# Hybrid electric vehicle

A **hybrid electric vehicle** (HEV) is a type of hybrid vehicle and electric vehicle which combines a conventional internal combustion engine (ICE) propulsion system with an electric propulsion system. The presence of the electric powertrain is intended to achieve either better fuel economy than a conventional vehicle, or better performance. There are a variety of HEV types, and the degree to which they function as EVs varies as well. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors) and buses also exist.

The Toyota Prius is the world's top selling hybrid car, with cumulative global sales of 2.5 million units by February 2012.[1]

Modern HEVs make use of efficiency-improving technologies such as regenerative braking, which converts the vehicle's kinetic energy into electric energy to charge the battery, rather than wasting it as heat energy as conventional brakes do. Some varieties of HEVs use their internal combustion engine to generate electricity by spinning an electrical generator (this combination is known as a motor-generator), to either recharge their batteries or to directly power the electric drive motors. Many HEVs reduce idle emissions by shutting down the ICE at idle and restarting it when needed; this is known as a start-stop system. A hybrid-electric produces less emissions from its ICE than a comparably-sized gasoline car, since an HEV's gasoline engine is usually smaller than a comparably-sized pure gasoline-burning vehicle (natural gas and propane fuels produce lower emissions) and if not used to directly drive the car, can be geared to run at maximum efficiency, further improving fuel economy.

Ferdinand Porsche in 1901 developed the Lohner-Porsche Mixte Hybrid, the first gasoline-electric hybrid automobile in the world.[2] The hybrid-electric vehicle did not become widely available until the release of the Toyota Prius in Japan in 1997, followed by the Honda Insight in 1999.[3] While initially perceived as unnecessary due to the low cost of gasoline, worldwide increases in the price of petroleum caused many automakers to release hybrids in the late 2000s; they are now perceived as a core segment of the automotive market of the future.[4][5]



More than 4.5 million hybrid electric vehicles have been sold worldwide by the end of December 2011, led by Toyota Motor Company (TMC) with more than 3.5 million Lexus and Toyota hybrids,[6] followed by Honda Motor Co., Ltd. with cumulative sales of more than 800 thousand hybrids,[7] and Ford Motor Corporation with more than 185 thousand hybrids sold in the United States by December 2011.[8][9] Toyota is the market leader with hybrids sold in 80 countries and regions. Worldwide sales of hybrid vehicles produced by TMC reached 1.0 million units in May 2007; 2.0 million in August 2009; and the 4.0 million mark in April 2012.[10][11][12] Worldwide hybrid sales are led by the Toyota Prius, with cumulative sales of 2.6 million units sold through April 2012, and available in 70 countries and regions.[12] The United States is the world's largest hybrid market with 2.3 million hybrid automobiles and SUVs sold through April 2012,[8][9][13] and California is the biggest regional American market.[14] The Prius is the top selling hybrid car in the U.S. market, surpassing the 1 million milestone in April 2011.[15] Cumulative sales of the Prius in Japan reached the 1 million mark in August 2011.[16]

## Terminology

### Types of powertrain

Hybrid electric vehicles can be classified according to the way in which power is supplied to the drivetrain:

- In parallel hybrids, the ICE and the electric motor are both connected to the mechanical transmission and can simultaneously transmit power to drive the wheels, usually through a conventional transmission. Honda's Integrated Motor Assist (IMA) system as found in the Insight, Civic, Accord, as well as the GM Belted Alternator/Starter (BAS Hybrid) system found in the Chevrolet Malibu hybrids are examples of production parallel hybrids.[17] Current,

commercialized parallel hybrids use a single, small (<20 kW) electric motor and small battery pack as the electric motor is not designed to be the sole source of motive power from launch. Parallel hybrids are also capable of regenerative braking and the internal combustion engine can also act as a generator for supplemental recharging. Parallel hybrids are more efficient than comparable non-hybrid vehicles especially during urban stop-and-go conditions and at times during highway operation where the electric motor is permitted to contribute.[17]


The Toyota Highlander Hybrid has a series-parallel drivetrain.

- In series hybrids, only the electric motor drives the drivetrain, and the ICE works as a generator to power the electric motor or to recharge the batteries. The battery pack can be recharged through regenerative braking or by the ICE. Series hybrids usually have a smaller combustion engine but a larger battery pack as compared to parallel hybrids, which makes them more expensive than parallels. This configuration makes series hybrids more efficient in city driving.[17] The Chevrolet Volt is a series plug-in hybrid, although GM prefers to describe the Volt as an electric vehicle equipped with a "range extending" gasoline powered ICE as a generator and therefore dubbed an "Extended Range Electric Vehicle"[18] or EREV.[18][19][20]


The Saturn Vue Green Line is a mild hybrid.

- Power-split hybrids have the benefits of a combination of series and parallel characteristics. As a result, they are more efficient overall, because series hybrids tend to be more efficient at lower speeds and parallel tend to be more efficient at high speeds; however, the cost of power-split the hybrid is higher than a pure parallel.[17] Examples of power-split (referred to by some as "series-parallel") hybrid powertrains include current models of Ford, General Motors, Lexus, Nissan, and Toyota.[17][21]


The 2005-06 Chevrolet Silverado Hybrid is a mild hybrid using the electric motor mainly to power the accessories.

## Types by degree of hybridization

*Further information: Mild hybrid*

- Full hybrid, sometimes also called a strong hybrid, is a vehicle that can run on just the engine, just the batteries, or a combination of both.[22] Ford's hybrid system, Toyota's Hybrid Synergy Drive and General Motors/Chrysler's Two-Mode Hybrid technologies are full hybrid systems.[23] The Toyota Prius, Ford Escape Hybrid, and Ford Fusion Hybrid are examples of full hybrids, as these cars can be moved forward on battery power alone. A large, high-capacity battery pack is needed for battery-only operation. These vehicles have a split power path allowing greater flexibility in the drivetrain by interconverting mechanical and electrical power, at some cost in complexity.


The BMW Concept 7 Series ActiveHybrid is a mild hybrid with an electric motor designed to increase power and performance.

- Mild hybrid, is a vehicle that can not be driven solely on its electric motor, because the electric motor does not have enough power to propel the vehicle on its own.[22][23] Mild hybrids only include some of the features found in hybrid technology, and usually achieve limited fuel consumption savings, up to 15 percent in urban driving and 8 to 10 percent overall cycle.[22][23] A mild hybrid is essentially a conventional vehicle with oversize starter motor, allowing the engine to be turned off whenever the car is coasting, braking, or stopped, yet restart quickly and cleanly. The motor is often mounted between the engine and transmission, taking the place of the torque converter, and is used to supply additional propulsion energy when accelerating. Accessories can continue to run on electrical power while the gasoline engine is off, and as in other hybrid designs, the motor is used for regenerative braking to recapture energy. As compared to full hybrids, mild hybrids have smaller batteries and a smaller, weaker

motor/generator, which allows manufacturers to reduce cost and weight.[23]

Honda's early hybrids including the first generation Insight used this design,[23] leveraging their reputation for design of small, efficient gasoline engines; their system is dubbed Integrated Motor Assist (IMA). Starting with the 2006 Civic Hybrid, the IMA system now can propel the vehicle solely on electric power during medium speed cruising. Another example is the 2005-2007 Chevrolet Silverado Hybrid, a full-size pickup truck.[23] Chevrolet was able to get a 10% improvement on the Silverado's fuel efficiency by shutting down and restarting the engine on demand and using regenerative braking. General Motors has also used its mild BAS Hybrid technology in other models such as the Saturn Vue Green Line, the Saturn Aura Greenline and the Mailbu Hybrid.[23]

### Plug-in hybrids (PHEVs)

*Main article: Plug-in hybrid*

A plug-in hybrid electric vehicle (PHEV), also known as a plug-in hybrid, is a hybrid electric vehicle with rechargeable batteries that can be restored to full charge by connecting a plug to an external electric powersource. A PHEV shares the characteristics of both a conventional hybrid electric vehicle, having an electric motor and an internal combustion engine; and of an all-electric vehicle, also having a plug to connect to the electrical grid. PHEVs have a much larger all-electric range as compared to conventional gasoline-electric hybrids, and also eliminate the "range anxiety" associated with all-electric vehicles, because the combustion engine works as a backup when the batteries are depleted.[22][24][25]

The Chevrolet Volt is a plug-in hybrid able to run in all-electric mode up to 35 miles.

