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 (cars, light trucks, and two- and three-wheeled vehicles)
- Commercial light trucks (8,501–10,000 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 (LDV) fuel consumption into household usage and commercial fleet consumption.

Key assumptions

Key assumptions for transportation travel demand, efficiency, and energy consumption address light-duty vehicles (LDVs), 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, and fractional horsepower change. We developed input assumptions from multiple runs of the Volpe Corporate Average Fuel Economy (CAFE) Model[1] (**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 2018 levels based on U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) data.[2, 3] We project the shares of sales by size-class based on income per capita, fuel prices, and average predicted vehicle prices based on endogenous calculations within the MTCC.[4]

The MTCC uses the technologies listed in **Table 1** and **Table 2** for each manufacturer and size class to make a market adoption determination 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:

- The financial parameters used to determine a technology's economic effectiveness are evaluated based on the need to improve fuel economy to meet CAFE program standards compared with

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 joint attribute-based final CAFE and final vehicle greenhouse gas (GHG) emissions standards, as issued in 2020.[5] 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 2000 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 5spd (base only)	0.0%	$2.0	$0.0	0.0	0.0	1995	0.0%
Manual trans 6spd	1.7%	$371.2	$0.0	0.0	0.0	1995	0.0%
Manual trans 7spd	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%
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%

Table 1. Standard technology matrix for cars (cont.)

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2000 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
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 DEAC 4cyl	4.2%	$180.2	$0.0	10.0	0	2016	2.5%
SOHC DEAC 6cyl	4.2%	$212.6	$0.0	10.0	0	2010	2.5%
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%
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%
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%
SS12V (start-stop - 12V micro-hybrid)	2.7%	$229.1	$0.0	45.0	0.0	2005	0.0%
BISG (belt driven starter/alternator - 48V mild hybrid)	7.8%	$792.4	$0.0	80.0	0.0	2012	0.0%

Source: U.S. Energy Information Administration, AEO2022 National Energy Modeling System, run REF2022.011222A

Table 2. Standard technology matrix for light trucks

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2000 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 I-5% reduction	1.5%	$0.0	$0.3	0.0	-2.5	2005	0.0%
Mass reduction II-7.5% reduction	3.8%	$0.0	$0.7	0.0	-3.8	2009	0.0%
Mass reduction III-10% reduction	6.5%	$0.0	$1.3	0.0	-5.0	2011	0.0%
Mass reduction IV-15% reduction	9.0%	$0.0	$1.9	0.0	-7.5	2015	0.0%
Mass reduction V-20% reduction	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 6spd	2.2%	$371.2	$0.0	0.0	0.0	1995	0.0%
Manual trans 7spd	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%
7-speed automatic transmission, level 2 (base only)	7.9%	$237.6	$0.0	0.0	0.0	2009	0.0%
CVT (base only)	10.2%	$253.1	$0.0	0.0	0.0	1998	1.3%
CVT level 2 (replacing CVT)	13.8%	$190.2	$0.0	-25.0	0.0	2015	1.3%
Auto trans 8	12.7%	$110.2	$0.0	50.0	0.0	2009	1.3%
Auto trans 8 level 2	14.1%	$397.7	$0.0	50.0	0.0	2014	2.3%
Auto trans 8 level 3	14.8%	$628.0	$0.0	50.0	0.0	2016	2.3%
9-speed automatic transmission, level 2 (base only)	10.8%	$513.2	$0.0	50.0	0.0	2016	2.3%
Auto trans 10 level 2	14.0%	$513.2	$0.0	50.0	0.0	2016	0.0%
Auto trans 10 level 3	14.8%	$744.2	$0.0	50.0	0.0	2023	0.0%
DCT 6	12.7%	$30.6	$0.0	-10.0	0.0	2004	1.3%
DCT 8 (includes 7)	14.2%	$569.0	$0.0	0.0	0.0	2012	1.3%
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%
SOHC VVL 6cyl	2.8%	$314.8	$0.0	40.0	0.0	2000	2.5%
SOHC VVL 8cyl	2.8%	$419.7	$0.0	50.0	0.0	2000	2.5%
SOHC SGDI 4cyl	2.0%	$349.7	$0.0	20.0	0.0	2006	2.5%
SOHC SGDI 6cyl	2.0%	$524.6	$0.0	30.0	0.0	2006	2.5%
SOHC SGDI 8cyl	2.0%	$699.5	$0.0	40.0	0.0	2006	2.5%
SOHC DEAC 4cyl	4.2%	$180.2	$0.0	10.0	0.0	2016	2.5%
SOHC DEAC 6cyl	4.2%	$212.6	$0.0	10.0	0.0	2010	2.5%
SOHC DEAC 8cyl	4.2%	$239.7	$0.0	10.0	0.0	2004	2.5%
DOHC VVL 4cyl	2.8%	$316.2	$0.0	25.0	0.0	2000	1.3%
DOHC VVL 6cyl	2.8%	$474.2	$0.0	40.0	0.0	2000	1.3%
DOHC VVL 8cyl	2.8%	$632.3	$0.0	50.0	0.0	2000	1.3%
DOHC SGDI 4cyl	2.0%	$349.7	$0.0	20.0	0.0	2006	1.3%
DOHC SGDI 6cyl	2.0%	$524.6	$0.0	30.0	0.0	2006	1.3%
DOHC SGDI 8cyl	2.0%	$699.5	$0.0	40.0	0.0	2006	1.6%
DOHC DEAC 4cyl	4.2%	$180.2	$0.0	10.0	0.0	2016	1.6%
DOHC DEAC 6cyl	4.2%	$212.6	$0.0	10.0	0.0	2010	1.6%
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%

