DELAWARE VALLEY
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REGIONAL
PLANNING COMMISSION

November 2011

Ready to Roll?

Overview of Challenges and Opportunities for Alternative Fuel Vehicles in the Delaware Valley

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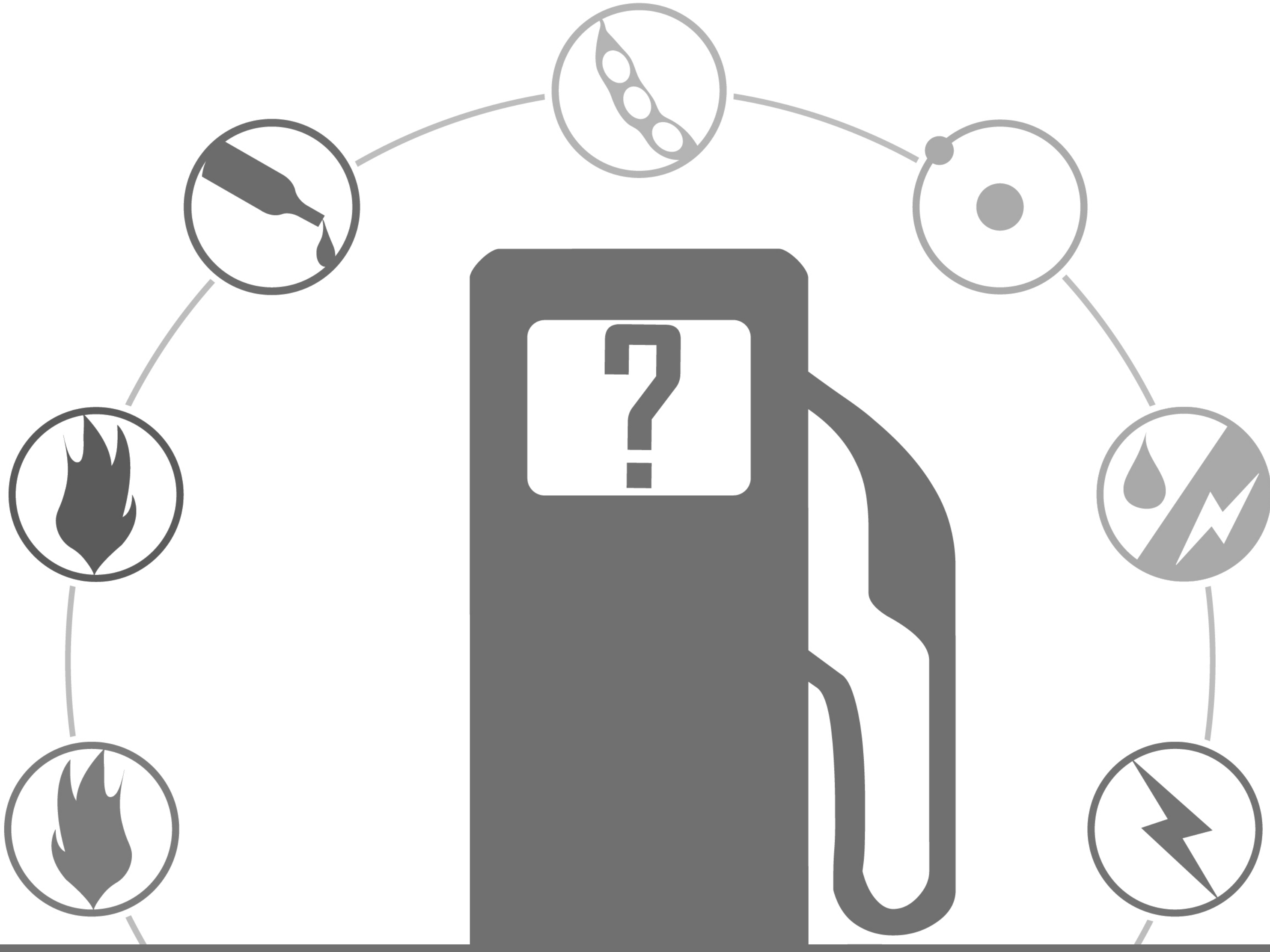

Ready to Roll?

Overview of Challenges and Opportunities for Alternative Fuel Vehicles in the Delaware Valley

The Delaware Valley Regional Planning Commission is dedicated to uniting the region's elected officials, planning professionals, and the public with a common vision of making a great region even greater. Shaping the way we live, work, and play, DVRPC builds consensus on improving transportation, promoting smart growth, protecting the environment, and enhancing the economy. We serve a diverse region of nine counties: Bucks, Chester, Delaware, Montgomery, and Philadelphia in Pennsylvania; and Burlington, Camden, Gloucester, and Mercer in New Jersey. DVRPC is the federally designated Metropolitan Planning Organization for the Greater Philadelphia Region — leading the way to a better future.

The symbol in our logo is adapted from the official DVRPC seal and is designed as a stylized image of the Delaware Valley. The outer ring symbolizes the region as a whole while the diagonal bar signifies the Delaware River. The two adjoining crescents represent the Commonwealth of Pennsylvania and the State of New Jersey.

DVRPC is funded by a variety of funding sources including federal grants from the U.S. Department of Transportation's Federal Highway Administration (FHWA) and Federal Transit Administration (FTA), the Pennsylvania and New Jersey departments of transportation, as well as by DVRPC's state and local member governments. The authors, however, are solely responsible for the findings and conclusions herein, which may not represent the official views or policies of the funding agencies.

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Figures and Tables

Ready to Roll?

This report analyzes alternative fuel vehicle (AFV) fuels and technologies in the context of the Delaware Valley region. An executive summary of the Delaware Valley Regional Planning Commission's (DVRPC) *Ready to Roll?: Overview of Challenges and Opportunities for Alternative Fuel Vehicles in the Delaware Valley* is available as an additional publication.[1] *Ready to Roll?* provides an introduction to AFV fuels and technologies and the opportunities for and challenges facing implementation of AFVs. It then provides detailed summaries of AFV fuels and technologies. A short appendix provides the U.S. Department of Energy's (U.S. DOE) definition of alternative fuels and compares it to the definition used in this report.

Overview and Context

Questions about the long-term availability, price, and national security implications of petroleum use, as well as concerns about air pollution and greenhouse gas (GHG) emissions, have spurred a wide range of policies and actions at all level of governments to reduce our dependence on petroleum. On-road transportation—which accounts for close to one-third of Greater Philadelphia's total energy use—is almost completely dependent on petroleum. A key strategy to reduce the use of petroleum is to reduce its use in our region's passenger vehicles. These policies fall into three broad categories:

1. making it easier for people to get to work, shopping, and recreation without spending as much time in a car or with shorter car trips (e.g., policies that encourage mixed-use, center-oriented development and provision of bike, pedestrian, and transit infrastructure);
2. increasing the fuel efficiency of petroleum-fueled vehicles; and
3. developing and promoting a fuels and vehicle infrastructure less dependent on petroleum—often called AFVs.

This report provides an overview of AFVs for policymakers and citizens, focusing primarily on the third category above. It is intended as an introduction, and contains references to resources that provide more in-depth information.

Introduction

This report summarizes major issues and challenges associated with the increased use of AFVs in Greater Philadelphia. Many of the these issues and challenges—such as the economic and environmental viability of fuel production, the development of infrastructure for delivering and storing fuels, and the relative cost of fuels and vehicles—are shared to some degree by most, if not all, AFVs.

Our current petroleum-based transportation system is deeply engrained; not only do most of the vehicles use petroleum, but the supporting elements, such as fueling infrastructure, vehicle maintenance availability, and fuel production and distribution systems, are also all narrowly focused on petroleum-based vehicles. A successful transition toward a more widespread use of AFVs will require a systematic, coordinated, and simultaneous development of the required supporting elements throughout the transportation system.

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[1] DVRPC publication number 10055A, available at http://www.dvrpc.org.

What Is an AFV?

AFVs use combinations of vehicle fuels and technologies to reduce the use of petroleum in on-road vehicles. These include low-carbon fuels (sometimes blended with petroleum), electricity, and hybrid technologies combining internal combustion engines (ICEs) with electric motors. The fuels and technologies are illustrated in Figure 1. The AFVs covered in this report include those most widely available today or likely to become available in the next 10 to 20 years. These fall into three broad types:

1. *vehicles powered by an ICE using a fuel other than gasoline or diesel*
   Low-carbon fuels, such as biofuels, compressed natural gas (CNG), and propane can be used to power traditional ICE vehicles, often with little or no engine modifications.
2. *vehicles powered by a battery-driven electric motor*
   Electric motor-powered vehicles use batteries charged by plugging into the electric grid, or by producing electricity using an on-board ICE-powered generator or hydrogen fuel cell.
3. *hybrid electric vehicles (HEVs)*
   HEVs are driven by both an ICE and an electric motor, with a transmission that draws on one or the other as required.

Note that this definition of an AFV differs somewhat from the definition used by the U.S. DOE.[2]

Figure 1 provides a simplified overview of the relationship between the most common AFV technologies. Fuel/energy sources are shown on the left. Listed first are liquid fuels (gasoline, ethanol, and biodiesel) and gases (natural gas and propane) that are burned in ICEs. These are followed by electricity used to charge batteries. The electricity grid is shown first, followed by a hydrogen fuel cell, which allows on-board non-combustion conversion of hydrogen to electricity.

As the illustration shows, batteries may also be charged by on-board generation of electricity powered by an ICE. As indicated, there are several different battery technologies that provide power to an electric motor. Either an electric motor or an ICE can drive the vehicle via the drive train, or they can work together in an HEV. Two other technologies are shown as well. The first is regenerative braking, which uses the energy of stopping the car to charge the battery. The second is “idle stop,” which stops the engine when the vehicle is not moving, and then instantly restarts it when it is needed. Although idle-stop technology is widely used in hybrid vehicles, it can also be deployed in traditional vehicles.

As the diagram shows, an almost limitless number of AFVs can be configured using various combinations of fuels and technologies—no one AFV will use all the fuels and technologies, of course, but it will be made up of some combination. On the following pages are schematic illustrations (Figures 2–5) of how four types of AFV currently on the market are configured.

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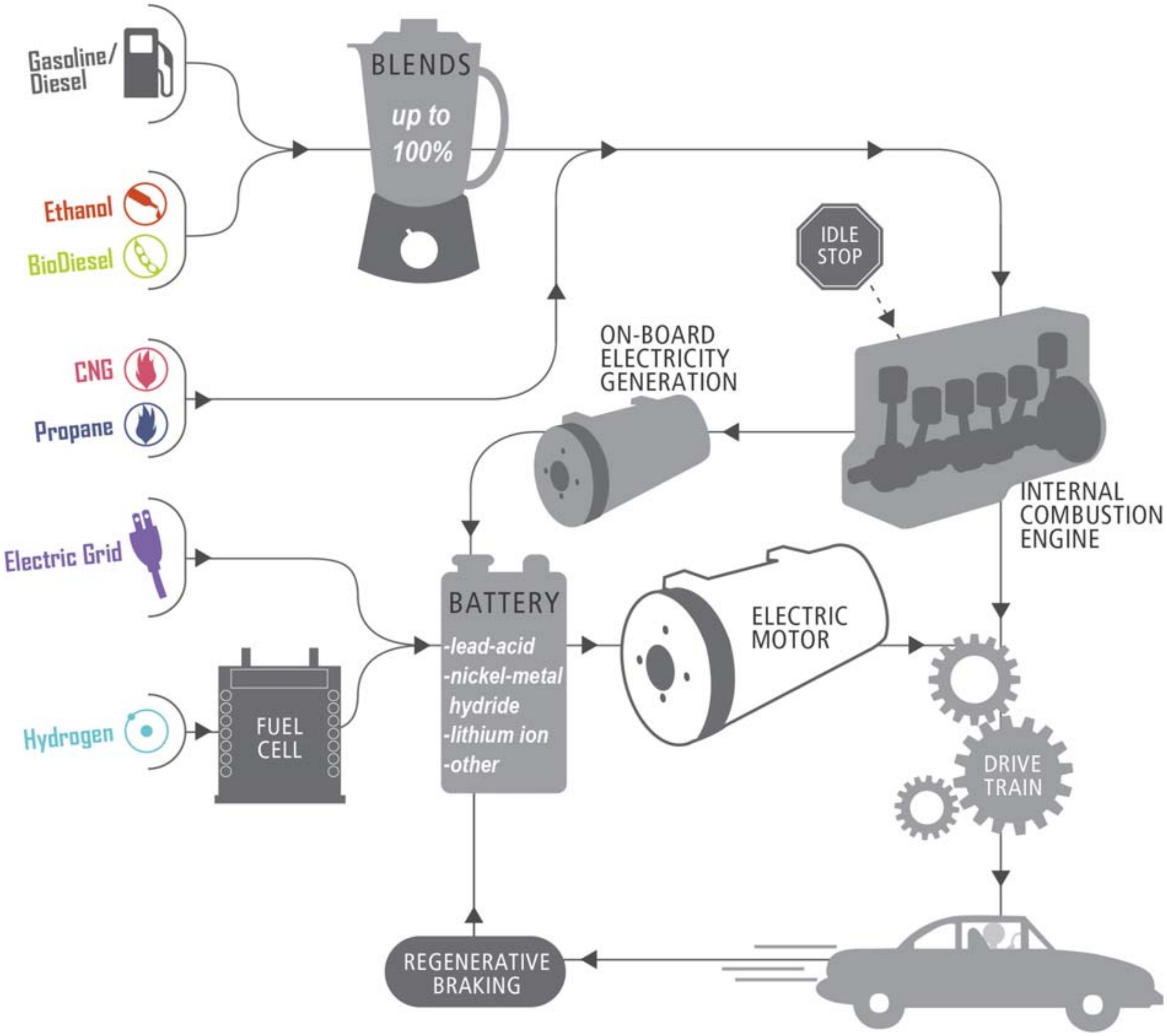
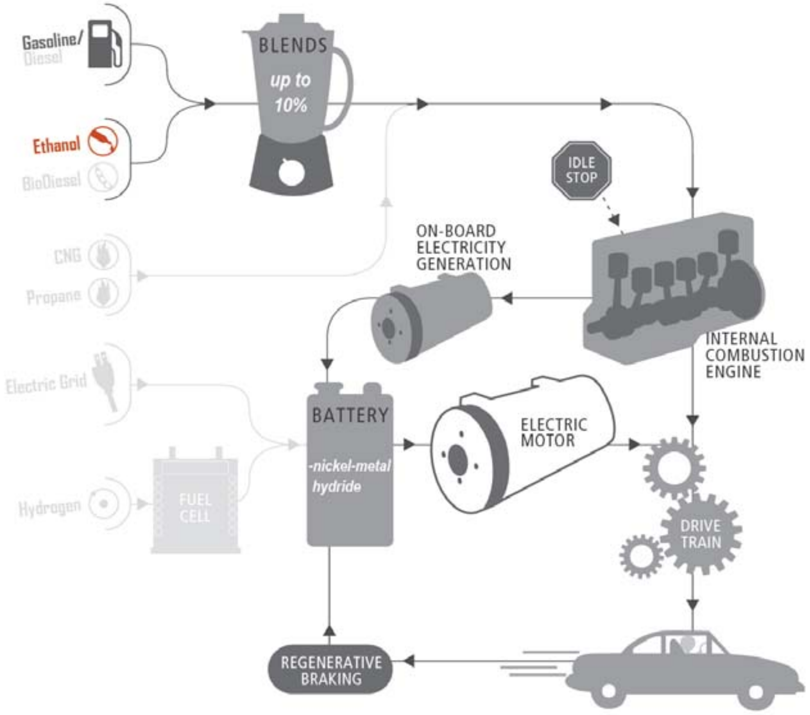
[2] See Appendix A for a full description of the U.S. Department of Energy (U.S. DOE) definition of an AFV. See Table 4 in Appendix A for a comparison of alternative fuels identified in this report with those identified as alternative fuels by the U.S. DOE.

Figure 1: Schematic of Alternative Fuel Vehicle Components



Source: DVRPC, 2011.

