Transportation Demand

The NEMS Transportation Demand Module estimates transportation energy consumption across the nine Census Divisions (see Figure 5) and over ten fuel types. Each fuel type is modeled according to fuel-specific technology attributes applicable by transportation mode. Total transportation energy consumption is the sum of energy use in eight transport modes: light-duty vehicles (cars and light trucks), commercial light trucks (8,501-10,000 lbs gross vehicle weight), freight trucks (>10,000 lbs gross vehicle weight), buses, freight and passenger aircraft, freight and passenger rail, freight shipping, and miscellaneous transport such as recreational boating. Light-duty vehicle fuel consumption is further subdivided into personal usage and commercial fleet consumption.

Key assumptions

Light-duty vehicle assumptions

The light-duty vehicle Manufacturers echnology Choice Model (MTCM) includes 63 fuel savingtechnologies with data specific to cars and light trucks (Tables 7.1 and 7.2) including incremental fueleconomy improvement, incremental cost, first year of introduction, and fractional horsepower change.

The vehicle sales share module holds the share of vehicle sales by manufacturers constant within a vehicle size class at 2008 levels based on National Highway Traffic and Safety Administration (NHTSA) data [1]. Environmentall Protection Agency (EPA) size class sales shares are projected as a function of income per capita, fuel prices, and average predicted vehicle prices based on endogenous calculations within the MTCM [2] .

The MTCM utiizes 63 new technologies for each size class and manufacturer based on the cost-effectiveness of each technology and an initial availability year. The discounted stream of fuel savings is compared to the marginal cost of each technology. The fuel economy module assumes the following:

- The economic effectiveness of all fuel technologies are evaluated on a varying basis to meet a strict CAFE standard.
- Fuel economy standards reflect current law through model year 2016, according to NHTSA model year 2011 final rulemaking and joint EPA and NHTSA rulemaking for 2012 through 2016. For model years 2017 through 2020, the standards reflect EIA assumed increases that ensure a light vehicle combined fuel economy of 35 mpg is achieved by model 2020. For model years 2021 though 2030, fuel economy standards are held constant at model year 2020 levels with fuel economy improvements still possible based on an economic cost benefit analysis only.
- Expected future fuel prices are calculated based on an extrapolation of the growth rate between a five year moving average of fuel price 3 years and 4 years prior to the present year. This assumption is founded upon an assumed lead time of 3 to 4 years to significantly modify the vehicles offered by a manufacturer.

Table 7.1. Standard technology matrix for cars[1]

	Fuel Efficiency Change %	Incremental Cost (2000$)	Incremental Cost ($/Unit Wt.)	Absolute Incremental Weight (Lbs.)	Per Unit Incremental Weight (Lbs./Unit Wt.)	Introduc-tion Year	Horse-power Change%
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1990	0
Material Substitution III	6.6	0	0.6	0	-10	1998	0
Material Substitution IV	9.9	0	0.9	0	-15	2006	0
Material Substitution V	13.2	0	1.2	0	-20	2014	0
Drag Reduction II	1.5	16	0	0	0	1988	0
Drag Reduction III	3.0	32	0	0	0.2	1992	0
Drag Reduction IV	4.2	45	0	0	0.5	2000	0
Drag Reduction V	5.0	53.5	0	0	1	2010	0
Roll-Over Technology	-1.5	100	0	0	2.2	2004	0
Side Impact Technology	-1.5	100	0	0	2.2	2004	0
Adv Low Loss Torque Converter	2	25	0	0	0	1999	0
Early Torque Converter Lockup	0.5	25.6	0	0	0	2002	0
Aggressive Shift Logic	1.5	30.5	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	2.5	106.5	0	20	0	1995	0
6-Speed Automatic	2.9	259	0	30	0	2003	0
6-Speed Manual	0.5	91.4	0	20	0	1995	0
CVT	5.0	240.5	0	-25	0	1998	0
Automated Manual Trans	7.3	138.6	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1980	0
OHC/AdvOHV-4 Cylinder	2.0	99	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	2.0	115.7	0	0	0	1987	2.5
OHC/AdvOHV-8 Cylinder	2.0	132.3	0	0	0	1986	2.5
4-Valve/4-Cylinder	8	205	0	10	0	1988	4.25
4-Valve/6-Cylinder	8	280	0	15	0	1992	4.25
4 Valve/8-Cylinder	8	320	0	20	0	1994	4.25
5 Valve/6-Cylinder	8	300	0	18	0	1998	5
VVT-4 Cylinder	2.0	48.9	0	10	0	1994	1.25
VVT-6 Cylinder	2.0	97.8	0	20	0	1993	1.25
VVT-8 Cylinder	2.0	97.8	0	20	0	1993	1.25
VVL-4 Cylinder	2.0	162.2	0	25	0	1997	2.5
VVL-6 Cylinder	2.0	245.4	0	40	0	2000	2.5
VVL-8 Cylinder	2.0	317.5	0	50	0	2000	2.5
Camless Valve Actuation-4cyl	13.6	400.9	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	13.6	561.3	0	55	0	2020	3.25
Camless Valve Actuation-8cyl	13.6	721.6	0	75	0	2020	3.25
Cylinder Deactivation	5.3	152.3	0	10	0	2004	0
Turbocharging/Supercharging	6.3	324.7	0	-100	0	1980	3.75
Engine Friction Reduction I	2.3	54	0	0	0	1992	0.75
Engine Friction Reduction II	2.8	60.9	0	0	0	2000	1.25
Engine Friction Reduction III	4.0	138.7	0	0	0	2008	1.75
Engine Friction Reduction IV	6.5	177	0	0	0	2016	2.25
Stoichiometric GDI/4-Cylinder	2.4	293.8	0	20	0	2006	2.5
Stoichiometric GDI/6-Cylinder	2.4	377.6	0	30	0	2006	2.5
Lean Burn GDI	10.0	640.5	0	20	0	2020	0
5W-30 Engine Oil	0.5	4.0	0	0	0	1998	0
5W-20 Engine Oil	2	16.7	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	1.5	90.6	0	0	0	2004	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2007	0
Tires II	1.8	15.8	0	-8	0	1995	0
Tires III	2.7	19.9	0	-12	0	2005	0
Tires IV	3.8	22.9	0	-16	0	2015	0
Front Wheel Drive	6	250	0	0	-6	1980	0
Four Wheel Drive Improvements	1.3	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	-2.5
42V-Engine Off at Idle	6.8	496.6	0	45	0	2005	0
Tier 2 Emissions Technology	-1	120	0	20	0	2006	0
Increased Size/Weight	-0.5	0	0	0	2.55	2006	0
Variable Compression Ratio	4	350	0	25	0	2015	0

[1] Fractional changes refer to the percentage change from the base technology.

Sources: Energy and Environment Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002).

Table 7.2. Standard technology matrix for light trucks[1]

	Fuel Efficiency Change%	Incremental Cost (2000$)	Incremental Cost ($/UnitWt.)	Absolute Incremental Weight (Lbs.)	Per Unit Incremental Weight (Lbs./ UnitWt.)	Introduc-tion Year	Horse-power Change%
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1994	0
Material Substitution III	6.6	0	0.6	0	-10	2002	0
Material Substitution IV	9.9	0	0.9	0	-15	2010	0
Material Substitution V	13.2	0	1.2	0	-20	2018	0
Drag Reduction II	2.0	32	0	0	0	1992	0
Drag Reduction III	4.1	57	0	0	0.2	1998	0
Drag Reduction IV	6.4	89	0	0	0.5	2006	0
Drag Reduction V	7.8	109	0	0	1	2014	0
Roll-Over Technology	-1.5	100	0	0	2.2	2006	0
Side Impact Technology	-1.5	100	0	0	2.2	2006	0
Adv Low Loss Torque Converter	2	25	0	0	0	2005	0
Early Torque Converter Lockup	0.5	25.6	0	0	0	2003	0
Aggressive Shift Logic	1.5	30.5	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	2.5	106.5	0	20	0	1995	0
6-Speed Automatic	2.9	259	0	30	0	2003	0
6-Speed Manual	0.5	91.4	0	20	0	1995	0
CVT	7.0	138.6	0	-25	0	1998	0
Automated Manual Trans	3.4	157.5	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1985	0
OHC/AdvOHV-4 Cylinder	2.0	99	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	2.0	115.7	0	0	0	1990	2.5
OHC/AdvOHV-8 Cylinder	2.0	132.3	0	0	0	1990	2.5
4-Valve/4-Cylinder	7	205	0	10	0	1998	4.25
4-Valve/6-Cylinder	7	280	0	15	0	2000	4.25
4 Valve/8-Cylinder	7	320	0	20	0	2000	4.25
5 Valve/6-Cylinder	7	300	0	18	0	2010	5
VVT-4 Cylinder	2.0	48.9	0	10	0	1998	1.25
VVT-6 Cylinder	2.0	97.8	0	20	0	1997	1.25
VVT-8 Cylinder	2.0	97.8	0	20	0	1997	1.25
VVL-4 Cylinder	2.0	161.2	0	25	0	2002	2.5
VVL-6 Cylinder	2.0	245.4	0	40	0	2001	2.5
VVL-8 Cylinder	2.0	317.5	0	50	0	2006	2.5
Camless Valve Actuation-4cyl	13.6	400.9	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	13.6	561.3	0	55	0	2020	3.25
Camless Valve Actuation-8cyl	13.6	721.6	0	75	0	2020	3.25
Cylinder Deactivation	5.3	152.3	0	10	0	2004	0
Turbocharging/Supercharging	6.3	481.3	0	-100	0	1987	3.75
Engine Friction Reduction I	2.5	25	0	0	0	1992	0.75
Engine Friction Reduction II	3.5	63	0	0	0	2000	1.25
Engine Friction Reduction III	5	178.0	0	0	0	2010	1.75
Engine Friction Reduction IV	6.5	177	0	0	0	2016	2.25
Stoichiometric GDI/4-Cylinder	2.4	293.9	0	20	0	2008	2.5
Stoichiometric GDI/6-Cylinder	2.4	377.7	0	30	0	2010	2.5
Lean Burn GDI	10.8	640.5	0	20	0	2010	0
5W-30 Engine Oil	0.5	4.0	0	0	0	1998	0
5W-20 Engine Oil	2	16.7	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	1.5	90.2	0	0	0	2005	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2008	0
Tires II	0.0	30	0	-8	0	1995	0
Tires III	1.3	15.4	0	-12	0	2005	0
Tires IV	2.7	19.5	0	-16	0	2015	0
Front Wheel Drive	2	250	0	0	-3	1984	0
Four Wheel Drive Improvements	1.3	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	2.5
42V-Engine Off at Idle	6.8	434.9	0	45	0	2005	0
Tier 2 Emissions Technology	-1	160	0	20	0	2006	0
Increased Size/Weight	-0.8	0	0	0	3.75	2006	0
Variable Compression Ratio	4	350	0	25	0	2015	0

[1]Fractional changes refer to the percentage change from the base technology.

