Chapter 4.

TECHNOLOGIES

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Many Hybrid Nameplates Have Entered the U.S. Market

In 1999, the Honda Insight debuted as the first hybrid-electric vehicle (HEV) on the market, followed closely by the Toyota Prius in 2000. While the Prius continues to be the best selling HEV, many other manufacturers have entered the market. As of 2010 there were 32 different HEVs sold. Likely due to the economic recession and relatively low gasoline prices, the total sales of HEVs peaked in 2007 at just over 350 thousand vehicles.

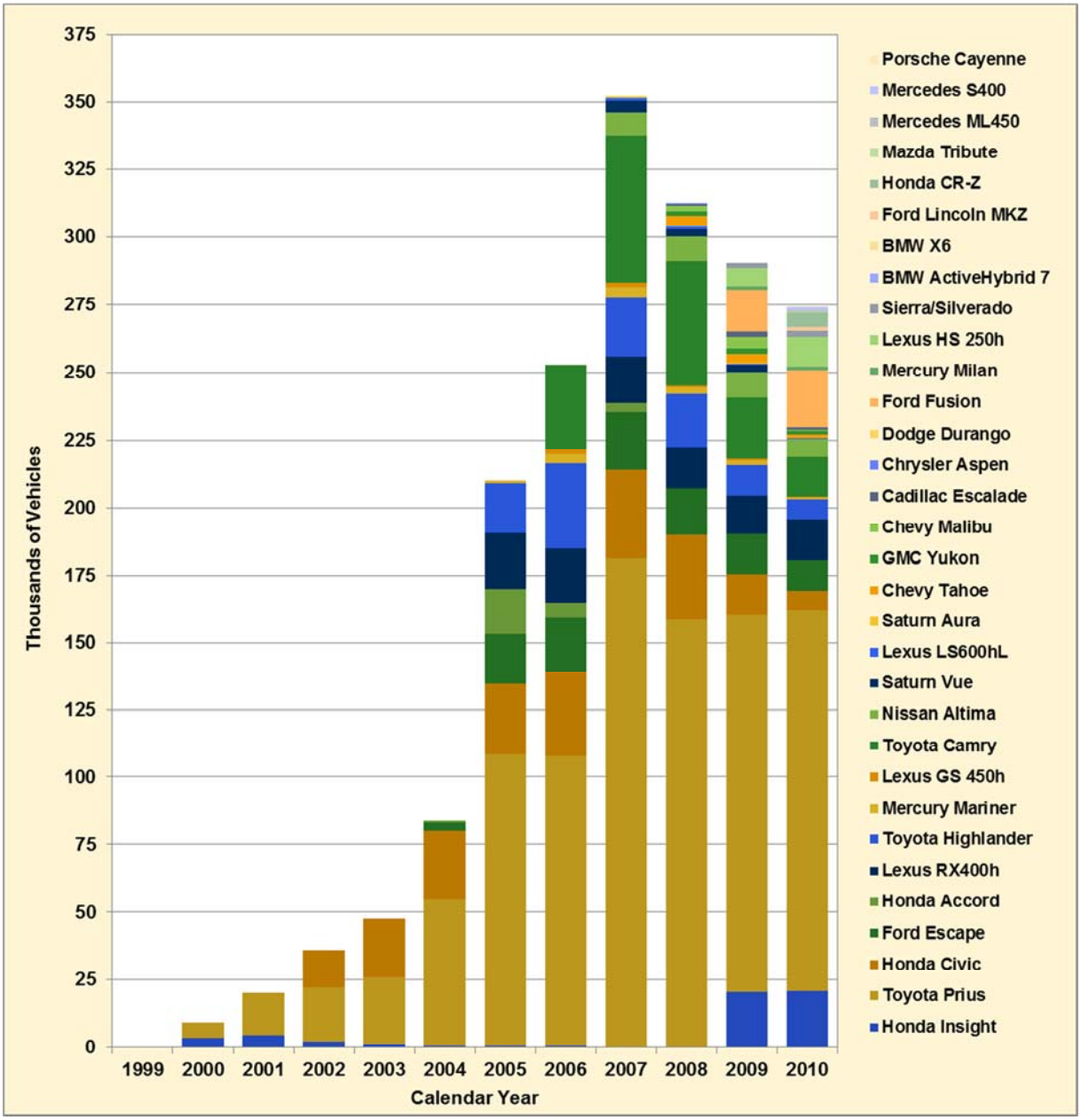


FIGURE 68. Hybrid-Electric Vehicle Sales, 1999-2010

Source:

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

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

Though Honda was the first manufacturer of hybrid-electric vehicles (HEV), 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.

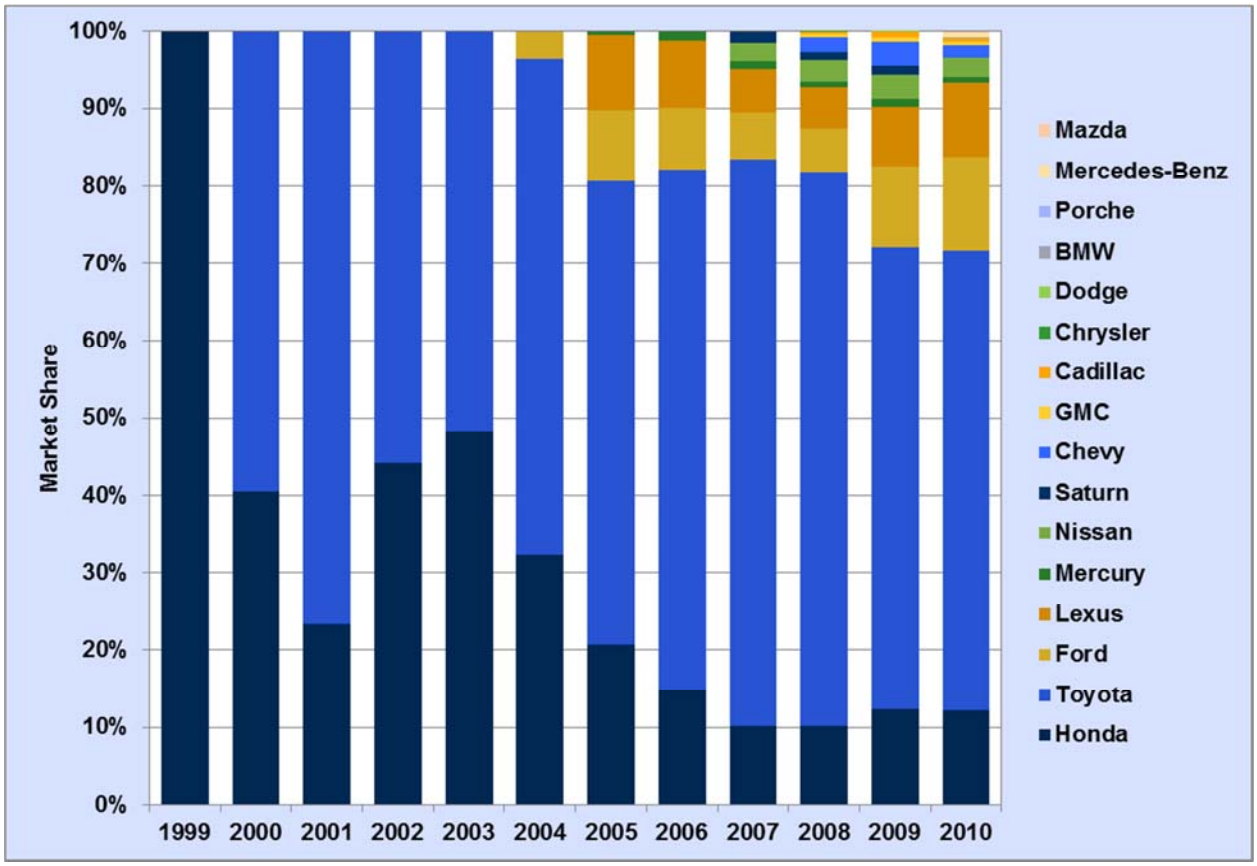


FIGURE 69. Hybrid-Electric Vehicle Market Share, 1999-2010

Source:

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

Hybrid and Electric Cargo Trucks are 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 17 models from eight manufacturers of hybrid cargo trucks on the market. Two of those, Ford and Navistar, also manufacture fully electric trucks, along with Modec and Smith Electric Vehicles. 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 12. Hybrid and Electric Cargo Trucks on the Market

Make	Model	Body Type/Application	GVW Class
Gasoline Hybrid			
Bright Automotive	IDEA	Cargo Van	1
Ford	E450	Step Van, Shuttle Bus	3
GMC	TC5500	Utility	5
Diesel Hybrid			
Freightliner	Business Class M2e Hybrid	City Delivery, Utility, Delivery Tractor	7, 8
Freightliner CCC	MT-45, MT-55	Walk-in Van	
Kenworth	T270	Delivery, Utility	6
Kenworth	T370	Delivery, Utility	7
Mack/Volvo	TerraPro Hybrid	Refuse	8
Navistar, Inc	DuraStar Hybrid (Truck)	Beverage, Box Van, Refrigeration, Landscape Dump, Utility, Crane, Tree Trimmer, Recovery Towing, Armored Vehicle, Stake Flat, Grapple, Road Patch Truck, Refined Fuels, Propane Tank	6, 7
Navistar, Inc	4300	Utility, Digger Derrick, Air Compressor	6, 7, 8
Navistar, Inc	DuraStar Hybrid (4x2) Tractor	Beverage Diminishing Load	7
Navistar, Inc	WorkStar Hybrid (Truck)	4x4 Utility, Landscape Dump, Snowplow, Digger Derrick, Utility, Crane, Stake Flat, Box Van, Recovery Towing, Refined Fuels, Propane Tank	6, 7
Peterbilt	320 Hybrid (Hydraulic Launch Assist)	Refuse	8
Peterbilt	330 Hybrid	Delivery van	6
Peterbilt	337 Hybrid	City Delivery, Fire & Rescue, Beverage, Municipal, Refuse, Utility	6, 7
Peterbilt	348 Hybrid	Municipal, Service, Utility	7, 8
Peterbilt	386 Hybrid	Long Haul	8
Full Electric			
Ford	Transit Connect	Cargo Van	1
Modec	Chassis Cab, Dropside & Box Van	Chassis Cab, Dropside, Box Van, Refrigerated Box Van, Tail Lift, Tipper	3
Navistar, Inc	eStar	Delivery Van	3
Smith Electric Vehicles	Newton	Food Distribution, Parcel Delivery, Chilled Food Distribution, Short Haul, Utility, Airport Operations, Public Sector	5, 6, 7

Source:

Environmental Defense Fund, Innovation Exchange. http://business.edf.org/projects/fleet-vehicles/hybrid-trucks-financial-incentives-guide/available-models-medium-heavy-duty-

New Plug-In Vehicles are on the Horizon

The recent debut of the Chevrolet Volt and the Nissan Leaf is just the beginning of cars that plug into electric outlets. There are already several other plug-ins currently available from Tesla, Ford, and Smart, with more models planned by various manufacturers for 2012 - 2014. The concept vehicles listed are not all-inclusive, as many different manufacturers have concepts for future plug-in vehicles.

