THE PROMISE OF ALTERNATIVE AUTOMOTIVE FUELS AND TECHNOLOGY

A JOINT ECONOMIC COMMITTEE STUDY

Chairman Jim Saxton (R-NJ)

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Abstract

➢There are many alternative ways to power vehicles that have a long history of practical application, from alcohol fuel used in auto racing to electricity that powers locomotives.

➢Fundamental advances in electronics, micro processing, and chemistry are poised to transform core engine and drive train technology in mass-produced vehicles, which essentially has not changed in a century.

➢Fuel is but a part of a system of automotive propulsion, and automotive technology will progress in as yet unpredictable ways. Therefore, one cannot identify an "optimal" fuel alternative to gasoline or diesel at this time. Indications are that the transportation sector will become increasingly flexible and tap diverse energy sources.

➢Brazil produces ethanol from sugar cane and mandates ethanol pumps at filling stations; South Africa has long made synthetic diesel from coal. These countries may or may not have made the right choice for their circumstances. Either way, they have not attracted a significant following. The experience of the telecommunications and information processing industry shows the benefit of allowing competing entrepreneurial visions and business models to sort out alternative technologies.

Joint Economic Committee
433 Cannon House Office Building
Washington, DC 20515
Phone: 202-226-3234
Fax: 202-226-3950

Internet Address:
http://www.house.gov/jec/

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INTRODUCTION

There are many different types of automotive fuel. Most were known and put to practical use when the automotive age began in the 19th century. The special requirements of the automobile put a premium on high fuel energy density and manageable fuel volatility. Gasoline and diesel fuel compare favorably to most alternative fuels in one or both of these respects and tend to maximize driving range, safety, and ease of refueling. Most importantly, petroleum-based fuel has been less costly to produce on an increasing scale than the alternatives. In combination with the enduring efficiency of the four-stroke piston engine under varied, everyday operating conditions, gasoline and diesel have come to dominate automotive engineering. Mass-produced vehicle engines are optimized for gasoline or diesel[1] and a dedicated refueling infrastructure has been built. The predominant engine designs and virtually ubiquitous filling stations give petroleum further competitive advantages over rival fuels. However, three major developments are prompting innovations that may challenge the preeminence of liquid petroleum-based fuels:

- ***Dependence on foreign sources of oil***. The use of oil as a political weapon by foreign governments was not a factor in the original fuel competition.
- ***Environmental impact***. Emissions were not an important consideration in the early days of automotive development and since then have been addressed without changing core fuel technology. Global warming concerns, however, are increasing pressure to curtail the use of traditional fossil fuels.
- ***Technological progress***. Advances in electronics, micro processing, and chemistry have enhanced various aspects of automotive engineering and are poised to transform the core of automotive technology. Engines and drive trains today are still mechanical devices using pistons, shafts, belts, and levers, set in motion by the combustion of the same basic fuel as a century ago.

2003 Jeep Grand Cherokee Engine. Photo courtesy of DaimlerChrysler.

[1] Gasoline engines accomplish fuel combustion through spark plugs that ignite the gaseous fuel mixture inside the cylinder heads. Diesel engines accomplish combustion without spark plugs through higher compression inside the cylinder heads, which generates sufficient heat to ignite the gas spontaneously. Optimal ignition timing and compression ratios vary with alternative fuels (as they do for different gasoline fuel grades).

Mass-marketed automobiles and fuels are at the cusp of technological changes that promise to reduce oil consumption and harmful emissions. Following is a review of the many fuels and technologies that have the potential to change how automobile engines function.

THE NATURE OF FUEL COMPETITION

Indications are that the transportation sector is not moving toward an "optimal" substitute for gasoline or diesel but toward diverse energy sources. Various alternative fuels already have made inroads as complements and supplements to the fuel supply:

- ***Additives and blends***. Alternative fuels in low concentration complement mainstay fuels without requiring changes to vehicles or separate fueling facilities. Blending the fuel supply can improve the performance of many vehicles in terms of combustion and emissions without raising costs prohibitively.
- ***Specialized applications***. Vehicles dedicated to a localized service area, such as fleets of city buses, can be fueled centrally. They avoid the need to build an extensive refueling infrastructure and acquaint the public with a new fueling process. At the same time, reduced emissions especially benefit densely populated urban areas.
- ***Flexible fuel use***. Alternative fuel vehicles intended for general use can retain the capability to run on gasoline or diesel. Flex-fuel vehicles have modified engines that can run on any combination of ethanol or gasoline, including pure ethanol. Bi-fuel vehicles have a dual fueling system and can run on liquid or gaseous fuels. Hybrid vehicles have two separate but coordinated propulsion systems, one conventional and one electric, the latter charged onboard with help from the former.