Sources: Energy and Environment Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002). National Highway Traffic Safety Administration, Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (April 2008). U.S. Environmental Protection Agency, Interim Report: New Powertrain Technologies and Their Projected Costs (October 2005).

Degradation factors are used to convert new vehicle tested fuel economy values to "on-road" fuel economy values (Table 7.3). The 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.

Table 7.3. Car and light truck degradation factors

	2005	2010	2015	2020	2030	2035
Cars	78.3	81.8	82.3	82.8	83.8	83.8
Light Trucks	85.9	84.0	84.0	84.0	84.0	84.0

Source: U.S. Energy Information Administration, *Transportation Sector Model of the National Energy Modeling System*, Model Documentation 2010, DOE/EIA-M070(2007), (Washington, DC, 2010).

Commercial light duty fleet assumptions

The Transportation Demand Module divides commercial light-duty fleets into three types: business, government, and utility. Based on this classification, commercial light-duty fleet vehicles vary in survival rates and duration of in-fleet use before sale for use as personal vehicles (Table 7.4). The average length of time passenger cars are kept before being sold for personal use is 4 years for business use, 5 years for government use, and 6 years for utility use. Of total automobile sales to fleets, 80.6 percent are used in business fleets, 6.5 percent in government fleets, and 12.9 percent in utility fleets. Of total light truck sales to fleets, 59.5 percent are used in business fleets, 3.6 percent in government fleets, and 36.8 percent in utility fleets [3]. Both the automobile and light truck shares by fleet type are held constant from 2005 through 2035. In 2006, 18.1 percent of all automobiles sold and 18.2 percent of all light trucks sold were for fleet use. The share of total automobile and light truck sales to decline over the forecast period based on historic trends.

Table 7.4. 2005 percent of fleet alternative fuel vehicles by fleet type by size class

	Mini	Subcompact	Compact	Midsize	Large	2-Seater
Car						
Business	0.0	10.5	10.7	42.7	36.1	0.0
Government	0.0	2.8	40.0	2.8	54.4	0.0
Utility	0.0	7.9	34.7	12.3	45.1	0.0
	SM Pk	**LG Pk**	**SM Van**	**LG Van**	**SM Util**	**LG Util**
Light Truck						
Business	7.9	35.1	7.9	26.6	5.5	16.8
Government	6.7	50.8	28.4	4.6	1.6	7.8
Utility	8.2	52.1	6.0	32.7	0.3	0.7

Source: CNEAF Alternatives to Traditional Transportation Fuels 2005 (Part II - User and Fuel Data).
http://www.eia.doe.gov/cneaf/alternate/page/aftables/afvtransfuel_II.html #in use

Alternative-fuel shares of fleet vehicle sales by fleet type are held constant at 2005 levels. Size class sales shares of vehicles are also held constant at 2005 levels (Table 7.5) [4]. Individual sales shares of new vehicles purchased by technology type are assumed to remain constant for utility, government, and for business fleets [5] (Table 7.6).

Annual VMT per vehicle by fleet type stays constant over the forecast period based on the Oak Ridge National Laboratory fleet data.

Fleet fuel economy for both conventional and alternative-fuel vehicles is assumed to be the same as the personal new vehicle fuel economy and is subdivided into six EPA size classes for cars and light trucks.

Table 7.5. Commercial fleet size class shares by fleet and vehicle type
percentage

Fleet Type by Size Class	Automobiles	Light Trucks
Business Fleet		
Mini	3.1	2.5
Subcompact	23.4	8.4
Compact	26.6	23.3
Midsize	36.2	8.1
Large	9.9	14.2
2-seater	0.8	43.6
Government Fleet		
Mini	0.2	6.7
Subcompact	4.6	43.6
Compact	20.6	10.4
Midsize	28.6	17.1
Large	46.0	3.8
2-seater	0.0	18.4
Utility Fleet		
Mini	1.5	7.3
Subcompact	12.5	36.7
Compact	10.0	11.8
Midsize	59.2	18.9
Large	16.4	7.2
2-seater	0.4	16.1

Source: Oak Ridge National Laboratory, Fleet Characteristics and Data Issues. Stacy Davis and Lorena Truett, final report prepared for the Department of Energy, Energy Information Administration, Office of Energy Analysis. (Oak Ridge, TN, January 2003).

Table 7.6. Share of new vehicle purchases by fleet type and technology type
percentage

Technology	Business	Government	Utility
Cars			
Gasoline	99.6	79.4	99.7
Ethanol Flex	0.3	19.0	0.1
Electric	0.01	0.01	0.00
CNG Bi-Fuel	0.1	1.4	0.1
LPG Bi-Fuel	0.01	0.00	0.00
CNG	0.1	0.2	0.1
LPG	0.00	0.00	0.00
Light Trucks			
Gasoline	96.1	69.0	99.7
Ethanol Flex	3.4	28.0	0.1
Electric	0.01	0.00	0.00
CNG Bi-Fuel	0.3	2.6	0.1
LPG Bi-Fuel	0.00	0.01	0.01
CNG	0.2	0.4	0.0
LPG	0.00	0.00	0.01

Sources: CNEAF Alternatives to Traditional Transportation Fuels 2005 (part II - User and Fuel Data). http://www.eia.doe.gov/cneaf/alternate/page/aftables/afvtransfuel_II.html #in use.

The light commercial truck model

The Light Commercial Truck Module of the NEMS Transportation Model represents light trucks that have a 8,501 to 10,000 pound gross vehicle weight rating (Class 2B vehicles). These vehicles are assumed to beused primarily for commercial purposes.

The module implements a twenty-year stock model that estimates vehicle stocks, travel, fuel economy, and energy use by vintage. Historic vehicle sales and stock data, which constitute the baseline from which the forecast is made, are taken from a recent Oak Ridge National Laboratory study [6]. The distribution of vehicles by vintage, and vehicle scrappage rates are derived from R.L. Polk company registration data [7],[8]. Vehicle travel by vintage was constructed using vintage distribution curves and estimates of average annual travel by vehicle [9],[10].

The growth in light commercial truck VMT is a function of industrial output for agriculture, mining, construction, total manufacturing, utilities, and personal travel. These groupings were chosen for their correspondence with output measures being forecast by NEMS. The overall growth in VMT reflects a weighted average based on the distribution of total light commercial truck VMT by sector. Forecasted fuel efficiencies are assumed to increase at the same annual growth rate as conventional gasoline light-duty trucks (<8,500 pounds gross vehicle weight).

Consumer vehicle choice assumptions

The Consumer Vehicle Choice Module (CVCM) utilizes 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 nesting predicts penetration among similar technologies within a technology set (i.e., gasoline versus diesel hybrids). The third level choice determines market share among the different technology sets [11]. The technology sets include:

- Conventional fuel capable (gasoline, diesel, compressedx natural gas (CNG) and liquefied petroleum gas (LNG), and flex-fuel),
- Hybrid (gasoline and diesel),
- Plug in hybrid (10 mile all-electric range and 40 mile all-electric range)
- Dedicated alternative fuel (CNG and LPG),
- Fuel cell (gasoline, methanol, and hydrogen), and
- Electric battery powered (v-100 mile range and 200 mile range) [12]

The vehicle attributes considered in the choice algorithm include: price, maintenance cost, battery replacement cost, range, multi-fuel capability, home refueling capability, fuel economy, acceleration and luggage space. With the exception of maintenance cost, battery replacement cost, and luggage space, vehicle attributes are determined endogenously [13]. Battery costs for plug-in hybrid electric and all-electric vehicles are based on a production based function over several technology phase periods. The fuel attributes used in market share estimation include availability and price. Vehicle attributes vary by six EPA size classes for cars and light trucks and fuel availability varies by Census division. The NMNL model coefficients were developed to reflect purchase decisions for cars and light trucks separately.

Where applicable, CVCM fuel efficient technology attributes are calculated relative to conventional gasoline miles per gallon. It is assumed that many fuel efficiency improvements in conventional vehicles will be transferred to alternative-fuel vehicles. Specific individual alternative-fuel technological improvements are also dependent upon the CVCM technology type, cost, research and development, and availability over time. Make and model availability estimates are assumed according to a logistic curve based on the initial technology introduction date and current offerings. Coefficients summarizing consumer valuation of vehicle attributes were derived from assumed economic valuation compared to vehicle price elasticities. Initial CVCM vehicle stocks are set according to EIA surveys [14]. A fuel switching algorithm based on the relative fuel prices for alternative fuels compared to gasoline is used to determine the percentage of total VMT represented by alternative fuels in bi-fuel and flex-fuel alcohol vehicles.

Freight truck assumptions

The freight truck module estimates vehicle stocks, travel, fuel efficiency, and energy use for three size classes of trucks: light-medium (Class 3), heavy-medium (Classes 4-6), and heavy (Classes 7-8). Within the size classes, the stock model structure is designed to cover 34 vehicle vintages and to estimate energy use by four fuel types: diesel, gasoline, LPG, and CNG. Fuel consumption estimates are reported regionally (by Census Division) according to the distillate fuel shares from the State Energy Data Report [15]. The technology input data specific to the different types of trucks including the year of introduction, incremental fuel efficiency improvement, and capital cost of introducing the new technologies, are shown in Table 7.7.

