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Advanced Vehicle Technologies: Energy, Environment, and Development Issues

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Advanced Vehicle Technologies: Energy, Environment, and Development Issues

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. 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 the1970s. 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 two major Japanese manufacturers have introduced high-efficiency production vehicles to the American market, and the major American manufacturers have plans to introduce similar vehicles. 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 on fuel cell vehicles. This initiative replaces the Partnership for a New Generation of Vehicles (PNGV), which focused on hybrid technologies and the development of an 80 mile-per-gallon sedan. 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.

This report discusses three major vehicle technologies — electric vehicles, hybrid electric vehicles, and fuel cell vehicles — as well as advanced component technologies. Each technology is discussed in terms of cost, fueling and maintenance infrastructure, and performance. The report also discusses key legislation in the 108th Congress, as well as federal, state, and local activity relevant to these technologies. This report will be updated as events warrant.

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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 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, will focus on long-term research on fuel cells and hydrogen fuel.

The United States is not alone in pursuing these new technologies. Two major Japanese manufacturers have introduced compact cars that can achieve two to three times the fuel economy of the standard conventional vehicle.[1] 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. In Europe, for example, gasoline prices range from 3 to 5 dollars per gallon.

The three advanced propulsion technologies closest to commercialization are electric vehicles, hybrid vehicles, and fuel cell vehicles. In an electric vehicle, the vehicle runs exclusively on electricity which 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. 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.

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[1]Eric C. Evarts, "First fleet of 'green' cars about to hit the road," *Christian Science Monitor*. January 11, 2000.

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 a standard 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 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.[2]

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 U.S. 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 recently, especially in California, have led to questions about the long-term viability of EVs.

Commercially, these vehicles have not been well-received by consumers.[3] By 1998, only about 3,500 privately owned EVs were on the road, mainly in California.[4] Only a few car companies currently produce electric vehicles, and most of those are only available for lease by large fleets. Further, because consumer demand has been low, some companies have discontinued production of electric vehicles.[5] However,

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[2]However, there may be concerns over increasing pollution in areas near a power generation facility, though it is generally easier to control emissions for a stationary source than from a mobile source.

[3]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.

[4]Department of Energy, Energy Information Administration (EIA), *Alternatives to Traditional Transportation Fuels, 2000.*

[5]"Honda Stops Making Electric Cars, Roiling California Regulators," *Wall Street Journal.*
(continued...)

California's upcoming ZEV mandate (see "Other Issues," below) may promote EV sales.

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,[6] which was considerably higher than a comparable 1999 Chevrolet Cavalier at $13,670.[7]

However, fuel costs are much lower for EVs than for conventional vehicles. A small conventional vehicle can achieve a fuel cost of approximately $690 per year.[8] An electric vehicle, however, can achieve a considerably lower cost of $390 to $480 per year.[9] 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, its is unlikely that even a very large increase in petroleum prices would be sufficient to make 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.[10]

Currently, there are federal and state tax credits for the purchase of electric vehicles. The federal credit is worth 10% of the purchase price of the vehicle, up to $4,000. This credit, which is part of the Energy Policy Act of 1992, will be reduced by 25% each year between 2004 and 2006, and will expire after 2006.[11] In some areas, these vehicles are also exempted from high occupancy vehicle (HOV) lane restrictions, parking restrictions, and/or vehicle registration fees.

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[5](...continued)
April 30, 1999. p. B7.

[6]General Motors, *EV1 Electric*, at [http://www.gmev.com/]. It must be noted that this vehicle is currently only available for lease to consumers.

[7]Chevrolet, *Chevrolet Metro.* [http://www.chevrolet.com].

[8]John DeCicco, Jim Kliesch, and Martin Tomas, *ACEEE's Green Book: The Environmental Guide to Cars & Trucks.* Washington, D.C. 2000.

[9]Ibid.

[10]Most manufacturers are researching to improve battery life, and are also considering warrantying batteries for the life of the vehicle.