TABLE 13. Plug-In Vehicles Available or Coming Soon

Manufacturer	Specific Product	Availability	All-Electric Range	Specifications
Chevrolet	Volt	Available	40 miles	1.4-liter engine, 16 kWh lithion ion battery, 150-hp electric motor
Ford	Transit Connect	Available	80 miles	2.0L Duratec 1-4 Engine, 28 kWh lithium-ion battery
Nissan	Leaf	Available	100 miles	24 kWh lithium-ion battery
Smart	ED	Available	70 miles	16 kWh lithion-ion battery, 55 kW electric motor
Tesla	Roadster	Available	200 miles	53 kWh battery, 185 kWh, 248 hp electric motor
Think	City	Available	120 miles	24 KWh battery
BMW	ActiveE	2012	100 miles	32 kWh lithium-ion battery
BYD	e6 Wagon	2012	200 miles	1.0-liter engine, iron-phosphate Fe battery, 75kW motor
BYD	F3DM	2012	60 miles	1.0-liter engine, 16 kWh lithium-ion battery, 50kW traction motor
Coda	Electric Sedan	2012	120 miles	34 kWh lithium-ion battery
Ford	Focus Electric	2012	100 miles	23 kWh lithium-ion battery
Fisker	Karma	2012	50 miles	2.0-liter engine, 22 kWh lithion-ion battery, 400-hp electric motors (2)
Honda	Fit EV	2012	75 miles	6 kW lithium-ion battery, 120 kW electric motor
Mitsubishi	i	2012	75 miles	16 kWh lithium-ion battery, 47 kW motor
Tesla	Model S	2012	150 miles	80 kWh litium-ion battery,
Toyota	FT-EV	2012	50 miles	all electric
Toyota	Prius Plug-In Hybrid	2012	13 miles	lithium-ion battery, 1.8-liter aluminum 4-cyl engine
Toyota	Rav4 EV	2012	100 miles	
Volvo	V70 Plug-In Hybrid	2012	30 miles	11.3 kWh battery
BMW	i3	2013	100 miles	22 kWh lithium-ion battery, 170 hp electric motor
BMW	Vision	2013	30 miles	11 kWh lithium-ion battery, 3 cyl diesel engine
Volkswagen	E-Up!	2013	80 miles	18 kWh battery, 80 hp electric motor
Volkswagen	E-Golf	2014	95 miles	26.5 kWh battery, 85kW electric motor
Audi	A1 E-Tron	Concept	30 miles	12 kWh lithium-ion battery, 102 hp electric motor, 252cc Wankel rotary engine
Misubishi	PX-MiEV	Concept	30 miles	10 kWh lithium-ion battery, 1.6-liter 114 hp 4-cyl engine
Vision	S500	Concept	18 miles	4 kW 60 hp V6 gas engine, 10 kWh lithium-ion battery, 4 15 kW electric motor
Volvo	C30	Concept	90 miles	24 kWh battery

Source:

Plugincars.Com. http://www.plugincars.com/cars

PrimeEarth EV Energy was the Largest Hybrid-Electric Battery Supplier in 2010

PrimeEarth EV Energy, a joint venture of Panasonic and Toyota, is the supplier for Toyota, Nissan, and GM hybrid trucks. Nearly 75% of the hybrid vehicles sold in model year 2010 run on PrimeEarth batteries. Sanyo is the other large battery supplier, supplying batteries to Ford and Honda. Two other companies, Johnson Controls-Saft and SB LiMotive supply batteries for other manufacturers with low hybrid sales. In 2011, the partnership between Johnson Controls and Saft came to an end.

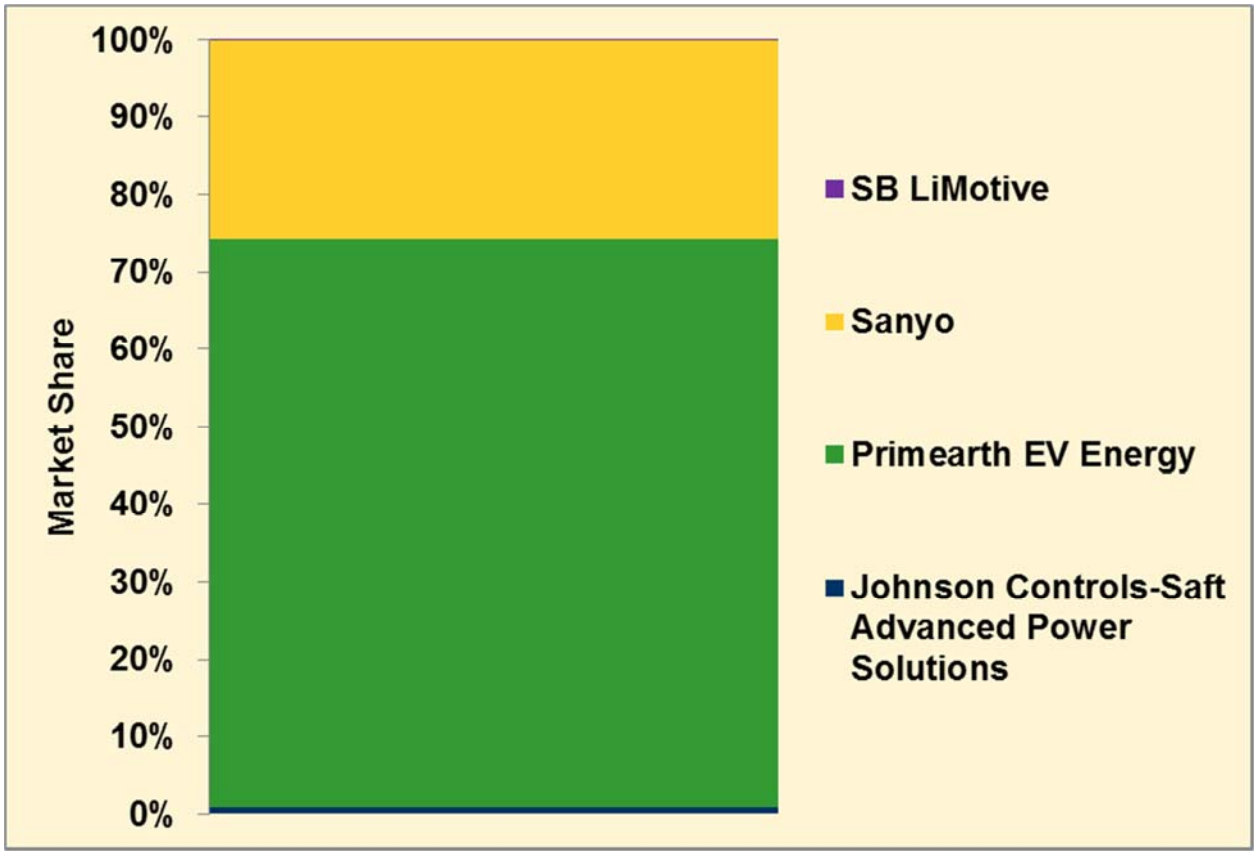


FIGURE 70. Battery Market Share, 2010

Note: Primearth EV Energy was formerly known as Panasonic EV Energy.

Sources:

Estimated using hybrid vehicle sales in 2010 and battery suppliers for hybrid vehicles.

Hybrid vehicle sales – U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/data/docs/hev_sales.xls

Battery supplier for each vehicle – compiled from various public sources, Oak Ridge National Laboratory.

Batteries for Upcoming Electric and Hybrid-Electric Vehicles

There are new models of battery-electric vehicles (BEV) and hybrid-electric vehicles (HEV) in the market in model years 2011 and 2012. The first HEVs used nickel-metal hydride (NiMH) batteries, but many of the new HEVs and BEVs use lithium-ion (Li-ion) batteries.

