

An hourglass-shaped graphic with a globe inside. The top bulb is dark blue, and the bottom bulb is light blue. The globe is a darker shade of blue. The hourglass is centered on the page.

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*Advanced Vehicle Technologies: Energy, Environment, and  
Development Issues*

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December 6, 2007

**Abstract.** This report provides an introduction to the research, development, and commercialization of alternative vehicle technologies, specifically electric vehicles, hybrid electric vehicles, and fuel cell vehicles. It provides a description of the technology, and discusses issues such as cost, maintenance and fueling infrastructure, and performance for each type of vehicle. The report also discusses current congressional action on issues affecting these vehicles, as well as actions by the Administration and state and local governments.

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# Advanced Vehicle Technologies: Energy, Environment, and Development Issues

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December 6, 2007

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*Prepared for Members and Committees of Congress*

## Summary

Research and development of cleaner and more efficient vehicle technologies has been ongoing for the past few decades. Much of this research started in response to the oil shocks of the 1970s, which triggered concerns about rising fuel costs and growing dependence on imported fuel. The urgency of those concerns was lost as fuel prices declined in the 1980s and 1990s. At the same time, however, rising concerns about vehicle contributions to air pollution and global climate change added a new dimension to the issue. Recently, instability in world oil prices and political concerns have reawakened the energy dependence concerns of the 1970s. Meanwhile, research on new technologies continues, with a particular focus on commercialization. Despite widespread agreement in principle on the benefits of decreased dependence on petroleum and the internal combustion engine, the practical challenges posed by a transition to advanced vehicle technologies are formidable. Nonetheless, significant research and development progress has been made since the 1970s.

These new technologies have sparked more interest as some major auto manufacturers have introduced high-efficiency production vehicles to the American market, and others have plans to introduce similar vehicles in the future. Furthermore, interest has grown recently as a result of higher petroleum prices, and the announcement of new emission regulations for passenger vehicles.

In January 2002, the Bush Administration announced the FreedomCAR initiative, which focuses federal research on fuel cell vehicles. In conjunction with FreedomCAR, in January 2003, President Bush announced the Hydrogen Fuel Initiative, which focuses federal research on hydrogen fuel and fuel cells for stationary applications. The goal of these initiatives is to improve the competitiveness of hydrogen fuel cell vehicle technologies. However, fuel cell vehicles share many components with hybrid and pure electric vehicles. Thus, this research will likely promote advanced vehicle technologies in general.

This report discusses four major vehicle technologies—electric vehicles, hybrid electric vehicles, plug-in hybrids, and fuel cell vehicles—as well as advanced component technologies. Each technology is discussed in terms of cost, fueling and maintenance infrastructure, and performance.

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## Introduction

Technology using electrical energy to power automobiles has been in existence for over a century. However, for a number of reasons, including the energy density of petroleum fuels, the internal combustion engine has been the power source of choice for automobiles and most other vehicles. However, with the oil shocks of the past few decades, as well as an increasing awareness of the emissions of air pollutants and greenhouse gases from cars and trucks, interest in the use of electrical power train systems has grown. While there are other potential replacements for the internal combustion engine, such as compressed air, these other technologies have not been the subject of much interest scientifically or politically.

Much of the federal advanced vehicle research has come through the Partnership for a New Generation of Vehicles (PNGV) and the FreedomCAR program, consortia of the federal government and the “Big Three” American automobile manufacturers. PNGV focused on near-term goals and the development of hybrid electric vehicles, while FreedomCAR, which replaced PNGV in 2002, focuses on long-term research on fuel cells and hydrogen fuel.

The United States is not alone in pursuing these new technologies. Japanese manufacturers were the first to introduce high-efficiency gasoline-electric hybrid vehicles in the U.S. market. The development of these vehicles is a response to global pressures to lower emissions and improve fuel economy. In that context, it is worth noting that in most developed countries, gasoline and diesel fuel prices are considerably higher than they are in the United States.

Four advanced propulsion technologies of key interest are electric vehicles, hybrid vehicles, plug-in hybrids, and fuel cell vehicles. In an electric vehicle, the vehicle runs exclusively on electricity that is supplied from an electric utility provider, eliminating combustion on-board the vehicle. A hybrid vehicle integrates an electrical system with an internal combustion engine to utilize the benefits of each system. A plug-in hybrid system allows a vehicle to be charged in the same manner as a pure electric vehicle, allowing an all-electric range. The additional hybrid system allows for the vehicle to use a combustion engine when the batteries are depleted. In a fuel cell vehicle, instead of combustion, a chemical conversion process is used, leading to higher levels of efficiency. In addition to altering the propulsion system, many other efficiency-related technologies, such as improved aerodynamics and low-resistance tires can be incorporated into both new and conventional vehicles.

