

Financing the Infrastructure to Support Alternative Fuel Vehicles: How Much Investment is Needed and How Will It Be Funded?

Prepared by:



Go Further

Ellen Hughes-Cromwick
Director and Chief Economist
Corporate Economics and Strategic Issues
Ford Motor Company
One American Road
Dearborn, MI 48126



Joshua Cregger
Project Manager
Center for Automotive Research
3005 Boardwalk, Suite 200
Ann Arbor, MI 48108

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All statements, findings, and conclusions in this report are those of the authors and do not necessarily reflect those of the Global Interdependence Center, Ford Motor Company, or the Center for Automotive Research.

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FINANCING THE INFRASTRUCTURE TO SUPPORT ALTERNATIVE FUEL VEHICLES: HOW MUCH INVESTMENT IS NEEDED AND HOW WILL IT BE FUNDED?

ABSTRACT

Countries around the world have implemented regulatory requirements to improve fuel economy and reduce greenhouse gas emissions from vehicles. These regulations encourage automakers to sell alternative fuel vehicles (AFVs), which use fuels such as natural gas, electricity, hydrogen, and biofuels. Automakers are already making investments in developing and manufacturing AFVs. There are many challenges to increasing AFV market share and providing appropriate support of fueling infrastructure for these unconventional vehicles. The cost of installing new refueling infrastructure is high. The lack of available breadth of the fueling infrastructure is one factor which may reduce consumer acceptance and confidence in this new technology.

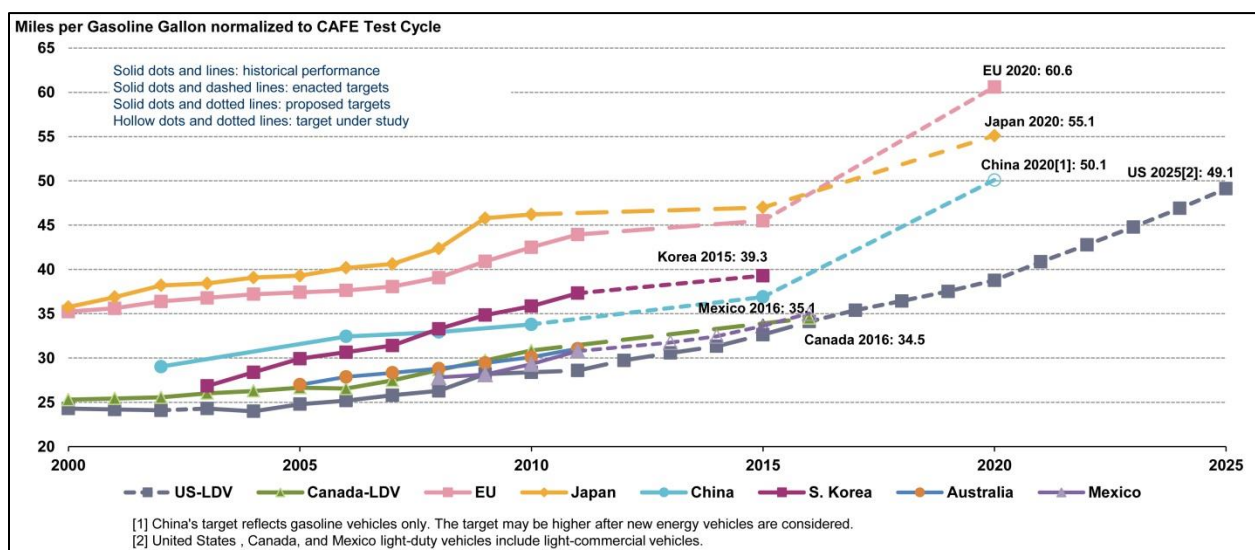
Private rates of return from investing in such infrastructure can be low or negative for the private sector, and the required infrastructure spending may be in excess of the private sector's ability to finance. However, infrastructure for fueling may also have "public good" attributes, thereby providing a role for government funding. This paper describes several different types of alternative fuels and summarizes the existing infrastructure investments to support AFVs in several countries and one U.S. state (Brazil, China, the European Union, the United States, and California). This research offers a long run projection of what the likely future investment requirements would be, in order to support future AFV volumes. The authors have also included an assessment of the gap between what infrastructure investment is needed for successful growth of AFV sales and what has been built out so far, with particular attention to selected countries.

Several examples of public financing programs and public-private partnerships to encourage sales of AFVs, construction of refueling infrastructure, and adoption of other environmental technologies are detailed. This paper will describe the costs and benefits of various funding models (e.g. tax incentives, government loan programs, convertible bonds, and joint ventures) which have been or could be put in place to support AFV infrastructure investment spending.

INTRODUCTION

Countries around the world have implemented regulations which incentivize fuel economy improvements and reductions in greenhouse gas (GHG)¹ emissions from vehicles (see Figure 1 below). The purpose of these regulations is largely, although not exclusively, to reduce the impact of GHG emissions—which include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and other gases—on the environment, as well as to enhance energy security by reducing reliance on foreign energy imports. In addition to encouraging automakers to improve performance of gasoline-powered, internal combustion engine vehicles, these regulations encourage automakers to sell alternative fuel vehicles (AFVs), which are powered by other fuels, such as natural gas, electricity, hydrogen, and biofuels.

Figure 1: Fuel Economy Standards for Select Countries, MPG, 2000-2025



Source: ICCT 2012

In the United States, fuel economy targets are mandated by Corporate Average Fuel Economy (CAFE) standards. While there are complex dynamics involving efficiency, cost, and consumer demands, CAFE standards are “the single most powerful regulatory mechanism affecting energy use in the U.S. transportation sector.”² Policies driving innovation in vehicle fuel efficiency are important, because the long-run energy outlook suggests the potential for high and volatile oil prices.

On a global scale, there will be high growth in the driving age population over the next decade, and demand for vehicles is rising. In developing countries like China, absent policy, the number of vehicles on the road will increase considerably, intensifying the already severe pollution and congestion issues in urban areas. More efficient vehicles and AFVs will be required to meet future mobility needs across the world.

¹ Numerous abbreviations are used throughout this paper. Each abbreviation, along with the associated term, is listed in Appendix A.

² EIA. (2012). “Annual Energy Outlook 2012 with Projections to 2035.” DOE/EIA-0383(2012). Energy Information Administration, United States Department of Energy. June 2012. <[http://www.eia.gov/forecasts/aeo/pdf/0383\(2012\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf)>.

Automakers are already making investments in developing and manufacturing AFVs. In 2012, Ford sold a record 11,600 natural gas vehicles—more than three times as many as it sold in 2010. Honda also saw increased interest in its natural gas-powered Honda Civic GX; General Motors and Chrysler recently began offering natural gas pickup trucks.³

Plug-in electric vehicles (PEVs) include battery electric vehicles (BEVs) such as the Nissan Leaf and Focus Electric, plug-in hybrid electric vehicles (PHEVs) such as the Chevrolet Volt, Prius Plug-in, and C-MAX Energi. The only PEV available on the U.S. market in 2009 was the Tesla Roadster. During 2012, 13 PEV models were available in the United States; in 2013, PEV offerings will increase to 28 models.

Some automakers have introduced hydrogen-powered fuel cell electric vehicles as fleet demonstration models (e.g., the Honda Clarity FCX). There have also been several automakers who have publically announced their intention to offer a hydrogen fuel cell vehicle for sale by 2015.

Biofuels are already gaining popularity, with many fleets using biodiesel. In Brazil, flexible fuel (flex-fuel) vehicles capable of running on E85, a blend of ethanol and gasoline, constituted 87 percent of new vehicle sales in 2012;⁴ flex-fuel vehicles are popular in the United States as well, with nearly 1.5 million sold in 2010.⁵

In order to facilitate the shift toward AFVs, many challenges will have to be overcome. One of the greatest challenges to promoting AFV adoption is putting into place a new and upgraded infrastructure which is necessary to provide AFV owners with adequate access to these unconventional fuels. The cost of installing new refueling infrastructure is high, and the adoption of AFVs uncertain, making private investment risky and relatively unattractive. Due to current political and economic realities, securing public funding for infrastructure investment could also be a challenge.

Previous studies have concluded that a “substantial refueling network is a pre-condition for the market’s accepting alternative fuel vehicles.”⁶ Without sufficient refueling infrastructure available, consumer acceptance and confidence in AFV technology could suffer. For some fuels, such as electricity and compressed natural gas, however, home systems for charging and refueling could permit consumer adoption even without the construction of publicly available infrastructure.

Once AFVs have achieved commercial scale and a high utilization of their refueling infrastructure, the infrastructure costs will be minor on a per vehicle basis.⁷ The transition to commercial scale, however, is a significant challenge as it represents a high risk for investors: the utilization of refueling infrastructure could remain low for a prolonged period or the fuel could fail to gain popularity altogether.

³ Durbin, Dee-Ann. (2013). “Natural Gas Vehicles Making Inroads; Sales Rising.” Associated Press. March 5, 2013. <<http://bigstory.ap.org/article/natural-gas-vehicles-making-inroads-sales-rising>>.

⁴ ANFAVEA. (2013). “Carta da ANFAVEA.” Associação Nacional dos Fabricantes de Veículos Automotores. January 2013. <<http://www.anfavea.com.br/cartas/Carta320.pdf>>.

⁵ EERE. (2013). Alternative Fuels Data Center. Energy Efficiency & Renewable Energy, United States Department of Energy. Accessed February 13, 2013. <<http://www.afdc.energy.gov/>>.

⁶ Greene, David L. (1990). “Fuel Choice for Multi-Fuel Vehicles.” Contemporary Economic Policy. Volume 8, Issue 4, pp. 118-137. October 1990.

⁷ NPC. (2012). “Chapter 5: Infrastructure.” Advancing Technology for America’s Transportation Future. National Petroleum Council. August 11, 2012. <http://www.npc.org/FTF-report-080112/Chapter_5-Infrastructure-021113.pdf>.

The concurrent development of alternative fuel vehicles and alternative fuel vehicle infrastructure is also a frequently cited challenge as it poses a “chicken-and-egg” problem. Automakers will not be able to sell AFVs if there is not adequate refueling infrastructure for vehicle owners; conversely, fuel providers will not be able to recover their investments if there are not enough AFVs on the road that need fuel.

This paper describes several different types of alternative fuels and summarizes the existing infrastructure investments to support AFVs in several countries and one U.S. state (Brazil, China, the European Union, the United States, and California). This research offers a long run projection of what likely future investment requirements would be in order to support future AFV volumes. The authors have also included an assessment of the gap between what infrastructure investment is needed for successful growth of AFV sales and what has been built out so far, with particular attention to selected countries.

Several examples of public financing programs and public-private partnerships to encourage sales of AFVs, construction of refueling infrastructure, and adoption of other environmental technologies are detailed. This discussion will also cover the costs and benefits of various funding models (e.g., tax incentives, government loan programs, convertible bonds, and joint ventures) which have been or could be put in place to support AFV infrastructure investment spending.

ALTERNATIVE FUELS

Gasoline has been the dominant fuel for road transportation for the past century, but there have always been alternative fuels. Early alternatives to the gasoline-powered, internal combustion engine included steam engines, electric motors, and diesel engines. While electric and steam-powered vehicles almost completely disappeared from the roads, diesel engines eventually became the popular choice for heavy-duty vehicles and, in some regions, even became common in passenger vehicles.

Interest in alternative fuel vehicles has risen and fallen several times in the history of the automobile. Gasoline was clearly established as the fuel of choice by 1920, but interest in alternative fuels increased in the 1970s and early 1980s in reaction to oil shortages in the '70s. During this time, the United States adopted CAFE standards to increase fuel efficiency in vehicles and Brazil enacted its Programa Nacional do Álcool, spurring production of ethanol for vehicle fuel.

Interest in alternative fuels waned, however, as oil prices declined and the limitations of these fuels became apparent. Higher petroleum prices, desire to reduce national dependence on foreign energy, and efforts to reduce GHG emissions in the 2000s renewed interest in alternative fuels, causing many countries to promote alternative fuels.

The definition of alternative fuels is somewhat flexible and can be used to refer to various subsets of fuels. One frequently cited definition is the United States Energy Policy Act of 1992,⁸ which classified the following as alternative fuels:

- Methanol, ethanol, and other alcohols
- Blended gasoline with at least 85 percent alcohol
- Natural gas and natural gas-derived liquid fuels
- Liquefied petroleum gas (propane)
- Coal-derived liquid fuels
- Hydrogen
- Electricity
- Non-alcoholic fuels derived from biological materials⁹
- P-Series fuels¹⁰

AFVs are associated with a variety of costs and infrastructure needs. For instance, stations to provide alternative fuels, especially for natural gas and hydrogen, will be necessary prior to consumers purchasing vehicles requiring those fuels. Infrastructure for electric vehicles is less essential; electric outlets are fairly ubiquitous, and early adopters are likely to do the majority of their charging at home. Biofuel adoption has already begun in the form of blended fuels that use existing infrastructure. The majority of vehicles in use that are capable of using higher biofuel concentrations are also capable of

⁸ EERE. (2013). Alternative Fuels Data Center.

⁹ This includes pure biodiesel (B100), which was classified as an alternative by the U.S. Department of Energy fuel in 1996.

¹⁰ P-series fuels are renewable, liquid fuels that contain a mixture of ethanol and other flammable hydrocarbons such as butane and pentane. The U.S. Department of Energy classified three P-Series fuels as alternative fuels in 1999.

running on plain gasoline, making them completely backwards compatible (that is, able to use old infrastructure as well as new infrastructure) and less dependent on new infrastructure.

Gasoline, diesel, and several alternative fuels are discussed in subsequent sections; however, this report will focus primarily on natural gas, electricity, hydrogen, and biofuels. These four fuels can displace petroleum use and have the potential to reduce GHG emissions and improve energy security.

Gasoline

Gasoline is the primary fuel used to power light-duty vehicles. Gasoline is a petroleum-derived, liquid fuel and is considered a conventional, incumbent fuel. In the United States, gasoline is referred to as gas; in Europe, it is referred to as petrol.

Nearly half (19 gallons) of a barrel (42 gallons) of crude oil can be refined into gasoline.¹¹ The remaining portion of crude oil can produce diesel fuel, jet fuel, residual fuel oils, and other products.

The infrastructure required to produce, distribute, and dispense gasoline developed along with the automobile. As one of the earliest fuels for motor vehicles, gasoline has a well-established infrastructure in most countries, where it is widely available for purchase.

Diesel

Diesel, like gasoline, is a petroleum-based, liquid fuel. It can be used in diesel engines and is not typically considered an alternative fuel. It is, however, sometimes included as an alternative to gasoline, because the use of a diesel engine can improve a vehicle's fuel economy. While diesel itself produces more GHG emissions per gallon than gasoline (10,180 grams CO₂/gallon compared to 8,887 grams CO₂/gallon), due to its higher fuel efficiency, diesel vehicles produce fewer GHGs on a per-mile basis.¹² Further, diesel engines emit less carbon monoxide than gasoline engines, approximately the same volatile organic compounds (VOCs), more nitrogen oxides (NO_x), and airborne particulates (which aren't emitted by gasoline engines).¹³

The diesel engine, sometimes called a compression-ignition engine, was invented in the late 1800s. It was created as a replacement for steam engines and was initially used in ships, locomotives, and stationary applications.¹⁴ Because early diesel engines were viewed as slow, large, heavy, and inflexible, they were not commonly used in road vehicles until engine improvements allowed them to be made smaller and lighter. In the 1930s, in both Europe and North America, diesel engines began to be used in buses, trucks, and military vehicles.¹⁵

¹¹ EIA. (2012). "Frequently Asked Questions." United States Energy Information Administration. September 5, 2012. <<http://www.eia.gov/tools/faqs/>>.

¹² This effect can easily be illustrated with vehicles, such as the Volkswagen Passat, that have both gasoline and diesel versions. The Passat diesel gets 34 mpg, and the gasoline-powered Passat gets 26 mpg gasoline. The diesel version gets 30.7 percent higher fuel economy, but only a 17.3 percent reduction in CO₂.

¹³ Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence: Evidence From Gasoline and Diesel Cars." *RAND Journal of Economics*. Volume 3, Issue 2, pp. 275-297. Summer 2002.

¹⁴ Hard, Mikael and Andrew Jamison. (1997). "Alternative Cars: The Contrasting Stories of Steam and Diesel Automotive Engines." *Technology in Society*. Volume 19, Number 2, pp. 145-160. April 1997.

¹⁵ Hard, Mikael and Andrew Jamison. (1997). "Alternative Cars."

Over the years, many fueling stations have been constructed to serve drivers of diesel vehicles. In the United States, where few light vehicles use diesel fuel, it is available at nearly half (42 percent) of retail gasoline stations.¹⁶ In Europe, where more than half of all light vehicles sold each year run on diesel,¹⁷ the fuel is available at nearly every gas station.¹⁸ Because diesel fuel has a relatively high degree of availability, financing diesel infrastructure will not be discussed in this paper.

Natural Gas

Natural gas is a naturally occurring fossil fuel composed mainly of methane. It is commonly used to heat buildings and generate electricity. Natural gas is cleaner-burning than other fossil fuels (such as coal and oil) and produces lower quantities of GHGs when burned. It can be used as a fuel for vehicles in two forms: compressed natural gas (CNG) or liquefied natural gas (LNG).

There is a wide variety of new, heavy-duty natural gas-powered vehicles currently available on the market. The only light vehicle available in the United States is the Honda Civic GX. There is also the option of aftermarket conversion: new equipment can be installed in a gasoline or diesel vehicle to make it run on natural gas. Most light-duty CNG vehicles in the United States today have been converted from running on petroleum-based fuels.

Natural gas is an attractive fuel for transportation because CNG and LNG vehicles generally have a high driving range on a full tank of fuel, refueling time is short, and natural gas is inexpensive compared to gasoline. In addition, natural gas vehicles produce lower GHGs compared to gasoline or diesel vehicles.

Compressed Natural Gas

CNG is stored in pressurized containers at 3,000-3,600 pounds per square inch (PSI).¹⁹ The fuel is sold in units that have an energy content identical to that of a gallon of gasoline and are appropriately named gasoline gallon equivalents (GGEs). A GGE of CNG is 126.67 cubic feet at standard temperature and pressure, weighs approximately 5.66 pounds, and when pressurized at 3,600 PSI takes up a volume of 3.82 gallons.

Liquefied Natural Gas

LNG-powered vehicles are more expensive than CNG vehicles and are usually medium- or heavy-duty vehicles used to travel long distances. Vehicles powered by LNG require a specialized and expensive tank (double-walled, vacuum-insulated) in order to keep the fuel cold. Because LNG is kept at high pressure and low temperature, it is more energy dense than CNG; one GGE of LNG is 1.5 gallons.²⁰

¹⁶ U.S. Coalition for Advanced Diesel Cars. (2013). "Where is Clean Diesel Available?" U.S. Coalition for Advanced Diesel Cars Website. Accessed February 27, 2013

<<http://www.cleandieseldelivers.com/CLEAN%20DIESEL%20101/Where%20is%20Clean%20Diesel%20Fuel%20Available.html>>.

¹⁷ Mock, Peter. (2012). "European Vehicle Market Statistics: Pocketbook 2012." The International Council on Clean Transportation. October 29, 2012. <<http://www.theicct.org/european-vehicle-market-statistics-2012>>.

¹⁸ Gordon-Bloomfield, Nikki. (2012). "U.S. Car Buyers Like Hybrids, Europeans Go For Diesels; Why?" Green Car Reports. September 26, 2012. <http://www.greencarreports.com/news/1079415_u-s-car-buyers-like-hybrids-europeans-go-for-diesels-why>.

¹⁹ EERE. (2013). Alternative Fuels Data Center.

²⁰ EERE. (2013). Alternative Fuels Data Center.

