Chapter 4

TECHNOLOGIES

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Market Penetration for New Automotive Technologies Takes Time

When a new technology is developed, it takes years to get that technology into the new cars and light trucks that are produced. Fuel injection was one of the quickest technology penetrations, with nearly 100% of market share after 16 years. Lockup transmission use peaked at 30 years with 92% of the market, but has declined due to the use of other new technologies, such as continuously variable transmissions. Similarly, multi-valve use increased to 93% before declining slightly as turbo-charging and super-charging increased. Variable valve timing use recently grew to about 97% of the light vehicle market. Front-wheel drive is primarily used in cars, thus its penetration has been limited by the number of light trucks produced.

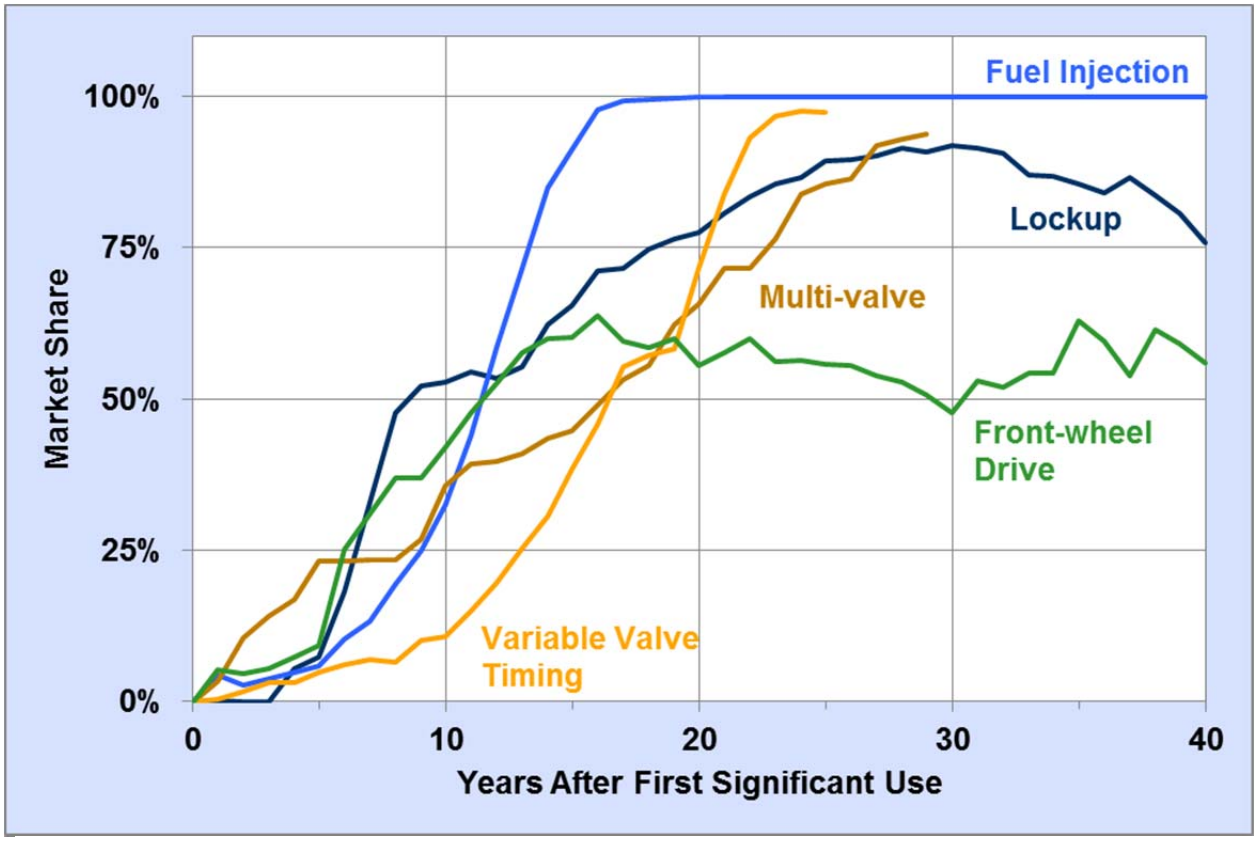


FIGURE 103. Light Vehicle Technology Penetration after First Significant Use

Source:

U.S. Environmental Protection Agency, *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2015*, EPA-420-S-15-001, December 2015. http://www.epa.gov/otaq/fetrends.htm

Gasoline Direct Injection Captures 46% Market Share in Just Eight Years from First Significant Use

Gasoline direct injection (GDI) has seen rapid adoption since its first significant use. As automakers strive for improved fuel economy, many have turned to the combined benefits of GDI and turbocharging for increasing power output from downsized engines. This is evident in the rapid rise of turbo-charged engines in the last five years shown. Cylinder deactivation, which is seen mostly in 6- and 8- cylinder applications, has also seen greater use particularly in the last year, reaching nearly 13% market share. Stop-start technology in non-hybrid vehicles is relatively new in the U.S. market and has only been around for four years since its first significant use. However, in just four years, stop-start has reached almost 7% market share while gasoline hybrids have only grown to 4% market share in the past 16 years.

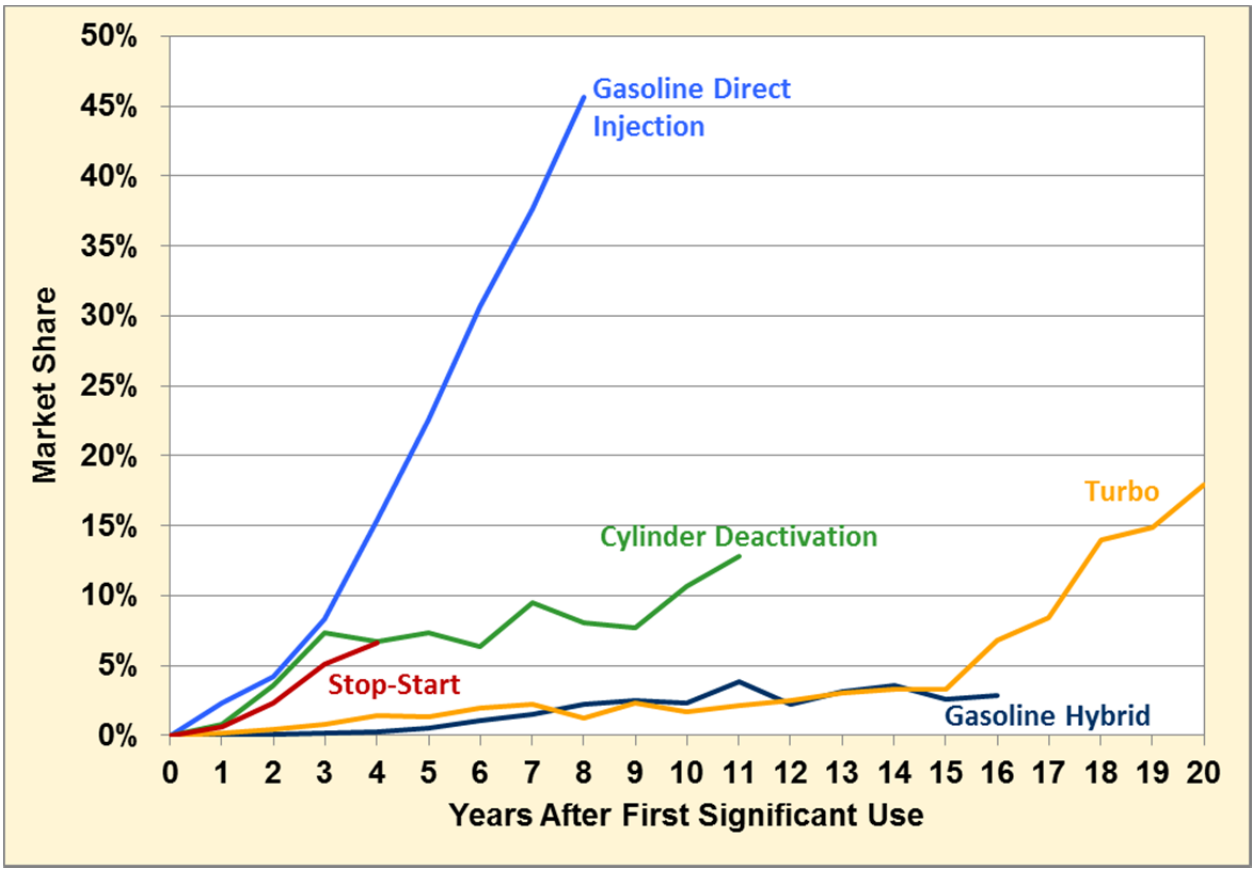


FIGURE 104. New Technology Penetration in Light Vehicles

Note: Stop-start technology data are for non-hybrid vehicles.

Source:

U.S. Environmental Protection Agency, *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2015*, EPA-420-S-15-001, December 2015. http://www.epa.gov/otaq/fetrends.htm

Hybrid Sales Decline by 22% from 2013 to 2015

In 1999, the Honda Insight debuted as the first hybrid-electric vehicle (HEV) in the U.S. market, followed closely by the Toyota Prius in 2000. Since that time, many other manufacturers have entered the hybrid market. From 2008 to 2011, sales of hybrid vehicles declined but increased substantially in 2012 and 2013. Sales dropped again in 2014 and 2015 with 2015 sales at about 384,000 vehicles.

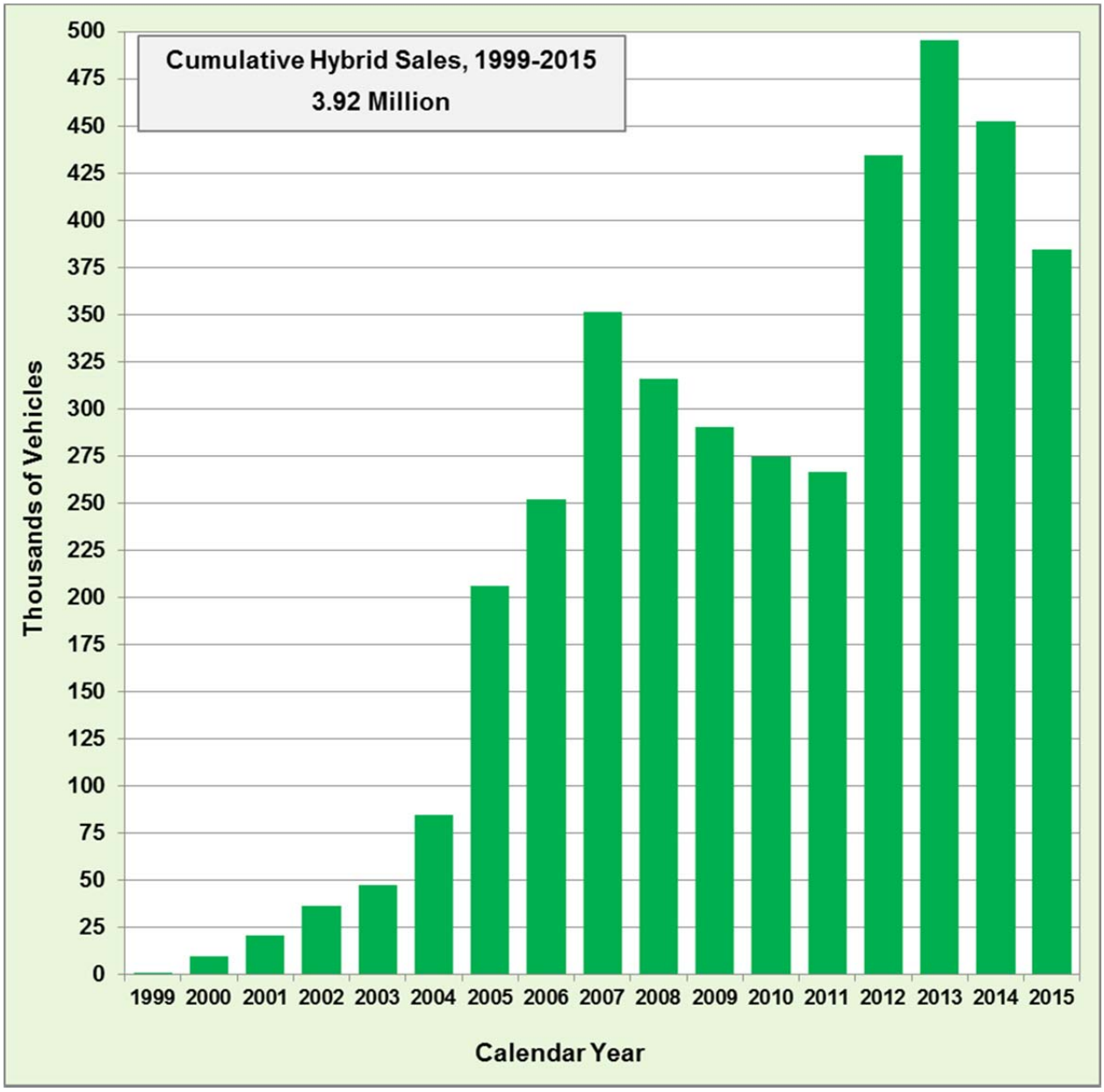


FIGURE 105. Hybrid-Electric Vehicle Sales, 1999-2015

Source:
Provided by Yan (Joann) Zhou, Argonne National Laboratory.
http://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates

Toyota Reigns as Leader of U.S. Hybrid-Electric Vehicle Market Share

Though Honda was the first manufacturer to introduce a hybrid-electric vehicle (HEV) in the United States, Toyota has held more than 50% of the market share since 2000. Ford entered the HEV market in 2004 with an Escape HEV; Lexus began selling the RX400h a year later. Mercury, Nissan, and Saturn joined the other manufacturers selling HEVs in 2007. Thereafter, many more manufacturers began selling HEVs, though some are sold in small volumes.

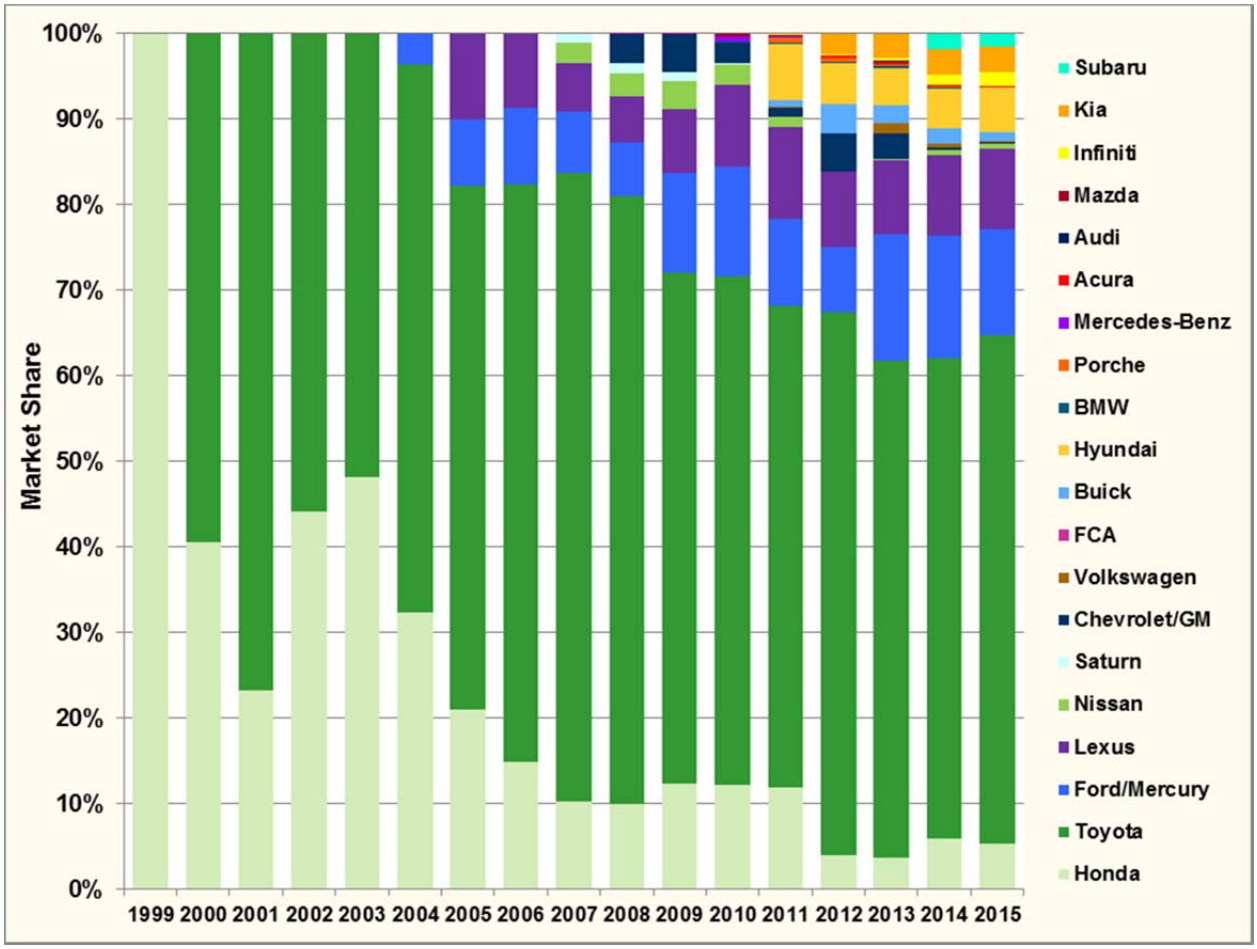


FIGURE 106. Hybrid-Electric Vehicle Market Share, 1999-2015

Source:
U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/data/

Sales from Introduction: Some Plug-In Vehicles Beat Hybrid-Electric Sales in the First Four Years

The Toyota Prius hybrid-electric vehicle (HEV) was first released in the U.S. market in January 2000 and 324 were sold in the first month. The Chevrolet Volt, a hybrid-electric plug-in, and the Nissan Leaf, an all-electric plug-in vehicle, were first released in December 2010. The Prius plug-in hybrid-electric vehicle (PHEV) began sales in April 2012. The chart below shows a comparison of the sales of the Prius HEV from when it was first introduced, to the sales of the Volt, the Leaf, the Prius PHEV, and the Tesla Model S when they were first introduced.