Table 2. Standard technology matrix for light trucks (cont.)

Technology	Fuel efficiency change (percentage)	Incremental cost in year 2000 dollars	Incremental cost (dollars per unit weight)	Absolute incremental weight (pounds)	Per unit incremental weight (pounds per unit weight)	Introduction year	Horsepower change (percentage)
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%
Turbocharging and downsizing with cylinder deactivation, 6cyl	16.6%	$436.3	$0.0	-100.0	0.0	2020	3.8%
Turbocharging and downsizing with cylinder deactivation, 8cyl	16.6%	$852.9	$0.0	-100.0	0.0	2020	3.8%
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%

Source: U.S. Energy Information Administration, AEO2022 National Energy Modeling System, run REF2022.011222A

We use levels of shortfall, expressed as degradation factors, to convert the new LDV as-tested fuel-economy values to on-road fuel economy values.[6] Degradation factors represent adjustments made 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 2020 through 2050.

The LDV Vehicle Miles Traveled (VMT) Component uses fuel prices, personal income, employment, number of vehicles per licensed driver, and population demographics to generate projections of demand for personal travel. We use population demographic distribution assumptions from the U.S. Census Bureau and divide them into 2 gender and 5 age categories for 10 total 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	-0.0324	-0.0122	-0.0165	-0.0150	-0.0096
Female	0.0100	-0.0140	-0.0084	-0.0003	-0.0368
ALPHA					
Male	0.1015	1.4667	1.4044	0.5871	-0.1083
Female	1.9156	-0.3144	-2.1115	-1.7768	-0.8011
BETAVMT					
Male	0.9727	0.8378	0.5963	0.7324	0.8410
Female	0.7062	0.5702	0.5030	0.6034	0.8714
BETAINC					
Male	0.0000	-0.0764	0.0000	0.0307	0.0466
Female	-0.1260	0.1516	0.3238	0.2563	0.0797
BETAVPLD					
Male	0.1036	0.0000	0.2779	0.1792	0.0000
Female	0.0000	0.0000	0.0000	0.4777	0.5340
BETAEMP					
Male	0.0000	0.3525	0.4025	0.2694	-0.0266
Female	0.2019	0.3492	0.0890	0.1379	-0.4220

Source: U.S. Energy Information Administration, AEO2022 National Energy Modeling System, run REF2022.011222A.