Table 7.7. Standard technology matrix for freight trucks

	Medium Light Trucks			Medium Heavy Trucks			Heavy Trucks		
Technology Type	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)
AERO dynamic I: Cab top deflector, sloping hood and cab side flares	N/A	800	2.3	1995	750	2.3	1995	750	1.8
AERO Dynamic II: closing/Covering of gap between tractor and trailer, aero dynamic bumper, underside air baffles, wheel well covers	N/A	N/A	N/A	2004	800	3.6	2005	1500	2.3
AERO Dynamic: III Trailer leading and trailing edge curvatures	N/A	N/A	N/a	2005	400	0.9	2005	500	1.2
Aero Dynamics IV: pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2010	2500	4.5
Tires I: radials	1995	40	1.8	1995	180	1.8	1995	300	1.4
Tires II: low rolling resistance	2004	180	2.3	2005	280	2.3	2005	550	2.7
Tires III: super singles	N/A	N/A	N/A	N/A	N/A	N/A	2005	700	1.8
Tires IV: reduced rolling resistance from pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2015	500	1.1
Transmission: lock-up, electronic controls, reduced friction	2005	750	1.8	2005	900	1.8	2005	1000	1.8
Diesel Engine I: turbocharged, direct injection with better thermal management	2003	700	4.5	2004	1000	7.2	N/A	N/A	N/A
Diesel Engine II: integrated starter/ alternator with idle off and limited regenerative breaking	2005	1500	4.5	2005	1200	4.5	N/A	N/A	N/A
Diesel Engine III: improved engine with lower friction, better injectors, and efficient combustion	2012	2000	9.0	2008	2000	7.2	N/A	N/A	N/A
Diesel Engine IV: hybrid electric powertrain	2010	6000	36.0	2010	8000	36.0	N/A	N/A	N/A
Diesel Engine V: internal friction reduction - improved lubricants and and bearings	N/A	N/A	N/A	N/A	N/A	N/A	2005	500	1.8
Diesel Engine VI: inreased peak cylinder pressure	N/A	NA	N/A	N/A	N/A	N/A	2006	1000	3.6
Diesel Engine VII: improved injectors and more efficient combustion	N/A	N/A	N/A	N/A	N/A	N/A	2007	1500	5.4
Diesel Engine VIII: reduce waste heat improved thermal management	N/A	N/A	0.000	N/A	N/A	0.000	2010	2000	0.090
Gasoline Engine I: electronic fuel injection, DOHC, multiple values	2003	700	4.5	2003	1000	4.5	N/A	N/A	N/.A
Gasoline Engine II: Integrated starter/ alternator with idle off and limited regenerative breaking	2005	1000	4.5	2005	1200	7.2	N/A	N/A	N/A

Table 7.7. Standard technology matrix for freight trucks (cont.)

	Medium Light Trucks			Medium Heavy Trucks			Heavy Trucks		
Technology Type	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Year	Capital Cost (2000$)	Incr, Fuel Econ. Improvement (%)
Gasoline Engine III: direct injection (GDI)	2008	700	10.8	2008	1000	10.8	N/A	N/A	N/A
Gasoline Engine IV; hybrid electric powertrain	2010	6000	40.5	2010	8000	40.5	N/A	N/A	N/A
Weight Reduction I: high strength lightweight materials	2010	1300	4.5	2010	2000	4.5	2010	2000	9.000
Diesel Emission-Nox I: exhaust recirculation, timing retard, selective catalytic reduction	2002	250	-4.0	2003	400	-4.0	2003	500	-4.0
Diesel Emissions-NOx II: nitrogen enriched combustion air	2003	500	-0.5	2003	700	-0.5	2003	750	-0.5
Diesel Emissions-NOx III: non-thermal plasma catalyst	2007	1000	-1.5	2006	1200	-1.5	2007	1250	-1.5
Diesel Emissions-NOx IV: NOx absorber system	2007	1500	-3.0	2006	2000	-3.0	2007	2500	-3.0
Diesel Emission-PM I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesel Emission-PM II: catalytic particulate filter	2006	1000	-1.5	2006	1250	-2.5	2006	1500	-1.5
Diesel Emission- HC/CO I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesl Emission- HC/CO II: closed crankcase system	2005	50	0.0	2005	65	0.0	2005	75	0.0
Gasoline Emission- PM I: Improved oxidation catalyst	2005	250	-0.3	2005	350	-0.3	N/A	N/A	N/A
Gasoline Emission-Nox I: EGR/spark retard	2002	25	-0.015	2002	25	-0.015	N/A	N/A	0.000
Gasoline Emission-Nox II: oxygen sensors	2003	75	0.000	2003	75	0.000	N/A	N/A	0.000
Gasoline Emission-Nox III: secondary air/closed loop system	2008	50	0.000	2008	50	0.000	N/A	N/A	0.000
Gasoline Emission-HC/CO I: oxygen sensors	2003	75	0.000	2003	75	0.000	N/A	N/A	0.000
Gasoline Emission-HC/CO II: evap. canister w/improved vaccum, materials and connectors	2003	50	0.000	2003	50	0.000	N/A	N/A	0.000
Gasoline Emission-HC/CO III: oxidation catalyst	2005	250	-0.003	2005	350	0.000	N/A	N/A	0.000

The freight module uses projections of industrial output to estimate growth in freight truck travel. The industrial output is converted to an equivalent measure of volume output using freight adjustmentcoefficients [16],[17]. These freight adjustment coefficients vary by North American Industrial Classification System (NAICS) code with the deviation diminishing gradually over time toward parity. Freight truck load-factors (ton-miles per truck) by NAICS code are constants formulated from historical data [18].

Fuel economy of new freight trucks is dependent on the market penetration of various emission control technologies and advanced technology components [19]. For the advanced technology components, market penetration is determined as a function of technology type, cost effectiveness, and introduction year. Cost effectiveness is calculated as a function of fuel price, vehicle travel, fuel economy improvement, and incremental capital cost. Emissions control equipment is assumed to enter the market to meet regulated emission standards.

Heavy truck freight travel is estimated by class size and fuel type based on matching projected freight travel demand (measured by industrial output) to the travel supplied by the current fleet. Travel by vintage and size class is then adjusted so that total travel meets total demand.

Initial heavy vehicle travel, by vintage and size class, is derived using Vehicle Inventory and Use Survey (VIUS) data [20]. Initial freight truck stocks by vintage are obtained from R. L. Polk Co. and are distributed by fuel type using VIUS data [21]. Vehicle scrappage rates are also estimated using R. L. Polk Co. data [22].

Freight rail assumptions

The freight rail module uses the industrial output by NAICS code measured in real 1987 dollars and converts these dollars into an adjusted volume equivalent. Coal production from the NEMS Coal Market Module is used to adjust coal based rail travel. Freight rail adjustment coefficients (used to convert dollars to volume equivalents) are based on historical data and remain constant [23],[24]. Initial freight rail efficiencies are based on historic data taken from the Transportation Energy Databook [25]. The distribution of rail fuel consumption by fuel type is also based on historical data and remains constant over the projection [26]. Regional freight rail consumption estimates are distributed according to the State Energy Data Report [27].

Domestic and international shipping assumptions

Similar to the previous sub-module, the domestic freight shipping module uses the industrial output by NAICS code measured in real 1987 dollars and converts these dollars into an adjusted volume equivalent.

The freight adjustment coefficients (used to convert dollars to volume equivalents) are based on historical data. Domestic shipping efficiencies are based on the model developed by Argonne National Laboratory. The energy consumption in the international shipping module is a function of the total level of imports and exports. The distribution of domestic and international shipping fuel consumption by fuel type is based on historical data and remains constant throughout the forecast [28]. Regional domestic shipping consumption estimates are distributed according to the residual oil regional shares in the State Energy Data Report [29].

The air model

The air model is a thirteen region world demand and supply model (Table 7.8). For eac region, demand is computed for domestic travel (both takeoff and landing occur in the same region) and international travel (either takeoff or landing is in the region but not both). Once the demand for aircraft is determined, the stock efficiency module moves aircraft between regions to satisfy the demand.

Table 7.8. Thirteen regions for the world model

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	Western Europe
6	Africa	S. Africa
7	Mideast	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

Source: Jet Information Services, 2009 World Jet Inventory, data tables (2009)

Air travel demand assumptions

The air travel demand module calculates the domestic and international per-capita revenue passenger miles (RPM.P) for each region. Domestic and international revenue passenger miles are based on the historical data in Table 7.9, [30] per capita income for the U.S. per-capita GDP for the non-U.S. regions, and ticket prices. The revenue ton miles of air freight for the U.S. are based on merchandise exports, gross domestic product, and fuel cost. For the non U.S. regions, revenue ton miles are based on GDP growth in the region [31].

Airport capacity constraints based on the FAA's Airport Capacity Benchmark Report 2004 are incorporated into the air travel demand module using airport capacity measures. [32] Airport capacity is defined by the maximum number of flights per hour airports can routinely handle, the amount of time airports operate at optimal capacity, and passenger load factors. Capacity expansion is expected to be delayed due to the economic environment and fuel costs.

Aircraft stock/efficiency assumptions

The aircraft stock and efficiency module consists of a world regional stock model of wide body, narrow body, and regional jets by vintage. Total aircraft supply for a given year is based on the initial supply of aircraft for model year 2009, new passenger sales, and the survival rate by vintage (Table 7.10) [33]. New passenger sales are a function of revenue passenger miles and gross domestic product.

Wide and narrow body planes over 25 years of age are placed as cargo jets according to a cargo percentage varying from 50 percent of 25 year old planes to 100 percent of those aircraft 30 years and older. The available seat-miles per plane, which measure the carrying capacity of the airplanes by aircraft type increase gradually overtime. Domestic and international travel are combined into a single regional demand for seat-miles and passed to the Aircraft Fleet Efficiency Submodule, which adjusts the initial aircraft stocks to meet that demand. For each region, starting with the U.S., the initial stock is adjusted by moving aircraft between regions.