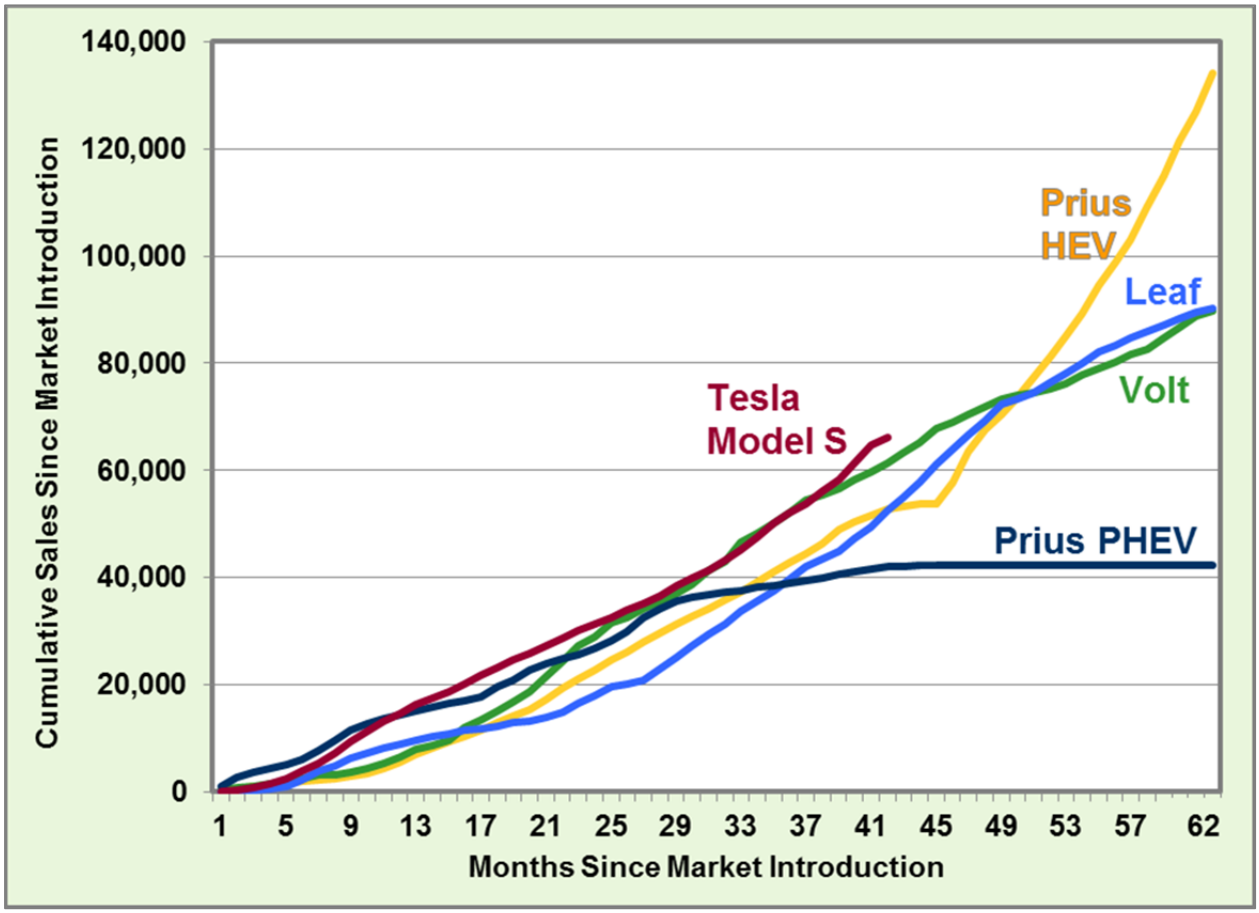


FIGURE 107. Monthly Sales since Market Introduction for Hybrid Vehicles and Plug-In Vehicles

Notes: The Prius HEV was first released in the U.S. market in January 2000.
The Prius PHEV was first released in the U.S. market in April 2012.
The Volt and Leaf were first released in the U.S. market in December 2010.
The Tesla Model S was first released in the U.S. market in June 2012. Tesla sales are estimated.

Source:
Provided by Yan (Joann) Zhou, Argonne National Laboratory. http://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates

Plug-In Vehicle Sales Total over 115,000 Units in 2015

The number of plug-in vehicles sold in the United States in 2015 fell to a little over 115,000, down from 119,000 the previous year. Nissan and Chevrolet had the best sellers in 2011 with the Leaf and the Volt, but were joined by several other manufacturers in 2012. There were 27 different plug-in models available in 2015, many selling less than 5,000 units. The biggest plug-in sellers in 2015 were the Tesla Model S, Nissan Leaf, Chevrolet Volt, BMW i3, and Ford Fusion Energi.

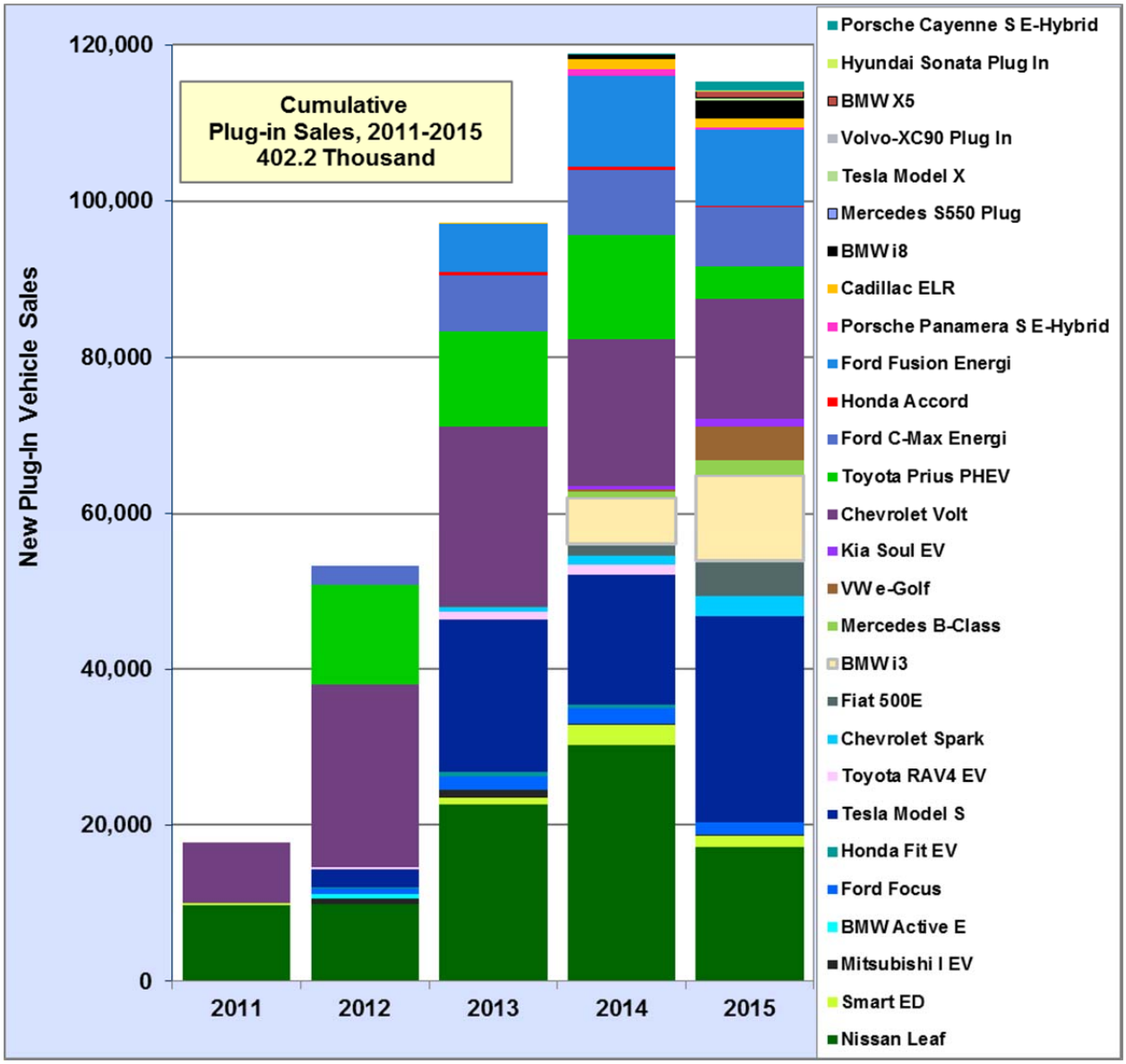


FIGURE 108. Plug-In Vehicle Sales, 2011-2015

Source:
Data provided by Yan (Joann) Zhou, Argonne National Laboratory. http://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates

There Are Thirteen Manufacturers that Produce All-Electric and Fuel Cell Vehicles

In model year 2016 there are 12 different models that plug into electrical outlets to get all of their fuel and two fuel cell vehicles that use hydrogen. The Tesla Model S has the longest range at 270 miles with the 85 or 90 kW-hr battery pack. The Mitsubishi i-Miev has the shortest range with only 62 miles. The two fuel cell vehicles have ranges from about 250-300 miles.

TABLE 30. Available All-Electric Plug-In and Fuel Cell Vehicles, Model Year 2016

Make and Model	Total Range (Miles)	Time to Charge Battery (Hours at 240V)	Specifications
All-Electric Plug-In Vehicles			
BMW-i3 BEV	81	4.0	125 kW AC Induction
Chevrolet Spark EV	82	7.0	105 kW ACIPM
Fiat 500e	84	4.0	82 kW AC Induction
Ford Focus Electric	76	3.6	107 kW AC PMSM
Kia Soul Electric	93	4.0	81 kW AC PMSM
Mercedes-Benz B250e	87	3.5	132 kW AC Induction
Mitsubishi i-Miev	62	7.0	49 kW DCPM
Nissan Leaf, 24 kW-hr 24 kW-hr 30 kW-hr	84 84 107	8.0 (3.6 kW charger) 5.0 (6.6 kW charger) 6.0	80 kW DCPM
smart fortwo electric drive	68	6.0	55 kW DCPM
Tesla Model S, 70 kW-hr	234	10.0 (std. charger) 3.75 (80 amp dual charger)	285 kW AC Induction
Tesla Model S, 85 kW-hr 90 kW-hr	265	12.0 (std. charger) 4.75 (80 amp dual charger)	285 kW AC Induction
Tesla Model S, AWD 70D AWD 85D AWD 90D AWD P85D AWD P90D	240 270 270 253 253	12.0 (std. charger) 4.75 (80 amp dual charger)	70 kW AC Induction 85 kW AC Induction 90 kW AC Induction 193 front, 375 rear, 85 kW 193 front, 375 rear 90 kW
Tesla Model X, AWD 90D AWD P90D	257 250	12.0 (std. charger) 4.75 (80 amp dual charger)	90 kW AC Induction 193 front, 375 rear, 90 kW
Volkswagen e-Golf	83	3.7 (7.2 kW charger) 7.0 (3.6 kW charger)	85 kW AC PMSM
Fuel Cell Vehicles			
Hyundai Tucson Fuel Cell	265	~5 minutes to refuel	180 V Lithium Ion
Toyota Mirai	312	~5 minutes to refuel	245 V NiMH

Notes: AC = Alternative current; ACIPM = Alternating current induction permanent magnet motor; DCPM = Direct current permanent magnet motor; kW = Kilowatt; PMSM = Permanent magnet synchronous motor; V = Voltage; NiMH = Nickel-metal hydride.

Source:
U.S. Department of Energy, Fuel economy data, http://www.fueleconomy.gov. Data accessed March 2016.

Hybrid-Electric Plug-In Vehicles Available from Nine Manufacturers

There are 9 different makes and 13 different models that plug into electrical outlets to get part of their fuel. The BMW i3 REx has the longest all-electric range (72 miles), but the shortest total range (150 miles). The Hyundai Sonata Plug-In Hybrid has the longest total range (600 miles)

Table 31. Available Hybrid-Electric Plug-In Vehicles, Model Year 2016

Make and Model	All-Electric Range (Miles)	Total Range (Miles)	Time to Charge Battery (Hours at 240V)	Specifications
Audi A3 e-tron	16	380	2.5	80 kW electric motor, 1.4 L, 4 cyl
Audi A3 e-tron ultra	17	430	2.5	80 kW electric motor, 1.4L, 4 cyl
BMW i3 REX	72	150	4.0	125 kW electric motor, 0.6 L 2 cyl
BMW i8	15	330	2.0	96 kW electric motor, 1.5L, 3 cyl
BMW X5 XDrive40e	14	540	3.0	83 kW electric motor, 2.0 L, 4 cyl
Cadillac ELR	40	340	5.0	55 and 174 kW electric motor, 1.4 L, 4 cyl
Cadillac ELR Sport	36	320	5.0	55 and 174 kW electric motor, 1.4 L, 4 cyl
Chevrolet Volt	53	420	4.5	48 and 87 kW electric motor, 1.5L, 4 cyl
Ford C-Max Energi Plug-in Hybrid	20	550	2.5	68 kW electric motor, 2.0 L, 4 cyl
Ford Fusion Energi Plug-in Hybrid	20	550	2.5	68 kW electric motor, 2.0 L, 4 cyl
Hyundai Sonata Plug-In Hybrid	27	600	2.7	50 kW electric motor, 2.0 L, 4 cyl
Mercedes-Benz S550e	14	450	2.8	85 kW electric motor, 3.0 L, 6 cyl
Porsche Cayenne S e-Hybrid	14	480	3.0	70 kW electric motor, 3.0 L, 6 cyl
Porsche Panamera S E-Hybrid	16	560	3.0	70 kW electric motor, 3.0 L, 6 cyl
Volvo XC90 AWD PHEV	14	350	3.0	34 and 65 kW electric motor, 2.0L, 4 cyl

Notes: kW = Kilowatt; L = Liter; cyl = Cylinder.

Source:
U.S. Department of Energy, Fuel economy data, http://www.fueleconomy.gov. Data accessed March 2016.