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-duty 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 2020, 61% were used in business (rental) fleets, 34% in commercial and utility fleets, 3% in government fleets, and 2% in ride-hailing or taxi fleets. Of total light truck sales to fleets in 2020, 39% were used in business (rental) fleets, 53% in commercial and utility fleets, 5% in government fleets, and 3% 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 IHS Markit Polk for cars and light trucks.[7] Car and light-truck shares by fleet type hold constant from 2020 through 2050. In 2020, 16% of all passenger cars and 18% of all light trucks sold were for fleet use. After 2020, the fleets' shares of total passenger car and light truck sales change as the sales distribution across census divisions varies.

Shares of vehicle sales by size class and fleet type remain at 2016 levels for both alternative- and conventional-fuel vehicles (**Table 4** and **Table 5**). We assume that after 2020, 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 6**). After returning to pre-pandemic 2019 levels in 2022, annual VMT per vehicle by fleet type stays constant during the projection period based on Polk vehicle registration and odometer data.

Table 4. Alternative-fuel new vehicle sales shares 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%

Source: IHS Markit Polk, National Vehicle Population Profile, various years

Table 5. Conventional-fuel new vehicle sales shares by fleet type and size class, 2016

Size class	Business	Government	Commercial and utility	Ride-hailing and taxi service
		Fleet type		
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%

Source: IHS Markit Polk, National Vehicle Population Profile, various years

Table 6. Share of new vehicle purchases by fleet type and powertrain, 2020

	Business	Government	Commercial and utility	Ride-hailing and taxi service
		Fleet type		
Car				
Gasoline	96.2%	73.3%	88.2%	92.9%
Diesel	0.0%	0.0%	0.0%	0.0%
Ethanol flex	3.1%	6.3%	0.6%	0.7%
Electric	0.0%	5.7%	4.2%	0.0%
Plug-in hybrid electric	0.0%	3.8%	0.9%	0.0%
Hybrid electric	0.7%	10.8%	6.1%	6.4%
Natural gas	0.0%	0.0%	0.0%	0.0%
LPG	0.0%	0.0%	0.0%	0.0%
Light Truck				
Gasoline	83.7%	85.8%	90.9%	92.4%
Diesel	0.0%	0.1%	1.1%	0.0%
Ethanol flex	16.2%	6.9%	5.1%	5.2%
Electric	0.0%	0.0%	0.1%	0.0%
Plug-in hybrid electric	0.0%	0.4%	0.4%	0.0%
Hybrid electric	0.1%	6.9%	2.4%	2.5%
Natural gas	0.0%	0.0%	0.0%	0.0%
LPG	0.0%	0.0%	0.0%	0.0%

Source: IHS Markit Polk, National Vehicle Population Profile, various years
Note: LPG = liquefied petroleum gas

We assume highly automated vehicles (HAVs), including SAE International automation Levels 4 and 5,[8] enter the ride-hailing or taxi service fleet in 2025, and their adoption will be determined by a fleet operator monthly return on investment calculation with assumed adoption rate limitations. We further

divide HAVs into three system configurations based on operational domain capabilities:

- Level 4a: Restricted to low-speed operations in limited geo-fenced areas
- Level 4b: Full-speed autonomous operation restricted to operation in limited geo-fenced areas that include any (legal) speed roads and where the environment is fairly controlled, such as 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: Operates autonomously on all roads and road types, at all (legal) road speed limits, and are 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 7**). 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 7. Key assumptions for highly automated taxi fleet choice model

Parameter	Non-HAV	L4a	L4b	L5
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

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 Transportation Demand Module 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 used primarily for commercial purposes. This component implements a 34-year stock model that estimates vehicle stocks, travel, fuel economy, and energy use by vintage (age).