Alternative fuels are positioned to increase their market penetration, but which ones will do so depends on how technology advances. Several major fuel types can be produced by different methods and from different substances. Moreover, a given fuel can find use in different *systems* of vehicle propulsion. For example: Hydrogen can be produced from hydrocarbons or by splitting water; it can be carried as a gas in high-pressure tanks or converted from methane, natural gas, or even gasoline by a "reformer" onboard a vehicle; hydrogen can be burned in combustion engines; and it can be used in fuel cells that produce electricity to drive an electric motor. It is not yet clear what methods of producing various fuels will prove to be superior, what propulsion technologies will establish lasting advantages, or whether alternative technologies will combine to form synergies. The fuel competition is part of this larger competitive picture. **The competition to our current way of powering vehicles will come from alternative *systems* of automotive technology and fuel supply**. New systems will encompass changes to vehicle technology, fuel technology, the fueling process, and the fuel infrastructure and may recast how the automotive transportation sector is structured.

ALTERNATIVE FUEL CATEGORIES

The Department of Energy recognizes eight alternative fuels: alcohol fuels ethanol and methanol, fuels derived from biological materials, coal-derived liquid fuels, liquefied petroleum gas, natural gas, hydrogen, and electricity. We group these fuels into three categories—combustible liquids, combustible gases, and electricity—according to their approximate substitutability for gasoline and diesel in prevailing vehicle types. Liquids generally are closer substitutes for gasoline and diesel than gases are, and electricity, strictly speaking, is not a fuel. It bears emphasis, however, that technology can change the relative economics of alternative fuels. Within each group, major types of feedstock and production methods also are identified, as these relate to the source of supply and cost.

Combustible Liquids*	Combustible Gases*	Electricity
Biofuel	Liquefied Petroleum Gas	Fuel Cells
Ethanol-Crops, Cellulose	Natural Gas	Power Grid & Batteries
Methanol-Wood	Hydrogen	Hybrid Drive Train
Biodiesel-Vegetable oil,fat		
Synthetic Fuel**		
Diesel-Coal, N.Gas, Biomass		
Methanol-Methane		

* At normal temperature and pressure.
** Not including fuel made from synthetic crude oil derived, for example, from oil sands.

Combustible liquids. The term "biofuel" is applied to fuels derived from biomass. Production of biofuel typically entails either (1) fermentation of organic matter and subsequent distillation to obtain concentrated alcohol, or (2) conversion of oils from vegetables and animal fat. When biofuel is mixed in low concentration with conventional fuel, the resulting blends require little or no engine modifications and no segregation of the fuel supply. However, blends containing high concentrations of biofuel produced by these methods generally do require engine modifications and separate fueling facilities. Fuel also can be derived from biomass through gasification, in which case the fuel can be referred to either as "biofuel," based on the feedstock, or as "synthetic" fuel, based on the production method. Fuel produced from minerals always is considered synthetic. Alcohol can be produced from petroleum through refining. Diesel can be produced from coal through gasification. Synthetic diesel can be a perfect substitute for regular diesel. (It is not practical to produce gasoline synthetically from a source other than petroleum.)

Combustible gases. Gaseous fuel typically is derived from natural gas or the crude oil refining process, but it also can be produced from other minerals or biomass.[2] Gaseous automotive fuel requires only minor engine modification to optimize combustion, but it must be carried onboard a vehicle in either compressed or liquid form in reinforced tanks. Fueling is accomplished with sealed nozzles under pressure and generally takes longer

[2] During World War II, wood burning gasifiers were not uncommon both here and in Europe. Vehicles fitted with a gasifier ran their engines on the gas produced mostly from wood.

than filling a tank with liquid fuel. So-called bi-fuel vehicles have two separate fuel systems, one for gasoline or diesel, and the other for gas.

Electricity. Electric engines represent a complete departure from combustion engine technology, but combustible fuels still play a role in electric vehicle propulsion. Batteries or fuel cells power an electric motor that moves the vehicle. Battery-powered vehicles charged by the power grid draw on whatever energy source electric utilities employ. Hybrid electric vehicles run partially on electricity while still relying on a combustion engine. Fuel cells chemically produce electricity by reacting hydrogen with oxygen. Since hydrogen does not occur naturally by itself, traditional fuels may be used in its production. Electric and hybrid vehicles demonstrate most clearly that fuel is only a part of a system of automotive transportation that can be configured in many ways.