Electricity

Electricity can be produced using a wide variety of feedstocks (e.g., oil, coal, natural gas, nuclear, hydroelectric, wind, and solar). Conventional motor vehicles have batteries and require electricity to operate; in the 1990s, automakers began developing hybrid electric vehicles (HEVs) which use an electric motor to augment the vehicle's internal combustion engine (ICE). More recently, however, automakers have developed PEVs, which are more dependent on electric motors for propulsion and are able to connect to the electric grid to charge their large batteries.

In this paper, PEV is a broad term that encompasses both BEVs and PHEVs. BEVs operate solely on battery power and cannot use other fuels; popular models in the United States include the Nissan Leaf, Tesla Model S, and Ford Focus Electric. PHEVs, like regular hybrids, can run off either a battery or a gasoline engine. However, they have a much larger battery than hybrid vehicles, can run on electricity for longer periods of time, and are able to plug into an outlet to charge. Popular models of PHEV include the Chevrolet Volt, Prius Plug-in and Ford C-MAX Energi.

While driving, vehicles dependent solely on electricity create no tailpipe emissions. From a lifecycle "well-to-wheels" perspective, however, generation of the electricity used to power electric vehicles can be quite energy intensive and may still create significant pollution, depending on what kinds of power plants were used. Most regions in the United States produce electricity for the grid such that the use of an electric vehicle would result in fewer GHG emissions per mile traveled than would be produced using a similar gasoline-powered vehicle. In some areas where hydroelectric and nuclear power comprise a large share of grid capacity, electric vehicles have significantly lower emissions; in other areas, such as the Midwest, which relies on coal-burning power plants for much of its electricity, electric vehicles and conventional vehicles are responsible for comparable GHG emissions.

PEVs can use different types of systems to charge their batteries. In North America, a regular outlet delivers 120 volts; chargers designed for use in this type of outlet are known as Level 1 chargers. Depending on the size of the vehicle's battery, a Level 1 charger could take between 8 and 20 hours to fully charge the battery.²¹ For lower charging times, a vehicle owner can use a Level 2 charger, requiring a specialized 240-volt outlet, much like that used for most electric clothes dryers. Most garages lack 240-volt outlets; PEV owners will likely need to have one installed by an electrician in order to use a Level 2 charger.

Even faster charging can be achieved through the use of Level 2 DC systems (also referred to as DC Fast Charge, formerly referred to as Level 3 systems), which rely on direct current rather than alternating current, and are capable of charging a PEV in a half hour or less. Level 2 DC charging is not currently standardized; the primary competing standards are the CHAdeMO DC fast charger framework and the SAE J1772 Combo standard. CHAdeMO is used by Japanese automakers Mitsubishi, Nissan, Subaru, and Toyota, while SAE J1772 Combo has support from U.S. (Chrysler, Ford, and General Motors) and European (Audi, BMW, Daimler, Porsche, and Volkswagen) automakers.²² In the United States,

²¹ EIA. (2012). "Annual Energy Outlook 2012."

²² SAE. (2012). "J1772 'combo connector' shown at the 2012 Electric Vehicle Symposium." Society of Automobile Engineers. May 3, 2012. <<http://ev.sae.org/article/11005>>.

CHAdeMO support is limited to Nissan and Mitsubishi—other automakers are using SAE J1772 Combo. A third competing standard is the Tesla Supercharger which is not compatible with either of the other systems. Level 2 DC charging uses a power supply of up to 500 volts, which could yield a power of 50 to 100 kilowatts (kW).²³ Even with Level 2 DC charging, PEVs will take substantially longer to charge than ICE vehicles take to refill.²⁴

Early PEV owners will do the majority of their charging at home due to lack of public charging infrastructure and long recharging times. In many places, the expansion of charging infrastructure is viewed as a way to give PEV drivers greater range, confidence, and convenience. This has led to the rapid expansion of public charging networks in the United States and Europe in recent years.

Hydrogen

Hydrogen (H₂) is rarely found alone in nature, but can be produced from sources such as water (H₂O), methane, and other organic materials. The majority of methane is currently produced through a process known as steam methane reforming (SMR), which uses natural gas to produce hydrogen. In SMR, a processing device called a reformer creates a catalytic reaction between steam and natural gas at high temperatures to produce hydrogen and carbon monoxide. Carbon monoxide can be used in a secondary reaction with steam to produce additional hydrogen gas along with carbon dioxide.

Hydrogen can also be produced through electrolysis, which uses electricity to split water molecules into hydrogen and oxygen molecules. Hydrogen produced by splitting water has the potential to be essentially emissions free if the electricity comes from renewable sources. Electrolysis is rarely used for hydrogen production, however, because hydrogen can be produced more economically through the use of fossil fuels.

Hydrogen is used in several industrial processes such as fertilizer production, food processing, metal treatment, and petroleum refining. Although hydrogen is not currently widely used as a transportation fuel, it can be used to power vehicles using combustion engines or a device called a fuel cell.²⁵

Combustion of Hydrogen

Hydrogen can be blended with natural gas and used to power natural gas vehicles. This blended fuel has decreased NO_x emissions when it is burned in natural gas vehicles.

Hydrogen Fuel Cells

Hydrogen fuel cell electric vehicles are a more high-profile use of hydrogen for automotive fuel. Fuel cells are able to convert hydrogen and oxygen into electricity and produce water as a byproduct. Because they can store a relatively large amount of hydrogen fuel in an on-board tank, fuel cell vehicles are not subject to the same range limitations as electric vehicles; however, the creation of a hydrogen

²³ SAE. (2012). "J1772 'combo connector' shown at the 2012 Electric Vehicle Symposium."

²⁴ EIA. (2012). "Annual Energy Outlook 2012."

²⁵ EERE. (2013). Alternative Fuels Data Center.

refueling infrastructure is seen as a greater challenge for fuel cell vehicles than the creation of an electric charging infrastructure is for electric vehicles.²⁶

Fuel cells were first commercially used to power space-exploration vehicles, but have since become more common for backup power sources in large buildings. Significant investment has been made in research and development directed at creating a commercially viable hydrogen fuel cell vehicle.

Some automakers have introduced hydrogen fuel cell demonstration models, and several have announced the introduction of hydrogen fuel cell vehicles for sale by 2015. These vehicles will be primarily introduced in Europe, Asia, California, and Hawaii where there has been significant government effort to begin building a hydrogen refueling infrastructure.²⁷

Biofuels

Biofuels are renewable fuels made from corn, sugarcane, soybeans, and other plant materials. Current biofuels are generally made from feedstocks which might otherwise be used to produce food. There is, currently, a significant research push to develop biofuels derived from other feedstocks (e.g., switchgrass and willow) which do not compete with food production and can be grown on marginal land unsuitable for other crops.

While biofuels still release GHGs when burned, they can be considered carbon neutral because the carbon contained in biofuels was previously absorbed from the atmosphere by plants undergoing photosynthesis. Two common biofuels are ethanol and biodiesel; “drop-in” biofuels are another class of biofuels that are just beginning to emerge.

Ethanol

Ethanol is created through the fermentation of corn in the United States and sugar cane in Brazil. Gasoline is often blended with a specific amount of ethanol (e.g., ten percent in the United States and 20-25 percent in Brazil). Ethanol is also available in significantly higher blends; E85, for instance, contains up to 85 percent ethanol. While conventional vehicles can handle lower level blends which may contain only ten percent ethanol, special vehicles optimized to burn ethanol are required to burn E85.

Vehicles capable of burning ethanol were developed in the past, but they could not run on conventional gasoline. A decade ago, automakers began offering flex-fuel vehicles containing sensors which allow the powertrain to be automatically calibrated to handle a variety of gasoline-ethanol blends.

U.S. policy has been used to promote the sale of flex-fuel vehicles as a way of addressing the “chicken-and-egg” problem of AFV sales and refueling infrastructure installation. While incentives for vehicles, fuel, and stations have existed for several years, availability of E85 is still rather limited at stations across the country. While flex-fuel vehicles constitute the largest portion of current U.S. AFV sales (over one million units annually), most run primarily on gasoline due to limited infrastructure availability, lack of consumer awareness, and the high per-mile cost of using E85 compared to gasoline. While the price of

²⁶ NAS. (2013). “Transitions to Alternative Vehicles and Fuels.” Committee on Transitions to Alternative Vehicles and Fuels; Board on Energy and Environmental Systems; Division on Engineering and Physical Sciences; National Research Council. National Academy of Sciences. March 2013. <https://download.nap.edu/catalog.php?record_id=18264>.

²⁷ NAS. (2013). “Transitions to Alternative Vehicles and Fuels.”

E85 is usually lower than that of gasoline on a per-gallon basis, E85 contains about 30 percent less energy, making it a more expensive fuel per mile driven.²⁸ As most flex-fuel vehicles use no more ethanol than a conventional gasoline-powered vehicle, their capacity to function as an AFV often goes unused.

Biodiesel

Biodiesel is primarily produced from vegetable oils (soybeans in the United States), but can also be made from animal fats or recycled restaurant grease. It is similar to petroleum diesel, but is cleaner-burning and has reduced emissions when compared to petroleum diesel. Biodiesel is commonly used in B20, a blend containing 20 percent biodiesel and 80 percent petroleum diesel. Because biodiesel has approximately eight percent less energy content than petroleum diesel, a gallon of B20 has one or two percent less energy than a gallon of petroleum diesel.²⁹

Drop-in Biofuels

Drop-in biofuels are a variety of fuels currently being developed; significant public and private research and development efforts are underway to develop such fuels from biomass feedstocks.³⁰ These biofuels are direct replacements for petroleum-based fuels, and will not require specialized vehicles or infrastructure.³¹ While gasoline blends of up to 10 or 15 percent and diesel blends of up to 20 percent can be used in existing vehicles and dispensing infrastructure, ethanol and biodiesel are not considered “drop-in” biofuels.

Comparison of Fuels

Average price and fuel economy data for vehicles using various fuels is displayed in Table 1. This data represents average values from various 2012 and 2013 vehicle models.³² The data allows for a rough comparison of different AFVs. The estimate for combined miles per gallon equivalent (MPG/e), which estimates how many miles a vehicle can travel on one GGE, will be used for further analysis in a later section of the paper.

As previously mentioned, each of the AFV technologies discussed in this paper has the potential to displace petroleum use and reduce GHG emissions. The environmental effects of AFVs vary by technology type. While AFVs powered by electricity or hydrogen may have no tailpipe emissions, every

²⁸ Clean Cities. (2013). “Clean Cities Alternative Fuel Price Report, January 2013.” Energy Efficiency & Renewable Energy, United States Department of Energy. January 2013. <http://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_jan_2013.pdf>.

²⁹ EERE. (2013). Alternative Fuels Data Center.

³⁰ Such feedstocks for drop-in biofuels include crop residues, woody biomass, dedicated energy crops, and algae.

³¹ NAS. (2013). “Transitions to Alternative Vehicles and Fuels.”

³² For all fuel types, the MPG/e value was calculated as the average MPG/e of a selection of model year 2012 and 2013 vehicles, as given by the EPA, via fuelconomy.gov. For gasoline vehicles, the selected vehicles were the 25 top-selling cars in calendar year 2012, per Automotive News. For BEVs, the average MPG/e was calculated from the values of all vehicles for which this information was available. Similarly, all PHEVs for which information was available were included - save for the Fisker Karma, which was excluded as an extreme outlier. The effect of removing the Karma was to increase the MPG/e estimate, as the Karma's MPG/e is only 54, whereas all other PHEVs possess MPG/e values in the range of 94 through 100. Only one CNG passenger car was listed for the 2012 and 2013 model years - the 2012 Honda Civic CNG. Thus, the CNG MPG/e estimate represents this vehicle. The MPG/e estimate for E85 vehicles was calculated from the MPG achieved by flex fuel vehicles, when fueled by E85 (All E85-capable vehicles listed are flex fuel vehicles). The vehicles included for this calculation were the flex fuel versions of the 25 top selling, calendar year 2012 passenger cars. The MPG/e of the Honda FCX Clarity was used as a proxy for hydrogen fuel cell vehicles because data on other fuel cell vehicles was not available.

fuel type is responsible for some amount of emissions from a lifecycle perspective.³³ Differences in GHG emissions by fuel type are discussed in Appendix B.

Table 1: Vehicle Price and Fuel Economy by Fuel Type

Fuel	Vehicle Base Price	Combined MPG/e	Fuel Consumed per 100 Miles (GGE)
Gasoline	\$19,170	27.2	3.7
Diesel	\$21,148	33.9	2.9
Compressed Natural Gas	\$26,155	31.0	3.2
Electricity (BEV)	\$42,177	98.6	1.0
Hydrogen	-	61.0	1.6
Biofuel (flex-fuel using E85)	\$21,561	17.4	5.8

Note: The average consumption for BEVs was 34.9 kilowatt-hours (kWh) per 100 miles traveled. One gallon of gasoline contains energy equivalent to 33.7 kWh: $34.9/33.7 \approx 1.04$. The Honda Civic CNG and Honda FCX Clarity were used as representative vehicles for CNG and Hydrogen due to lack of data on other vehicles. Price information on the Honda FCX Clarity was not available.

Source: EERE 2013 and Honda 2013

³³ EERE. (2013). Alternative Fuels Data Center.

CASE STUDIES

This section documents some high-profile examples of large investments in which new, sustainable technologies have seen significant adoption and displaced incumbent technologies. These case studies include the production of E85 and adoption of flex-fuel vehicles in Brazil, the spread of diesel technology in the European light-duty vehicle fleet, and the development of renewable energy capacity in Germany.

Biofuels Growth in Brazil

Brazil is well known as the dominant country for ethanol production and consumption. Its inexpensive sugarcane ethanol is competitive with gasoline, and its vehicle fleet can largely run off of a wide variety of gasoline-ethanol blends. Much of Brazil's prominence in the ethanol market is due to government involvement (through incentives and legislation) over the course of nearly four decades, as well as market forces, industry partnerships, and technology development. Brazil's foray into ethanol production began with the creation of its Programa Nacional do Álcool (Proalcool), promoting ethanol production.

The Proalcool

The Proalcool began on November 14, 1975 in response to low sugar prices and the oil crisis of 1973.³⁴ It was originally introduced as a measure to produce ethanol which would be blended with gasoline (anhydrous ethanol).³⁵ The program was designed to meet several goals, including:

- expanding ethanol production beyond traditional regions,
- increasing ethanol production capacity in both agricultural and processing sectors, and
- mitigating the cost of transporting ethanol.

The program also described financial incentives and specified that Proalcool-related investments would be financed by the national system of banks.³⁶ The original language used in the Proalcool indicated that sugarcane, manioc (a root vegetable), or other appropriate feedstocks could be used to produce ethanol. Due to existing idle capacity at sugarcane processing facilities and the low price of sugar in the mid-1970s, Brazilian ethanol is now almost exclusively produced from sugarcane.

Initially, the Proalcool concentrated on production of anhydrous ethanol and set a national goal of producing 3.5 billion liters of ethanol by 1980. This was an ambitious goal. In 1974, a year before the program's inception, Brazil had produced only 625 million liters of sugarcane ethanol in the 130 ethanol distilleries existing at the time.³⁷ Weak international sugar prices and the 1979 oil crisis provided further support for alternative fuels, and Brazil's policy shifted from using ethanol as a gasoline additive to using ethanol as a replacement for gasoline. This policy shift resulted in increasing the production goal to 10.7 billion liters by 1985.

³⁴ Cordonnier, Vanessa M. (2008). "Ethanol's Roots: How Brazilian Legislation Created the International Ethanol Boom" William & Mary Environmental Law and Policy Review. Volume 33, Issue 1. pp. 287-317. 2008. <<http://scholarship.law.wm.edu/wmelpr/vol33/iss1/6>>.

³⁵ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

³⁶ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

³⁷ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

To support demand for ethanol, in 1980 the national government set the price of unblended ethanol at no more than 65 percent of the price of gasoline. Due to poor sales of ethanol and ethanol-powered vehicles in 1981, the Brazilian government undertook several initiatives. It began working with vehicle manufacturers to improve ethanol-powered engines. The government also lowered the price cap for ethanol to 59 percent of the price of gasoline, introduced a purchasing incentive that reduced the sales tax on ethanol-powered vehicles, and set the national gasoline blend at 20 percent ethanol. By the mid-1980s, ethanol-powered vehicles constituted over 92 percent of all light vehicles sold in Brazil.³⁸

Fall of the Ethanol Car and the Rise of Flex-Fuel Vehicles

In the late 1980s, production of ethanol and sales of ethanol-powered vehicles fell sharply. Gasoline prices dropped, and Brazil ended Proalcool subsidies to ethanol producers.³⁹ In the early 1990s, Brazil began to suffer from ethanol shortages, as producers switched from making ethanol to refining sugar when sugar prices increased.⁴⁰ These shortages reduced consumer confidence in ethanol as a fuel, and sales of ethanol-powered vehicles dropped to 27 percent of sales in 1990. Throughout the decade, sales of ethanol-powered vehicles continued to decline until 1997 and 1998 when they were less than a tenth of a percent of new vehicle sales.⁴¹

In 2003, flex-fuel vehicles, which can run off of any combination of ethanol and gasoline, were introduced to the Brazilian market. The Brazilian government taxed these vehicles at a lower rate than gasoline cars, and the ethanol market in Brazil began to recover.⁴² In 2003, flex-fuel vehicles constituted nearly four percent of vehicle sales. Within a few years, they rose to over 80 percent of the Brazilian light vehicle market. In 2012, 87 percent of new vehicles sold were flex-fuel vehicles.⁴³

Fuel Blending

In the early years of the Proalcool, the ethanol-gasoline blend fluctuated continuously and varied by location. In 1976, only the major regions producing sugarcane—Sao Paulo and the Northeast, as well as neighboring states—were required to sell gasoline blended with 10 to 15 percent ethanol. In 1977, gasoline sold in the city of Sao Paulo had to be blended with 20 percent ethanol; the other regions were required to sell a 12 percent blend. By 1979, the government required a 20 percent blend for the entire country.⁴⁴ In recent years, the Brazilian government has mandated that all gasoline contain 25 percent ethanol. This amount is subject to change depending on the quality of the sugarcane harvest. In October 2011, Brazil cut the ethanol blend from 25 percent to 20 percent.⁴⁵

³⁸ ANFAVEA. (2011). "Brazilian Automotive Industry Yearbook 2011." Associação Nacional dos Fabricantes de Veículos Automotores. São Paulo, 2011. <http://www.virapagina.com.br/anfavea2011/files/anfavea_2011.pdf>.

³⁹ Lemos, William. (2007). "The Brazilian Ethanol Model." ICIS News. February 5, 2007. <<http://www.icis.com/Articles/2007/02/12/4500680/the-brazilian-ethanol-model.html>>.

⁴⁰ Dickerson, Maria. (2005). "Brazil's ethanol effort helping lead to oil self-sufficiency." The Seattle Times. June 17, 2005. <http://seattletimes.com/html/nationworld/2002339093_brazilfuel17.html>.

⁴¹ ANFAVEA. (2011). "Brazilian Automotive Industry Yearbook 2011."

⁴² Garten Rothkopf. (2007) "A Blueprint for Green Energy in the Americas." Prepared for the Inter-American Development Bank. April 2, 2007. <<http://www.aladda.com/trabajos/Interdevelopment3Bank2Bio0Fuels.pdf>>.

⁴³ ANFAVEA. (2011). "Brazilian Automotive Industry Yearbook 2011."

⁴⁴ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

⁴⁵ Millard, Peter and Stephan Nielson. (2012). "Brazil Ministry Calls for Return of Ethanol Fuel Blend to 25%." Bloomberg. October 9, 2012. <<http://www.bloomberg.com/news/2012-10-09/brazil-ministry-calls-for-return-of-ethanol-fuel-blend-to-25-.html>>.