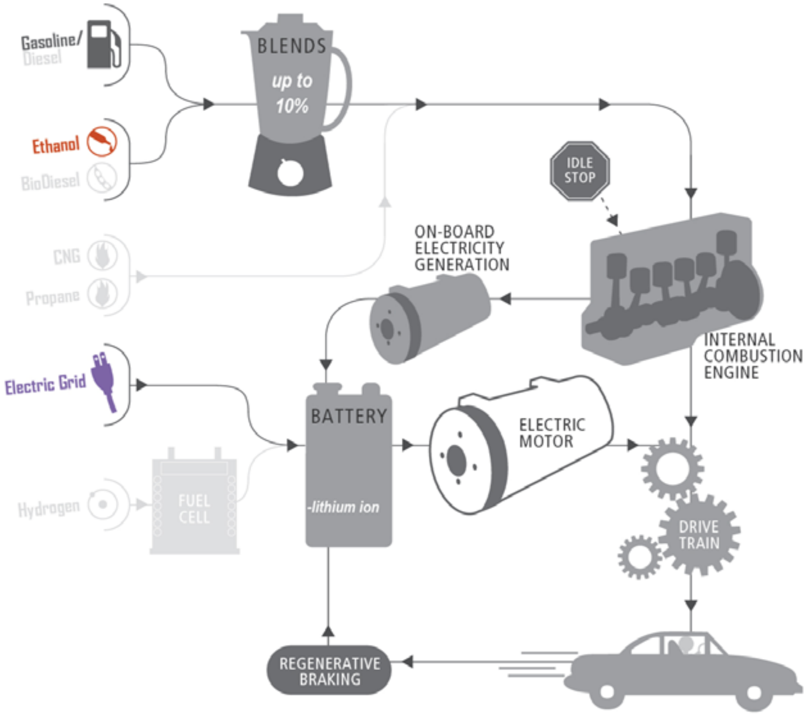
Figure 2: Schematic of Alternative Fuel Vehicle Components in a Hybrid Electric Vehicle



Source: DVRPC, 2011.

Figure 2, above, shows the configuration of a hybrid electric vehicle, such as the Toyota Prius. It is a gasoline-fueled vehicle using both an internal combustion engine and an electric motor to drive the vehicle's wheels. The electric motor is powered by batteries that are charged using an on-board generator. It also has controls to turn the internal combustion engine off when the vehicle is stopped ("idle stop").

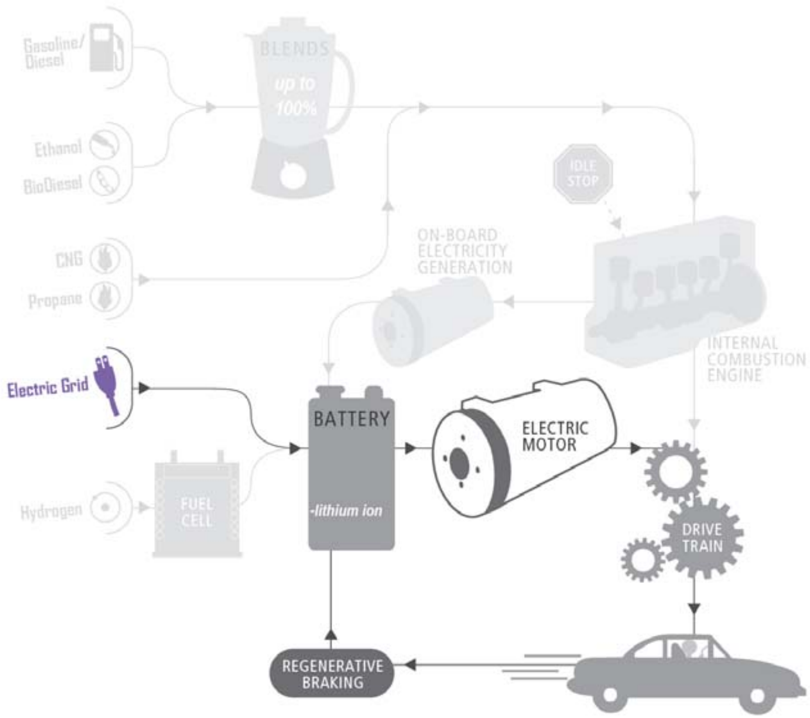
Figure 3: Schematic of Alternative Fuel Vehicle Components in a Plug-In Hybrid Electric Vehicle



Source: DVRPC, 2011.

Figure 3, above, shows the schematic of a plug-in hybrid electric vehicle, such as General Motors' Chevrolet Volt. It is powered by an electric motor using a battery charged by plugging the car into the grid. If the battery becomes discharged in use, an on-board gasoline-fueled internal combustion engine (ICE) recharges the battery via a generator. When the vehicle commands more power than the electric motor can provide, the on-board gasoline-fueled ICE directly assists in driving the wheels.

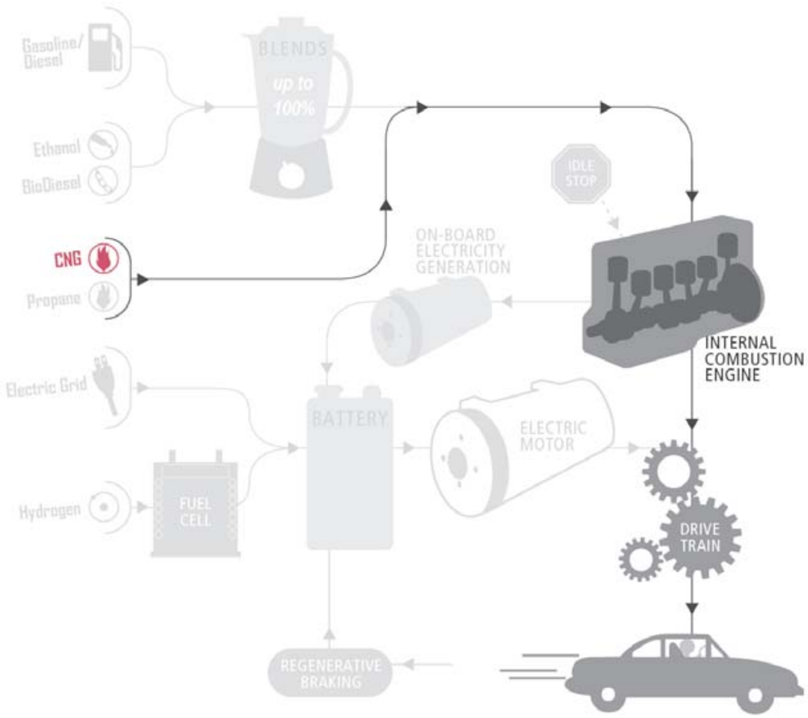
Figure 4: Schematic of Alternative Fuel Vehicle Components in an All-Electric Vehicle



Source: DVRPC, 2011.

Figure 4, above, shows an all-electric vehicle, such as the Nissan Leaf. It is powered by an electric motor using a lithium ion battery charged by plugging in the car to the electricity grid.

Figure 5: Schematic of Alternative Fuel Vehicle Components in a Natural Gas Vehicle



Source: DVRPC, 2011.

Figure 5, above, shows a vehicle powered by compressed natural gas, such as the Honda Civic GX. It is powered by an internal combustion engine that burns natural gas instead of gasoline.

The Crux of the Challenge

The singular characteristic of energy use in the on-road transportation sector is that moving vehicles must carry their energy source with them to power their movement.[3] Thus, the most effective vehicle fuels meet two criteria: (1) the fuels have a high energy density (the amount of energy in a given volume or weight of fuel), and (2) the fuel is convenient to replenish in the vehicle (refueling is fast, easy, and readily available). Gasoline meets both these criteria better than any of the current alternatives; in a very small volume, a vehicle can hold enough gasoline to move itself several hundred miles, and it only takes a few minutes to replenish that fuel at any of a very large number of fueling stations.

This report indicates the following:

- While some liquid biofuels have an energy density approaching that of gasoline, and can be replenished very quickly in the vehicle, their production has environmental impacts that in some cases approach or exceed those of gasoline production, and they do not yet have a distribution network approaching that of gasoline.
- Battery-powered, electric-powered vehicles do not yet have an energy density that allows a vehicle range approaching that of the gasoline-powered vehicle, and refueling time (that is, recharge time) is significantly longer than it is for gasoline. While in theory these vehicles could be refueled anywhere the electricity grid extends, the siting and expense of refueling infrastructure remains a barrier (e.g., for those in dense urban areas without off-street parking). Emissions from these vehicles depend on the source of the electricity used to charge them. Battery production has significant negative impact on the environment.
- Natural gas and propane are inexpensive fuels, and refueling is relatively quick. However, the energy density of these fuels is low, and there is not a wide network of refueling stations. They are well-suited for vehicle fleets that start and end the day in a central location where refueling can take place. Production of these fuels has significant negative impact on the environment.
- Hydrogen, which provides energy for fuel cell electric vehicles, can achieve a fast refueling time, but the energy density is very low. Production of hydrogen is currently relatively expensive, and is sourced from fossil fuels with significant negative environmental impact.

A successful transition away from our petroleum-based road transportation system will require a combination of technological advances, such as improvements in production of biofuels, improvements in battery storage, and faster battery recharge times.

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[3] Limited exceptions include electrified rail and trolleys, and electric buses and rail powered by catenary electricity.

AFVs in the United States

As Table 1 below indicates, fewer than 700,000 of the 229,000,000 vehicles (about 0.3 percent) in use are AFVs (this number excludes HEVs). Many of these are fleet vehicles, fueled at a central facility run by the fleet operator.

Table 1: Number of Alternative Fuel Vehicles in Use in the United States (2008)

Fuel	Number of vehicles (2008)	Share (2008)
Ethanol, 85 percent (E85)[a]	450,327	58.06%
Liquefied Petroleum Gas (LPG)	151,049	19.47%
Compressed Natural Gas (CNG)	113,973	14.69%
Electric	56,901	7.34%
Liquefied Natural Gas (LNG)	3,101	0.40%
Hydrogen	313	0.04%
Other Fuels	3	0.00%
Total	**775,667**	

Note: The alternative fuel vehicles (AFVs) included in the EIA breakdown do not include certain vehicles that the Delaware Valley Regional Planning Commission has chosen to include in this study, such as hybrid electric (gas and diesel), as these are not considered AFVs according to the EIA.

[a] This includes only those E85-capable vehicles "believed to be used as AFVs, primarily fleet-operated vehicles; excludes other vehicles with E85-fueling capability." Fuel use data provided in the same source table indicates these vehicles tend to have much lower VMT than their gasoline-fueled counterparts.

Source: U.S. Energy Information Administration (EIA), *Annual Energy Review 2008,* Table 10.5, http://www.eia.gov/FTPROOT/multifuel/038408.pdf (accessed April 11, 2011).

Federal and State Support for AFVs

There are several federal-, state- and regional-level policies and programs to encourage or require the development of AFVs that may have a direct impact on the presence of alternative fuels and vehicle technologies in the DVRPC region.

The U.S. Environmental Protection Agency's (U.S. EPA) Renewable Fuels Standard 2 (RFS2)[4] requires blending of 36 billion gallons of renewable fuel into transportation fuel by 2022. This is projected to meet seven percent of total annual gasoline and diesel consumption that year. The U.S. DOE anticipates that—largely due to RFS2—the share of renewable fuels in the transportation sector will increase from less than two percent of the total to approximately nine percent by 2030.

The Commonwealth of Pennsylvania mandates in-state production and sale of cellulosic ethanol fuel, as well as biodiesel, through the Biofuel Development and In-State Production Incentive Act of 2008. The Act mandates that specified levels of ethanol and biodiesel be blended in all

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[4] U.S. Environmental Protection Agency, "Renewable Fuel Standard (RFS)," last modified October 13, 2010, http://www.epa.gov/otaq/fuels/renewablefuels/index.htm.

gasoline and diesel fuel sold in the state when in-state production reaches specified thresholds, thus guaranteeing a market for Pennsylvania-produced biofuels.[5]

The Northeast/Mid-Atlantic Low Carbon Fuels Standard Program (LCFS)[6] is being developed by 11 Northeast and Mid-Atlantic states, including Pennsylvania and New Jersey. The current proposed LCFS is a market-based program that would require Northeast/Mid-Atlantic fuel suppliers to reduce the carbon intensity of fuels supplied to the region over time. The 11 participating states are currently developing and reviewing an economic analysis of the proposed program.

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[5] In Pennsylvania, Act 78 of 2008 developed volume standards that establish percentages of cellulosic ethanol required in all gasoline sold once in-state production volumes have been met. Act 78 requires "All gasoline sold or offered for sale to ultimate consumers…contain at least 10% cellulosic ethanol by volume as determined by an appropriate environmental protection agency or American Society for Testing Materials standard method of analysis one year after the in-state production volume of 350,000,000 gallons of cellulosic ethanol has been reached or sustained for three months on an annualized basis…"

[6] Northeast States for Coordinated Air Use Management, "Regional Low Carbon Fuel Standard Program: An Overview of the Northeast and Mid-Atlantic States Initiative," last modified January 6, 2010, http://www.nescaum.org/topics/low-carbon-fuels.

Issues Associated with Expanded Use of AFVs

There are a number of critical issues associated with the widespread use of AFVs. These issues, outlined in Figure 6 on page 14, include fuel production, storage, and distribution, as well as vehicle range. In addition, the cost of vehicles, fuels, and refueling infrastructure is also important. These issues are discussed in greater detail in the following pages.

Fuels: Production, Distribution, Refueling, and Cost

There are four major issue areas associated with the fuels used to power AFVs: production, distribution, refueling, and cost. This section provides an overview of these issues. Note that subsequent sections will provide additional detail and references for each fuel.

Fuel Production

The production impacts of fuels used to power AFVs are defined here as the environmental and economic costs associated with bringing the fuel from its source to the distribution system. Depending on the fuel, this involves generation (e.g., for hydrogen and electricity), extraction (e.g., for petroleum-based fuels), or cultivation of raw materials (e.g., for biofuels), and their refinement and conversion into useable vehicle fuels. The specific production method used for a particular fuel greatly affects lifecycle emissions.[7] For example, the GHG content of electricity depends upon the carbon content of the fuel used for its generation.

The key issues associated with the four major categories of renewable fuels being produced today are outlined below. The fuels are biofuels, natural gas, grid electricity, and hydrogen.

> **Biofuels**: Biofuels production for the transportation sector involves cultivating a feedstock either through growing a crop (including algae) or collecting organic waste products, and then converting and refining that feedstock into a fuel. The energy used and emissions generated to produce both the feedstock and to refine the feedstock into fuel must be taken into account when calculating the impacts of biofuel production. The net energy and GHG emissions associated with biofuel production have received high-profile analysis. Production of ethanol from corn, for example, produces a GHG lifecycle improvement over gasoline ranging from only 0 to 14 percent, depending on land use and production methods. In addition, concerns have been raised by many observers that using food crops for fuel production may threaten valuable agricultural land and increase the cost of food.
>
> **Natural Gas**: Natural gas is predominately a domestically produced fuel, which is often cited as a major selling point. Natural gas trapped in sub-surface porous rock reservoirs is extracted via drilling or by water injection, known as "fracking." Oil and gas reservoirs also contain natural gas, with processing required to separate the gas from petroleum liquids and to remove contaminants. Extraction of natural gas has many potential environmental impacts, including damage to the landscape, destruction of wildlife habitat, and pollution of drinking water. The ongoing controversy in Pennsylvania regarding the Marcellus shale is about natural gas extraction.

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[7] Lifecycle GHG emissions are the aggregate quantity of GHGs related to the full fuel cycle, including all stages of fuel and feedstock production and distribution, from feedstock generation and extraction through distribution and delivery and use of the finished fuel. (Source: U.S. Environmental Protection Agency, "EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels," last modified January 12, 2011, http://www.epa.gov/oms/renewablefuels/420f09024.htm.)