TABLE 14. Batteries for Selected Upcoming Electric and Hybrid-Electric Vehicles

Vehicle	Model Year	Vehicle type	Battery type	Supplier
Chrysler Fiat 500EV (expected)	2012	BEV	Li-ion	SB LiMotive
Ford Fusion/Mariner/MKZ Hybrid	2011	HEV	NiMH	Sanyo
Ford Escape Hybrid (discontinued for 2012)	2011	HEV	NiMH	Sanyo
Ford Focus Electric (expected)	2012	BEV	Li-ion	LG Chem/ Compact Power
GM Volt	2011	PHEV	Li-ion	LG Chem/ Compact Power
GM Silverado/Sierra Hybrid, Yukon/Tahoe/Escalade Hybrid	2012	HEV	NiMH	Primearth EV Energy
GM Buick Lacrosse/Regal eAssist	2012	start/ stop	Li-ion	Hitachi
Honda Insight, CR-Z, Civic Hybrid	2011	HEV	NiMH	Sanyo
Honda Civic Hybrid	2012	HEV	Li-ion	Not available
Hyundai Sonata/Optima Hybrid	2011	HEV	Li-ion	LG Chem
Mitsubishi MiEV	2012	BEV	Li-ion	Toshiba
Nissan Leaf	2011	BEV	Li-ion	Automotive Energy Supply Corp
Nissan Infinti M35h	2012	HEV	Li-ion	Automotive Energy Supply Corp
Toyota Camry/Highlander/Lexus hybrids	2011	HEV	NiMH	Primearth EV Energy
Toyota Prius Hybrids	2011	HEV	NiMH	Primearth EV Energy
Toyota Prius Plug-in	2012	PHEV	Li-ion	Sanyo
VW Touareg Hybrid	2011	HEV	NiMH	Sanyo

Note: Compact Power is a wholly owned U.S. subsidiary of LG Chem.

Sanyo is now owned by Panasonic.

Primearth EV Energy was formerly known as Panasonic EV Energy, a joint venture between Toyota and Panasonic. Majority owned by Toyota at present.

Automotive Energy Supply Corp is a joint venture between NEC and Nissan.

SB LiMotive is a joint venture between Bosch and Samsung SDI that recently purchased Cobasys, LLC (joint venture between ECD Ovonics and Chevron Texaco).

Source:

Compiled from public sources by Josh Pihl, Oak Ridge National Laboratory, December 2011.

Flex-Fuel Vehicle Offerings Double in MY 2011

In the last five years, GM and Chrysler have been the front-runners in the number of flex-fuel models offered to the public (includes cars and light trucks). Ford and Nissan have offered flex-fuel models each of the last five years, too. Toyota's first flex-fuel vehicle was offered in 2009. Other manufacturers, like Mercedes-Benz, Mazda, and Saab expanded their flex-fuel offerings in 2011, such that there were 68 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 E-85 and/or gasoline.

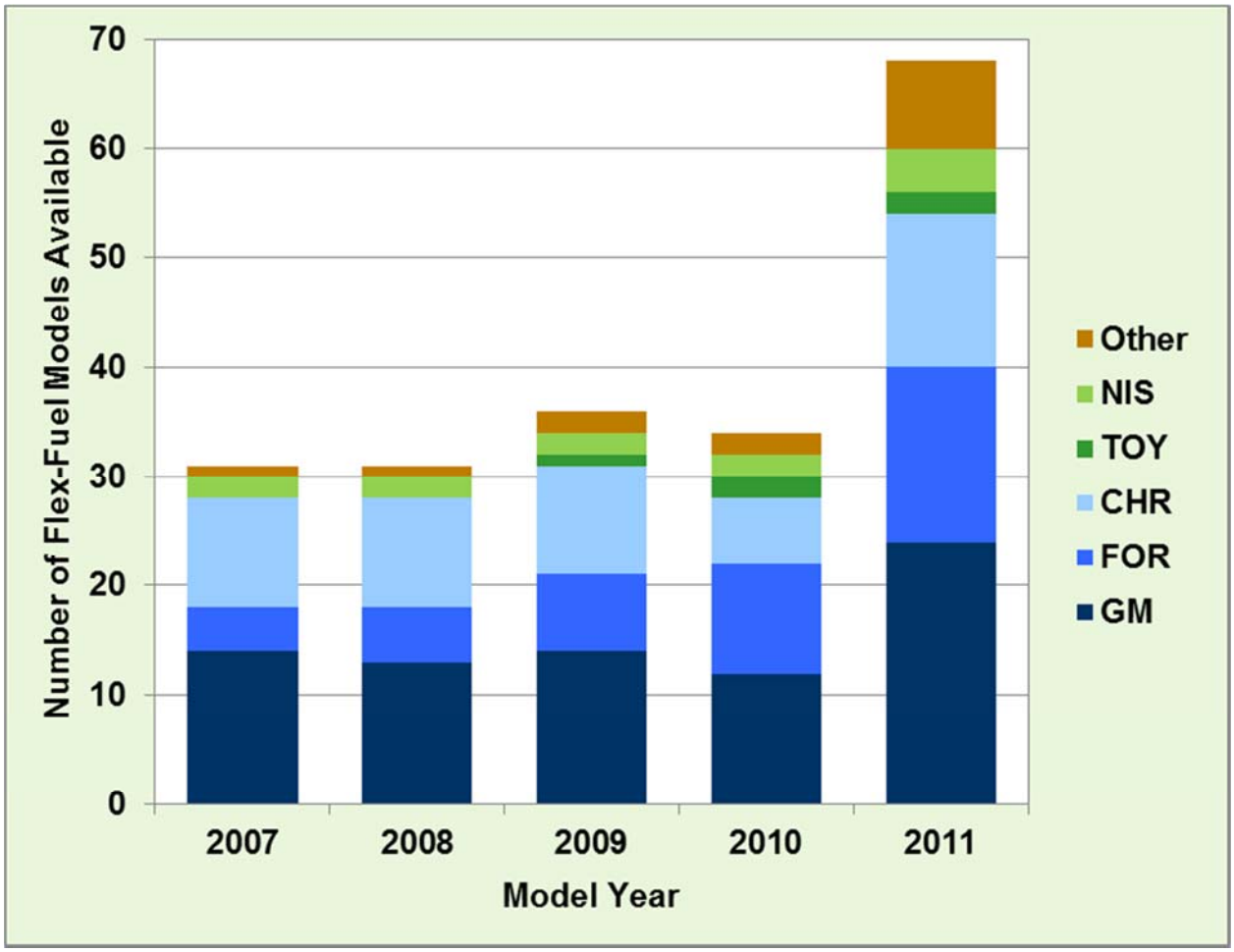
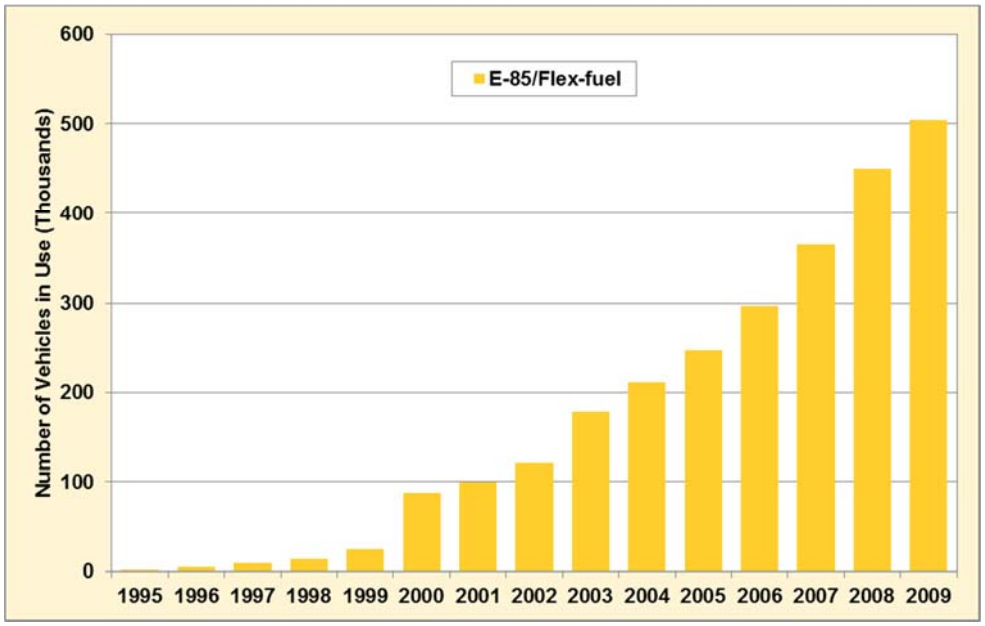


FIGURE 71. Number of Flex-Fuel Models Available

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

Alternative Fuel Vehicles in Use are Mostly Flex-Fuel Vehicles

There are over 500 thousand vehicles in use that run on E-85, often called flex-fuel vehicles. This includes only those vehicles believed to be using E-85, which are primarily fleet-operated vehicles. The number of vehicles using liquefied petroleum gas (LPG) has declined since 2003, while electric vehicles (not including hybrids) have increased.



Note: Includes only those vehicles believed to be using E-85.

Note:
Electricity does not include hybrid vehicles. LPG = Liquefied petroleum gas. CNG = Compressed natural gas. LNG = Liquefied natural gas.