Infrastructure Financing

The original Proalcool language recognized the financing challenges resulting from its ambitious goals. It explicitly stated that investments and other expenses related to the Proalcool would be financed by Brazil's national system of banks.⁴⁶ Investments used for installation, modernization, and expansion of distilleries would be handled by the Banco Nacional do Desenvolvimento Economico, the Banco do Brasil, the Banco do Nordeste do Brasil, and the Banco da Amazonia, while investments needed to increase sugarcane production would be handled by Sistema Nacional de Credito Rural. The National Monetary Council would assist regions where sugarcane was not traditionally produced.⁴⁷ In addition, the sugar and ethanol industry in Brazil has invested approximately \$40 million per year in research and development since 1979. As a result, sugarcane and ethanol yields per acre have greatly improved.⁴⁸

Early on in the program, the Brazilian government installed ethanol storage tanks between the centers of production and the centers of consumption. The government was then able to slowly adapt the existing gasoline transportation infrastructure to accommodate ethanol. For example, Petrobras was able to use a Sao Paulo oil pipeline to alternately transport oil and ethanol.⁴⁹

Sugar mills with alcohol plants already in operation needed only simple modifications to produce ethanol. In the 1970s, ethanol was largely produced (fermented and distilled) in new facilities which were frequently built next to existing sugar mills (called anexas). By producing ethanol at sugar mills that had expanded their distillation capacity, the sugarcane processing industry was able to minimize new investments. In addition, this system of modifying existing plants created a high degree of flexibility, as it allowed the industry to switch between producing sugar and ethanol. When higher production goals were set for 1985, anexas could not provide all of the ethanol that was required; new and larger distilleries were needed. By 1985, the new dedicated production facilities produced over half of Brazil's ethanol output. The National Petroleum Council was required to establish a program to supply ethanol to petroleum companies at a pre-established, fixed price. From the production facilities (anexas or larger production facilities) ethanol was sold to Petrobras, the Brazilian national petroleum company. Petrobras then mixed the ethanol into gasoline and distributed it across the country.⁵⁰

Vehicles

In 1979, the major automakers in Brazil signed an agreement with the national government to produce vehicles that ran on ethanol alone, rather than on a mixture of gasoline and ethanol, and they agreed to phase out production of gasoline-powered vehicles. The goal of the 1979 agreement set specific production targets of 250,000 vehicles by 1980, 300,000 by 1981, and 350,000 by 1982. To boost sales and increase awareness, the government created a media campaign for ethanol-powered vehicles and gave special preference to these vehicles for government fleet procurement.⁵¹

⁴⁶ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

⁴⁷ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

⁴⁸ USDA. (2006). "The Economic Feasibility of Ethanol Production from Sugar in The United States." United States Department of Agriculture. July 2006. <<http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf>>.

⁴⁹ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

⁵⁰ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

⁵¹ Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

Sales of ethanol-powered vehicles skyrocketed in the early 1980s; 36 percent of new vehicles sold in 1982 were ethanol-powered as were 84 percent of those sold in 1983. By 1985, over 90 percent of Brazil's new cars were ethanol-powered; 2.4 million of Brazil's ten million registered light vehicles were fueled completely by ethanol; the rest were fueled by gasoline blended with ethanol.⁵²

Lessons Learned

The success of Brazil's program was affected by market price fluctuations; when sugar prices were high and gasoline prices were low, sugarcane was processed into sugar for export rather than into ethanol for domestic fuel production, resulting in fuel shortages. This issue resulted in the decline of ethanol-powered vehicles, but was ultimately solved by the introduction of flex-fuel vehicles, which were able to take advantage of a constantly shifting fuel blend.

Brazil's experience with biofuel adoption spans nearly four decades and offers a rich and detailed case study of a national government push to rapidly increase alternative fuel and alternative fuel vehicle production. While the Proalcool program encouraged uneven growth in the ethanol industry and successes in selling ethanol-powered vehicles began to decline little more than a decade after the program commenced, it was responsible for unprecedented sales shifts and it set the stage for the success of flex-fuel vehicles in the past decade. Some of the methods used by the Brazilian government may be feasible only in more authoritarian states, but others could be applied in more democratic, market-based economies.

Many of the government incentive programs (subsidies, tax breaks, preferential procurement, and financing), partnerships, mandates, and regulations could be successfully implemented in other countries seeking to promote alternative fuels. Similar initiatives could be feasible in other countries with governmental and industry support, informed consumers, and carefully planned policies.

Diesel Adoption in Europe

One of the most noteworthy shifts in passenger car markets in recent decades is the rapid adoption of diesel-powered vehicles. This development was most pronounced in Europe where diesels represented 3.3 percent of all vehicles on the road in 1980 and increased to 32 percent by 2007 and 35.3 percent by 2010.⁵³

While diesel-engine automobiles were available on the European market as far back as the 1930s, early diesel engines were perceived as slow, large, heavy, and inflexible.⁵⁴ The traditional diesel engine had both advantages and drawbacks when compared to the gasoline engine. As already mentioned, diesel engines have better fuel economy than gasoline engines; their high fuel economy also means they can be driven further on a full tank of fuel. Diesel engines have also been considered more reliable and durable. Despite these advantages, the adoption of diesel engines in the light-duty vehicle fleet has

⁵² ANFAVEA. (2011). "Brazilian Automotive Industry Yearbook 2011."

⁵³ Ajanovic, Amela. (2011). "The Effects of Dieselization of the European Passenger Car Fleet on Energy Consumption and CO₂ Emissions." Presented at 34th IAEE International Conference: Institutions, Efficiency and Evolving Energy Technologies. Stockholm, Sweden. June 19-23, 2011.

ACEA. "The Automobile Industry Pocket Guide: 2012." European Automobile Manufacturers Association. September 18, 2012. <http://www.acea.be/images/uploads/files/ACEA_POCKET_GUIDE_2012_UPDATED.pdf>.

⁵⁴ Hard, Mikael and Andrew Jamison. (1997). "Alternative Cars."

been hindered due to their being louder, creating bad odors, and having lower horsepower, speed, and acceleration compared to gasoline engines of equal size.⁵⁵

For many decades, the diesel engine was relegated to buses and trucks (both light- and heavy-duty). Since the 1970s, however, diesel vehicles have gained popularity in Europe due to technological improvements and a favorable tax treatment.⁵⁶ In 1990, the diesel share of passenger car sales in Europe was 14 percent; by 1999, it had grown to more than 28 percent.⁵⁷ As of 2011, diesels constituted 55 percent of passenger cars sold in the European Union.⁵⁸ There is significant variation among European Union member states, with diesel vehicles constituting only 10 percent of new vehicle sales in Greece, but 70 percent or more of sales in Belgium, France, Ireland, Portugal, Spain, and the United Kingdom.

The considerable growth of diesel technology in Europe compares to a relatively poor rate of adoption in the United States, where diesel's share of light-duty vehicles has ranged from one to four percent over the past decade. Much of the difference between the adoption rates of diesel in Europe and the United States can be attributed to differences in average fuel prices, tax policies, emissions standards, and consumer preferences.⁵⁹ In addition, the U.S. diesel vehicles sold during the 1980s were dirty and low-quality, giving diesel vehicles a bad reputation in the United States.

In December 2012, the average end user prices for gasoline and diesel were between \$3 - \$4 per gallon in the United States; in many European countries, the per-gallon price varied from \$6 - \$8 for gasoline and \$5 - \$7 for diesel depending on the country.⁶⁰ Higher European fuel costs are not a result of limited availability or higher costs associated with producing or delivering fuel; the base cost of fuels is not substantially different in Europe and the United States. The reason that fuels are more expensive in Europe is rooted in tax policy: average fuel taxes in Europe (30-60 percent of end-user fuel cost) are significantly higher than in the United States (12-13 percent of end-user fuel cost).

In 1993 the European Union established minimum fuel tax levels for member countries, to avoid a "race to the bottom" in fuel taxes. Current minimum tax rates are equal to \$1.76 per gallon for gasoline and \$1.62 for diesel, although many countries have significantly higher fuel taxes.⁶¹ Considerably higher fuel prices provide Europeans with a greater incentive to purchase vehicles with higher fuel economy, providing a boost to fuel-efficient diesels.

In addition to higher overall fuel prices driving the adoption of diesel-powered vehicles, the price differential between gasoline and diesel prices in Europe makes diesel even more attractive. While

⁵⁵ Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence."

⁵⁶ Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence."

⁵⁷ Diesel Technology Forum. (2001). "Demand for Diesels: The European Experience." Diesel Technology Forum. July 2001. <<http://www.dieselforum.org/files/dmfile/DemandforDiesels.pdf>>.

⁵⁸ Mock, Peter. (2012). "European Vehicle Market Statistics: Pocketbook 2012."

⁵⁹ EIA. (2009). "Light-Duty Diesel Vehicles: Market Issues and Potential Energy and Emissions Impacts." Energy Information Administration, United States Department of Energy. January 2009. <[http://www.eia.gov/oiaf/servicerpt/lightduty/pdf/sroiaf\(2009\)02.pdf](http://www.eia.gov/oiaf/servicerpt/lightduty/pdf/sroiaf(2009)02.pdf)>.

⁶⁰ IEA. (2013). "End Use Petroleum Product Prices and Average Crude Oil Import Costs January 2013." International Energy Agency. January 2013. <<http://www.iea.org/stats/surveys/mps.pdf>>.

⁶¹ Transport & Environment. (2011). "Fueling Oil Demand: What Happened to Fuel Taxation in Europe?" European Federation for Transport and Environment. April 2011. <<http://www.transportenvironment.org/sites/te/files/media/2011%2004%2013%20fuel%20tax%20report%20final%20merged.pdf>>.

diesel is usually more expensive than gasoline in the United States, the opposite is often true in Europe. Over the course of a year, an average driver in Europe could save hundreds of dollars on fuel by driving a diesel-powered vehicle rather than a gasoline-powered one.⁶²

The price differential between gasoline and diesel is primarily driven by tax policy in Europe. The policy was intended to support freight transport, improve energy security, and reduce GHG emissions. In recent years, the majority of the emphasis has been on reducing GHG emissions.⁶³ In 2002, the European Union ratified the Kyoto Protocol in which it committed to an eight percent reduction target for 2008-2012 from its 1990 GHG emissions levels. In 2008, the European Union adopted even more aggressive targets for 2020 (20 percent of 1990 emissions levels), and in 2011, it created a roadmap that would lead to an 80 percent reduction from 1990 levels by 2050.⁶⁴

Figure 2 displays the differential tax in several European countries as of December 2012.⁶⁵ The table below the chart lists total passenger car sales for 2011 and diesel's share of those sales for each country. While in the United States, fuel taxes vary by state; the average tax paid by the end user is \$0.42 per gallon for gasoline and \$0.48 per gallon for diesel. In Canada, the tax is \$1.51 on gasoline and \$1.19 on diesel. Compared to North America, European taxes on fuel tend to be substantially higher, with a greater difference in gasoline and diesel taxes.

In addition to fuel taxes, many countries use vehicle-based taxes to encourage the purchase of diesels and other, high-efficiency vehicles. Austria, for example, has used an efficiency-based vehicle sales tax that creates a lower tax burden for the purchase of vehicles with higher fuel efficiency, such as diesels. France has instituted an annual vehicle tax that also favors diesels over gasoline-powered vehicles.⁶⁶

Diesel vehicles in Europe also have a comparative cost advantage in Europe compared to the United States due to less stringent European NOx regulations. U.S. regulations require diesel engines to use high-pressure fuel injection and after-treatment systems to reduce NOx emissions, adding more to the expense of diesel vehicles in the United States.

⁶² Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence."

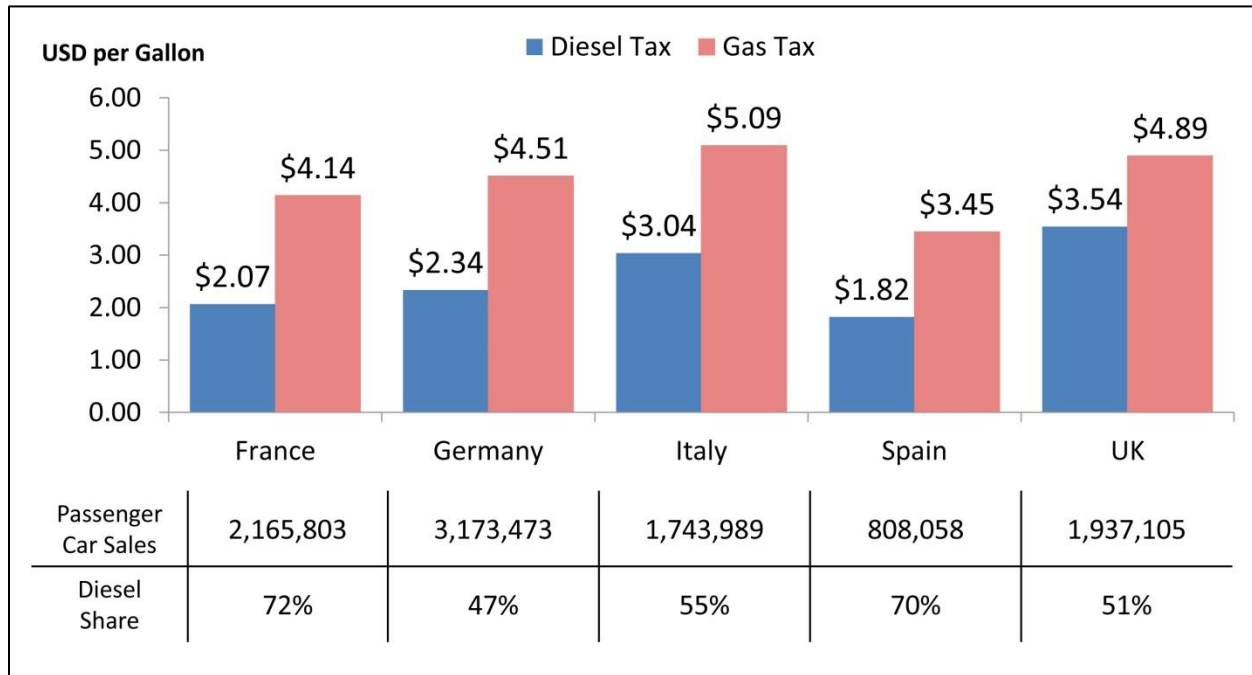
⁶³ Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence."
EIA. (2009). "Light-Duty Diesel Vehicles."

⁶⁴ Transport & Environment. (2011). "Fueling Oil Demand."

⁶⁵ IEA. (2013). "End Use Petroleum Product Prices."

⁶⁶ Verboven, Frank. (2002). "Quality-Based Price Discrimination and Tax Incidence."

Figure 2: Average End User Diesel and Gas Taxes for Selected EU Countries



Note: The dollar values represented in this chart represent only the taxes applied to fuels; they are in addition to the base cost of the fuel. Tax data reflect December 2012, and vehicle sales data reflect full-year, 2011.

Sources: IEA 2013 and ICCT 2012

Current Tier 2 vehicle emission standards in the United States limit NOx emissions to 0.07 grams per mile. The Euro 5 NOx standard allows for 0.29 grams per mile.⁶⁷ Euro 6 vehicle emission standards, which will take effect in 2014, will be even more stringent with respect to NOx and will likely increase the cost of new diesel vehicles in Europe. Due to economies of scale in automobile production, more stringent European NOx requirements could lead to a reduced cost for diesel vehicles in the United States.

The U.S. emissions standards have made the introduction of light-duty diesels somewhat cost-prohibitive, while the European Union has been more lenient on diesel emissions standards to be consistent with policies promoting diesel vehicles. If future European standards approach the U.S. standards, and manufacturers are able to develop cost-effective ways to meet those standards for diesels, it may pave the way for sales of more light-duty diesel vehicles to the U.S.

Renewable Energy Development in Germany

The promotion of renewable electricity generation in Germany is often alluded to in the media as a “shining example” of successful policy to encourage growth in the renewables sector.⁶⁸ In the mid-1970s, Germany began supporting the alternative energy sector through R&D funding; however, much of this effort was focused on moving away from oil and using more coal and nuclear energy. Following

⁶⁷ EIA. (2009). “Light-Duty Diesel Vehicles.”

⁶⁸ Seager, Ashley. “Germany sets shining example in providing a harvest for the world.” The Guardian. July 23, 2007. <<http://www.guardian.co.uk/business/2007/jul/23/germany.greenbusiness>>.

the Chernobyl disaster in the late 1980s, public opposition to nuclear energy grew as did concerns about GHG emissions and climate change. In response, Germany enacted wind and solar subsidies and the idea of a feed-in tariff began to emerge.⁶⁹

A feed-in tariff is a policy which creates a guaranteed market for small producers of renewable energy. This is achieved by requiring utilities to purchase electricity from these producers at predetermined rates. Individuals can then purchase and install renewable energy production equipment, such as photovoltaic solar arrays or wind turbines, and begin receiving payments from utilities for the electricity they produce.

Feed-in Tariff

Germany instituted a feed-in tariff to promote renewable energy production in 1990. The feed-in tariff required utilities to allow small providers of renewable electricity to sell electricity to the grid at 65 to 90 percent of the retail rate,⁷⁰ an amount considerably higher than the average cost of electricity generation.⁷¹ The idea for a feed-in tariff began in the United States with the Public Utility Regulatory Policies Act of 1978, which guaranteed prices based on projected long-term costs of fossil energy. The feed-in tariff policy in the United States was dismantled as energy markets became deregulated and energy costs were lower than anticipated.⁷²

In a similar turn of events, Germany's feed-in tariff decreased along with the price of electricity, following the liberalization of European energy markets in 1998. In order to fix the problem with its feed-in tariff and make renewable energy investment attractive, Germany enacted the Renewable Energy Sources Act (EEG) in 2000. The EEG involved long-term contracts and provided fixed feed-in tariff rates for 20 years.⁷³ The value of a feed-in tariff is dependent on the technology used to generate the electricity. For instance, solar photovoltaic generation received the highest feed-in tariff, which was €0.43/kWh in 2009. On-shore wind generation received €0.092/kWh, off-shore wind generation received €0.15/kWh, and biomass-based generation received €0.143/kWh. By comparison, the typical cost to produce electricity for a utility in Germany would be around €0.07/kWh, or even less. Overall, the markup of electricity to consumers in 2008 as a result of the feed-in tariff was €0.015/kWh, or approximately 7.5 percent of the total electricity rate paid by consumers.

Germany's renewable energy policies have been quite successful. From 1990, when the first feed-in tariff law was passed, to 2000, when the second feed-in tariff was passed, annual production of renewable energy more than doubled. It jumped from just over 17,000 gigawatt-hours (GWh), or 3.1 percent of generation, to more than 37,000 GWh, or 6.4 percent of generation.⁷⁴ By 2011, renewable energy generation had increased to nearly 122,000 GWh, which is equivalent to 20.1 percent of

⁶⁹ Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy from Denmark, Germany, and the United Kingdom." *Energy Policy*. Volume 35, Issue 11, pp. 5481-5495. November 2007.

⁷⁰ Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy."

⁷¹ Frondel, Manuel, Nolan Ritter, Christoph M. Schmidt, and Colin Vance. (2010). "Economic Impacts from the Promotion of Renewable Energy Technologies: The German Experience." *Energy Policy*. Volume 38, Issue 8, pp. 4048-4056. August 2010.

⁷² Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy."

⁷³ Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy."