New Plug-In and Fuel Cell Vehicles Are on the Horizon

There are ten new plug-in vehicles expected in model years 2016-2018 (three all-electric and seven hybrid-electric) and two fuel cell vehicles. The expected ranges of the all-electric vehicles go from 105 miles with the Hyundai Ioniq Electric to 200 miles with the Chevrolet Bolt EV and the Tesla Model 3. The hybrid-electric plug-ins, which also use gasoline, have expected electric ranges of 23-39 miles with total ranges of up to 600 miles. The fuel cell vehicles have ranges similar to conventional vehicles.

TABLE 32. Upcoming Plug-In and Fuel Cell Vehicles

Model Year	Make and Model	All-Electric Range (miles)	Total Range (miles)	Specifications
All-Electric Plug-In Vehicles				
2016	Chevrolet Bolt EV	~200	~200	60 kWh Li-ion battery; 240 volt charging unit; est 200 miles per charge
2017	Hyundai Ioniq Electric	~105	~105	88 kW motor, 28 kWh Li-ion battery pack
2017	Tesla Model 3	~200	~200	N/A
Hybrid-Electric Plug-In Vehicles				
2016	BMW 740e Plug-In Hybrid	23	N/A	2.0 L 4 cyl engine, 250 Nm Li-ion battery,
2016	Cadillac CT6 Plug-In Hybrid	30	N/A	2-motor EVT system, 2.0 L turbocharged 4 cyl engine, 18.4 kWh Li-ion battery
2017	Chrysler Pacifica Mini Van	30	530	3.6 L V6 engine; 16 kWh Li-ion battery pack;
2017	Hyundai Ioniq	~22-26	N/A	1.6 L 4 cyl engine, 43 hp electric motor, Li-ion polymer battery
2017	Kia Optima Plug-In Hybrid	~27	600	2.0 L 4 cyl engine, 50 kW electric motor, 9.8 kWh Lithium-polymer battery pack
2017	Mitsubishi Outlander Plug-In Hybrid	32.5	N/A	2-electric motors, 2.0 L 4 cyl engine, 12 kWh Li-ion battery pack
2018	Honda Accord Plug-In Hybrid	39	N/A	2 motors
Fuel Cell Vehicles				
2017	Mercedes-Benz GLC F-Cell	N/A	250-300	N/A
2016	Honda Clarity	N/A	300+	134 hp

Notes: Since these vehicles are not currently for sale, the all-electric ranges are company estimates and not the result of the Environmental Protection Agency tests. N/A = not applicable.

Sources:

U.S. Department of Energy, Fuel economy data, http://www.fueleconomy.gov and other industry sources. Data accessed March 2016.

Primearth EV Energy Supplied the Most Batteries by Number but Panasonic Supplied the Most Battery Capacity for Model Year 2015

Primearth EV Energy supplied a majority of the batteries for hybrid vehicles in 2015. While hybrid vehicle sales far outnumber plug-in vehicle sales, the capacity of hybrid batteries average only about 1.2 kW-hrs per battery. Panasonic, while supplying fewer batteries, produced them for plug-in vehicles that have much larger batteries so they supplied the greatest amount battery capacity. The battery capacity for a plug-in vehicle could be as high as 90 kW-hrs–a battery offering for the Tesla models. AESC and LG Chem also produced a substantial amount of battery capacity for plug-in vehicles in that year.

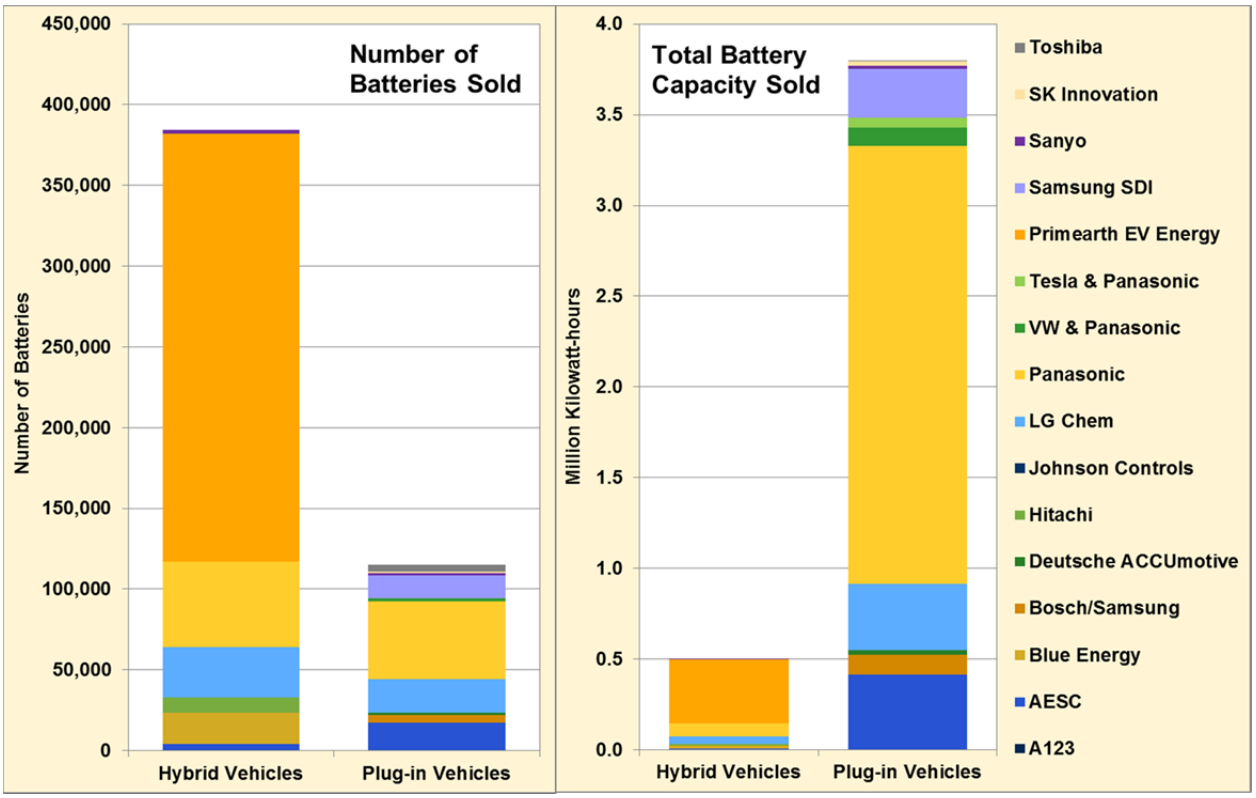


FIGURE 109. Battery Sales Estimates for Hybrid and Plug-In Vehicles, 2015

Sources:

Estimated using hybrid and plug-in sales data along with information on battery suppliers.

Vehicle Sales Data – Provided by Yan (Joann) Zhou, Argonne National Laboratory.
http://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates

Battery Suppliers – Compiled from public sources by John Thomas, Oak Ridge National Laboratory, January 2016.

Battery Capacity Varies Widely for Plug-In Vehicles

The all-electric plug-in vehicles have capacities ranging from 16 kW-hrs in the Mitsubishi iMiev to 90 kW-hrs in the Tesla Model S (and Model X). Plug-in hybrid-electric vehicles typically have smaller battery capacities than all-electric vehicles because their range is extended with a gasoline engine. All plug-in vehicles currently have lithium-ion (Li-ion) batteries.

TABLE 33. Batteries for Selected Available and Upcoming Plug-in Vehicles, Model Years 2015-2016

Model Year	Vehicle	Battery Capacity (kW-hrs)	Battery Type	Supplier
All-Electric Vehicles				
2015	BMW i3	22	Li-ion	Samsung SDI
2016	Chevrolet Spark EV	18.4	Li-ion	LG Chem
2016	Fiat 500e	24	Li-ion	Samsung, SB LiMotive, Bosch-Samsung partnership
2016	Ford Focus Electric	23	Li-ion	LG Chem
2016	Kia Soul EV	27	Li-ion	SK Innovation
2016	Mercedes-Benz B250e	28	Li-ion	Panasonic
2016	Mitsubishi iMiEV	16	Li-ion	Lithium Energy Japan
2016	Nissan Leaf	24	Li-ion	AESC
2016	Nissan Leaf	30	Li-ion	AESC
2016	Smart For Two Electric Drive	17.6	Li-ion	Deutsche ACCUmotive
2016	Tesla Model S70, S70D	70	Li-ion	Tesla/Panasonic
2016	Tesla Model S85, S85D, P85D	85	Li-ion	Tesla/Panasonic
2016	Tesla Model S90, S90D, P90D	90	Li-ion	Tesla/Panasonic
2016	Tesla Model X 90D, P90D	90	Li-ion	Tesla/Panasonic
2016	Volkswagen e-Golf	24.2	Li-ion	VW & Panasonic
Plug-In Hybrid-Electric Vehicles				
2016	Audi A3 Sportback eTron & etron ultra	8.8	Li-ion	Sanyo
2016	Mercedes-Benz S550e	8.7	Li-ion	Panasonic
2016	BMW X5 xDrive 4.0e	9	Li-ion	Samsung
2015	BMW i3 REX (range extender)	22	Li-ion	Samsung
2015	BMW i8	7.1	Li-ion	Samsung
2016	Cadillac ELR	17.1	Li-ion	LG Chem
2016	Chevrolet Volt	18.4	Li-ion	LG Chem
2016	Ford Fusion Energi	7.6	Li-ion	Panasonic
2016	Ford C-Max Energi	7.6	Li-ion	Panasonic
2016	Hyundai Sonata	9.8	Li-ion	LG chem
2015	Toyota Prius Plug-In	4.4	Li-ion	Panasonic
2016	Porsche Cayenne S e-Hybrid	9.4	Li-ion	Samsung
2016	Porsche Panamera S e-Hybrid	9.4	Li-ion	Samsung
2015	Porsche 918 Spyder	10.8	Li-ion	Samsung
2015	McLaren Automotive P1	6.8	Li-ion	Johnson Matthey Battery Systems
2016	Volvo XC90 T8	9.2	Li-ion	LG Chem

Notes: Automotive Energy Supply Corporation (AESC) is a joint venture between NEC and Nissan. Deutche ACCUmotive is a joint venture between Daimler and Evonik Industries AG. Primearth EV Energy is a joint venture between Panasonic and Toyota. Sanyo is a wholly-owned subsidiary of Panasonic.

Source:
Compiled from public sources by John Thomas, Oak Ridge National Laboratory, January 2016.

Hybrid-Electric Vehicles Typically Use Batteries with Capacities Less than 2 Kilowatt-Hours

Battery capacities for hybrid-electric vehicles range from 0.5 to 1.9 kilowatt-hours. Some manufacturers have moved to lithium-ion (Li-ion) or lithium-polymer batteries, while others continue with the nickel-metal hydride (NiMH) batteries.

TABLE 34. Batteries for Selected Hybrid-Electric Vehicles, Model Years 2015-2016

Model Year	Vehicle	Battery Capacity (kW-hrs)	Battery Type	Supplier
2016	Acura RLX Hybrid	1.3	Li-ion	Blue Energy
2016	Audi Q5 Hybrid	1.3	Li-ion	Sanyo
2015	BMW ActiveHybrid 3	1.4	Li-ion	A123
2016	BMW ActiveHybrid 5	1.4	Li-ion	A123
2015	BMW ActiveHybrid 7L	1.4	Li-ion	A123
2016	Buick LaCrosse eAssist	0.5	Li-ion	Hitachi
2016	Buick Regal eAssist	0.5	Li-ion	Hitachi
2016	Ford C-Max Hybrid	1.4	Li-ion	Panasonic
2016	Ford Fusion Hybrid	1.4	Li-ion	Panasonic
2015	Honda Accord Hybrid	1.3	Li-ion	Blue Energy
2015	Honda Civic Hybrid	0.7	Li-ion	Blue Energy
2016	Honda CR-Z Hybrid	0.7	Li-ion	Blue Energy
2016	Hyundai Sonata Hybrid	1.6	Li-ion polymer	LG Chem
2016	Inifiniti Q70 Hybrid	1.4	Li-ion	AESC
2015	Inifiniti Q50 Hybrid	1.4	Li-ion	AESC
2015	Inifiniti QX60 Hybrid	0.7	Li-ion	Hitachi
2016	Kia Optima	1.4	Li-ion polymer	LG Chem
2016	Lexus CT 200h	1.3	NiMH	Primearth EV Energy
2016	Lexus ES 300h	1.6	NiMH	Primearth EV Energy
2016	Lexus NX 300h	1.6	NiMH	Primearth EV Energy
2016	Lexus GS 450h	1.9	NiMH	Primearth EV Energy
2016	Lexus LS 600h L	1.9	NiMH	Primearth EV Energy
2015	Lexus RX 450h	1.9	NiMH	Primearth EV Energy
2016	Lincoln MKZ Hybrid	1.4	Li-ion	Panasonic
2015	Mercedes Benz E400 Hybrid	0.8	Li-ion	Panasonic
2015	Nissan Pathfinder Hybrid	0.7	Li-ion	Hitachi
2016	Porsche Cayenne S Hybrid	0.6	NiMH	Panasonic
2016	Suburu XV Crosstrek Hybiid	1.6	NiMH	Primearth EV Energy
2016	Toyota Avalon Hybrid	1.6	NiMH	Primearth EV Energy
2016	Toyota Camry Hybrid	1.9	NiMH	Primearth EV Energy
2016	Toyota Highlander Hybrid	1.3	NiMH	Primearth EV Energy
2016	Toyota Prius Eco	0.7	Li-ion	Toyota/Panasonic
2016	Toyota Prius c	0.9	NiMH	Primearth EV Energy
2016	Toyota Prius v	1.3	NiMH	Primearth EV Energy
2016	Toyota RAV4 Hybrid	1.6	NiMH	Primearth EV Energy
2016	Volkswagen Jetta Hybrid	1.1	Li-ion	Sanyo

Notes: Automotive Energy Supply Corporation (AESC) is a joint venture between NEC and Nissan. Primearth EV Energy is a joint venture between Panasonic and Toyota. Sanyo is a wholly-owned subsidiary of Panasonic. Blue Energy is a joint venture between GS Yuasa and Honda.

Source:
Compiled from public sources by John Thomas, Oak Ridge National Laboratory, January 2016.

Hybrid Medium and Heavy Vehicles on the Market

The first line production of commercial diesel-electric hybrid trucks was the International DuraStar Hybrid which began production in 2007. There are currently numerous models of hybrid cargo trucks on the market. Most of the hybrid trucks available are diesel-fueled and are used for a variety of purposes, ranging from delivery vehicles to long-haul trucks.

TABLE 35. Hybrid and Electric Cargo Trucks on the Market

Manufacturer	Model	Category
Hybrid Electric		
Autocar	E3 Hybrid	Refuse
Champion Bus Inc.	Defender	Shuttle Bus
Collins Bus Corp.	NexBus Gasoline Hybrid	School Bus
Daimler Buses North America	Orion VII Hybrid Low-Floor	Transit Bus
DesignLine Corp.	EcoSaver IV	Transit Bus
Ebus	EBUS22FC	Shuttle Bus
ElDorado National	Axess	Transit Bus
ElDorado National	E-Z Rider II BRT	Transit Bus
Foton America	FCB 30-foot; FCB 35-foot; FCB 40-foot	Transit Bus
Freightliner	M2 106	Tractor
Freightliner	M2 106 Hybrid	TractorVocational/Cab Chassis
Gillig Corp.	Diesel-Electric Hybrid Bus and CNG Bus	Transit Bus
Glaval Bus	Universal	Shuttle Bus
Hino	195h	Vocational/Cab Chassis
IC Bus	HC Hybrid Series	Shuttle Bus
International	DuraStar Hybrid	Vocational/Cab Chassis
Kenworth	T270 Hybrid	TractorVocational/Cab Chassis
Kenworth	T370 Diesel Electric Tractor	Tractor
Kenworth	T370 Hybrid Truck	Vocational/Cab Chassis
Motor Coach Industries	D4500 CT Hybrid Commuter Coach	Transit Bus
Navistar	HC300 Hybrid	School Bus
New Flyer	Xcelsior	Transit Bus
North American Bus Industries	31LFW / 35LFW / 40LFW	Transit Bus
North American Bus Industries	42BRT	Transit Bus
North American Bus Industries	60BRT	Transit Bus
North American Bus Industries	CompoBus	Transit Bus
Nova Bus	LFS Artic HEV	Transit Bus
Nova Bus	LFS HEV	Transit Bus
Nova Bus	LFX	Transit Bus
Peterbilt Motors	330 Hybrid	Vocational/Cab Chassis
Peterbilt Motors	337/338	TractorVocational/Cab Chassis
Peterbilt Motors	386HE	Tractor
Thomas Built Buses	Saf-T-Liner C2e Hybrid	School Bus
Turtle Top	Odyssey XLT	Shuttle Bus
Hybrid Hydraulic		
Peterbilt Motors	320 HLA	Refuse

Source:

U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, accessed March 10, 2016. http://www.afdc.energy.gov/vehicles/search

Electric and Hydrogen Fuel Cell Medium and Heavy Vehicles on the Market

There are 19 electric medium and heavy trucks available in a variety of body types—step vans, vocational vehicles, transit buses, school buses and tractors. In addition, there are seven hydrogen-fueled medium and heavy trucks on the market.