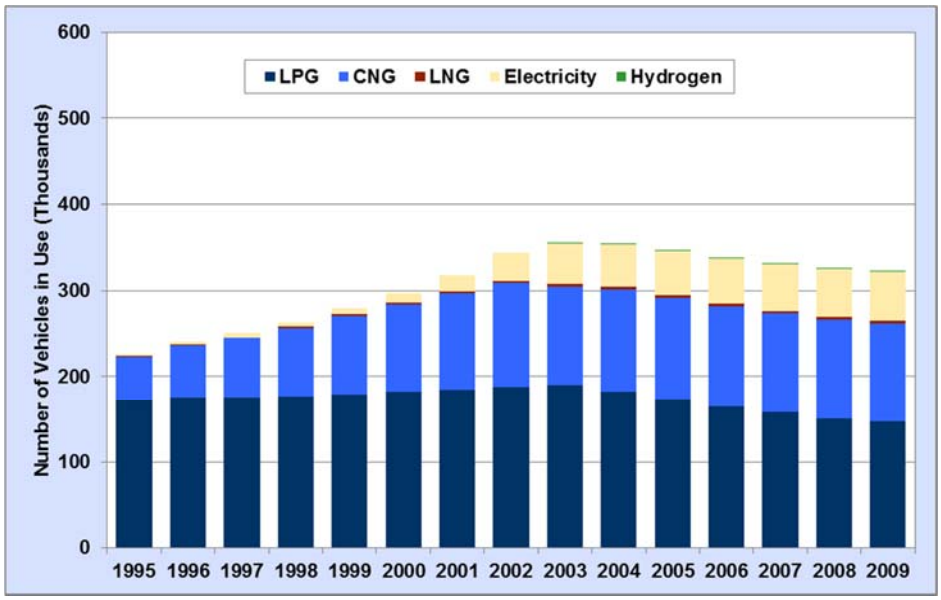


FIGURE 72. Number of Alternative Fuel Vehicles in Use, 1995-2010

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

Biofuel Stations Spread Beyond the Mid-West

E-85, which is 85% ethanol and 15% gasoline, is sold at 2,468 stations nationwide. Many stations are located in the Mid-West where the majority of ethanol feedstock is grown, but E-85 stations are found throughout the nation. B-20, which is 20% biodiesel, is sold at 631 stations across the country, with the predominance of stations in the Southeast. Data are as of October 31, 2011.

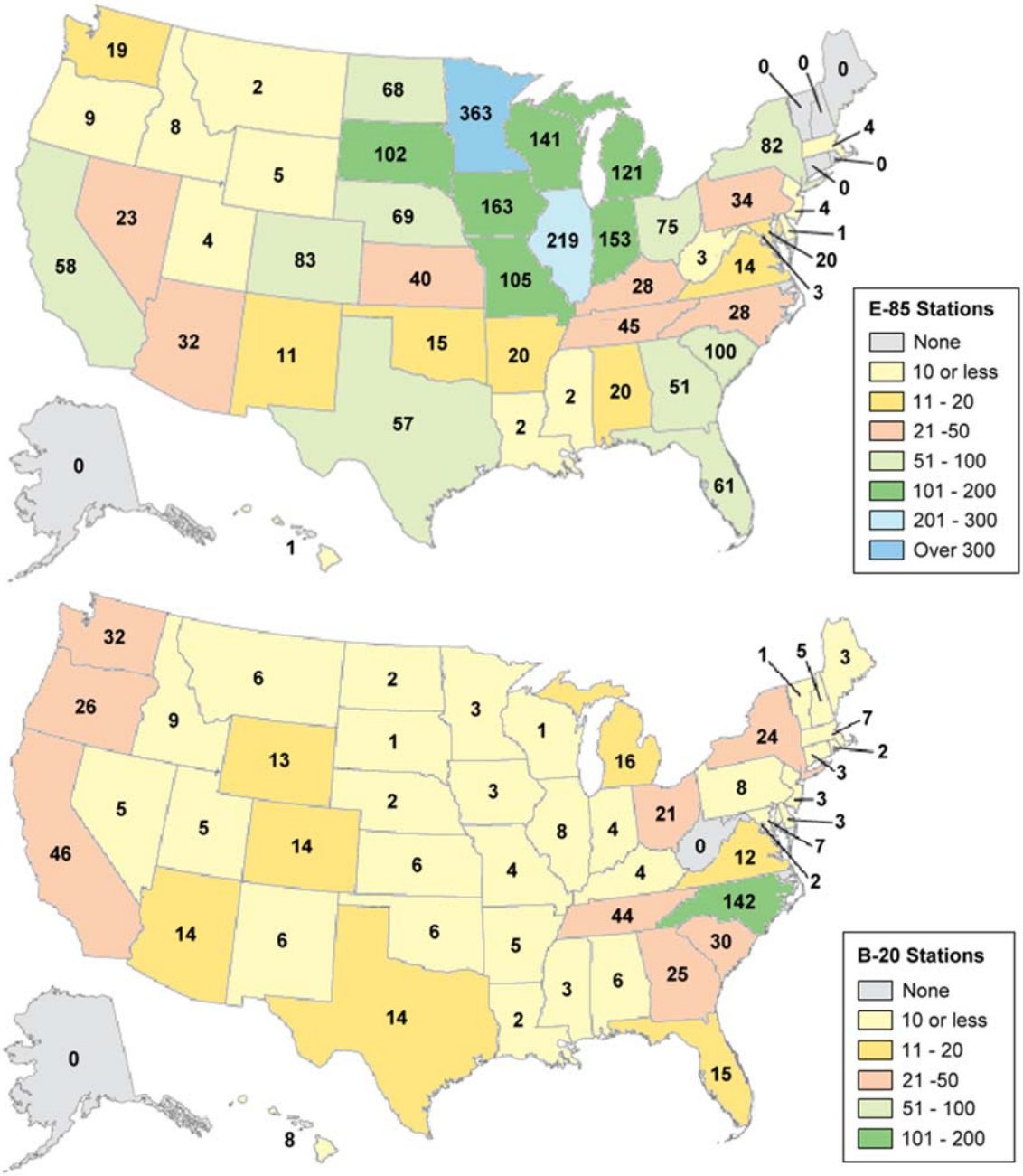


FIGURE 73. Number of E-85 (top) and B-20 Stations by State

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 2,563 propane stations across the county. Texas and California together comprise 28% of the propane stations. Natural gas, compressed or liquefied, is not as widely available as many other alternative fuels. There are 978 stations nationwide. New York and California have the most natural gas stations. Data are as of October 31, 2011.

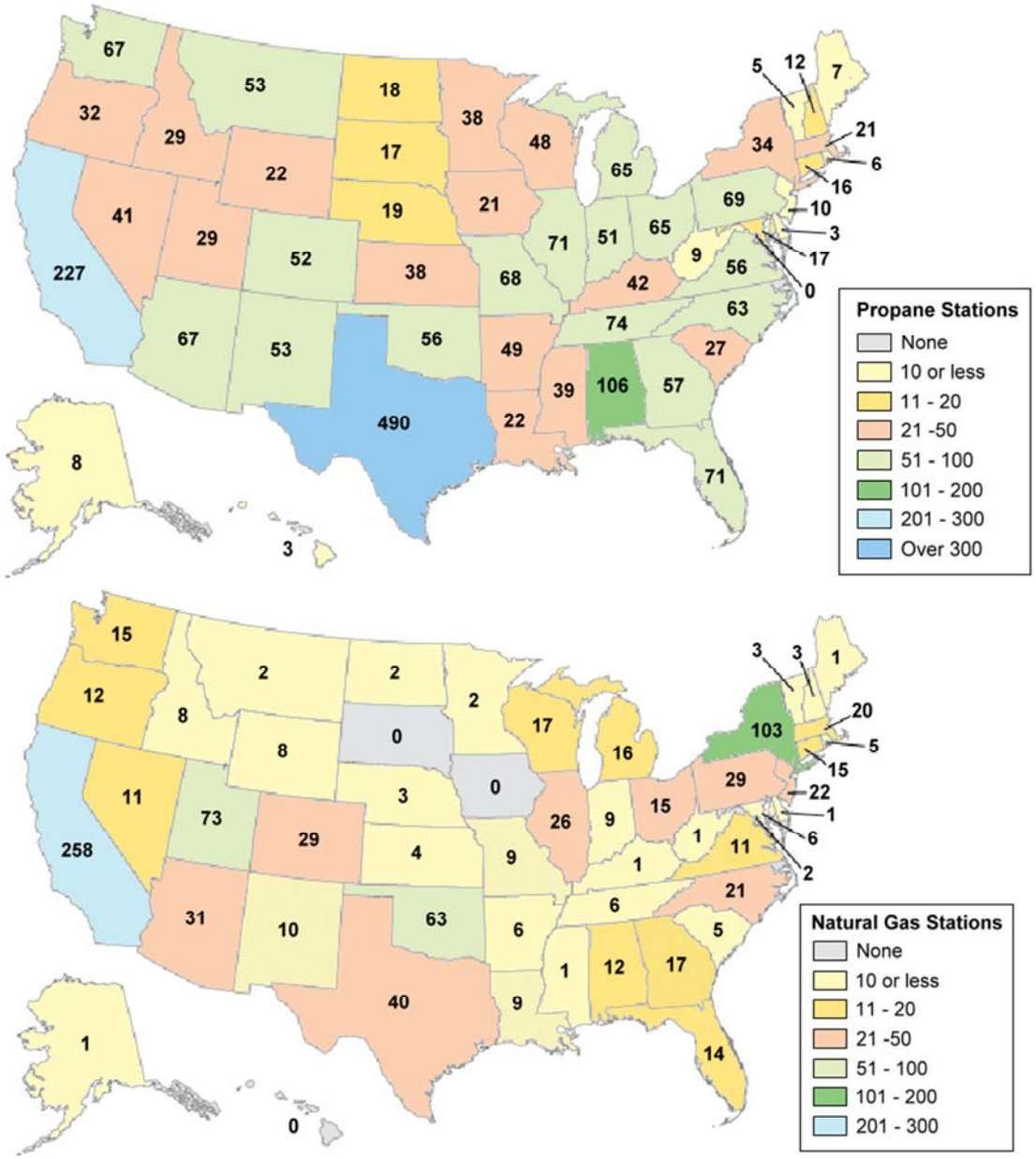


FIGURE 74. Number of Propane (top) and Natural Gas Stations by State

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 and Hydrogen Stations Growing

The number of electric vehicle charging stations has grown due to the debut of highway vehicles that use electricity. At this time, there are more electric stations than any other alternative fuel (4,420 stations). Hydrogen stations are mainly located in California and New York, where research and development is on-going for this fuel. Data are as of October 31, 2011.