⁷⁴ 1 GWh = 1,000,000 kWh

electricity generation in Germany.⁷⁵ By 2012, Germany had approximately one third of all installed solar photovoltaic generation capacity in the world.⁷⁶ Other countries, including Denmark, France, Italy, and Spain have followed Germany's lead in adopting feed-in tariffs for renewable energy.⁷⁷

As a result of its success, the feed-in tariff has survived, even though the ruling party in Germany has changed several times since the tariff was first enacted. While the tariff was criticized by the Christian Democrats when they were the opposition party, its success in job creation has led them to maintain the policy while in power.⁷⁸ In 2012, the rate for solar photovoltaic generation was decreased by 20 to 26 percent (depending on the size of the array) in an effort to stabilize the market.⁷⁹ More recently, Germany's success at converting its grid to renewable energy has been called into question as the country is installing many new coal-fired electric plants to replace nuclear plants as it moves away from reliance on nuclear power.⁸⁰

Other Financing Options for Renewable Energy

Rather than provide direct subsidies for renewable energy, policymakers in the United States are considering decreasing the costs of financing investments by allowing renewable energy projects to take advantage of instruments such as the master limited partnership (MLP) and the real estate investment trust (REIT).⁸¹

Companies could use a REIT or MLP to attract a broader range of investors for renewable energy projects. The two instruments do not pay corporate income taxes, but instead pass on earnings to investors who pay taxes on the income. The Internal Revenue Service could permit renewable energy projects to use REITs, but allowing such projects to use MLPs would require Congressional legislation.

⁷⁵ Böhme, Dieter (2012). "Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2011." Federal Ministry for Environment, Nature Conservation and Nuclear Safety. February 2012. <http://www.erneuerbare-energien.de/fileadmin/ee-import/files/pdfs/allgemein/application/pdf/ee_in_deutschland_graf_tab.pdf>.

⁷⁶ Burger, Scott. (2012). "Big Changes in German Solar Subsidy Policy Approved Today." Greentech Media. June 29, 2012. <<http://www.greentechmedia.com/articles/read/Big-Changes-in-German-Solar-Subsidy-Policy-Approved-Today>>.

⁷⁷ Frondel, Manuel, Nolan Ritter, Christoph M. Schmidt, and Colin Vance. (2010). "Economic Impacts." Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy."

⁷⁸ Lipp, Judith. (2007). "Lessons for Effective Renewable Electricity Policy."

⁷⁹ Burger, Scott. (2012). "Big Changes in German Solar Subsidy Policy Approved Today."

⁸⁰ Nicola, Stephan and Tino Anderson. (2012). "Merkel's Green Shift Forces Germany to Burn More Coal." Bloomberg. August 20, 2012. <<http://www.bloomberg.com/news/2012-08-19/merkel-s-green-shift-forces-germany-to-burn-more-coal-energy.html>>.

⁸¹ Cardwell, Diane. (2013). "Renewable Energy Industries Push for New Financing Options." The New York Times. January 30, 2013. <<http://dealbook.nytimes.com/2013/01/30/renewable-energy-industries-push-for-new-financing-options/>>.

EXISTING INFRASTRUCTURE INVESTMENTS IN SELECTED COUNTRIES

Countries around the world have begun investing in the infrastructure required to support AFVs. Infrastructure installation has been driven by both market and regulatory forces; the funding for it has been a mix of public and private investment. This section provides an overview of the existing AFV infrastructure in several locations, including Brazil, China, the European Union, the United States, and (specifically) California.

Brazil

Flex-fuel vehicles account for a higher share of the Brazilian vehicle fleet than any other, worldwide. In 2012, the number of newly registered flex-fuel vehicles in Brazil was 3,163,000, representing 87 percent of the market. Virtually all of the remaining vehicles were operating off of gasoline (7.5 percent) or diesel (5.4 percent).⁸²

The preponderance of flex-fuel vehicles in Brazil is the result of a long-standing ethanol blend mandate. In response to the 1973 oil crisis, the Brazilian government introduced mandatory ethanol-gasoline blending with the 1975 Proalcool. The early years of this program favored neat ethanol (100 percent ethanol), but instability in the ethanol supply and declining oil prices led many consumers to return to gasoline-fueled vehicles in the 1990s. As the availability of flex-fuel vehicles has increased and their prices declined, they have grown from representing just four percent of the Brazilian light-duty vehicle market in 2003 to 50 percent in 2005 and 87 percent today.⁸³

Data regarding the usage of other types of alternative fuels, and development of supporting infrastructure, is quite scarce in Brazil. The Natural & Bio Gas Vehicle Association provides annual estimates of CNG station counts for nearly all countries, worldwide. Their data indicates that a total of 1,790 CNG refueling stations were present in Brazil in 2012.⁸⁴

Estimates of electric vehicle charging stations in Brazil, whether from governments or associations, could not be found. Further review located a series of news articles from mid-2009, addressing the opening of the country's first EV charging station—a road-side, solar-powered charge point intended for topping off the batteries of electric motorcycles.⁸⁵

The Brazilian government is currently considering a mandate for electric utility companies to install electric vehicle charging points in urban areas. A mandate could facilitate the adoption of plug-in vehicles and attract investment in automotive production facilities to build electric vehicles.⁸⁶

⁸² ANFAVEA. (2013). "Carta da ANFAVEA."

⁸³ ANFAVEA. (2013). "Carta da ANFAVEA."

⁸⁴ NGVA. (2012). "Worldwide NGV Statistics." Natural & Bio Gas Vehicle Association - Europe. December 20, 2012. <<http://www.ngvaeurope.eu/worldwide-ngv-statistics>>.

⁸⁵ Frayssinet, Fabiana. (2009). "TRANSPORT-BRAZIL: Recharge Your Batteries Here." Inter Press Service News Agency. July 6, 2009. <<http://www.ipsnews.net/2009/07/transport-brazil-recharge-your-batteries-here/>>.

⁸⁶ Nielsen, Stephan. (2013). "Brazil May Require Electric-Vehicle Charging Stations Next Year." Bloomberg News. February 25, 2013. <<http://www.bloomberg.com/news/2013-02-25/brazil-may-require-electric-vehicle-charging-stations-next-year.html>>.

China

Data on the implementation of alternative, and even conventional, fuels in China is fairly scarce in English-language sources. Available data indicate that China currently has an estimated 1,300 – 2,500 CNG refueling stations and more than a million CNG vehicles in operation.⁸⁷ No information relating to the use of, and infrastructure for, E85 and diesel fuels could be located. Only limited and outdated English language information regarding gasoline infrastructure could be found. Some sources suggested the total number of gas stations in China was just below 100,000 in 2009.

In July of 2012, the Chinese central government published goals for BEV, PHEV and hydrogen-fueled vehicle adoption. The Chinese government has targeted production of 500,000 PHEVs and BEVs by 2015, and total production and sales of PHEV, BEV and hydrogen vehicles of 5,000,000 by 2020. The report also indicates that the current count of charging stations throughout the country stands at 168, across 25 cities.⁸⁸ An older, March 2011, report in the English-language edition of the Chinese *People's Daily* indicates that the 90 charging stations existent at that time hosted a total of over 5,200 charging points—nearly 58 charging points per station. The article further states that the Five Year Plan covering the 2011 through 2015 period calls for the construction of 2,351 new charging stations, providing an additional 220,000 charging points by 2015.⁸⁹

The cities of Beijing, Guangzhou, Guiyang, and Shanghai have set license plate quotas, limiting the number of new vehicles that could be registered in those cities each year. Guangzhou has dedicated ten percent of its 120,000 license plate quota to AFVs, including all-electric autos, plug-in hybrids, and hybrid vehicles.⁹⁰ Buyers of AFVs in Guangzhou will also qualify for 10,000 yuan in subsidies from the government. In the first half of 2013, Beijing will announce preferential policies for electric vehicles: electric car buyers will be able to register their vehicles without entering the city license plate lottery and would be eligible for a subsidy of up to 120,000 yuan.⁹¹

European Union

Approximately 47,000 alternative fuel stations exist across the EU member states.⁹² With the recent movement towards the development of an official, EU-wide clean fuel distribution strategy, this number is likely to increase substantially over the course of this decade. Specific, per-country targets have been

⁸⁷ NGVA. (2012). "Worldwide NGV Statistics."

Huo, Hong, Qiang Zhang, Fei Liu, and Kebin He. (2012). "Climate and Environmental Effects of Electric Vehicles versus Compressed Natural Gas Vehicles in China: A Life-Cycle Analysis at Provincial Level." *Environmental Science & Technology*. Volume 47, Issue 3, pp. 1711-1718. February 2013.

⁸⁸ Green Car Congress. (2012). "China publishes plan to boost fuel-efficient and new energy vehicles and domestic auto-industry; targeting 500k PHEVs and EVs in 2015, rising to 2M by 2020." July 9, 2012. <<http://www.greencarcongress.com/2012/07/china-20120709.html>>.

⁸⁹ Meng, Yan. (2011) "China has largest electric vehicle charging network." *People's Daily Online*. March 3, 2011. <<http://english.peopledaily.com.cn/90001/90778/7307489.html>>.

⁹⁰ China Daily. (2012). "Limits revised to promote green autos." *China.org.cn*. August 6, 2012. <http://www.china.org.cn/environment/2012-08/06/content_26140796.htm>.

⁹¹ Xinhua. (2013). "Beijing unveils preferential policies for electric vehicles." *Xinhua*. March 7, 2013. <http://news.xinhuanet.com/english/china/2013-03/07/c_132216404.htm>.

⁹² Exergia. (2012) "Assessment of the implementation of a European alternative fuels strategy and possible supportive proposals." Produced by Exergia, Energy and Environment Consultants for the European Commission. August 10, 2012. <<http://ec.europa.eu/transport/themes/urban/studies/doc/2012-08-cts-implementation-study.pdf>>.

"NGVA. (2012). "Worldwide NGV Statistics."

European Commission. (2013). "MEMO/13/24 Clean power for transport – Frequently asked questions." European Commission. January 24, 2013. <http://europa.eu/rapid/press-release_MEMO-13-24_en.htm>.

set for the number of publicly available electric vehicle charging points, totaling 795,000 across all 27 countries by 2020.⁹³

These ambitious goals represent a nearly 68 fold increase from the current level of vehicle charging infrastructure. In 2011, a total of 11,749 charging points for battery and plug-in hybrid electric vehicles existed across the European Union member states. The top six countries contained 9,293 (79.1 percent) of these: Germany hosted 1,937 (16.5 percent); the Netherlands, 1,700 (14.5 percent); and France, 1,600 (13.6 percent); while Spain, Italy and Portugal each possessed nearly 1,350 charging points (11.5 percent).⁹⁴

The European Union member states contain 4,084 outlets for E85. These are primarily concentrated within the countries of Sweden and the United Kingdom, which host more than 83 percent of European E85 stations. The two countries have approximately 1,700 E85 stations each.⁹⁵

In 2012, there were 2,860 CNG retail outlets across the European Union. These stations are highly concentrated within two countries: Germany and Italy each account for 31.6 percent of the EU total, with 904 and 903 stations respectively. Austria ranks third, with 203 stations in total—a 7.1 percent share.⁹⁶

In 2011, Europe contained approximately 131,000 petrol stations.⁹⁷ While information on the share of stations providing diesel fuel is unavailable, anecdotal evidence suggests that it is available from the vast majority of them; according to the European Petroleum Industry Association, approximately 35 percent of the European passenger car fleet was diesel-operated in 2011, up from 15 percent in the mid-1990s.⁹⁸

United States

The United States hosts a total of 14,636 locations where alternative fuel vehicles can obtain fuel. Of these locations, CNG is available at 1,197 stations, E85 is available from 2,596, and electricity is available at 7,219. There are 58 locations where hydrogen is available, but these locations are often used for government or private test fleets and are largely unavailable to the public.⁹⁹ There are approximately 160,000 gas stations in the United States, so any individual alternative fuel has only a fraction of the coverage of gasoline.¹⁰⁰

In the past few years, public charging infrastructure in the United States has expanded rapidly. For instance, as of November 2010, the DOE's Alternative Fueling Station Database contained just over 600 electric recharging locations (including public, private, and planned stations), but by the end of January 2013, the database listed more than 7,000 locations.¹⁰¹ The charging stations average 2.2 outlets per

⁹³ European Commission. (2013). "IP/13/40 EU launches clean fuel strategy." European Commission. January 24, 2013.

<http://europa.eu/rapid/press-release_IP-13-40_en.htm#PR_metaPressRelease_bottom>.

⁹⁴ European Commission. (2013). "MEMO/13/24 Clean power for transport."

⁹⁵ Exergia. (2012). "Assessment of the implementation of a European alternative fuels strategy."

⁹⁶ NGVA. (2012). "Worldwide NGV Statistics."

⁹⁷ Europaia. (2011). "2011 Annual Report." European Petroleum Industry Association. 2011.

<<https://www.europia.eu/content/default.asp?PageID=412&DocID=35264>>.

⁹⁸ Europaia. (2011). "2011 Annual Report."

⁹⁹ EERE. (2013). Alternative Fuels Data Center.

¹⁰⁰ NPC. (2012). "Chapter 5: Infrastructure."

¹⁰¹ EERE. (2013). Alternative Fuels Data Center.

station, for a total of 15,989 outlets in total. The overwhelming majority—12,620 outlets—provide Level 2 charging, while only 231 are Level 2 DC charging.¹⁰²

The geographic spread of alternative fuel stations is highly dependent upon the specific fuel type examined. Minnesota contains 14 percent of the nation’s E85 stations, and the Midwest region as a whole contains 64 percent.¹⁰³ Table 2 below summarizes the concentration of stations, by fuel type, at the state level. California has highest share of filling stations for four of the seven alternative fuel types, and is within the top three for six types. California is a special case, warranting further examination.

Table 2: State Rankings for AFV Fueling Stations by Fuel Type

Fuel Type	1st	2nd	3rd
Biodiesel	NC (19%)	CA (11%)	TN (6%)
CNG	CA (21%)	NY (9%)	OK (8%)
E85	MN (14%)	IL (8%)	IA (7%)
Electric	CA (24%)	TX (9%)	WA (7%)
Hydrogen	CA (41%)	NY (16%)	MI (7%)
LNG	CA (62%)	TX (14%)	AZ (9%)
LPG	TX (17%)	CA (8%)	IN (6%)
TOTAL	CA (20%)	TX (9%)	WA (6%)

Note: Rankings are based on each state’s share of AFV fueling stations for each type of fuel. For example, of all biodiesel stations in the United States, 19% are in NC, 11% are in CA, and 6% are in TN.

Source: EERE 2013

AFV Policies

In President Barack Obama’s 2013 State of the Union message, he proposed the creation of an “Energy Security Trust” to fund work on alternative fuels for transportation. The trust would be financed using royalties received by the federal government from oil and gas companies drilling on federal land.¹⁰⁴

The Energy Policy Act of 2005 established the federal Renewable Fuels Standard (RFS) which required the blending of biofuels with conventional transportation fuels and set quantity targets for the time period from 2006 to 2012. The Energy Independence and Security Act of 2007, amended the RFS, increasing these targets and extending them through 2022. The targets require the blending of 36 billion gallons of renewable fuel into transportation fuel by 2022.¹⁰⁵ As a point of reference, current annual consumption of petroleum-based fuels in the United States is approximately 139 billion gallons of gasoline and 51 billion gallons of diesel.¹⁰⁶

¹⁰² EERE. (2013). Alternative Fuels Data Center.

¹⁰³ EERE. (2013). Alternative Fuels Data Center.

¹⁰⁴ Wald, Matthew L. (2013). “Using Federal Oil Revenues to Cut America’s Oil Use” The New York Times. February 13, 2013. <<http://green.blogs.nytimes.com/2013/02/13/using-federal-oil-revenues-to-cut-americas-oil-use/>>.

¹⁰⁵ EPA. (2013). “Renewable Fuel Standard (RFS).” United States Environmental Protection Agency Website. Accessed March 4, 2013. <<http://www.epa.gov/otaq/fuels/renewablefuels/index.htm>>.

¹⁰⁶ NPC. (2012). “Chapter 5: Infrastructure.”

As of January 2012, production capacity for ethanol was around 14 billion gallons annually,¹⁰⁷ and in 2011, the U.S. ethanol industry produced more than 13.9 million gallons of ethanol.¹⁰⁸ Biodiesel capacity in 2012 was 2.1 billion gallons; actual production was nearly 970 million gallons.¹⁰⁹ Given these production estimates, corn-based ethanol and biodiesel are exceeding RFS targets.

Although the EPA has significantly reduced targets for cellulosic ethanol production for 2010 to 2013,¹¹⁰ the new targets are still high when compared to actual production levels of cellulosic ethanol. Commercial cellulosic ethanol production was non-existent in 2010 and 2011 and only 20,000 gallons in 2012 (less than one percent of even the reduced EPA target).¹¹¹ Most of the production last year came from plants that were just starting up in late 2012; the U.S. Energy Information Administration notes that cellulosic ethanol production could be as high as 5 million gallons for 2013.

Currently E10 (a blend of 90 percent gasoline and 10 percent ethanol) is dispensed from 96 percent of gasoline pumps in the United States.¹¹² In 2011, the U.S. Environmental Protection Agency (EPA) approved the sale of E15 (gasoline containing 15 percent ethanol) for use in 2001 model year and newer vehicles. The approval was seen as controversial, as most vehicles on the road in the United States were not designed to use fuel blended with such a high concentration of ethanol, and use of E15 could potentially damage vehicle components in some vehicles. In late March 2013, the Alliance of Automobile Manufacturers and the Association of Global Automakers,¹¹³ along with other parties, petitioned the U.S. Supreme Court to overturn a previous circuit court ruling that the trade associations did not have the legal standing to challenge the EPA's approval of E15.¹¹⁴

In the United States, sales of flex-fuel vehicles have been stimulated by CAFE incentives; automakers received CAFE credits for selling flex-fuel vehicles.¹¹⁵ Current CAFE incentives are scheduled to expire after model year 2016.¹¹⁶ There will still be incentives for the production and sales of E85, and some incentive to produce flex-fuel vehicles will still exist because such vehicles will be able to achieve lower tailpipe GHG emissions when operating on E85. The EPA has noted that it believes automakers will continue to manufacture flex-fuel vehicles and it does not anticipate offering additional incentives for

¹⁰⁷ EIA. (2012). "U.S. Fuel Ethanol Plant Production Capacity Report." United States Energy Information Administration. May 30, 2012. <<http://www.eia.gov/petroleum/ethanolcapacity/index.cfm>>.

¹⁰⁸ EIA. (2012). "Table 10.3 Fuel Ethanol Overview, 1981-2011." Annual Energy Review. United States Energy Information Administration. September 27, 2012. <<http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1003>>.

¹⁰⁹ EIA. (2013). "Table 1. U.S. Biodiesel Production Capacity and Production." Monthly Biodiesel Production Report. United States Energy Information Administration. February 27, 2013. <<http://www.eia.gov/biofuels/biodiesel/production/table1.pdf>>.

¹¹⁰ Cellulosic ethanol targets were reduced from 100 million to approximately 5 million gallons in 2010, from 250 million to 6.6 million gallons in 2011, from 500 million to 8.7 million gallons in 2012, and from 1 billion gallons to 14 million gallons in 2013.

CRS. (2010). "Renewable Fuel Standard (RFS): Overview and Issues" Congressional Research Service. July 14, 2010. <<http://crs.ncseonline.org/nle/crsreports/10Jul/R40155.pdf>>.

¹¹¹ EIA. (2013). "Cellulosic biofuels begin to flow but in lower volumes than foreseen by statutory targets." United States Energy Information Administration. February 26, 2013. <<http://www.eia.gov/todayinenergy/detail.cfm?id=10131>>.

¹¹² Shepardson, David. (2013). "Automakers ask Supreme Court to take up ethanol challenge." Detroit News. March 26, 2013. <<http://www.detroitnews.com/article/20130326/AUTO01/303260382>>.

¹¹³ Together, the two trade associations represent 24 different automakers including the Detroit 3 (Chrysler, Ford, and General Motors) as well as major Japanese (Honda, Nissan, and Toyota) and German automakers (BMW, Mercedes-Benz, and Volkswagen).