Grid Electricity: Electricity can be generated from a wide variety of energy sources, including combustion of fossil fuels or biomass, nuclear fission, wind, hydropower, solar energy, wave and tidal energy, and other sources. The mix of sources for a particular user depends upon the generation resource connected to the sub-grid that serves that user. According to the U.S. EPA's eGRID,[8] the 2005 resource generation mix for the DVRPC region, served by the RFC East sub-region, is 45 percent coal, 38 percent nuclear, 9.6 percent gas, 4 percent oil, and approximately 1 percent each of other fossil fuels, hydropower, and biomass. Wind comprised 0.1 percent of the power. The annual GHG emissions rate for our region is 1,224 pounds carbon dioxide equivalent (CO_2e)/MWh.[9]

Hydrogen: Hydrogen is produced by transforming hydrogen-rich materials such as water and hydrocarbons, most of which can be domestically sourced. However, producing hydrogen at a competitive price is a key challenge to its widespread use as a fuel. Several processes are currently used and under development to produce hydrogen, with the costs of production and GHG emissions varying for each method.[10] Currently, steam methane (natural gas) reforming (SMR) accounts for about 95 percent of the hydrogen produced in the United States.[11] SMR produces almost 12 kilograms (kg) CO_2e of GHGs for every kg of hydrogen produced. In addition, the hydrogen produced by SMR contains less energy than the energy required to produce it.[12]

Fuel Distribution and Refueling Infrastructure

An extensive distribution and refueling infrastructure is in place for gasoline and diesel fuel, including pipelines, trucks, and filling stations. This section provides an overview of this infrastructure for the four fuel types noted above. More detail for each fuel may be found in subsequent sections.

Biofuels: In theory, biofuels could be distributed through a pipeline, trucking, and filling station system similar to that used for petroleum. However, due to various incompatibilities of some biofuels with elements of that system, significant changes or investments in parallel capacity would need to be made. In addition, without sufficient demand, investment in fueling infrastructure is not economically viable.

Natural Gas: An existing natural gas distribution system extends across much of the region. Adding vehicle fueling stations to this network is technically feasible. However, without broad demand for natural gas as a vehicle fuel, it is not financially feasible. Thus, most natural gas fueling is limited to dedicated fleet fueling.

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[8] U.S. Environmental Protection Agency, "eGRID2007 Version 1.1: Year 2005 Summary Tables," last modified December, 2008, http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_SummaryTables.pdf.

[9] This incorporates a grid loss factor of 6.409 percent. (Source: S. Rothschild and A. Diem, "The Value of eGRID and eGRIDweb to GHG Inventories," prepared for the U.S. Environmental Protection Agency, Washington, DC, December 2009, http://www.epa.gov/cleanenergy/documents/egridzips/The_Value_of_eGRID_Dec_2009.pdf.)

[10] U.S. Department of Energy, Fuel Cell Technologies Program, "Fuel Cells," November 2010, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_production.pdf.

[11] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "What is Hydrogen?," last modified January 27, 2011, http://www.afdc.energy.gov/afdc/fuels/hydrogen_what_is.html.

[12] P. L. Spath and M. K. Mann, "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming," prepared for the National Renewable Energy Laboratory, Golden, Colorado, Revised February 2001, http://www.nrel.gov/docs/fy01osti/27637.pdf.

Grid Electricity: The electric grid brings electricity to virtually all parts of the region. Current battery technology generally requires recharge times measured in hours, not minutes. Thus, recharging stations are most conveniently located where vehicle owners spend a lot of time, such as home or work.[13] Also, because of the length of recharging time, the recharging infrastructure needs to be much larger (one gas pump can service hundreds of cars per day; one charging station can service only a handful). This requires a very large capital investment. In addition, the implications for the electric grid for vehicle charging are unclear.

Hydrogen: Currently hydrogen is distributed through tanks and mobile units. A pipeline infrastructure would be the most cost-effective way to distribute the fuel, though developing this infrastructure would be very costly. Research is actively being conducted on storing hydrogen in solid compounds; however, these remain at the lab scale.

The absence of a robust public infrastructure for fueling AFVs is indicated by Table 2, which shows only 38 public refueling stations in the region for alternative fuels, less than 2 percent of the number of gasoline stations in the region.[14,15]

Table 2: Refueling Stations in the Delaware Valley Regional Planning Commission Region

Fuel	Number of Public Refueling Stations	Percent of Gasoline Stations
Gasoline	1314	--
Biodiesel (B20 or >)	2	0.15%
Compressed Natural Gas (CNG)	5	0.38%
Ethanol (E85)	4	0.30%
Liquefied Petroleum Gas (LPG)	11	0.84%
Electric	0	0.00%
All other than gasoline		1.67%

Sources: U.S. Department of Energy Alternative Fuels and Advanced Vehicles Data Center, "Alternative Fueling Station Locator," last modified January 14, 2010, http://www.afdc.energy.gov/afdc/locator/stations/; U.S. Census Bureau, *2007 Economic Census*, http://www.census.gov/econ/census07/.

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[13] One concept proposed to address this barrier, championed by the company *Better Place*, is battery swapping. This would allow an EV user to physically change out a depleted battery with a fully charged one at a battery service station. This concept has largely faced skepticism from vehicle manufacturers, who do not support the level of standardization needed to make it successful (http://www.euractiv.com/en/innovation/better-place-ceo-biggest-obstacle-electric-cars-auto-industry-scepticism-interview-500451).

[14] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Alternative Fueling Station Locator," last modified January 14, 2010, http://www.afdc.energy.gov/afdc/locator/stations/.

[15] In addition, there are 23 private alternative fueling stations, most of which are government owned and operated.

Cost of Fuel

In order for an AFV to be competitive with traditional gasoline- or diesel-powered ICEs, the fuel must be competitive on a cost-per-mile basis. Currently, this means that renewable fuels must be able to achieve a range of \$2.00 to \$3.00 per gallon gasoline equivalent (untaxed). As shown in Table 3, as of October 2010 the only alternative fuels that are cost competitive with traditional fuel within the DVRPC region are CNG and biodiesel (B20), at \$2.11 and \$2.97 per gallon, respectively.

Table 3: October 2010 Energy Equivalent Prices of Various Fuels

Fuel	Cost per Gallon	Cost of the Energy-Equivalent per Gallon of Gasoline (GGe)	Fuel cost per Mile for 30 Miles per Gallon (MPG) Car (¢ per mile)
Gasoline	\$2.72	\$2.72	9.1
Diesel	\$3.11	\$2.72	9.1
Compressed Natural Gas (CNG) (\$/GGe)	\$2.11	\$2.11	7.0
Ethanol (E85)	\$2.43	\$3.38	11.3
Propane	\$3.10	\$4.23	14.1
Biodiesel (B20)	\$2.97	\$2.70	9.0
Biodiesel (B99-B100)	\$3.59	\$3.37	11.2
Electricity	—	—	3.7

Note: Central Atlantic average price. Electricity cost assumes 3 miles per kWh and an electricity cost of 11 cents per kWh.

Sources: U.S. Department of Energy, "Clean Cities Alternative Fuel Price Report," last modified March 1, 2011, http://www.afdc.energy.gov/afdc/price_report.html; GGe calculations by Delaware Valley Regional Planning Commission based on U.S. Department of Energy (U.S. DOE) information, except for CNG, which comes from U.S. DOE Clean Cities Alternative Fuel Price Report.

Other Challenges

In addition to the issues directly associated with fuel production, distribution, refueling, and cost discussed above, there are several related challenges.

Energy Capacity: Some fuels, including hydrogen and electricity, are difficult to store on a vehicle in large enough quantities to meet power or range requirements for some applications. This is particularly challenging for heavy trucks; there are no current viable technologies for replacement of ICEs in heavy vehicles except for very short distances.

Vehicle Availability: Many AFVs are on the horizon for future development. The vast majority of AFVs made available over the past decade were flex-fuel E85 (85 percent ethanol fuel mix) vehicles, though the majority of these may not have been driven using E85 fuel. HEVs,[16] which are not included in the U.S. DOE's definition of an AFV, made up an overwhelming majority of the AFVs sold in the United States over the past decade. However, traditional AFVs and HEVs combined still only make up approximately two percent of total on-road vehicles in use today. Furthermore, General Motors' (GM) Chevrolet Volt and Nissan's Leaf were not available at launch to residents of the DVRPC region.

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[16] 32 models of HEVs were available in the United States in 2010; 1,888,971 HEVs were sold in the United States between 1999 and 2010 (http://www.afdc.energy.gov/afdc/data/docs/hev_sales.xls).

Vehicle Cost: In part because of new technologies, and in part due to a smaller scale of production, many AFVs currently cost significantly more to own and operate than their conventional gasoline-powered counterparts. This cost difference narrows as the price of new technology decreases and the price of gasoline relative to other fuels increases. Part of the difference is made up for by tax credits. However, the longevity of these credits is questionable in the current political environment.

Ease and Familiarity of Use: Because AFVs are new, they may have some operational features that are unfamiliar, and may require training or public education and awareness campaigns to overcome apprehension naturally associated with the adoption of new technology.

Figure 6: Summary of Alternative Vehicles Issues

Fuel or Vehicle Type			Description	Vehicle Range	Ease of refueling	Cost
Powered by an internal combustion engine (ICE) using a fuel other than gasoline	Biofuels	Ethanol	Ethanol is an alcohol most commonly produced by fermenting sugars found in sugar-starch feedstocks. Potential for production from cellulosic feedstocks. General used blended with gasoline as E85 (85 percent ethanol and 15 percent gasoline) or other blends.	Ethanol and biodiesel have energy densities comparable to gasoline.	Refueling time for biodiesel and ethanol is comparable to diesel and gasoline. However, the distribution and refueling infrastructure required for ethanol and biodiesel is incompatible with the existing system, so a parallel system will have to be constructed at a high cost. As a result, there is limited access to refueling stations for biodiesel and ethanol.	Slightly more expensive than counterpart fossil fuel on a gallon equivalency basis.
		Biodiesel	Biodiesel is a form of diesel fuel produced from new or recycled vegetable oils or animal fats. Like ethanol, biodiesel is most commonly used blended with its petroleum diesel as B20 (20 percent biodiesel and 80 percent conventional diesel) or other blends.			
	Fossil Fuels	Natural Gas	Natural gas is a clear, odorless gas that is a mixture of hydrocarbons, composed primarily of methane produced either by gas wells or in conjunction with crude oil production. For light-duty vehicles natural gas is primarily used in compressed gaseous state, or Compressed Natural Gas (CNG); for heavy-duty vehicles natural gas is used as a liquid, or Liquefied Natural Gas (LNG).	Energy density of natural gas and propane is low compared to gasoline and diesel.	Similar to biodiesel and ethanol, the refueling time for natural gas and propane is comparable to gasoline and diesel. While pipeline infrastructure has been developed for natural gas, refueling stations are rare. Natural gas and propane may be best suited for fleets of limited range.	
		Propane	Propane (also known as Liquefied Petroleum Gas [LPG]) is a byproduct of natural gas processes and petroleum refining.			
Powered by an electric motor		Grid Electricity	Electric-powered motor vehicles can be charged in several ways and using several configurations of vehicle technologies. Some connect directly into the electric grid, some utilize an ICE-assisted generator, and some convert hydrogen into electricity using a fuel cell.	Range without ICE assist is very low compared to gasoline at 40–100 miles per charge.	Refueling times and charging locations for grid-charged electric vehicles from 30 minutes to 12 hours depending on voltage. Location of refueling stations is problematic. On-board charging systems have short refueling times.	Grid electricity lower cost than gasoline. On-board ICE, low. Hydrogen, high.
		On-board ICE-Powered Generator				
		On-board Hydrogen Fuel Cell				
Hybrid vehicle		Electric + Gasoline or Diesel	Hybrid electric vehicles are powered by a combination of electric motor and ICE.	Range comparable with traditional vehicle.	Same as for traditional ICE.	Lower cost due to higher fuel economy.

Source: DVRPC, 2011.

Conclusion

A successful transition away from our petroleum-based road transportation system will require a combination of technological advances, such as improvements in production of biofuels, improvements in battery storage, and faster battery recharge times. The key findings of DVRPC's *Ready to Roll?* report include:

- Some liquid biofuels have an energy density approaching that of gasoline, and can be replenished very quickly in the vehicle, making them strong candidates as replacement fuels. Ethanol and biodiesel can be produced using feedstocks and technology that results in significantly lower GHG emissions compared to gasoline and diesel. However, some methods of ethanol production pose environmental and economic impacts comparable to those of gasoline. In addition, the current pipeline and distribution network is much less extensive than for gasoline.

  To address these barriers:
  - continue research into low-cost biofuel production using production processes that have lower GHG emissions and environmental impacts than current processes;
  - develop policies regarding installing pipeline and distribution infrastructure for biofuels, including fueling pumps at gasoline stations and fleet fueling operations; and
  - encourage fleets to purchase biofueled vehicles in order to build demand.

- Natural gas and propane are widely available, affordable fuels, and refueling is relatively quick. GHG emissions are significantly lower than for gasoline. However, the energy density of these fuels is low, and there is not a wide network of refueling stations. Natural gas and propane are well suited for vehicle fleets that start and end the day in a central location where refueling can take place. Similar to gasoline, the production of these fuels has significant negative impact on the environment.

  To address these barriers:
  - develop policies to encourage purchase of natural gas vehicles and installing natural gas fueling infrastructure for fleets; and
  - develop policies to ensure transparency, cleaner extraction techniques, and proper safeguards to lessen the impacts of natural gas extraction and refinement.

- EVs do not yet have an energy capacity that allows a vehicle range approaching that of the gasoline-powered vehicle, and refueling time (charging time) is significantly longer than it is for gasoline. While in theory EVs could be refueled anywhere the electricity grid extends, the siting and expense of refueling infrastructure remains a barrier (e.g., for those in dense urban areas without off-street parking). Emissions from these vehicles depend on the source of the electricity used to charge them. Battery production has significant negative impact on the environment.

  To address these barriers:
  - continue research into increasing battery capacity and reducing charge time;
  - prepare the electric grid and pricing system for vehicle charging;
  - continue efforts to reduce GHG content of electricity; and
  - encourage appropriate fleet purchases of EVs.

- Hydrogen, which provides energy for fuel cell EVs, can achieve a fast refueling time, but the energy density is very low, requiring large on-board hydrogen storage capacities or short ranges. Production of hydrogen is currently relatively expensive, and is sourced from fossil fuels.

Detailed Summaries of Alternative Fuel Vehicle Fuels and Technologies

The feasibility with which AFVs can compete in the marketplace depends on a number of factors. This section provides a detailed discussion of these factors for the following key AFVs and technologies:

- Biofuels
  - Ethanol
  - Biodiesel
- Low-carbon fossil fuels
  - Natural gas
  - Propane
- Electric Vehicles
- Hydrogen Fuel Cell Vehicles
- Hybrid Electric Vehicles and Plug-In Hybrid Electric Vehicles

The performance parameters outlined below are used in this section to discuss the benefits and challenges associated with each fuel and vehicle technology.

Fuel production and distribution: This parameter discusses how the fuel is extracted, produced, manufactured, and distributed, and notes key environmental and economic impacts, including whether the fuel is produced within the region or domestically. In the case of electric vehicles, batteries are discussed under this parameter.

Fuel availability: This parameter addresses whether fueling/charging infrastructure is readily available, and what types of modifications or investments in infrastructure might be necessary. The existence of mandates for increasing availability of a fuel will also be discussed here.

Cost: This parameter addresses the relative price of AFVs and their fuels, including the relative costs of maintenance, compared to traditional models. This parameter will also assess the availability of external sources of funding to offset the incremental cost of AFVs.

Operating and maintenance costs: This parameter discusses the relative price of fuel and maintenance of an AFV compared to traditional models.

Infrastructure needs and compatibility with existing infrastructure: This parameter identifies any infrastructure in addition to fueling stations outlined in "fuel availability" needed to make an AFV operable (such as storage or alterations to the roadway). This parameter will also discuss any issues associated with parking an AFV.

Performance: This parameter discusses performance characteristics such as vehicle range, fueling time, acceleration, power, and cruise speeds relative to traditional models.

Fuel efficiency: This parameter addresses the energy content of a fuel and the relative energy needed for a particular vehicle technology.

Emissions impacts: This parameter discusses the impacts of a particular fuel or vehicle technology on GHG emissions, relative to petroleum-based ICEs. This parameter will assess both tailpipe emissions as well as those emitted during the production and distribution of a fuel. It will also discuss significant impacts on non-GHG emissions.

Safety: This parameter identifies any safety issues associated with a particular fuel or vehicle technology. These issues might include fuel toxicity, flammability, or localized environmental hazards posed by the production or use of a fuel that are a threat to public health and safety. This parameter also identifies safety concerns associated with the use of a vehicle, such as reduced noise level, performance in the case of a crash, or any first-response issues.