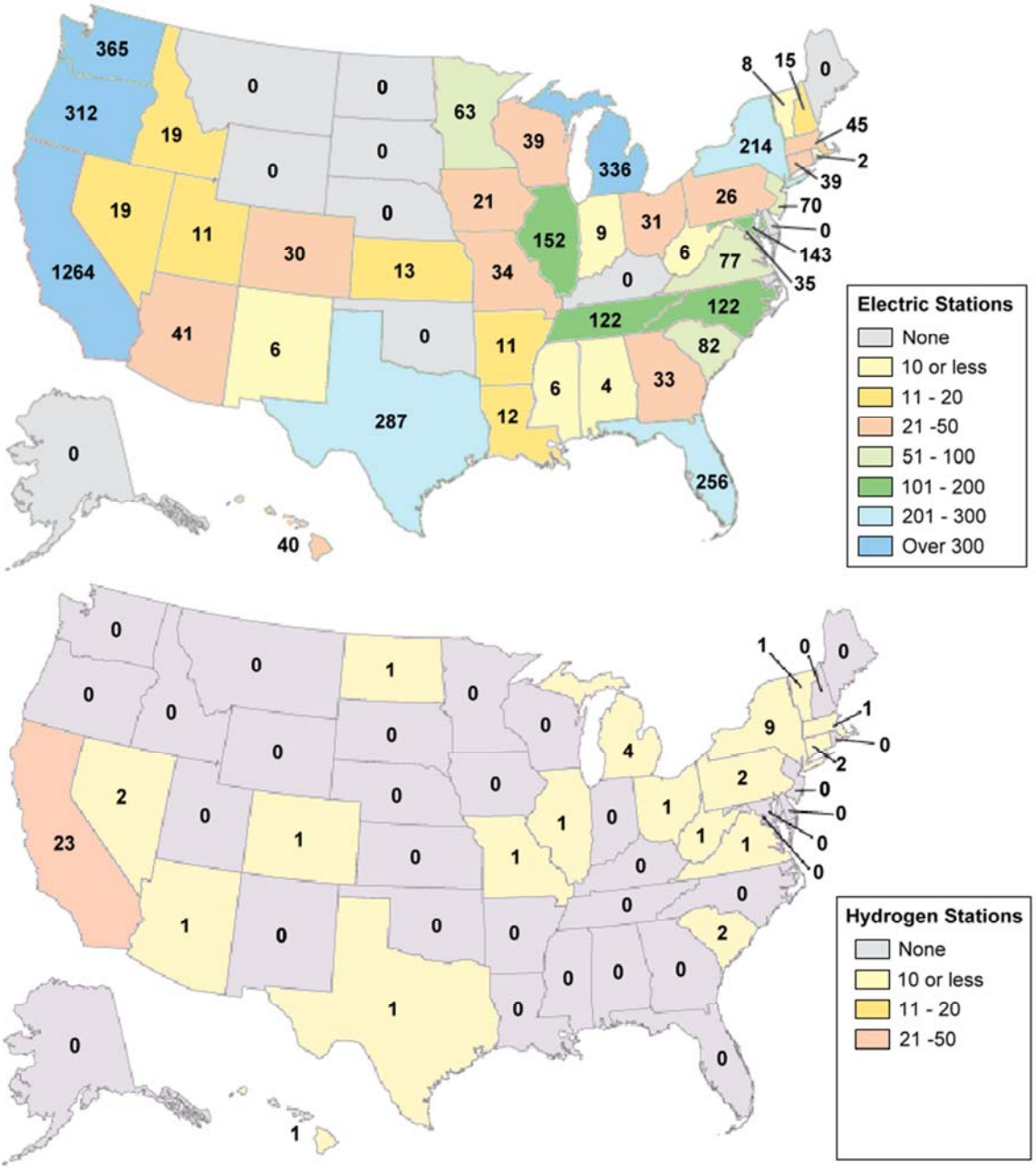


FIGURE 75. Number of Electric (top) and Hydrogen Stations by State

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 16 million gasoline-equivalent gallons (GGEs) of biofuels (E-85 and biodiesel) were used in 2010. Federal use of other alternative fuels has been less than one million GGEs combined in 2009 and 2010. Note the large difference in the scales of the two graphs.

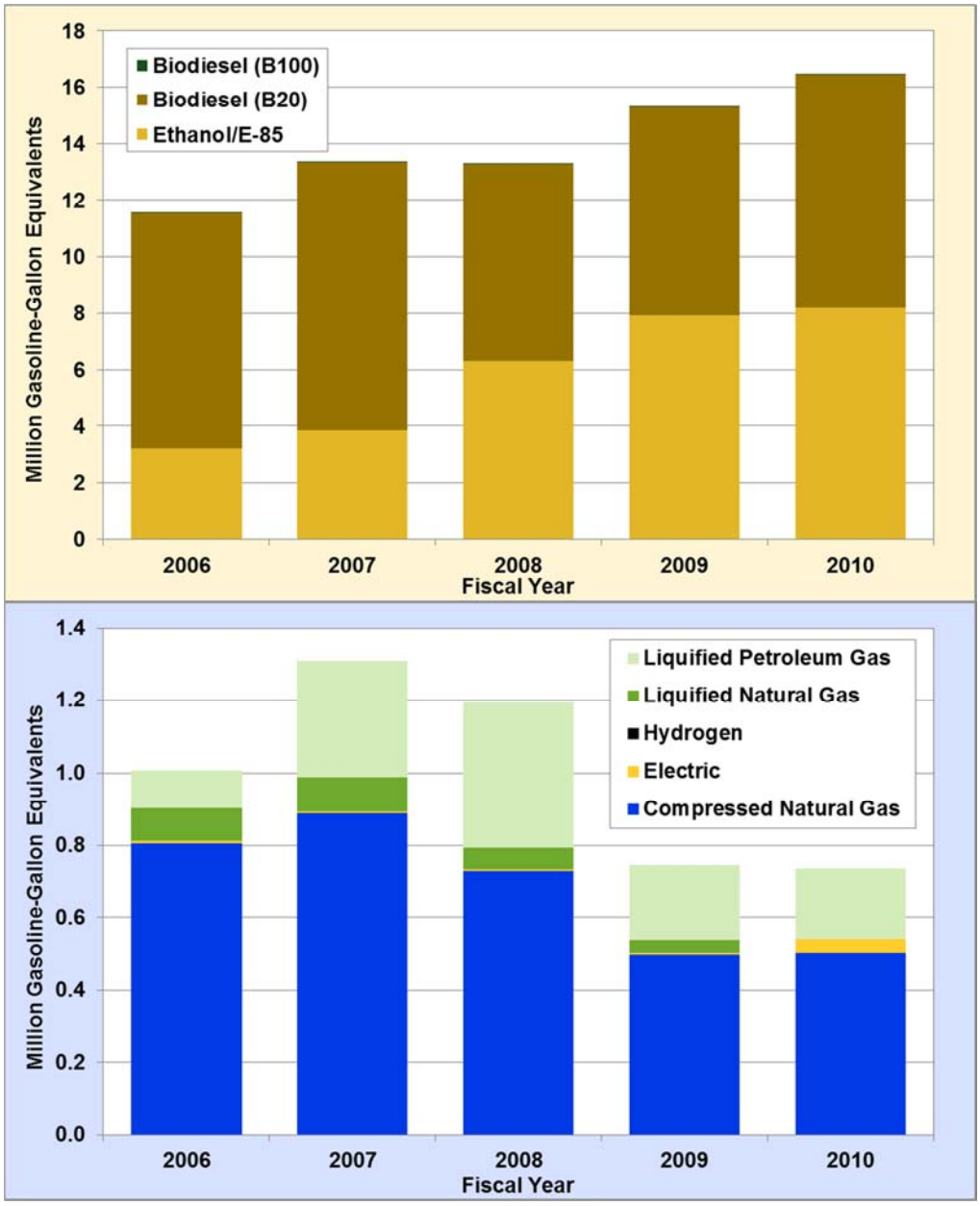


FIGURE 76. Alternative Fuel Use by the Federal Government

Source:

U.S. General Services Administration, *FY 2010 Federal Fleet Report*, Washington, DC, 2011.
http://www.gsa.gov/portal/content/102943

E-85 Vehicles Top Diesels in the Federal Government Fleet

Though gasoline vehicles are the most prevalent in the Federal Government fleet, there are more E-85 vehicles than diesels in the inventory. The number of gasoline hybrid vehicles and electric vehicles both rose substantially between 2009 and 2010.