MAJOR FUEL ALTERNATIVES

Combustible Liquids—Biofuel

Biofuels can be produced domestically and therefore reduce reliance on foreign sources of energy. Biofuels generally also burn more cleanly than gasoline and diesel and, in particular, emit fewer greenhouse gases that are suspected of contributing to global warming. In some cases, some compounds can increase with biofuels.

Ethanol (ethyl alcohol) from food-crops. Ethanol was the fuel originally used in the four-stroke piston engine invented by Nicolas Otto in 1876. It was the closest competitor to gasoline in the beginning of the 20th century. The Ford Model T was a flex-fuel vehicle that could run on alcohol or gasoline. In the U.S., ethanol is grain alcohol made mainly from corn that is denatured (made unfit for human consumption). In Brazil, it is made from sugarcane.[3] Ethanol has been a gasoline additive for many years, as it increases the octane rating and reduces engine "knock."[4] It is also an oxygenate that typically reduces harmful hydrocarbon and carbon monoxide emissions by adding oxygen to gasoline, causing it to burn more completely.[5] Ethanol can be blended with gasoline in concentrations up to 10 percent (E10 gasohol) without requiring vehicle adaptation or separate fueling facilities. Higher concentrations, such as E85 (85 percent ethanol) which is being more widely introduced, require vehicle modifications reportedly costing as little as $100 per vehicle when made at the factory. Today there are approximately five million flex-fuel vehicles in the U.S. that can run on any combination of unleaded gasoline and ethanol.

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[3] Enzymes first must convert cornstarch into sugar for fermentation. Sugarcane does not require this step.

[4] Compression inside the cylinder heads of gasoline engines can cause premature fuel ignition, which gives off a knocking sound. Octane raises the compression at which the gas ignites and allows for properly timed sparked ignition. Ethanol has a high octane rating and therefore is helpful in reducing engine knock. (Lead also raises the octane rating of gasoline and was a standard additive for many years until it was banned due to its harmful emissions.)

[5] Emissions from ethanol blends are lower than from untreated gasoline but somewhat higher compared to gasoline blended with MTBE (see discussion of methanol on page 5).

Ethanol has significantly lower energy density than gasoline resulting in lower mileage, although engines designed to optimize combustion through timing and compression adjustments could mitigate some of the difference. Ethanol is corrosive. It mixes with water and reacts with metal, rubber, and fiberglass in ways that gasoline does not. (Alcohol is a solvent.) Hence, it is necessary to keep ethanol separate from gasoline supply facilities, which include filling station pumps, tanks, and refined products pipelines. In high concentration, ethanol thus requires additions to the existing supply structure. As a pure fuel substitute, ethanol's competitiveness with gasoline depends to a greater extent on relative production costs.[6]

Ethanol from cellulose. Nature produces alcohol by fermentation of sugar, which exists sufficiently in fruits, vegetables, and grains to have enabled man for ages to make wine, beer, and mash, and in turn extract concentrated alcohol through distillation. However, these sources require cultivation and have other uses. Ethanol would cost less if plants that require little or no cultivation (switch grass) and plant parts that have no other uses (stalks and stems) could be fermented efficiently. The cellulose in agricultural waste products and other "biomass" unfit for human consumption unfortunately does not contain the kind of sugar (or starch that converts to sugar) that feeds the fermentation process. Progress is being made, however, in extracting sugar from wheat and barley straw and producing cellulosic ethanol in pilot biorefineries. Construction of cellulosic ethanol plants on a commercial scale now is being proposed with federal help.[7] If biochemistry can turn organic waste into fuel on a commercial basis, it would enhance the fuel supply significantly.