Ethanol

Definition

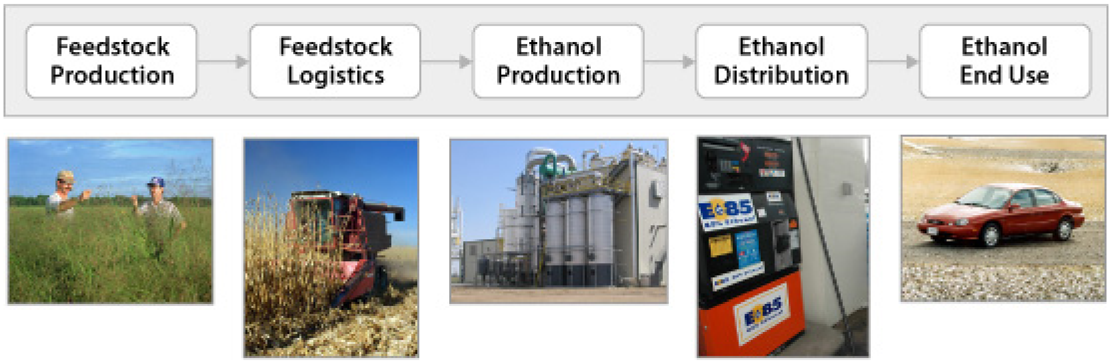
Ethanol fuel can power ICEs as a raw fuel, though it is considered an alternative fuel as a blend of 85 percent ethanol and 15 percent gasoline, also known as E85. The AFVs that can be powered with E85 are known as *flexible-fuel vehicles* (FFVs). FFVs have minor fuel system modifications from traditional ICEs that allow them to run on E85, gasoline, or any combination of the two fuels at up to 85 percent ethanol.

A lower blend of ethanol (typically 10 percent) with gasoline, also called gasohol or occasionally E10, is widely used at petroleum pumping stations in the United States to power traditional ICEs.[17] All gasoline vehicles sold in the United States since 1970 can run on gasohol.[18] The ethanol in these low-level blends serves to oxygenate the fuel and lower the emissions of vehicles.

Fuel Production and Distribution

Figure 7 indicates the steps involved in producing and distributing ethanol fuel. These steps include cultivation of biomass feedstock, transport of the feedstock to ethanol production facilities, production of ethanol, and distribution of the fuel through pipelines and trucks to the final point of providing ethanol to fueling stations for use by drivers. This section discusses these steps.

Figure 7: Ethanol Supply Chain Diagram



Source: U.S. Department of Energy Alternative Fuels and Advanced Vehicles Data Center, "Ethanol Basics," last modified July 10, 2009, http://www.afdc.energy.gov/afdc/ethanol/basics.html.

Ethanol is an alcohol that can be produced by fermenting sugars found in sugar-starch feedstocks (e.g. corn, sugar cane, beets, potatoes). Recent pilot-scale facilities have successfully produced ethanol from cellulosic feedstocks (e.g., woody crops, wood waste, switchgrass, agricultural residues, municipal solid wastes, as well as corn stover). In the United States, most ethanol is produced from sugar-starch feedstocks, primarily corn, although the U.S. DOE is actively researching the production of ethanol from cellulosic feedstocks. A primary concern with ethanol is the quantity of energy required to produce the fuel and the associated GHG emissions.

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[17] The widespread use of gasohol in fueling stations can be traced back to the 1990 Clean Air Act Amendments, which required the use of reformulated gasoline, or oxygenated fuel, for federally designated non-attainment areas, including the DVRPC region. The Energy Policy Act of 2005 requires an increasing amount of renewable fuel use, and as a result states have enacted mandates to promote the production of ethanol.

[18] U.S. Energy Information Administration, "Biofuels in the U.S. Transportation Sector," http://www.eia.doe.gov/oiaf/analysispaper/biomass.html (accessed April 11, 2011).

In addition, there is concern about the impact on the worldwide price and availability of food associated with using food crops and land to produce fuel.

Cellulosic feedstocks are significantly more difficult and costly to convert to ethanol than sugar-starch feedstocks, and are not yet able to be used at a commercial scale. However, cellulosic feedstocks are far more abundant than sugar-starch feedstocks and their production is less harmful to the environment, as they can be grown on marginal lands not suitable for other crops. Overall, cellulosic feedstocks require less energy, fossil fuels, and petroleum-derived fertilizer to grow, collect, and convert to ethanol than do sugar-starch feedstocks.[19]

Currently, no ethanol feedstock cultivation or fuel production takes place in the DVRPC region. Statewide, however, Pennsylvania mandates in-state production and sale of cellulosic ethanol fuel, as well as biodiesel, through the Biofuel Development and In-State Production Incentive Act of 2008. As noted above, the Act mandates that specified levels of ethanol and biodiesel be blended in all gasoline and diesel fuel sold in the state when in-state production reaches specified thresholds, thus guaranteeing a market for biofuels produced in Pennsylvania.[20]

Ethanol producers face a fundamental distribution challenge: most ethanol plants are concentrated in the Midwestern United States, where corn is grown, but gasoline consumption is highest along the East and West Coasts.

The U.S. Department of Agriculture estimates that 90 percent of ethanol used today is transported by rail or truck and the remaining 10 percent by barge or pipeline.[21] While pipeline distribution of ethanol would be less expensive and use less energy, ethanol has been shown to corrode pipelines and absorb water if used in existing pipelines. Therefore, pipeline distribution of ethanol would require development of a dedicated pipeline system or require significant changes to existing pipelines.[22]

Fuel Infrastructure and Availability

There are currently four E85 refueling stations in the DVRPC region: one in Shemong, NJ (Burlington County); and three in southeastern PA–Philadelphia, Exton (Chester County), and Jeffersonville (Montgomery County).[23] Figure 8 shows proposed locations for additional refueling stations planned as part of the Pennsylvania E85 Corridor Project.

Fuel Cost

The price of ethanol fuel varies from region to region. As noted in Table 3 (see page 12), in October 2010 gasoline was approximately 12 percent more expensive per gallon than ethanol fuel for the Central Atlantic region ($2.43 per gallon of E85 versus $2.72 per gallon of gasoline).

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[19] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Cellulosic Ethanol Feedstocks," last modified July 10, 2009, http://www.afdc.energy.gov/afdc/ethanol/feedstocks_cellulosic.html.

[20] In Pennsylvania, Act 78 of 2008 developed volume standards that establish percentages of cellulosic ethanol required in all gasoline sold once in-state production volumes have been met. Act 78 requires "All gasoline sold or offered for sale to ultimate consumers…contain at least 10% cellulosic ethanol by volume as determined by an appropriate environmental protection agency or American Society for Testing Materials standard method of analysis one year after the in-state production volume of 350,000,000 gallons of cellulosic ethanol has been reached or sustained for three months on an annualized basis…"

[21] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Ethanol Distribution," last modified December 29, 2010, http://www.afdc.energy.gov/afdc/ethanol/distribution.html.

[22] Ibid.

[23] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Alternative Fueling Station Locator."

However, because a gallon of ethanol fuel contains less energy than a gallon of gasoline, resulting in more fuel needed to travel the same distance, the cost for the energy equivalent of one gallon of gasoline is $3.38 per gallon, 24 percent higher than gasoline.

Capital Cost and Availability
According to the U.S. DOE, there are almost eight million FFVs on U.S. roads today. FFVs have historically been the least expensive of AFVs, costing only slightly more than their gasoline counterparts. Vehicle costs for FFV models are similar in price range to gasoline models. There were 34 E85 FFVs available in the 2010 model year. More than 30 models have been available each year since 2007.[24]

As noted above, FFVs can run on any blend of ethanol and gasoline up to E85. Because most FFVs are not available as gasoline-only models and can run solely on gasoline, many FFV owners are either unaware that they are driving vehicles that can be powered by E85 or choose to fuel them only with gasoline rather than seek out E85 refueling stations. Thus the sales of FFVs do not reflect or predict the sales of E85.

Vehicle Performance and Fuel Efficiency
E85 contains about 30 percent less energy per gallon than gasoline. Vehicles running on E85 have a lower driving range per gallon than traditional gasoline-powered vehicles because the energy content of a gallon of ethanol is lower than gasoline, and it takes 1.39 gallons of E85 to equal one gallon of gasoline. The lower energy density of E85 results in a shorter driving range for E85-powered FFVs. For instance, an FFV that can travel 400 miles on a tank of gasoline would travel 287 miles on a tank of E85.

Emissions Impacts
Biofuels are expected to contribute significantly to meeting the volume mandates of the Energy Independence and Security Act of 2007 through year 2022. The U.S. EPA conducted an analysis comparing the 30-year lifecycle GHG emissions from biofuels (including biodiesel and ethanol) to the lifecycle GHG emissions for the gasoline or diesel it is expected to replace.[25] The U.S. EPA defines lifecycle emissions as “the aggregate quantity of GHGs related to the full fuel cycle, including all stages of fuel and feedstock production and distribution, from feedstock generation and extraction through distribution and delivery and use of the finished fuel.” The 30-year lifecycle GHG emissions for ethanol fuels versus those from gasoline range from 34 percent *higher* than gasoline (for corn ethanol using coal dry mill)[26] to 124 percent *lower* than gasoline lifecycle emissions (ethanol produced from switchgrass). Ethanol produced from cellulosic feedstocks generally has higher reduction percentages compared to gasoline than sugar-starch feedstocks. For regulatory purposes, the U.S. EPA has determined that corn-based ethanol meets the legal threshold of having GHG emissions at least 20 percent lower than gasoline.

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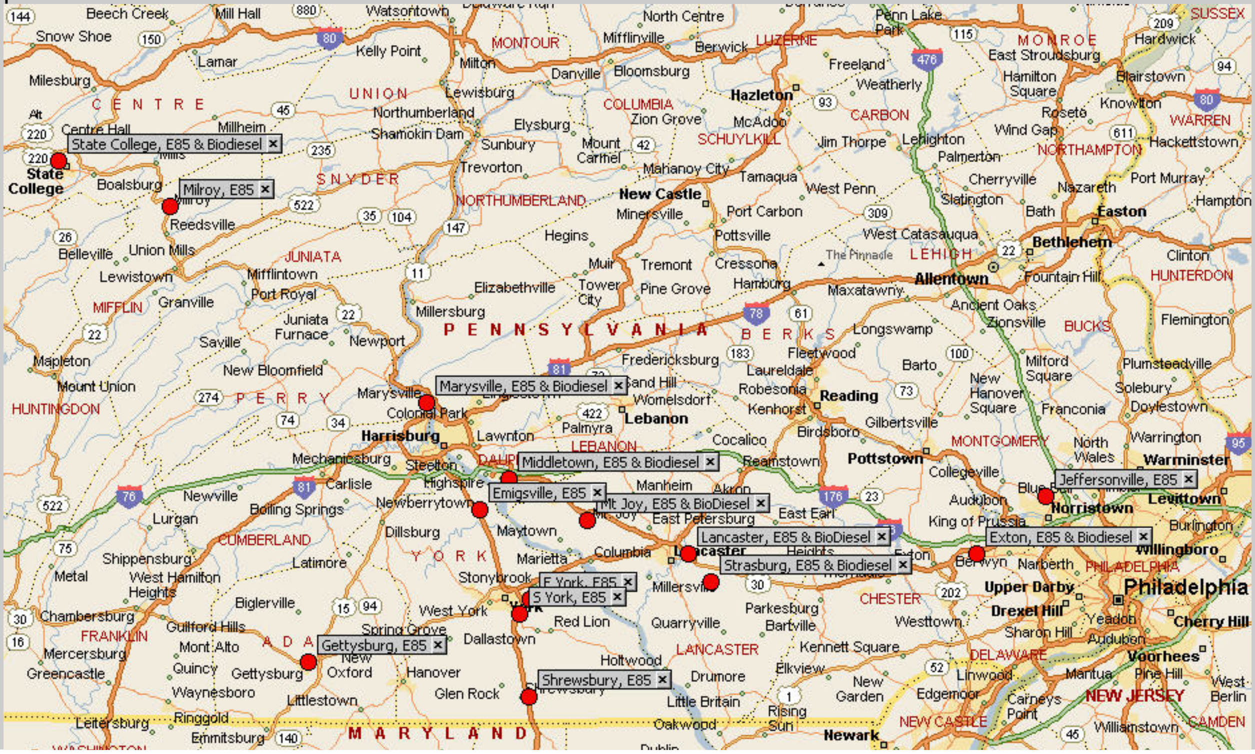
[24] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, “Light-Duty Vehicle Search,” last modified September 15, 2010, http://www.afdc.energy.gov/afdc/vehicles/light?fuel_type_code=E85_GSLN.

[25] U.S. Environmental Protection Agency, “EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels,” last modified January 12, 2011, http://www.epa.gov/oms/renewablefuels/420f09024.htm.

[26] For a description of dry mill and wet mill ethanol production plants, see http://www.afdc.energy.gov/afdc/ethanol/production_starch_sugar.html.

Figure 8: Pennsylvania E85 Corridor Project

The Pennsylvania E85 Corridor Project consists of 14 E85 refueling stations positioned along a 100-mile east–west corridor connecting State College to Philadelphia. The project was coordinated by the Philadelphia Clean Cities Coalition, which received an Alternative Fuels Incentive Grant (AFIG) from the Pennsylvania Department of Environmental Protection and a U.S. Department of Energy (U.S. DOE) grant in 2006. Total project costs were $914,800, with 70 percent supported by the AFIG grant and 30 percent from the U.S. DOE.



Source: Greater Philadelphia Clean Cities Coalition, 2007.

A 2008 study by the National Renewable Energy Laboratory (NREL) compared the emissions from using E85 versus gasoline in an FFV. The NREL study found that most emissions decreased or showed no statistically significant difference with E85 compared with gasoline, while methane emissions increased.

Safety

Like gasoline, ethanol and its vapors are highly flammable. Moreover, the addition of ethanol to gasoline may affect the natural attenuation of BTEX (benzene, toluene, ethylbenzene, and xylenes), a group of volatile organic compounds (VOCs) found in gasoline.[27] A slowing of the natural attenuation process in groundwater and soil may have an impact on public drinking water supplies.

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[27] D. W. Rice and Rosanne D. Depue, “Environmental Assessment of the Use of Ethanol as a Fuel Oxygenate: Subsurface Fate and Transport of Gasoline Containing Ethanol,” Report to the California State Water Resources Control Board, October 2001, http://www-erd.llnl.gov/ethanol/etohdocII/misc/ETOHExSm.pdf.

Biodiesel

Definition

Biodiesel is a form of diesel fuel produced from vegetable oils, animal fats, or recycled restaurant greases. Production from other sources, including algae, is emerging. Biodiesel has similar physical properties to petroleum diesel, and can be blended with diesel fuel in any proportion. Biodiesel blends are expressed as the percentage in which it is contained in the fuel. B100, for example is 100 percent biodiesel, with no petroleum diesel in its content. Common blends of biodiesel include B2, B5, and B20. Blends of B20 or higher (including B100) qualify for alternative fuel credits under the Energy Policy Act of 1992.[28]

Fuel Production and Distribution

The United States is the second-largest producer and user of biodiesel in the world. More than 320 million gallons of biodiesel were consumed in the United States in 2008.[29] According to the National Biodiesel Board, an industry group, U.S. production of biodiesel increased from 112 million gallons in 2005 to 315 million gallons in 2010.[30]

In the United States, biodiesel is produced primarily from soybean oil, though biodiesel can also be made from other agricultural products such as rapeseed oil (canola) and other feedstocks, including vegetable oils, tallow and animal fats, and restaurant waste and trap grease.[31] The U.S. DOE estimates that there is enough virgin soy oil, recycled restaurant grease, and other feedstocks available in the United States to provide feedstock for about 1.7 billion gallons of biodiesel per year, which would provide approximately 5 percent of on-road diesel used in the United States.[32]

As of August 2009, Pennsylvania biodiesel producers had an annual production capacity of 110 million gallons. The biodiesel produced in Pennsylvania is refined from a number of feedstocks, including animal fats (29 percent of total production), vegetable oil such as soy or canola (26 percent), greases (24 percent), and beef tallow or solid animal fats (21 percent).[33]

Biodiesel is distributed from the point of production by truck, train, or barge. Biodiesel is most commonly distributed to the customer or retail fueling station pre-blended. Pipeline distribution of biodiesel, which would be the most economical option, is still in the experimental phase.

