in ton-mile demand and is applied to historical freight truck VMT by region and commodity type.[xix, xx] We then distribute projected VMT by size class and vintage based on annual VMT schedules from Vehicle Inventory and Use Survey (VIUS) data.[xxi]

Fuel economy of new freight trucks depends on the market penetration of advanced technology components.[xxii] 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 determine initial freight truck stocks by vintage and fuel type by analyzing S&P Global R.L. Polk data. We also estimate vehicle scrappage rates using S&P Global R.L. Polk data.

Freight rail

The Rail Freight 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.[xxiii] 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.[xxiv] 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.[xxv]

The Transportation Energy Data Book provides domestic shipping efficiencies, and the Department of the Army Corps of Engineers provides historical ton-miles.[xxvi, xxvii] 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.[xxviii]

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 is 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 (for example, biofuels and water injection) are also under development by industry but have not yet reached wide-scale adoption; we are considering the modeling options for future NEMS programs that are not in the current program.

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.[xxix]

Air Travel Submodule

The Air Travel Submodule is a 16-region world demand and supply model for passenger and cargo transport (Table 9). 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 9. Sixteen regions for the Air Travel Submodule, AEO2023

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, 2020 World Jet Inventory, data tables (2021)
Note: *Annual Energy Outlook 2023*=AEO2023.

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 2021 and are based on historical relationships between population, gross domestic product (GDP), RPMs, and RTMs from 1995 to 2020.[xxx, xxxi] Freight RTMs are split between belly freight (carried in the cargo holds of passenger aircraft) and dedicated freighters.

Table 10. Regional population, gross domestic product (GDP), per capita GDP, domestic and international revenue passenger miles (RPM), and per capita RPM, 2020

Region	Population (million)	GDP (billion 2015 purchasing power parity)	Domestic route RPM (billion)	International route RPM (billion)	GDP per capita	Domestic RPM per capita	International RPM per capita
United States	331	19,247	304	100	58,074	917	301
Canada	38	1,647	12	22	43,298	315	588
Mexico	207	3,393	29	18	16,368	142	86
OECD Europe	590	23,103	160	150	39,141	272	254
Japan	126	5,101	27	27	40,336	214	212
Australia and New Zealand	31	1,395	19	25	45,397	618	821
South Korea	51	2,142	6	20	41,779	111	383
Russia	146	3,676	64	13	25,189	439	86
Other Europe and Eurasia	195	2,823	6	17	14,442	29	85
China	1,440	23,640	364	43	16,417	253	30
India	1,382	8,647	38	18	6,258	28	13
Other non-OECD Asia	1,217	12,097	82	91	9,936	68	75
Middle East	251	4,762	25	65	18,980	100	257
Africa	1,340	6,301	12	25	4,703	9	19
Brazil	213	2,914	29	11	13,697	136	52
Non-OECD Americas	234	2,498	9	22	10,671	39	96

Data source: GDP and population: NEMS Macroeconomic Activity Module [US], Oxford Economics [non-US], RPM: ICAO Annual Report and Traffic by Flight Stage, and Bureau of Transportation Statistics, Air Carrier Statistics (Form 41 Traffic).
Note: International RPMs are allocated to the origin region. Totals may not equal sum of components because of independent rounding.

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 2020 (Table 11), new passenger aircraft sales, and the survival rate by vintage (Table 11 and Table 12).[xxxii]

Table 11. Active passenger and cargo aircraft supply by region, 2020

	Age of aircraft in years					
Passenger and cargo aircraft type	**New**	**1 to 10[a]**	**11 to 20**	**21 to 30**	**More than 30**	**Total**
Passenger—narrow-body						
United States	71	1426	1040	577	41	3084
Canada	19	77	60	32	13	182
Mexico	18	250	60	12	10	332
OECD Europe	100	1187	878	204	8	2277
Japan	5	187	74	0	0	261
Australia and New Zealand	0	121	111	12	0	244
South Korea	3	69	83	5	1	158
Russia	8	201	175	56	17	449
Other Europe and Eurasia	7	184	100	83	19	386
China	88	2217	709	23	3	2952
India	52	347	116	3	4	470
Other non-OECD Asia	10	579	149	29	12	769
Middle East	23	246	83	76	40	445
Africa	13	108	131	79	37	355
Brazil	3	138	108	7	0	253
Non-OECD Americas	0	110	57	32	48	247
Passenger—wide-body						
United States	33	223	66	131	13	433
Canada	3	40	18	8	0	66
Mexico	0	45	13	0	0	58
OECD Europe	37	411	176	93	3	683
Japan	9	153	85	21	0	259
Australia and New Zealand	0	22	13	0	0	35
South Korea	3	60	31	16	0	107
Russia	1	32	33	22	0	87
Other Europe and Eurasia	0	15	8	8	2	33
China	6	417	65	2	0	484
India	2	28	11	0	0	39
Other non-OECD Asia	10	285	68	13	2	368
Middle East	12	402	89	23	23	537
Africa	4	90	27	6	3	126
Brazil	0	23	7	2	0	32
Non-OECD Americas	0	4	6	12	0	22
Passenger—regional jet						
United States	40	661	1003	176	28	1868
Canada	4	78	67	86	50	281
Mexico	0	50	48	27	12	137
OECD Europe	9	308	313	133	56	810
Japan	0	66	37	8	0	111