We derived the distribution of vehicles by vintage and vehicle scrappage rates from analysis of registration data from IHS Markit Polk.[9] We constructed vehicle travel by vintage by using vintage distribution curves and estimates of average annual travel by vehicle.[10, 11] 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.[12] 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 (NMNL) 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.[13] The technology sets include:
- Conventional fuel capable: gasoline, diesel, flex-fuel, bi-fuel compressed natural gas (CNG), and bi-fuel liquefied petroleum gas (LPG)
- Hybrid: gasoline and diesel hybrid-electric vehicles (HEVs), and gasoline plug-in hybrid electric vehicles (PHEVs) with 20-mile all-electric range (PHEV20) and 50-mile all-electric range (PHEV50)
- Dedicated alternative fuel: CNG and LPG
- Fuel cell: hydrogen and methanol
- Electric battery powered: 100-mile range (0–150 miles), 200-mile range (151–250 miles), and 300-mile range (251+ 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.[14] 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 NMNL 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 technological 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. Historical vehicle sales are based on analysis of IHS Markit Polk and sales data from the EPA Engines and Vehicles Compliance Information System.[15, 16] We calibrated CVCC vehicle sales in the first projection year (2021) to the October 2021 year-to-date sales data from 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 bi-fuel and flex-fuel ethanol vehicles.

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 8**). 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 is designed to cover 34 vehicle vintages and to estimate 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 (SEDS).[18] 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 9**).

Table 8. 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	-

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 9. 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%

Table 9. Standard technology matrix for freight trucks (cont.)

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%

Table 9. Standard technology matrix for freight trucks (cont.)

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	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	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%

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

Sources: 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)

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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 with geographic information system data that we use to determine regional distances between origin or destination points.[19] VMT growth is derived from growth in ton-mile demand and is applied to historical freight truck VMT by region and commodity type.[20, 21] We then distribute projected VMT by size class and vintage based on annual VMT schedules from Vehicle Inventory and Use Survey (VIUS) data.[22]

Fuel economy of new freight trucks depends on the market penetration of advanced technology components.[23] 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 through analysis of IHS Markit Polk data, and they are distributed by fuel type using VIUS data. We also estimate vehicle scrappage rates using IHS Markit Polk data.

Freight rail

The Rail Freight Component uses the industrial output by NAICS code measured in real 2009 dollars and a ton-mile per dollar output measure to project rail ton-miles by census division and commodity, which is developed from the Freight Analysis Framework.[24] We use coal production from the NEMS Coal Market Module to adjust data for coal transported by rail. We develop freight rail historical ton-miles from U.S. Department of Transportation data.[25] Historic freight rail efficiencies are based on historical data from the U.S. Department of Transportation.[26] The 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.[27]

Domestic and international waterborne freight

Similar to the previous component, the domestic freight shipping within the Waterborne Freight Component uses the industrial output by NAICS code measured in real 2009 dollars and a ton-mile per dollar output measure to project domestic marine ton-miles by census division and industrial commodity to develop rates of domestic marine travel.[28, 29]

The Transportation Energy Data Book provides domestic shipping efficiencies.[30] The energy consumption in 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 for LNG as a marine fuel starting in 2013 based on fuel economics.[31] Historical estimates of regional domestic shipping fuel shares are distributed according to regional shares in our State Energy Data System (SEDS).[32]

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), and 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), the allowed amount of sulfur emissions from ships is 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 available for operations on open seas, 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; modeling options are up for consideration in future NEMS programs but 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 report we released in 2015, which includes methodology and assumptions for projecting fuel demand within North American ECAs.[33]

Air Travel Submodule

The Air Travel Submodule is a 13-region world demand and supply model for passenger and cargo transport (**Table 10**). 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 10. Thirteen regions for the Air Travel Submodule, AEO2022