Technological availability, economic viability, and efficiency characteristics of new aircraft are assumed to grow at a fixed rate. Fuel efficiency of new aircraft acquisitions represents an improvement over the stock efficiency of surviving airplanes. A generic set of new technologies (Table 7.11) are introduced in different years and with a set of improved efficiencies over the base year (2007). Regional shares of all types of aircraft fuel use are assumed to be constant and are consistent with the State Energy Data Report estimate of regional jet fuel shares.

Legislation and regulations

Energy Independence and Security Act of 2007 (EISA2007)

The EISA2007 legislation requires the development of fuel economy standards for work trucks (8,500 lbs. to less than 10,000 lbs GVWR) and commercial medium- and heavy-duty on-highway vehicles (10,000 lbs or more GVWR). The new fuel economy standards require consideration of vehicle attributes and duty requirements and can prescribe standards for different classes of vehicles, such as buses used in urban operation or semi-trucks used primarily in highway operation. The Act provides a minimum of 4 full model years lead time before the new fuel economy standard is adopted and 3 full model years after the new fuel economy standard has been established before the fuel economy standards for work trucks can be modified. Because these fuel economy standards are pending and NEMS does not currently model fuel economy regulation for work trucks or commercial medium- and heavy- duty vehicles, this aspect of the Act is not included in *AEO2011*.

A fuel economy credit trading program is established based on EISA2007. Currently, CAFE credits earned by manufacturers can be banked for up to 3 years and can only be applied to the fleet (car or light truck) from which the credit was earned. Starting in model year 2011 the credit trading program will allow manufacturers whose automobiles exceed the minimum fuel economy standards to earn credits that can be sold to other manufacturers whose automobiles fail to 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 fail to achieve the prescribed standards. While the credit trading program begins in 2011, EISA2007 allows manufacturers to apply credits earned to any of the 3 model years prior to the model year the credits are earned, and to any of the 5 model years after the credits are earned. The transfer of credits within a manufacturer's fleet is limited to specific maximums. For model years 2011 through 2013, the maximum transfer is 1.0 mpg; for model years 2014 through 2017, the maximum transfer is 1.5 mpg; and for model years 2018 and later, the maximum credit transfer is 2.0 mpg. NEMS currently allows for sensitivity analysis of CAFE credit banking by manufacturer fleet, but does not model the trading of credits across manufacturers. The *AEO2011* does not consider trading of credits since this would require significant modifications to NEMS and detailed technology cost and efficiency data by manufacturer, which is not readily available.

Table 7.9. 2009 Regional population, gdp, per capita gdp domestic and international rpm and per-capita rpm

Region	Population (million)	GDP (2006$)	GDP_PC
United States	308.2	12,987	42,140.8
Canada	33.5	1,240	37,063.8
Central	209.4	1,793	8,563.6
Central Amercia	377.2	3,773	10,001.5
Europe	545	15,150	27,817.6
Africa	1,010.0	2,432	2,408.0
Middle East	208.7	2,797	13,401.7
Russia	340.1	2,704	7,952.7
China	1,343.8	8,431	6,274.1
Northeast Asia	176.3	5,047	28,627.6
Southeast Asia	1,044.4	3,423	3,277.7
Southwest Asia	1,203.0	4,122	3,426.4
Oceania	25.4	896	35,277.1

Region	RPM (billion)	RPM_PC (thousand)
Domestic		
United States	551.8	1,790.4
Canada	26.5	792.7
Central America	16.1	77.0
South America	56.9	150.7
Europe	387.4	711.4
Africa	22.4	22.2
Middle East	30.3	145.2
Russia	30.4	89.3
China	168.9	125.7
Northeast Asia	54.7	310.5
Southeast Asia	58.7	56.2
Southwest Asia	26.9	22.4
Oceania	46.4	1,825.9
International		
United States	228.0	739.7
Canada	50.5	1,508.5
Central America	63.5	303.1
South America	52.0	137.7
Europe	351.0	644.5
Africa	56.3	55.7
Middle East	98.4	471.2
Russia	25.5	74.8
China	68.6	51.1
Northeast Asia	88.0	499.2
Southeast Asia	124.1	118.8
Southwest Asia	41.0	34.1
Oceania	40.5	1,596.4

Source: Global Insight 2006 chained weighted dollars, Boeing Current Market Outlook 2009

Table 7.10. 2009 Regional passenger and cargo aircraft supply

		Age of Aircraft (years)				
Aircraft Type	**New**	**1-10**	**11-20**	**21-30**	**>30**	**Total**
Passenger						
Narrow Body						
United States	102	1584	1276	589	187	3738
Canada	11	132	81	22	7	253
Central	6	203	41	80	51	381
Central Amercia	35	253	126	149	104	667
Europe	230	1629	919	165	21	2964
Africa	10	157	133	163	100	563
Middle East	66	201	127	60	32	486
Russia	30	176	368	308	234	1116
China	157	745	258	12	0	1172
Northeast Asia	25	127	109	12	3	276
Southeast Asia	40	212	206	119	25	602
Southwest Asia	39	188	58	34	6	325
Oceania	14	161	34	2	1	212
Wide Body						
United States	11	251	251	122	19	654
Canada	2	31	32	24	0	89
Central America	1	11	9	5	0	26
South America	5	39	40	7	2	93
Europe	34	377	338	39	5	793
Africa	7	55	46	30	14	152
Middle East	39	214	114	73	9	449
Russia	7	21	70	58	0	156
China	6	135	114	1	0	256
Northeast Asia	14	153	179	18	0	364
Southeast Asia	31	192	155	24	8	410
Southwest Asia	8	50	35	24	1	118
Oceania	7	52	60	4	0	123
Regional Jets						
United States	48	1809	197	6	9	2069
Canada	4	120	40	0	25	189
Central America	1	74	32	3	0	110
South America	21	45	38	8	3	117
Europe	83	465	338	39	1	926
Africa	5	38	36	34	15	128
Middle East	12	59	47	4	4	126
Russia	3	52	36	65	30	186
China	20	92	8	2	0	122
Northeast Asia	8	12	2	0	0	22
Southeast Asia	2	12	21	26	7	68
Southwest Asia	1	9	7	4	3	24
Oceania	5	20	33	5	0	63
Cargo						
Narrow Body						
United States	0	3	72	122	224	421
Canada	0	0	1	15	19	35
Central	0	1	2	4	9	16
Central America	0	0	0	14	43	57
Europe	0	1	28	57	10	96
Africa	0	0	4	15	58	77
Middle East	0	0	2	5	8	15
Russia	1	4	3	2	5	15

Table 7.10. 2009 Regional passenger and cargo aircraft supply (cont)

		Age of Aircraft (years)				
Aircraft Type	**New**	**1-10**	**11-20**	**21-30**	**>30**	**Total**
China	0	2	20	10	0	32
Northeast Asia	0	0	0	0	0	0
Southeast Asia	0	0	0	12	10	22
Southwest Asia	0	0	3	9	4	16
Oceania	0	0	0	9	3	12
Wide Body						
United States	7	93	215	214	103	632
Canada	0	0	0	3	2	5
Central America	0	3	0	3	1	7
South America	2	5	1	6	5	19
Europe	7	36	39	63	7	152
Africa	0	0	1	2	1	4
Middle East	7	5	15	18	5	50
Russia	0	1	8	3	0	12
China	6	28	43	6	0	83
Northeast Asia	0	35	23	0	0	58
Southeast Asia	0	35	18	5	0	58
Southwest Asia	0	0	5	3	1	9
Oceania	0	0	0	0	0	0
Regional Jets						
United States	0	0	1	0	0	1
Canada	0	0	0	0	0	0
Central America	0	0	2	0	0	2
South America	0	0	0	0	0	0
Europe	0	0	15	11	0	26
Africa	0	0	0	0	1	1
Middle East	0	0	0	0	0	0
Russia	0	0	0	0	0	0
China	0	0	0	0	0	0
Northeast Asia	0	0	0	0	0	0
Southeast Asia	0	0	1	0	0	1
Southwest Asia	0	0	0	0	0	0
Oceania	0	0	1	1	0	2
Survival Curve (fraction)	**New**	**5**	**10**	**20**	**35**	
Narrow Body	1.000	0.9998	0.9992	0.9960	0.9200	
Wide Body	1.000	0.9980	0.9954	0.9860	0.8500	
Regional Jets	1.000	0.9967	0.9900	0.9400	0.8350	

Source: Jet Information Services, 2009 World Jet Inventory (2009)

Table 7.11. Standard technology matrix for air travel

Technology	Introduction Year	Fractional Efficiency Improvement	Jet Fuel Trigger Price (87$/gal)
Technology #1	2008	0.03	1.34
Technology #2	2014	0.07	1.34
Technology #3	2020	0.11	1.34
Technology #4	2025	0.15	1.34
Technology #5	2030	0.20	1.34
Technology #6	2018	0.00	1.34

Source: Jet Information Services, 2009 World Jet Inventory, data tables (2009)

The CAFE credits specified under the Alternative Motor Fuels Act (AMFA) through 2019 are extended. Prior to passage of this Act, the CAFE credits under AMFA were scheduled to expire after model year 2010. Currently, 1.2 mpg is the maximum CAFE credit that can be earned from selling alternative fueled vehicles. EISA2007 extends the 1.2 mpg credit maximum through 2014 and reduces the maximum by 0.2 mpg for each following year until it is phased out by model year 2020. NEMS does model CAFE credits earned from alternative fuel vehicles sales.

American Recovery and Reinvestment Act of 2009 and Energy Improvement and Extension Act of 2008

ARRA Title I, Section 1141, modified the EIEA2008 Title II, Section 205, tax credit for the purchase of new, qualified plug-in electric drive motor vehicles. According to the legislation, a qualified plug-in electric drive motor vehicle must draw propulsion from a traction battery with at least 4 kilowatthours of capacity and be propelled to a significant extent by an electric motor which draws electricity from a battery that is capable of being recharged from an external source of electricity.