Chinese battery manufacturer and automaker BYD Auto released the F3DM PHEV-62 (PHEV-100 km) hatchback to the Chinese fleet market on December 15, 2008, for 149,800 yuan (US $22,000).[26][27] General Motors launched the 2011 Chevrolet Volt series plug-in in December 2010.[28][29] The Volt displaced the Toyota Prius as the most fuel-efficient car sold in the United States.[30][31]

## History

*Further information: History of plug-in hybrids*

### Early days

In 1900, while employed at Lohner Coach Factory, Ferdinand Porsche developed the *Mixte*,[2][32] a 4WD series-hybrid version of "*System Lohner-Porsche*" electric carriage previously appeared in 1900 Paris World Fair. The Mixte included a pair of generators driven by 2.5-hp Daimler IC engines to extend operating range and it could travel nearly 65 km on battery alone. It was presented in the Paris Auto Show in 1901.[2][33][34] The Mixte broke several Austrian speed records, and also won the Exelberg Rally in 1901 with Porsche himself driving. The Mixte used a gasoline engine powering a generator, which in turn powered electric hub motors, with a small battery pack for reliability. It had a top speed of 50 km/h and a power of 5.22 kW during 20 minutes.

The Lohner-Porsche Mixte Hybrid was the first gasoline-electric hybrid automobile.

George Fischer sold hybrid buses to England in 1901; Knight Neftal produced a racing hybrid in 1902.[35]

In 1905, Henri Pieper of Germany/Belgium introduced a hybrid vehicle with an electric motor/generator, batteries, and a small gasoline engine. It used the electric motor to charge its batteries at cruise speed and used both motors to accelerate

or climb a hill. The Pieper factory was taken over by Imperia, after Pieper died..[36] The 1915 *Dual Power*, made by the Woods Motor Vehicle electric car maker, had a four-cylinder ICE and an electric motor. Below 15 mph (24 km/h) the electric motor alone drove the vehicle, drawing power from a battery pack, and above this speed the "main" engine cut in to take the car up to its 35 mph (56 km/h) top speed. About 600 were made up to 1918.[37]The Woods hybrid was a commercial failure, proving to be too slow for its price, and too difficult to service. The United States Army's 1928 Experimental Motorized Force tested a gasoline-electric bus in a truck convoy.

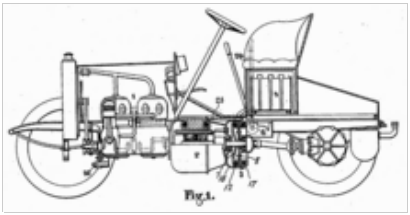


Figure 1 of Henri Pieper's 1905 Hybrid Vehicle Patent Application.

In 1931 Erich Gaichen invented and drove from Altenburg to Berlin a 1/2 horsepower electric car containing features later incorporated into hybrid cars. Its maximum speed was 25 miles per hour (40 km/h), but it was licensed by the Motor Transport Office, taxed by the German Revenue Department and patented by the German Reichs-Patent Amt. The car battery was re-charged by the motor when the car went downhill. Additional power to charge the battery was provided by a cylinder of compressed air which was re-charged by small air pumps activated by vibrations of the chassis and the brakes and by igniting oxyhydrogen gas. An account of the car and his characterization as a "crank inventor" can be found in Arthur Koestler's autobiography, Arrow in the Blue, pages 269-271, which summarize a contemporaneous newspaper account written by Koestler. No production beyond the prototype was reported.

## Predecessors of current technology

A more recent working prototype of the HEV was built by Victor Wouk (one of the scientists involved with the Henney Kilowatt, the first transistor-based electric car). Wouk's work with HEVs in the 1960s and 1970s earned him the title as the "Godfather of the Hybrid".[38] Wouk installed a prototype hybrid drivetrain (with a 16 kilowatts (21 hp) electric motor) into a 1972 Buick Skylark provided by GM for the 1970 Federal Clean Car Incentive Program, but the program was stopped by the United States Environmental Protection Agency (EPA) in 1976 while Eric Stork, the head of the EPA's vehicle emissions control program at the time, was accused of a prejudicial coverup.[39]

The regenerative braking system, the core design concept of most production HEVs, was developed by electrical engineer David Arthurs around 1978, using off-the shelf components and an Opel GT. However the voltage controller to link the batteries, motor (a jet-engine starter motor), and DC generator was Arthurs'. The vehicle exhibited 75 miles per US gallon (3.1 L/100 km; 90 $mpg_{-imp}$) fuel efficiency, and plans for it (as well as somewhat updated versions) are still available through the Mother Earth News web site. The Mother Earth News' own 1980 version claimed nearly 84 miles per US gallon (2.8 L/100 km; 101 $mpg_{-imp}$).

In 1989, Audi produced its first iteration of the Audi Duo (the Audi C3 100 Avant Duo) experimental vehicle, a plug-in parallel hybrid based on the Audi 100 Avant quattro. This car had a 9.4 kilowatts (12.8 PS; 12.6 bhp) Siemens electric motor which drove the rear roadwheels. A trunk-mounted nickel-cadmium battery supplied energy to the motor that drove the rear wheels. The vehicle's front roadwheels were powered by a 2.3 litre five-cylinder petrol engine with an output of 100 kilowatts (136 PS; 134 bhp). The intent was to produce a vehicle which could operate on the engine in the country, and electric mode in the city. Mode of operation could be selected by the driver. Just ten vehicles are believed to have been made; one drawback was that due to the extra weight of the electric drive, the vehicles were less efficient when running on their engines alone than standard Audi 100s with the same engine.

Two years later, Audi, unveiled the second duo generation, the Audi 100 Duo - likewise based on the Audi 100 Avant quattro. Once again, this featured an electric motor, a 21.3 kilowatts (29.0 PS; 28.6 bhp) three-phase machine, driving the rear roadwheels. This time, however, the rear wheels were additionally powered via the Torsen centre differential from the main engine compartment, which housed a 2.0 litre four-cylinder engine.[*citation needed*]

In 1992, Volvo ECC was developed by Volvo. The Volvo ECC was built on the Volvo 850 platform. In contrast to most production hybrids, which use a gasoline piston engine to provide additional acceleration and to recharge the battery storage, the Volvo ECC used a gas turbine engine to drive the generator for recharging.

The Clinton administration initiated the Partnership for a New Generation of Vehicles (PNGV) program on 29 September

1993, that involved Chrysler, Ford, General Motors, USCAR, the DoE, and other various governmental agencies to engineer the next efficient and clean vehicle.[40] The United States National Research Council (USNRC) cited automakers' moves to produce HEVs as evidence that technologies developed under PNGV were being rapidly adopted on production lines, as called for under Goal 2. Based on information received from automakers, NRC reviewers questioned whether the "Big Three" would be able to move from the concept phase to cost effective, pre-production prototype vehicles by 2004, as set out in Goal 3.[41] The program was replaced by the hydrogen-focused FreedomCAR initiative by the George W. Bush administration in 2001,[42] an initiative to fund research too risky for the private sector to engage in, with the long-term goal of developing effectively carbon emission- and petroleum-free vehicles.

1998 saw the Esparante GTR-Q9 became the first Petrol-Electric Hybrid to race at Le Mans, although the car failed to qualify for the main event. The car managed to finished second in class at Petit Le Mans the same year.

## Modern hybrids

*See also: List of hybrid vehicles*

Automotive hybrid technology became widespread beginning in the late 1990s. The first mass-produced hybrid vehicle was the Toyota Prius, launched in Japan in 1997, and followed by the Honda Insight, launched in 1999 in the United States and Japan.[3] The Prius was launched in Europe, North America and the rest of the world in 2000.[44] The first generation Prius sedan has an estimated fuel economy of 52 miles per US gallon (4.5 L/100 km; 62 $mpg_{imp}$) in the city and 45 miles per US gallon (5.2 L/100 km; 54 $mpg_{imp}$) in highway driving. The two-door first generation Insight was estimated at 61 miles per US gallon (3.9 L/100 km; 73 $mpg_{imp}$) miles per gallon in city driving and 68 miles per US gallon (3.5 L/100 km; 82 $mpg_{imp}$) on the highway.[3]


1997 Toyota Prius (first generation).

The Toyota Prius sold 300 units in 1997, 19,500 in 2000, and cumulative worldwide Prius sales reached the 1 million mark in April 2008.[44] By early 2010, the Prius global cumulative sales were estimated at 1.6 million units.[45][46] Toyota launched a second generation Prius in 2004 and a third in 2009.[47] The 2010 Prius has an estimated U.S. Environmental Protection Agency combined fuel economy cycle of 50 miles per US gallon (4.7 L/100 km; 60 $mpg_{imp}$).[47]