Methanol (methyl or wood alcohol). Originally produced from the distillation of wood products, methanol today is produced principally from methane. Methanol has an extensive history as a fuel and a gasoline additive. Since 1965, the United States Auto Club has mandated the use of methanol and banned the use of gasoline in the races it sanctions. The ban was imposed after a crash at the Indianapolis 500 in which gasoline-powered cars burned more intensely than a methanol-powered car. Methanol also is used to produce MTBE (methyl tertiary butyl ether), which until recently was a common oxygenate for gasoline. In anything other than trace amounts, methanol is highly toxic. It mixes with water, and concern over groundwater contamination from leaking fuel tanks has led to the replacement of MTBE by ethanol as a gasoline additive.[8]

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[6] BP and Dupont are collaborating to introduce "biobutanol" an advanced biofuel that can be produced from the same kind of agricultural feedstock as ethanol as well as from petroleum. Butanol is a type of alcohol that is more similar to gasoline than ethanol in terms of energy density. In addition, it can be blended with gasoline at the refinery, can use the existing fuel infrastructure without major modification, and has the potential to be used in higher concentration than ethanol in unmodified vehicles. See Angel White, "Biofuels in Transportation," *Oil & Gas Journal*, October 16, 2006, p. 15.

[7] John J. Fialka and Scott Kilman, "Big Players Join Race to Put Farm Waste Into Your Gas Tank," *Wall Street Journal*, June 29, 2006.

[8] The Indy Racing League switched to a fuel mixture of 10 percent ethanol and 90 percent methanol in 2006; it plans to switch to an all-ethanol formula in 2007. Alcohol fuel is linked to car racing by the fact that it allows for high cylinder compression, which increases engine power, and production in farm

Biodiesel. In 1893, Rudolf Diesel invented the diesel engine. At the 1900 Paris Exposition his invention was fueled with peanut oil.[9] Vegetable oil has higher viscosity than petroleum diesel, but it can be used in nearly pure form with some engine modifications in modern diesel-powered vehicles. Today, alternative diesel fuel is produced from vegetable oils, including soybean and canola oils, animal fats, and cooking grease. Typically, the organically derived oils are transesterified, i.e., combined with alcohol (ethanol or methanol) in the presence of a catalyst to form an ethyl or methyl ester. Biomass also can yield diesel fuel via a completely different process, as described in the section entitled "Biomass-to-liquid" below. Biodiesel is sold in five to twenty percent blends with conventional diesel at about 450 filling stations in the U.S.[10] Biodiesel can supplement the conventional diesel supply with domestic sourced feedstock and emits fewer greenhouse gases than petroleum-based diesel. Dedicated production of foodstuffs for fuel, however, raises the same question for biodiesel as it does for ethanol, namely whether an increasing scale will lead to increasing cost.[11]

Combustible Liquids—Synthetic Diesel

Gasification of various kinds of feedstock has been possible since the Industrial Revolution and led to the use of so-called producer's gas long before it became feasible to pipe natural gas to market over long distances. Turning gases into synthetic fuel that is liquid at normal temperature and pressure is made possible by the "Fischer-Tropsch" process invented in the 1920s. Two German scientists, Franz Fischer and Hans Tropsch, used coal as their feedstock for gasification and produced fuel by their gas-to-liquids process that is suitable for use in regular diesel engines without modification.

Coal-to-liquid (CTL). In World War II, when crude oil was scarce, Germany supplied its military with synthetic diesel fuel made from coal. Since the War, South Africa has used this process on an industrial scale as it was isolated from the world community due to apartheid and has abundant (low quality) domestic coal reserves, but no crude oil. In the U.S., commercial application of the coal-to-liquids fuel process has been hindered by high production costs and environmental concerns, although it is the subject of government-funded research.[12]

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communities where it has a long tradition as a homemade fuel. Stock car racing has its origins in rural alcohol production and transport of "moonshine," illegally produced alcohol.

[9] "Transportation Fuels from Biomass: An Interesting, But Limited Option," George C. Marshall Institute, May 2006.

[10] Vehicle manufacturers usually recommend use of bends with no more than five percent biodiesel content. Biodiesel still lacks the fuel standards established for ethanol in terms of its exact composition and concentration. Also, see "Alternative Fuels and Advanced Technology Vehicles: Issues in Congress," by Brent D. Yacobucci, CRS, RL33564, July 20, 2006.

[11] Algae is a potential source of biodiesel, also referred to as "biocrude." Algal oil is similar to soybean oil but can be gown on marginal lands and is easier to process than many other forms of biomass. (Conventional crude oil is the product of decomposed prehistoric biomass, including algae.)

[12] For an overview of coal-to-liquids issues see Patrick Barta, "South Africa Has a Way to Get More Oil: Make It From Coal," *Wall Street Journal*, August 16, 2006.

Biomass-to-liquid (BTL). Gasifying cellulose or any other organic material and applying the Fischer-Tropsch process to the gas is an alternative to fermentation-distillation and transesterification. Gasification and gas liquefaction are long established industrial processes that have progressed over time and can produce large-scale synthetic fuel supplies, whereas the fermentation of organic material other than fruits and crops still awaits commercial application.