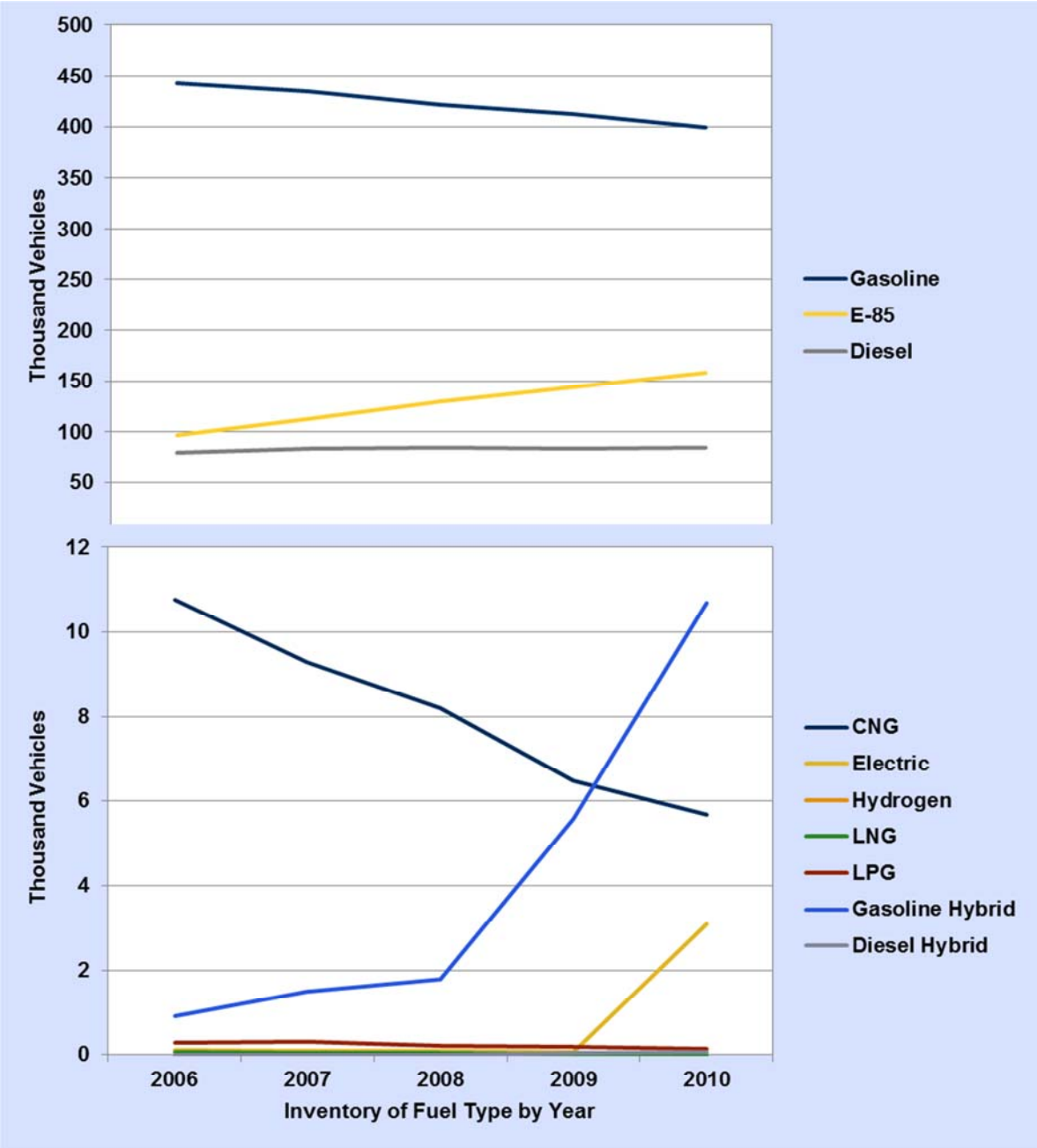


FIGURE 77. Federal Government Vehicles by Fuel Type, 2006-2010

Source:
U.S. General Services Administration, FY 2010 Federal Fleet Report, Washington, DC, 2011.
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 Merck & Co. has just under 6,000 alternative fuel vehicles, most of them flex-fuel. Ninety-five percent of Schwan's Home Service vehicles and Ferrellgas vehicles run on propane.

TABLE 15. Top 25 Commercial Fleets Using Alternative Fuel and Advanced Technology Vehicles, 2009

	Company	Total Alt Fuel	CNG*	Propane*	Flex-Fuel	Biodiesel	Hybrid/ Electric*	Total Vehicles	Percent Alt Fuel	Percent Hybrid/Electric
1	Merck & Co., Inc.	5,849			5,800		49	7,317	80%	1%
2	Schwan's Home Service Inc.	5,800		5,800				6,094	95%	0%
3	State Farm Mutual Auto Insurance Company	4,471			4,339	1	131	14,376	31%	1%
4	GE Healthcare	3,875			3,875			5,614	69%	0%
5	Xerox Corp.	3,825			3,675		150	10,450	37%	1%
6	Bristol-Myers Squibb Co.	3,562			3,550		12	5,557	64%	0%
7	Ferrellgas	3,530		3,530				3,733	95%	0%
8	Eli Lilly & Co.	3,174			3,000	174		5,113	62%	0%
9	Johnson & Johnson Services Inc.	3,037			912		2,125	9,850	31%	22%
10	Honeywell International Inc.	2,319			2,319			4,189	55%	0%
11	Consolidated Edison Company of New York	1,804	20			1,761	23	3,608	50%	1%
12	Florida Power & Light	1,524			10	1,251	263	1,851	82%	14%
13	United Parcel Service (UPS)	1,448	725	720			3	72,633	2%	0%
14	DSWaters of America	1,236		1,131			105	1,573	78%	7%
15	Monsanto Co.	1,131			1,125		6	3,365	34%	0%
16	Liberty Mutual Insurance	1,018			1,018			3,505	29%	0%
17	Delta Airlines	861	4	124	0		733	1,546	56%	47%
18	Comcast Corp.	852			756		96	40,158	2%	0%
19	National Grid	832	730	15	52		35	3,000	28%	1%
20	Ecolab Inc.	809			809			7,311	11%	0%
21	Alliant Energy	804			4	800		1,837	44%	0%
22	Novartis Pharmaceuticals	797					797	8,102	10%	10%
23	Federal Express Corp.	786	90	696				36,701	2%	0%
24	Schneider Electric/Square D	770			750		20	1,535	50%	1%
25	BMHC (BMC West/SelectBuild)	738		418	315		5	2,670	28%	0%

Note: Total Alt Fuel and Percent Alt Fuel columns include hybrid/electric vehicles.

Source:

Bobit Publishing, *Automotive Fleet 500*, "Top 50 Green Commercial Fleets," 2009.
http://www.fleet-central.com/TopFleets/pdf/top50green_09.pdf

*Includes dedicated and bi-fuel vehicles.

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 an average of 129 pounds per vehicle from 1995 to 2009 while the use of high and medium strength steels has increased by 200 lbs. 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 43% 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.

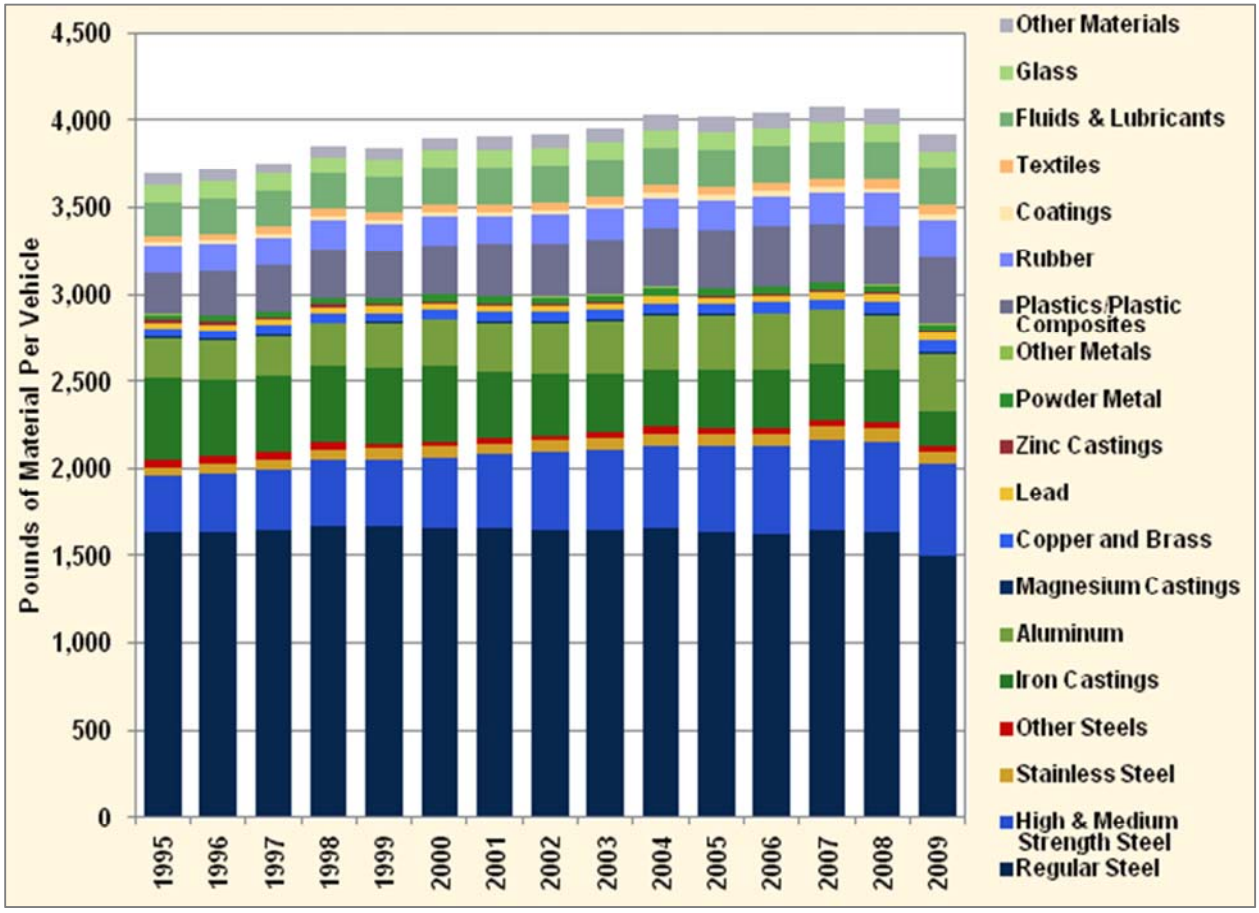


FIGURE 78. Average Materials Content of Light Vehicles, 1995-2009

Source:
Ward's AutoInfoBank. http://wardsauto.com

How Can Fuel Consumption be Reduced for 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 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.