2000 Honda Insight (first generation).

The Audi Duo III was introduced in 1997, based on the Audi B5 A4 Avant, and was the only Duo to ever make it into series production.[2] The Duo III used the 1.9 litre Turbocharged Direct Injection (TDI) diesel engine, which was coupled with an 21 kilowatts (29 PS; 28 bhp) electric motor. Unfortunately due to low demand for this hybrid because of its high price, only about sixty Audi Duos were produced. Until the release of the Audi Q7 Hybrid in 2008, the Duo was the only European hybrid ever put into production.[2][48]


2010 Honda Insight (second generation).

The Honda Civic Hybrid was introduced in February 2002 as a 2003 model, based on the seventh generation Civic.[49] The 2003 Civic Hybrid appears identical to the non-hybrid version, but delivers 50 miles per US gallon (4.7 L/100 km; 60 $mpg_{imp}$), a 40 percent increase compared to a conventional Civic LX sedan.[49] Along with the conventional Civic, it received styling update for 2004. The redesigned 2004 Toyota Prius (second generation) improved passenger room, cargo area, and power output, while increasing energy efficiency and reducing emissions. The Honda Insight first generation stopped being produced after 2006 and has a devoted base of owners. A second generation Insight was launched in 2010. In 2004, Honda also released a hybrid version of the Accord but discontinued it in 2007 citing

disappointing sales.[50]

The 2010 Ford Fusion Hybrid was launched in the U.S. in March 2009.[43]

The Ford Escape Hybrid, the first hybrid electric sport utility vehicle (SUV) was released in 2005. Toyota and Ford entered into a licensing agreement in March 2004 allowing Ford to use 20 patents[*citation needed*] from Toyota related to hybrid technology, although Ford's engine was independently designed and built.[*citation needed*] In exchange for the hybrid licenses, Ford licensed patents involving their European diesel engines to Toyota.[*citation needed*] Toyota announced calendar year 2005 hybrid electric versions of the Toyota Highlander Hybrid and Lexus RX 400h with 4WD-i, which uses a rear electric motor to power the rear wheels negating the need for a transfer case.

In 2006, General Motors Saturn Division began to market a mild parallel hybrids in the form of the 2007 Saturn Vue Green Line which utilized GM's Belted Alternator/Starter (BAS Hybrid) System combined with a 2.4 litre L4 engine and a FWD automatic transmission. The same hybrid powertrain was also used to power the 2008 Saturn Aura Greenline and Mailbu Hybrid models. As of December 2009, only the BAS equipped Malibu is still in (limited) production.

In 2007, Lexus released a hybrid electric version of their GS sport sedan, the GS 450h, with a power output of 335 bhp.[51] The 2007 Camry Hybrid became available in Summer 2006 in the United States and Canada. Nissan launched the Altima Hybrid with technology licensed by Toyota in 2007.[52]

Commencing in the fall of 2007 General Motors began to market their 2008 Two-Mode Hybrid models of their GMT900 based Chevrolet Tahoe and GMC Yukon SUVs, closely followed by the 2009 Cadillac Escalade Hybrid[53] version.[54] For the 2009 model year, General Motors released the same technology in their half-ton pickup truck models, the 2009 Chevrolet Silverado[55] and GMC Sierra[56] Two-Mode Hybrid models.

The Ford Fusion Hybrid officially debuted at the Greater Los Angeles Auto Show in November 2008,[57] and was launched to the U.S. market in March 2009, together with the second generation Honda Insight and the Mercury Milan Hybrid.[43]



## Latest developments

2009–2010

The 2011 Honda CR-Z hybrid was launched in Japan in February 2010, followed by the US in August 2010.[58]

The Hyundai Elantra LPI Hybrid was unveiled at the 2009 Seoul Motor Show, and sales began in the South Korean domestic market in July 2009. The Elantra LPI (Liquefied Petroleum Injected) is the world's first hybrid vehicle to be powered by an internal combustion engine built to run on liquefied petroleum gas (LPG) as a fuel. The Elantra PLI is a mild hybrid and the first hybrid to adopt advanced lithium polymer (Li–Poly) batteries.[60][61] The Elantra LPI Hybrid delivers a fuel economy rating of 41.9 miles per US gallon (5.61 L/100 km; 50.3 $mpg_{imp}$) and $CO_2$ emissions of 99 g/km to qualify as a Super Ultra Low Emission Vehicle (SULEV).[60]

The Mercedes-Benz S400 BlueHybrid was unveiled in the 2009 Chicago Auto Show,[62] and sales began in the U.S. in October 2009.[63][64] The S400 BlueHybrid is a mild hybrid and the first hybrid car to adopt a lithium ion battery.[62][65] The hybrid technology in the S400 was co-developed by Daimler AG and BMW.[23][62] The same hybrid technology is being used in the BMW ActiveHybrid 7, expected to go on sales in the U.S. and Europe by mid 2010.[66] In December 2009 BMW began sales of its full hybrid BMW ActiveHybrid X6, while Daimler launched the Mercedes-Benz ML450 Hybrid by lease only.[67][68]

The 2011 Toyota Auris Hybrid is the first mass-produced hybrid electric

Sales of the Honda CR-Z began in Japan in February 2010, followed by the U.S. and European markets later in the year, becoming Honda's third hybrid electric car

in the market.[58][69] Honda also launched the 2011 Honda Fit Hybrid in Japan in October 2010, and unveiled the European version, the Honda Jazz Hybrid, at the 2010 Paris Motor Show, which went on sale in some European markets by early 2011.[70]

vehicle built in Europe.[59]

Mass production of the 2011 Toyota Auris Hybrid began in May 2010 at Toyota Manufacturing UK (TMUK) Burnaston plant and became the first mass-produced hybrid vehicle to be built in Europe.[59] Sales in the U.K. began in July 2010, at a price starting atGB£18,950 (US$27,450), GB£550 (US$800) less than the Toyota Prius.[71][72] The 2011 Auris Hybrid shares the same powertrain as the Prius, and combined fuel economy is 74.3 $mpg_{imp}$ (3.80 L/100 km; 61.9 $mpg_{US}$).[73][74]

The 2011 Lincoln MKZ Hybrid was unveiled at the 2010 New York International Auto Show[75] and sales began in the U.S. in September 2010.[76] The MKZ Hybrid is the first hybrid version ever to have the same price as the gasoline-engine version of the same car.[77] The Porshe Cayenne Hybrid was launched in the U.S in late 2010.[29]

2011–2012

Volkswagen announced at the 2010 Geneva Motor Show the launch of the 2012 Touareg Hybrid, which went on sale on the U.S. in 2011.[78][79] VW also announced plans to introduce diesel-electric hybrid versions of its most popular models in 2012, beginning with the new Jetta, followed by the Golf Hybrid in 2013 together with hybrid versions of the Passat.[80][81] Other gasoline-electric hybrids released in the U.S. in 2011 are the Lexus CT 200h, the Infiniti M35 Hybrid, the Hyundai Sonata Hybrid and its siblling the Kia Optima Hybrid.[82][83][84]

2013 Volkswagen Jetta Hybrid


The 2012 Toyota Prius c was released in the U.S. in March 2012, and was launched in Japan as Toyota Aqua in December 2011.

The Peugeot 3008 HYbrid4 will be launched in the European market in the second half of 2011 and is expected to become the world's first production diesel-electric hybrid. According to Peugeot the new hybrid delivers a fuel economy of up to 62 miles per US gallon (3.8 L/100 km; 74 $mpg_{imp}$) and $CO_2$ emissions of 99g/km on the European test cycle.[85][86]

The Toyota Prius v, launched in the U.S. in October 2011, is the first spinoff from the Prius family. Sales in Japan began in May 2011 as the Prius Alpha. The European version, named Prius +, is scheduled to be launched by mid 2012.[87] The Prius Aqua was launched in Japan in December 2011, and was released as the Toyota Prius c in the U.S. in March 2012.[88] The Prius c is slated for market launch in Australia during the first quarter of 2012.[89] The production version of the 2012 Toyota Yaris Hybrid was introduced at the March 2012 Geneva Motor Show and it is scheduled to go on sale in Europe in 2012.[90]

Other hybrids scheduled to be released in the U.S. during 2012 are the Audi Q5 Hybrid, BMW 5 Series ActiveHybrid, Audi A6 Hybrid, Audi A8 Hybrid, BMW 3 series Hybrid, Ford C-Max Hybrid, Volkswagen Jetta Hybrid,[84] and the Acura ILX Hybrid.[91]

## Sales and rankings

More than 4.5 million hybrid electric vehicles have been sold worldwide by the end of December 2011, led by Toyota Motor Company (TMC) with more than 3.5 million Lexus and Toyota hybrids,[6] followed by Honda Motor Co., Ltd. with cumulative sales of more than 800 thousand hybrids,[7] and Ford Motor Corporation with more than 185 thousand hybrids sold in the United States.[8][9][92]

Toyota hybrids combined with Lexus reached 1 million hybrids sold in the U.S. by February 2009;[93] worldwide sales of hybrids by both brands totaled over 2 million vehicles by August 2009,[11] 3 million units by February 2011, and reached the 4 million mark in April 2012. Of these, 2.63 million units correspond to the original Prius, representing 65.8% of cumulative TMC sales, and Prius family vehicle sales accounted for 71.8% TMC worldwide volume.[12] As the top selling hybrid in both the U.S. and Japanese markets, the Toyota Prius totaled global cumulative sales of 2.0 million units as of September 30, 2010.[94] U.S. sales of the Toyota Prius reached the 1.0 million milestone in early April 2011,[15] and cumulative sales of the Prius in Japan exceeded the 1 million mark in August 2011.[16]

The Toyota Prius is the top selling hybrid in the U.S. and Japan.