Fuel Infrastructure and Availability

As noted in the section on ethanol, above, the Pennsylvania Biofuels Development and In-State Production Incentive Act of 2008 mandates that specified levels of biodiesel be blended in all

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[28] U.S. Department of Energy, "Just the Basics: Biodiesel," August, 2003, http://www1.eere.energy.gov/vehiclesandfuels/pdfs/basics/jtb_biodiesel.pdf.

[29] U.S. Energy Information Administration, "Alternatives to Traditional Transportation Fuels 2008," Table C1, http://www.eia.doe.gov/cneaf/alternate/page/atftables/afv_atf.html#consumption (accessed April 11, 2011).

[30] National Biodiesel Board, "FAQs," http://www.biodiesel.org/resources/faqs/ (accessed April 11, 2011).

[31] U.S. Energy Information Administration, "Biofuels in the U.S. Transportation Sector."

[32] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Biodiesel Production," last modified December 28, 2010, http://www.afdc.energy.gov/afdc/fuels/biodiesel_production.html.

[33] Pennsylvania Department of Agriculture, Pennsylvania Department of Transportation, "Report to the Pennsylvania General Assembly on 2% Biodiesel Infrastructure Certification," August 2009, ftp://ftp.dot.state.pa.us/public/bureaus/Press/Biodiesel.pdf.

diesel fuel sold in the state when in-state production reaches specified thresholds, thus guaranteeing a market for Pennsylvania-produced biodiesel. According to the threshold triggers, as of January 1, 2010, all diesel fuel sold in Pennsylvania contains two percent biodiesel (B2) by volume. The mandated biodiesel blend level will increase according to the following schedule[34]:

- 5 percent biodiesel by volume one year after in-state production of biodiesel reaches 100 million gallons;
- 10 percent biodiesel by volume one year after in-state production of biodiesel reaches 200 million gallons; and
- 20 percent biodiesel by volume one year after in-state production of biodiesel reaches 400 million gallons.

Biofuel blends that constitute a renewable fuel (blends of B20 and higher) are not widely available in the region, however. Currently, there are only two public refueling stations selling biodiesel blends of B20 or greater in the DVRPC region, both located in Pennsylvania.[35] Biodiesel and biodiesel blends are being purchased by school districts and municipalities for use in school buses and other fleet vehicles. The Energy Cooperative, a distributor supplying biodiesel at any blend level to customers in southeastern Pennsylvania, sold over 2.8 million gallons of biodiesel blends and approximately 475,000 gallons of B100 to school districts and municipalities in southeastern Pennsylvania in 2009.[36]

Fuel Cost

The average price to customers of B20 sold in southeastern Pennsylvania in 2009 was $1.84 per gallon.[37] By October 2010, the average price of B20 rose to $2.97, in part due to the suspension of the federal tax credit for biodiesel suppliers at the end of 2009. As noted in Table 3 on page 12, the cost of B20 was essentially the same as gasoline on an energy equivalent basis.

Vehicle Performance and Fuel Efficiency

Pure biodiesel contains about 10 percent less energy per gallon than petroleum diesel. This equates to approximately one to two percent lower energy content for B20, though the loss in fuel economy is negligible for most users.[38]

B20 is the most common biodiesel blend in the United States. B20 is compatible with most existing diesel engines and generally does not require the need for engine modifications, although, as noted below, some manufacturer's warranties may not permit its use. Higher levels of biodiesel or pure B100 pose some operational challenges, however. Biodiesel has a higher cloud point than petroleum diesel, which can cause the fuel to solidify and clog fuel filters and

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[34] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Pennsylvania Incentives and Laws for Ethanol," last modified February 19, 2010, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/PA/ETH.

[35] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Biodiesel Refueling Stations in Pennsylvania," last modified January 14, 2010, http://www.afdc.energy.gov/afdc/progs/ind_state.php/PA/BD.

[36] Chester County (Great Valley SD, Tredyffrin-Easttown SD, Owen J Roberts SD, Chester County Intermediate Unit, Coatesville Area SD, Downingtown Area SD, Twin Valley SD, West Chester Area SD), Delaware County (Radnor Township SD, Haverford Township SD), Montgomery County (Springfield Township SD, Colonial SD, Lower Moreland SD, Upper Merion SD), City of Philadelphia.

[37] Oil Price Information Service, "OPIS Biodiesel Rack Prices," 2009, 2010 (information provided via e-mail from the Energy Cooperative).

[38] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "B20 and B100: Alternative Fuels," last modified April 13, 2010, http://www.afdc.energy.gov/afdc/fuels/biodiesel_alternative.html.

injectors in engines under cold conditions. While this is primarily an issue at higher blends, it can manifest itself even at lower blends, particularly with lower-quality fuels.

Higher levels of biodiesel or pure B100 may cause the fuel to solidify and clog fuel filters and injectors in engines under cold conditions due to the higher cloud point of biodiesel than petroleum diesel. B100, therefore, is recommended for use only by professional fleets with maintenance departments prepared to deal with this fuel.

Biodiesel serves as an excellent lubricant for diesel engines and does not leave deposits inside fuel lines, storage tanks, or fuel delivery systems over time as conventional diesel does. However, users of higher blends of biodiesel must be aware of challenges with fuel gelling in cold temperatures, and the ability of biodiesel to retain water, which might cause corrosion of vehicle and fueling components. As a result of these challenges, many vehicle manufacturers will not cover engines and parts that use biodiesel blends greater than B5.[39]

Users must be aware of lower energy content per gallon and potential issues with impact on engine warranties, low-temperature gelling, solvency/cleaning effect if regular diesel were previously used, and microbial contamination.

Emissions Impacts

According to the U.S. DOE, the production and use of biodiesel creates 78 percent less carbon dioxide (CO_2) emissions than conventional diesel fuel. Combustion of biodiesel additionally provides a 56 percent reduction in hydrocarbon emissions and yields significant reductions in carbon monoxide and soot particles compared to petroleum-based diesel fuel. Also, biodiesel can reduce the carcinogenic properties of diesel fuel by 94 percent.[40] GHG and air-quality benefits of biodiesel are roughly commensurate with the blend; B20 use provides about 20 percent of the benefit of B100 use and so forth.

Safety

Biodiesel is biodegradable and non-toxic, making it safe to handle and transport.

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[39] U.S. Department of Energy, “Biodiesel,” last modified April 11, 2011, http://www.fueleconomy.gov/feg/biodiesel.shtml.

[40] U.S. Department of Energy, “Just the Basics: Biodiesel.”

Natural Gas

Definition

Natural gas is a clear, odorless[41] gas extracted from underground reserves that is a mixture of hydrocarbons. Natural gas consists primarily of methane but may also include limited concentrations of ethane, propane, butane, pentane, water vapor, CO_2, hydrogen sulfide, nitrogen, and helium.

There are two ways in which natural gas can be used in natural gas vehicles (NGVs). CNG is stored in specialized tanks at 3,000 to 3,600 pounds (lbs.) of pressure per square inch and is primarily used in light-duty vehicles (LDVs). Liquefied natural gas (LNG) is purified and condensed into a liquid by cooling the gas to –260°F. It is primarily used in heavy-duty vehicles (HDVs) such as trash trucks and heavy-duty buses.[42]

NGVs use the same basic ICE as conventional gasoline vehicles, with minor changes in compression ratio, ignition timing, and the emissions control system. NGVs can be dedicated, bi-fuel, or dual-fuel vehicles and are available as light-, medium-, and heavy-duty vehicles. Due to refueling and fuel capacity issues discussed below, natural gas vehicles are best suited for fleet applications, where they can be refueled at a central location.

Fuel Production and Distribution

In 2010, the United States consumed 24,134 billion cubic feet of natural gas, of which 21,571 billion cubic feet was produced domestically. Pennsylvania has a large natural gas supply, with over 57,000 producing wells. However, as of 2010, only 0.14 percent of the natural gas consumed in the United States was used for fueling vehicles. LNG is imported at a greater rate than CNG; 431 billion cubic feet of LNG were imported in 2010.[43]

While natural gas is an alternative vehicle fuel, it is a fossil fuel, not a renewable fuel. As with most fossil fuels, world production is struggling to keep pace with demand, although new extraction techniques promise large increases in production and proven reserves. There are several methods for producing natural gas. Natural gas trapped in sub-surface porous rock reservoirs can be extracted via drilling and water injection, a process known as hydraulic fracturing or “fracking.” Oil and gas reservoirs also contain natural gas, but processing is required to separate the gas from petroleum liquids and to remove contaminants. In addition, small amounts of natural gas are now being generated from renewable sources such as landfill gas and water/sewage treatment facilities.

The extraction of natural gas can result in many adverse environmental impacts, including damage to the landscape, destruction of wildlife habitat, pollution of drinking water, and damage to rural infrastructure. There is widespread concern that fracking may damage water quality. Natural gas extraction from the Marcellus Shale deposits in regions of Pennsylvania and other states is a topic of ongoing political controversy at the time of writing.

To be transported through pipeline networks, natural gas must meet quality specifications with respect to heat, water content, and hydrocarbon dew point, and must be free of compounds that

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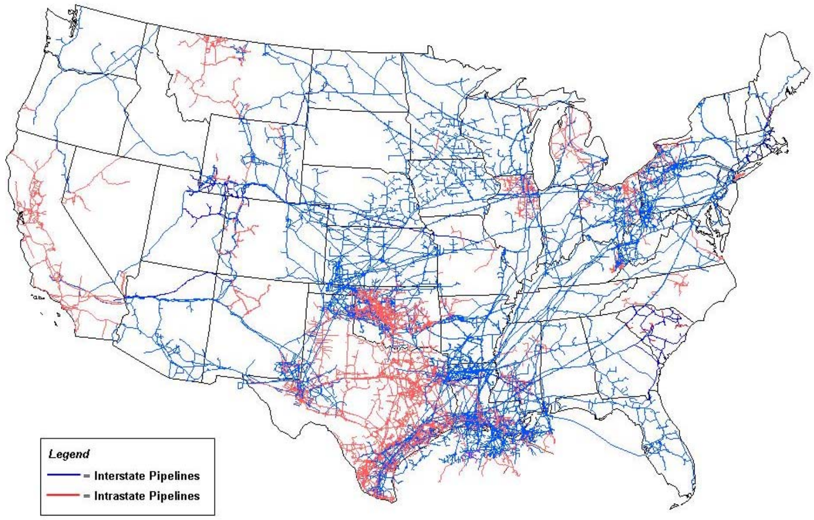
[41] The odor associated with natural gas is due to the addition of butanethiol or other odorant during processing.

[42] U.S. Environmental Protection Agency, “Clean Alternative Fuels: Liquefied Natural Gas,” March 2002, http://www.afdc.energy.gov/afdc/pdfs/epa_lng.pdf.

[43] U.S. Energy Information Administration, “Natural Gas,” http://www.eia.doe.gov/naturalgas/data.cfm (accessed April 11, 2011).

can corrode pipelines, such as hydrogen-sulfide dioxide. The United States has an extensive natural gas distribution system in place, which can quickly and economically distribute natural gas within the lower 48 states. This network includes 300,000 miles of transmission pipelines (see Figure 9). An additional 1.9 million miles of distribution pipes transports gas within utility service areas.

Figure 9: Natural Gas Transmission Pipeline Network



Source: Energy Information Administration, 2009.

Fuel Infrastructure and Availability

Most natural gas fueling stations dispense CNG, which is either compressed on-site or compressed off-site and transported to the fueling station in tanks. The availability of LNG stations is more limited.

There are a total of 19 CNG filling stations and no LNG filling stations within a 50-mile radius of Center City Philadelphia, all of which are affiliated with fleet applications.[44] Only five of these allow public access, all of which are in Pennsylvania and are owned and operated by PECO Energy. This paucity of public infrastructure limits the appeal of CNG for passenger vehicles.

Fuel Cost and Operating and Maintenance Cost

CNG currently costs about $1.15 less per gallon than gasoline and diesel on an energy-equivalent basis.[45] A report by the Transit Cooperative Research Program estimated the cost of NGV fueling infrastructure at $800 to $1,000 for each standard cubic foot per minute (scf/min) capacity when estimating the capital cost of a typical CNG compressor station. Fuel dispensing and fuel storage facilities required for LNG typically cost $15,000 to $22,000 per vehicle. Because LNG burns more cleanly than diesel, it can result in longer engine life and reduced maintenance costs. Maintenance savings are anticipated for vehicles using LNG when compared with gasoline-powered vehicles because of the reduced frequency of oil changes.

Vehicle Cost and Availability[46]

Honda is the only manufacturer to offer light-duty NGVs for sale in the United States for model year 2011. CNG-compatible medium-duty vehicles typically include trucks, vans, cargo vehicles, shuttle buses, and street sweepers. CNG-compatible HDVs include large trucks such as cement mixers and refuse haulers, as well as transit and school buses. Trucks in general are

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[44] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, “Alternative Fueling Station Locator.”

[45] U.S. Department of Energy, “Alternative Fuel Price Report,” last modified March 1, 2011, http://www.afdc.energy.gov/afdc/pdfs/afpr_jul_10.pdf.

[46] More information about heavy-duty NGVs, including 39 CNG vehicles and 18 LNG vehicles, is available from the U.S. DOE at http://www.afdc.energy.gov/afdc/vehicles/search/heavy.

suitable for both CNG and LNG use because they have high fuel consumption rates, which reduces the payback time for the increased vehicle cost (see below).

NGVs are typically more expensive than equivalent gasoline- or diesel-powered vehicles. Light-duty CNG vehicles typically cost $3,000 to $6,000 more per vehicle than conventional vehicles. Heavy-duty LNG vehicles can cost between $30,000 to $50,000 more than conventional vehicles.[47] However, many state and federal incentives are available to reduce costs.[48] In addition, the lower cost of natural gas can offset the higher upfront purchase price for vehicles.

Vehicle Performance and Fuel Efficiency

As a result of the similarity between NGVs and conventional vehicles, CNG performance tends to be very similar to conventional vehicles.[49] CNG vehicles typically have a driving range of around 120 to 180 miles, and a fuel economy of 24 miles per gallon of gasoline equivalent (MPGe) in city driving conditions, and 36 MPGe highway. Because CNG has only a quarter the energy by volume as does gasoline, CNG vehicles require more frequent refueling than gasoline vehicles with the same sized fuel tank.

Due to the lower energy density per unit volume (British thermal units [Btu]/gallon) of natural gas (both CNG and LNG) compared to gasoline and diesel, NGVs require more space for fuel storage in order to achieve the same range as conventional vehicles. This presents a trade-off in vehicle design between range and available cargo space.[50]

A vehicle powered by CNG gets about the same fuel economy as a conventional gasoline vehicle on a gasoline gallon equivalent (GGe) basis. A GGe equals about 125 cubic feet (935 gallons) of uncompressed natural gas. Compression reduces this volume significantly (depending on the technology), but even at high compression ratios a CNG vehicle requires a larger tank and has a shorter range than a comparable conventional vehicle. LNG takes up a smaller volume than CNG. About 1.5 gallons of LNG hold the same energy as a gallon of gasoline, meaning that only about 50 percent more LNG fuel is required to achieve the same travel range as a conventional vehicle.[51]

Emissions Impacts

The EPA estimates that CNG vehicles can reduce carbon monoxide emissions by 90 to 97 percent, and CO_2 emissions by 25 percent compared to conventional vehicles. Nitrogen oxide emissions can be reduced by 35 to 60 percent. Non-methane hydrocarbon emissions can be reduced by 50 to 75 percent. In addition, fewer toxic and carcinogenic pollutants, little to no particulate matter (PM), and no evaporative emissions are produced by CNG vehicles.[52]

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[47] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "The Next Generation Natural Gas Vehicle Activity," September 2003, http://www1.eere.energy.gov/cleancities/pdfs/34650.pdf.

[48] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Natural Gas Incentives and Laws," last modified September 16, 2010, http://www.afdc.energy.gov/afdc/fuels/natural_gas_laws.html.