Region number	Region	Major countries in region
1	United States	United States
2	Canada	Canada
3	Central America	Mexico
4	South America	Brazil
5	Europe	France, Germany, United Kingdom
6	Africa	Nigeria, South Africa
7	Middle East	Egypt
8	Russia	Russia
9	China	China
10	Northeast Asia	Japan, Korea
11	Southeast Asia	Vietnam
12	Southwest Asia	India
13	Oceania	Australia, New Zealand

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 2020 and are based on historical relationships between population, gross domestic product (GDP), RPMs, and RTMs from 1995 to 2019.[34] Freight RTMs are split between belly freight (carried in the cargo holds of passenger aircraft) and dedicated freighters.

Table 11. 2020 regional population, gross domestic product (GDP), per capita GDP, domestic and international revenue passenger miles (RPM), and per capita RPM

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	19,241	304	95	58,054	917	287
Canada	38	1,640	15	14	43,144	395	368
Central America	223	3,164	12	32	14,169	54	143
South America	431	5,631	42	20	13,071	97	46
Europe	631	23,732	195	115	37,612	309	182
Africa	1,238	5,045	14	18	4,077	11	15
Middle East	362	6,380	21	58	17,626	58	160
Russia	295	5,449	75	11	18,451	254	37
China	1,448	24,112	361	27	16,651	249	19
Northeast Asia	204	7,290	35	29	35,820	172	142
Southeast Asia	693	9,220	51	46	13,296	74	66
Southwest Asia	1,857	10,956	37	19	5,899	20	10
Oceania	42	1,439	20	13	34,341	477	310

Sources: GDP and population: EIA Macro [US], Oxford Economics [non-US], RPM: Boeing Current Market Outlook 2020–2039 and Bureau of Transportation Statistics, Air Carrier Statistics (Form 41 Traffic). We equally split International RPMs are between origin and destination regions.
Note: 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 12**), new passenger aircraft sales, and the survival rate by vintage (**Table 13**).[35]

Table 12. Active passenger and cargo aircraft supply by region, 2020

Passenger and cargo aircraft type	New	1 to 10	11 to 20	21 to 30	More than 30	Total
Passenger—narrow-body						
United States	81	1,686	1,471	933	75	4,165
Canada	19	150	123	79	23	375
Central America	16	280	106	39	25	450
South America	9	388	260	60	58	766
Europe	97	1,866	1,526	549	40	3,981
Africa	1	118	150	127	49	444
Middle East	41	407	199	126	45	777
Russia	14	353	285	159	42	839
China	90	2,478	772	59	3	3,312
Northeast Asia	9	304	207	13	6	530
Southeast Asia	11	804	257	39	10	1,110
Southwest Asia	55	451	215	15	6	687
Oceania	-	148	164	21	-	333
Passenger—wide-body						
United States	39	270	155	240	31	696
Canada	3	53	48	37	8	146
Central America	-	20	6	4	-	30
South America	-	85	28	15	-	128
Europe	40	541	359	179	5	1,084
Africa	6	111	44	11	6	172
Middle East	13	558	173	48	34	813
Russia	1	59	56	48	3	166
China	9	520	116	21	-	657
Northeast Asia	12	247	139	66	-	452
Southeast Asia	10	384	135	20	-	539
Southwest Asia	2	55	34	11	2	102
Oceania	-	66	51	2	-	119
Passenger—regional jet						
United States	40	717	1,385	260	33	2,395
Canada	8	105	124	130	72	431
Central America	-	78	93	50	24	245
South America	5	169	85	86	35	375
Europe	13	418	512	219	78	1,227
Africa	5	107	195	157	64	523
Middle East	-	42	51	69	14	176
Russia	4	214	108	52	22	396
China	20	159	59	9	-	227

Table 12. Active passenger and cargo aircraft supply by region, 2020 (cont.)