Natural gas-to-liquid (GTL). The Fischer-Tropsch process works best with natural gas. The company that produces oil from coal in South Africa, Sasol Ltd., collaborated with Qatar, co-owner of the world's largest natural gas field, to build the first commercial sized GTL plant.[13] (A smaller facility already existed in Malaysia.) Shell, ExxonMobil and ChevronTexaco have committed $20 billion to build GTL facilities in Qatar. GTL is an ultra clean automotive fuel that contains no sulfur, making it an ideal blending agent as the U.S. and Europe tighten emissions standards on diesel.

GASES[14]

Gases burn more cleanly than gasoline or diesel, which is their main attraction as a fuel. Gas-powered vehicles are the most common alternative fuel vehicles in the U.S. They find use mostly in fleets. Natural gas powered city buses, identifiable by their raised roofs, are an example. While the U.S. has substantial natural gas reserves, large increases in consumption would raise the prospect of increased imports. Nevertheless, liquefied natural gas (LNG) is becoming more readily available in different parts of the world and may form a global market less prone to foreign manipulation than crude oil.

Liquefied petroleum gas (LPG). LPG is by far the most commonly used alternative fuel. Also known as propane, LPG is a by-product of natural gas processing and petroleum refining. Because it is a gas at normal temperature, the mixture must be liquefied and stored under pressure for use in vehicles. There were about 194,000 LPG vehicles out of 230 million gasoline and diesel-powered vehicles in 2004. Domestic consumption amounted to about 242 million gasoline equivalent gallons. LPG tends to be used in light and medium-duty vehicles that are customized rather than mass-produced. There were 3,451 refueling sites in the 50 states at the end of 2004.

Natural gas. Natural gas consists mainly of methane, but also contains ethane, propane, butane, and pentane. Onboard vehicles it is stored either as compressed natural gas (CNG) or liquefied natural gas (LNG). Natural gas is the second most used alternative fuel with 170 million gas equivalent gallons consumed in 2004.[15]

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[13] Russell Gold, "In Qatar, Oil Firms Make Huge Bet on Alternative Fuel," *Wall Street Journal*, February 15, 2005.

[14] The information presented is obtained largely from "Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues," by Brent D. Yacobucci, CRS, RL30758, January 7, 2005.

[15] Fuel ethanol is consumed in greater quantity than CNG, but as an additive to gasoline (gasohol) is not considered an alternative fuel.

There were about 146,000 natural gas vehicles and about 960 public refueling stations (900 for CNG and 60 for LNG) in 44 states, mostly in California. Refueling systems are available for home installation, but the fueling process is slow and requires operator training.

Hydrogen.[16] Hydrogen is the most abundant element in the universe and can be produced from virtually any primary energy source. It can be produced either by processing hydrocarbon fuels or splitting water. Most hydrogen is produced from natural gas (methane) at oil refineries and chemical plants. Hydrogen can be burned in combustion engines. Various car companies are experimenting with hydrogen as a combustible fuel for contemporary automobiles.[17]

ELECTRICITY

Electrical power is clean and efficient. Electrical drive systems transfer energy far more efficiently than the internal combustion engine and the mechanical drive train. 80 to 85 percent of the energy contained in gasoline is lost in a conventional vehicle; just over 12 percent reaches the wheels. By contrast, 75 percent or more of the energy in a battery reaches the wheels of an electrically powered vehicle. Electrical drive systems have been employed by locomotives and 300-ton mining trucks but until recently were too large and costly for an automotive platform.[18] The amount of electronic equipment in automobiles has been increasing. The share of a vehicle's production cost attributable to software and electronics is expected to reach 40 percent by 2010.[19] As advances shrink the size and cost of power supplies, semiconductor switches, sensors and microprocessors, automotive electronics will move beyond accessories and take over the drive train.[20]

Fuel cells. Electric vehicles (EV) are propelled by an electric motor fed by fuel cell or battery power. A fuel cell vehicle generates electricity by chemical reaction using non-conventional fuel that is stored onboard or derived through onboard reformation of conventional fuel, although development of the latter is no longer widely pursued. Most fuel cells use pure hydrogen, but some can use hydrogen-rich fuels (hydrocarbons). A fuel cell is an electrochemical device that uses hydrogen and oxygen to produce electricity and makes continuous use of the input fuel. It does not merely store electrical energy as batteries do. Individual fuel cells have low output power and are arranged in stacks to generate the required voltage.