While these various technologies are promising, they must overcome certain obstacles before they will be competitive in the marketplace. There are three main barriers to their widespread use: cost, infrastructure, and performance. Cost is a factor since without subsidies, consumers are unlikely to purchase new vehicles in large numbers if the new vehicles are not cost-competitive with conventional vehicles. Also, convenient infrastructure must exist for both fueling and maintenance of these vehicles. Finally, the performance of the new vehicles must be comparable to that of conventional vehicles.

## Electric Vehicles

An electric vehicle (EV) is powered by an electric motor, as opposed to a gasoline or diesel engine. Power is supplied to the motor by batteries, which are charged through a central charging station (which can be installed in the owner’s garage) or through a portable charger on board the

vehicle, which is plugged into an electrical outlet. Because no fuel is consumed in EVs, and the vehicles therefore do not produce emissions, they are considered to be zero emission vehicles (ZEVs) in certain air quality control regions. Although there are emissions attributable to the production of electricity to charge the vehicles, the overall fuel-cycle of EVs tends to lead to lower levels of toxic and ozone-forming emissions—as well as greenhouse gases—than those of conventional vehicles. Also, since pollution attributable to electric vehicles occurs at power plants, it is generally emitted in areas with relatively low population density.<sup>1</sup>

Another potential public policy benefit of electric vehicles is that they can reduce U.S. dependence on foreign oil, since only about 3% of electricity in the United States is generated from petroleum. Furthermore, transportation dependence on all forms of fossil fuels can be reduced, since approximately 30 to 35% of electricity in the U.S. is generated from non-fossil fuels. However, high electricity costs in recent years have led to questions about the long-term viability of EVs.

Commercially, these vehicles have not been well-received by consumers.<sup>2</sup> By 1998, only about 4,200 EVs were on the road, mainly in California.<sup>3</sup> By 2005, this number had increased to roughly 51,000.<sup>4</sup> However, only a few car companies currently produce electric vehicles, and most of those are only available for lease by large fleets. EVs for personal use have declined as automakers have taken most personal EVs off the market.<sup>5</sup> While the number of EVs has increased, the amount of fuel used per vehicle has decreased, as have, presumably, miles traveled per vehicle. Between 1998 and 2005, while the number of EVs increased more than 10-fold, electricity for vehicle fuel increased only about five-fold.<sup>6</sup>

## Cost

One of the most significant barriers to wide acceptance of electric vehicles is their higher purchase cost. For example, the manufacturer's suggested retail price for a 1999 General Motors EV1 was approximately \$33,995,<sup>7</sup> which was considerably higher than a comparable 1999 Chevrolet Cavalier at \$13,670.<sup>8</sup>

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<sup>1</sup> However, there may be concerns over increasing pollution in areas near a power generation facility, though it is generally easier to control criteria pollutant emissions for a stationary source than from a mobile source. In addition, the development of carbon capture and storage at powerplants could improve the greenhouse gas balance of electric vehicles.

<sup>2</sup> It is important to note that many of the technologies discussed in this report are in relatively early stages of research and development and thus are not directly comparable to the internal combustion engine, which has been a mass market product for nearly a century.

<sup>3</sup> Department of Energy, Energy Information Administration (EIA), *Alternatives to Traditional Transportation Fuels, 2000*.

<sup>4</sup> EIA, *Alternatives to Traditional Transportation Fuels 2005*. August 2006.

<sup>5</sup> "Honda Stops Making Electric Cars, Roiling California Regulators," *Wall Street Journal*. April 30, 1999. p. B7.

<sup>6</sup> EIA, op. cit.

<sup>7</sup> General Motors, *EV1 Electric*, at <http://www.gmев.com/>. It must be noted that this vehicle is currently only available for lease to consumers.

<sup>8</sup> Chevrolet, *Chevrolet Metro*. <http://www.chevrolet.com>.

However, fuel costs tend to be much lower for EVs than for conventional vehicles. In 2002, a small conventional vehicle could achieve a fuel cost of approximately \$690 per year.<sup>9</sup> An electric vehicle, however, could achieve a considerably lower cost of \$390 to \$480 per year.<sup>10</sup> This difference, while significant, fails to make up for the additional purchase or lease cost for an electric vehicle. With increased petroleum prices, the cost savings for EVs may make them more attractive. However, it is unlikely that even a very large increase in petroleum prices would be sufficient to make the current generation of electric vehicles cost-competitive.

In terms of maintenance costs, electric vehicles have fewer moving parts, which reduces wear. However certain parts, such as replacement batteries, tend to be expensive.<sup>11</sup>

Through 2006, there was a federal tax credit for the purchase of an electric vehicle. The federal credit was worth 10% of the purchase price of the vehicle, up to \$2,000. This credit was part of the Energy Policy Act of 1992.<sup>12</sup> In some areas, EVs are also exempted from high occupancy vehicle (HOV) lane restrictions, parking restrictions, and/or vehicle registration fees, which may provide an additional incentive for their use.