TABLE 36. Electric and Hydrogen Fuel Cell Medium and Heavy Vehicles on the Market

Manufacturer	Model	Category
Electric		
Balqon	Mule M150	Vocational/Cab Chassis
Balqon	XE-20	Tractor
Balqon	XE-30	Tractor
Boulder Electric Vehicle	DV-500 Delivery Truck	Step Van
BYD (Build Your Dream)	40 ft. Transit Bus	Transit Bus
BYD (Build Your Dream)	60 ft. Transit Bus	Transit Bus
Capacity Trucks	HETT	Tractor
DesignLine Corp.	Eco-Smart 1	Transit Bus
Electric Vehicles International	EVI-MD	Vocational/Cab Chassis
Electric Vehicles International	WI EVI	Step Van
Enova Systems	Enova Ze Step Van	Step Van
GGT Electric	Electric	Vocational/Cab Chassis
Navistar-Modec EV Alliance	eStar	Step Van
New Flyer	Xcelsior	Transit Bus
Proterra	EcoRide BE35	Transit Bus
Smith Electric Vehicles	Newton	Vocational/Cab Chassis
Smith Electric Vehicles	Newton Step Van	Step Van
Trans Tech	ETrans	School Bus
ZeroTruck	ZeroTruck	Vocational/Cab Chassis
Hydrogen Fuel Cell		
Capacity Trucks	ZETT	Tractor
Ebus	EBUS22FC	Shuttle Bus
ElDorado National	Axess	Transit Bus
New Flyer	Xcelsior	Transit Bus
Van Hool	A300L Fuel Cel	Transit Bus
Vision Motor Corp.	Tyrano	Tractor
Vision Motor Corp.	ZETT	Tractor

Source:

U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, accessed March 10, 2016. http://www.afdc.energy.gov/vehicles/search

Flex-Fuel Vehicle Offerings Decline by 11% for Model Year 2015

In the last five years, GM, FCA, and Ford have been the front-runners in the number of flex-fuel models offered to the public (includes cars and light trucks). Nissan and Toyota have offered flex-fuel models each of the last five years, too. Other manufacturers, like Volkswagen and Mercedes-Benz expanded their flex-fuel offerings in 2012 through 2013. In 2015 there were 71 different flex-fuel vehicle models available. The manufacturers receive credits in the Corporate Average Fuel Economy program for producing flex-fuel vehicles, which run on E85 and/or gasoline.

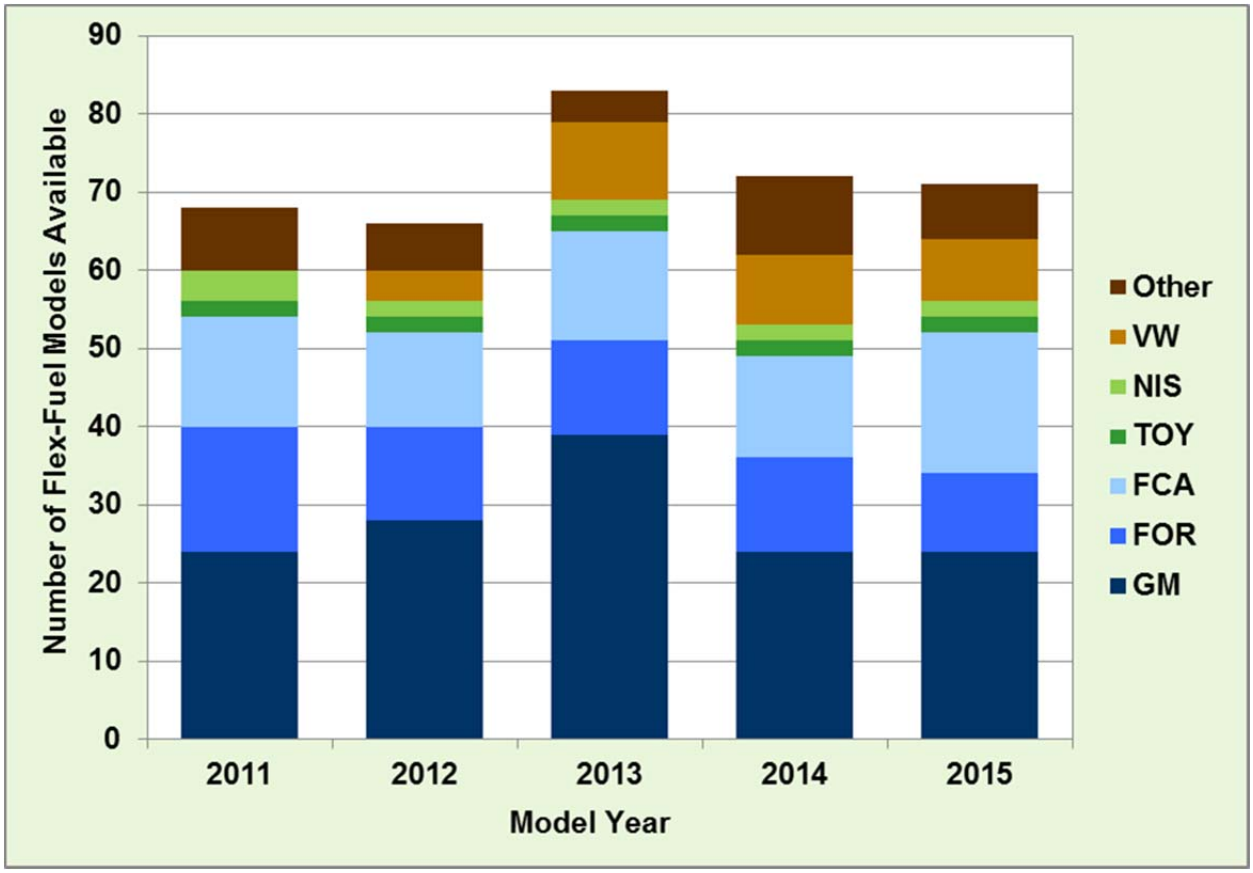


FIGURE 110. Number of Flex-Fuel Models Available, 2011-2015

Source:
U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/vehicles/search

Alternative Fuel Vehicles Supplied Are Mostly Flex-Fuel Vehicles

In lieu of "vehicles in use" the Energy Information Administration now publishes the number of vehicles supplied each year from original equipment manufacturers and conversions. These data will more closely align with sales than with vehicle population. Unfortunately there is no estimate of how many flex-fuel vehicles are actually using E85 or how many gallons of E85 are consumed.

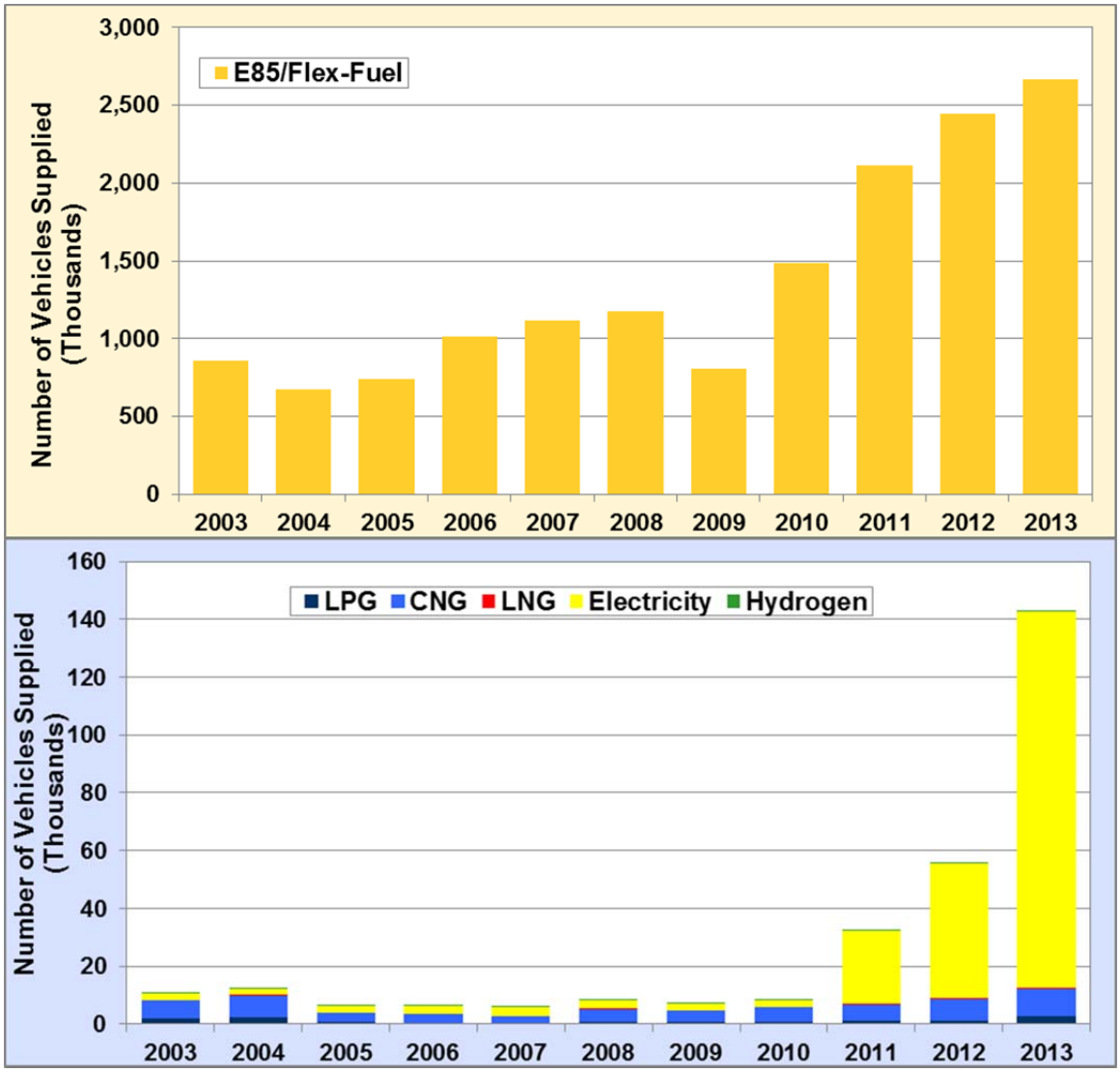


FIGURE 111. Number of Alternative Fuel Vehicles Supplied, 2003-2013

Note: Electricity includes only vehicles that plug into an outlet and does not include low-speed vehicles. LPG = Liquefied petroleum gas; CNG = Compressed natural gas; LNG = Liquefied natural gas.

Source:
U.S. Department of Energy, Energy Information Administration.
http://www.eia.gov/renewable/afv/supply.cfm

Electric Charging Stations Are the Fastest Growing Type of Alternative Fueling Station

The number of electric charging stations (plugs) grew from about 3,500 in 2011 to over 30,000 in 2015. It should be noted that beginning in 2011, electric charging stations refers to individual plugs rather than a station which may have multiple plugs. Electric vehicle charge times are much longer than refueling times for other fuel types so the number of plugs is critical, but it can inflate the station count for electricity relative to the other alternative fuel types. In 2015, there were about 3,600 propane stations, 3,000 E85 stations, and 1,600 compressed natural gas (CNG) refueling stations. The other fuel types (biodiesel, liquefied natural gas (LNG) and hydrogen) altogether have less than 1,000 stations nationwide.

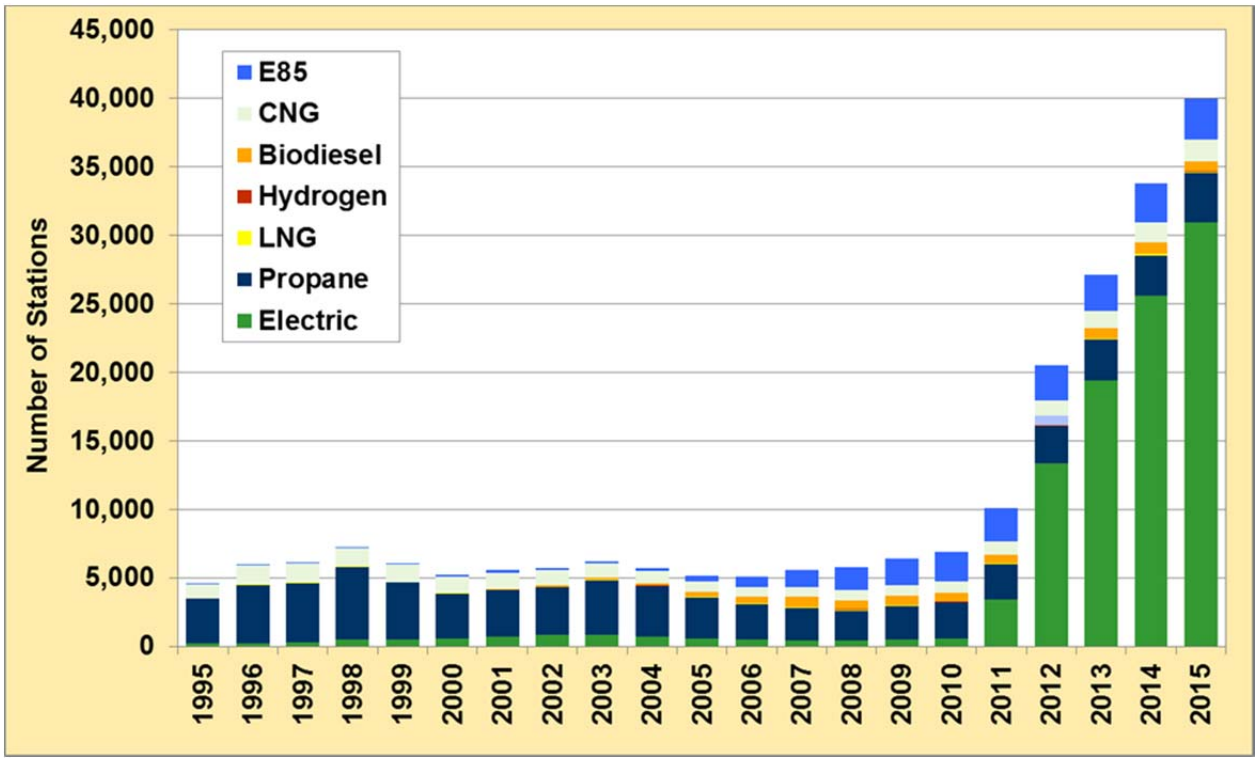


FIGURE 112. Alternative Fueling Stations by Fuel Type, 1995-2015

Notes:

- Starting in 2011, electric charge equipment was counted by the plug rather than by the geographical location. This is different than other fuels, which only count the geographical location regardless of how many dispensers or nozzles are on site.
- Stations selling low-level biodiesel blends (less than B20) are included in the station listing only for the years 2005-2007.
- Stations are counted once for each type of fuel sold.
- Includes public and private stations.

Source:

U.S. Department of Energy, Alternative Fuels Data Center, "Alternative Fueling Station Counts by State," data accessed February 2016. http://www.afdc.energy.gov/data/10332

Biofuel Stations Spread beyond the Midwest

E85, which is nominally 85% ethanol and 15% gasoline, is sold at 3,127 stations nationwide. Many stations are located in the Midwest where the majority of ethanol feedstock is grown, but E85 stations are found throughout the nation. Biodiesel is sold at 712 stations across the country, with the predominance of stations in the Southeast. Data are as of March 9, 2016.