The tax credit for the purchase of a plug-in electric vehicle is $2,500, plus, starting at a battery capacity of 5 kilowatthours, an additional $417 per kilowatthour battery credit up to a maximum of $7,500 per vehicle. The tax credit eligibility and phase-out are specific to an individual vehicle manufacturer. The credits are phased out once a manufacturer's cumulative sales of qualified vehicles reach 200,000. 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. The credit is reduced to 50 percent of the total value for the first two calendar quarters of the phase-out period and then to 25 percent for the third and fourth calendar quarters before being phase out entirely thereafter. The credit applies to vehicles with a gross vehicle weight rating of less than 14,000 pounds.

ARRA also allows a tax credit of 10 percent against the cost of a qualified electric vehicle with a battery capacity of at least 4 kilowatthours subject to the same phase out rules as above. The tax credits for qualified plug-in electric drive motor vehicles and electric vehicles are included in *AEO2011*.

Energy Policy Act of 1992 (EPACT)

Fleet alternative-fuel vehicle sales necessary to meet the EPACT regulations are derived based on the mandates as they currently stand and the Commercial Fleet Vehicle Module calculations. Total projected AFV sales are divided into fleets by government, business, and fuel providers (Table 7.12).

Because the commercial fleet model operates on three fleet type representations (business, government, and utility), the federal and state mandates are weighted by fleet vehicle stocks to create a composite mandate for both. The same combining methodology is used to create a composite mandate for electric utilities and fuel providers based on fleet vehicle stocks [34].

Low Emission Vehicle Program (LEVP)

The LEVP was originally passed into legislation in 1990 in the State of California. It began as the implementation of a voluntary opt-in pilot program under the purview of Clean Air Act Amendments of 1990 (CAAA90), which included a provision that other States could opt in to the California program to achieve lower emissions levels than would otherwise be achieved through CAAA90. 14 states have elected to adopt the California LEVP.

The LEVP is an emissions-based policy, setting sales mandates for 6 categories of low-emission vehicles: low-emission vehicles (LEVs), ultra-low-emission vehicles (ULEVs), super-ultra low emission vehicles (SULEVs), partial zero-emission vehicles (PZEVs), advanced technology partial zero emission vehicles (AT-PZEVs), and zero-emission vehicles (ZEVs). The LEVP requires that in 2005 10 percent of a manufacturer's sales are ZEVs or equivalent ZEV earned credits, increasing to 11 percent in 2009, 12 percent in 2012, 14 percent in 2015, and 16 percent in 2018 where it remains constant thereafter. In August 2004, CARB enacted further amendments to the LEVP that place a greater emphasis on emissions reductions from PZEVs and AT-PZEVs and

Table 7.12. EPACT legislative mandates for AFV purchases by fleet type and year
percent

Year	Federal	State	Fuel Providers	Electric Utilities
2005	75	75	70	90

Source: EIA, Energy Efficiency and Renewable Energy (Washington, DC, 2005) http://www1.eere.energy.gov/femp/about/fleet-requirements.html, http://www1.eere.energy.gov/vehicles and fuels/epact/state/state-gov.html.

requires that manufacturers produce a minimum number of fuel cell and electric vehicles. In addition, manufacturers are allowed to adopt alternative compliance requirements for ZEV sales that are based on cumulative fuel cell vehicle sales targets for vehicles sold in all States participating in California's LEVP. Under the alternative compliance requirements, ZEV credits can also be earned by selling battery electric vehicles. Currently, all manufacturers have opted to adhere to the alternative compliance requirements. The mandate still includes phase-in multipliers for pure ZEVs and allows 20 percent of the sales requirement to be met with AT-PZEVs and 60 percent of the requirement to be met with PZEVs. AT-PZEVs and PZEVs are allowed 0.2 credits per vehicle. EIA assumes that credit allowances for PZEVs will be met with conventional vehicle technology, hybrid vehicles will be sold to meet the AT-PZEV allowances, and that hydrogen fuel cell vehicles will be sold to meet the pure ZEV requirements under the alternative compliance path.

Transportation alternative cases

High and Low Technology cases

In the high technology and low technology cases for cars and light trucks, the conventional fuel saving technology characteristics are based on NHTSA and EPA values [35]. Tables 7.13 7.14, 7.15, 7.16 summarize the High and Low Technology matrices for cars and light trucks. Tables 7.17 and 7.18 reflect the high and low technology case assumptions for freight trucks. These reflect optimistic and pessimistic values, with respect to efficiency improvement and capital cost, for advanced engine and emission control technologies as reported by ANL [36]. For the Air Module, the high technology case reflects earlier introduction years for the new aircraft technologies and a greater penetration share. The low technology case simulates a delay in the introduction of new aircraft technologies. Tables 7.19 and 7.20 reflect these cases.

Table 7.13. High technology matrix for cars

	Incremental Fuel Efficiency Change (%)	Incremental Cost (1990$)	Incremental Cost ($/Unit Wt.)	Absolute Incremental Weight (Lbs.)	Per Unit Incremental Weight (Lbs./Unit Wt.)	Introduc-tion Year	Horse-power Change (%)
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1990	0
Material Substitution III	6.6	0	0.6	0	-10	1998	0
Material Substitution IV	9.9	0	0.9	0	-15	2006	0
Material Substitution V	13.2	0	1.2	0	-20	2014	0
Drag Reduction II	1.6	16	0	0	0	1988	0
Drag Reduction III	3.2	32	0	0	0.2	1992	0
Drag Reduction IV	6.3	45	0	0	0.5	2000	0
Drag Reduction V	8	53.5	0	0	1	2010	0
Roll-Over Technology	-1.5	100	0	0	2.2	2004	0
Side Impact Technology	-1.5	100	0	0	2.2	2004	0
Adv Low Loss Torque Converter	2	25	0	0	0	1999	0
Early Torque Converter Lockup	1	25.6	0	0	0	2002	0
Aggressive Shift Logic	2	30.5	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	8	106.5	0	20	0	1995	0
6-Speed Automatic	3.4	259	0	30	0	2003	0
6-Speed Manual	2	91.4	0	20	0	1995	0
CVT	8	240.5	0	-25	0	1998	0
Automated Manual Trans	12	120.4	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1980	0
OHC/AdvOHV-4 Cylinder	3	93.1	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	3	108.9	0	0	0	1987	2.5
OHC/AdvOHV-8 Cylinder	3	124.7	0	0	0	1986	2.5
4-Valve/4-Cylinder	8.8	205	0	10	0	1988	4.25
4-Valve/6-Cylinder	8.8	280	0	15	0	1992	4.25
4 Valve/8-Cylinder	8.8	320	0	20	0	1994	4.25
5 Valve/6-Cylinder	9	300	0	18	0	1998	5
VVT-4 Cylinder	3	35	0	10	0	1994	1.25
VVT-6 Cylinder	3	87.5	0	20	0	1993	1.25
VVT-8 Cylinder	3	90	0	20	0	1993	1.25
VVL-4 Cylinder	3	144.3	0	25	0	1997	2.5
VVL-6 Cylinder	3	220.0	0	40	0	2000	2.5
VVL-8 Cylinder	3	285.0	0	50	0	2000	2.5
Camless Valve Actuation-4cyl	15.1	363.8	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	15.1	513.0	0	55	0	2020	3.25
Camless Valve Actuation-8cyl	15.1	675.5	0	75	0	2020	3.25
Cylinder Deactivation	7.5	60.1	0	10	0	2004	0
Turbocharging/ Supercharging	7.5	324.7	0	-100	0	1980	3.75
Engine Friction Reduction I	2.3	54	0	0	0	1992	0.75
Engine Friction Reduction II	3.5	60.9	0	0	0	2000	1.75
Engine Friction Reduction III	5	52.1	0	0	0	2008	1.75
Engine Friction Reduction IV	6.5	177	0	0	0	2016	2.25
Stoichiometric GDI/4-Cylinder	2.9	234.9	0	20	0	2006	2.5
Stoichiometric GDI/6-Cylinder	2.9	307.9	0	30	0	2006	2.5
Lean Burn GDI	10	640.5	0	20	0	2020	0
5W-30 Engine Oil	1	3	0	0	0	1998	0
5W-20 Engine Oil	2	16.7	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	2	84.2	0	0	0	2004	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2007	0
Tires II	2	6.1	0	-8	0	1995	0
Tires III	3.5	12.3	0	-12	0	2005	0
Tires IV	5	16.9	0	-16	0	2015	0
Front Wheel Drive	6	250	0	0	-6	1980	0
Four Wheel Drive Improvements	2	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	-2.5
42V-Engine Off at Idle	7.5	496.6	0	45	0	2005	0
Tier 2 Emissions Technology	-1	120	0	20	0	2006	0
Increased Size/Weight	-1.7	0	0	0	2.55	2003	0
Variable Compression Ratio	4	350	0	25	0	2015	0

Source: Energy and Environmental Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002). National Highway Traffic Safety Administration, Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (April 2008). U.S. Environmental Protection Agency, Interim Report: New Powertrain Technologies and Their Projected Costs (October 2005)