The United States is the leading hybrid market with more than 2.18 million units sold through January 2012;[8][9][95] followed by Japan with more than 1.5 million units sold through 2011,[96][97][98][99][100] and Europe with more than 450 thousand hybrids by January 2012.[99][101] The top seller hybrid in the U.S. is the Toyota Prius, with cumulative sales of 1,091,564 units through December 2011, followed by the Honda Civic Hybrid, with cumulative sales of 209,216 vehicles since 2002, and the Toyota Camry Hybrid, with 178,805 units sold since 2006. The top selling hybrid in the U.S. by an American manufacturer is the Ford Escape Hybrid, with cumulative sales of 116,556 vehicles since 2004, followed by the siblings Lincoln MKZ/Mercury Milan/Fusion Hybrids, with sales of 57,471 units since 2009.[8][9]

**Top national markets for hybrid electric vehicles between 2007 and 2011**

| Country | Number of registered hybrids 2011 | Number of registered hybrids 2010 | Number of registered hybrids 2009[14] | Percent of global hybrid registrations 2009 | Number of registered hybrids 2008[102] | Percent of global hybrid registrations 2008 | Number of registered hybrids 2007[103] | Percent of global hybrid registrations 2007 |
|---|---|---|---|---|---|---|---|---|
| Japan | - | | 334,000[104] | 45.1% | 94,259 | 18.4% | 69,015 | 13.8% |
| United States | 268,752[9] | 274,210[8] | 290,271[8] | 39.2% | 312,386[8] | 61.0% | 352,274[8] | 70.4% |
| Canada | - | | 16,167(1) | 2.2% | 19,963[105] | 3.9% | 14,828 | 3.0% |
| Netherlands | - | | 16,000[106] | 2.2% | 11,814 | 2.3% | - | - |
| United Kingdom | 23,370[107] | 22,127[107] | 14,645[108] | 2.0% | 15,385[108] | 3.0% | 15,971[108] | 3.2% |
| France | 13,340[109] | 9,443[110] | 9,399[111] | 1.3% | 9,137[111] | 1.8% | 7,268[112] | 1.4% |
| Germany | 12,622[113] | 10,661[114] | 8,374[114] | 1.1% | 6,464[114] | 1.2% | 7,591[114] | 1.5% |
| *World* | - | - | 740,000[115] | | 511,758 | | 500,405 | |

Notes: (1) Cumulative sales until November 2009 only.[14]

## U.S. market

*Further information: Hybrid electric vehicles in the United States*

The fleet of hybrid electric vehicles in the United States is the largest in the world, and cumulative sales surpassed the 2 million mark in May 2011.[116] Since their inception in 1999, a total of 2,303,825 hybrid electric automobiles and SUVs have been sold through April 2012, led by the Toyota Prius family with 1,175,034 units sold, representing a 51.0% market share.[8][9][95]

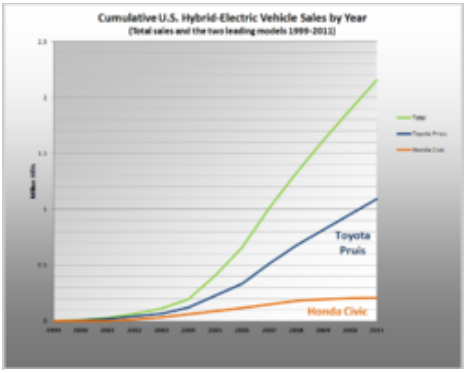
The top ten selling hybrids in 2011 were the Prius (136,463 units), Hyundai Sonata Hybrid (19,672 units), Honda Insight (15,549 units), Lexus CT 200h (14,381 units), Honda CR-Z (11,330 units), Ford Fusion Hybrid (11,286 units), Lexus RX400h/450h (10,723 units), Ford Escape Hybrid (10,089 units), Toyota Camry Hybrid (9,241 units), and Lincoln MKZ Hybrid (5,739 units).[9] California has been the state leading hybrid sales in the U.S. with 55,553 vehicles sold in 2009,[14] 74,932 in 2008,[102] and 91,417 in 2007.[103] In 2009 it was followed by New York (15,438) and Florida (14,949).[14] In terms of new hybrids sold per capita, the District of Columbia was the leader in 2009 with 3.79 hybrids per 1000 residents, followed by California (1.54) and Washington (1.53).[14]

The Ford Escape Hybrid is the top selling hybrid in the U.S. from an American carmaker.

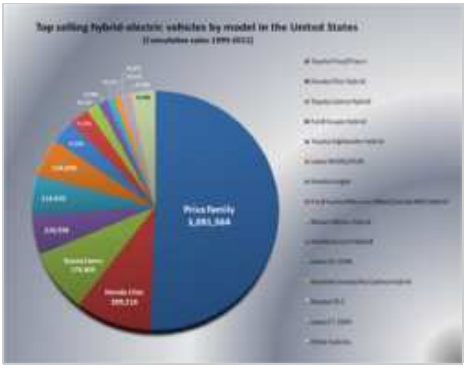
The top 5 U. S. metropolitan area markets for sales of hybrid electric vehicles in 2009 were Los Angeles (26,677), New York (21,193), San Francisco (15,799), Washington, D.C. (11,595), and Chicago (8,990).[14] The following table summarizes the top metropolitan area markets in terms of new hybrids sold per capita.

**Top U.S. metropolitan markets for hybrid electric vehicles in 2008-2009**[14][117]

| Rank 2009 | Metropolitan Area | New registered hybrids per 1000 households (2009) | Rank 2008 | Metropolitan Area | New registered hybrids per 1000 households (2008) |
|---|---|---|---|---|---|
| 1 | Portland, OR | 8.8 | 1 | Portland, OR | 12.17 |
| 2 | Helena, MT | 6.7 | 2 | San Francisco, CA | 8.84 |
| 3 | San Francisco, CA | 6.7 | 3 | Monterey, CA | 7.16 |
| 4 | Washington, DC | 5.1 | 4 | Santa Barbara, CA | 6.94 |
| 5 | Los Angeles, CA | 4.8 | 5 | San Diego, CA | 6.57 |
| 6 | San Diego, CA | 4.7 | 6 | Los Angeles | 6.08 |
| 7 | Seattle, WA | 4.7 | 7 | Charlottesville, VA | 5.42 |
| 8 | Juneau, AK | 4.6 | 8 | Seattle, WA | 4.90 |
| 9 | Santa Barbara, CA | 4.4 | 9 | Washington, DC | 4.85 |
| 10 | Monterey, CA | 4.3 | 10 | Sacramento, CA | 4.85 |
| *U.S. metropolitan area average* | | 1.8 | *U.S. metropolitan area average* | | 2.18 |




**Cumulative U.S. total hybrid sales by year (1999-2011)**[8][9]



**U.S. HEV sales by top selling models (cumulative 1999-2011)**[8][9]

Considering hybrid sales between January 2010 through September 2011, the top selling metropolitan region was the San Francisco Bay Area, with 8.4% of all new cars sold during that period, followed by Monterey-Salinas with 6.9%, and Eugene, Oregon, with 6.1%. The following seven top selling markets are also on the West Coast, including Seattle-Tacoma and Los Angeles with 5.7%, San Diego with 5.6%, and Portland with 5.4%. The Washington D.C. Metro Area, with 4.2%, is the next best selling region out of the West Coast.[118]

## Japanese market

Toyota's hybrid sales in Japan since 1997, including both Toyota and Lexus models, passed the 1 million mark in July 2010,[96] and reached 1.7 million by April 2012.[12] Cumulative sales of the original Prius in Japan reached the 1 million mark in August 2011[16] and sales of the Prius family vehicles reached 1,356,300 units in April 2012.[12] Cumulative sales of Honda's hybrid vehicles since November 1999 reached 25,239 units by January 2009,[99] and in March 2010, Honda announced that the new 2010 Insight broke through 100,000 sales in Japan in just one year after its introduction.[100]

Hybrid sales in Japan almost tripled in 2009 as compared to 2008 as a result of government incentives that included a scrappage program, tax breaks on hybrid vehicles and other low emission cars and trucks, and a higher levy on gasoline that rose prices in the order of US$4.50.[45][115][119] New hybrid car sales jumped from 94,259 in 2008[102] to 334,000 in 2009,[104] and hybrid sales in 2009 represented around 10% of new vehicles sales in Japan. In contrast, the U.S. market share was 2.8% for the same year.[45] These record sales allowed Japan to surpass the U.S. in total new hybrid sales, with the Japanese market representing almost half (48%) of the worldwide hybrid sales in 2009 while the U.S. market represented 42% of global sales.[104] The Toyota Prius became the first hybrid to top annual new car sales in Japan with 208,876 units sold in 2009.[45][120] The Insight ranked fifth in overall sales in 2009 with 93,283 units sold.[45]

The Toyota Prius α was launched in Japan in May 2011.