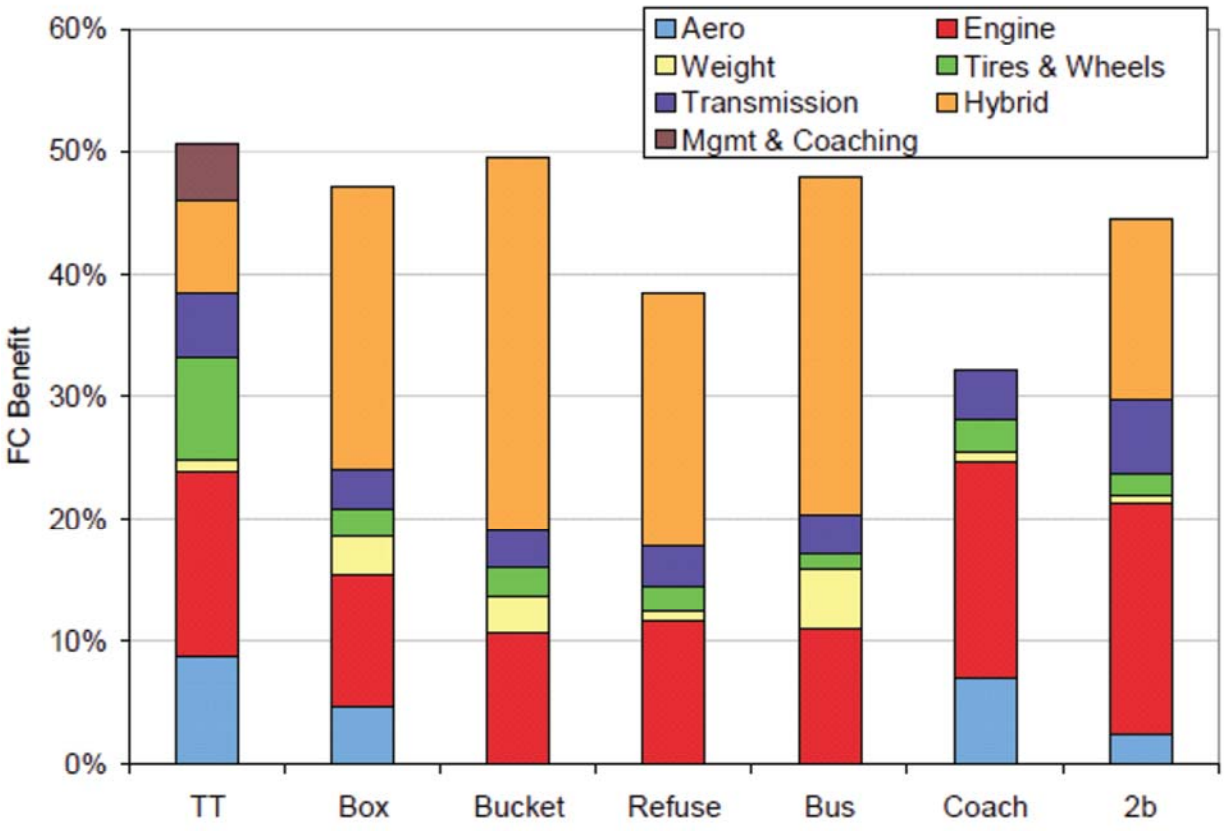


FIGURE 79. Comparison of 2015-2020 New Vehicle Potential Fuel Saving Technologies

Note: 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

SmartWay Technology Program Encourages Heavy Truck Efficiencies

As part of SmartWay Transport Partnership, begun in 2004, the U.S. Environmental Protection Agency 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 16. SmartWay Certified Manufacturers

Tractors	Trailers	Low Rolling Resistance Tires	
Daimler	Great Dane Trailers	Arisun	Hankook
Kenworth	Hyundai Translead	BF Goodrich	Kumho
Mack	Manac Inc.	Bridgestone	Linglong
Navistar	Stoughton Trailers, LLC	Continental	Michelin
Peterbilt	Strick Trailers, LLC	Double Coin	Roadmaster (Cooper)
Volvo	Utility Trailer Manufacturing Co	Dunlop Tire	Sailun
	Vanguard National Trailer Corp	Falken	Sumitomo
	Wabash National Corp	Firestone	Toyo Tires
	Wilson Trailer Co.	General	Triangle
		Goodyear	Westlake
		GT Radial	Yokohama

Source:

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

Some 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, as well as those still under development that show promise for further improvements to performance and efficiency.

TABLE 17. Fuel Saving Engine Technologies

Engine Technologies Currently Being Used	
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.
Cylinder Deactivation	Cylinder deactivation allows the engine to shut down some of its cylinders during light load operation for greater fuel efficiency.
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.
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.
Dual Port Injection	Rather than a single injector per port, a dual injector arrangement improves combustion and increases performance and fuel economy.
Variable Displacement Oil Pump	Rather than pump oil through the engine at a constant rate and pressure, the intensity and rate of pumping can be varied to meet the needs of the engine at different load levels.
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 air flow to cool the engine.
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 NO_X after combustion. Other systems compromise the combustion process to limit the formation of NO_X 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.
Engine Technologies Under Development	
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.

Source:

Compiled from published sources by Bob Boundy, Roltek, Inc., Clinton, TN, 2011.

Hybrid Technologies and Transmission Technologies Can Improve Fuel Economy

There are many different implementations of hybrid technology but most fall within the basic classifications shown in the table below. Similarly, there are many different strategies for improving transmission efficiency and performance. Shown are the more prevalent technologies and strategies.

TABLE 18. Drivetrain Technologies

Hybrid Technologies	
Integrated Starter/Generator	Often referred to as "Start-Stop" or "Mild Hybridization", this system shuts off the engine during deceleration and when stopped but instantly restarts the engine when the accelerator is depressed. This type of system can be integrated with regenerative breaking. General Motors first introduced this technology in 2008 with the Malibu Hybrid and is implementing an advanced form of this technology which they have termed eAssist beginning with 2011 Buick modes.
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.
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.
Transmission Technologies	
Continuously Variable Transmission (CVT)	Continuously variable 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.
Automated Manual Transmission (AMT)	Automated manual transmissions operate like a manual transmission but without a clutch pedal. The shifting can be entirely computer controlled or allow driver input through shifter paddles or buttons mounted on the steering wheel. AMT transmissions are increasingly used on heavy trucks in urban settings and are also found in light duty vehicles as well.
Dual Clutch Transmission	A dual clutch transmission is an automated manual transmission that uses two clutches to select gears. One clutch selects the odd gears (1, 3, & 5) while the other selects the even gears (2, 4, & 6). The advantage of this arrangement is that gears are preselected by the alternate clutch allowing for instantaneous shifts that maintain torque to the wheels at all times. Eliminating the power interruption between shifts that occurs with a single clutch improves both performance and efficiency.
Increased Number of Gears	More gears allow the engine to remain closer to its optimal speed as the vehicle accelerates and decelerates. To maintain an optimal engine speed and improve fuel economy and performance, manufacturers have been increasing the number of gears in both manual and automatic transmissions. Manual transmissions now commonly have 6 speeds while conventional automatic transmissions have reached 8 speeds and manufactures continue to develop transmissions with even more gear ratios.

Source:

Compiled from published sources by Bob Boundy, Roltek, Inc., Clinton, TN, 2011.

Heavy Vehicles Use Hybrid Technologies in Different Ways

FIGURE 80. 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 81. Hybrid Bus

FIGURE 82. 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: (Pictures from the National Renewable Energy Laboratory.)
National Research Council and Transportation Research Board, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, 2010.

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.

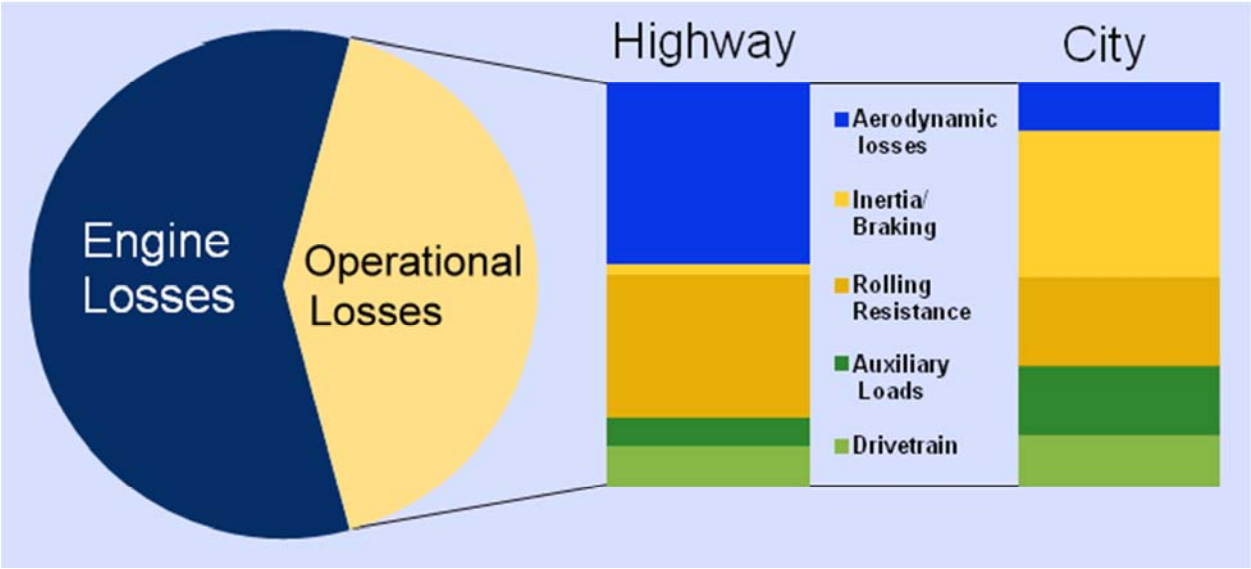


FIGURE 83. Class 8 Truck-Tractor Energy Losses

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 adopted as widely. 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