[49] Science Applications International Corporation, "Greenhouse Gas Emission Reductions and Natural Gas Vehicles: A Resource Guide on Technology Options and Project Development," prepared for the National Energy Technology Laboratory, September 2002, http://www.netl.doe.gov/products/ccps/pubs/NGV_guide.PDF.

[50] Ibid.

[51] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "CNG and LNG: Alternative Fuels," last modified February 19, 2010, http://www.afdc.energy.gov/afdc/fuels/natural_gas_cng_lng.html.

[52] U.S. Environmental Protection Agency, "Clean Alternative Fuels: Compressed Natural Gas," March 2002, http://www.afdc.energy.gov/afdc/pdfs/epa_cng.pdf.

However, when lifecycle emissions are accounted for, the CO_2 reduction advantage drops to about 17 percent. Because methane (CH_4) has 23 times the Global Warming Potential of CO_2, smaller volumes of methane emissions have magnified climate change consequences. More research should be done to quantify the non-tailpipe emissions of NGVs, which are currently not well understood for medium- and heavy-duty vehicles.[53]

Relative to diesel, LNG produces half the PM, significantly lower carbon monoxide emissions, reduces nitrogen oxide and volatile organic hydrocarbon emissions by 50 percent or more, and reduces CO_2 emissions by as much as 25 percent (depending on the source of the natural gas). However, similar to CNG, LNG produces increased methane emissions.[54]

Natural gas can be blended with hydrogen to make a blend called "hythane." Vehicles fueled with hydrogen/natural gas blends offer the potential for additional emissions benefits, such as a reduction in nitrogen oxide emissions. At the same time, these fuel blends can help pave the way for fuel cell vehicles by building early demand for hydrogen infrastructure.[55]

Safety

Natural gas is a vapor rather than a liquid, so unlike liquid fuels, which pool on the ground when leaked or spilled, natural gas dissipates into the atmosphere because it is lighter than air. Therefore, vehicles should be stored outdoors or driven frequently.[56] In the absence of proper ventilation systems, gas build-up could result in the risk of a fire or explosion, and could also cause asphyxiation. Because natural gas is odorless, odorants are added to facilitate leak detection. During the liquefaction process, however, these odorants are removed, making detection of leaks more challenging for LNG. To improve safety, natural gas storage tanks are made of steel, aluminum, and/or composite materials that can resist puncture better than standard gasoline tanks.

The primary hazard of LNG is frostbite due to direct skin exposure. Fire and explosion hazards of released LNG are similar to those of CNG.[57] Because LNG is stored at temperatures well below freezing, only trained personnel should maintain LNG vehicles.[58]

Local Examples

Lower Merion School District began using CNG-powered school buses in 1995. The district now operates 64 CNG buses, as well as five work vans powered by CNG. These vehicles have logged over 10,000,000 miles to date, displacing over 1,000,000 gallons of diesel fuel. The project has taken advantage of over $1,000,000 in grant funding, and has enabled the district to generate over $250,000 in excise tax revenues.[59]

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[53] Science Applications International Corporation.

[54] U.S. Environmental Protection Agency, "Clean Alternative Fuels: Liquefied Natural Gas," March 2002, http://www.afdc.energy.gov/afdc/pdfs/epa_lng.pdf.

[55] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Hydrogen/Natural Gas (HCNG) Fuel Blends," last modified July 10, 2009, http://www.afdc.energy.gov/afdc/fuels/natural_gas_blends.html.

[56] U.S. Environmental Protection Agency, "Clean Alternative Fuels: Liquefied Natural Gas."

[57] Science Applications International Corporation.

[58] U.S. Environmental Protection Agency, "Clean Alternative Fuels: Liquefied Natural Gas."

[59] Mike Andre, Lower Merion School District, January 27, 2010.

Propane

Definition

Propane, also known as liquefied petroleum gas (LPG), is a byproduct of natural gas processing and petroleum refining. Propane is a colorless, non-toxic gas that turns to a liquid state under moderate pressure, making it easier to transport and store in vehicle fuel tanks.

Propane is most commonly used in fleet applications, including light- and heavy-duty trucks, buses, taxicabs, police cars, and rental and delivery vehicles. LPG may be found in vehicles with dedicated as well as bi-fuel configurations, and is the most prevalent alternative fuel in use in the United States today.[60]

Fuel Production and Distribution

Most propane is domestically produced as a byproduct of natural gas processing and petroleum refining, with approximately equal amounts of production derived from each of these sources. Propane is moved from point of production to bulk distribution terminals via pipeline, railroad, barge, truck, or tanker ship. Propane is then moved in trucks to the end user by propane dealers.

Fuel Infrastructure and Availability

There are eight public propane refueling stations in the DVRPC region; all are located in Pennsylvania (the majority of these refueling stations are located at U-Haul facilities).

Fuel Cost

Propane fuel is currently $1.51 more expensive than gasoline on an energy-equivalent basis.

Vehicle Cost and Availability

While a few HDVs are manufactured by original equipment manufacturers (OEMs), there are currently no light-duty propane vehicles manufactured by OEMs. Certified installers can convert LDVs for propane operation. These conversions in the United States require U.S. EPA approval and a licensed propane conversion technician. The cost to convert an LDV gasoline vehicle to dedicated propane fuel ranges from $4,000 to $12,000

Propane vehicles are touted as having lower operating costs than gasoline vehicles. The use of propane can result in an engine life of up to two times that of gasoline engines. Propane use in fleet vehicles can result in a reasonable payback to offset the higher upfront capital costs of the vehicles, due to the fact that fleet vehicles are high-mileage, high-fuel-consumption vehicles that operate in a limited area.[61]

Vehicle Performance and Fuel Efficiency

The energy content per gallon of propane is less than gasoline, meaning it achieves fewer miles per gallon than gasoline. As a result, more propane (or a larger fuel tank) is needed if the vehicle is to travel the same distance as a similar gasoline or diesel vehicle.

The driving range for bi-fuel vehicles is comparable to that of gasoline vehicles. The range of dedicated gas-injection propane vehicles is generally less than gasoline vehicles because of the 25 percent lower energy content of propane and lower efficiency of gas-injection propane fuel

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[60] U.S. Department of Transportation, Report to Congress, “Transportation’s Role in Reducing U.S. Greenhouse Gas Emissions, Volume 1: Synthesis Report,” April 2010, page 2-7, ntl.bts.gov/lib.32000/32700/32779/DOT_Climate_Change_Report_-_April_2010_-_Volume_1_and_2.pdf.

[61] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, “Propane Vehicle Availability,” last modified March 17, 2011, http://www.afdc.energy.gov/afdc/vehicles/propane_availability.html.

systems. Extra storage tanks can increase range, but the additional weight displaces payload capacity. Propane vehicle power, acceleration, and cruising speed are similar to those of gasoline-powered vehicles.

Emissions Impacts

Though sourced from natural gas (which itself contains mostly methane, a potent GHG), propane gas itself is not a GHG. Depending on the vehicle technology and application, propane can reduce GHG emissions by 17 percent relative to conventional gasoline vehicles.[62] The use of propane in LDVs can also result in reductions in all criteria pollutants, with the largest reductions found for VOC and PM, compared to gasoline.[63]

Safety

While in a liquid state, propane has a low relative flammability range compared to any alternative fuel. However, propane leaks occur in a gas state, which are more likely to ignite than gasoline leaks. If leaked into the environment, propane is non-toxic, slightly soluble, and biodegrades rapidly in soil, water, or air.[64]

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[62] U.S. DOT, page 2-11.

[63] U.S. DOT, page 2-40.

[64] U.S. Environmental Protection Agency, “Clean Alternative Fuels: Propane,” March 2002, http://www.afdc.energy.gov/afdc/pdfs/epa_propane.pdf.

Electric Vehicles

Definition

EVs run entirely on electricity, with no ICE. In an EV, a battery or other energy storage device is used to store electricity, which powers an electric motor. EV batteries must be replenished by plugging the vehicle into an external power source when the vehicle is stationary.[65] The electricity used to charge the battery generally comes from the electricity grid. It is also feasible to charge an EV using an off-grid renewable generation technology, such as solar photovoltaics or wind generation.

Fuel Production and Distribution

Electricity can be generated from a wide variety of energy sources, including combustion of fossil fuels or biomass, nuclear fission, wind, hydropower, solar energy, wave and tidal energy, and other sources. The mix of sources for a particular user depends upon the generation resource connected to the sub-grid that serves that user. According to the U.S. EPA's eGRID,[66] the 2005 resource generation mix for the DVRPC region, served by the RFC East eGRID sub-region, is 45 percent coal, 38 percent nuclear, 9.6 percent natural gas, 4 percent oil, and approximately 1 percent each of other fossil fuels, hydropower, and biomass. Wind comprised 0.1 percent of the power.

Fuel Infrastructure and Availability

Charging infrastructure is one of the main barriers to widespread adoption of electric vehicles. While most plug-in cars can charge in a standard wall outlet (1.8 kilowatt [kW], 120V), fully recharging the battery pack can take four to eight hours at this level. Single-phase, 220V service is available to all residential customers but typically will require professional installation of additional circuit breakers, lines, and a dedicated outlet. A charging rate of 1 kWh/h can be obtained using ordinary 120 volt technology with a charger size of 1.2 kW. Higher rates may be obtained by investing in 240 volt chargers.[67] Thus, the benefit of reduced charging time comes at an additional initial capital cost.[68]

Experts agree that up to 90 percent of U.S. cars, trucks, and sport utility vehicles (nearly 200 million vehicles) could be charged using the present generation and transmission capacity of the U.S. electrical grid if most charging is done during off-peak hours.[69] EVs plugged in during off-

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[65] Some vehicles can generate electricity on-board to charge the battery, using, for example, a small ICE or a fuel cell. These are discussed elsewhere in this report. In addition, Google and other companies are experimenting with plug-less charging systems.

[66] U.S. Environmental Protection Agency, "eGRID2007 Version 1.1, Year 2005 Summary Tables," http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_SummaryTables.pdf.

[67] D. Kammen, D. Lemoine, et al., "Evaluating the Cost-Effectiveness of Greenhouse Gas Emission Reductions from Deploying Plug-in Hybrid Electric Vehicles," Brookings-Google Plug-in Hybrid Summit, Washington, DC, July 2008.

[68] A. Elgowainy, et al., "Well-to-Wheels," Argonne National Laboratory, February 2009.

[69] J. Dowds et al., "A Review of Results from Plug-in Hybrid Electric Vehicle Impact Studies," Report to the University of Vermont Transportation Research Center, 2009. P. Denholm and W. Short, "Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles (Revised)," 2006. S. W. Hadley and A. Tsvetkova, "Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation," Oak Ridge National Laboratory, 2008. Stephen Letendre and Paul Denholm, "New Load, or New Resource," *Public Utilities Fortnightly,* December 2006, 28–37. R. G. Pratt et al., "The Smart Grid: An Estimation of the Energy and CO_2 Benefits," prepared for the U.S. Department of Energy by the Pacific Northwest National Laboratory, January 2010.

peak hours might also help flatten the daily electric load cycle, which would have the effect of improving grid efficiency and lowering electricity costs.[70]

The City of Philadelphia plans to install 20 new charging stations in the city using a $140,000 Alternative Fuels Incentive Grant from the Commonwealth of Pennsylvania.

Operating Cost

A review of studies that examined fuel costs for EVs found agreement that electricity is a less expensive source of energy than gasoline per mile traveled. For example, if electricity costs $0.08 per kWh (national average) and gasoline costs $2.77 per gallon, an electric vehicle could drive for 3 cents per mile compared with 13 cents per mile for gasoline.[71] However, studies have also found that the lower operating costs of EVs do not currently offset their higher purchase prices over the lifetime of the vehicle. This could change, depending on future oil and electricity prices, and reductions in battery costs.[72]

Electric cars are much simpler to maintain than conventional cars because they have fewer moving parts and do not require oil changes. Therefore, they may be less expensive to maintain than conventional vehicles.

Some business models exist that, if successful, may dramatically alter the cost of owning an EV. The company *Better Place* is promoting a pricing plan that would keep battery ownership with the company, thus lowering vehicle ownership costs while also addressing the refueling infrastructure issue by building battery swapping and recharging stations. This program was launched in Denmark in March 2011. Note, however, that several major automobile manufacturers have voiced reluctance to commit to a shared battery system due to the design constraints it would impose. Several companies are also developing software and distributed infrastructure to charge vehicles under centralized direction, which could take advantage of real-time pricing, and feed energy back and forth from the vehicles to the electrical grid.[73]

Vehicle Cost and Availability

The Nissan Leaf is the only light-duty EV available in the United States from a major auto manufacturer. Nissan Motors announced that the 13,000 Leafs the company planned to manufacture had been reserved only one month after beginning to take pre-orders. GM's Chevrolet Volt is a plug-in hybrid electric vehicle (PHEV) that has a gasoline ICE that both runs a generator to charge the battery and provides direct power to the wheels when necessary. Tesla Motors offers a custom-order, highway-capable, all-electric vehicle that has a range of 220 miles per charge. Conversion kits are also available to transform a conventional LDV into one that runs on electricity. Ford offers an all-electric version of its Transit Connect vans. Many major and smaller manufacturers are working on developing EVs, including Ford, Toyota, Renault, BMW, and Porsche.

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[70] M. J. Scott et al., "Impact Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids, Part 2: Economic Assessment," *Journal of EUEC* 1 (2007): 1–19.

[71] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Benefits of Hybrid, Plug-in Hybrid, and All-Electric Vehicles," last modified April 5, 2011, http://www.afdc.energy.gov/afdc/vehicles/plugin_hybrids_benefits.html.

[72] J. Dowds et al.

[73] Daniel M. Kammen and Derek M. Lemoine, "DRAFT-Economic Assessment of All-Electric Vehicles," University of California, Berkeley, February 2009.

EVs are more expensive than gasoline-powered cars, largely due to the high cost of the batteries used. Current prices are in the $40,000 to $50,000 range.

In Greater Philadelphia, PhillyCarShare plans to add 16 EVs to its 250-car fleet by summer 2011. ZipCar, another car-sharing company in the region, will add two EVs to its Philadelphia fleet. These vehicles will take advantage of 20 new charging stations that the City of Philadelphia plans to install.

Vehicle Performance and Fuel Efficiency

A typical EV can operate at about 4 mi/kWh, and would have a battery size of about 25 kWh. These vehicles have a range of about 40 to 100 miles before recharging, which is significantly lower than conventional vehicles, which can usually exceed 300 miles before refueling. This is a limitation for many potential owners, particularly for single-car households. However, electric vehicles are almost twice as energy-efficient as gasoline-powered vehicles. For example, electric motors convert 75 percent of the chemical energy from their batteries to power the wheels, while ICEs only convert 20 percent of the energy stored in gasoline.[74]

Electric vehicles can accelerate more quickly and smoothly than internal combustion vehicles, because an electric motor is able to generate maximum torque at standstill. The Tesla electric Roadster for example, can accelerate from 0 to 60 mph in 4 seconds. Electric motors also operate much more quietly than ICEs.

Emissions Impacts

Although the production of grid electricity may contribute to air pollution, EVs are considered zero-emission vehicles because their motors produce no exhaust or emissions. Emissions that can be attributed to EVs are produced at the electrical generating plant. The annual GHG emissions rate for the eGRID RFC East sub-region that serves our region is 1,224 lbs carbon dioxide equivalent (CO_2e)/MWh.[75]

Not surprisingly, the marginal electricity mix used to charge the vehicle has a significant impact on the well-to-wheels GHG emissions of EVs. For EVs operated on electricity from very low-GHG plants, such as wind turbines or nuclear plants, EVs can reduce GHG emissions by as much as 85 percent relative to conventional ICE vehicles.

Parking

Parking EVs in a location suitable for charging may be an issue for some owners. For example, if an EV owner has a house with a garage, he or she should have few if any issues with being able to park and charge the vehicle. However, someone who lives in an apartment building in an urban location and whose vehicle is normally parked on the street or in a shared lot will potentially have challenges finding a location to charge an EV.

Safety

See issues related to pedestrian and bicyclist safety, below, in the section on hybrid electric vehicles.

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[74] U.S. Department of Energy, "Electric Vehicles," last modified April 12, 2011, http://fueleconomy.gov/feg/evtech.shtml.