¹¹⁴ Shepardson, David. (2013). "Automakers ask Supreme Court to take up ethanol challenge."

¹¹⁵ Voegelé, Erin. (2012). "EPA, DOT finalize fuel efficiency rule, address biofuel comments." Ethanol Producer Magazine. August 29, 2012. <<http://ethanolproducer.com/articles/9070/epa-dot-finalize-fuel-efficiency-rule-address-biofuel-comments>>.

¹¹⁶ EIA. (2012). "Annual Energy Outlook 2012."

these vehicles.¹¹⁷ Over the past several years, sales of flex-fuel vehicles in the United States have topped one million units, and, for model year 2011, EPA estimates that approximately two million units were produced.¹¹⁸ If, however, this policy shift does decrease the number of flex-fuel vehicles sold in the United States, the estimated number of flex-fuel vehicles in the 2030 U.S. vehicle fleet could be substantially reduced.

Funding of Infrastructure

Public funding for transportation infrastructure in the United States is becoming a major issue. As vehicles become more efficient, the federal and state governments receive less from fuel taxes. These taxes are responsible for 40 percent of state highway revenues and comprise over 90 percent of the federal highway trust fund.¹¹⁹ Making matters worse, few of these taxes are indexed to inflation, so the real value of the taxes collected per gallon sold is decreasing with each passing year. While some states are looking at increasing their gasoline taxes, other solutions that could potentially address the problem of financing public road infrastructure are also being considered.

The governor of Virginia recently proposed discontinuing the gasoline tax and increasing the state's sales tax to fund road construction and maintenance. His proposal would create an annual fee for vehicles using alternative fuels, because they do not pay gasoline taxes, but they drive on public roads. This proposal is controversial, largely because it moves the burden of funding roads to a broader base, disconnecting the cost of roads from the users of roads. It has, however, received media coverage across the United States, bringing the issue of road funding to national attention.

Some other states have considered charging drivers based on their mileage. This idea is also controversial as many drivers are apprehensive about the possibility of their vehicles being tracked; although, not all methods for implementing a mileage-based user fee would require vehicle tracking. Oregon is currently running a small pilot program testing five different systems that could support a mileage-based fee.¹²⁰

California

The State of California has more alternative fuel stations than any other state in the United States, with a total count of 2,163 across all alternative fuel types—just below 15 percent of the U.S. total. When considering electric vehicle recharging by the number of outlets, rather than the number of charging stations, this total climbs to 4,599, or about 20 percent of the national total of 23,406 alternative fuel stations.¹²¹ Focusing in on specific fuel types, California is found to contain 74 fueling stations which offer E85, 257 providing CNG, and a total of 1,460 charging stations, providing a total of 3,896 outlets for battery electric and plug-in hybrid vehicle recharging, across all non-residential sources.¹²²

¹¹⁷ Voegelé, Erin. (2012). "EPA, DOT finalize fuel efficiency rule, address biofuel comments."

¹¹⁸ Voegelé, Erin. (2012). "EPA, DOT finalize fuel efficiency rule, address biofuel comments."

¹¹⁹ Schwartz, John. (2013). "Governments Look for New Ways to Pay for Roads and Bridges." The New York Times. February 14, 2013. <http://www.nytimes.com/2013/02/15/us/looking-for-new-ways-to-pay-for-roads-and-bridges.html?_r=1&>.

¹²⁰ Schwartz, John. (2013). "Governments Look for New Ways to Pay for Roads and Bridges."

¹²¹ EERE. (2013). Alternative Fuels Data Center.

¹²² EERE. (2013). Alternative Fuels Data Center.

According to the most recent *California Retail Fuel Outlet Annual Report*, compiled by the California Energy Commission, there were approximately 8,300 gasoline stations in California in 2011. Of these, 49 percent—or 4,067 stations—also provided diesel fuel.¹²³ Data on the number of pumps available per fuel type is not reported.

Alternative fuel stations are concentrated around the large urban clusters of Los Angeles, San Francisco and San Diego. The heaviest presence is within the LA area. While gas and diesel stations are also mostly concentrated in Los Angeles County, most alternative fuel stations are near to nonexistent outside of these areas.¹²⁴

AFV Policies

California's environmental policies are unique among the states. This is most clearly demonstrated by the state's exemption from the national Environmental Protection Agency's vehicle emission regulations. This exemption was granted as California was the only state to have enacted such regulations prior to the development of national standards.¹²⁵

Several programs and regulations enacted by the government of California influence, and likely are the primary force behind, the prevalence of alternative fuel infrastructure within the state. Two programs are particularly relevant: the *California Hydrogen Highway* and *Clean Fuels Outlet Regulation*.

The *California Hydrogen Highway* program was enacted by executive order in April of 2004. Through this initiative, \$19 million was appropriated for the construction of hydrogen fueling stations, across fiscal years 2005, 2006 and 2007.¹²⁶ This program resulted in the construction of 15 state-funded hydrogen fueling stations by the end of 2012, with funding available for another nine stations.¹²⁷

The *Clean Fuels Outlet Regulation* (CFOR), a much more general program, was first enacted in 1990 to encourage consumer adoption of "clean fuel" vehicles, by ensuring retail access to alternative fuels. This program mandates specific minimum fueling station counts for various types of alternate fuels. Once the statewide fleet of vehicles operated off a fuel type is projected to breach a threshold limit of 20,000, filling station owners and lessors are required to add capacity for that fuel until a government-determined minimum level of fueling capacity is reached, as represented by the number of filling stations offering that fuel type.¹²⁸ Current law requires filling station owners and lessors to install fuel capacity based on the number of stations owned, but proposed amendments scheduled for

¹²³ California Energy Commission. (2012) "Annual Reporting Results – California Retail Fuel Outlet Annual Report (A15)." California Energy Commission, State of California. 2012. <http://energyalmanac.ca.gov/gasoline/piira_retail_survey.html>.

¹²⁴ EERE. (2013). Alternative Fuels Data Center.

¹²⁵ Transport Policy. (2012) "US: Section 177 States." Transportpolicy.net. November 29, 2012. <http://transportpolicy.net/index.php?title=US:_Section_177_States>.

ARB. (2013). "Key Events in the History of Air Quality in California." California Air Resources Board, State of California. February 6, 2012. <<http://www.arb.ca.gov/html/brochure/history.htm>>.

¹²⁶ ARB. (2012). "Historical Activities of the CA Hydrogen Highway Network." California Air Resources Board, State of California. September 17, 2012. <http://www.arb.ca.gov/msprog/zevprog/hydrogen/hydrogen_cah2net.htm>.

¹²⁷ ARB. (2012). "Government Funded Hydrogen Stations." California Air Resources Board, State of California. November 27, 2012. <http://www.arb.ca.gov/msprog/zevprog/hydrogen/hydrogen_stations.htm>.

¹²⁸ ARB. (2012). "Clean Fuels Outlet Regulation." California Air Resources Board, State of California. April 27, 2012. <<http://www.arb.ca.gov/fuels/altfuels/cf-outlets/cf-outlets.htm>>.

ARB. (2000). "California Code of Regulations Title 13, Chapter 8. Clean Fuels Program December 2000." California Air Resources Board. December 2000. <<http://www.arb.ca.gov/fuels/altfuels/cf-outlets/cforeg2000.pdf>>.

consideration in June 2013 would shift the compliance burden to companies that import or refine oil based on their share of the gasoline market.¹²⁹

¹²⁹ ARB. (2013). "Staff Report: Initial Statement Of Reasons - Proposed Amendments to the Clean Fuels Outlet Regulation." California Air Resources Board, State of California. February 13, 2013. <<http://www.arb.ca.gov/regact/2013/cfo2013/cfo13isor.pdf>>.

FUTURE INFRASTRUCTURE INVESTMENT

The cost of fuel production and distribution infrastructure to support the adoption of alternative fuel vehicles has been calculated in the past by various organizations, such as Argonne National Laboratory, the National Petroleum Council (NPC), the UC Davis Institute of Transportation Studies, and the National Academy of Sciences.¹³⁰ There are a variety of methods that can be used to determine the number of stations needed to supply a particular alternative fuel to vehicles. Some approaches rely on the vehicle driving range and network path distance to determine the number and placement of stations needed to cover a certain area,¹³¹ while others use estimated fuel demand to determine the number of stations needed.

The analysis used in this paper specifically examines the amount and cost of an alternative fuel dispensing infrastructure. It is based on a modified version of the methods used by the California *Clean Fuels Outlet Regulation* to set requirements in California for the number of stations which must provide various alternative fuels.¹³² The analysis also uses cost estimates for installing equipment for various fuels at stations.

Clean Fuels Outlet Regulation

The CFOR mandates a minimum number of retail fueling stations that must provide a designated alternative fuel, based on the number of vehicles using that fuel. A more detailed explanation of CFOR can be found in Appendix C.

The station count mandate does not apply until the statewide number of vehicles utilizing a fuel is at least 20,000 vehicles. The number of AFVs on the road is used to calculate expected annual fuel demand, which is then divided by expected capacity per station to generate the number of required stations.

For liquid fuels, each station is assumed to provide 300,000 GGEs per year, until the number of vehicles is sufficiently high to require 5 percent of all retail gasoline outlets to stock the fuel. At this point, it is assumed that each station provides 600,000 GGEs. For fuels dispensed as a gas it is assumed that each station provides 400,000 therms, or 456,000 GGEs annually.¹³³

¹³⁰ Wang, Michael, Kevin Stork, Anant Vyas, Marianne Mintz, Margaret Singh, and Larry Johnson. (1997). "Assessment of PNGV Fuels Infrastructure - Phase 1 Report: Additional Capital Needs and Fuel-Cycle Energy and Emissions Impacts." Center for Transportation Research, Argonne National Laboratory. January 1997. <<http://www.osti.gov/bridge/servlets/purl/527447-49UIKS/webviewable/527447.pdf>>. Wang, Michael, Marianne Mintz, Margaret Singh, Kevin Stork, Anant Vyas, and Larry Johnson. (1998). "Assessment of PNGV Fuels Infrastructure - Phase 2 Report: Additional Capital Needs and Fuel-Cycle Energy and Emissions Impacts." Center for Transportation Research, Argonne National Laboratory. April 1998. <<http://www.ornl.gov/~webworks/cpr/y2003/misc/117881.pdf>>. NPC. (2012). "Chapter 5: Infrastructure."

Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways: A Research Summary for Decision Makers." Institute of Transportation Studies, University of California, Davis. October 2011. <<http://www.steps.ucdavis.edu/steps-book/STEPS%20Book%20%28web%20version%29%20Sept2011.pdf>>.

NAS. (2013). "Transitions to Alternative Vehicles and Fuels."

¹³¹ Capar, Ismail, Michael Kuby, V. Jorge Leon, and Yu-Jiun Tsai. (2013). "An arc cover-path-cover formulation and strategic analysis of alternative-fuel station locations." *European Journal of Operational Research*. Volume 227, Issue 1, pp. 142-151. May 2013.

¹³² ARB. (2000). "California Code of Regulations Title 13, Chapter 8. Clean Fuels Program."

¹³³ 1 Therm = 100,000 BTUs and 1 Gallon of Gasoline = 114,000 BTUs = 1.14 Therms, therefore 400,000 therms * 1.14 therms/GGE = 456,000 GGE.

Required Infrastructure

Using the CFOR assumptions as a guideline, calculations were made to determine the ratio of light-duty vehicles to fueling stations, for each fuel type. The calculations also required assumptions on fleet average fuel economy for each fuel. California's assumed fuel supply capacity of 300,000 GGEs/year for liquid fuel was used for E85 stations and 456,000 GGE/year for gaseous fuel was used for CNG stations.

Stations with electric chargers were assumed to have charging capacity such that, over the course of a year, they could provide enough electricity to allow an electric vehicle to travel as far as an average gasoline vehicle could with 300,000 gallons of gasoline. Using this assumption, stations with electric recharging equipment would each be equipped with just over six Level 2 DC charging outlets per station.

If a hydrogen vehicle with a fuel economy of 60 miles/kg H₂ were to travel as far as a gasoline vehicle with a fuel economy of 27.2 mpg using 300,000 gallons of gasoline, it would require approximately 136,000 kg of hydrogen. Early hydrogen stations are assumed to have a capacity of approximately 160 kg H₂/day, or 58,400 kg H₂/year. The lower capacity of hydrogen refueling stations implies that 2.33 times as many hydrogen refueling stations would be required to provide 300,000 GGEs/year.¹³⁴

For a given fuel type, the number of stations required is calculated using the expression:

$$\text{Number of Stations Required} = \frac{\frac{AVMT * LDV}{MPG/e}}{\text{Average Fuel Volume per Station}}$$

Where:

AVMT = Average vehicle miles traveled

LDV = Number of light-duty vehicles, including passenger cars and light-duty trucks

MPG/e = Miles per gallon equivalent

Unlike the California law, for this paper there is no distinction made between fleet vehicles and vehicles owned by individuals. Infrastructure estimates for this paper can be interpreted as including both private and public refueling infrastructure (including home refueling systems). In addition, publicly available data on annual AFV sales or the number of AFVs in operation frequently does not distinguish between fleet and non-fleet vehicles. Thus, it is reasonable to include them together in calculations.

Rewriting the above expression in terms of vehicles per required station gives:

$$\frac{LDV}{\text{Required Station}} = \frac{MPG/e * \text{Average Fuel Volume per Station}}{AVMT}$$

Where:

AVMT = Average vehicle miles traveled

LDV = Number of light-duty vehicles, including passenger cars and light-duty trucks

MPG/e = Miles per gallon equivalent

MPG/e values from Table 1, station capacity assumptions described earlier in this section, and an AMVT of 15,000 were used to calculate the number of vehicles supported per alternative fuel station. The

¹³⁴ 373 kg H₂/day ÷ 160 kg H₂/day = 2.33

results from these calculations rounded to the nearest ten vehicles are displayed in Table 3 below. If the number of gasoline vehicles per required station is calculated using the same assumptions, there would be 540 vehicles per station. This compares to the approximately 1,500 vehicles per gasoline station in the United States.¹³⁵ If AFVs ever become a large portion of vehicles on the road, the number of vehicles per station will likely increase (as seen in the difference between the projected and actual values for gasoline), thus reducing the per-vehicle cost of infrastructure.

Table 3: Number of Light-Duty Vehicles per Station by Fuel Type

Fuel Type		Vehicles per Station
Natural Gas (CNG)		940
Flex-Fuel (E85)		350
Plug-in Electric (BEV & PHEV)		1,950
Hydrogen (Fuel Cell)		520
Gasoline	Projection	540
	Actual (U.S.)	1,500

Note: Calculations based off of CFOR assumptions as well as assumptions outlined in Table 1

Sources: NPC 2012

The number of vehicles per station was used to calculate the infrastructure cost per vehicle. In order to do this, an estimate of the infrastructure cost of equipping stations to provide a new type of fuel was divided by the number of vehicles per station. In addition, infrastructure costs for individual vehicles, such as the purchase and installation of home chargers for PEVs or home refueling stations for CNG vehicles, were included. The infrastructure cost per vehicle can be found for each fuel in Table 4.

The cost estimates assumed that the cost of upgrading a station would be \$1,000,000 for CNG,¹³⁶ \$84,000 for E85,¹³⁷ \$300,000 for electricity (assuming three Level 2 DC chargers with two plugs each),¹³⁸ and \$2,500,000 for hydrogen.¹³⁹ In addition to station costs, the cost of home systems was assumed to be \$500 for CNG¹⁴⁰ and \$2,000 for electricity (Level 2 charger and installation of a 240-volt outlet in the garage).¹⁴¹

¹³⁵ 240 million vehicles ÷ 160,000 stations = 1,500 vehicles per station

¹³⁶ TIAX. (2012). "U.S. and Canadian Natural Gas Vehicle Market Analysis: Compressed Natural Gas Infrastructure, Final Report." Prepared by TIAX for America's Natural Gas Alliance. May 2012. <http://www.ngvc.org/pdfs/Anga_Infrastructure_CNG_Full.pdf>.

¹³⁷ Moriarty, Kristi, Caley Johnson, Ted Sears, and Paul Bergeron. (2009). "E85 Dispenser Study." Technical Report NREL/TP-7A2-47142. National Renewable Energy Laboratory. December 2009. <<http://www.afdc.energy.gov/pdfs/47172.pdf>>.

¹³⁸ eTec. (2010). "Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene." Electric Transportation Engineering Corporation, an ECotality Company. April 2010. <<http://www.oregon.gov/ODOT/HWY/OIPP/docs/EVDeployGuidelines3-1.pdf>>.

¹³⁹ Melaina, Marc W. and Michael Penev. (2012). "Hydrogen Refueling Infrastructure Cost Analysis." National Renewable Energy Laboratory. May 15, 2012. <http://www.hydrogen.energy.gov/pdfs/review12/an020_melaina_2012_o.pdf>.

¹⁴⁰ GE. (2012). "GE Researchers Developing At-Home Refueling Station for NG Vehicles." General Electric. July 18, 2012. <<http://www.genewcenter.com/Press-Releases/GE-Researchers-Developing-At-Home-Refueling-Station-for-NG-Vehicles-39c7.aspx>>.

Eaton. (2012). "Eaton to Develop Affordable Home Refueling Station for Natural Gas Vehicles; Project Complements Eaton Advancements in Electric Vehicle Charging Stations." Eaton Corporation. July 20, 2012. <http://www.eaton.com/Eaton/OurCompany/NewsEvents/NewsReleases/PCT_378453>.

¹⁴¹ Morrow, Kevin, Donald Karner, and James Francfort. (2008). "U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity: Plug-in Hybrid Electric Vehicle Charging Infrastructure Review." No. 58517. Battelle Energy Alliance, Idaho National Laboratory. November 2008. <<http://avt.inl.gov/pdf/phev/pevInfrastructureReport08.pdf>>.

The home refueling system is a significant cost for CNG infrastructure (32 percent of infrastructure cost), and the home charger represents the vast majority of the cost of electric vehicle infrastructure (93 percent of infrastructure cost). Owners of CNG vehicles could potentially forego the installation of a home refueling system; owners of plug-in vehicles will likely require charging infrastructure at home, as long charging times make reliance on public charging infrastructure challenging. As public natural gas infrastructure becomes more available, it is less likely that CNG vehicle owners will find it necessary to install home refueling stations, reducing the infrastructure cost per vehicle.

While plug-in vehicles will likely require home charging infrastructure for quite some time, costs of home charging infrastructure could come down over the years. For instance, Level 2 charging devices were assumed to cost \$700 - \$1,000 for the device and \$1,000 installation of a 240-volt outlet in a garage; these costs could come down over time, as production and competition scale up. Installation costs could decline further if houses are designed with 240-volt outlets in the garage. In addition, by using Level 1 chargers, which can plug directly into the 120-volt outlets that already exist in most garages, the infrastructure cost per vehicle could be more than halved.

The use of Level 1 chargers is more practical if there are more publicly available 120-volt outlets for vehicles. One way to achieve such public infrastructure is to change building codes to require more external outlets or the creation of an “EV Friendly Building” certification which could be used by contractors, landlords, and businesses for marketing purposes and integrated into sustainability initiatives. A secondary electricity market is not currently legal in the United States. Drivers using these public outlets could not be charged for their use; this could become an issue for businesses in the longer-term if adoption of electric vehicles becomes widespread.

Another infrastructure issue related to the proliferation of electric vehicles is that if the charging locations for these vehicles are located near each other, they could potentially require upgrades to the electric distribution infrastructure, such as the installation of larger transformers. Utilities have researched this issue, and have structured their own infrastructure plans to take into account the adoption of electric vehicles.¹⁴² In addition, utilities have identified strategies, such as lower pricing for off-peak vehicle charging, to reduce local electric loads and limit investment. While successful adoption of electric vehicles will undoubtedly require a significant amount of upstream investment in the grid, the investment will vary widely based on where vehicles charge. This consideration is not included in the analysis in this paper. As stated, for electric vehicles, public stations are considered a secondary source of energy; it has been assumed that recharging will primarily be done at home. Home charging infrastructure is considered part of consumer expenditures, but is included in the calculation of infrastructure cost per vehicle.