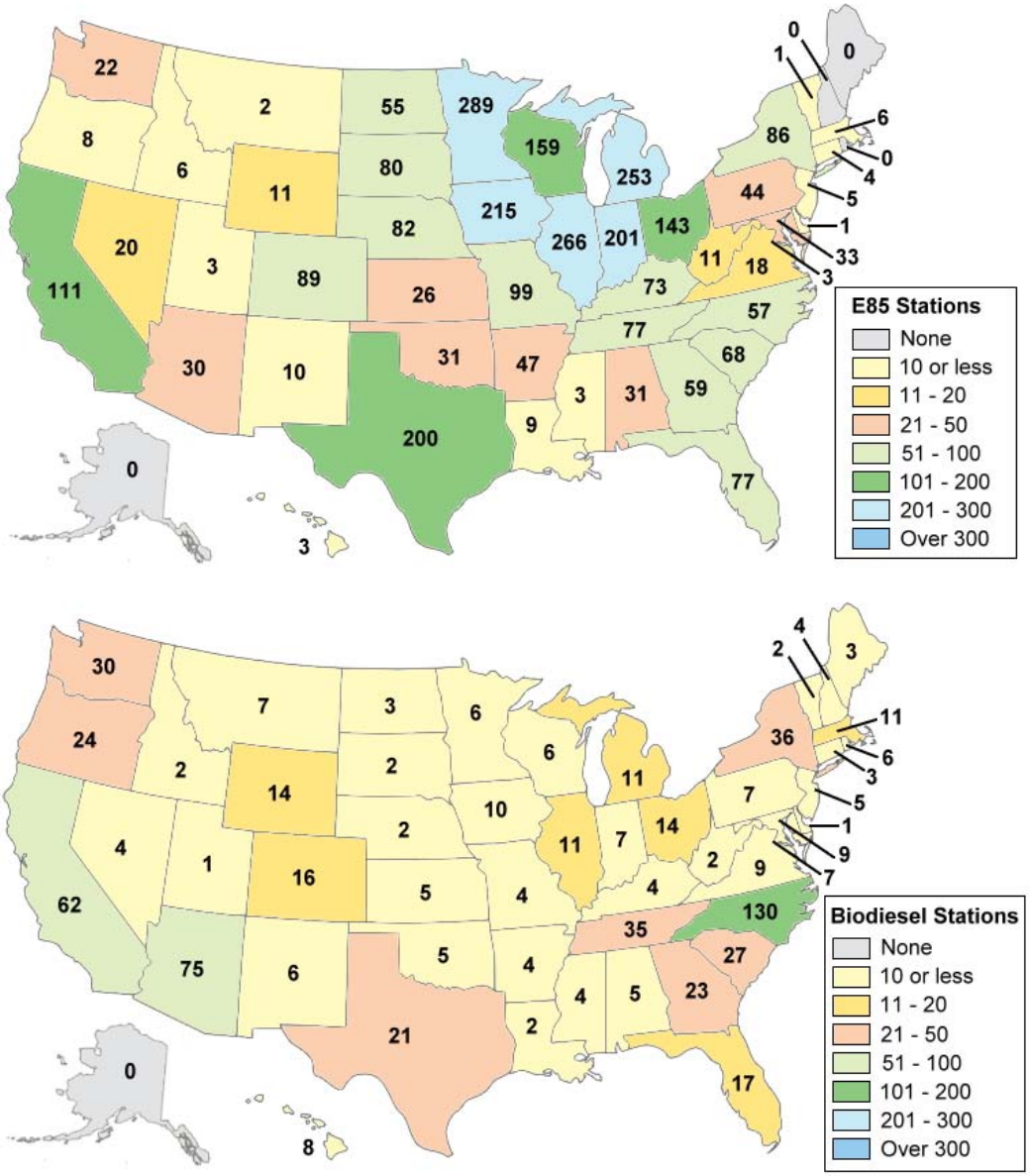


FIGURE 113. Number of E85 (top) and Biodiesel Stations by State, 2016

Note: Includes public and private stations.

Source:
U.S. Department of Energy, Alternative Fuel and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/fuels/stations_counts.html

Most States Have Stations with Propane and Natural Gas

There is a wide distribution of the 3,759 propane stations across the country. Texas and California together comprise 23% of the propane stations. Natural gas, compressed or liquefied, is not as widely available as many other alternative fuels. There are 1,748 stations nationwide. California and Texas have the most natural gas stations. Data are as of March 9, 2016.

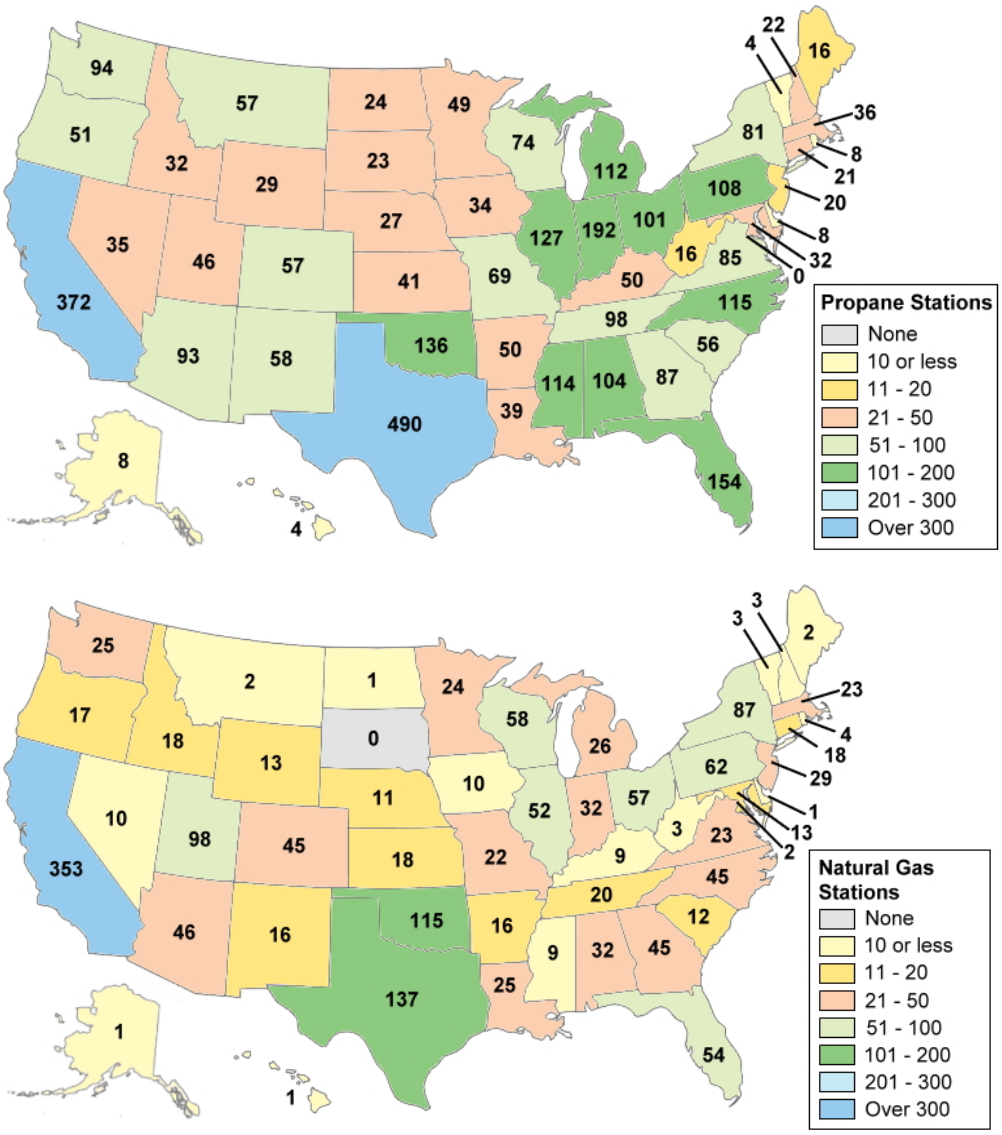


FIGURE 114. Number of Propane (top) and Natural Gas Stations by State, 2016

Note: Includes public and private stations.

Source:
U.S. Department of Energy, Alternative Fuel and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/fuels/stations_counts.html

Number of Electric Stations and Electric Charging Units Increasing

There are more electric stations than any other alternative fuel (14,966 stations). The number of charging units is of particular importance for electric vehicles due to the length of time it takes vehicles to charge compared to other types of fueling stations. While most refueling is completed in a matter of minutes, electric vehicles may occupy a charging unit for hours so it is important to know the total number of available charging units. Data are as of March 9, 2016.

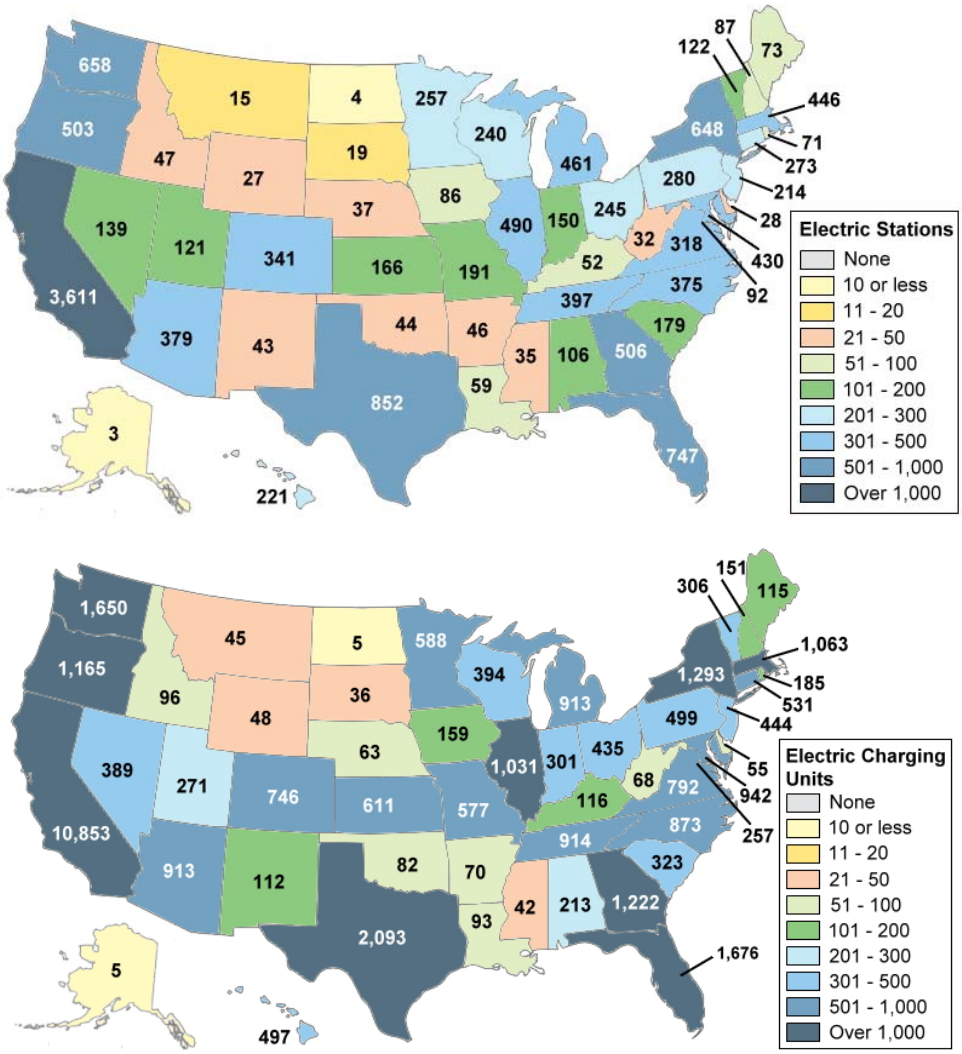


FIGURE 115. Number of Electric Stations (top) and Electric Charging Units by State, 2016

Note: Includes public and private stations and units. About 84% of stations and units are public.

Source:
U.S. Department of Energy, Alternative Fuel and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/fuels/stations_counts.html

Hydrogen Stations Are Mainly in California

Hydrogen stations are mainly located in California where the first hydrogen-fueled light vehicles are available. Other states may have hydrogen refueling stations for research and development purposes. There are 14 states with at least one hydrogen refueling station. Data are as of March 9, 2016.

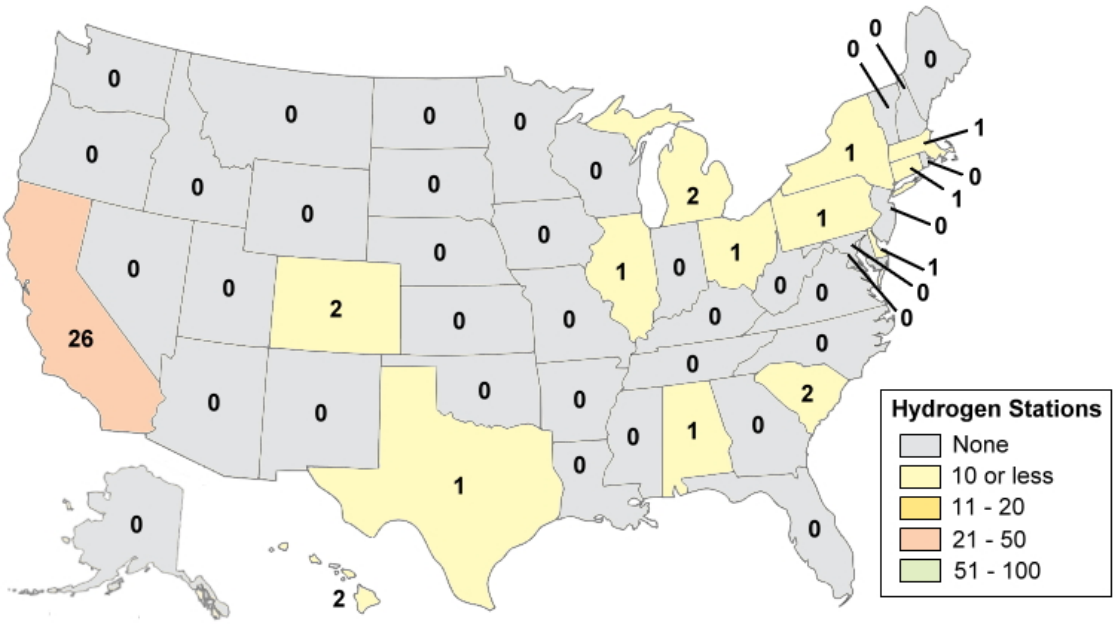


FIGURE 116. Number of Hydrogen Stations by State, 2016

Note: Includes public and private stations.

Source:
U.S. Department of Energy, Alternative Fuel and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/fuels/stations_counts.html

Federal Government Uses Alternative Fuel

The Federal Government is a large user of alternative fuel. Over 18 million gasoline-equivalent gallons (GGEs) of biofuels (E85 and biodiesel) were used in 2014. Federal use of other alternative fuels has been less than one million GGEs combined in 2010-2014. Note the large difference in the scales of the two graphs.