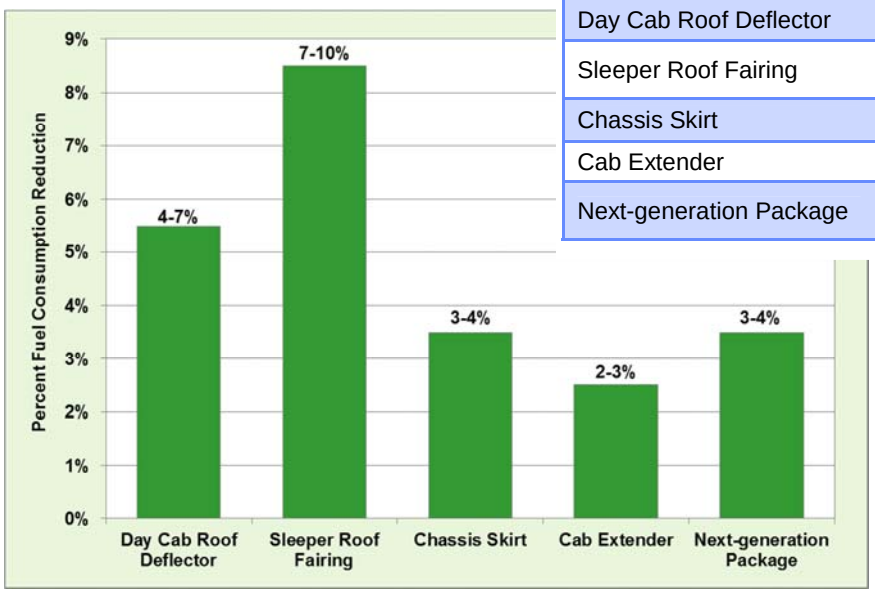


FIGURE 84. Fuel Consumption Reduction Rate, Approximate Cost, and Industry Adoption Rate for Aerodynamic Technologies

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 lbs. of weight added, there is a 0.5% penalty in fuel consumption. Trailer skirts alone can add more than 200 lbs. 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.

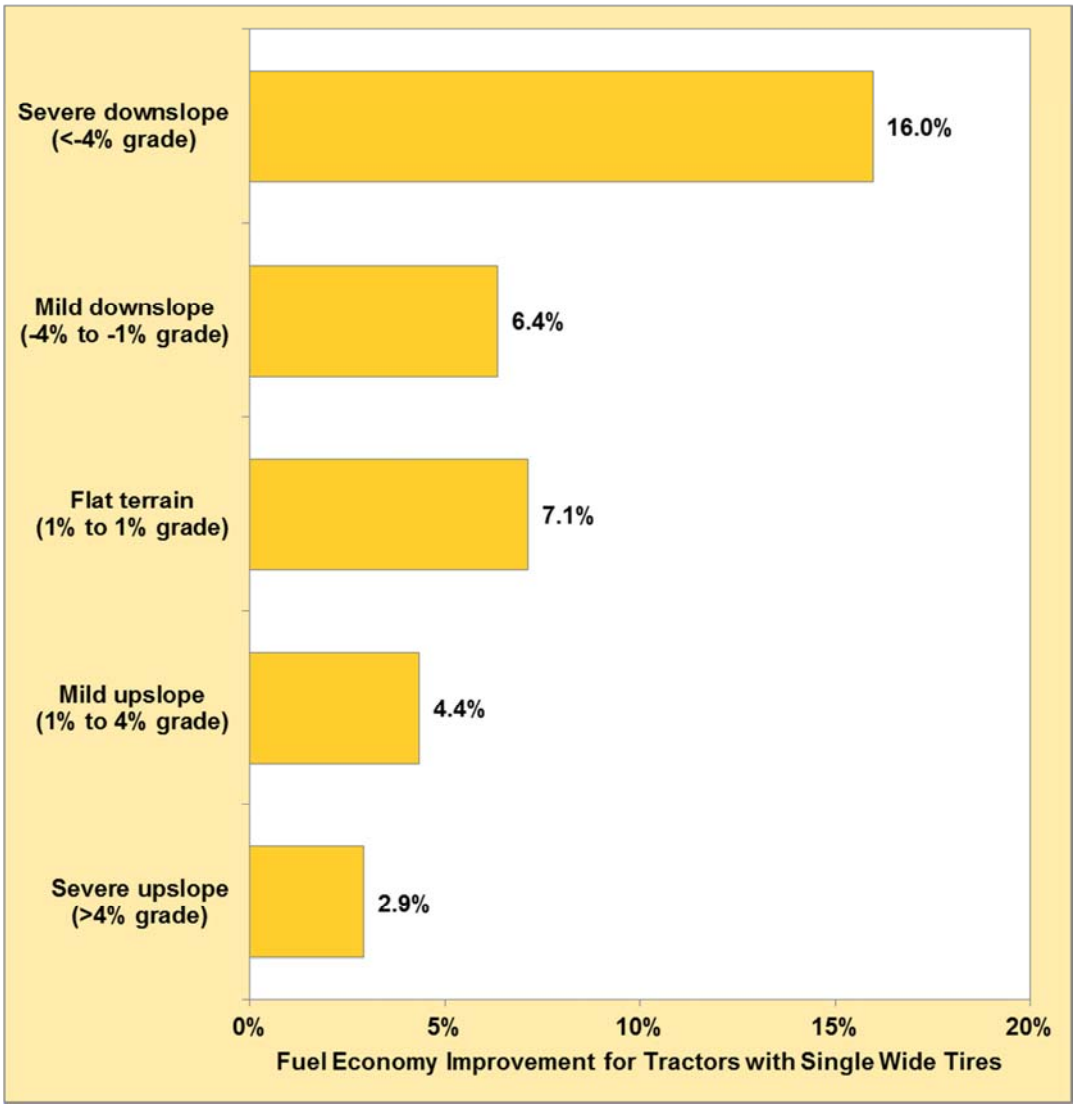


FIGURE 85. Fuel Economy Improvement for Class 8 Tractors with Single Wide Tires

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

Truck Stop Electrification Reduces Idle Fuel Consumption

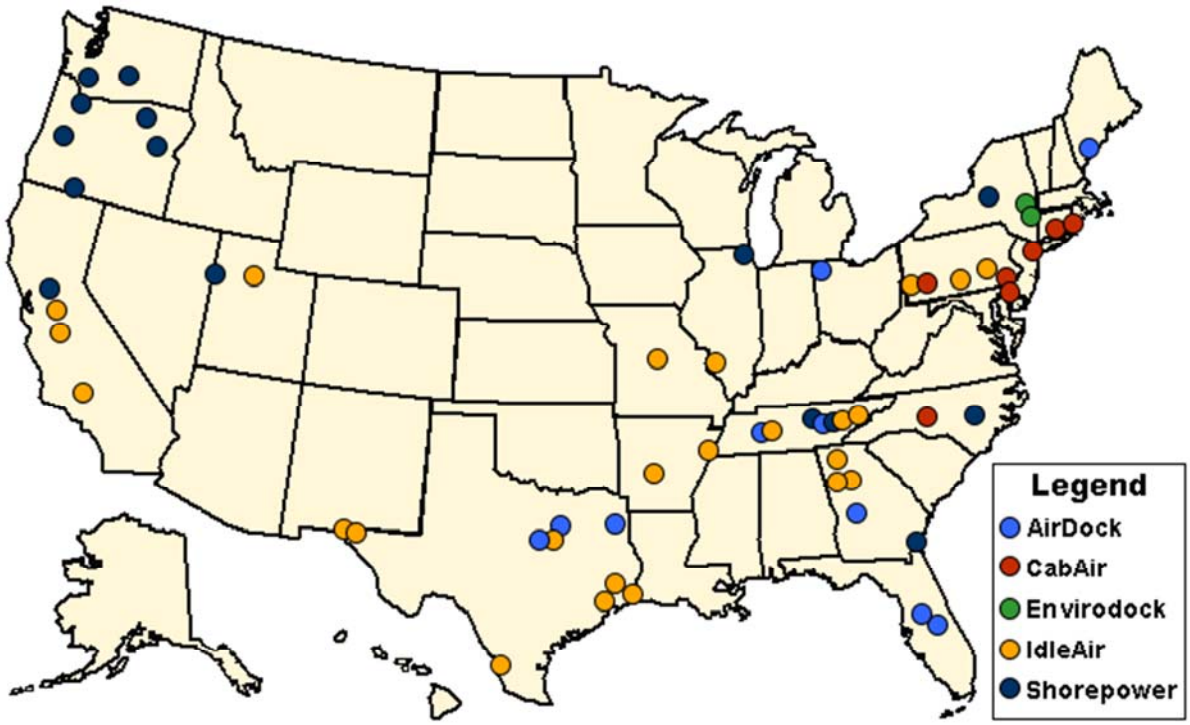


FIGURE 86. Map of Truck Stop Electrification Sites

TABLE 19. Number of Truck Stop Electrification Sites by State

State	Number of Sites
Arkansas	2
California	4
Connecticut	2
Delaware	2
Florida	2
Georgia	5
Illinois	2
Maine	1
Missouri	1
North Carolina	2
New Jersey	1
New York	3
Ohio	1
Oregon	5
Pennsylvania	4
Tennessee	7
Texas	10
Utah	2
Washington	2
Total	**58**

The U.S. Department of Transportation mandates that truckers rest for 10 hours after driving for 11 hours, during which time they often park at truck stops idling the engines to provide heating, cooling and use of electrical appliances. Electrification at truck stops allows truckers to "plug-in" vehicles to operate the necessary systems without idling the engine. There are currently 58 publicly accessible electrification sites across the nation. Some of these sites require special equipment to be installed on the truck and others do not. Presently, five companies equip electrification sites: Shorepower, CabAire, EnviroDock, AireDock, and IdleAir.

Source:
Alternative Fuels and Advanced Vehicles Data Center.
http://www.afdc.energy.gov/afdc/progs/tse_listings.php