Passenger and cargo aircraft type	Age of aircraft in years					
	New	1 to 10	11 to 20	21 to 30	More than 30	Total
Passenger—regional jet (cont.)						
Northeast Asia	-	67	47	14	-	128
Southeast Asia	4	250	112	41	13	416
Southwest Asia	2	100	53	21	1	175
Oceania	1	65	80	183	60	388
Cargo—narrow-body						
United States	-	-	16	147	127	290
Canada	-	-	-	19	5	24
Central America	-	-	1	16	17	34
South America	-	-	-	14	38	52
Europe	-	-	11	101	74	186
Africa	-	-	1	13	29	43
Middle East	-	-	-	4	5	9
Russia	-	-	3	5	1	9
China	-	-	1	102	6	109
Northeast Asia	-	-	-	3	-	3
Southeast Asia	-	-	-	12	26	38
Southwest Asia	-	-	-	9	10	19
Oceania	-	-	-	10	11	21
Cargo—wide-body						
United States	20	175	110	324	247	856
Canada	-	-	-	13	5	18
Central America	-	-	1	4	7	12
South America	-	6	6	3	17	32
Europe	8	66	53	58	58	235
Africa	-	10	-	10	16	36
Middle East	2	53	7	13	35	108
Russia	1	19	6	15	21	61
China	4	42	36	24	17	119
Northeast Asia	-	30	13	16	3	62
Southeast Asia	2	14	23	12	8	57
Southwest Asia	-	-	-	3	4	7
Oceania	-	2	6	-	-	8
Cargo—regional jet						
United States	-	-	2	23	13	38
Canada	-	-	2	4	8	14
Central America	-	-	1	8	1	10
South America	-	-	-	5	7	12
Europe	1	1	3	46	62	112
Africa	-	-	2	6	2	10

Table 12. Active passenger and cargo aircraft supply by region, 2020 (cont.)

			Age of aircraft in years			
Passenger and cargo aircraft type	New	1 to 10	11 to 20	21 to 30	More than 30	Total
Cargo—regional jet (cont.)						
Middle East	-	-	-	1	1	2
Russia	-	-	-	-	-	-
China	-	-	-	-	-	-
Northeast Asia	-	-	-	-	-	-
Southeast Asia	-	-	-	10	3	13
Southwest Asia	-	-	-	4	1	5
Oceania	-	-	-	2	12	14

Source: Jet Information Services, 2020 World Jet Inventory (2021)
Note: Totals may not equal sum of components because of independent rounding.

Table 13. Aircraft survival curve fractions

		Age of aircraft in years			
Aircraft type	New	5	10	20	40
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

Source: EIA analysis of 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 a rate of 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 AEO2022 Reference case includes the joint attribute-based SAFE and vehicle GHG emissions standards for MY2021 through MY2026. Fuel economy standards are then 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,[36] 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 GVWR more than 8,500 pounds (Classes 2b through 8). The HD National Program standards begin for MY2014 vehicles and engines and are 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 implemented (that is, phased in) by MY2027.[37] 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, CAFE credits earned by manufacturers can be banked for up to three years and can be applied only to the fleet (car or light truck) from which the credit was earned. 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 oil 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 earned to any of the three model years before the model year the credits are earned and to any of the five model years after the credits are earned. The transfer of 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; and for MY2018 and later, the maximum

credit transfer is 2.0 mpg. NEMS currently allows for sensitivity analysis of CAFE credit banking by manufacturer fleet, 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 the passage of this act, the CAFE credits under AMFA were scheduled to expire after MY 2010. EISA2007 extended the 1.2 mpg credit maximum through 2014 and reduced the maximum by 0.2 mpg for each following year until being phased out at the start of MY2020. NEMS models CAFE credits earned from alternative-fuel vehicle sales.

American Recovery and Reinvestment Act of 2009 (ARRA) and Energy Improvement and Extension Act of 2008 (EIEA2008)

The tax credit (EIEA2008 Title II, Section 205), for purchasing new, qualified plug-in electric-drive motor vehicles was modified under ARRA Title I, Section 1141. Under the modified law, a qualified plug-in electric-drive motor vehicle must draw propulsion from a traction battery with at least 4 kilowatthours (kWh) of capacity and be propelled to a significant extent by an electric motor that draws electricity from a battery that can be recharged from an external source of electricity.