## Infrastructure

Another key obstacle to more widespread use of electric vehicles is the lack of fueling (charging) and maintenance infrastructure. For example, there were approximately 700 public charging stations in 2004, mostly in California and Arizona.<sup>13</sup> Currently, that number is only 440. This represents less than 1% of the roughly 125,000 gasoline stations nationwide.<sup>14</sup> The lack of recharging infrastructure is not only inconvenient, but also limits long-distance travel, since Arizona and California account for the vast majority of all recharging sites currently in operation.

Adding to the problem of fueling infrastructure, is the lack of maintenance infrastructure. Few mechanics have experience servicing EVs, and most work must be done at a certified dealer. For this reason, most EV leases include free dealer maintenance over the period of the contract. On the other hand, one advantage of electric vehicles is that they have fewer moving parts and thus may be more durable, and require less frequent maintenance.

## Performance

Another major concern with electric vehicles is their performance. The batteries used to power the vehicles tend to be quite heavy, limiting the range of these vehicles.<sup>15</sup> While a conventional

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<sup>9</sup> John DeCicco, Jim Kliesch, and Martin Tomas, *ACEEE's Green Book: The Environmental Guide to Cars & Trucks*. Washington, D.C. 2000.

<sup>10</sup> Ibid.

<sup>11</sup> Most manufacturers are researching to improve battery life, and are also considering warranting batteries for the life of the vehicle.

<sup>12</sup> P.L. 102-486; 26 U.S.C. 30. For more information on the EV tax credit, see CRS Report RS22351, *Tax Incentives for Alternative Fuel and Advanced Technology Vehicles*, by Brent D. Yacobucci.

<sup>13</sup> Department of Energy, Alternative Fuels Data Center (AFDC), *Refueling Sites*.

<sup>14</sup> Department of Commerce, Bureau of the Census, *County Business Patterns for the United States*. <http://www.census.gov/epcd/cbp/view/cbpview.html>.

<sup>15</sup> Battery weight is a major obstacle to improving the range of these vehicles. For this reason, there has been considerable research and development progress, especially with nickel-metal hydride (NiMH) batteries, which have (continued...)

passenger car can travel 300 to 400 miles before refueling, until recently, electric cars generally could only travel about 100 to 150 miles before needing to be recharged. With new developments in battery technology, EV range has increased. However, even new EVs are unlikely to have the range of a conventional vehicle.

Furthermore, while refilling the tank of a conventional vehicle requires only a few minutes, a full residential recharge for an electric vehicle can take five to eight hours, although new chargers may shorten this time significantly.<sup>16</sup> For fleet vehicles, or for short-distance commuting, these performance characteristics might not greatly affect their marketability, but the feasibility of EVs for long-distance, intercity travel is unlikely with current technology, even if the fueling infrastructure is greatly expanded.<sup>17</sup>

A lesser concern with electric vehicles is an unconventional driving style. To provide maximum efficiency and range, the driver must accelerate and brake very smoothly, or range is significantly diminished. Because of this, some drivers may not be comfortable or proficient operating an electric vehicle.<sup>18</sup>

The greatest performance benefit from an EV is that, as was stated above, there are no emissions from the vehicle itself. Furthermore, the overall toxic and ozone-forming emissions tend to be much lower than with conventional vehicles since it can be easier to control emissions at a power plant than it is to control combustion vehicle emissions. An added benefit is a reduction in noise pollution since EVs are significantly quieter than conventional vehicles.

Greenhouse gas emissions caused by EVs tend to be lower than those from conventional vehicles, depending on the local fuel mix used in power generation<sup>19</sup> and the efficiency of the power distribution grid. But if electricity transmission and distribution losses are high, total energy consumption attributable to electric vehicles may exceed conventional vehicles.

## Other Issues

A major issue for vehicle manufacturers, and a motivation for increased research and development on electric vehicles, is California's zero-emissions mandate.<sup>20</sup> This mandate would require manufacturers to sell ZEVs and other super-low-emission vehicles. However, many technical and market barriers have hindered the implementation of the program. Most recently, the California Air Resources Board amended the program, allowing manufacturers two methods to certify compliance. First, manufacturers were able to generate credits for future use by introducing a limited number of fuel cell vehicles (see discussion below on fuel cells) by 2005.

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extended EV range significantly.

<sup>16</sup> John O'Dell, "A Clean Air Detour?: Fuel-efficient, Low-emissions Hybrids are Here," *Los Angeles Times*. February 2, 2000. p. G.1.

<sup>17</sup> There has been some research into the use of modular battery packs to eliminate the need for recharging—depleted batteries are exchanged for fully charged batteries at a service station—but problems with design and feasibility have hindered progress in this area.