NAS. (2010). “Transitions to Alternative Transportation Technologies—Plug-in Hybrid Electric Vehicles.” Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies; National Research Council. National Academy of Sciences. 2010. <http://www.nap.edu/catalog.php?record_id=12826>.

¹⁴² Tudor, Cody, Eric Sprung, Linh Nguyen, and Russ Tatro. (2012). “Plug-In & Hybrid Electric Vehicle Charging Impacts: A Survey of California’s Utility Companies.” California Smart Grid Center . Presented at 2012 IEEE 13th International Conference on Information Reuse & Integration (IRI). August 8-12, 2012.

Table 4: Infrastructure Cost per Vehicle by Fuel Type

Fuel Type	Infrastructure Cost Per Vehicle
Natural Gas (CNG)	\$1,560
Flex-Fuel (E85)	\$240
Plug-in Electric (BEV & PHEV)	\$2,160
Hydrogen (Fuel Cell)	\$4,840

Note: Calculations based on assumptions from Table 3 as well as infrastructure cost estimates

Sources: Eaton 2012, eTec 2010, GE 2012, Melaina and Penev 2012, Moriarty et al. 2009, Morrow et al. 2008, NAS 2010, and TIAX 2012

Service stations cost well over \$1 million per site, including the cost of real estate. If one were to reproduce the current 160,000 service stations that currently provide gasoline, it would cost well over \$160 billion, or \$670 per vehicle.¹⁴³ Since many of these costs have already been paid, it is easier to create infrastructure for new fuels. For instance, underground storage tanks can be retrofitted to store new fuel types; the average refueling station in an urban area has significant unused space that could be used for the installation of new tanks.¹⁴⁴ Stations in rural and suburban environments tend to have even more unused space available.

Comparison of Infrastructure Costs to Other Estimates

The infrastructure costs per vehicle, detailed in Table 4, are similar to those cited by the NPC in a recent publication.¹⁴⁵ The NPC paper calculated the cost to build infrastructure to dispense alternative fuels if one-third of gasoline consumption was replaced by an alternative fuel. Assuming that the average fuel economy of vehicles converting to alternative fuels is equal to the average economy of vehicles using gasoline, NPC's aggregate estimates of infrastructure cost can be converted to per vehicle terms by dividing them by 80,000,000.¹⁴⁶ Table 5 displays the range of estimates from the NPC along with the estimates produced in this paper.

Table 5: NPC Estimate of Infrastructure Cost per Vehicle by Fuel Type

Fuel Type	NPC Low	NPC High
Natural Gas (CNG)	\$1,250	\$2,500
Flex-Fuel (E85)	\$250	\$500
Plug-in Electric (BEV & PHEV)	\$875	\$1,625
Hydrogen (Fuel Cell)	\$3,438	\$5,375

Source: Adapted from NPC 2012

The per-vehicle cost estimate for CNG infrastructure is in the middle of the range provided by NPC, as is the cost estimate for electric vehicle infrastructure. The cost estimate for E85 infrastructure is just below the lower estimate from NPC, but the NPC estimate included distribution infrastructure for E85 as well as dispensing infrastructure.

¹⁴³ NPC. (2012). "Chapter 5: Infrastructure."

¹⁴⁴ Moriarty, Kristi, Caley Johnson, Ted Sears, and Paul Bergeron. (2009). "E85 Dispenser Study."

¹⁴⁵ NPC. (2012). "Chapter 5: Infrastructure."

¹⁴⁶ The light-duty fleet in the United States is approximately 240,000,000 vehicles; a third of that would be 80,000,000 vehicles.

The only fuel with a cost significantly outside the range provided by NPC was for electric vehicle infrastructure, which was estimated as being \$543 more than the NPC high estimate of \$1,625 per vehicle. This difference is likely due to a difference in assumptions about the cost of home charging infrastructure which is almost entirely responsible for the per-vehicle cost of electric charging infrastructure.

A literature review conducted for a UC Davis study on the cost of transitioning to an AFV system suggested that investment for a mature hydrogen transportation system would be equal to \$1,400 - \$2,000 per vehicle. However, infrastructure to serve the first million vehicles would be equivalent to \$5,000 - \$10,000 per vehicle.¹⁴⁷ Given that the projections used to determine the number of hydrogen fuel cell vehicles in operation for 2030 are significantly below \$1 million, the \$4,840 infrastructure investment required per vehicle can be considered a low estimate.

The same review suggested that \$375 to \$700 per vehicle would be required for the delivery (distribution and dispensing) infrastructure for E85.¹⁴⁸ Compared to the UC Davis E85 infrastructure estimate, the \$240 per vehicle estimate is low (although the \$240 estimate includes dispensing but not distribution infrastructure).

The UC Davis cost range for installing home chargers for PEVs is \$800 - \$2,100, in line with the \$2,000 assumption for home chargers.¹⁴⁹ It is worth noting, however, that if the lower cost estimate of \$800 for home Level 2 chargers is used instead of \$2,000, the assumed cost per vehicle (including home chargers and public infrastructure) would decrease by more than half, leading to much lower PEV infrastructure costs.

Table 6: NAS Estimate of Infrastructure Cost per Vehicle by Fuel Type

Fuel Type	NAS Estimate
Natural Gas (CNG)	\$810
Flex-Fuel (E85)	\$2,760
Plug-in Electric (BEV & PHEV)	\$650-2,930
Hydrogen (Fuel Cell)	\$1,750

Source: Adapted from NAS 2013

A recent study by the National Academy of Sciences found that infrastructure costs for alternative fuels were between \$1,000 and \$3,000 per vehicle.¹⁵⁰ Cost estimates for initial investment in infrastructure are displayed in Table 6. These costs include some centralized costs paid by industry such as production and distribution infrastructure as well as distributed costs paid by retailers, vehicle owners, and ratepayers, such as dispensing infrastructure.

¹⁴⁷ Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways."

¹⁴⁸ Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways."

¹⁴⁹ Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways."

¹⁵⁰ NAS. (2013). "Transitions to Alternative Vehicles and Fuels."

Infrastructure Estimates by Country

In order to use the per vehicle infrastructure cost estimates to calculate infrastructure expenditure for selected countries in 2030, estimates of vehicle sales for coming years and the number of AFVs in operation for 2030 had to be generated. Alternative fuel vehicle sales for Europe, the United States, and China through 2030 were extrapolated using trends from sales data and forecasts from a variety of sources.¹⁵¹

Table 7: AFV Sales in 2030 by Fuel Type by Country

Fuel Type	Europe	United States	China
Natural Gas (CNG)	1,000,000	77,000	530,000
Flex-Fuel (E85)	160,000	2,800,000	-
Plug-in Electric (BEV & PHEV)	1,500,000	460,000	1,500,000
Hydrogen (Fuel Cell)	21,000	830	-
Total AFVs	2,700,000	3,300,000	2,100,000
Total Sales	28,000,000	19,000,000	33,000,000
AFV Market Share	9.6%	17.4%	6.4%

Note: Resulting sales estimates are rounded to two significant digits; individual values may not add to totals.

Sources: AFDC 2013, Durbin 2013, LMC Automotive 2013, Mock 2012, and Perkowski 2012

Table 7 depicts AFV sales for the year 2030. The extrapolated sales estimates in this paper do not represent an official forecast, and are intended to be used only as a thought experiment. Other estimates of AFV sales and AFVs in operation could be substituted and used to calculate infrastructure costs. Estimates of AFV sales and AFVs in operation are based on sales and forecast data, and can be seen in Figures 3, 4, and 5 for Europe, the United States, and China respectively.

The United States appears to have the largest light-duty AFV sales in 2030, with more than 17 percent of vehicles sold being classified as AFVs. It is worth noting, however, that nearly 85 percent all of AFVs projected to be sold in the United States are flex-fuel vehicles, which can use any mixture of gasoline and ethanol up to E85. If flex-fuel vehicles were removed from AFV market share, China's AFV market share would be unchanged and Europe's would drop to 9.1 percent. In the United States, however, removing flex-fuel vehicles from the AFV market share calculation would decrease it to only 2.6 percent.

In the United States, the majority of flex-fuel vehicles are primarily fueled with regular gasoline rather than E85.¹⁵² Unless refueling habits change, flex-fuel vehicles will provide only limited improvements in greenhouse gas emissions and petroleum dependence. While flex-fuel vehicles are projected to be the dominant type of AFV in the United States, other AFV technologies, such as CNG vehicles or PEVs, will likely have a greater effect. As mentioned previously, policy changes in the near future could also lead to a decline in flex-fuel vehicle sales, which would result in a lower sales trajectory than the one depicted in Figure 4.

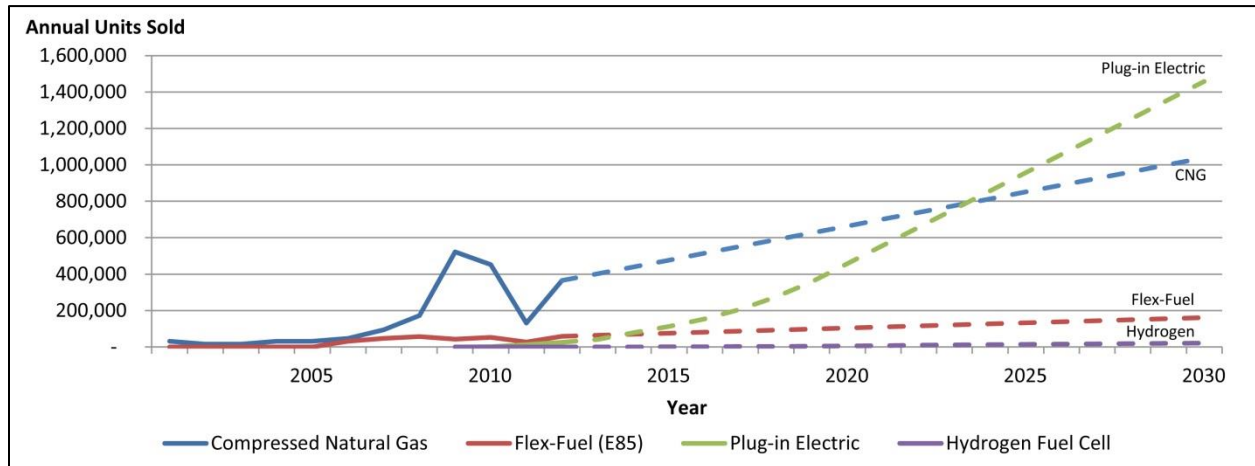
¹⁵¹ These sources included LMC Automotive, Pike Research, the U.S. DOE Alternative Fuels Data Center, Forbes, and the International Council on Clean Transportation.

¹⁵² Voegelé, Erin. (2012). "EPA, DOT finalize fuel efficiency rule, address biofuel comments."

Based on the assumption that vehicle lifetime is 13 years, the number of AFVs in operation in 2030 was estimated by summing the annual vehicle sales for each fuel type for the 13 years, from 2018 to 2030. Sales data and forecasts on flex-fuel and hydrogen fuel cell vehicles were limited for China, so those fuels were examined only for Europe and the United States. Information on electric and CNG vehicles was available for all three countries, allowing estimates to be made for each. Electric and CNG vehicles are the most popular replacements for conventional vehicles in China; China’s CNG vehicle programs date back to the late 1990s.¹⁵³

The number of AFVs in operation by country for 2030, as seen in Table 8, indicates that CNG and plug-in electric vehicles will comprise the majority of the AFVs in operation in Europe. In contrast, flex-fuel vehicles will dominate the market in the United States. China will have the largest number of electric vehicles in operation, but will also have a considerable number of CNG vehicles on its roads. By 2030, hydrogen fuel cell vehicles will be relatively new and constitute only a fraction of the AFVs in operation in these countries.

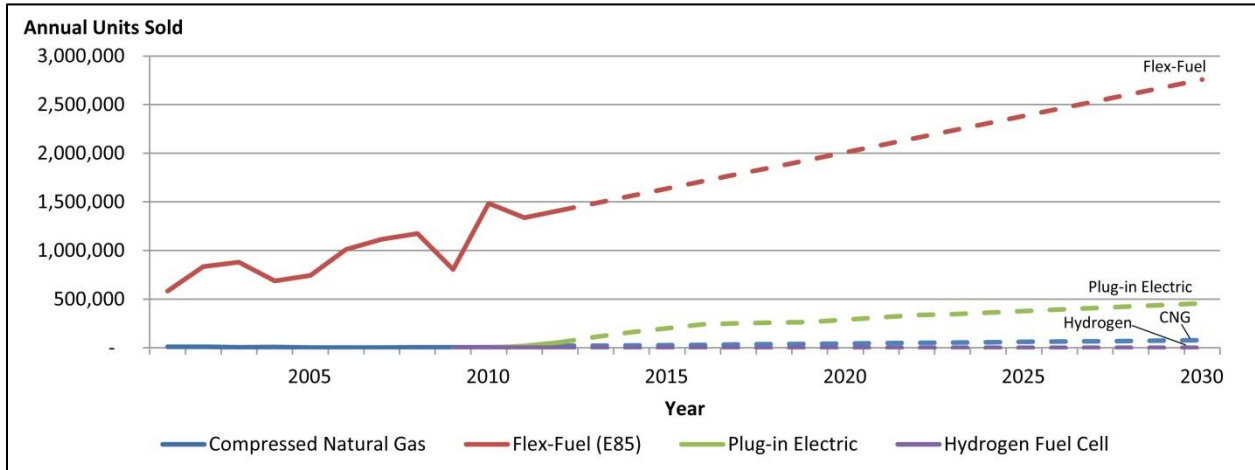
Figure 3: AFV Sales for Europe from 2001-2030 by Fuel Type



Sources: AFDC 2013, Durbin 2013, LMC Automotive 2013, Mock 2012, and Perkowski 2012

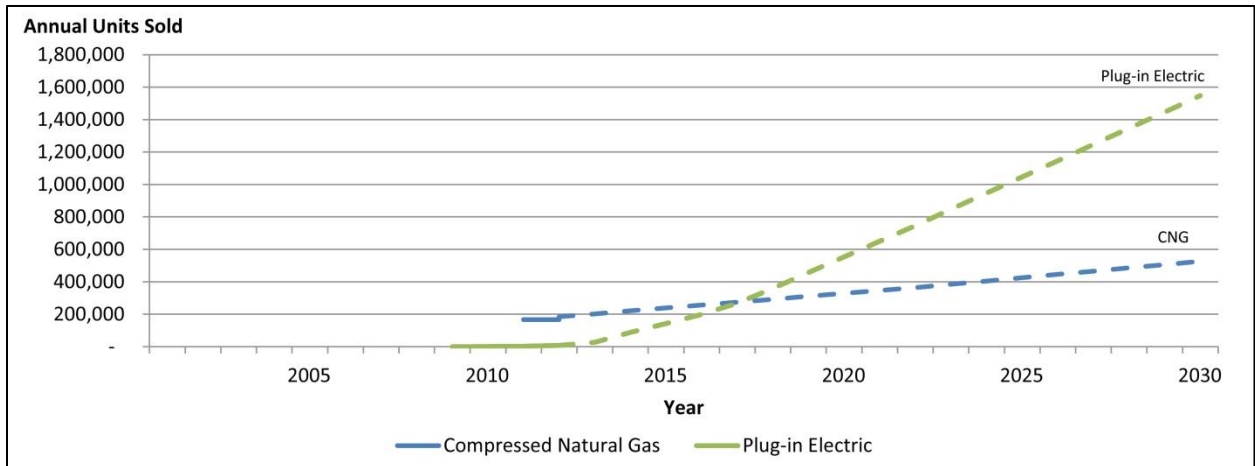
¹⁵³ Huo, Hong, Qiang Zhang, Fei Liu, and Kebin He. (2012). "Climate and Environmental Effects of Electric Vehicles versus Compressed Natural Gas Vehicles in China."

Figure 4: AFV Sales for the United States from 2001-2030 by Fuel Type



Sources: AFDC 2013, Durbin 2013, LMC Automotive 2013, Mock 2012, and Perkowski 2012

Figure 5: AFV Sales for China from 2001-2030 by Fuel Type



Sources: AFDC 2013, Durbin 2013, LMC Automotive 2013, Mock 2012, and Perkowski 2012

Table 8: Total AFVs in Operation in 2030 by Fuel Type by Country

Fuel Type	Europe	United States	China
Natural Gas (CNG)	11,000,000	740,000	5,300,000
Flex-Fuel (E85)	1,600,000	30,000,000	-
Plug-in Electric (BEV & PHEV)	11,000,000	4,700,000	12,000,000
Hydrogen (Fuel Cell)	160,000	5,100	-
Total AFVs	21,000,000	35,000,000	15,000,000

Note: Resulting sales estimates are rounded to two significant digits; individual values may not add to totals.

Sources: AFDC 2013, Durbin 2013, LMC Automotive 2013, Mock 2012, and Perkowski 2012

Infrastructure costs by country were generated using the 2030 AFVs in operation estimates from Table 8 in conjunction with the estimates of infrastructure cost per vehicle by fuel type from Table 4. The estimated infrastructure costs for fuel type are displayed below in Table 9.

Table 9: Infrastructure Cost by Country in Millions Nominal 2013 \$US

Fuel Type	Europe	United States	China
Natural Gas (CNG)	\$17,160	\$1,154	\$8,268
Flex-Fuel (E85)	\$384	\$7,200	-
Plug-in Electric (BEV & PHEV)	\$23,760	\$10,152	\$25,920
Hydrogen (Fuel Cell)	\$774	\$25	-
Total AFV Infrastructure	\$42,078	\$18,531	\$34,188

Note: Based on estimates from Table 4 and Table 8

As shown in Table 9, by 2030, Europe will have spent the greatest amount of money on AFV infrastructure at \$42.1 billion. The investment required in the United States will be \$18.5 billion, and the investment required in China will be \$34.2 billion. While the United States will have almost as many AFVs in operation as Europe and China combined, it will have spent less than either country on AFV fuel dispensing infrastructure due to its heavy reliance on flex-fuel vehicles, which require less infrastructure investment per vehicle.

Gap between Current Investment and 2030 Investment

As described in previous sections, Europe, the United States, and China have already begun investing in AFV infrastructure. Information on the extent of the infrastructure and the expenditures required for installation is somewhat limited. Given these limitations, it is difficult to calculate the true spending on infrastructure construction.

In addition, much of the existing infrastructure will need to be expanded or replaced between now and 2030. This is especially true for hydrogen infrastructure, as the majority of existing hydrogen fueling stations were created to support research, pilot studies, or small fleets. These stations have significantly lower capacities than would be required for commercial operation. Therefore, this analysis assumes that all hydrogen stations required for 2030 will be built in the future. For this reason, spending on hydrogen stations is not estimated along with spending on CNG, E85, and electric vehicle infrastructure.

Using the same information on infrastructure costs that was used to generate the country estimates for infrastructure spending to support the AFVs in operation by 2030, estimates of past spending on infrastructure total \$8.2 billion for the selected regions. Total spending in Europe was the highest at \$3.6 billion. China spent the second most at \$2.6 billion, and the United States spent \$2.0 billion.

Subtracting the values calculated for previous infrastructure spending from the total required by 2030 results in \$86.6 billion in additional investment between now and 2030 in the selected countries. Europe will need to invest an additional \$38.5 billion, China will need to invest an additional \$31.6 billion, and the United States will need to invest an additional \$16.5 billion in AFV infrastructure by 2030.