Table 7.14. High technology matrix for light trucks

	Fuel Efficiency Change (%)	Incremental Cost (2000$)	Incremental Cost ($/Unit Wt.)	Absolute Incremenal Weight (Lbs.)	Per Unit Incremental Weight (Lbs./Unit Wt.)	Introduc-tion Year	Horse-power Change (%)
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1994	0
Material Substitution III	6.6	0	0.6	0	-10	2002	0
Material Substitution IV	9.9	0	0.9	0	-15	2010	0
Material Substitution V	13.2	0	1.2	0	-20	2018	0
Drag Reduction II	2.3	32	0	0	0	1992	0
Drag Reduction III	4.1	57	0	0	0.2	1998	0
Drag Reduction IV	6.4	89	0	0	0.5	2006	0
Drag Reduction V	7.8	109	0	0	1	2014	0
Roll-Over Technology	-1.5	100	0	0	2.2	2006	0
Side Impact Technology	-1.5	100	0	0	2.2	2006	0
Adv Low Loss Torque Converter	2	25	0	0	0	2005	0
Early Torque Converter Lockup	0.5	25.6	0	0	0	2003	0
Aggressive Shift Logic	2.0	35	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	8	106.5	0	20	0	1995	0
6-Speed Automatic	3.4	259	0	30	0	2003	0
6-Speed Manual	2	91.4	0	20	0	1995	0
CVT	8	130.0	0	-25	0	1998	0
Automated Manual Trans	3.4	120.4	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1985	0
OHC/AdvOHV-4 Cylinder	3.5	93.1	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	3.5	108.9	0	0	0	1990	2.5
OHC/AdvOHV-8 Cylinder	3.5	124.7	0	0	0	1990	2.5
4-Valve/4-Cylinder	7.0	205	0	10	0	1998	4.25
4-Valve/6-Cylinder	7.0	280	0	15	0	2000	4.25
4 Valve/8-Cylinder	7.0	320	0	20	0	2000	4.25
5 Valve/6-Cylinder	7.0	300	0	18	0	2010	5
VVT-4 Cylinder	3	48.9	0	10	0	1998	1.25
VVT-6 Cylinder	3	97.8	0	20	0	1997	1.25
VVT-8 Cylinder	3	97.8	0	20	0	1997	1.25
VVL-4 Cylinder	3	144.3	0	25	0	2002	2.5
VVL-6 Cylinder	3	220	0	40	0	2001	2.5
VVL-8 Cylinder	3	285	0	50	0	2006	2.5
Camless Valve Actuation-4cyl	15.1	363.8	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	15.1	513	0	55	0	2020	3.25
Camless Valve Actuation-8cyll	15.1	657.5	0	75	0	2020	3.25
Cylinder Deactivation	7.5	60.1	0	10	0	2004	0
Turbocharging/Supercharging	7.5	339	0	-100	0	1987	3.75
Engine Friction Reduction I	2.5	25	0	0	0	1992	0.75
Engine Friction Reduction II	3.5	31.2	0	0	0	2000	1.25
Engine Friction Reduction III	5	62.5	0	0	0	2010	1.75
Engine Friction Reduction IV	6.5	67.5	0	0	0	2016	2.75
Stoichiometric GDI/4-Cylinder	2.9	234.9	0	20	0	2008	2.5
Stoichiometric GDI/6-Cylinder	2.9	307.9	0	30	0	2010	2.5
Lean Burn GDI	11.5	640.5	0	20	0	2010	0
5W-30 Engine Oil	0.8	4	0	0	0	1998	0
5W-20 Engine Oil	2	16.7	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	2	84.2	0	0	0	2005	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2008	0
Tires II	0.0	30	0	-8	0	1995	0
Tires III	1.5	5.6	0	-12	0	2005	0
Tires IV	3.5	11.8	0	-16	0	2015	0
Front Wheel Drive	2	250	0	0	-3	1984	0
Four Wheel Drive Improvements	1.5	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	-2.5
42V-Engine Off at Idle	7.5	434.9	0	45	0	2005	0
Tier 2 EmissionsTechnology	-1	160	0	20	0	2006	0
Increased Size/Weight	-2.5	0	0	0	3.75	2006	0
Variable Compression Ratio	4	350	0	25	0	2015	0

Source: Energy and Enviromental Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002). National Highway Traffic Safety Administration, Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (April 2008). U.S. Environmental Protection Agency, Interim Report: New Powertrain Technologies and Their Projected Costs (October 2005)

Table 7.15. Low technology matrix for cars[1]

	Fuel Efficiency Change (%)	Incremental Cost (2000$)	Incremental Cost ($/Unit Wt.)	Absolute Incremental Weight (Lbs.)	Per Unit Incremental Weight (Lbs./Unit Wt.)	Introduction Year	Fractional Horsepower Change (%)
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1990	0
Material Substitution III	6.6	0	0.6	0	-10	1998	0
Material Substitution IV	9.9	0	0.9	0	-15	2006	0
Material Substitution V	13.2	0	1.2	0	-20	2014	0
Drag Reduction II	1.5	16.0	0	0	0	1988	0
Drag Reduction III	3.0	32.0	0	0	0.2	1992	0
Drag Reduction IV	4.2	45.0	0	0	0.5	2000	0
Drag Reduction V	5.0	53.5	0	0	1	2010	0
Roll-Over Technology	-1.5	100	0	0	2.2	2004	0
Side Impact Technology	-1.5	100	0	0	2.2	2004	0
Adv Low Loss Torque Converter	2	25	0	0	0	1999	0
Early Torque Converter Lockup	0.5	25.6	0	0	0	2002	0
Aggressive Shift Logic	1.0	30.5	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	2.5	106.5	0	20	0	1995	0
6-Speed Automatic	2	259	0	30	0	2003	0
6-Speed Manual	0.5	91.4	0	20	0	1995	0
CVT	2	240.5	0	-25	0	1998	0
Automated Manual Trans	4.0	175.0	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1980	0
OHC/AdvOHV-4 Cylinder	3.5	105.0	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	1.5	122.5	0	0	0	1987	2.5
OHC/AdvOHV-8 Cylinder	1.5	140.0	0	0	0	1986	2.5
4-Valve/4-Cylinder	8	205	0	10	0	1988	4.25
4-Valve/6-Cylinder	8	280	0	15	0	1992	4.25
4 Valve/8-Cylinder	8	320	0	20	0	1994	4.25
5 Valve/6-Cylinder	8	300	0	18	0	1998	5
VVT-4 Cylinder	1.0	50.4	0	10	0	1994	1.25
VVT-6 Cylinder	1.0	114.4	0	20	0	1993	1.25
VVT-8 Cylinder	1.0	178.5	0	20	0	1993	1.25
VVL-4 Cylinder	2.0	178	0	25	0	1997	2.5
VVL-6 Cylinder	2.0	270	0	40	0	2000	2.5
VVL-8 Cylinder	2.0	349	0	50	0	2000	2.5
Camless Valve Actuation-4cyl	12.1	433	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	12.1	609.4	0	55	0	2020	3.25
Camless Valve Actuation-8cyl	12.1	785.8	0	75	0	2020	3.25
Cylinder Deactivation	4.0	245	0	10	0	2004	0
Turbocharging/Supercharging	5.0	324.7	0	-100	0	1980	3.75
Engine Friction Reduction I	2.3	54	0	0	0	1992	0.75
Engine Friction Reduction II	2.0	60.9	0	0	0	2000	1.25
Engine Friction Reduction III	3.0	196.4	0	0	0	2008	1.75
Engine Friction Reduction IV	6.5	177	0	0	0	2016	2.25
Stoichiometric GDI/4-Cylinder	1.9	352	0	20	0	2006	2.5
Stoichiometric GDI/6-Cylinder	1.9	447.0	0	30	0	2006	2.5
Lean Burn GDI	10.0	640.5	0	20	0	2020	0
5W-30 Engine Oil	0.5	6.0	0	0	0	1998	0
5W-20 Engine Oil	2	16.7	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	1.0	96.2	0	0	0	2004	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2007	0
Tires II	1.5	35	0	-8	0	1995	0
Tires III	1.5	35	0	-12	0	2005	0
Tires IV	1.5	35	0	-16	0	2015	0
Front Wheel Drive	6	250	0	0	-6	1980	0
Four Wheel Drive Improvements	1.3	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	-2.5
42V-Engine Off at Idle	5.5	496.6	0	45	0	2005	0
Tier 2 Emissions Technology	-1	120	0	20	0	2006	0
Increased Size/Weight	-1.7	0	0	0	2.55	2006	0
Variable Compression Ratio	4	350	0	25	0	2015	0

[1]Fractional changes refer to the percentage change from the 1990 values.

Sources: Energy and Environment Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002). National Highway Traffic Safety Administration, Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (April 2008). U.S. Environmental Protection Agency, Interim Report: New Powertrain Technologies and Their Projected Costs (October 2005)

Table 7.16. Low technology matrix for light trucks[1]