<sup>18</sup> In fact, these techniques can also affect the range and fuel economy of conventional vehicles, but to a much lesser degree.

<sup>19</sup> This is especially true of the high greenhouse gas emissions from coal-fired power plants.

<sup>20</sup> *California Code of Regulations*. Section 1962(e), title 13.

Second, the manufacturers must produce a mix of vehicles, with 2% of sales coming from ZEVs, 2% from other advanced-technology vehicles, and 6% from conventional super-low-emission vehicles (SULEVs). Environmentalists have criticized the most recent amendments to the program for not requiring more extensive mandates.<sup>21</sup>

The original legislation required 2% of MY 1998 vehicle sales to be ZEVs and SULEVs, and 5% of MY 2001 sales, but these initial requirements were removed in 1996 to encourage market-based introduction of ZEVs. Other states have adopted the California program, including New York, Maine, Massachusetts, New Jersey, and Maryland.<sup>22</sup>

## Hybrid Electric Vehicles

A type of vehicle that can address some of the problems associated with electric vehicles is a hybrid electric vehicle (HEV). HEVs combine an electric motor and battery pack with an internal combustion engine to improve efficiency. In current HEVs, the batteries are recharged during operation, eliminating the need for an external charger. In development are plug-in hybrids (PHEVs) that combine some of the benefits of HEVs and pure EVs (see the next section). Either way, range and performance can be significantly improved over electric vehicles.

The combustion and electric systems of HEVs are combined in various configurations. In one configuration (series hybrid), the electric motor supplies power to move the wheels, while the combustion engine is connected to a generator that powers the motor and recharges the batteries. In another configuration (parallel hybrid), the combustion engine provides primary power, while the electric motor adds extra power for acceleration and climbing, or the electric motor is the primary power source, with extra power provided by the engine. In some parallel hybrid systems, the engine and electric motor work in tandem, with either system providing primary or secondary power depending on driving conditions.

The hybrid drive train allows the combustion engine to operate at or near peak efficiency most of the time. This can lead to significantly higher levels of overall vehicle system efficiency. The higher efficiency of these vehicles allows them to achieve very high fuel economy and lower emissions. For example, the hybrid Honda Civic is rated at 40 miles per gallon (mpg) in the city, and 45 mpg on the highway. A gasoline-fueled Honda Civic sedan, by comparison, achieves a rating of 25 mpg city and 36 mpg highway.<sup>23</sup> Fuel economy improvements can help cut demand for foreign petroleum, and the higher efficiency enables hybrid vehicles to attain, and even surpass, the range of conventional vehicles, even with a smaller fuel tank. Furthermore, since these vehicles utilize conventional fuel, the fueling infrastructure problems associated with electric vehicles can be eliminated.

HEV sales have increased significantly over the past several years. From the introduction of the Honda Insight in the United States in 1999 through the end of 2006, approximately 650,000 HEVs were sold in the United States.<sup>24</sup> Several hybrid vehicles are currently available in the U.S.

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<sup>21</sup> Carolyn Whetzel, "California Adopts Changes to ZEV Program Giving Automakers Reprieve From Quotas," *Daily Environment Report*. April 25, 2003. p. A-13.

<sup>22</sup> In New Jersey and Maryland, the program will be adopted only if neighboring states also adopt the program.

<sup>23</sup> U.S. Department of Energy, *Fuel Economy.gov Website*. <http://www.fueleconomy.gov>.

<sup>24</sup> Electric Drive Transportation Association (EDTA), *Hybrid Sales Figures/Tax Credits for Hybrids*. Accessed (continued...)

market, and most major manufacturers have introduced hybrid models or plan to do so over the next few years.<sup>25</sup>

Currently, purchasers of an HEV may qualify for a tax credit. The credit, established in the Energy Policy Act of 2005, is based on the fuel economy and projected fuel savings compared to a baseline conventional vehicle. The value of the tax credit is up to \$3,400, depending on those factors.<sup>26</sup> The number of vehicles produced by a single manufacturer eligible for the tax credit is limited. Once an automaker produces 60,000 vehicles, the credit begins to phase out. Toyota reached the limit in 2006, and tax credits for Toyota hybrids were completely phased out October 1, 2007.<sup>27</sup>

## Cost

One of the key selling points for hybrids is that while they are more expensive than conventional vehicles, they are much less expensive than pure electric vehicles. However, these vehicles are still relatively expensive. All of the current hybrids are priced several thousand dollars above comparable conventional vehicles. Further, it has been claimed that current hybrid prices are subsidized by the manufacturers.<sup>28</sup>

The higher purchase price of these vehicles is offset, to some degree, by lower fuel costs. Due to the higher fuel efficiency of hybrids, fuel can be significantly lower with hybrids than with conventional vehicles (see **Table 1**). These savings, along with proposed tax credits for the purchase of hybrids, could cover the incremental cost of purchasing a hybrid as opposed to a conventional vehicle. Furthermore, some consumers may be willing to pay a premium for a more “environmentally friendly” car.