	Age of aircraft in years					
Passenger and cargo aircraft type	**New**	**1 to 10[a]**	**11 to 20**	**21 to 30**	**More than 30**	**Total**
Passenger—regional jet (cont.)						
Australia and New Zealand	1	46	59	124	33	262
South Korea	0	0	2	0	0	2
Russia	2	127	50	15	14	206
Other Europe and Eurasia	5	45	38	29	11	123
China	20	135	41	8	0	184
India	0	81	17	3	0	101
Other non-OECD Asia	4	163	111	66	20	360
Middle East	0	22	27	59	12	120
Africa	3	70	147	129	57	403
Brazil	4	85	41	34	9	169
Non-OECD Americas	0	49	38	44	30	161
Cargo—narrow-body						
United States	0	0	16	137	108	261
Canada	0	0	0	16	5	21
Mexico	0	0	0	11	26	37
OECD Europe	0	0	11	89	23	123
Japan	0	0	0	0	0	0
Australia and New Zealand	0	0	0	9	9	18
South Korea	0	0	0	1	0	1
Russia	0	0	3	3	0	6
Other Europe and Eurasia	0	0	0	5	7	12
China	0	0	1	23	0	24
India	0	0	0	8	0	8
Other non-OECD Asia	0	0	0	11	23	34
Middle East	0	0	0	3	2	5
Africa	0	0	0	8	18	26
Brazil	0	0	0	6	12	18
Non-OECD Americas	0	0	1	5	3	9
Cargo—wide-body						
United States	20	174	109	273	84	640
Canada	0	0	0	13	2	15
Mexico	0	6	5	5	4	20
OECD Europe	8	64	51	50	17	182
Japan	0	8	7	4	0	19
Australia and New Zealand	0	2	4	0	0	6
South Korea	0	21	6	9	0	36
Russia	1	14	5	1	0	20
Other Europe and Eurasia	0	5	1	11	11	28
China	4	41	34	9	0	84

Passenger and cargo aircraft type	New	1 to 10[a]	11 to 20	21 to 30	More than 30	Total
		Age of aircraft in years				
Cargo—wide-body (cont.)						
India	0	0	0	0	0	0
Other non-OECD Asia	2	14	22	2	2	40
Middle East	2	50	4	3	17	74
Africa	0	9	1	4	0	14
Brazil	0	0	2	1	0	3
Non-OECD Americas	0	0	0	1	3	4
Cargo—regional jet						
United States	0	0	1	18	11	30
Canada	0	0	1	3	6	10
Mexico	0	0	0	5	2	7
OECD Europe	1	1	3	34	39	77
Japan	0	0	0	0	0	0
Australia and New Zealand	0	0	0	2	9	11
South Korea	0	0	0	0	0	0
Russia	0	0	0	0	0	0
Other Europe and Eurasia	0	0	0	0	6	6
China	0	0	0	0	0	0
India	0	0	0	0	0	0
Other non-OECD Asia	0	0	0	12	4	16
Middle East	0	0	0	0	1	1
Africa	0	0	2	5	1	8
Brazil	0	0	0	0	0	0
Non-OECD Americas	0	0	0	5	3	8

Data source: Jet Information Services, 2020 World Jet Inventory (2021)

[a]age group 1–10 includes new

Note: Totals may not equal sum of components because of independent rounding.

Table 12. Aircraft survival curve fractions

Aircraft type	New	5	10	20	40
		Age of aircraft in years			
Passenger—narrow-body	1.000	0.988	0.985	0.962	0.842
Passenger—wide-body	1.000	0.989	0.988	0.971	0.805
Passenger—regional jet	1.000	0.986	0.983	0.966	0.892
Cargo—narrow-body	1.000	1.000	1.000	0.990	0.884
Cargo—wide-body	1.000	1.000	1.000	0.999	0.844
Cargo—regional jet	1.000	1.000	1.000	0.994	0.936

Data source: Jet Information Services, 2019 World Jet Inventory data, and Dray, Lynnette. “An Analysis of the Impact of Aircraft Lifecycles on Aviation Emissions Mitigation Policies.” *Journal of Air Transport Management* (May 1, 2013)

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 0.8% 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

Light-Duty Vehicle Combined Safer Affordable Fuel-Efficient (SAFE) standards

The AEO2023 Reference case includes the joint attribute-based SAFE and vehicle greenhouse gas emissions standards for model year (MY) 2021 through MY2023 and updated CAFE standards for MY2024 through MY2026.[xxxiii] Fuel economy standards are held constant in subsequent model years, although fuel economy improvements are still possible based on continued improvements in economic effectiveness.