A total of 315,669 Prii were sold domestically in 2010, making the Prius the country's best-selling vehicle for the second straight year. Also the Prius broke Japan's annual sales record for a single model for the first time in 20 years, surpassing the Toyota Corolla, which in 1990 set the previous sales record with 300,008 units.[121] The Prius sold 252,528 units in 2011, becoming the best-selling vehicle for the third-consecutive year. This figure includes sales of the Prius α, launched in May 2011, and the Toyota Aqua, launched in December. Despite keeping to the top selling spot, total Prius sales for 2011 were 20% lower than 2010 due partly to the disruptions caused by the March 2011 Tōhoku earthquake and tsunami, and also because government incentives for hybrid cars were scaled back.[122][123] Nevertheless, during the 2011 Japanese fiscal year (April 1, 2011 through March 31, 2012), hybrid vehicles accounted for 16% of all new car sales in the country.[124] In May 2012, hybrid sales reached a record market share of 19.7% of new car sales in the country, including kei cars. Sales were led by the conventional Prius followed by the Toyota Aqua. Also during this month, hybrid sales represented 25% of Honda sales and 46% of Toyota sales in the country.[125]



## European market

Sales of hybrids in Europe went up from around 9,000 units in 2004 to 39,880 in 2006, with Toyota accounting for 91% of hybrid sales and Honda with 3,410 units sold that year. Cumulative sales of Toyota hybrids since 2000 reached 69,674 units in 2006, while Honda hybrid sales reached over 8,000 units.[126] By January 2009, Honda had sold 35,149 hybrids in Europe, of which 34,757 were Honda Civic Hybrids.[99] During 2008 combined sales of Toyota and Lexus hybrids in Europe were 57,819 units, representing 5.2% of total Toyota sales in the region. Toyota sales were led by Prius with 41,495 units.[127] Cumulative sales of the Toyota Prius reached 100,000 units in 2008 and the 200,000 mark was reached in July 2010. The UK has been one of the leading European markets for the Prius since its inception, with 20% of Prius sales in Europe.[128]

Toyota's European hybrid sales reached 70,529 vehicles in 2010, including sales of 15,237 Toyota Auris Hybrids.[129] Sales reached 84,839 units in 2011, including 59,161 Toyota and 25,678 Lexus hybrid vehicles. The Auris hybrid sold 32,725 units in 2011. Lexus hybrids made up 85% of total sales in Western Europe in 2011. Toyota and Lexus hybrids represented 10% percent of Toyota's European new car sales in 2011.[6][130] As of January 2012, Toyota Motor Company has sold 400,000 Lexus and Toyota hybrids in Europe since the introduction of the Prius in 2000.[101][131]

As of December 2011, the total number of hybrids registered in the UK since 2006 reached 100,455 vehicles.[107][108] Honda has sold in the UK more than 22,000 hybrid cars since the Insight was launched in the country in 2000.[132] On 1 January 2010, there were 39.3 thousand hybrid cars registered in the Netherlands, up from 23 thousand the previous year.

Most of the registered hybrid cars belong to corporate fleets due to tax incentives established in the country in 2008.[106][133] A total of 48,587 hybrid cars have been registered in France since 2007.[109][110][111][112] Among the 13,340 units registered in 2011, the top selling models in the French market were the Toyota Auris (4,740 units), the Prius (2,429 units), and the Honda Jazz Hybrid (1,857 units). The Peugeot 3008 HYbrid4, launched in late 2011, sold 401 units.[109] The total number of registered hybrid cars in Germany reached 47,642 vehicles on January 1, 2012.[134] A total of 10,350 hybrid cars were registered in Spain in 2011, up 22% from 2010 sales. The top selling hybrids were the Toyota Prius, Toyota Auris HSD and the Lexus CT 200h, which together represented 83,2% of new hybrid car sales in the country.[135]

# Technology

The varieties of hybrid electric designs can be differentiated by the structure of the hybrid vehicle drivetrain, the fuel type, and the mode of operation.

In 2007, several automobile manufacturers announced that future vehicles will use aspects of hybrid electric technology to reduce fuel consumption without the use of the hybrid drivetrain. Regenerative braking can be used to recapture energy and stored to power electrical accessories, such as air conditioning. Shutting down the engine at idle can also be used to reduce fuel consumption and reduce emissions without the addition of a hybrid drivetrain. In both cases, some of the advantages of hybrid electric technology are gained while additional cost and weight may be limited to the addition of larger batteries and starter motors. There is no standard terminology for such vehicles, although they may be termed mild hybrids.

## Engines and fuel sources



### Fossil fuels

*Main article: Fossil fuel*

Free-piston engines could be used to generate electricity as efficiently as, and less expensively than, fuel cells.[136]

Gasoline

Gasoline engines are used in most hybrid electric designs, and will likely remain dominant for the foreseeable future. While petroleum-derived gasoline is the primary fuel, it is possible to mix in varying levels of ethanol created from renewable energy sources. Like most modern ICE powered vehicles, HEVs can typically use up to about 15% bioethanol. Manufacturers may move to flexible fuel engines, which would increase allowable ratios, but no plans are in place at present.

Diesel

Diesel-electric HEVs use a diesel engine for power generation. Diesels have advantages when delivering constant power for long periods of time, suffering less wear while operating at higher efficiency. The diesel engine's high torque, combined with hybrid technology, may offer substantially improved mileage. Most diesel vehicles can use 100% pure biofuels (biodiesel), so they can use but do not need petroleum at all for fuel (although mixes of biofuel and petroleum are more common). If diesel-electric HEVs were in use, this benefit would likely also apply. Diesel-electric hybrid drivetrains have begun to appear in commercial vehicles (particularly buses); as of 2007, no light duty diesel-electric hybrid passenger cars are currently available, although prototypes exist. Peugeot is expected to produce a diesel-electric hybrid version of its 308 in late 2008 for the European market.[137]

PSA Peugeot Citroën has unveiled two demonstrator vehicles featuring a diesel-electric hybrid drivetrain: the Peugeot 307, Citroën C4 Hybride HDi and Citroën C-Cactus.[138] Volkswagen made a prototype diesel-electric hybrid car that achieved 2 L/100 km (140 $mpg_{imp}$; 120 $mpg_{US}$) fuel economy, but has yet to sell a hybrid vehicle. General Motors has been testing the Opel Astra Diesel Hybrid. There have been no concrete dates suggested for these vehicles, but press statements have suggested production vehicles would not appear before 2009.

At the Frankfurt Motor Show in September 2009 both Mercedes and BMW displayed diesel-electric hybrids.[139]

Robert Bosch GmbH is supplying hybrid diesel-electric technology to diverse automakers and models, including the Peugeot 308.[140]

So far, production diesel-electric engines have mostly appeared in mass transit buses.[*citation needed*]

FedEx, along with Eaton Corp. in the USA and Iveco in Europe, has begun deploying a small fleet of Hybrid diesel electric delivery trucks.[141] As of October 2007, Fedex operates more than 100 diesel electric hybrids in North America, Asia and Europe.[142]

Liquefied petroleum gas

Hyundai introduced in 2009 the Hyundai Elantra LPI Hybrid, which is the first mass production hybrid electric vehicle to run on liquefied petroleum gas (LPG).[60]


Hyundai Elantra LPI Hybrid.