**Table 1. Cost Difference for Hybrid (MY07) and Conventional (MY07) Honda Civic Sedans**

Hybrid purchase price (MSRP) <sup>a</sup>	\$22,600
Lifetime fuel cost savings (10-year life) <sup>b</sup>	\$2,662
Federal tax credit <sup>b</sup>	\$2,100
Hybrid net cost	\$17,838
Conventional purchase price (MSRP)	\$17,760
Net cost difference	\$78

a. It has been argued that this price has been subsidized by the manufacturer.

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December 2, 2007. <http://www.electricdrive.org/index.php?tg=articles&topics=7>.

<sup>25</sup> Several municipalities currently operate heavy buses with hybrid drivetrains, and research and development on these larger vehicles are ongoing.

<sup>26</sup> P.L. 109-58, Sec. 1341. Internal Revenue Service *Hybrid Cars and Alternative Fuel Vehicles*. Updated October 12, 2007; available at <http://www.irs.gov/newsroom/article/0,,id=157632,00.html>.

<sup>27</sup> Internal Revenue Service, *Toyota Hybrid Begins Phaseout on October 1*. IRS Notice IR-2006-145. September 20, 2006.

<sup>28</sup> “Science and Technology: Hybrid Vigour?,” *The Economist*. January 29, 2000. p. 94.

- b. Fuel cost savings are over 10-year ownership (15,000 miles per year), at a gasoline price of \$3.10 per gallon (annual savings of \$303), and a 3% discount rate. EPA rated combined fuel economy for the hybrid sedan is 42 mpg, and 29 mpg for the gasoline sedan (both with manual transmission). It should be noted that a shorter ownership period, lower gasoline prices, or a higher discount rate will decrease the value of these fuel savings. Fuel costs, consumption, and gasoline price are from <http://www.fueleconomy.gov/>.
- c. Internal Revenue Service. *Hybrid Cars and Alternative Fuel Vehicles*. Updated October 12, 2007.

## Infrastructure

Another key advantage of hybrid vehicles over pure electrics is that no new fueling infrastructure must be installed, since the vehicles are fueled by gasoline or diesel. This allows hybrid owners to purchase and operate these vehicles anywhere in the country, and long-distance travel will not be limited by the fueling infrastructure. Furthermore, maintenance of the combustion components in the vehicle can rely on the existing service infrastructure.

However, as with pure electric vehicles, maintenance of the electric components in hybrid vehicles generally must happen at licensed dealers, who will have more access to the technology. This may limit the acceptability for rural customers who may live a good distance from the dealership, but is less likely to harm acceptance of urban and suburban customers.

## Performance

The most notable features of hybrid vehicles are higher fuel economy and extended range. The efficiency of the hybrid drive system allows a significant increase in fuel economy compared to conventional vehicles, cutting fuel costs. Also, the improved fuel economy means that vehicle range is greatly extended with hybrids, even if a slightly smaller fuel tank is used. This higher efficiency also leads to lower emissions of greenhouse gases, as well as lower emissions of toxic and ozone-forming pollutants. Further, depending on design, the hybrid system can also be used to boost horsepower and acceleration.<sup>29</sup>

## Plug-in Hybrid Vehicles

A recent development in advanced vehicle technologies is the expected introduction in the next few years of plug-in hybrid electric vehicles (PHEVs). A PHEV uses a much higher-capacity battery pack than a typical hybrid, and adds the ability to charge the vehicle on grid power. With the larger batteries, an all-electric range of 20 to 40 miles (or more) could be achieved. In this way, most commuters might be able to travel to and from work solely on electrical grid power. Only when traveling long distances might the combustion engine be necessary.

Potential advantages include the ability to use electric power, which tends to be less expensive per mile than gasoline. Thus, some of the increased purchase cost of a PHEV over a conventional vehicle could be made up in future fuel savings. In addition, PHEVs could provide some of the environmental benefits of pure electric vehicles, including lower fuel-cycle pollutant and greenhouse gas emissions, without some of the performance drawbacks.

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<sup>29</sup> However, increasing power necessarily compromises some or all of the fuel economy gains from hybridization.

## Cost

It is expected that because of the higher-capacity batteries necessary for PHEVs compared to hybrids, costs could be several thousand dollars more than a hybrid, and thus significantly more expensive than a conventional vehicle. Some or all of this additional cost could be made up through energy cost savings over the life of the vehicle. Electricity tends to be less expensive than gasoline per mile, and it is expected that most consumers would be able to run most of the time on electricity. One key concern is that the duty cycle of PHEV batteries is far more rigorous than that of “conventional” hybrids, and thus the batteries may need to be replaced more often, increasing life-cycle costs.