	Fractional Fuel Efficiency Change (%)	Incremental Cost (2000$)	Incremental Cost ($/UnitWt.)	Absolute Incremental Weight (Lbs.)	Per Unit Incremental Weight (Lbs./UnitWt.)	Introduction Year	Fractional Horse-power Change (%)
Unit Body Construction	4	100	0	0	-6	1980	0
Material Substitution II	3.3	0	0.4	0	-5	1994	0
Material Substitution III	6.6	0	0.6	0	-10	2002	0
Material Substitution IV	9.9	0	0.9	0	-15	2010	0
Material Substitution V	13.2	0	1.2	0	-20	2018	0
Drag Reduction II	1.5	32	0	0	0	1992	0
Drag Reduction III	4.1	57	0	0	0.2	1998	0
Drag Reduction IV	6.4	89	0	0	0.5	2006	0
Drag Reduction V	7.8	109	0	0	1	2014	0
Roll-Over Technology	-1.5	100	0	0	2.2	2006	0
Side Impact Technology	-1.5	100	0	0	2.2	2006	0
Adv Low Loss Torque Converter	2	25	0	0	0	2005	0
Early Torque Converter Lockup	0.5	25.6	0	0	0	2003	0
Aggressive Shift Logic	1.5	30.5	0	0	0	1999	0
4-Speed Automatic	4.5	285	0	10	0	1980	0
5-Speed Automatic	2.5	112	0	20	0	1995	0
6-Speed Automatic	2.0	259.0	0	30	0	2003	0
6-Speed Manual	0.5	91.4	0	20	0	1995	0
CVT	3.0	200	0	-25	0	1998	0
Automated Manual Trans	3.4	157.5	0	0	0	2004	0
Roller Cam	2	16	0	0	0	1985	0
OHC/AdvOHV-4 Cylinder	1.8	105	0	0	0	1980	2.5
OHC/AdvOHV-6 Cylinder	1.8	122.5	0	0	0	1990	2.5
OHC/AdvOHV-8 Cylinder	1.8	140	0	0	0	1990	2.5
4-Valve/4-Cylinder	7	205	0	10	0	1998	4.25
4-Valve/6-Cylinder	7	280	0	15	0	2000	4.25
4 Valve/8-Cylinder	7	320	0	20	0	2000	4.25
5 Valve/6-Cylinder	7	300	0	18	0	2010	5
VVT-4 Cylinder	1.0	48.9	0	10	0	1998	1.25
VVT-6 Cylinder	1.0	97.8	0	20	0	1997	1.25
VVT-8 Cylinder	1.0	97.8	0	20	0	1997	1.25
VVL-4 Cylinder	2.0	178	0	25	0	2002	2.5
VVL-6 Cylinder	2.0	270	0	40	0	2001	2.5
VVL-8 Cylinder	2.0	349	0	50	0	2006	2.5
Camless Valve Actuation-4cyl	12.1	433	0	35	0	2020	3.25
Camless Valve Actuation-6cyl	12.1	609.4	0	55	0	2020	3.25
Camless Valve Actuation-8cyl	12.1	785.8	0	75	0	2020	3.25
Cylinder Deactivation	4.0	190.4	0	10	0	2004	0
Turbocharging/Supercharging	5.0	650	0	-100	0	1987	3.75
Engine Friction Reduction I	2.0	36	0	0	0	1992	0.75
Engine Friction Reduction II	1.5	63	0	0	0	2000	1.25
Engine Friction Reduction III	1.5	235.7	0	0	0	2010	1.75
Engine Friction Reduction IV	1.5	177	0	0	0	2016	2.25
Stoichiometric GDI/4-Cylinder	1.9	352.8	0	20	0	2008	2.5
Stoichiometric GDI/6-Cylinder	1.9	447.4	0	30	0	2010	2.5
Lean Burn GDI	10.0	640.5	0	20	0	2010	0
5W-30 Engine Oil	0.5	6.0	0	0	0	1998	0
5W-20 Engine Oil	1.0	37.5	0	0	0	2003	0
OW-20 Engine Oil	3.1	150	0	0	0	2030	0
Electric Power Steering	1.0	96.2	0	0	0	2005	0
Improved Alternator	0.3	15	0	0	0	2005	0
Improved Oil/Water Pump	0.5	10	0	0	0	2000	0
Electric Oil/Water Pump	1	93.4	0	0	0	2008	0
Tires II	0.0	30	0	-8	0	1995	0
Tires III	1.0	35	0	-12	0	2005	0
Tires IV	1.0	35	0	-16	0	2015	0
Front Wheel Drive	2	250	0	0	-3	1984	0
Four Wheel Drive Improvements	1.0	93.8	0	0	-1	2000	0
42V-Launch Assist and Regen	7.5	280	0	80	0	2005	-2.5
42V-Engine Off at Idle	5.5	434.9	0	45	0	2005	0
Tier 2 Emissions Technology	-1	160	0	20	0	2006	0
Increased Size/Weight	-2.5	0	0	0	3.75	2006	0
Variable Compression Ratio	4	350	0	25	0	2015	0

[1]Fractional changes refer to the percentage change from the 1990 values.

Sources: Energy and Environment Analysis, Documentation of Technology included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks (September, 2002). National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (Copyright 2002). National Highway Traffic Safety Administration, Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (April 2008). U.S. Environmental Protection Agency, Interim Report: New Powertrain Technologies and Their Projected Costs (October 2005)

Table 7.17. High technology matrix for freight trucks

	Medium Light Trucks			Medium Heavy Trucks			Heavy Trucks		
Technology Type	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)	Introduction Cost	Capital Cost (2000$)	Incr. Fuel Econ. Improvement (%)
Areo dynamic I: Cab top deflector, sloping hood and cab side flares	N/A	N/A	N/A	1995	750	2.8	1995	750	2.3
Closing/covering of gap between trackor and trailer aero dynamic bumper, underside air baffles, wheel well covers	N/A	N/A	N/A	2004	800	4.1	2008	1800	2.3
Trailer leading and trailing edge curvatures	NA	N/A	N/A	2005	400	1.3	2005	500	1.6
Aero Dynamics IV: pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2010	2500	6.0
Tires I: radials	1995	40	2.8	1995	180	2.8	1995	300	2.4
Tires II: low rolling resistance	2004	180	3.3	2005	280	3.3	2005	550	3.7
Tires III: super singles	N/A	N/A	N/A	N/A	N/A	N/A	2005	700	2.8
Tires IV: reduced rolling resistance from pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2015	500	1.1
Transmission: lock-up, electronic controls, reduced friction	2005	750	2.3	2005	900	2.3	2005	1000	2.3
Diesel Engine I:turbo-charged, direct injection with better thermal management	2003	600	4.5	2004	900	7.2	N/A	N/A	N/A
Diesel Engine II:integrated starter/alternator with idle off and limited regenerative breaking	2005	1500	4.5	2005	1200.	4.5	N/A	N/A	N/A
Diesel Engine III: improved engine with lower friction, better injectors, and efficient combustion	2012	2000	8.0	2008	2000	8.2	N/A	N/A	N/A
Diesel Engine IV: hybrid electric powertrain	2010	6000	36.0	2010	7000	36.0	N/A	N/A	N/A
Diesel Engine V: internal friction reduction - improved lubricants and bearings	N/A	N/A	N/A	N/A	N/A	N/A	2005	500	1.8
Diesel Engine VI: increased peak cylinder pressure	N/A	N/A	N/A	N/A	N/A	N/A	2006	1000	3.6
Diesel Engine VII: improved injectors and more efficient ore efficient combustion	N/A	N/A	N/A	N/A	N/A	N/A	2007	1500	5.4
Diesel Engine VIII: reduce waste heat improved thermal waste heat improved thermal magement	N/A	N/A	N/A	N/A	N/A	N/A	2010	2000	9.0
Gasoline Engine I: electronid fuel injection, DOHC, multiple values	2003	700	4.5	2003	1000	4.5	N/A	N/A	N/A
Gasoline Engine II: integrated starter/alternator with idle off and limited reogenerative breaking	2005	1000	4.5	2005	1200	7.2	N/A	N/A	N/A
Gasoline Engine III: direct injection (GDI)	2008	700	10.8	2008	1000	10.8	N/A	N/A	N/A
Gasoline Engine IV: hybrid electric powertrain	2010	6000	405	2010	8000	40.5	N/A	N/A	N/A
Weight Reduction I: high strength lightweight materials	2010	1300	4.5	20070	2000	4.5	2005	2000	9.0
Diesel Emission-NO_x I: exhaust reciculation, timing retard, selective catalytic reduction	2002	250	-3.0	2003	400	-3.0	2003	500	-0.3
Diesel Emissions-NOx II: nitrogen enriched combustion air	2003	500	-0.5	2003	700.	-0.5	2003	750	-0.5
Diesel Emissions - NOx III: non-thermal plasma catalyst	2007	1000	-1.0	2006	1200	-1.0	2007	1250	-1.0
Diesel Emissions - NOx IV: NOx absorber system	2007	1500	-2.0	2006	2000	-2.0	2007	2500	-2.0
Diesel Emission - PM I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesel Emission - PM II: catalytic particulate filter	2006	1000	-1.0	2006	1250	-2.0	2006	1500	-1.0
Diesel Emission - HC/CO I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesel Emission - HC/CO II: closed crankcase catalyst	2005	50	0.0	2005	65	0.0	2005	75	0.0
Gasoline Emission - PM I: Improved oxidation catalyst	2005	250	-0.3	2005	350	-0.3	N/A	N/A	N/A
Gasoline Emission - NOx I: EGR/spark retard	2002	25	-1.0	2002	25	-1.0	N/A	N/A	N/A
Gasoline Emission - NOx II: oxygen sensors	2003	75	0.0	2003	75	0.0	N/A	N/A	N/A
Gasoline Emission - NOx III: secondary air/closed loop system	2008	50	0.0	2008	50	0.0	N/A	N/A	N/A
Gasoline Emission - HC/CO I: oxygen sensors	2003	75	0.0	2003	75	0.0	N/A	N/A	N/A
Gasoline Emission - HC/CO II: evap. canister w/improved vaccum, materials, and connectors	2003	50	0.0	2003	50	0.0	N/A	N/A	N/A
Gasolline Emission - HC/CO III: oxidatio catalyst	2005	250	-0.3	2005	350	-0.3	N/A	N/A	N/A