Hydrogen

Hydrogen can be used in cars in two ways: a source of combustible heat, or a source of electrons for an electric motor. The burning of hydrogen is not being developed in practical terms; it is the hydrogen fuel-cell electric vehicle (HFEV) which is garnering all the attention. Hydrogen fuel cells create electricity fed into an electric motor to drives the wheels. Hydrogen is not burned, but it is consumed. This means molecular hydrogen, $H_2$, is combined with oxygen to form water. $2H_2$ ($4e^-$) + $O_2$ --> $2H_2O$ ($4e^-$). The molecular hydrogen and oxygen's mutual affinity drives the fuel cell to separate the electrons from the hydrogen, to use them to power the electric motor, and to return them to the ionized water molecules that were formed when the electron-depleted hydrogen combined with the oxygen in the fuel cell. Recalling that a hydrogen atom is nothing more than a proton and an electron; in essence, the motor is driven by the proton's atomic attraction to the oxygen nucleus, and the electron's attraction to the ionized water molecule.

An HFEV is an all-electric car featuring an open-source battery in the form of a hydrogen tank and the atmosphere. HFEVs may also comprise closed-cell batteries for the purpose of power storage from regenerative braking, but this does not change the source of the motivation. It implies the HFEV is an electric car with two types of batteries. Since HFEVs are purely electric, and do not contain any type of heat engine, they are not hybrids.

**Biofuels**

*Main articles: biofuel and flexifuel vehicle*

Hybrid vehicles might use an internal combustion engine running on biofuels, such as a flexible-fuel engine running on ethanol or engines running on biodiesel. In 2007 Ford produced 20 demonstration Escape Hybrid E85s for real-world testing in fleets in the U.S.[143][144] Also as a demonstration project, Ford delivered in 2008 the first flexible-fuel plug-in hybrid SUV to the U.S. Department of Energy (DOE), a Ford Escape Plug-in Hybrid, capable of running on gasoline or E85.[145]


The Ford Escape Hybrid was the first hybrid electric vehicle with a flex-fuel engine capable of running on E85 fuel.

The Chevrolet Volt plug-in hybrid electric vehicle would be the first commercially available flex-fuel plug-in hybrid capable of adapting the propulsion to the biofuels used in several world markets such as the ethanol blend E85 in the U.S., or E100 in Brazil, or biodiesel in Sweden.[146][147] The Volt will be E85 flex-fuel capable about a year after its introduction.[148][149]

## Electric machines

In *split path* vehicles (Toyota, Ford, GM, Chrysler) there are two electrical machines, one of which functions as a motor primarily, and the other functions as a generator primarily. One of the primary requirements of these machines is that they are very efficient, as the electrical portion of the energy must be converted from the engine to the generator, through two inverters, through the motor again and then to the wheels.

Demonstration Ford Escape E85 flex-fuel plug-in hybrid.

Most of the electric machines used in hybrid vehicles are brushless DC motors (BLDC). Specifically, they are of a type called an interior permanent magnet (IPM) machine (or motor). These machines are wound similarly to the induction motors found in a typical home, but (for high efficiency) use very strong rare earth magnets in the rotor. These magnets contain neodymium, iron and boron, and are therefore called Neodymium magnets. The magnet material is expensive, and its cost is one of the limiting factors in the use of these machines.

### Design considerations

In some cases, manufacturers are producing HEVs that use the added energy provided by the hybrid systems to give vehicles a power boost, rather than significantly improved fuel efficiency compared to their traditional counterparts.[150] The trade-off between added performance and improved fuel efficiency is partly controlled by the software within the hybrid system and partly the result of the engine, battery and motor size. In the future, manufacturers may provide HEV owners with the ability to partially control this balance (fuel efficiency vs. added performance) as they wish, through a user-controlled setting.[151] Toyota announced in January, 2006 that it was considering a "high-efficiency" button. [*citation needed*]



### Conversion kits

*Main article: Electric vehicle conversion*

One can buy a stock hybrid or convert a stock petroleum car to a hybrid electric vehicle using an aftermarket hybrid kit.[152]

## Environmental impact

### Fuel consumption

*Main article: Fuel efficiency*

Current HEVs reduce petroleum consumption under certain circumstances, compared to otherwise similar conventional vehicles, primarily by using three mechanisms:[153]

Reducing wasted energy during idle/low output, generally by turning the ICE off
2. Recapturing waste energy (i.e. regenerative braking)
3. Reducing the size and power of the ICE, and hence inefficiencies from under-utilization, by using the added power from the electric motor to compensate for the loss in peak power output from the smaller ICE.

Any combination of these three primary hybrid advantages may be used in different vehicles to realize different fuel usage, power, emissions, weight and cost profiles. The ICE in an HEV can be smaller, lighter, and more efficient than the one in a conventional vehicle, because the combustion engine can be sized for slightly above *average* power demand rather than *peak* power demand. The drive system in a vehicle is required to operate over a range of speed and power, but an ICE's highest efficiency is in a narrow range of operation, making conventional vehicles inefficient. On the contrary, in most HEV designs, the ICE operates closer to its range of highest efficiency more frequently. The power curve of electric motors is better suited to variable speeds and can provide substantially greater torque at low speeds compared with internal-combustion engines. The greater fuel economy of HEVs has implication for reduced petroleum consumption and

vehicle air pollution emissions worldwide[154]

## Noise

*See also: Electric vehicle warning sounds*

Reduced noise emissions resulting from substantial use of the electric motor at idling and low speeds, leading to roadway noise reduction,[155] in comparison to conventional gasoline or diesel powered engine vehicles, resulting in beneficial noise health effects (although road noise from tires and wind, the loudest noises at highway speeds from the interior of most vehicles, are not affected by the hybrid design alone).

Reduced noise may not be beneficial for all road users, as blind people or the visually impaired consider the noise of combustion engines a helpful aid while crossing streets and feel quiet hybrids could pose an unexpected hazard.[156] The U.S. Congress and the European Commission are exploring legislation to establish a minimum level of sound for plug-in electric and hybrid electric vehicles when operating in electric mode, so that blind people and other pedestrians and cyclists can hear them coming and detect from which direction they are approaching. Tests have shown that vehicles operating in electric mode can be particularly hard to hear below 20 mph (32 km/h).[157][158] In January 2010 the Japanese Ministry of Land, Infrastructure, Transport and Tourism issued guidelines for hybrid and other near-silent vehicles.[159]

A 2009 study conducted by the U.S. National Highway Traffic Safety Administration found that crashes involving pedestrian and bicyclist have higher incidence rates for hybrids than internal combustion engine vehicles in certain vehicle maneuvers. These accidents commonly occurred on in zones with low speed limits, during daytime and in clear weather.[160]



Even though no specific national regulation has been enacted in most countries as of mid 2010, some carmakers announced they have decided to address this safety issue shared by regular hybrids and all types of plug-in electric vehicles, and as a result, the upcoming Nissan Leaf and Chevrolet Volt, both due in late 2010, and the new Nissan Fuga hybrid and the Fisker Karma plug-in hybrid, both due in 2011, will include synthesized sounds to alert pedestrians, the blind and others to their presence.[161][162][163][164]

There is also aftermarket technology available in California to make hybrids sound more like conventional combustion engine cars when the vehicle goes into the silent electric mode (EV mode).[165] On August 2010 Toyota began sales in Japan of an onboard device designed to automatically emit a synthesized sound of an electric motor when the Prius is operating as an electric vehicle at speeds up to approximately 25 kilometres per hour (16 mph). Toyota plans to use other versions of the device for use in gasoline-electric hybrids, plug-in hybrids, electric vehicles as well as fuel-cell hybrid vehicles planned for mass production.[159]

## Pollution

*See also: Hybrid Scorecard*

Battery toxicity is a concern, although today's hybrids use NiMH batteries, not the environmentally problematic rechargeable nickel cadmium. "Nickel metal hydride batteries are benign. They can be fully recycled," says Ron Cogan, editor of the Green Car Journal. Toyota and Honda say that they will recycle dead batteries and that disposal will pose no toxic hazards. Toyota puts a phone number on each battery, and they pay a $200 "bounty" for each battery to help ensure that it will be properly recycled.