## Infrastructure

A key question on the infrastructure for PHEVs is whether they will be able to be plugged into a standard household outlet,<sup>30</sup> or whether an additional charging station would be necessary. If no additional charging station is required, then presumably consumers could recharge their vehicles overnight at their homes.<sup>31</sup> Beyond those requirements, concerns have been raised over the additional electric power needed if a large number of PHEVs are plugged into the grid.

## Performance

A key benefit of a PHEV is that it can run on electric power, but without the range limitations of a pure EV. A PHEV’s all-electric range would likely be limited to commuting distances, with the combustion engine engaging on longer trips. Another key benefit to PHEVs is that by relying mainly on electric power, total fuel cycle pollutant and greenhouse gas emissions will likely be lower than those of conventional vehicles, although the degree of reduction will depend on the source of the electric power (coal, natural gas, nuclear, or renewable), and the amount of electric vs. gasoline fuel used by the vehicle.<sup>32</sup>

## Fuel Cell Vehicles

An advanced vehicle further from commercialization is a fuel cell vehicle (FCV). A fuel cell can be likened to a “chemical battery.”<sup>33</sup> Unlike a battery, however, a fuel cell can run continuously, as long as the fuel supply is not exhausted. In a fuel cell, hydrogen reacts with oxygen to generate an electric current. Hydrogen is supplied to the fuel cell as either pure hydrogen or a through hydrogen-rich fuel (such as methanol, natural gas, or gasoline) that is processed (reformed) on-board the vehicle. There is a physical limit to the voltage that one fuel cell can provide, so fuel cells are arranged in “stacks” to generate a high voltage that is used to power an electric motor.

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<sup>30</sup> Either a 120-volt outlet, or a higher-voltage 240-volt outlet like those used for electric clothes dryers.

<sup>31</sup> In the case of a 240-volt outlet, an electrician would likely be needed to install it.

<sup>32</sup> Electric Power Research Institute and Natural Resources Defense Council, *Environmental Assessment of Plug-In Hybrid Electric Vehicles*. Volumes 1 and 2. July 2007.

<sup>33</sup> For more information, see CRS Report RS21442, *Hydrogen and Fuel Cell Vehicle R&D: FreedomCAR and the President’s Hydrogen Fuel Initiative*, by Brent D. Yacobucci.

This chemical process eliminates the need for charging a battery, which is necessary with electric vehicles, while producing much lower emissions than combustion vehicles. In fact, if pure hydrogen fuel is used, the only product from the reaction will be water. With hydrogen fuel, an FCV would qualify as a zero emission vehicle.<sup>34</sup> Using other fuels,<sup>35</sup> while the vehicle is no longer a ZEV, emissions would still be drastically cut as compared to conventional vehicles. Furthermore, because potential fuel supplies for FCVs include natural gas, methanol, or pure hydrogen—the latter two produced from natural gas<sup>36</sup>—another potential benefit from fuel cells will be their ability to reduce the transportation demand for foreign petroleum.<sup>37</sup>

While currently available only to a few consumers (on a demonstration basis), fuel cells have been touted as likely to be one of the most important technologies in the history of the automobile.<sup>38</sup> They are currently very expensive, and thus there has been a great deal of interest in research and development to improve their marketability. Because of their potential to revolutionize the automotive industry, all major manufacturers are working to develop fuel cell vehicles, and some manufacturers have introduced a limited number of vehicles for lease; others intend to introduce vehicles for limited leases in the near future.<sup>39</sup> Demonstration projects are ongoing with fuel cell passenger cars, sport utility vehicles, and transit buses. Many of these demonstrations are in conjunction with the California Fuel Cell Partnership, a consortium of auto manufacturers, fuel providers, fuel cell developers, and state and federal agencies.

## Cost

Arguably, the largest barrier to the production of FCVs is cost. It currently costs approximately \$2,000 to \$3,000 to produce a gasoline engine for a conventional passenger car.<sup>40</sup> In the early 2000s, a comparable fuel cell stack cost around \$35,000, according to industry estimates, but a leading producer of fuel cells estimates that costs could be cut to \$3,500 in the future.<sup>41</sup> Since there are fewer moving parts in a fuel cell vehicle, maintenance costs would likely be lower, so the added cost of the fuel cell system may be offset by lower maintenance costs. Further research and development would be necessary to achieve these benefits.

Another key cost issue will be fuel costs. Fuel costs are a concern because there is no hydrogen fueling infrastructure currently, and the use of methanol and natural gas as transportation fuels is currently limited.<sup>42</sup> Consumers might have to pay a premium for these fuels, in order to support a growing infrastructure. However, since hydrogen fuel and methanol would likely be produced from natural gas, price fluctuations caused by changing supply in petroleum markets could be dampened, although natural gas price fluctuations would certainly have an effect.