All four AFV types discussed in this analysis are based on technologies (vehicles and refueling infrastructure) that are more expensive to implement than their gasoline- and diesel-powered equivalents. In addition, some of these vehicles will require substantial adaptation on the part of consumers (e.g., charging at home, more careful planning of routes, and the use of new refueling infrastructure). Successful adoption will depend on consistent and sustained policies to promote the adoption of AFVs and required support infrastructure.

FINANCING MODELS TO SUPPORT INFRASTRUCTURE INVESTMENT

Many types of infrastructure can be classified as “public goods.” The consumption of these goods cannot exclude many from using it. Air quality, parks, national defense, and roads are examples of goods which have such attributes. This matters greatly in our discussion of funding approaches, since public goods tend to be underfunded. Unless there is an ability to obtain a private return on the investment by “privatizing” the good, the business case for supporting the infrastructure is challenging. The existence of the public good attributes of infrastructure is one reason why there has historically been substantial government funding.

There are many benefits to infrastructure investment and promoting funding approaches which incentivize such activity. Infrastructure investment is well documented in its benefit to economies, both in terms of jobs and future productivity. One recent study evaluated the employment effects of U.S. infrastructure spending and found that 18,000 jobs (direct, indirect, and induced) could be created for every \$1 billion of new investment spending.¹⁵⁴ The study results indicate that this is more job creation than would materialize from a tax cut of similar size. Infrastructure spending is particularly supportive of construction and manufacturing employment, which tend to be good paying middle class jobs. As a supportive (albeit tangential) study shows, manufacturing employment can have very high jobs multipliers. The Center for Automotive Research has analyzed the direct, indirect, and induced jobs multiplier for one automotive factory job. The most recent update calculated a jobs multiplier of 10.0, meaning that nine additional jobs are created for every one automotive assembly job.¹⁵⁵ To the extent that infrastructure investment promotes growth in manufacturing, such activity will have substantial payback to employment growth. While this research does not analyze that impact, the study cited supports this assessment.

As discussed previously, several types of fueling infrastructure can be provided by the private sector with appropriate market incentives for investment. For example, a natural gas distributor has an incentive to build pipelines to support an expansion of natural gas retail outlets. With ample demand, the distributor could charge an embedded fee in the gas transmission price to cover the amortized costs of the infrastructure investment. In light of tight government budgets, infrastructure build-out of natural gas infrastructure may be more forthcoming than for other, more expensive infrastructure with public good attributes.

Economic theory shows that public sector provision of infrastructure which has public good attributes is justified. Left to the private sector, such infrastructure would not be funded to the optimal point where

¹⁵⁴ Heintz, James, Robert Pollin, and Heidi Garrett-Peltier. (2009). “How Infrastructure Investments Support the U.S. Economy: Employment, Productivity, and Growth.” Political Economy Research Institute (PERI), University of Massachusetts-Amherst. January 16, 2009. Page 3. <http://www.peri.umass.edu/fileadmin/pdf/other_publication_types/green_economics/PERI_Infrastructure_Investments>.

¹⁵⁵ Hill, Kim, Bernard Swiecki, Deb Menk, Joshua Cregger, and Michael Schultz. (2013). “Economic Contribution of the Ford Motor Company Michigan Assembly Plant to the Michigan Economy.” Center for Automotive Research. Prepared for Michigan Economic Development Corporation and Ford Motor Company. March 2013. <<http://www.cargroup.org/?module=Publications&event=View&pubID=99>>.

social benefits exceed social costs. The private sector underprovision of infrastructure is documented in economic literature.¹⁵⁶

At the same time, as was the case in Brazil, there may be public policy objectives (regardless of the public-private infrastructure attributes) which would warrant sizable public sector investment. In Brazil, the government saw a need to support domestic agricultural interests that were already producing sugar and alcohol, as well as to reduce the country's dependence on oil. As a result of government intervention, Brazil's fuel infrastructure was quickly transformed by the development of infrastructure needed to produce, distribute, and dispense ethanol.

There are many methods that can be used to provide support for AFV infrastructure. These include direct public support, the use of infrastructure banks, formation of public-private partnerships, and private financing (including innovative mechanisms such as "green bonds"). These methods are described in the following sections along with examples of how they have been used in the past and how they could be used to further the development of AFV infrastructure.

Public Support

Policy support from national, state, and local government can play a significant role in encouraging the adoption of AFVs and investment in AFV infrastructure. Such support may be required for a few decades if technological progress is slow. For example, a particular AFV technology may require 20 years of subsidies before it achieves a significant enough share of vehicles in operation to support a functional system of refueling stations.¹⁵⁷

AFVs have enjoyed significant public support in the past. In addition to the many programs offered in the United States, 28 states have some type of grant program to support AFVs, 39 states (and the District of Columbia) have AFV tax incentives, 22 states have AFV loan programs, and 23 states have rebate programs for the purchase of AFVs and fuel.¹⁵⁸ These state programs are not detailed in this paper, but several general types of government support are discussed, including direct government expenditures, municipal bonds, subsidies, and regulatory policies.

Direct Government Expenditures

The most direct form of government investment in infrastructure would involve the government building, owning, operating, and maintaining the infrastructure. The U.S. highway system is an example of such a funding model. This model would be a very expensive undertaking and could face major public opposition, especially in market economies. A more likely approach would involve the use of direct grants, in which the government would award grants to organizations. In the United States, direct grants are often issued for pre-commercial, high-risk, high-reward research. Recent examples of direct grants

¹⁵⁶ Winston, Clifford. (2012). "On the Performance of the U.S. Transportation System: Caution Ahead." Brookings Institution, October 2012. Forthcoming Paper in the Journal of Economic Literature.

¹⁵⁷ NAS. (2013). "Transitions to Alternative Vehicles and Fuels."

¹⁵⁸ EERE. (2013). Alternative Fuels Data Center.

include ARPA-E grants for a variety of AFV technologies and USDA research grants to spur production of bioenergy and bio-based products.¹⁵⁹

Municipal Bonds

One method that a state or local government can use to raise money to finance infrastructure needs is through the use of municipal bonds. Such bonds have been used to finance capital projects, such as transportation infrastructure (e.g., streets, highways, and bridges), schools, hospitals, water and wastewater systems, electric utilities, and other public projects. These bonds can be issued by states, counties, cities, and other agencies and districts.¹⁶⁰ Investors purchasing municipal bonds are essentially lending money to the issuer, and in return will receive interest payments (usually twice a year). When the bond reaches maturity—one to three years for short-term bonds and, more than a decade for long-term bonds—investors will receive their principal.

Municipal bonds are usually exempt from taxes and considered relatively low risk, but provide a relatively low rate of return. Investors may choose to purchase bonds for their stability, especially if they wish to balance out their holdings of higher-risk, higher-return stocks. Payments to bondholders may be general obligations, or they could be tied to specific revenues (e.g., rates paid by infrastructure users).

Bonds are sometimes issued on behalf of private entities, such as colleges or hospitals, that have agreed to repay the issuer.¹⁶¹ State and local governments, wishing to encourage adoption of AFVs in particular regions, could issue bonds to raise money that could be used to assist in the deployment of fueling infrastructure.

Subsidies

The use of tax expenditures, or subsidies, has seen extensive use as a strategy for green technology adoption. Unlike the feed-in tariff which was paid by German utilities (and ultimately ratepayers) to promote the installation of renewable energy, the United States has used the “Production Tax Credit,” allowing producers of renewable energy to claim a tax credit of 2.2 cents per kilowatt-hour produced for the first decade of operation.¹⁶² Tax policy has been used to promote AFVs, either through tax credits or exemptions on purchasing vehicles, annual registration taxes, home charging infrastructure installation, or alternative fuel production. Several European countries have implemented tax cuts on “low-carbon” vehicles.¹⁶³ In the United States, a tax credit of up to \$7,500 has been offered for the purchase of electric

¹⁵⁹ ARPA-E. (2013). Advanced Research Projects Agency, United States Department of Energy. Website. Accessed March 20, 2013. <<http://arpa-e.energy.gov/>>.

USDA. (2012). “USDA Grants Support Sustainable Bioenergy Production.” United States Department of Agriculture. Release No. 0360.12. December 14, 2012. <<http://www.usda.gov/wps/portal/usda/usdahome?contentid=2012/12/0360.xml&contentidonly=true>>.

¹⁶⁰ SEC. (2011). “Municipal Bonds.” United States Securities and Exchange Commission. January 28, 2011. <<http://www.sec.gov/answers/bondmun.htm>>.

¹⁶¹ SEC. (2011). “Municipal Bonds.”

¹⁶² DSIRE. (2013). “Renewable Electricity Production Tax Credit (PTC).” Database of State Incentives for Renewables & Efficiency. January 3, 2013. <http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F>.

¹⁶³ ILLS. (2011). “Green Stimulus Measures.” EC-IILS Joint Discussion Paper Series No. 15. International Institute for Labor Studies, International Labour Organization. November 16, 2011. <http://www.ilo.org/inst/research/addressing-crisis-challenges/discussion-paper-series/WCMS_194185/lang--en/index.htm>.

vehicles.¹⁶⁴ By using tax policy to encourage the adoption of AFVs, governments can help increase demand for alternative fuels and make AFV infrastructure investments more feasible.

In addition to the purchase of AFVs, governments have also supported the production of alternative fuels. In the United States, various tax credits and other incentives have been made available by federal and state governments for production, blending, and sale of vehicle fuels, including compressed natural gas, liquefied petroleum gas, hydrogen, electricity, E85, cellulosic ethanol, and biodiesel.¹⁶⁵

Regulatory Policies

Outside of financing infrastructure investment, national governments are able to institute performance-based policies (e.g., fuel economy or GHG emissions standards) and technology mandates (e.g., renewable fuels standards or targets). These policies promote the development of AFVs and alternative fuel infrastructure, without necessarily requiring direct government expenditures. The United States has both performance-based (i.e., CAFE) and technology mandate (i.e., RFS) policies. Globally, countries with performance-based fuel economy standards include Australia, Brazil, Canada, China, and South Korea, and countries with technology mandates include Brazil, Canada, and Russia.¹⁶⁶

In addition, national and local governments have used fleet purchasing programs to create initial demand for fuel as well as provide visibility for AFVs. In the United States, government fleet purchasing programs were responsible for purchasing a large portion of hybrid vehicles sold in specific years.¹⁶⁷ Government agencies have also driven the purchase of flex-fuel vehicles in both the United States and Brazil.¹⁶⁸

California has instituted a unique regulation requiring the installation of AFV refueling infrastructure at gas stations. The Clean Fuels Outlet Regulation compels station owners to install infrastructure based on the number of AFVs owned in the state. Such a regulation ensures that refueling capacity is available for these vehicles, but it exposes private businesses to ventures that they may not otherwise have been willing to undertake.

In the United States, at the state and local levels, other non-monetary policies have been used to incentivize consumers to purchase AFVs. Many locations have allowed drivers of certain AFVs access to carpool lanes (also known as high occupancy vehicle, or high occupancy toll lanes) even if there is only one occupant in the vehicle. Discounted, or more convenient, parking for AFVs is another incentive that has been used at the local level.

¹⁶⁴ IRS. (2013). "Plug-In Electric Drive Vehicle Credit (IRC 30D)." United States Internal Revenue Service. February 5, 2013. <[http://www.irs.gov/Businesses/Plug-In-Electric-Vehicle-Credit-\(IRC-30-and-IRC-30D\)](http://www.irs.gov/Businesses/Plug-In-Electric-Vehicle-Credit-(IRC-30-and-IRC-30D))>.

¹⁶⁵ RFA. (2012). "Tax Incentives." Renewable Fuels Association. April 2012. <<http://www.ethanolrfa.org/pages/tax-incentives>>.

¹⁶⁶ GFEI. (2013). "Cleaner, More Efficient Vehicles." Global Fuel Economy Initiative. Accessed March 20, 2013. <<http://www.unep.org/transport/gfei/autotool/index.asp>>.

¹⁶⁷ Hill, Kim and Joshua Cregger. (2011). "Deployment Rollout Estimate of Electric Vehicles 2011-2015." Center for Automotive Research. January 2011. <<http://www.cargroup.org/?module=Publications&event=View&pubID=12>>.

¹⁶⁸ Corts, Kenneth S. (2010). "Building out alternative Fuel retail infrastructure: Government fleet spillovers in E85." *Journal of Environmental Economics and Management*. Volume 59, Issue 3, pp. 219-234. May 2010.

Infrastructure Development Banks

Infrastructure banks are one option for securing funding for large projects. Europe and Brazil have existing development banks designed to help secure funding for large infrastructure projects. Both banks have experience financing investment in AFV infrastructure. There has also been discussion around the idea of creating an infrastructure bank in the United States, which could potentially finance a variety of projects, including AFV infrastructure.

The European Investment Bank (EIB) is a nonprofit, long-term lending institution.¹⁶⁹ The bank's shareholders are the member states of the European Union; its goals are to significantly contribute "to growth, employment, economic and social cohesion and environmental sustainability." The EIB finances a portion (30 to 50 percent) of each project it supports, drawing its lending resources from bond issues on the international market. The bank's high rating means it can borrow at low rates, reducing the cost of project capital. Projects financed by the bank are subject to "strict economic, technical, environmental and social standards," and the bank has a large, skilled staff to assess projects and provide technical support and expertise. The EIB has experience financing projects to deploy AFVs, such as the acquisition of electric vehicles and installation of charging points in Spain and the Netherlands.¹⁷⁰

The Brazilian Development Bank, or Banco Nacional de Desenvolvimento Econômico e Social (BNDES), is the primary source of financing for development in Brazil.¹⁷¹ The bank has a long history in directing the growth of industry and expansion of infrastructure. Like EIB, BNDES analyses and provides support to projects in a variety of sectors. Its goals are to support "innovation, local development, and socio-environmental development." When Proalcool was introduced in the 1970s, BNDES supported investments in infrastructure used to process sugarcane and distill ethanol fuel.¹⁷² BNDES continues to support the transportation sector in Brazil by funding investments in automaker operations and sustainable transportation systems.¹⁷³

In the United States, there have been many proposals to create a national infrastructure bank that could fund large projects costing \$100 million or more.¹⁷⁴ The infrastructure bank would require a federal appropriation for initial capitalization, but would leverage a large amount of private investment (five private dollars for every federal dollar). Its goal would be to increase infrastructure investment without requiring large upfront government funding.

By using a merit-based approach for project approval, the bank would depoliticize the selection process—making it more competitive and resulting in the funding of projects with better economic and social justification.¹⁷⁵ Due to the private nature of the bank, its decisions would be subject to greater scrutiny by investors who have an interest in sound projects that are able to deliver a reasonable return

¹⁶⁹ EIB. (2013). The European Investment Bank. Website. Accessed March 21, 2013. <<http://www.eib.org/>>.

¹⁷⁰ EIB. (2013). The European Investment Bank.

¹⁷¹ BNDES. (2013). Brazilian Development Bank. Website. Accessed March 21, 2013. <http://www.bndes.gov.br/SiteBNDES/bndes/bndes_en/>.

¹⁷² Cordonnier, Vanessa M. (2008). "Ethanol's Roots."

¹⁷³ BNDES. (2013). Brazilian Development Bank.

¹⁷⁴ Galston, William A. and Korin Davis. (2012). "Setting Priorities, Meeting Needs: The Case for a National Infrastructure Bank." Brookings Institute. December 13, 2012.

<http://www.brookings.edu/~media/research/files/papers/2012/12/13%20infrastructure%20galston%20davis/1213_infrastructure_galston_davis.pdf>.

¹⁷⁵ Galston, William A. and Korin Davis. (2012). "Setting Priorities, Meeting Needs."

on investment. Once a project is completed, it would repay the investment bank through user fees or other revenues, thus allowing the bank to provide returns for investors.

More than 30 U.S. states have already established their own infrastructure banks.¹⁷⁶ Most of these state infrastructure banks have limited capital and have not undertaken many projects. They also tend to be limited in the types of infrastructure projects they can fund and may still run into problems (e.g., investment projects that cross state or even national borders, which could be more easily solved by a larger, national infrastructure bank).

Due to the large scale of investments required to provide AFV infrastructure and the coordination necessary to ensure that fuel is available along major corridors, a large infrastructure bank capable of cross-border projects could go a long way towards making new infrastructure possible in the United States. Development banks in the European Union and Brazil already have extensive experience financing AFV infrastructure projects.

Public-Private Partnerships

Government involvement with industry is likely to be needed to help coordinate commercial deployment of alternative vehicles with the fueling infrastructure for AFVs, but government efforts may be limited by political and economic issues. In addition, the inclusion of private interests can help reduce costs and complete projects more quickly. Infrastructure projects can be funded using traditional public or private financing methods or alternative approaches, such as a public-private partnership (PPP).

The potential benefits of PPPs are illustrated in the following example: Along the border between southern Indiana and Louisville, Kentucky, two similar bridges are being constructed. Due to differences in state laws, one is being built and maintained using public funds, while the other is making use of a PPP.¹⁷⁷ The bridge being built and managed by the PPP has already saved \$225 million on the proposed cost of construction. In addition, because the construction of the bridge has been bundled with the maintenance and operating costs of its first 35 years, the PPP considered design alternatives to ensure that the bridge would have lower maintenance costs.

In the United States, financing through PPPs is growing at a healthy rate; infrastructure funding involving PPPs has increased fivefold from 1998 to 2007. Compared to many other countries, however, the United States still has a relatively low level of PPP financing. From 1990 to 2006, \$10 billion in funding for U.S. transportation infrastructure was committed; for the same period in the United Kingdom, a much smaller country in terms of its geography and economy, the amount of transportation infrastructure investment financed through PPPs was \$50 billion.¹⁷⁸

There are many types of PPPs that could be used to assist in the deployment of AFV infrastructure. U.S. Department of Energy (DOE) Section 136 collateralized loans used to finance automaker investment in

¹⁷⁶ Galston, William A. and Korin Davis. (2012). "Setting Priorities, Meeting Needs."

¹⁷⁷ Economist. (2013). "Building Infrastructure: A River Runs through It." The Economist. March 2nd, 2013.

<http://www.economist.com/news/united-states/21572794-natural-experiment-infrastructure-river-runs-through-it>.

¹⁷⁸ Economist. (2013). "Building Infrastructure."

advanced technology vehicles and various cost-share grants to develop AFV infrastructure are discussed as examples.

Collateralized Loans

Collateralized loans are a secured asset. In the event of a default on a loan, the debtor will release the asset to the lender. Collateralized loans result in less risk for the lender, and may make it easier or less expensive to obtain funding. In the event of a loan default, the lender can sell the asset to recover some of the losses.

The Section 136 loans administered by the DOE are one example of collateralized loans being used to support AFV adoption. Under Section 136 of the Energy Independence and Security Act of 2007, the Advanced Technology Vehicles Manufacturing (ATVM) loans program was created. In September 2008, Congress appropriated \$7.5 billion which was to be leveraged to support loans totaling \$25 billion.¹⁷⁹ The long-term, low-interest¹⁸⁰ loans were designed for automakers and auto suppliers for "reequipping, expanding or establishing manufacturing facilities in the United States" to produce high fuel-economy vehicles, including AFVs.¹⁸¹

Loan recipients have included Fisker Automotive, Ford Motor Company, Nissan North America, Tesla Motors, and Vehicle Production Group. Ford received the largest amount from the program, with \$5.9 billion in loans. Nissan also received a large loan of over \$1.4 billion. To date, only \$8.4 billion of the \$25 billion has been lent out.¹⁸² While Section 136 loans were used to encourage automaker investment in production facilities, a similar loan program could be used to support investment in refueling infrastructure. With congressional action, the Section 136 program itself could even be expanded to include alternative fuel providers in addition to automakers and suppliers.