The tax credit for purchasing a plug-in electric vehicle is $2,500 and, starting at a battery capacity of 5 kWh, an additional $417 per kWh battery credit up to a maximum of $7,500 per vehicle. The tax credit eligibility and phaseout are specific to a vehicle manufacturer. The credits are phased out once a manufacturer's cumulative sales of qualified vehicles reach 200,000 vehicles. The phaseout period begins two calendar quarters after the first date in which a manufacturer's sales reach the cumulative sales maximum after December 31, 2009.[38] The credit is reduced to 50% of the total value for the first two calendar quarters of the phase-out period and then to 25% for the third and fourth calendar quarters before being phased out entirely. The credit applies to vehicles with a GVWR of less than 14,000 pounds.

ARRA also allows a tax credit of 10% against the cost of a qualified electric vehicle with a battery capacity of at least 4 kWh, subject to the same phaseout rules as above. The sales projections include the tax credits for qualified plug-in electric drive motor vehicles and electric vehicles.

Energy Policy Act of 1992 (EPACT1992)

Fleet alternative-fuel vehicle sales required to meet the EPACT1992 regulations are based on the current 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 14**).

Table 14. 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%

Source: 10 C.F.R. § 490.201 1996

Because the commercial fleet model operates on multiple fleet types, the federal and state

requirements are weighted by fleet vehicle stocks to create a single requirement for both. The same combining methodology is used to create a composite mandate 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.[39] 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 nm from 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.[40,41] 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 will 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.

Low-Emission Vehicle Program (LEVP)

The LEVP was originally passed into law in 1990 in California. The program began as a voluntary opt-in pilot program under the Clean Air Act Amendments of 1990 (CAAA1990), which includes a provision that other states could opt in to the California program to achieve lower emissions levels than would otherwise be achieved through CAAA1990. The California LEVP has been adopted by 15 states. California amended and expanded the program in 1998 to cover more vehicles, increase stringency, and add zero-emission vehicle (ZEV) credits.

The LEVP is a fleet-averaged, emissions-based policy for smog-forming pollutants and sets sales requirements for six categories of low-emission vehicles:

- Low-emission vehicles (LEV)
- Ultra-low-emission vehicles (ULEV)
- Super-ultra-low-emission vehicles (SULEV)
- Partial zero-emission vehicles (PZEV)
- Advanced technology partial zero-emission vehicles (AT-PZEV)
- Zero-emission vehicles (ZEV)

California has amended the LEVP a number of times, most recently in 2014, to cover more vehicles, increase stringency, and add ZEV credits.

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. Nine other states (Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont) have adopted California's ZEV program. 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. Banked credits from over-compliance can be used in later years to help meet credit requirements. Full ZEVs must account for 16% of the MY2025 credits, to be met by the sale of vehicles powered by either electricity or hydrogen fuel cells.

The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule, finalized on September 27, 2019, preempts state programs that regulate vehicle GHG, fuel economy, and ZEV programs based on EPA's and NHTSA's statutory authority to set nationally applicable vehicle emission and fuel economy standards. The transportation module retains the capability to model these programs, but because of the change in regulation, the state-based ZEV requirements are set to zero after 2019.

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

The California Global Warming Solutions Act of 2006 set a statewide reduction of 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 1990 levels. Senate Bill 32 and Assembly Bill 32 provisions direct state policies that affect transportation sector model assumptions to target a higher adoption of ZEVs and other alternative powertrains and to target a decrease in travel.

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[39] U.S. Environmental Protection Agency, "MARPOL Annex VI" (Washington, DC, January 14, 2015).

[40] U.S. Environmental Protection Agency, op. cit., Note 39.

[41] 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.