[11]P.L. 102-486; 26 U.S.C. 30. For a detailed discussion of the EV tax credit, see CRS Report 98-193 E, *Global Climate Change: The Energy Tax Incentives in the President's FY2001 Budget.*

Infrastructure

Another key obstacle to more widespread use of electric vehicles is the lack of fueling (charging) and maintenance infrastructure. For example, in California and Arizona, there are approximately 600 public charging stations,[12] plus approximately 1,100 General Motors chargers installed for private use (generally in owner's garages).[13] This is about 6% of the approximately 10,000 gasoline refueling stations in the two states.[14] The lack of recharging infrastructure is not only inconvenient, but also limits long-distance travel, since Arizona and California account for 74% of all recharging sites currently in operation. Georgia accounts for another 10%.

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.[15] While a conventional passenger car can travel 300 to 400 miles before refueling, currently available electric cars generally can only travel about 100 to 150 miles before needing to be recharged. Furthermore, while refilling the tank of a conventional vehicle requires only a few minutes, a full residential recharge for an electric vehicle can take 5 to 8 hours. Some high-speed chargers can charge a vehicle in 3 to 4 hours, but these quick charges shorten the life of the batteries, which are expensive to replace.[16] 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.[17]

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[12]Department of Energy, Alternative Fuels Data Center (AFDC), *US Refueling Site Counts by State and Fuel Type As of 6/27/2002.* [http://www.afdc.doe.gov/refuel/state_tot.shtml].

[13]General Motors, op. cit.

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

[15]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 extended EV range significantly.

[16]John O'Dell, "A Clean Air Detour?; Fuel-efficient, Low-emissions Hybrids are Here," *Los Angeles Times.* February 2, 2000. p. G.1.

[17]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.

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.[18]

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 is 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 may be lower or higher than those from conventional vehicles, depending on the local fuel mix used in power generation[19] and the efficiency of the power distribution grid. Furthermore, if electricity transmission and distribution losses are high, 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.[20] 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 may comply by introducing a limited number of fuel cell vehicles (see discussion below on fuel cells) by 2005. 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. Environmentalists have criticized the most recent amendments to the program for not requiring more extensive mandates.[21]

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.[22]

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

[19]This is especially true of the high greenhouse gas emissions from coal-fired power plants.

[20]*California Code of Regulations*. Section 1962(e), title 13.

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

[22]In New Jersey and Maryland, the program will be adopted only if neighboring states also adopt the program.

Congressional Action

The key piece of EV-related legislation in the 108th Congress is the CLEAR ACT (H.R. 1054 and S. 505).[23] Both versions of the bill would replace the existing EV tax credit with a new credit, based on vehicle weight, payload, and range. For the purchase of a new electric passenger car, the bill would provide between $4,000 and $6,000. Further, the bill would provide a tax credit of up to $1,500 for the purchase of neighborhood electric vehicles (small, low-speed EVs). Provisions from the CLEAR ACT were inserted into the Senate version of H.R. 6 (the comprehensive energy bill) although the credit is slightly lower ($3,500 to $6,000). The House version of H.R. 6 would not change the structure of the existing EV tax credit, but would eliminate the phase-down of the credit, without extending the termination date. The conference report on H.R. 6 (H.Rept. 108-375) incorporates the House language.

Hybrid Electric Vehicles

A type of vehicle that may address many 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 some HEVs, the batteries are recharged during operation, eliminating the need for an external charger. In other cases, the vehicle must still be plugged in at the end of the day. 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 which 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 Insight is rated at 61 miles per gallon (mpg) in the city, and 70 mpg on the highway. A gasoline-fueled Honda Civic Hatchback, by comparison, achieves a rating of 32 mpg city and 37 mpg highway.[24] Fuel economy improvements can help cut demand for foreign petroleum, and the higher efficiency enables hybrid vehicles

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[23]For more information on the CLEAR ACT, see CRS Report RS21277, *Alternative Fuel Vehicle Tax Incentives and the CLEAR ACT.*

[24]DeCicco, et. al., op. cit.