Greenhouse gas emissions (GHG) standards and fuel efficiency standards for medium- and heavy-duty engines and vehicles

On September 15, 2011, EPA and NHTSA jointly announced a final rule called the HD National Program,[xxxiv] which established GHG emissions and fuel consumption standards for the first time for on-road, heavy-duty trucks and their engines. The freight transport submodule incorporates the standards for heavy-duty vehicles (HDVs) with a GVWR of more than 8,500 pounds (Classes 2b through 8). The HD National Program standards began for MY2014 vehicles and engines and were fully phased in by MY2018. Standard compliance is modeled among 13 HDV regulatory classifications that represent the discrete vehicle categories set forth in the rule. 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 began for MY2021 vehicles and will be fully phased in by MY2027.[xxxv] The same vehicle classes and their engines are included, but the second round also adds heavy-haul tractors (increasing the number of regulator classifications to 14) and trailers (begins MY2018), which were previously unregulated under the HD National Program. The standards are held constant in subsequent model years.

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. Tranferring 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.

EISA2007 extended the CAFE credits under the Alternative Motor Fuels Act (AMFA) through 2019. Before Congress passed this act, the CAFE credits under AMFA were scheduled to expire after MY2010. EISA2007 extended the 1.2 mpg credit maximum through 2014 and reduced the maximum by 0.2 mpg for each following year until the credit phased out at the start of MY2020. NEMS models CAFE credits earned from alternative-fuel vehicle sales.

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 offers up to $7,500 to purchasers of eligible electric and hydrogen fuel-cell vehicles.[xxxvi] 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. So, we used the official U.S. government forecasted expenditures on the IRA clean vehicle credit to estimate impacts on battery-electric vehicle and PHEV adoption.[xxxvii]

The IRA also provides a production tax credit of $35 per kilowatthour to U.S. battery manufacturers for domestically produced batteries. We did not include this credit in the projection due to the uncertainty around the potential impact it could have on battery costs and electric vehicle 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 electric vehicle pricing is uncertain at this time. In addition, electric vehicle 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.

Energy Policy Act of 1992 (EPACT1992)

We based fleet alternative-fuel vehicle sales that are required to meet the EPACT1992 regulations on legal requirements and the Commercial Fleet Vehicle Component calculations. Total projected alternative-fuel vehicle (AFV) sales are divided into fleets by government, business, and fuel providers (Table 13).

Table 13. Energy Policy Act of 1992 requirements for alternative-fuel vehicle purchases, by fleet type and year

Year	Federal	State	Fuel providers	Electric utilities
2005	75%	75%	70%	90%

Data source: 10 C.F.R. § 490.201 1996

Because the commercial fleet model operates in multiple fleet types, the federal and state requirements are weighted by fleet vehicle stocks to create a single requirement for both. We use the same combining methodology to create a composite requirement for electric utilities and fuel providers based on fleet vehicle stocks.

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.[xxxviii] 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.[xxxix, xl] 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 Zero-Emission Vehicle regulations for model years 2018 and beyond

On July 10, 2014, the California Air Resource Board (CARB) issued a new rule for its Zero Emission Vehicle (ZEV) program for MY2018 and later. The ZEV program affects MY2018 and later vehicles, and it requires automakers to earn credits for alternative-fuel vehicles based on a percentage of their LDV sales in California. Sixteen other states (Colorado, Connecticut, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, Virginia, and Washington) have adopted all or part of California's ZEV program.[xli] The ZEV sales requirement is administered through credits that are earned for selling specific types of vehicles, including but not limited to, battery-electric and plug-in, hybrid-electric vehicles. The value of the credits for vehicles sold within each category depends on certain vehicle characteristics, such as the electric driving range of electric vehicles. The total percentage requirement starts at 4.5% for MY2018 sales and increases to 22% for MY2025 sales. Manufacturers can carry over excess credits from one year to the next, which allows credits to be banked. Manufacturers can use banked credits from overcompliance in later years to help meet credit requirements. Full ZEVs must account for 16% of the MY2025 credits, to be met by selling vehicles powered by either electricity or hydrogen fuel cells.

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 greenhouse gases (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

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