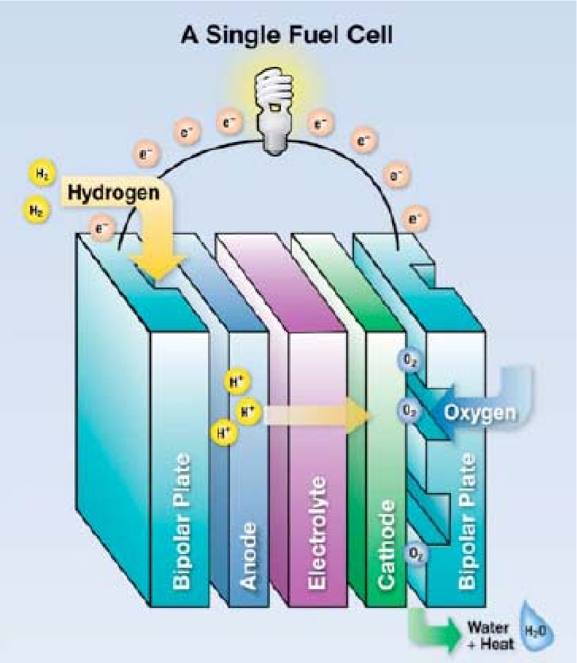
[75] This incorporates a grid loss factor of 6.409 percent (S. Rothschild and A. Diem, "The Value of eGRID and eGRIDweb to GHG Inventories," prepared for the U.S. Environmental Protection Agency, Washington, DC, December 2009, http://www.epa.gov/cleanenergy/documents/egridzips/The_Value_of_eGRID_Dec_2009.pdf).

Hydrogen Fuel Cell Vehicles

Definition

Hydrogen fuel cell vehicles use an on-board fuel cell stack to convert the chemical energy in hydrogen into electricity,[76] which in turn is used to maintain the battery charge and power an electric motor. The on-board electricity-generating capacity of a hydrogen fuel cell allows for more rapid fueling and a longer range than plug-in electric vehicles. Hydrogen fuel cells for vehicles are at an early stage of development, though research and development efforts are bringing the technology, as well as the accompanying hydrogen distribution and storage infrastructure, closer to commercialization. Many challenges remain, including vehicle cost and durability, the availability of a distribution infrastructure, hydrogen storage, and the ability to produce hydrogen in a clean and cost-effective manner.

Figure 10: A Fuel Cell



Source: U.S. Department of Energy, http://www.hydrogen.energy.gov/pdfs/doe_fuelcell_factsheet.pdf.

Fuel Production and Distribution

Because hydrogen is not an abundant gas in the atmosphere, it is most readily produced from hydrogen-rich materials such as water, hydrocarbons (including fossil fuels), biomass, and other materials—most of which can be domestically sourced. There are a number of process technologies currently being developed to produce hydrogen from these materials, and the costs of production and GHGs emitted vary by production method.[77] Currently, steam methane reforming (SMR) accounts for about 95 percent of the hydrogen produced in the United States.[78] SMR produces almost 12 kg CO_2e of GHGs for every kg of hydrogen produced. In addition, the hydrogen produced by SMR contains less energy than the energy required to produce it.[79]

Uncompressed hydrogen has a low energy density by volume compared to other fuels such as gasoline. This poses challenges for its distribution and storage. According to the U.S. DOE, pipeline distribution of hydrogen is the least expensive way to distribute large volumes of hydrogen throughout the United States. However, the current hydrogen pipeline infrastructure in the United States is very small (approximately

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[76] A fuel cell uses hydrogen (or a hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte and two catalyst-coated electrodes (a porous anode and cathode), as shown in Figure 10.

[77] For more information on these production methods, please see http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_production.pdf.

[78] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "What is hydrogen?," last modified January 27, 2011, http://www.afdc.energy.gov/afdc/fuels/hydrogen_what_is.html.

[79] P. L. Spath and M. K. Mann, "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming," Report to the National Renewable Energy Laboratory, Revised February 2001, http://www.nrel.gov/docs/fy01osti/27637.pdf.

1,200 miles, compared to more than one million miles of natural gas pipelines).[80] Due to this limited distribution capacity, most hydrogen used today is produced near the point of end use: either in large plants 25 to 100 miles from point of end use or on-site at refueling stations.

Though pipelines are the most viable and least expensive way to distribute hydrogen, the high initial capital cost of new pipeline construction constitutes a major barrier to expanding hydrogen pipeline delivery infrastructure. The U.S. DOE states that an infrastructure system to enable long-distance distribution of hydrogen must be developed before hydrogen can become a mainstream energy carrier.

On-board hydrogen storage is a major challenge to the viability of hydrogen fuel cell vehicles.[81] Hydrogen fuel cell vehicles that are commercially available today store hydrogen on board as a gas in high-pressure tanks. High-pressure tank storage is considered a cost-effective solution for the near term, though this storage method is heavy and costly. Two other methods for on-board storage of hydrogen are being developed, including:

- *Storage as a liquid at sub-zero temperatures (–423°F).* Hydrogen is densest as a liquid, allowing for more gas to be stored by volume than storage under high pressure as a gas. Liquid storage, however, costs 30 times more than compressed storage and poses safety issues. Liquid storage is not likely to be commercially viable for at least a decade.
- *Materials-based storage.* Materials-based storage systems (i.e., solids that hold hydrogen) have the potential to be small and lightweight and may prove to be the best solution in the long term. However, they are still in the early stages of development.

Hydrogen storage is also challenging due to its small molecular size, which makes leaks very difficult to prevent. Hydrogen can also be stored on board through a secondary fuel such as methanol, ethanol, or natural gas. These secondary fuels must be converted into hydrogen gas by an on-board device called a reformer.

Fuel Infrastructure and Availability

There are no hydrogen fueling stations operating in the DVRPC region.

Fuel Cost

Efficiently and economically producing hydrogen is one of the challenges of using hydrogen as a fuel. As with all fuels, hydrogen must be cost competitive with conventional fuels in order to be accepted. A 2006 U.S. DOE analysis of hydrogen production costs illustrated the sensitivity of hydrogen production costs to the cost of natural gas.[82] The volatility of natural gas prices may pose challenges for the reliability of hydrogen production costs. Research into alternative methods of producing hydrogen is ongoing.

Vehicle Cost and Availability

The National Research Council suggests hydrogen fuel cell vehicles could be ready for commercialization by 2015–2020. These vehicles will not likely be cost competitive until after 2020, but are projected by some advocates as able to comprise 80 percent of new vehicles

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[80] U.S. Department of Energy, Energy Efficiency and Renewable Energy, “Fuel Cell Technologies Program: Delivery,” November 2010, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_delivery.pdf.

[81] U.S. Department of Energy, “Challenges,” last modified April 12, 2011, http://www.fueleconomy.gov/feg/fcv_challenges.shtml.

[82] U.S. Department of Energy, Hydrogen Program, “Hydrogen Cost Competitive on a Cents per Mile Basis—2006,” May 22, 2006, http://www.hydrogen.energy.gov/pdfs/5038_h2_cost_competitive.pdf.

entering the fleet by 2050.[83] As of 2011, hydrogen fuel cell vehicles are not commercially available in the United States.[84] However, manufacturers are producing small fleets of fuel cell vehicles for leasing and evaluation.[85]

Fuel cell system costs have reduced by more than 80 percent between 2002 and 2009, yet these systems are still nearly twice as expensive as a traditional ICE.[86] The fuel cell system cost in 2009 was $51/kW,[87] compared to the U.S. DOE target of $30/kW.[88] Still in the early stages of development, fuel cell vehicles are too expensive to compete with conventional gasoline or diesel vehicles.

Operating and Maintenance Costs

Due to their experimental nature, reliable estimates of expected operating and maintenance costs for fuel cell vehicles are not available.

Vehicle Performance and Fuel Efficiency

Current models of hydrogen fuel cell vehicles can run up to 300 miles using high-pressure on-board storage tanks. However, this technology is not considered viable in the long term due to its weight.

Hydrogen fuel cells convert 40–60 percent of the fuel's energy into useful energy. This is at least twice as efficient as ICEs, which convert only 20 percent of gasoline's energy.[89] Hydrogen also has a high-energy density by weight compared to gasoline—one gallon of gasoline, which weighs about 6 lbs, contains about the same amount of energy as 2.2 lbs (1 kg) of hydrogen gas.

However, as mentioned above, the low volumetric energy density of hydrogen makes it difficult to store enough hydrogen to power the same distance as an ICE. Gasoline has over 2,500 times as much energy per unit volume as uncompressed hydrogen. To enable a driving range comparable to internal combustion vehicles (300 miles or more), the U.S. DOE estimates that a standard passenger vehicle would have to store 11–29 lbs of hydrogen,[90] requiring a much larger tank than a conventional car even when the hydrogen is highly compressed.

Emissions Impacts

Hydrogen fuel cell vehicles emit no tailpipe criteria air pollutants, air toxins, or GHGs; however, as noted above, the SMR method most widely used to produce hydrogen fuel does emit pollutants. The U.S. DOE estimates that by 2020, hydrogen fuel cell vehicles will use between

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[83] Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council, "Transitions to Alternative Transportation Technologies--A Focus on Hydrogen," 2008, http://www.nap.edu/catalog.php?record_id=12222.

[84] U.S. Department of Energy, "Recently Tested Vehicles," last modified April 12, 2011, http://www.fueleconomy.gov/feg/fcv_sbs.shtml.

[85] Honda, "Honda FCX Clarity Overview," http://automobiles.honda.com/fcx-clarity/ (accessed April 12, 2010).

[86] U.S. Department of Energy, "Challenges."

[87] Cost given in 2002 dollars.

[88] U.S. Department of Energy, Hydrogen Program, "Fuel Cell System Cost—2009," October 7, 2009, http://www.hydrogen.energy.gov/pdfs/9012_fuel_cell_system_cost.pdf.

[89] U.S. Department of Energy, Fuel Cell Technologies Program, "Hydrogen and Fuel Cell Technologies Program: Fuel Cells," November 2010, https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_fuelcell_factsheet.pdf.

[90] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Hydrogen as an Alternative Fuel," last modified January 27, 2011, http://www.afdc.energy.gov/afdc/fuels/hydrogen_alternative.html.

15 and 95 Btu per mile and generate 40 to 200 grams per mile of CO_2e, compared to 4550 Btus used and 410 grams per mile of CO_2e estimated for a conventional petroleum vehicle[91] in 2020.[92]

Safety

According to the U.S. DOE, "Hydrogen can be used as safely as other common fuels we use today when guidelines are observed and users understand its behavior."[93] Hydrogen burns more easily than other fuels, though at low concentrations it will burn similarly to gasoline. The flame of hydrogen combustion has significantly less radiant heat than a hydrocarbon fire, reducing the risk of a secondary fire.

Like natural gas, hydrogen is odorless, colorless, and tasteless. However, there is no known odorant light enough to "travel with" hydrogen as butanethiol does in natural gas. Thus, leakage detection systems are built into vehicles.

Hydrogen is non-toxic and non-poisonous. As a gas, it will not contaminate groundwater, and a release of hydrogen is not known to contribute to atmospheric or water pollution.

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[91] Fuel economy of 28 miles per gallon (MPG) was used.

[92] U.S. Department of Energy, Offices of Vehicle Technologies & Fuel Cell Technologies, "Wells to Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles," October 25, 2010, http://www.hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf.

[93] U.S. Department of Energy, Fuel Cell Technologies Program, "Safety, Codes and Standards," February 2011, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_safety.pdf.

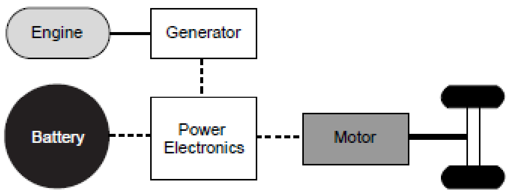
Hybrid Electric Vehicles and Plug-In Hybrid Electric Vehicles

Definition

HEVs, including PHEVs, use both an ICE and an electric motor. At low energy demand, the electric motor alone drives the vehicle using battery power. When more power is demanded, the ICE kicks in, to provide additional power.

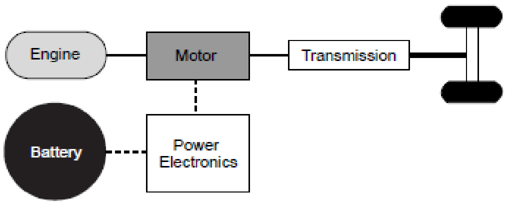
In both HEVs and PHEVs, the battery pack charges when the vehicle's ICE is running and when the driver uses the brakes. In a PHEV, the battery pack can also be charged by plugging it into an electrical outlet. The battery pack for PHEVs and HEVs is typically lighter, smaller, and less expensive than in an EV, and PHEVs typically have larger batteries than HEVs. The key distinction between PHEVs and HEVs is that the PHEV is able to gain its primary energy directly from the electricity grid, while the HEV cannot be connected to an external power source to charge the battery but derives its propulsion energy from gasoline, either directly or via the generator. When an HEV or PHEV idles, the ICE shuts off completely.

Figure 11: Series Hybrid Electric Vehicle Drive Train



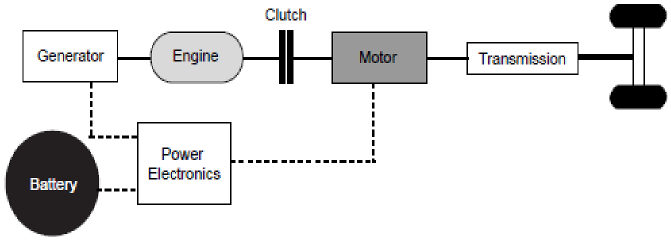
Source: D. Friedman, "A New Road: The Technology and Potential of Hybrid Vehicles," Union of Concerned Scientists, January 2003.

Figure 12: Parallel Hybrid Electric Vehicle Drive Train



Source: D. Friedman, "A New Road: The Technology and Potential of Hybrid Vehicles," Union of Concerned Scientists, January 2003.

Figure 13: Series-Parallel Hybrid Electric Vehicle Drive Train



Source: D. Friedman, "A New Road: The Technology and Potential of Hybrid Vehicles," Union of Concerned Scientists, January 2003.

There are two major types of HEVs: *series* and *parallel*, as shown in Figure 11, Figure 12, and Figure 13 at left.[94] In a series HEV, the ICE provides power to charge the battery, but the electric motor is the only means of driving the wheels. In a parallel HEV, the wheels are connected to both the electric motor and ICE. Vehicles with some combination of the two systems also exist.

In a series HEV, the motor receives electricity from a battery pack or from the ICE. Series hybrids operate best under slower conditions characterized by stop-and-go driving. They are less efficient in highway driving conditions.

In a parallel HEV, both the engine and motor can drive the wheels. Parallel HEVs typically have smaller battery packs than series HEVs, and the batteries are usually charged almost entirely from regenerative braking. Parallel drive trains operate more efficiently in highway conditions but are slightly less efficient than series HEVs in city driving conditions.

Many vehicles, including the Toyota Prius, use a combination series-parallel drive train. This

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[94] D. Friedman, "A New Road: The Technology and Potential of Hybrid Vehicles," Union of Concerned Scientists, January 2003, http://www.ucsusa.org/assets/documents/clean_vehicles/hybrid2003_final.pdf.

configuration has the potential to perform better than either the series or parallel hybrid, by taking advantage of the efficiencies of both.

Fuel Production and Distribution

HEVs do not have any special issues related to fuel production and distribution, because they use regular gasoline. However, this means that they are also subject to the environmental impacts associated with the extraction, production, distribution, and use of fossil fuels. PHEVs are also subject to these impacts, as well as the impacts of electricity generation and distribution discussed in the EV section.

Fuel Infrastructure and Availability

HEVs do not present any issues in terms of fuel availability, because they use regular gasoline available at gas stations everywhere. PHEVs can also take advantage of existing gasoline fueling infrastructure. For PHEVs, the same issues related to charging infrastructure that were described in the EV section apply.

Fuel Cost and Operating and Maintenance Costs

So far, five-year maintenance costs for HEVs have been lower than for conventional vehicles, mostly due to reduced engine and brake maintenance. Although batteries are expensive to replace, a great deal of progress has been made in extending their useful lifetimes so that most batteries now last for 150,000 miles or more.[95] Hybrids use less fuel than conventional vehicles, thus saving money over time compared to conventional vehicles.