**Economic and environmental performance comparison among EPA's top ten 2012 most fuel efficient hybrid models available in the U.S.**[166][167]

| Vehicle | Year model | EPA City mileage | EPA Highway mileage | Annual fuel cost [(1)] | Tailpipe emissions (grams | EPA Air Pollution Score | Annual Petroleum Use |
|---|---|---|---|---|---|---|---|

| | | (mpg) | (mpg) | (USD) | per mile $CO_2$) | Other/Cal[2] | (barrel) |
|---|---|---|---|---|---|---|---|
| Toyota Prius c | 2012 | 53 | 46 | $1,150 | 178 | NA | 6.6 |
| Toyota Prius (3rd gen) | 2010/11/12 | 51 | 48 | $1,150 | 178 | 7/9 | 6.6 |
| Honda Civic Hybrid | 2012 | 44 | 44 | $1,300 | 202 | 7/9 | 7.5 |
| Toyota Prius v | 2012 | 44 | 40 | $1,350 | 212 | 7/8 | 7.8 |
| Lexus CT 200h | 2011/12 | 43 | 40 | $1,350 | 212 | 7/8 | 7.8 |
| Honda Insight (2nd gen) | 2012 | 41 | 41 | $1,350 | 212 | 7/9 | 7.8 |
| Toyota Camry Hybrid LE (XV50) | 2012 | 43 | 39 | $1,400 | 217 | 7/9 | 8.0 |
| Toyota Camry Hybrid XLE (XV50) | | 40 | 38 | $1,400 | 222 | 7/9 | 8.2 |
| Ford Fusion Hybrid Lincoln MKZ Hybrid | 2010/11/12 | 41 | 36 | $1,450 | 228 | 7/9 | 8.4 |
| Hyundai Sonata Hybrid Kia Optima Hybrid | 2011/12 | 35 | 40 | $1,550 | 240 | NA | 8.9 |

Source: U.S. Department of Energy and U.S. Environmental Protection Agency[166][167] For the complete performance list of all hybrids available in the U.S. see: Hybrid electric vehicles in the United States.
Notes: (1) Estimates assumes 15,000 miles (24,000 km) per year (45% highway, 55% city) using average fuel price $3.79/gallon (national average as of March 12, 2012).[168]
(2) **Other:** All states except California and Northeastern States; **Cal:**California and Northeastern states.
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# Vehicle types

## Motorcycles

Companies such as Zero Motorcycles[169] and Vectrix have market-ready all-electric motorcycles available now, but the pairing of electrical components and an internal combustion engine (ICE) has made packaging cumbersome, especially for niche brands.[170]

Also, eCycle Inc produces series diesel-electric motorcycles, with a top speed of 80 mph (130 km/h) and a target retail price of $5500.[171]

Peugeot HYmotion3 compressor,[172][173] a hybrid scooter is a three-wheeler that uses two separate power sources to power the front and back wheels. The back wheel is powered by a single cylinder 125 cc, 20 bhp (15 kW) single cylinder motor while the front wheels are each driven by their own electric motor. When the bike is moving up to 10 km/h only the electric motors are used on a stop-start basis reducing the amount of carbon emissions.[174]

SEMA has announced that Yamaha is going to launch one in 2010, with Honda following a year later, fueling a competition to reign in new customers and set new standards for mobility. Each company hopes to provide the capability to reach 60 miles (97 km) per charge by adopting advanced lithium-ion batteries to accomplish their claims. These

proposed hybrid motorcycles could incorporate components from the upcoming Honda Insight car and its hybrid powertrain. The ability to mass-produce these items helps to overcome the investment hurdles faced by start-up brands and bring new engineering concepts into mainstream markets.[170]

## Automobiles and light trucks

*See also: List of hybrid vehicles*

## High performance cars

As emissions regulations become tougher for manufacturers to adhere to, a new generation of high-performance cars will be powered by hybrid technology (for example the Porsche GT3 hybrid racing car). Aside from the emissions benefits of a hybrid system, the immediately available torque which is produced from electric motor(s) can lead to performance benefits by addressing the power curve weaknesses of a traditional combustion engine.[175]

## Taxis

*See also: Hybrid taxi*

In 2000 North America's first hybrid electric taxi was put into service in Vancouver, British Columbia, operating a 2001 Toyota Prius which traveled over 332,000 kilometres (206,000 mi) before being retired.[176][177] Many of the major cities in the world are adding hybrid taxis to their taxicab fleets, led by San Francisco and New York City.[178] By 2009 15% of New York's 13,237 taxis in service are hybrids, the most in any city in North America, and also began retiring its original hybrid fleet after 300,000 and 350,000 miles (480,000 and 560,000 km) per vehicle.[178][179] Other cities where taxi service is available with hybrid vehicles include Tokyo, London, Sydney, Melbourne, and Rome.[180]

Toyota Camry hybrid-electric taxi.

## Buses

*Main article: Hybrid electric bus*


Hybrid-powered bus

Hybrid technology for buses has seen increased attention since recent battery developments decreased battery weight significantly. Drivetrains consist of conventional diesel engines and gas turbines. Some designs concentrate on using car engines, recent designs have focused on using conventional diesel engines already used in bus designs, to save on engineering and training costs. Several manufacturers are currently working on new hybrid designs, or hybrid drivetrains that fit into existing chassis offerings without major re-design. A challenge to hybrid buses may still come from cheaper lightweight imports from the former Eastern block countries or China, where national operators are looking at fuel consumption issues surrounding the weight of the bus, which has increased with recent bus technology innovations such as glazing, air conditioning and electrical systems. A hybrid bus can also deliver fuel economy though through the hybrid drivetrain. Hybrid technology is also being promoted by environmentally concerned transit authorities.

## Trucks

*Main article: Hybrid electric truck*

In 2003, GM introduced a hybrid diesel-electric military (light) truck, equipped with a diesel electric and a fuel cell auxiliary power unit. Hybrid electric light trucks were introduced in 2004 by Mercedes Benz (Sprinter) and Micro-Vett SPA (Daily Bimodale). International Truck and Engine Corp. and Eaton Corp. have been selected to manufacture diesel-electric hybrid trucks for a US pilot program serving the utility industry in 2004. In mid 2005 Isuzu introduced the Elf

Diesel Hybrid Truck on the Japanese Market. They claim that approximately 300 vehicles, mostly route buses are using Hinos HIMR (Hybrid Inverter Controlled Motor & Retarder) system. In 2007, high petroleum price means a hard sell for hybrid trucks[181] and appears the first U.S. production hybrid truck (International DuraStar Hybrid).[182]

Other vehicles are:

- Big mining machines like the Liebherr T 282B dump truck or Keaton Vandersteen LeTourneau L-2350 wheel loader are powered that way. Also there was several models of BelAZ (7530 and 7560 series) in USSR (now in Belarus) since the middle of 1970th.[183]
- NASA's huge Crawler-Transporters are diesel-electric.
- Mitsubishi Fuso Canter Eco Hybrid is a diesel-electric commercial truck.
- Azure Dynamics Balance Hybrid Electric is a gasonline-hybrid electric medium dutry truck based on the Ford E-450 chassis.
- Hino Motors (a Toyota subsidiary) has the world's first production hybrid electric truck in Australia (110 kW/150 hp diesel engine plus a 23 kW/31 hp electric motor).[184]

Hino hybrid diesel-electric truck.

Other hybrid petroleum-electric truck makers are DAF Trucks, MAN AG with MAN TGL Series, Nissan Motors and Renault Trucks with Renault Puncher.

Hybrid electric truck technology and powertrain maker: ZF Friedrichshafen.

By a voice vote, the United States House of Representatives approved the Heavy Duty Hybrid Vehicle Research, Development, and Demonstration Act of 2009 (http://hdl.loc.gov/loc.uscongress/legislation.111hr445) ( for heavy duty plug-in hybrid vehicles) authored by representative James Sensenbrenner.



## Military vehicles

The United States Army's manned ground vehicles of the Future Combat System all use a hybrid electric drive consisting of a diesel engine to generate electrical power for mobility and all other vehicle subsystems. However, with the current 2010 DOD budget all FCS land vehicles have been put on hold. Other military hybrid prototypes include the Millenworks Light Utility Vehicle, the International FTTS, HEMTT model A3,and the Shadow RST-V.

## Locomotives

*Main article: Hybrid Locomotive*

In May 2003, JR East started test runs with the so called NE (new energy) train and validated the system's functionality (series hybrid with lithium ion battery) in cold regions. In 2004, Railpower Technologies had been running pilots in the US with the so called Green Goats,[185] which led to orders by the Union Pacific[186] and Canadian Pacific[187] Railways starting in early 2005.

Railpower offers hybrid electric road switchers,[188] as does GE.[189] Diesel-electric locomotives may not always be considered HEVs, not having energy storage on board, unless they are fed with electricity via a collector for short distances (for example, in tunnels with emission limits), in which case they are better classified as dual-mode vehicles.