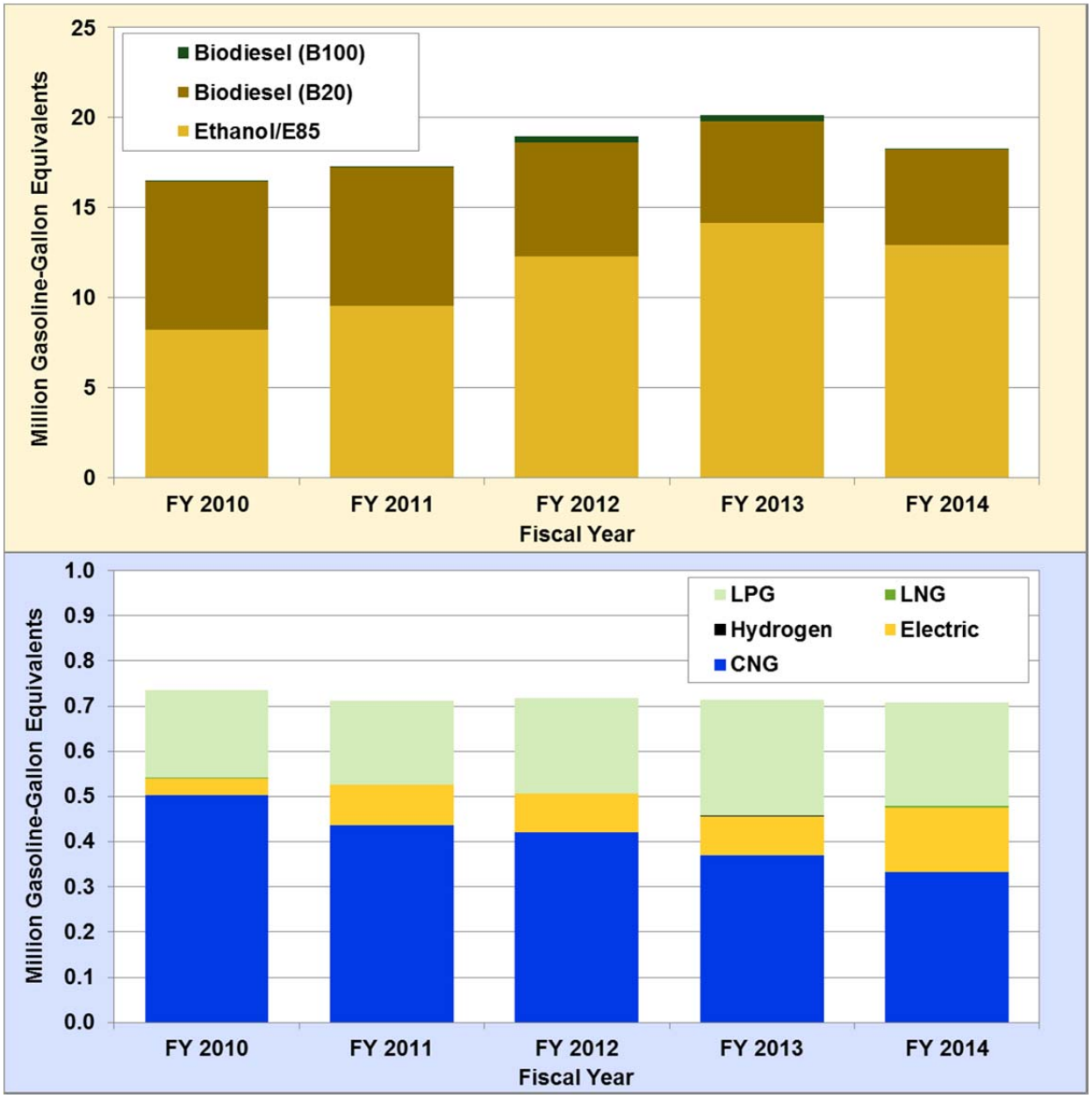


FIGURE 117. Alternative Fuel Use by the Federal Government, 2010-2014

Source:

U.S. General Services Administration, *FY 2014 Federal Fleet Report*, Washington, DC, 2015. http://www.gsa.gov/portal/content/102943

E85 Vehicles Top Diesels in the Federal Government Fleet

Though gasoline vehicles are the most prevalent in the Federal Government fleet, there are more E85 vehicles than diesels in the inventory. The number of gasoline hybrid vehicles and electric vehicles both rose substantially between 2010 and 2014.

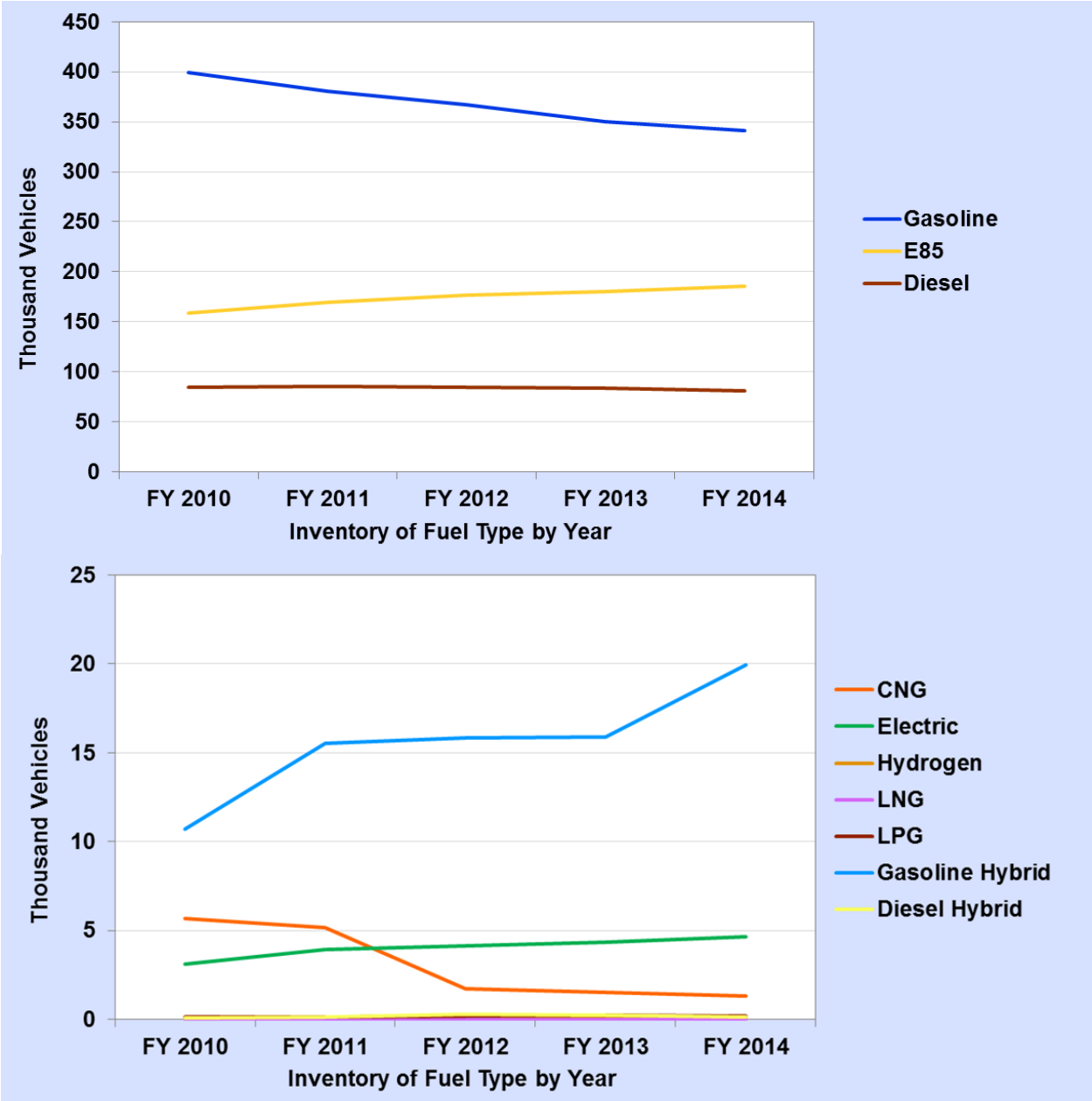


FIGURE 118. Federal Government Vehicles by Fuel Type, 2010-2014

Source:
U.S. General Services Administration, *FY 2014 Federal Fleet Report*, Washington, DC, 2015.
http://www.gsa.gov/portal/content/102943

Commercial Fleets Use Alternative Fuel and Advanced Technology Vehicles

Some commercial fleet owners are realizing the advantages of using alternative fuels and advanced technology vehicles. A list of the top "green" fleets compiled by Bobit Publishing shows that Waste Management uses more than 12,000 alternative fuel vehicles, most of them biodiesel.

TABLE 37. Top 25 Commercial Fleets Using Alternative Fuel and Advanced Technology Vehicles, 2015

	Company	CNG*	Propane*	Flex-Fuel	Biodiesel	Hybrid/ Electric*	Total Alt Fuel
1	Waste Management	933	10	0	11,000	388	12,331
2	AT&T	7,726	0	668	0	2,518	10,912
3	Archer Daniels Midland	0	0	10,214	0	255	10,469
4	Elan Pharmaceuticals	6,051	0	0	0	2,168	8,219
5	Honeywell International, Inc.	514	0	3,500	1,500	1,307	6,821
6	Abbott	1,144	20	2,100	2,300	4	5,824
7	Merck & Co., Inc.	0	0	3,932	0	725	4,657
8	New Jersey Natural Gas Company	3	0	4,402	0	212	4,617
9	AstraZeneca Pharmaceuticals	0	0	1,873	0	2,671	4,544
10	Allergan	0	77	4,175	0	1	4,253
11	Cook's Pest Control, Inc.	200	500	1,000	1,000	1,000	3,800
12	G&K Services	712	0	294	1,201	1,266	3,473
13	Safeway, Inc.	0	0	3,400	0	0	3,400
14	Kraft Foods	0	0	3,000	0	67	3,067
15	Air Products & Chemicals, Inc.	215	118	48	0	2,244	2,631
16	AutoZone	0	0	2,489	0	0	2,489
17	Republic Services	60	0	0	1,741	530	2,331
18	Norfolk Southern Railway Co.	0	0	2,157	0	0	2,157
19	Liberty Mutual Insurance	0	0	0	1,638	504	2,142
20	Yum! Brands Restaurants	0	0	2,000	0	30	2,030
21	Serco Group	30	151	0	0	1,832	2,013
22	McDonald's Corp.	0	0	2,000	0	2	2,002
23	Colgate-Palmolive	0	0	0	0	1,792	1,792
24	Pfizer, Inc.	0	0	1,300	50	35	1,385
25	Aflac	0	0	845	0	0	845

*Includes dedicated and bi-fuel vehicles.

Source:

Bobit Publishing, *Automotive Fleet 500*, "Top 50 Green Fleets," 2015.
http://digital.automotive-fleet.com/FL5002015

Use of Lightweight Materials Is on the Rise

As automakers strive to improve fuel economy, they have turned increasingly to lightweight materials to reduce overall vehicle weight. For example, most light vehicle engine blocks are now made of aluminum rather than cast iron, and in many cases, aluminum wheels have replaced heavier steel wheels as standard equipment. Use of regular steel has declined by over 200 lb per vehicle from 1995 to 2013 while the use of high and medium strength steels has increased by 325 lb per vehicle. The increased use of high and medium strength steel is significant because it allows manufacturers to improve the structural integrity of vehicles while keeping the overall vehicle weight to a minimum. The use of plastics and composites has also increased by 40% and lightweight magnesium castings have seen greater use in dashboards and other interior applications such as seat components, replacing the heavier steel components that were previously used.

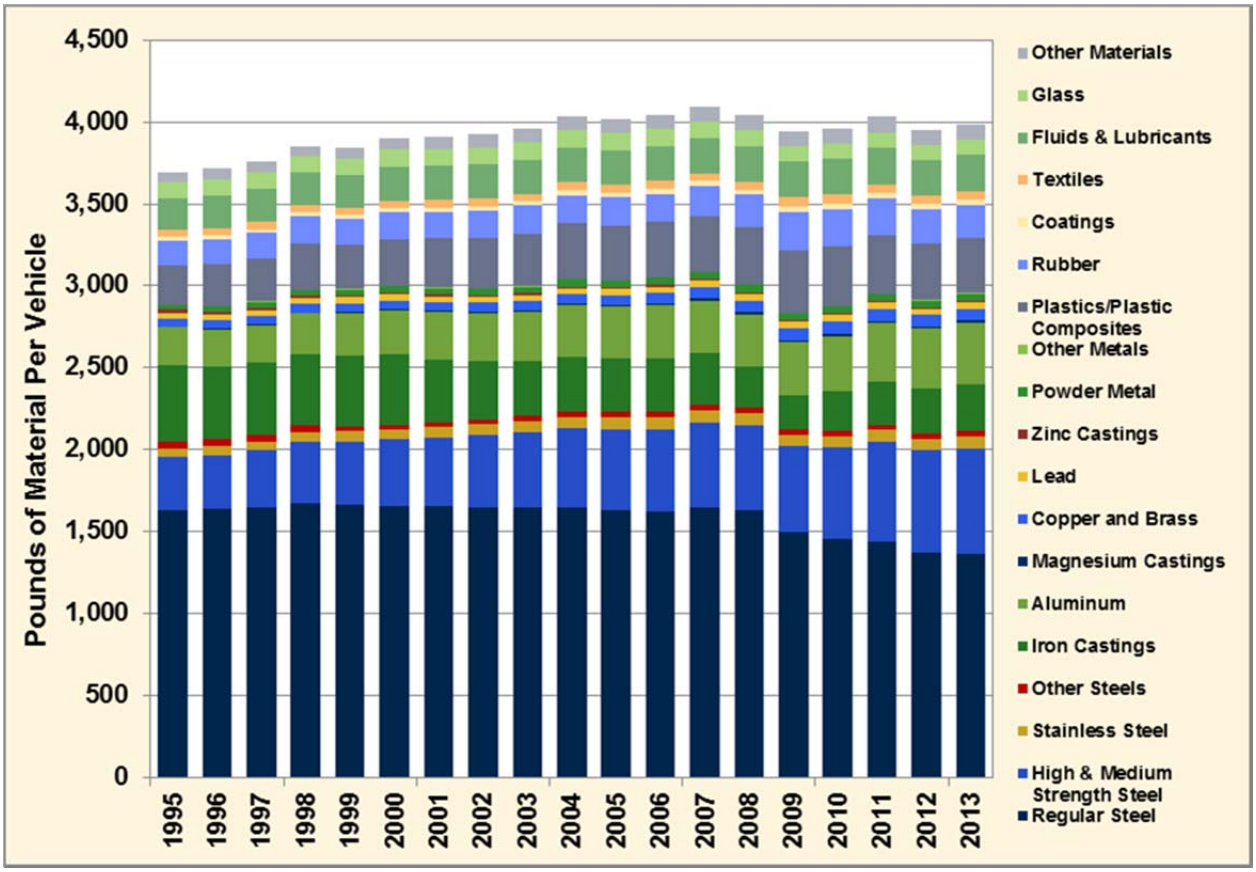


FIGURE 119. Average Materials Content of Light Vehicles, 1995-2013

Source:
Ward's Automotive Group. http://wardsauto.com

Hybridization and Other Engine Technologies Show the Most Promise for Improving Fuel Economy of Medium and Heavy Trucks

As a precursor to the Federal heavy truck fuel economy standards recently finalized, the National Academy of Sciences produced a study of the technologies and approaches to reducing fuel consumption (FC) in medium and heavy trucks. They determined that the most effective technologies in terms of fuel consumption reduction are: hybridization; replacement of gasoline engines with diesel engines; improvement in diesel engine thermal efficiency; improvement in gasoline engine thermal efficiency; aerodynamics, especially on tractor-trailers; reduced rolling resistance; and weight reduction. Hybridization and other engine technologies show the most promise for improving fuel economy of medium and heavy trucks.