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<sup>34</sup> Like electric cars, however, there will be emissions due to the production and distribution of the hydrogen fuel.

<sup>35</sup> In these cases, an extra component, called a reformer, is used to separate hydrogen from the fuel.

<sup>36</sup> The eventual goal is to produce hydrogen fuel from renewable sources, but that technology not yet marketable.

<sup>37</sup> Recent high natural gas prices have led to questions of the viability of natural gas as a fuel source for FCVs.

<sup>38</sup> Environmental and Energy Study Institute (EESI), *Fuel Cell Fact Sheet*. February 2000.

<sup>39</sup> Because of production costs and other barriers, these will likely be very small production runs, and the vehicles are likely to be heavily subsidized by the manufacturers.

<sup>40</sup> "GM's Fuel-Cell-Powered Precept Hyped as Efficient and Fast," *The Salt Lake Tribune*. January 12, 2000. p. D9.

<sup>41</sup> "Ballard Reduces Fuel Cell Costs," *Detroit News*. November 30, 1999.

<sup>42</sup> Expanding current natural gas or methanol infrastructure will likely be less expensive than comparable hydrogen infrastructure.

## Infrastructure

Another major barrier to the use of FCVs is that there is no infrastructure for the distribution of hydrogen fuel, and little methanol or natural gas infrastructure for transportation. As of December 2007, there were only about 750 natural gas refueling sites in the United States, and few, if any, methanol sites. The feedstock for methanol, and the likely feedstock (in the near future) for hydrogen fuel is natural gas, although other feedstocks, such as biomass or coal, could be used.<sup>43</sup> Hydrogen derived from renewable energy could also be possible in the future, but that technology is far from commercialization.

Until the distribution infrastructure for hydrogen, methanol, or natural gas is developed, it is possible that gasoline will be the fuel of choice for fuel cell passenger vehicles.

As with electric vehicles, no maintenance infrastructure exists for servicing these vehicles. The technology is radically different from conventional vehicles, and most maintenance would likely have to occur at certified dealers.

## Performance

One limit on the performance of fuel cell vehicles has been their weight. Fuel cells have been demonstrated on larger vehicles, such as buses. However, because of size and weight, until recently, passenger and cargo space has been sacrificed in prototypes of smaller fuel cell vehicles. However, many of these issues have been addressed in more recent prototypes. Another potential concern is that on-board reformers for converting gasoline or other fuels to hydrogen are very heavy. Therefore, much research has focused not only on cutting the cost of fuel cell systems, but decreasing their weight, as well.

Another performance concern is one of fuel storage. Since hydrogen is not very dense, the fuel must be highly concentrated, and must be compressed (requiring a high-pressure tank), liquified (requiring a cooling system for the storage tank), chemically bonded with a storage material (such as a chemical or metal hydride), or stored in a tank with a complicated geometry (e.g., nanotubes). Each of these storage systems has problems, such as added weight, safety risks, or expensive raw materials that limit their acceptability.<sup>44</sup> Therefore, research is ongoing to improve both the storage capacity and safety of hydrogen fuel.

On the environmental side, the emissions from fuel cell vehicles are extremely low. Using hydrogen, there are no emissions of toxic or ozone-forming pollutants. Using other fuels, the reformer limits the efficiency of the fuel cell system, but emissions are still much lower than with conventional engines. Depending on the emissions attributable to the production and distribution of the fuel, fuel cell vehicles may perform better environmentally than any other technology for all types of emissions, including greenhouse gases. However, this is not a guarantee, especially if coal is used to generate hydrogen and no technology is developed to recapture carbon dioxide from the production process.

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<sup>43</sup> Department of Energy, Alternative Fuels Data Center, *Hydrogen General Information*. [http://www.afdc.doe.gov/altfuel/hyd\\_general.html](http://www.afdc.doe.gov/altfuel/hyd_general.html).

<sup>44</sup> It should be noted that high-pressure on-board storage of hydrogen could potentially be safer than current gasoline tanks.

## Other Issues

Currently, the main issue for fuel cells is research and development (R&D). All major automobile manufacturers are spending considerable amounts of money on fuel cell R&D. In January 2002, the Bush Administration announced the FreedomCAR program, which focuses federal vehicle research on fuel cell vehicles. To complement this program, in January 2003, the Administration announced the Hydrogen Fuel Initiative, which focuses research on hydrogen fuel and infrastructure, as well as research on fuel cells for other applications (e.g., backup power).

## Component Technologies

Another way to improve the fuel economy and emissions characteristics of vehicles is to use advanced components that reduce friction, decrease vehicle weight, or improve system efficiency. Many high-technology vehicles that are available to the public utilize these technologies, but some of these technologies could also be incorporated into the design of conventional vehicles.