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.

The only hybrid vehicles currently available in the U.S. market are the Honda Insight, the Honda Civic Hybrid, and the Toyota Prius. Over the next few years, however, most major manufacturers plan to introduce hybrid passenger vehicles. Further, while the currently available hybrids are smaller cars, manufacturers are also developing larger hybrids such as mini-vans and sport utility vehicles.[25]

Until recently, HEVs were treated as conventional vehicles because they run on gasoline or diesel fuel. However, the Internal Revenue Service announced on May 21, 2002, that it will allow taxpayers to claim a clean-burning fuel vehicle tax deduction of $2,000.[26]

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. Both of the current Honda and Toyota vehicles, which are compact cars, are currently priced several thousand dollars above comparable conventional vehicles, despite being heavily subsidized by the manufacturers.[27]

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 costs are significantly lower with hybrids than with conventional vehicles. Depending on fuel prices, these savings could be $250 or more per year.[28] (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 to drive a "different" kind of car.

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[25]Several municipalities currently operate heavy buses with hybrid drivetrains, and research and development on these larger vehicles is ongoing.

[26]Internal Revenue Service, *News Release: IRS Moves to Clarify Taxpayer Deduction for Hybrid Vehicles.* May 21, 2002. Release No. IR-2002-64.

[27]"Science and Technology: Hybrid Vigour?," *The Economist.* January 29, 2000. p. 94.

[28]DeCicco, et. al., op. cit.

Table 1. Cost Difference for Hybrid (MY04) and Conventional (MY04) Honda Civic Sedans

Hybrid purchase price (MSRP)[a]	$19,650
Fuel cost savings[b]	$1,800
$2000 Federal income tax deduction[c]	$500
Hybrid net cost	$17,350
Conventional purchase price (MSRP)	$17,260
Net cost difference	$90

[a] This price has been subsidized by the manufacturer to motivate sales.
[b] Fuel cost savings are over ten-year ownership (15,000 miles per year), at a gasoline price of $1.40 per gallon. EPA rated combined fuel economy for the hybrid sedan is 48 mpg, and 34 mpg for the gasoline sedan (both with manual transmission). It should be noted that a shorter ownership period will decrease the value of these fuel savings.
[c] Based on a maximum deduction of $2000 and a tax rate of 25%. This is the marginal tax rate for a married couple, filing jointly with an income of $63,278 (the median income for a family of four in the United States). From the U.S. Census Bureau, [http://www.census.gov/hhes/income/4person.html], updated October 8, 2003, accessed January 28, 2004.

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 will allow 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 will most likely need to occur at licensed dealers, who will have first 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.

Congressional Action

As with electric vehicles, the most significant piece of legislation is the CLEAR ACT, which would establish a tax credit for the purchase of new hybrid electric vehicles. A new passenger car or light truck would qualify for a tax credit of between $250 and $4,000, depending on fuel efficiency and drivetrain design. Heavy-duty hybrid vehicles would be eligible for larger tax credits. The Senate version of H.R. 6 establishes a similar credit, although the amount of the credit varies from the CLEAR ACT. The House version of H.R. 6 contains no similar provision. The conference report on H.R. 6 would provide a tax credit of $400 to $3,400, depending on fuel economy and fuel savings, for the purchase of hybrid passenger vehicle.

Fuel Cell Vehicles

A third type of new vehicle is a fuel cell vehicle (FCV). A fuel cell can be likened to a "chemical battery."[29] 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) which 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 which is used to power an electric motor.

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.[30] Using other fuels,[31] while the vehicle is no longer a ZEV, emissions would still be drastically cut as compared to conventional vehicles. Furthermore, because the eventual fuel supply for FCVs will likely be natural gas, methanol or pure hydrogen — the latter two produced from natural gas[32] — another potential benefit from fuel cells will be their ability to reduce the transportation demand for foreign petroleum.[33] However, because of technical challenges with

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[29]For more information on fuel cells, see CRS Report RS32196, *A Hydrogen Economy and Fuel Cells: An Overview.*

[30]Like electric cars, however, there will be emissions due to the production and distribution of the hydrogen fuel.