Cost-Share Grants

One way that governments can gain greater investment from grant money is to require matching funds from other organizations. The U.S. highway program is funded in this way, with the federal government providing \$4 for every \$1 of state funds spent on highway projects (up to an annual allocation specified for each state). Government grants which require private company investment have been used to deploy AFV infrastructure. Some examples of these projects include Clean Cities, ChargePoint America, and the EV Project, each of which was awarded cost-sharing grants from the DOE.¹⁸³

The Clean Cities partnership is comprised of nearly 100 local coalitions and more than 10,000 public and private stakeholders. The mission of Clean Cities is to reduce petroleum consumption in the transportation sector. In August 2009, the DOE awarded 25 cost-share grants totaling \$300 million for Clean Cities projects from funds allocated by the American Recovery and Reinvestment Act. The 25 projects involved investment in a variety of AFV fuel technologies, including biofuels (E85 and B20),

¹⁷⁹ EERE. (2013). Alternative Fuels Data Center.

¹⁸⁰ The loans have an interest rate of around five percent and can be paid back within 25 years.

¹⁸¹ DOE. (2013). "ATVM." Loan Programs Office, United States Department of Energy. Accessed March 21, 2013. <https://lpo.energy.gov/?page_id=43>.

¹⁸² DOE. (2013). "ATVM."

¹⁸³ Hill, Kim and Joshua Cregger. (2011). "Deployment Rollout Estimate of Electric Vehicles 2011-2015."

CNG, LPG, and electricity.¹⁸⁴ The projects funded by the grant money involved purchasing vehicles and installing infrastructure.

In 2010, the DOE awarded a total of \$115 million in grants to Electric Transportation Engineering Corporation (eTec), a subsidiary of ECOTality North America, for the “EV Project.” The project used the money to provide free residential chargers for electric vehicles to qualifying electric vehicle owners in selected cities. The project also covered the majority of charger installation costs. When applying for the proposal, eTec had the support of more than 40 government and industry partners, including Nissan North America. With matching funds from partners, the total funding for the EV Project is \$230 million. The project installed 15,000 charging stations.¹⁸⁵

The ChargePoint America program is a \$37 million program sponsored by Coulomb Technologies and made possible through a \$15 million investment of stimulus money from the U.S. DOE. Ford, Chevrolet, and Smart USA are part of ChargePoint America. The goal of the program is to install 5,000 Level 2 charging stations in both public and private locations. Individuals may have a station installed free of charge if they reside in one of ten selected regions and purchase an eligible vehicle. As of April 2012, the program had installed more than 2,400 charging stations.¹⁸⁶

Private Financing

Private infrastructure projects can make use of corporate finance, which has a higher risk associated with it, but may be less expensive and complicated than procuring public financing or creating a PPP. Corporate finance is typically used for lower cost projects where the required funding is not significant enough to warrant other options or where the private entity is so large that projects can be funded through its balance sheet without representing an excessively high amount of risk. When completed, projects will provide a revenue stream which is used to recover the initial investment, pay off debt, and reward investors. For projects with environmental benefits, such as AFV infrastructure, an innovative method of investor funding with returns tied to fees from carbon credits could also be possible.

Surcharges and User Fees to Recoup Investment Outlays

It is common to use surcharges to pay off loans, to fund future maintenance, or to fund construction of new infrastructure. Often surcharges are used on airline tickets to repay debt that was issued to build airports. Many state governments in the United States are considering instituting mileage-based user fees which would pay for public roads; frequently a portion of income from toll roads goes to pay down debt and finance new infrastructure investments.¹⁸⁷ Toll road projects are usually financed using debt that is backed by future revenues. While most roads and highways are owned by public entities, private participation is becoming more common in major highway projects due to the use of tolls.

¹⁸⁴ DOE. (2009). “Recovery Act Awards for Alternative Fuels and Advanced Vehicle Pilot Program.” U.S. Department of Energy. August 26, 2009. <http://michigan.gov/documents/recovery/Clean_Cities_Recovery_Act_Award_List_8_25_09_v4_290161_7.pdf>.

¹⁸⁵ ECOTality. (2010). “The EV Project Expands To Texas.” ECOTality North America. July 15, 2010. <http://www.ecotality.com/pressreleases/07142010_Expansion_Texas.pdf>.

¹⁸⁶ ChargePoint. (2013). ChargePoint America. Website. Accessed March 22, 2013. <<http://www.chargepointamerica.com/>>.

¹⁸⁷ GAO. (2006). “Highway Finance: States’ Expanding Use of Tolling Illustrates Diverse Challenges and Strategies.” GAO-06-554. United States Government Accountability Office. June 2006. <<http://www.gao.gov/assets/260/250670.pdf>>.

Refueling stations could charge similar fees and include them in the cost of fuel. Once the market is saturated with refueling stations, the ability to recover investment costs through fuel fees will be more limited, but when stations are relatively scarce, they will have more freedom to charge higher fees to pay off their infrastructure investment. This is especially true if many of the stations in a region have a single owner and competition is scarce. Once initial stations are built and consumers begin buying AFVs, higher station utilization will make the alternative fuel market more attractive for new entrants; any infrastructure surcharges built into the fuel price will be reduced to more competitive levels.

Green Bonds

One innovative way to attract private investors is for companies producing the infrastructure, such as electric charging stations for battery electric vehicles, to offer “green bonds.” These bonds would be issued by the companies in order to raise needed capital for infrastructure investment. The securities could be structured as a convertible bond with a strike price at which the bond value would convert to company stock. In this way, the bond valuation over time can be linked to the company’s success at achieving the infrastructure build-out and in obtaining a stream of income for the infrastructure, such as user fees.

These bonds are called “green” because there may be an added feature, should a carbon credit market become more widespread. In the European Union, a carbon permits system caps the emissions of more than 11,000 power stations, factories and airlines. The emissions from these facilities represent about 40 percent of EU greenhouse gases.¹⁸⁸ However, a global emissions cap and trading scheme would be necessary in order for green bonds to incorporate the added feature of securing carbon credits for investments in these securities. Since the bond proceeds would be directly earmarked to fund infrastructure for alternative fuel vehicles, a carbon credits entity could evaluate the amount of CO₂ reduction associated with the replacement rate from higher CO₂ emitting fueling infrastructure to lower ones. While this would be an indirect benefit to the infrastructure investment, such a scheme could provide some benefit to investors which would not detract from credits earned by companies producing and selling the alternative fuel vehicles.

Such a market for CO₂ credits has encountered limited success to date. EU carbon emissions futures are presently trading at between €3.50-4.00 per metric ton. This is a very low price, down nearly 60 percent in the last four months.¹⁸⁹ Even so, there is a case to be made for green bonds which could generate more unconventional financing mechanisms to support fueling infrastructure for alternative fuel vehicles, including dedicated infrastructure exchange-traded funds. At this juncture, this financing concept is in its infant stage, but could grow quickly should there be widespread consumer choice toward alternative fuel vehicles.

Funding the Infrastructure of the Future

This paper discusses several different examples of financing mechanisms that could be used to generate the funding needed to construct the necessary infrastructure. Public support for AFV infrastructure

¹⁸⁸ Gregorio, David. (2013). “Skeptical Environmentalist’ Opposes Propping up EU Carbon Credits.” Reuters. March 14, 2013. <<http://www.reuters.com/article/2013/03/14/us-eu-carbon-lomborg-idUSBRE92D1DB20130314>>.

¹⁸⁹ Market Watch. (2013). “ICE ECX EUA Futures.” Market Watch, Wall Street Journal. Accessed March 20, 2013. <<http://www.marketwatch.com/>>.

could involve the use of mechanisms (e.g., grants, bonds, and subsidies as well as regulatory policies) that require investment or support the adoption of AFVs. Infrastructure development banks such as the EIB in Europe, the BNDES in Brazil, or a potential bank in the United States could provide low-cost capital to AFV infrastructure projects that are in line with development goals. Such banks can leverage private investment and make decisions based on expected benefits rather than political considerations. Public-private partnerships can offer many of the benefits of public and/or private financing while overcoming some of their limitations. Traditional private financing models will also be important, especially in later stages of AFV infrastructure development when AFVs are more established and investment is less risky. In addition, more innovative private financing methods, such as the green bond idea, could play a role in financing AFV infrastructure.

Brazil's development of a biofuels industry offers many lessons on the power of regulations and investments financed by large development banks. Places like China or California may be able to create demand for AFVs and force fuel providers to offer alternative fuels using top-down regulations like those used by Brazil to create an ethanol-powered transportation system. In Europe and the rest of the United States, it may be more difficult to achieve high AFV penetrations and encourage development of infrastructure, but infrastructure banks and PPPs can help reduce project risk and attract private investors, facilitating the AFV infrastructure build-out.

CONCLUSIONS

Countries around the world have implemented vehicle regulations to improve vehicle fuel economy and reduce GHG emissions from vehicles. Many have also created incentive programs to encourage the adoption of AFVs, and automakers have already started making investments in developing, manufacturing, and selling AFVs. Despite all of this support, AFVs face many challenges to adoption.

One of the greatest challenges is the chicken-and-egg issue of concurrently developing AFVs and alternative fueling infrastructure. Because the cost of installing new refueling infrastructure is high and the adoption of AFVs is uncertain, private investment is risky and relatively unattractive. In addition, current political and economic realities could make securing public funding challenging.

There will be significant changes in mobility in the coming decades. Billions of dollars have already been spent creating fueling stations for AFVs around the world. If the forecasts and trends used in this research are accurate, \$86.6 billion in additional AFV fuel infrastructure investment will be required in Europe, the United States, and China by 2030. Specifically for the countries examined in this paper, Europe will need to invest an additional \$38.5 billion, China will need to invest an additional \$31.6 billion, and the United States will need to invest an additional \$16.5 billion. If AFVs are more successful than expected, the required infrastructure investment could be much higher.

While this paper used forecasts and trends to come up with one scenario of possible AFV penetration by 2030, the actual number of vehicles in operation could vary significantly depending on costs, government policies, and many other factors. In addition, certain factors may not have been taken into account when generating forecasts. For example, while CNG vehicle sales in the United States increased from around 5,000 to 20,000 in the past few years due to the current low fuel costs brought about by fracking, the forecast for CNG vehicle sales only reaches 40,000 by 2019, resulting in a relatively low trajectory for CNG vehicle adoption in the United States. Even if CNG vehicles are adopted only by fleet owners with private, centralized refueling infrastructure, improvements in CNG vehicles coupled with a plentiful supply of low-cost fuel could result in a trajectory for U.S. CNG sales that is much higher than the one used in this paper.

While the majority of the world's vehicles may still be reliant on petroleum-based fuels by 2030, even a small AFV market share will require the support of expensive fuel infrastructure. As the cost of new refueling stations will be in the tens of billions of dollars for the three regions examined, there will be ample room for many different financing models to provide funding for these projects.

All of the methods discussed in this paper could potentially be used to finance infrastructure. The type of government and existing institutions will be big determinants as to whether AFV infrastructure in a particular country will be financed through public or private mechanisms. Another major determinant of which financing methods would be most appropriate is the rate of AFV adoption. In markets with low levels of AFV sales, public financing will typically be required to create AFV infrastructure, and in mature markets with a high penetration of AFVs, private capital will be available to invest in the infrastructure needed to meet consumer demands. In midrange scenarios where some AFVs are already on the roads,

but not enough to encourage private investment, public-private partnerships and infrastructure banks will be useful to provide the support infrastructure needed to maintain AFV sales and help the market reach maturity.

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APPENBDIX A: ABBREVIATIONS

Abbreviation	Term
AFV	alternative fuel vehicle
AVTM	Advanced Technology Vehicles Manufacturing loans (USA)
B20	a blend of biodiesel (20%) and diesel (80%)
BEV	battery electric vehicle
BNDES	Brazilian Development Bank
CAFE	Corporate Average Fuel Economy (USA)
CFOR	Clean Fuels Outlet Regulation (California)
CH ₄	methane
CNG	compressed natural gas
CO ₂	carbon dioxide
DOE	U.S. Department of Energy
E85	a blend of ethanol (85%) and gasoline (15%)
EEG	Renewable Energy Sources Act (Germany)
EIB	European Investment Bank
eTec	Electric Transportation Engineering Corporation
Flex-fuel	flexible fuel
GGE	gasoline gallon equivalent
GHG	greenhouse gas
GWh	gigawatt-hour
H ₂	hydrogen
H ₂ O	water
HEV	hybrid electric vehicle
ICE	internal combustion engine
kW	kilowatt
kWh	kilowatt-hour
LNG	liquefied natural gas
MLP	master limited partnership
N ₂ O	nitrous oxide
NOx	nitrogen oxides
NPC	National Petroleum Council
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PPP	public-private partnership
Proalcool	Programa Nacional do Álcool (Brazil)
PSI	pounds per square inch
REIT	real estate investment trust
RFS	renewable fuels standard
SMR	steam methane reforming
VOCs	volatile organic compounds

APPENDIX B: COMPARISON OF GHG EMISSIONS FROM AFVS

Each of the alternative fuels discussed in this paper (i.e., compressed natural gas, electricity, hydrogen, and ethanol) has the potential to displace petroleum use and reduce GHG emissions. The environmental effects of AFVs vary by technology type. While AFVs powered by electricity or hydrogen may have no tailpipe emissions, every fuel type is responsible for some amount of emissions from a lifecycle perspective.¹⁹⁰

While natural gas is a fossil fuel, compared with vehicles that rely on diesel and gasoline, natural gas vehicles produce lower levels of some types of emissions. Vehicles powered by CNG emit approximately 6 – 11 percent less lifecycle GHG emissions compared to gasoline-powered vehicles.¹⁹¹

Lifecycle emissions of PEVs vary drastically depending on how the electricity used for charging is generated: PEVs produce fewer lifecycle GHG emissions using electricity from power plants using relatively cleaner fuels (e.g., nuclear, renewable, and hydroelectric power plants), than they do when they rely on fossil fuel plants (e.g., coal, oil, or natural gas). Depending on the mix of fuels used to produce electricity, typical estimates suggest that BEVs could reduce GHG emissions by 20 – 50 percent and PHEVs could reduce GHG emissions by 20 – 60 percent, compared to gasoline vehicles.¹⁹²

Hydrogen can be produced from many different energy resources, and its lifecycle GHG emissions vary widely depending on how it is produced. Hydrogen fuel cell vehicles reduce GHG emissions by 30 – 55 percent with hydrogen produced using SMR (natural gas feedstock) and up to 95 percent using hydrogen produced from renewable feedstocks.¹⁹³

Ethanol releases GHGs when it is used to power vehicles, but unlike the fossil carbon released by petroleum-based fuels, much of the CO₂ released in the combustion on ethanol is offset by the CO₂ that was captured by the crops grown to produce ethanol. Corn-based ethanol can reduce lifecycle GHG emissions by up to 52 percent compared to gasoline. The use of cellulosic ethanol, which is produced from plants that are less reliant on petroleum-based fertilizers, could reduce GHG emissions by as much as 86 percent.¹⁹⁴

¹⁹⁰ EERE. (2013). Alternative Fuels Data Center.

¹⁹¹ EERE. (2013). Alternative Fuels Data Center.

¹⁹² Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways."

¹⁹³ Ogden, Joan and Lorraine Anderson. (2011). "Sustainable Transportation Energy Pathways."

¹⁹⁴ EERE. (2013). Alternative Fuels Data Center.

APPENDIX C: CALIFORNIA CLEAN FUELS OUTLET REGULATION

In brief, the CFOR mandates that a minimum number of retail fueling stations provide a designated alternative fuel, for a given number of vehicles using that fuel. The station count mandate does not apply until the statewide number of vehicles utilizing a fuel is at least 20,000 vehicles. Station count estimates apply to a *compliance year*, defined as the May 1st through April 30th period, and are defined no later than 14 months prior to the start of the compliance year.

Applicable fuels are determined by the Executive Officer of the California Air Resource Board, by review of Department of Motor Vehicle records, and projected production volumes included by manufacturers in their vehicle emissions certification data. For each designated fuel, a fleet size estimate is calculated, according to the following formula:

$$\begin{array}{rcccl} \text{Number} & & \text{(Projected Sales for} & & \\ \text{of} & & \text{Corresponding Model Year} & & \\ \text{Vehicles} & = & \text{+} & & \text{Total Vehicles Using} \\ & & \text{Sales for Previous Model} & + & \text{the Fuel, Registered} \\ & & \text{Year)} & & \text{with the DMV as of} \\ & & \text{+} & & \text{July 30th, Two Years} \\ & & \text{Sales Two Model Years} & + & \text{Prior} \\ & & \text{Prior} & & \\ & & \text{-----} & & \\ & & 2 & & 6 \end{array}$$

Provided an estimate of at least 20,000 vehicles, the process continues to determination of the *Total Projected Maximum Volume (TPMV)*, essentially, an estimate of maximum demand for the alternative fuel.

The TPMV is determined as the sum of the *Maximum Demand Volumes (MXDV)*, which are calculated separately for each model year and vehicle class. Model years considered are 1994 through the model year corresponding to the compliance year for which station count numbers are being calculated. Vehicle classes considered are passenger cars, light-duty trucks, and medium-duty vehicles. TPMV and MXDV are measured in gasoline-equivalent gallons per year for liquid fuels and in therms per year, for gaseous fuels.

For a given fuel, vehicle class and model year, the MXDV is calculated as the number of vehicles within that class and model year, using that fuel, multiplied by the average annual vehicle miles traveled of that group, with this product divided by the average fuel economy of that group. Thus, for a given fuel type, the TPMV is given by the expression on the following page.

$$TPMV = \sum_{i=1}^{MY} \frac{PC_{MY} * AVMT_{PC,MY}}{AFE_{PC,MY}} + \sum_{i=1}^{MY} \frac{LDT_{MY} * AVMT_{LDT,MY}}{AFE_{LDT,MY}} + \sum_{i=1}^{MY} \frac{MDV_{MY} * AVMT_{MDV,MY}}{AFE_{MDV,MY}}$$

Where:

TMPV = Total Projected Maximum Volume

PC = Passenger Cars

LDT = Light-Duty Trucks

MDV = Medium-Duty Vehicles

MY = Model Year, for model years 1994 through the model year corresponding with the relevant compliance year.

AVMT = Average Vehicle Miles Traveled for a vehicle class and model year

AFE = Average Fuel Economy for a vehicle class and model year

The number of required fuel outlets is calculated from TPMV.

$$\text{Required Fuel Outlets} = \frac{\text{TPMV} - \text{Discounted Fuel Volume for Fleet Vehicles} + \text{Total Fuel Volume from Vehicle Conversions}}{\text{Fuel Throughput Volume per Station}}$$

As fleet vehicles are presumed to perform a majority of their refueling at a central, fleet location, a share of the fuel volume which fleet vehicles would require is removed from consideration. Likewise, in determining whether the 20,000 vehicle threshold has been reached, the same share of fleet vehicles is ignored. The share of fleet vehicles removed from consideration is determined by the Executive Officer of the California Air Resource Board, and is intended to represent the portion of fleet fueling performed at fleet stations. The CFOR specifies that no more than 75 percent of fleet vehicles shall be removed.

For liquid fuels, the *Fuel Throughput Volume per Station* is assumed to be 300,000 gasoline equivalent gallons per year, until the number of vehicles using that fuel is high enough that the CFOR requires more than 5 percent of all retail gasoline outlets to stock the fuel. At this point, the assumed *Fuel Throughput Volume per Station* is 600,000 GGEs. For fuels dispensed as a gas (e.g., CNG), the *Fuel Throughput Volume per Station* is instead a constant 400,000 therms, or 456,000 GGEs.¹⁹⁵

¹⁹⁵ 1 Therm = 100,000 BTUs and 1 Gallon of Gasoline = 114,000 BTUs = 1.14 Therms, therefore 400,000 therms * 1.14 therms/GGE = 456,000 GGE.