### Lightweight Materials

An effective way to improve efficiency is to reduce the weight of the vehicle. However, simply reducing weight while using the same materials and structural design can compromise passenger safety. Therefore, newer vehicles are making extensive use of advanced materials such as composite or plastic body panels, and high-strength, lightweight aluminum structural components. The use of some of these materials may even make a vehicle more recyclable.<sup>45</sup> Furthermore, conventional materials can improve safety while reducing weight, if more sophisticated structural designs are used.

### Decreased Resistance

Another way to improve efficiency is to decrease resistance, both from drag and from friction between the wheels and the road. Wind resistance can be decreased through redesigning the body to a more aerodynamic shape. In addition, the use of “slippery” body panels<sup>46</sup> can further decrease drag, as can decreasing the profile of parts such as side-view mirrors, tires, and the radio antenna. Rolling friction can be limited through the use of low-resistance tires.

### Regenerative Braking

A key component in the efficiency of electric vehicles (including hybrids and fuel cell vehicles) is a regenerative braking system. This system allows some of the vehicle’s kinetic energy to be recaptured as electricity when the brakes are applied. In braking, the motor acts as a generator,

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<sup>45</sup> Automobiles are currently one of the most recycled consumer products with over 65% of vehicle mass (mostly steel) reused.

<sup>46</sup> These are made from plastics with a very low coefficient of friction.

taking kinetic energy from the wheels and converting it to electrical energy, which is fed back to the batteries.<sup>47</sup> This technology is already available on consumer EVs and HEVs.

## **Variable Valve Timing**

Computers can be used to electronically adjust valve timing to optimize engine efficiency. This improved efficiency can be used to lower fuel consumption and/or increase power output. Variable valve timing is currently available on many passenger vehicles.

## **42-Volt Systems**

Some new fuel-saving technologies will require more power than is provided by standard 14-volt electrical systems. A 42-volt system would provide the power to these new systems. Further, increasing power requirements from existing and future conveniences such as climate control, power accessories, and audio/video devices will soon require greater power than a 14-volt system can provide.<sup>48</sup>

## **Integrated Starter-Generator**

An integrated starter-generator can be used in conventional vehicles to reduce fuel consumption and improve acceleration. As with a hybrid vehicle, using the high-torque device allows the engine to shut off when the vehicle is stopped. When power is applied, the engine can restart in less than one second.<sup>49</sup> It is believed that the integrated starter-generator could improve fuel economy of conventional vehicles by as much as 20%. However, because the integrated starter-generator requires a considerable amount of electrical power, it is being developed concurrently with 42-volt electrical systems.

## **Cylinder Deactivation**

Fuel consumption can also be reduced through cylinder deactivation. When less power is needed, one or more engine cylinders can be deactivated. These cylinders can then be reactivated if power needs increase. This technology could be particularly useful in applications where a six-, eight-, or ten-cylinder engine may be needed to boost acceleration, haul a trailer, or carry a large payload, but is not needed when loads are lighter. Cylinder deactivation is currently available in several vehicles, including certain models of the Chrysler 300 sedan, the GMC Envoy SUV, and the Honda Odyssey minivan.

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<sup>47</sup> In fact, the efficiency of the regenerative braking system is a key factor in the amount of the credit available in the Administration's proposed tax credit for hybrid vehicles.

<sup>48</sup> Paul Sharke, "Power of 42," *Mechanical Engineering*, April 2002, pp. 40-42.

<sup>49</sup> Richard Truett, "Engineers Search Tech Menu for More Ways to Save Fuel," *Automotive News*, May 14, 2001, p. 36.

## Conclusions

The use of advanced vehicle technologies can help curb consumption of fossil fuels, especially petroleum, and reduce emissions of toxic and ozone-forming pollutants, as well as greenhouse gases. In general, the most promising current technologies incorporate electric motors and batteries in their design, while all take advantage of new design techniques and advanced materials to reduce resistance, cut vehicle weight, and better conserve energy. However, most of these technologies are still in various stages of development and have not yet proven marketable to most consumers.

The three key issues for the marketability of advanced technology vehicles are cost, infrastructure, and performance. Consumers must be willing and able to purchase the vehicles, so purchase cost and overall life-cycle cost of these vehicles must be competitive. In addition, consumers must be able to expect that refueling and servicing these vehicles will be relatively convenient. Finally, the overall performance of the vehicles—in terms of fuel economy, range, driveability, safety, and emissions—must be acceptable.

While most advanced vehicles meet some of these requirements, no new vehicle has yet met all of them. Therefore, research and development has been a key issue in the discussion of these vehicles, as have efforts to make the vehicles more affordable and the infrastructure more accessible. These vehicles may help the federal government in its role of promoting energy security and environmental protection if research and development can bring them to a point where they can be successfully marketed to American consumers.

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