[31]In these cases, an extra component, called a reformer, is used to separate hydrogen from the fuel.

[32]The eventual goal is to produce hydrogen fuel from renewable sources, but that technology not yet marketable.

[33]Recent high natural gas prices have led to questions of the viability of natural gas as a fuel

(continued...)

hydrogen fuel, it is possible that the first commercially-available FCVs will be gasoline- or diesel-powered.

While not currently available to consumers, fuel cells have been touted as likely to be one of the most important technologies in the history of the automobile.[34] 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 two major manufacturers have introduced vehicles for lease; others intend to introduce vehicles for lease starting in 2004.[35] 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.[36] A comparable fuel cell stack costs 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.[37] 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 infrastructure currently, and the use of methanol and natural gas as transportation fuels is extensive.[38] 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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[33](...continued)
source for FCVs.

[34]Environmental and Energy Study Institute (EESI), *Fuel Cell Fact Sheet.* February, 2000.

[35]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.

[36]"GM's Fuel-Cell-Powered Precept Hyped as Efficient and Fast," *The Salt Lake Tribune.* January 12, 2000. p. D9.

[37]"Ballard Reduces Fuel Cell Costs," *Detroit News.* November 30, 1999.

[38] 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, and little methanol or natural gas infrastructure for transportation. As of June 2002, there were only about 1300 natural gas refueling sites in the United States, and very few 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.[39] 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 passenger vehicles. However, gasoline fuel cell systems are not as efficient as other systems. For this reason, gasoline systems are seen as a stepping-stone to other, more efficient fuel cell systems in the future.

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., nanotubules). Each of these storage systems has problems, such as added weight, safety risks, or expensive raw materials that limit their acceptability.[40] Therefore, research is ongoing to improve both the storage capacity and safety of hydrogen fuel. For pressurized hydrogen, some of the same problems are associated with natural gas storage, although to a lesser degree.

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[39] Department of Energy, Alternative Fuels Data Center, *Hydrogen General Information*. [http://www.afdc.doe.gov/altfuel/hyd_general.html].

[40] It should be noted that high-pressure on-board storage of hydrogen could potentially be safer than current gasoline tanks.

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.

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. Further, on January 9, 2002, the Bush Administration announced that the current advanced vehicle technology research program, PNGV, would be replaced by the FreedomCAR program. While PNGV focused on hybrid technology, the FreedomCAR program focuses on fuel cells vehicles. To complement this program, in January 2003, the Administration announced the President's 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).

Congressional Action

The CLEAR ACT would provide tax credits for the purchase of fuel cell vehicles. Depending on design characteristics, the bill would provide a tax credit of $4,000 to $12,000 for the purchase of a fuel cell passenger car or light truck; the credits are larger for heavy-duty vehicles. There are similar provisions in all three versions of H.R. 6. However, under H.R. 6, the credit for a passenger vehicle would range from $4,000 to $8,000.

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. Most 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 simply 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.[41] 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[42] 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, taking kinetic energy from the wheels and converting it to electrical energy which is fed back to the batteries.[43] 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 several 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.[44]

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[41] Automobiles are currently one of the most recycled consumer products with over 65% of vehicle mass (mostly steel) reused.

[42] These are made from plastics with a very low coefficient of friction.

[43] 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.

[44] Paul Sharke, "Power of 42," *Mechanical Engineering.* April, 2002. pp. 40-42.

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.[45] 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 truck applications where an eight- or ten-cylinder engine may be needed to haul a trailer or carry a large payload, but is not needed when loads are lighter.

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 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

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[45]Richard Truett, "Engineers Search Tech Menu for More Ways to Save Fuel," *Automotive News.* May 14, 2001. p. 36.

protection if research and development can bring them to a point where they can be successfully marketed to American consumers.