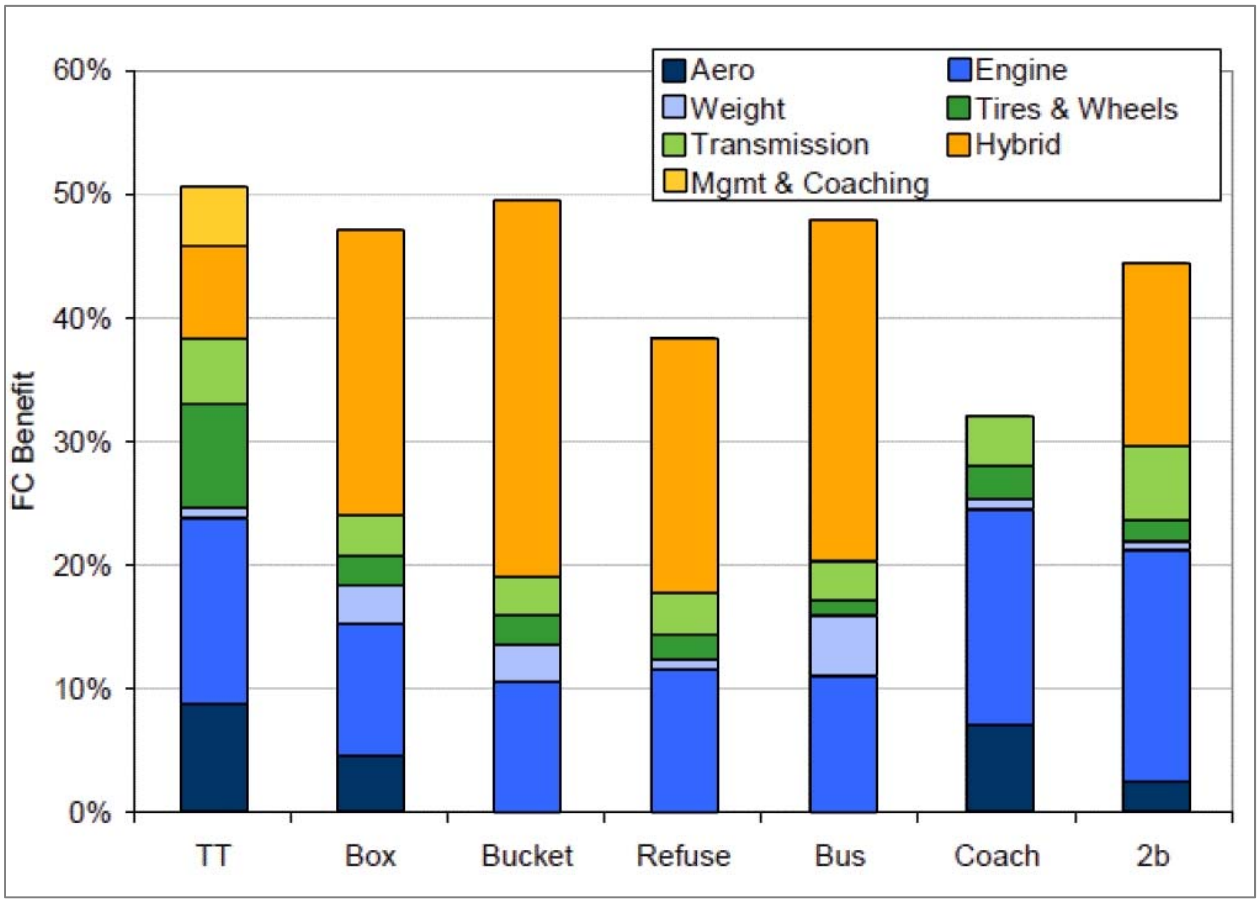


FIGURE 120. Comparison of 2015-2020 New Vehicle Potential Fuel Saving Technologies

Notes: FC Benefit = fuel consumption benefit; TT = tractor-trailer; Box = Class 3-6 box truck; Bucket = Class 3-6 bucket truck; Refuse = Class 8 refuse truck; Bus = transit bus; Coach = motor coach; 2b = Class 2b pickups and vans; Areo = aerodynamics; Mgmt = management.

Source:

TIAX, LLC. As shown in the National Research Council and Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010. http://www.nap.edu/catalog.php?record_id=12845

Heavy Vehicles Use Hybrid Technologies in Different Ways

FIGURE 121. Hybrid Bucket Truck

Hybridization of medium and heavy trucks can lead to significant gains in efficiency but optimum configuration of the hybrid system and potential gains in efficiency are highly dependent on the application. Bucket trucks that spend much of their time in a stationary position but running the engine to power the boom could benefit greatly from separating driving power requirements from stationary operation requirements. Engine run time could be drastically reduced through the electrification of auxiliary equipment.

Other heavy vehicles that operate at low speed and with frequent stops like a city bus or refuse truck may benefit more from a hydraulic hybrid system. Still in the prototype phase of development, the EPA claims a potential decrease in fuel consumption by as much as 50%. The hydraulic hybrid system is particularly well suited to heavy truck applications because the hydraulic system can recapture about 70% of the kinetic energy while the storage system is very efficient. This favors a duty cycle that involves a high degree of regenerative breaking but lower sustained power requirements.

FIGURE 123. Hybrid Bus

FIGURE 122. Tractor Trailer

Long-haul class 8 tractor-trailers have a unique set of requirements that favors a different approach to hybridization. The duty cycle involves long periods of sustained work followed by long periods at rest. While driving, tractor trailers can benefit from the electrification of engine driven devices like air conditioning, power steering, water pumps and fans that are normally belt driven. Accessories which are connected to the engine by a belt create a parasitic loss on the engine while it is running. Electrically-powered accessories only draw power when in use, which can provide fuel savings, especially for devices with intermittent use.

When stopped overnight, trucks are often left to idle in order to power the cabin accessories while the driver is at rest. This consumes up to one gallon of diesel per hour. Some truck stops have begun providing external power services in an attempt to reduce overnight idling. Another approach is to integrate smaller heating and cooling systems into the truck that use considerably less fuel than the regular engine.

Source:

National Research Council and Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010.

(Pictures from the National Renewable Energy Laboratory.)

SmartWay Technology Program Encourages Heavy Truck Efficiencies

As part of SmartWay Transport Partnership, begun in 2004, the U.S. Environmental Protection Agency (EPA) certifies tractors and trailers that incorporate efficient technologies. When manufacturers equip tractors and trailers with certified SmartWay specifications and equipment, they are given a SmartWay designation

An EPA-certified SmartWay **tractor** is characterized by a model year 2007 or later engine; integrated sleeper-cab high roof fairing; tractor-mounted side fairing gap reducers; tractor fuel-tank side fairings; aerodynamic bumper and mirrors; options for reducing periods of extended engine idling (auxiliary power units, generator sets, direct-fired heaters, battery-powered HVAC system, and automatic engine start/stop system); and options for low-rolling resistance tires (single wide or dual) mounted on aluminum wheels.

An EPA-certified SmartWay **trailer** is characterized by side skirts; weight-saving technologies; gap reducer on the front or trailer tails (either extenders or boat tails); and options for low-rolling resistance tires (single wide or dual) mounted on aluminum wheels.

TABLE 38. SmartWay Certified Tractor and Trailer Manufacturers

Tractors	Trailers
Daimler	Great Dane Trailers
Kenworth	Hyundai Translead
Mack	Manac Inc.
Navistar	Stoughton Trailers, LLC
Peterbilt	Strick Trailers, LLC
Volvo	Utility Trailer Manufacturing Company
	Vanguard National Trailer Corporation
	Wabash National Corporation
	Wilson Trailer Co.

Certain tires, known as low rolling resistance tires, can reduce nitrogen oxide emissions and fuel use by three percent or more. Currently, the EPA has 251 different brands of tires on their list of verified low rolling resistance tires.

Source:
U.S. Environmental Protection Agency, SmartWay Technology Program.
http://www.epa.gov/smartway/forpartners/technology.htm

New Engine Technologies Can Improve Fuel Economy and Reduce Emissions

The table below shows some of the notable technologies that have been adopted by manufacturers to improve to performance and efficiency.

TABLE 39. Fuel-Saving Engine Technologies

Technology	Description
Engine Friction Reduction	Reduction of engine friction losses can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, and piston surface treatments, etc.
Cylinder Deactivation	Cylinder deactivation allows the engine to shut down some of its cylinders during light load operation for greater fuel efficiency.
Intake Cam Phasing	Valvetrains with intake cam phasing modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed.
Coupled Cam Phasing	Valvetrains with coupled (or coordinated) cam phasing modify the timing of both the inlet valves and the exhaust valves an equal amount by phasing the camshaft of a single overhead cam engine or an overhead valve engine.
Dual Cam Phasing	Dual (independent) cam phasing controls the intake and exhaust valve opening and closing events independently. This allows the option of controlling valve overlap, which can be used as an internal exhaust-gas recirculation strategy.
Discrete Variable Valve Lift	Discrete variable valve lift increases efficiency by optimizing air flow over a broader range of engine operation which reduces pumping losses. Accomplished by controlled switching between two or more cam profile lobe heights.
Continuously Variable Valve Lift	Continuous variable valve lift is an electromechanically controlled system in which cam period and phasing is changed as lift height is controlled. This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled.
Variable Valve Timing and Lift (VVT&L)	Unlike gasoline engines that use a fixed valve lift, where the valve lift does not change with the speed and load of the engine, VVT&L allows the period of valve opening to vary based on need, which reduces pumping losses and valve train frictional loss. It also increases the compression ratio and reduces idle speed.
Dual Port Injection	Rather than a single injector per port, a dual injector arrangement improves combustion and increases performance and fuel economy.
Gasoline Direct Injection	Gasoline direct-injection technology injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency.
Direct Injection (with Turbocharging)	Direct fuel injection allows fuel to be injected directly into the cylinder so the timing and shape of the fuel mist can be controlled more precisely. This uses fuel more efficiently because of the higher compression ratios. The combination of direct injection and turbocharging has allowed manufacturers to downsize engines without compromising performance.
Turbocharging and Downsizing	Turbocharging and downsizing increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. This reduces pumping losses at lighter loads in comparison to a larger engine.
Turbocharging and Supercharging	Turbochargers and superchargers both use small impellers to force compressed air into the cylinders to improve combustion and boost power. Turbochargers are powered by the exhaust while superchargers are powered as an accessory through a mechanical connection to the engine.
Turbo Compounding	Used in heavy vehicle sectors, turbo compounding recovers waste heat energy from the exhaust stream and converts it into usable energy. Mechanical turbo compounding converts waste heat energy into kinetic energy and electric turbo compounding converts the waste heat energy into electrical energy.
Cooled Exhaust-Gas Recirculation	Cooled exhaust-gas recirculation increases the exhaust-gas recirculation used in the combustion process to increase thermal efficiency and reduce pumping losses.

TABLE 39. Fuel-Saving Engine Technologies (continued)

Technology	Description
Continuously Variable Transmission (CVT)	CVT transmissions control the ratio between engine speed and wheel speed, using a pair of variable-diameter pulleys connected by a belt or a chain that can produce an infinite number of engine and wheel speed ratios.
Increased Transmission Speeds	Increasing the number of speeds or gears increases engine efficiency. Manufacturers have been adding more gears to their automatic transmissions. Six-speed transmissions are now common and seven-, eight-, and nine- speed transmissions are available. Ten-speed transmissions will be introduced soon.
Dual Clutch Transmissions	A dual clutch transmission uses separate clutches (and separate gear shafts) for the even-numbered gears and odd-numbered gears. In this way, the next expected gear is pre-selected, which allows for faster and smoother shifting.
Early Torque Converter Lockup	A torque converter is a fluid coupling located between the engine and transmission in vehicles with automatic transmissions and continuously-variable transmissions. This fluid coupling allows for slip so the engine can run while the vehicle is idling in gear (as at a stop light), provides for smoothness of the powertrain, and also provides for torque multiplication during acceleration, and especially launch.
Aggressive Shift Logic	Aggressive shift logic can be employed in such a way as to maximize fuel efficiency by modifying the shift schedule to upshift earlier and inhibit downshifts under some conditions, which reduces engine pumping losses and engine friction.
High Efficiency Gearbox	A high efficiency gearbox offers continuous improvement in seals, bearings and clutches, super finishing of gearbox parts, and development in the area of lubrication, all aimed at reducing frictional and other parasitic losses.
Axle Disconnect for 4-wheel Drive System	Front or secondary axle disconnect for four-wheel drive systems provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses.
Selective Catalytic Reduction (SCR)	Though an emission control technology used for diesel engines, SCR saves fuel over other types of emission control systems because it allows the engine combustion to occur unhindered while treating the exhaust with urea to control NOX after combustion. Other systems compromise the combustion process to limit the formation of NOX or use fuel to maintain the filters resulting in a greater loss in fuel economy. Most heavy duty engine manufacturers have adopted SCR and it has been adopted by some light passenger vehicle manufacturers as well.
Bottoming Cycle Waste Heat Recovery	Bottoming cycle waste heat recovery systems like the Organic Rankin Cycle (ORC) use a fluid that is heated by waste engine heat which then expands to generate electricity and supplement the engine. It is used in heavy trucks.
Variable Displacement Oil Pump	Rather than pump oil through the engine at a constant rate and pressure, the intensity and rate of pumping are varied to meet the needs of the engine at different load levels.
Variable Speed Water Pump	Variable speed water pumps improve efficiency by limiting the output during low load periods rather than running at a fixed rate.
Low Drag Brakes	Low-drag brakes reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors.
Low Rolling Resistance Tires	Low-rolling-resistance tires have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, thereby reducing the energy needed to move the vehicle.
Aerodynamic Drag Improvements	Aerodynamic drag improvements are achieved by changing vehicle shape or reducing frontal area, including skirts, air dams, underbody covers, and more aerodynamic side view mirrors.
Active Grille Shutters	Active grille shutters on the front of vehicles close off a portion of the front grille which limits the amount of air entering the engine compartment. This reduced flow of air into the engine compartment improves the aerodynamics of the vehicle while still allowing enough airflow to cool the engine.

Source:

U.S. Environmental Protection Agency and U.S. Department of Transportation, *Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards,* EPA-420-R-12-901, August 2012. Additional data were compiled from published sources by Bob Boundy, Roltek, Inc., Clinton, TN, 2012. http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Joint_final_TSD.pdf

Turbocharging and Downsizing Engines Have Great Potential for Fuel Savings

TABLE 40. Costs and Fuel Savings for Selected Technologies, 2012

Technology	Reduction in Fuel Consumption (Percent)	Vehicle Attributes	Estimated Incremental Cost for 2017 (2010 dollars)
Engine Friction Reduction	2.0 to 2.7	I4	$59
		V6	$89
		V8	$118
Cylinder Deactivation	4.7 to 6.5	V6	$196
		V8	$220
Intake Cam Phasing	2.1 to 2.7	I4	$46
		OHC-V6/V8	$93
		OHV-V6/V8	$43
Coupled Cam Phasing	4.1 to 5.5	I4	$46
		OHC-V6/V8	$93
		OHV-V6/V8	$43
Dual Cam Phasing	4.1 to 5.5	I4	$95
		OHC-V6/V8	$205
		OHV-V6/V8	$104
Discrete Variable Valve Lift	2.8 to 3.9	OHC-I4	$163
		OHC-V6	$236
		OHC-V8	$338
Continuously Variable Valve Lift	3.6 to 4.9	OHC-I4	$244
		OHC-V6	$448
		OHC-V8	$489
		OHV-V6	$1,205
		OHV-V8	$1,317
Stoichiometric Gasoline Direct Injection	1.5	I4	$277
		V6	$417
		V8	$501
Turbocharging and Downsizing	12.1 to 14.9	18-bar DOHC V6 to I4	$248
	16.4 to 20.1	24-bar DOHC V8 to V6	$1,188
	20.6 to 24.6	27-bar DOHC V8 to V6	$2,073
Cooled Exhaust-Gas Recirculation	5	All	$305
Aggressive Shift Logic - Level 1	1.9 to 2.7	All	$33
Aggressive Shift Logic - Level 2	5.1 to 7.0	All	$34
Early Torque Converter Lockup	0.4 to 0.5	Automatic	$30
High Efficiency Gearbox	3.8 to 5.7	Automatic/Dual clutch	$251
Increased Transmission Speeds	3.1 to 3.9	6-sp AT from 4-sp AT	-$9
	4.9 to 5.34	8-sp AT from 6-sp AT	$80
	11.1 to 13.1	8-sp DCT from 4-sp DCT	$62

TABLE 40. Costs and Fuel Savings for Selected Technologies, 2012 (continued)

Technology	Reduction in Fuel Consumption (Percent)	Vehicle Attributes	Estimated Incremental Cost for 2017 (2010 dollars)
Dual Clutch Transmissions	5 to 6	6-sp DCT-dry	-$116
	4 to 5	6-sp DCT-wet	-$82
	5 to 6	8-sp DCT-dry	-$16
	4 to 5	8-sp DCT-wet	$47
Low Rolling Resistance Tires Level 1	1.9	10% lower resistance	$7
Low Rolling Resistance Tires Level 2	3.9	20% lower resistance	$73
Low Drag Brakes	0.8	All	$74
Axle Disconnect for 4-wheel Drive System	1.2 to 1.4	All 4-wheel drive	$98
Aerodynamic Drag Improvements	2 to 3	All	$213

Note: OHC = overhead cam; OHV = overhead valve; DOHC = dual overhead cam; AT = automatic transmission; sp = speed.