In a sense, PHEVs have two fuel tanks, because they can use gasoline like a hybrid or conventional vehicle, or they can charge their batteries from the electric grid and travel using this energy until low battery charge causes the vehicle to switch to the gasoline-powered hybrid electric mode. It seems likely, therefore, that PHEV users will be highly responsive to gasoline and electricity price signals.[96] Because they are new to the marketplace, reliable estimates of operating and maintenance costs for PHEVs are not yet available.

Vehicle Cost and Availability

A number of light-duty HEVs are currently available, and more enter the marketplace each year. Manufacturers have seen HEVs gain in popularity, as sales in the United States have grown by over 80 percent annually since 2000.[97] They have responded by increasing the number of models available each year. HEVs are also becoming more popular for medium- and heavy-duty buses and trucks.

The U.S. DOE Alternative & Advanced Vehicles website lists 29 light-duty hybrid vehicles for model year 2011.[98] The U.S. DOE also lists 46 heavy-duty hybrids of various types, including diesel/electric, gasoline/electric, CNG/electric, propane/electric, and fuel cell/electric. The list includes vehicles such as buses, trolleys, and tractors.[99]

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[95] Argonne National Laboratory, “Just the Basics: Hybrid Electric Vehicles,” http://www.transportation.anl.gov/pdfs/HV/522.pdf (accessed April 13, 2011).

[96] D. M.Lemoine, D. M. Kammen, and A. E. Farrell, “An Innovation and Policy Agenda for Commercially Competitive Plug-in Hybrid Electric Vehicles,” *Environmental Research Letters* 3 (2008).

[97] Ibid.

[98] See http://www.afdc.energy.gov/afdc/vehicles/search/light?fuel_type_code=HYBR for more information, including side-by-side comparisons.

[99] For more information, see http://www.afdc.energy.gov/afdc/vehicles/search/heavy.

GM's Chevrolet Volt is the only PHEV sold in the United States by a major manufacturer. Released in December 2010, the Volt has received a great deal of attention. The Volt won three major industry awards in 2011: *Motor Trend*'s 2011 Car of the Year, *Automobile Magazine*'s Automobile of the Year, and *Green Car Journal*'s Green Car of the Year. The Volt uses a series hybrid architecture, with a 111 kW (149 hp) electric drive motor, 16 kWh lithium-ion battery pack, and a 55 kW (74 hp) generator. The grid recharge capability provides electric-only operation for 40 miles, which would cover many typical commutes, while the generator and engine combination will allow the vehicle to drive efficiently for extended distances.

Mercedes-Benz is manufacturing a limited number of PHEV Sprinter vans for demonstration purposes. In addition, a few companies are converting light-duty HEVs into PHEVs, and a few are producing custom medium- and heavy-duty PHEVs. However, virtually all major automakers, as well as a number of small startup companies, now have PHEVs in development.[100]

Depending on the type of hybrid and how far it can drive using electric power only, buyers can expect an incremental cost increase ranging anywhere from $1,500 to $7,500.[101, 102]

The suggested retail price for the 2011 Chevrolet Volt starts at US$40,280 excluding any charges, taxes, or any incentives. Qualified buyers are eligible for a $7,500 federal tax credit, and other incentives may be available depending on jurisdiction. The primary driver of the high price is the cost of batteries, which makes payback difficult at current gasoline prices.

Vehicle Performance and Fuel Efficiency

Because of increased fuel economy, the range of hybrids is greater than conventional ICE vehicles. Some HEVs are able to drive 600 miles on a tank of fuel. HEVs have improved acceleration at lower speeds compared to conventional vehicles, due to the electric assist. HEVs also produce less noise and vibration when stopping and operating at low speeds. On the other hand, HEVs have reduced high-end torque compared to ICE vehicles, meaning that highway passing is often more difficult.

In a well-engineered PHEV, such as the Chevrolet Volt, performance differences between electric vehicle mode, charge-depleting mode, and charge-sustaining vehicle mode are nearly imperceptible to the driver. Trip length should be comparable with an HEV, although only the first 30–40 miles of a longer trip would be all electric.

Two of the most popular hybrid sedans, the Toyota Prius Hybrid and Honda Civic Hybrid are rated at 48/45 and 40/45, respectively.[103] In general, hybrids usually get between 30 to 50 miles per gallon (MPG) in city driving conditions. Fueleconomy.gov lists 32 hybrids, with city MPG ratings ranging from 17 (BMW ActiveHybrid X6) to 51 (Toyota Prius).

In general, HEVs are much more fuel efficient than their conventional counterparts, although straightforward comparisons are not always easy to make, because not all hybrids have direct

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[100] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "Availability of Hybrid, Plug-in Hybrid, and All-Electric Vehicles," last modified March 2, 2011, http://www.afdc.energy.gov/afdc/vehicles/electric_availability.html.

[101] Timothy Lipman and Mark Delucchi, "Hybrid-Electric Vehicle Design Retail and Lifecycle Cost Analysis," University of California, April 2003.

[102] For tax credits and incentives, see http://www.afdc.energy.gov/afdc/laws/laws/US/tech/3285.

[103] City/Highway; in miles per gallon. U.S. Environmental Protection Agency, "Green Vehicle Guide," http://www.epa.gov/greenvehicles (accessed April 13, 2011).

equivalents. One example, however, is the Honda Civic Hybrid, which is about twice as fuel efficient as the comparable Accord Coupe model, both of which are classified as compact cars (40 versus 21 MPG, city). Similarly, the Toyota Prius Hybrid is about twice as fuel efficient as the Toyota Camry in the mid-size category (51 versus 22 MPG, city). The Camry Hybrid, however, is only about 50 percent more fuel efficient than the regular Camry model (33 versus 22 MPG, city).

The combined electric/gasoline fuel efficiency of the Chevrolet Volt is estimated by the U.S. EPA at 93 MPG.

Emissions Impacts

Because hybrids have smaller, lighter engines which heat up quickly, they have reduced startup emissions, which help them achieve lower exhaust levels than conventional ICEs. However, hybrids also face some challenges with tailpipe emissions, due to frequent engine restarting and problems with evaporative canister purging.[104] These problems have been overcome in some hybrids, which have been able to achieve Super Ultra-Low Emissions Vehicle (SULEV) ratings.[105] PHEVs include a wide variety of options with respect to technical attributes, such as battery chemistry, the amount of grid electricity that can be stored in the battery, and power train and fuel choices, all of which could significantly impact the environmental benefits of the vehicle. While PHEVs offer the potential for significant reduction in petroleum energy use and GHG emissions, these benefits are subject to the same limitations as discussed in the EV section.[106]

Numerous studies have found significant gasoline displacement from PHEVs, relative to both conventional ICEs, as well as HEVs. This displacement may also cause a net reduction in GHG emissions, depending on the performance of the vehicle, and the GHG intensity of the electric source.[107] A 2007 study by the Electric Power Research Institute examined PHEVs with all-electric ranges of 10, 20, and 40 miles, and found gasoline displacement rates ranging from 42 to 78 percent relative to ICEs, and 12 to 66 percent relative to HEVs. Other studies have identified similar ranges. To assess the GHG impact of PHEVs, both the engine fuel and grid electricity powering the electric drive system must be examined.

Safety

A study by the National Highway Traffic Safety Association (NHTSA) analyzed crashes in which HEVs and ICE vehicles collided with pedestrians or bicyclists. HEVs were found to be twice as likely to be involved in a pedestrian or bicyclist crash in these situations as an ICE vehicle. Statistically significant effects were found in crashes in which a vehicle was stopping or slowing, backing up, turning, or entering or leaving a parking space. There was no statistically significant difference in the incidence rate of pedestrian crashes involving HEVs compared to ICEs when traveling straight. The study suggested that the increased pedestrian and bicyclist

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[104] David Friedman, 18.

[105] SULEV is a U.S. classification for conventionally powered or gasoline-electric hybrid vehicles designed to produce minimal emissions of certain categories of air pollution at their point of use, typically 90 percent less than that of an equivalent ordinary full gasoline vehicle for the controlled pollution categories. For more information, see http://en.wikipedia.org/wiki/Super_Ultra_Low_Emission_Vehicle.

[106] A. Elgowainy et al., "Well-to-Wheels Energy Use and Greenhouse Gas Emissions Analysis of Plug-in Hybrid Electric Vehicles," Argonne National Laboratory, February 2009, http://www.transportation.anl.gov/pdfs/TA/559.pdf.

[107] J. Dowds et al.

crash rates for HEVs were due to the fact that HEVs are much quieter than ICEs, especially at low speeds. However, NHTSA cautioned that the study relied upon a small sample size, so results should be interpreted with caution. Nevertheless, this is an issue that should be carefully considered in order to protect the safety of pedestrians and bicyclists in Greater Philadelphia. Sight-impaired pedestrians are especially vulnerable.[108] Similar issues apply to EVs and PHEVs.

Emergency response procedures for HEVs are similar to those for conventional vehicles, with the addition of special considerations for the high-voltage electric system components. Toyota, Ford, Honda, and other manufacturers have all published emergency response guides for their vehicles. These guides include information about how to identify a hybrid, safely handle and shut off electrical components in an emergency situation, safely put out fires, and properly tow the vehicle.

In general, HEVs and PHEVs do not sacrifice any level of driver safety compared to conventional vehicles and are subject to the same crash testing requirements.

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[108] Pennsylvania was one of 12 states evaluated in the study (U.S. Department of Transportation National Highway Traffic Safety Administration, “Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles,” September 2009, http://www-nrd.nhtsa.dot.gov/Pubs/811204.PDF).

Appendix A: U.S. Department of Energy Definition of Alternative Fuels

The U.S. Department of Energy (U.S. DOE) defines alternative fuel vehicles (AFV) as "any dedicated, flexible-fuel, or dual-fuel vehicle designed to operate on at least one alternative fuel."[109] A ***dedicated*** AFV can be powered by a single type of alternative fuel and cannot use pure gasoline or diesel fuel. A ***flexible-fuel*** AFV can be powered by either an alternative fuel, gasoline, or a mixture of the two in the same fuel tank. Though not classified as an alternative vehicle by the U.S. DOE, ***bi-fuel*** vehicles can be powered by either an alternative fuel or a traditional fuel such as gasoline or diesel, but not more than one at a time; the two fuels are stored in separate tanks within the vehicle.[110]

The federal definition of alternative fuels as defined under the Energy Policy Act of 1992 (EPACT92) has evolved through amendments by the Energy Reauthorization and Conservation Act of 1998, EPACT 2005, and the Energy Independence and Security Act of 2007 (EISA 2007). Under EPACT92, alternative fuels were defined as fuels which are not derived from petroleum, including the following: (1) methanol, ethanol, and other alcohols; (2) blends of 85 percent or more of alcohol with gasoline; (3) natural gas and liquid fuels domestically produced from natural gas; (4) liquefied petroleum gas; (5) coal-derived liquid fuels; and (6) hydrogen and electricity. The EISA 2007 amended EPACT92 by mandating greenhouse gas thresholds for all "renewable fuels," defined as "any motor vehicle fuel that is used to replace or reduce the quantity of fossil fuel present in a fuel mixture used to fuel a motor vehicle." The Renewable Fuel Standards 1 definition includes motor vehicle fuels produced from biomass material such as grain, starch, fats, greases, oils, and biogas. The definition specifically includes cellulosic biomass ethanol, waste-derived ethanol, and biodiesel, all of which are defined separately.

The U.S. DOE currently lists the following fuels as "alternative fuels":

- blends of 85 percent or more of methanol, denatured ethanol, and other alcohols with gasoline or other fuels;
- natural gas and liquid fuels domestically produced from natural gas;
- liquefied petroleum gas (propane);
- coal-derived liquid fuels;
- hydrogen;
- electricity;
- biodiesel (B100);
- fuels (other than alcohol) derived from biological materials; and
- P-Series fuels.[111]

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[109] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Epact Transportation and Regulatory Activities: Key Terms," last modified July 21, 2009, http://www1.eere.energy.gov/vehiclesandfuels/epact/key_terms.html#alt_fuel_vehicle.

[110] Most alternative vehicles are dedicated AFVs; flexible-fuel vehicles are for ethanol and P-Series; bi-fuel is commonly hybrid or compressed natural gas.

[111] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, "P-Series," last modified January 4, 2011, http://www.afdc.energy.gov/afdc/fuels/emerging_pseries.html.

Table 4: Comparison of Delaware Valley Regional Planning Commission and U.S. Department of Energy Alternative Fuel Definitions

Comparison of Delaware Valley Regional Planning Commission and U.S. Department of Energy Alternative Fuel Definitions

Fuel	DVRPC	U.S. DOE
Blends of 85 percent ethanol, 15 percent gasoline	X	X
Blends of 85 percent or more of other alcohols		X
Compressed natural gas produced from domestic resources	X	X
Liquefied petroleum gas	X	X
Coal-derived liquid fuels		X
Hydrogen	X	X
Electricity	X	X
Biodiesel	Blends of B5 or greater	B100
Fuels (other than alcohol) derived from biological materials		X
P-series fuels		X

Source: DVRPC, 2011

Appendix B: List of Acronyms

AFV: Alternative Fuel Vehicle
Btu: British Thermal Units
CNG: Compressed Natural Gas
CO_2: Carbon Dioxide
CO_2e: Carbon Dioxide Equivalent
DVRPC: Delaware Valley Regional Planning Commission
E85: Fuel Blend of 85 Percent Ethanol, 15 Percent Gasoline
EISA: Energy Independence and Security Act of 2007
EPACT: Energy Policy Act of 1992
EV: Electric Vehicle
FFV: Flex/Flexible-Fuel Vehicle
GGe: Gallon Gasoline Equivalent
GHG: Greenhouse Gas
GM: General Motors
HDV: Heavy-Duty Vehicle
HEV: Hybrid Electric Vehicle
ICE: Internal Combustion Engine
kW: Kilowatt
LCFS: Low Carbon Fuels Standard Program
LDV: Light-Duty Vehicle
LNG: Liquefied Natural Gas
LPG: Liquefied Petroleum Gas
MPG: Miles per Gallon
MPGe: Miles per Gallon Gasoline Equivalent
NGV: Natural Gas Vehicle
NHTSA: National Highway Traffic Safety Association
NREL: National Renewable Energy Laboratory
OEM: Original Equipment Manufacturer
PHEV: Plug-In Hybrid Electric Vehicle
PM: Particulate Matter
RFS2: Renewable Fuels Standard 2
SMR: Steam Methane Reforming
SULEV: Super Ultra Low-Emissions Vehicle
U.S. DOE: U.S. Department of Energy
U.S. DOT: U.S. Department of Transportation
U.S. EPA: U.S. Environmental Protection Agency
VOC: Volatile Organic Compound

Publication Title: Ready to Roll?: Overview of Challenges and Opportunities for Alternative Fuel Vehicles in the Delaware Valley

Publication Number: 10055B

Publication Date: November 2011

Geographic Area Covered: DVRPC Region (Bucks County, Burlington County, Camden County, Chester County, Delaware County, Gloucester County, Mercer County, Montgomery County, City of Philadelphia)

Key Words: alternative fuel vehicle, AFV, fuel, biofuel, biodiesel, ethanol, E85, cellulosic ethanol, feedstock, grid electricity, natural gas vehicle, NGV, compressed natural gas, CNG, liquefied natural gas, LNG, propane, liquefied petroleum gas, LPG, hydrogen, fuel cell, electric vehicle, EV, hybrid electric vehicle, HEV, plug-in hybrid electric vehicle, PHEV, greenhouse gases, GHG, transportation, infrastructure, pipeline, distribution, drive train, electric motor, internal combustion engine, ICE, flexible-fuel vehicles, FFV, transportation, battery, idle-stop, regenerative breaking, Energy Policy Act of 1992

Abstract: *Alternative Fuel Vehicles* (AFVs) use combinations of vehicle fuels and technologies to reduce the use of petroleum in on-road vehicles. These include low-carbon fuels (sometimes blended with petroleum), electricity, and hybrid technologies combining internal combustion engines with electric motors. DVRPC's *Ready to Roll?* report provides an overview for policymakers and citizens in the Greater Philadelphia region about the challenges and opportunities for expanded use of alternative fuel vehicles. The AFVs covered in this report include those most widely available today or likely to become available in the next 10 to 20 years.

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