## Marine and other aquatic

*Main article: Electric boat*

Producers of marine hybrid propulsion:

- eCycle Inc.[190]
- Solar Sailor Holdings

### Aircraft

Boeing has stated that for the subsonic concept, hybrid electric engine technology is a clear winner. Hybrid electric propulsion has the potential to shorten takeoff distance and reduce noise.[191]

## Hybrid Premium and Showroom Cost Parity

HEVs can be initially more expensive (the so-called "hybrid premium") than pure fossil-fuel-based ICE vehicles (ICEVs), due to extra batteries, more electronics and in some cases other design considerations (although battery renting can be used to reach the cost parity). The trade-off between higher initial cost (also called showroom costs) and lower fuel costs (difference often referred to as the payback period) is dependent on usage - miles traveled, or hours of operation, fuel costs, and in some cases, government subsidies. Traditional economy vehicles may result in a lower direct cost for many users (before consideration of any externality).

**Fuel use in vehicle designs**

| Vehicle type | Fuel used |
|---|---|
| All-petroleum vehicle | Most use of petroleum |
| **Regular hybrid electric vehicle** | Less use of petroleum, but non-pluginable |
| Plug-in hybrid vehicle | Residual use of petroleum. More use of electricity |
| All-electric vehicle | Most use of electricity |

*Consumer Reports* ran an article in April 2006 stating that HEVs would not pay for themselves over 5 years of ownership. However, this included an error with charging the "hybrid premium" twice.[192] When corrected, the Honda Civic Hybrid and Toyota Prius did have a payback period of slightly less than 5 years.[193] This includes conservative estimates with depreciation (seen as more depreciation than a conventional vehicle, although that is not the current norm) and with progressively-higher gas prices. In particular, the Consumer Reports article assumed $2/U.S. gallon for 3 years, $3/U.S. gallon for one year and $4/U.S. gallon the last year. As recent events have shown, this is a volatile market and hard to predict. For 2006, gas prices ranged from low $2 to low $3, averaging about $2.60/U.S. gallon.

A January 2007 analysis by Intellichoice.com shows that all 22 currently available HEVs will save their owners money over a five year period. The most savings is for the Toyota Prius, which has a five year cost of ownership 40.3% lower than the cost of comparable non-hybrid vehicles.[194]

A report in the *Greeley Tribune* says that over the five years it would typically take for a new car owner to pay off the vehicle cost differential, a hybrid Camry driver could save up to $6,700 in gasoline at current gasoline prices, with hybrid tax incentives as an additional saving.[195]

In countries with incentives to fight against global warming and contamination and promote vehicle fuel efficiency, the pay-back period can be immediate and all-combustion engine vehicles (ACEVs) can cost more than hybrids because they generate more pollution.

Toyota and Honda have already said they've halved the incremental cost of electric hybrids and see cost parity in the future (even without incentives).[196]

## Raw materials shortage

*See also: Rare earth metals availability and supply security*

The rare earth element dysprosium is required to fabricate many of the advanced electric motors and battery systems in hybrid propulsion systems.[197][198]

However, nearly all the rare earth elements in the world come from China,[199] and one analyst believes that an overall increase in Chinese electronics manufacturing may consume this entire supply by 2012.[198] In addition, export quotas on

Chinese rare earth exports have resulted in a generally shaky supply of those metals.[197][200]

A few non-Chinese sources such as the advanced Hoidas Lake project in northern Canada and Mt Weld in Australia are currently under development,[200] however it is not known if these sources will be developed before a shortage hits.

# Legislation and incentives

In order to encourage the purchase of HEVs, several countries have introduced legislation for incentives and ecotaxes.

## Canada

Residents of Ontario and Quebec in Canada can claim a rebate on the Provincial Retail Sales Tax of up to $2,000 CDN on the purchase or lease of a hybrid electric vehicle.[201] Ontario has a green license plate for hybrid car users and was to announce a slew of benefits to go along with it in 2008.[202] Residents in British Columbia are eligible for a 100% reduction of sales tax up to a maximum of $2,000 if the hybrid electric vehicle is purchased or leased before April 1, 2011, (extended in 2007/2008 budget from March 31, 2008, and expanded from a maximum of only $1,000 from April 1, 2008, to March 31, 2009, at which point the concession was scheduled to expire.)[203] Prince Edward Island residents can claim rebates on the Provincial Sales Tax of up to $3,000 CDN on the purchase or lease of any hybrid vehicles since March 30, 2004.[204]

## Israel

In Haifa, hybrid vehicles are entitled to a free parking in city's parking lots for domestic citizens.



## Japan

In 2009 the Japanese government implemented a set of policies and incentives that included a scrappage program, tax breaks on hybrid vehicles and other low emission cars and trucks, and a higher levy on gasoline that raised prices in the order of USD 4.50 per gallon. New hybrid car sales for 2009 were almost triple those for 2008.[45][119]

## Jordan

In Jordan, a full import customs and sales tax reduced for all hybrid vehicles from 80% to 60% of the vehicle list price based on the engine size.

## Netherlands

In the Netherlands, the vehicle registration tax (VRT), payable when a car is sold to its first buyer, can earn the owner of an HEV a discount up to €6,000.

## New Zealand

In Christchurch, hybrid vehicles are entitled to an hour free parking in city council parking buildings. Where those buildings already provide an hour free, hybrid vehicles are entitled to an extra hour free.

## Republic of Ireland

In the Republic of Ireland, a discount of up to €1500 on VRT for hybrids, and up to €2500 for plugin hybrids is available until 31 December 2012.[7] (http://www.revenue.ie/en/tax/vrt/vrt-guide.html#section11) Previously there was a potential reduction of 50% of VRT applicable before July 2008, when VRT rates were based on engine size, rather than the current CO2 emissions system.[8] (http://www.cartell.ie/2010/08/lower-vrt-on-eco-friendly-cars/)

## Sweden

In Sweden there is an "Eco car" subsidy of SEK 10 000 (~ USD 1.600) cash payout to private car owners. For fringe benefit cars there is a reduction of the benefit tax of 40% for EVs & HEVs and 20% for other "Eco cars".[205]

## United Kingdom

Drivers of HEVs in the United Kingdom benefit from the lowest band of vehicle excise duty (car tax), which is based on carbon dioxide emissions. In central London, these vehicles are also exempt from the £8 daily London congestion charge.[206] Due to their low levels of regulated emissions, the greenest cars are eligible for 100% discount under the current system. To be eligible the car must be on the current Power Shift Register.[207] At present, these include the cleanest LPG and natural gas cars and most hybrid-, battery- and fuel cell-electric vehicles.

## United States

*See also: Plug-in electric vehicles in the United States*

Some shopping malls in Northern Virginia have designated reserved parking spaces for electric hybrid cars.

### Federal

*Further information: Hybrid tax credit*

The purchase of hybrid electric cars qualifies for a federal income tax credit up to $3,400 on the purchaser's Federal income taxes.[208] The tax credit is to be phased out two calendar quarters after the manufacturer reaches 60,000 new cars sold in the following manner: it will be reduced to 50% if delivered in either the third or fourth quarter after the threshold is reached, to 25% in the fifth and sixth quarters, and 0% thereafter.[209]

As of April 2010 three auto manufactures have reached the 60,000 cap, Toyota Motor Company reached it in 2007, Honda in 2008, and as of April 1, 2010, all Ford Motor Company hybrid vehicles are also no longer eligible for this tax credit.[210] Vehicles purchased after December 31, 2010, are not eligible for this credit as this benefit will expire on this date.[208][210]

### States and local

- Certain states (e.g., New York, California, Virginia, and Florida) allow singly occupied HEVs to enter the HOV lanes on the highway. Initially, the Federal Highway Administration ruled that this was a violation of federal statute[211] until August 10, 2005, when George W. Bush signed the Transportation Equity Act of 2005 into law. In California, a total of 85,250 owners of the three eligible hybrid models benefited from free access to HOV lanes from 2004 to mid 2011.[212] This incentive expired on July 1, 2011, and now hybrids are required to comply the minimum passenger requirements to use the HOV lanes.[213]
- Some states, e.g. California, exempt hybrid electric cars from the biennial smog inspection, which costs over $50 (as of 2004).
- The city of San Jose, California issued a free parking tag until 2007 when it became issued for a fee annually for hybrid electric cars that were purchased at a San Jose dealership. The qualified owners do not have to pay for parking in any city garage or road side parking meters.
- The city of Los Angeles, California offers free parking to all HEVs which started on 1 October 2004. The experiment is an extension to an existing offer of free parking for all pure electrical vehicles.

California's clean air bumper sticker used to allow HEVs to access HOV lanes. Shown a RechargeIT's plug-in converted Prius (left) and a conventional Toyota Prius (right).

- In October 2005, the city of Baltimore, Maryland, started to offer discount on monthly parking in the city parking lots, and is considering free meter parking for HEVs. On 3 November 2005, the *Boston Globe* reports that the city council of Boston is considering the same treatment for hybrid electric cars.
- Annual vehicle registration fees in the District of Columbia are half ($36) that paid for conventional vehicles ($72).