Source:

U.S. Environmental Protection Agency and U.S. Department of Transportation, *Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*, EPA-420-R-12-901, August 2012. http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Joint_final_TSD.pdf

Fuel-Saving Engine Technologies under Development Show Promise

These fuel-saving technologies are currently under development but show promise to improve engine efficiency in the future.

TABLE 41. Fuel-Saving Engine Technologies under Development

Technology	Description
Homogenous Charge Compression Ignition (HCCI)	Homogenous Charge Compression Ignition is a combustion strategy that applies diesel technology to gasoline engines. A very lean mixture of gasoline and air are thoroughly mixed and compressed in the cylinder until auto-ignition occurs without the need for a spark. This achieves many of the benefits of a diesel engine such as high efficiency and torque without the emissions drawbacks associated with diesel.
Camless Valve Actuation	Rather than opening and closing the valves mechanically with a cam shaft, there are efforts to reduce these mechanical losses by opening and closing the valves electronically.
Variable Compression Ratio	In standard engines, the compression ratio is fixed across all operating conditions based on cylinder geometry. Variable compression ratio increases efficiency by altering the cylinder compression ratio. New engine designs can mechanically vary cylinder geometry. This allows for engines that can operate at a high-compression ratio under partial or light-load conditions and at a lower compression ratio under heavy-load conditions.
Advanced Corona Ignition System (ACIS)	As fuel mixtures become increasingly lean in gasoline engines, the importance of achieving maximum combustion efficiency is critical. In contrast to the traditional spark plug that produces a small, localized spark at the top of the combustion chamber, the ACIS provides a plasma burst throughout the combustion chamber, igniting the fuel air mixture more quickly and evenly. This not only improves fuel economy but could also reduce maintenance costs because the ACIS does not suffer from electrode erosion like a traditional sparkplug.
Dynamic Skip Fire (DSF)	A variable displacement technology that uses software to make firing decisions for individual cylinders based on vehicle speeds and load requirements. This differs from standard cylinder deactivation that has a fixed pattern of cylinders that are activated and deactivated.

Source:
Compiled from published sources by Bob Boundy, Roltek, Inc., Clinton, TN, 2012.

Hybrid Technologies Can Improve Fuel Economy

There are many different implementations of hybrid technology but most fall within these basic technologies.

TABLE 42. Hybrid Technologies

Technology	Description
Integrated Starter/Generator	Often referred to as "Stop-Start" or "Mild Hybridization", this system shuts off the engine during deceleration and when stopped but instantly restarts the engine when the break is released or the accelerator is depressed. This type of system can be integrated with regenerative breaking. General Motors has been marketing this system under the name eAssist beginning with 2011 Buick models. Other manufacturers including Ford and Kia are also offering Stop-Start options.
Parallel Hybrid	A parallel hybrid system is one where the wheels of the vehicle can be turned by either the gasoline engine or an electric motor or both at the same time. The Toyota Prius is an example of a parallel hybrid.
Series Hybrid	A series hybrid is only propelled by a single source, typically an electric motor while electricity is supplied by an engine that acts as a generator. The Chevrolet Volt functions primarily as a series hybrid when the gasoline engine is required.
Dual Mode Hybrid	A Dual Mode or Two Mode hybrid can operate in either parallel or series hybrid configuration depending on the circumstances. The dual mode hybrid is well suited to heavy applications like busses and light vehicles where towing is a consideration.
Plug-in Hybrid	A plug-in hybrid is often referred to as an extended range electric vehicle because of its ability to charge from a wall outlet and run entirely on electricity until the battery pack is depleted. Then an internal combustion engine is used to power the vehicle.
Hydraulic Hybrid	Hydraulic hybrid technology is still in the demonstration phase and is well suited to heavy duty vehicles in urban settings with frequent stops like refuse trucks and city buses. Due to the heavy weight of these vehicles, a tremendous amount of energy is lost during frequent starts and stops. A hydraulic system can recapture large amounts of energy very quickly and efficiently.
Electric Continuously Variable Transmission (eCVT)	The eCVT transmissions are designed for hybrid vehicles that require multiple combinations of inputs to drive the wheels whether an electric motor, gasoline engine or both. The eCVT transmission uses a combination of gears to provide variable gear ratios rather than a belt and cones or pulleys used in standard CVT transmissions.

Source:
Compiled from published sources by Bob Boundy, Roltek, Inc., Clinton, TN, 2012.

Most Highway Operational Energy Losses for Class 8 Trucks Are from Aerodynamics

For Class 8 long-haul tractor trailers, the engine accounts for more than half of the energy losses, whether the truck is traveling over the highway or in the city. Operational losses, however, are vastly different depending on whether the truck is on the highway or in the city. Overcoming aerodynamic drag is the greatest burden from an energy loss standpoint on the highway, followed by rolling resistance. In city driving, the braking (loss of inertia) plays a much bigger role in energy losses.

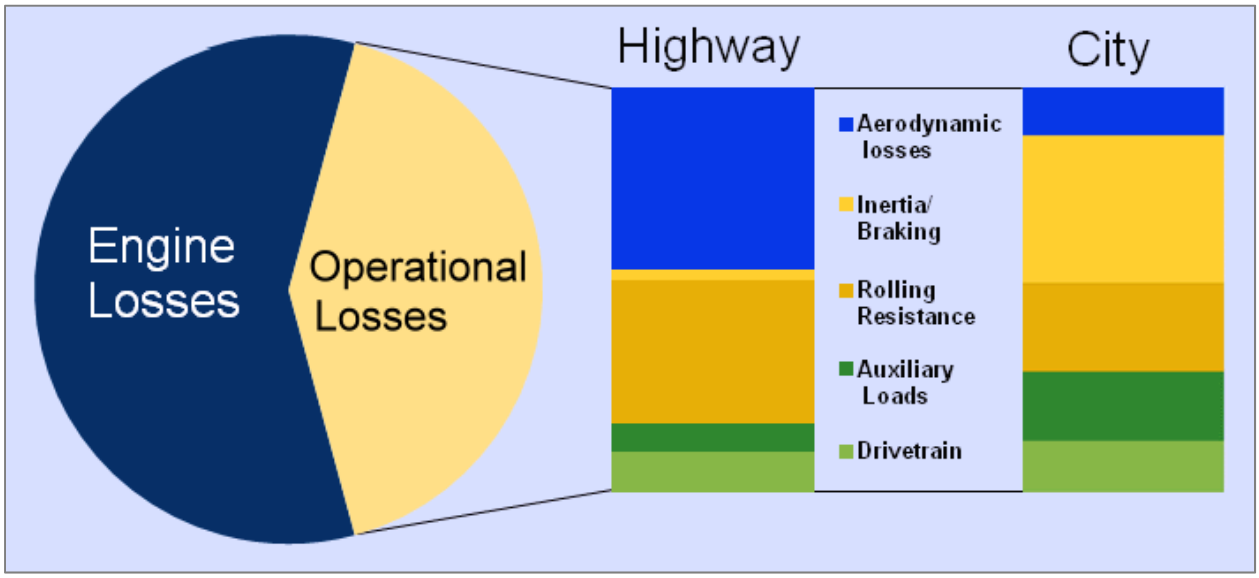


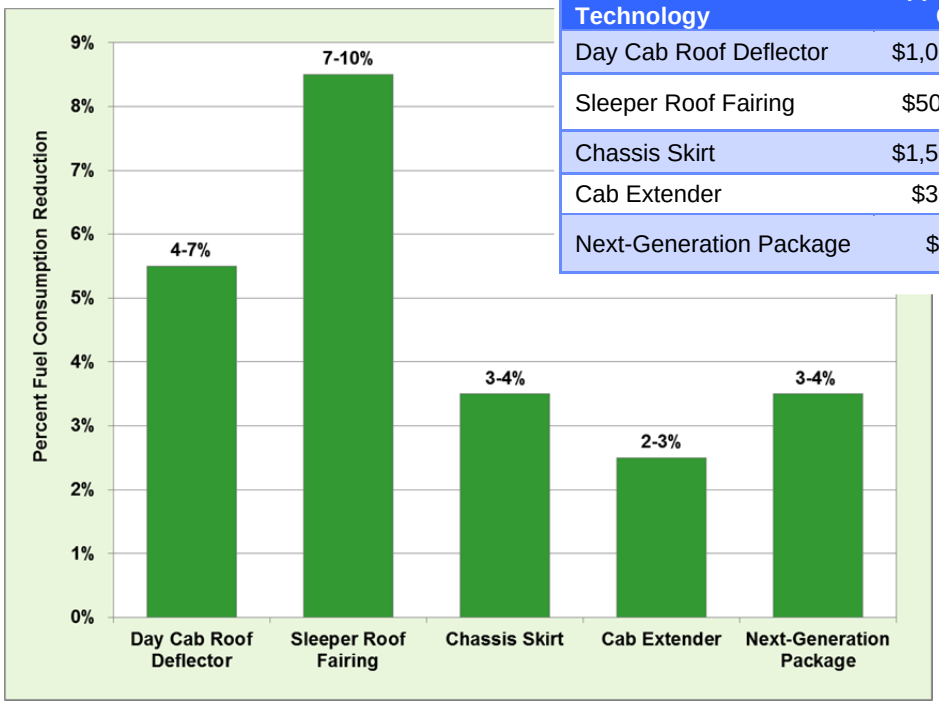
FIGURE 124. Class 8 Truck-Tractor Energy Losses

Note: Applies to Class 8 tractor with sleeper cab and van-type trailer at 65 miles per hour with a gross vehicle weight of 80,000 pounds.

Source:
National Research Council and Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010. http://www.nap.edu/catalog.php?record_id=12845

Some Aerodynamic Technologies Are Widely Adopted

Aerodynamic drag is a large energy loss point for Class 8 tractor-trailers. Aerodynamic devices like cab fairings that do not hinder performance and are usually free from accidental damage have been widely adopted. Other devices like chassis skirts that are more prone to road damage or gap reducers that reduce the gap between the cab and trailer to improve aerodynamics but prevent tight turns have not been as widely adopted. Boat tails that are fitted on the back of a trailer reduce drag but increase the length of the trailer, which can have practical or regulatory implications.



Technology	Approximate Cost	Industry Adoption Rate
Day Cab Roof Deflector	$1,000-1,300	Most
Sleeper Roof Fairing	$500-1,000	Standard equipment
Chassis Skirt	$1,500-2,000	50-60%
Cab Extender	$300-500	80-90%
Next-Generation Package	$2,750	2012 Introduction

FIGURE 125. Fuel Consumption Reduction Rate, Approximate Cost, and Industry Adoption Rate for Aerodynamic Technologies

Though there are potential savings with improved aerodynamics, there are challenges as well. Adding aerodynamic devices to trailers such as skirts or trailer bogies can be challenging; because the trailer and tractor are often owned separately and the fuel savings are realized by the owner of the tractor, there is often little incentive for the trailer owner to invest in fuel saving devices. Also, trailers outnumber tractors and tend to log fewer annual miles than tractors. This extends the payback period for investment in aerodynamic improvements to trailers. Additionally, for every 1,000 lb of weight added, there is a 0.5% penalty in fuel consumption. Trailer skirts alone can add more than 200 lb to the weight of a standard 53-foot trailer.

Note: Next-generation package = features designed and optimized for long-haul tractors in 2012.

Source:

National Research Council and Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010. http://www.nap.edu/catalog.php?record_id=12845

Single Wide Tires Improve Fuel Economy of Class 8 Trucks

A study done by Oak Ridge National Laboratory outfitted Class 8 trucks with monitoring equipment which measured the fuel economy of the vehicle along with many other variables. During the study period, the truck-tractors sometimes had standard dual tires and at other times used single very wide tires on the same roads with similar loads. The results of the study show fuel economy improvements due to single wide tires average 7.1% on flat terrain, but can be as much as 16% improvement on severe downslopes.

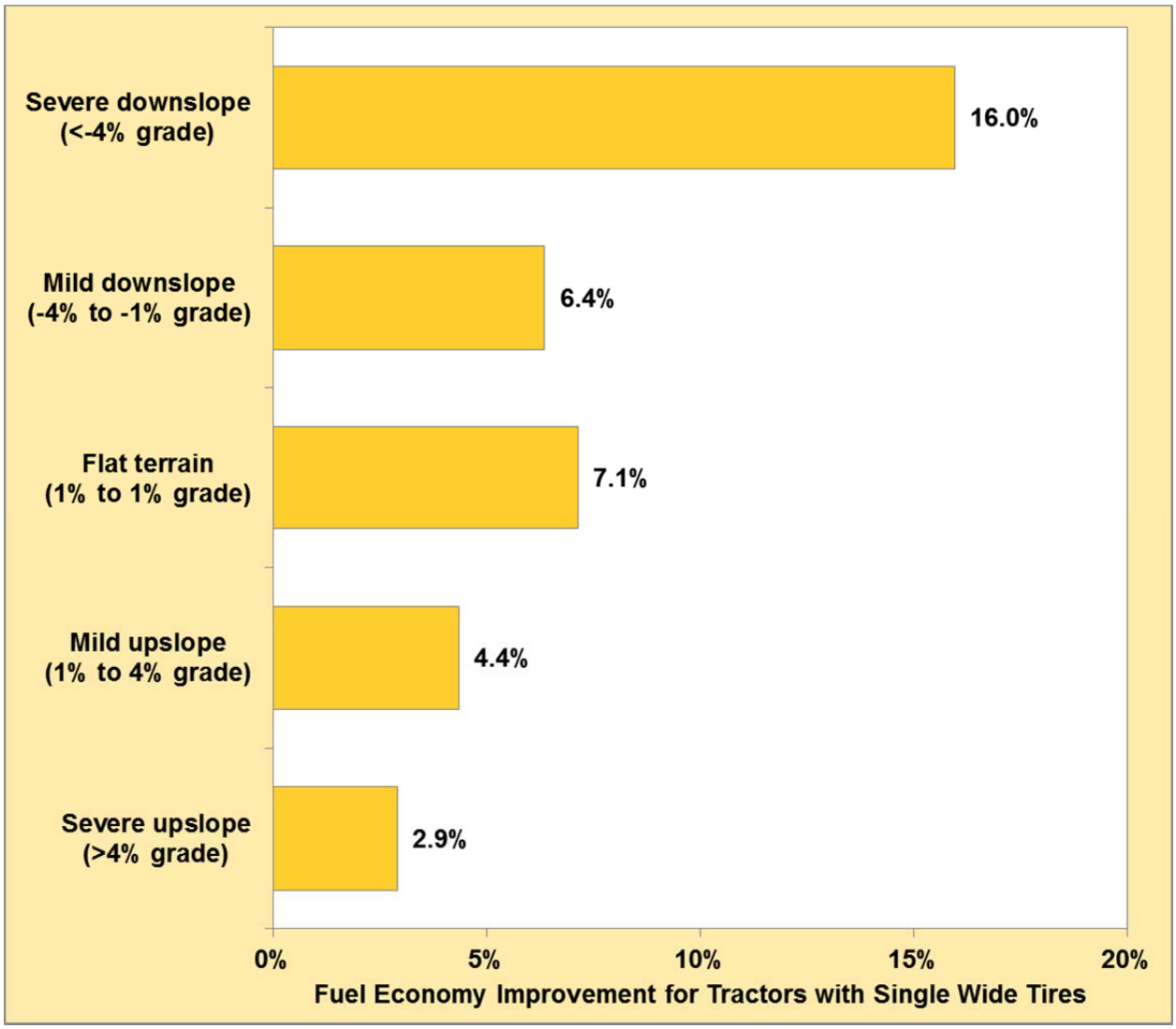


FIGURE 126. Fuel Economy Improvement for Class 8 Tractors with Single Wide Tires

Source:

Franzese, Oscar, *Effect of Weight and Roadway Grade on the Fuel Economy of Class-8 Freight Trucks*, Oak Ridge National Laboratory, ORNL/TM-2011/471, October 2011. http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2011_471.pdf

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