Table 7.18. Low Technology matrix for freight trucks

Technology Type	Medium Light Trucks			Medium Heavy Trucks			Heavy Trucks		
	Intro-duction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improve-ment (%)	Intro-duction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improve-ment (%)	Intro-duction Year	Capital Cost (2000$)	Incr. Fuel Econ. Improve-ment (%)
Areo dynamic I: Cab top deflector,sloping hood and cab side flares	N/A	N/A	N/A	1995	750	1.8	1995	750	1.3
Closing/covering of gap between tractor and trailer, aero dynamic bumper, underside are baffles, wheel well covers	N/A	N/A	N/A	2004	800	3.1	2005	1500	2.3
Trailer leading and trailing edge curvatures	N/A	N/A	N/A	2005	400	0.5	2005	500	0.8
Aero Dynamics IV: pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2010	2500	3.0
Tires I: radials	1995	40	0.8	1995	180	0.8	1995	300	0.4
Tires II: low rolling resistance	2004	180	1.3	2005	280	3.3	2005	550	1.7
Tires III: super singles	N/A	N/A	N/A	N/A	N/A	N/A	2005	700	0.8
Tires IV: reduced rolling resistance from pneumatic blowing	N/A	N/A	N/A	N/A	N/A	N/A	2015	500	1.1
Transmission: lock-up, electronic controls, reduced friction	2005	750	1.3	2005	900	1.3	2005	1000	1.3
Diesel Engine I: turbo-charged, direct injection with better thermal management	2003	800	4.5	2004	1100	7.2	N/A	N/A	N/A
Diesel Engine II: integrated starter/alternator with idle off and limited regenerative breaking	2005	1500	4.5	2005	1200	4.5	N/A	N/A	N/A
Diesel Engine III: improved engine with lower friction, better injectors, and efficient combustion	2012	2000	7.0	2008	2000	6.2	N/A	N/A	N/A
Diesel Enginee IV: hybrid electric powertrain	2010	6000	36.0	2010	9000	36.0	N/A	N/A	N/A
Diesel Engine V: internal friction reduction - improved lubricants and bearings	N/A	N/A	N/A	N/A	N/A	N/A	2005	500	1.8
Diesel Engine VI: increased peak cylinder pressure	N/A	NA	N/A	N/A	N/A	N/A	2006	1000	3.6
Diesel Engine VII: improved injectors and more efficient combustion	N/A	N/A	N/A	N/A	N/A	N/A	2007	1500	5.4
Diesel Engine VIII: waste heat improved thermal management	N/A	N/A	N/A	N/A	N/A	N/A	2010	2000	9.0
Gasoline Engine I: electronic fuel injection, DOHC, multiple values	2003	700	4.5	2003	1000	4.5	N/A	N/A	N/A
Gasoline Engine II: integrated starter/alternator with idle off and llimited regenerative breaking	2005	1000	4.5	2005	1200	7.2	N/A	N/A	N/A
Gasoline Engine III: direct injection (GDI)	2008	700	10.8	2008	1000	10.8	N/A	N/A	N/A
Gasoline Engine IV: hybrid electric powertrain	2010	6000	40.5	2010	800	40.5	N/A	N/A	N/A
Weight Reduction I: high strength lightweight materials	2010	1300	4.5	2010	2000	4.5	2010	2000	9.0
Diesel Emission-NOx 1: exhaust recirculation, timing retard, selective catalytic reduction	2002	250	-5.0	2003	400	-5.0	2003	500	-5.0
Diesel Emissions - NOx II: nitrogen enriched combustion air	2003	500	-0.5	2003	700	-0.5	2003	750	-0.5
Diesel Emissions - NOx III: non-thermal plasma catalyst	2007	1000	-7.0	2006	1200	-2.0	2007	1520	-2.0
Diesel Emissions - NOx IV: NOx absorber system	2007	1500	-4.0	2006	2000	-4.0	2007	2500	-4.0
Diesel Emission - PM I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesel Emission - PM II: catalytic particulate filter	2006	1000	-2.0	2006	1250	-3.0	2006	1500	-2.0
Diesel Emission - HC/CO I: oxidation catalyst	2002	150	-0.5	2002	200	-0.5	2002	250	-0.5
Diesel Emission - HC/CO II: closed crankcase system	2005	50	0.0	2005	65	0.0	2005	75	0.0
Gasoline Emission - PM I: improved oxidation catalyst	2005	250	-0.3	2005	350	-0.3	N/A	N/A	N/A
Gasoline Emission - NOx I: EGR/spark retard	2002	25	-2.0	2002	25	-2.0	N/A	N/A	N/A
Gasoline Emission - NOx II: oxygen sensors	2003	75	0.0	2003	75	0.0	N/A	N/A	N/A
Gasoline Emission - NOx III: secondary air/closed loop system	2008	50	0.0	2008	50	0.0	N/A	N/A	N/A
Gasoline Emission - HC/CO I: oxygen sensors	2003	75	0.0	2003	75	0.0	N/A	N/A	N/A
Gasoline emission - HC/CO II: evap. canister w/improved vaccum,materials, and connectors	2003	50	0.0	2003	80	0.0	N/A	N/A	N/A
Gasoline Emission - HC/CO III: oxidation catalyst	2005	250	-0.3	2005	350	-0.3	N/A	N/A	N/A

Table 7.19. High technology matrix for air travel

Technology	Introduction Year	Fractional Efficiency Improvement	Jet Fuel Trigger Price (87$/gal)
Technology #1	2008	0.03	1.34
Technology #2	2014	0.07	1.34
Technology #3	2015	0.11	1.34
Technology #4	2020	0.15	1.34
Technology #5	2025	0.22	1.34
Technology #6	2018	0.20	1.34
Technology #7	2025	0.08	1.00
Technology #8	2020	0.10	0.00

Source: Jet Information Services, 2009 World Jet Inventory, data tables (2009). Energy Information Administration, Transportation Sector Model of the National Energy Modeling System, Model Documentation 2010, DOE/EIA-M070(2010), (Washington, DC, 2010).

Table 7.20. Low technology matrix for air travel

Technology	Introduction Year	Fractional Efficiency Improvement	Jet Fuel Trigger Price (87$/gal)
Technology #1	2013	0.04	1.34
Technology #2	2019	0.07	1.34
Technology #3	2025	0.11	1.34
Technology #4	2030	0.15	1.34
Technology #5	2018	0.20	1.34

Source: Jet Information Services, 2009 World Jet Inventory, data tables (2009). Energy Information Administration, Transportation Sector Model of the National Energy Modeling System, Model Documentation 2010, DOE/EIA-M070(2010), (Washington, DC, 2010).

Notes and sources

[1] U.S. Department of Transportation, National Highway Traffic and Safety Administration, “Summary of Fuel Economy Performance”, (Washington, DC, December 2009).

[2] Goldberg, Pinelopi Koujianou, “Product Differentiation and Oligopoly In International Markets: The Case of The U.S. Automobile Industry,” Econometrica, Vol. 63, No.4 (July, 1995), 891-951.

[3] Oak Ridge National Laboratory, “Fleet Characteristics And Data Issues,” Davis, Stacy C, Lorena Truett, Oak Ridge National Laboratory, (Oak Ridge, TN, January 2003).

[4] Bobit Publishing Company, The Fleet Fact Book, various issues (Redondo Beech, California).

[5] Bobit Publishing Company, Note 4.

[6] Davis, Stacy C., Lorena F. Truett, “Investigation of Class 2B Trucks (Vehicles of 8,500 to 10,000 LBS GVWR),” Oak Ridge National Laboratory, ORNL/TM-2002/49, March 2002.

[7] Davis, Stacy C., Lorena F. Truett, op.cit., Note 6.

[8] Greenspan, Alan, and Darrel Cohen, “Motor Vehicle Stocks, Scrappage, and Sales,” Federal Reserve Board (Washington, DC, October 30, 1996).

[9] Oak Ridge National Laboratory, Transportation Energy Data Book: 29 and Annual (Oak Ridge, TN, 2010).

[10] Davis, Stacy C., Lorena F. Truett, op.cit., Note 6.

[11] Greene, David L. and S.M. Chin, “Alternative Fuels and Vehicles (AFV) Model Changes,” Center for Transportation Analysis, Oak Ridge National Laboratory, (Oak Ridge, TN, November 14, 2000).

[12] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, prepared by Interlaboratory Working Group, Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond, (Washington, DC, 1998).

[13] Energy and Environmental Analysis, Inc., Updates to the Fuel Economy Model (FEM) and Advanced Technology Vehicle (ATV) Module of the National Energy Modeling System (NEMS) Transportation Model, Prepared for the Energy Information Administration (EIA), (Arlington, VA, October 23, 2000).

[14] Energy Information Administration, Alternatives to Traditional Transportation Fuels 2005, http://www.eia.doe.gov/cneaf/alternate/page/aftables/afvtransfuel_II.html #in use.

[15] Energy Information Administration, State Energy Data Report 2008

[16] Decision Analysis Corporation of Virginia, “Re-estimation of Freight Adjustment Coefficients,” Report prepared for the Energy Information Administration (EIA), February 28, 1995).

[17] Reebie Associates, TRANSEARCH Freight Commodity Flow Database, (Greenwich, CT, 1992).

[18] U.S. Department of Commerce, Bureau of Census, Vehicle Inventory and Use Survey, ECO2TV, (Washington, DC, December 2004).

[19] Vyas, A., C. Saricks, and F. Stodolsky, “The Potential Effect of Future Energy Efficiency and Emissions Improving Technology on Fuel Consumption of Heavy Trucks,” Argonne National Laboratory, (Argonne, IL, 2002).

[20] Davis, Stacy C., “Memorandum on the Distribution of Trucks by Age and Weight: 2000 Truck Population,” Oak Ridge National Laboratory, (Oak Ridge, TN, November 2001)

[21] Davis, Stacy C., op. cit., Note 20.

[22] Schmoyer, Rick, “Scrappage of Heavy Trucks - Estimates for the Year 2000,” Oak Ridge National Laboratory, DRAFT, (Oak Ridge, TN, June 2001).

[23] Decision Analysis Corporation of Virginia, op. cit. Note 19.

[24] Reebie Associates, op. cit., Note 17.

[25] Oak Ridge National Laboratory, Op. cit. Note 9.

[26] U.S. Department of Transportation, Federal Railroad Administration, “1989 Carload Waybill

Statistics; Territorial Distribution, Traffic and Revenue by Commodity Classes,” (September 1991 and Prior issues).

[27] Energy Information Administration, op. cit., Note 15.

[28] Army Corps of Engineers, Waterborne Commerce of the United States, (Waterborne Statistics Center: New Orleans, LA, 1993).

Notes and sources

[29] Energy Information Administration, op. cit., Note 15.

[30] Bureau of Transportation Statistics, Office of Airline Information, Air Carrier Summary Data (Form 41, Schedules T-1 and T-2), (2009). http://www.transtats.bts.gov/DataIndex.asp; link: Air Carrier Summary Data (Form 41 and 298C Summary Data).

[31] Bureau of Transportation Statistics, op. cit., Note 30.

[32] U.S. Department of Transportation, Federal Aviation Administration, Airport Capacity Benchmark Report, 2004 (2004).

[33] Jet Information Services Inc., World Jet Inventory: Year-End 2009, (December 2009).

[34] Energy Information Administration, op. cit. Note 14

[35] Energy and Environmental Analysis, Inc., "Documentation of Technologies Included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks," Prepared for the Energy Information Administration, (Arlington, VA, September 30, 2002).

[36] Vyas, A., C. Saricks, and F. Stodolsky, "Projected Effect of Future Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks," Argonne National Laboratory, (Argonne, IL, 2001).