[16] "A Hydrogen Economy and Fuel Cells: An Overview," by Brent D. Yacobucci and Aimee E. Curtright, CRS Report RL32196, January 14, 2004.

[17] James Mackintosh, "Hydrogen is New Hope to Get Gas-Guzzlers Off the Road," *Financial Times*, June 8, 2005. Also, see "Advanced Technology Vehicles, Driving Innovation," (undated publication) Auto Alliance, www.autoalliance.org.

[18] Komatsu builds a 300-ton truck, the 930 E; the German-built Liebherr T282 B has a payload of 380 tons. Both are diesel-electric, i.e., propelled by electric motors that are powered by a diesel engine.

[19] "IBM and BMW Group Team to Capitalize on Shift Towards Software and Electronics-based Vehicle Innovation," IBM press release, September 22, 2003.

[20] Peter Huber and Mark Mills, "A Power Portfolio," *Forbes*, April 11, 2005.

Batteries. So-called plug-in electric vehicles carry a battery that is charged by connecting it to the power grid when the vehicle is parked. The main challenge presented by electricity is storing it, and advances in batteries are taking place. Earlier electric cars ran on lead-acid and nickel metal hydride batteries, whereas the new generation uses lithium-ion batteries similar to those in laptops and cell phones.[21] The fuel ultimately supplying the energy for locomotion is whatever power plants use to generate electricity, which could include any number of conventional and non-conventional sources. To the extent that the power supply for individual mobility is no longer specialized but merges with the stationary power supply, all of the advances underway in the energy field—for example, with respect to clean coal, and nuclear, wind, or solar power—can potentially benefit the transportation sector. A Department of Energy study found that off-peak capacity in the existing electric power system could fuel 84 percent of the 220 million vehicles in the U.S., if they were plug-ins and charged overnight.[22]

Hybrids. Hybrid electric vehicles (HEV) already have entered mass production (about 212,000 were sold in 2005)[23] and address the recharging issue by carrying an internal combustion as well as an electric engine. The battery powering the electric motor is charged by the conventional engine and the energy released when the brakes are engaged. Depending on the configuration, the two engines may run alternately or simultaneously. For example, the electric motor may be engaged at low speeds or one engine may supplement the other when a boost is needed for accelerating or traveling uphill. Plug-in hybrids with larger batteries that also can be charged off the power grid are attracting growing interest.[24] This type of HEV relies mainly on electric power and uses the combustion engine as backup, for example, during long distance travel. According to the Department of Energy study cited above, current batteries can easily hold the necessary charge for the national average round trip commuting distance of 33 miles per day.

OTHER DEVELOPMENTS

A recent RAND Corporation study found that the cost of renewable energy sources has been declining and projects a further cost reduction of 20 percent or more by the year 2025 if the trend continues. Renewable sources could produce 25 percent of the electricity and motor vehicle fuels used in the United States by 2025 at little or no additional cost compared to fossil fuels, assuming prices for the latter remain high and

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[21] Jennifer Saranow, "The Electric Car Gets Some Muscle," *Wall Street Journal*, July 27, 2006. Tesla Motor Corporation has been taking orders for the mid-2007 delivery of an electric-powered roadster said to have a range of 250 miles on a single charge, reach a top speed of 135 mph, and accelerate from zero to 60 mph in four seconds. Also, see "Electric Cars Merit New Look," USA Today, August 7, 2006.

[22] "Mileage from megawatts: Study finds enough electric capacity to 'fill up' plug-in vehicles across much of nation," Pacific Northwest National Laboratory press release, December 11, 2006, http://www.pnl.gov/news/release.asp?id=240.

[23] "Discover The Alternatives—A Progress Report on Enhancing Energy Security," The Alliance of Automobile Manufacturers, June 2006.

[24] See Sholnn Freeman, "GM Pledges to Make Plug-In Hybrid Vehicle," *Washington Post*, November 30, 2006.

the cost of producing renewable energy continues to decline. Renewable sources currently provide about six percent of all the energy used in the United States. The study does not postulate an optimal mix of renewable technologies or attempt to make claims about the probability of different outcomes for energy use.[25]

Petroleum-based fuel technology is not standing still. In particular, diesel, which traditionally pollutes more than gasoline, has benefited from "clean diesel" engine technology and is widely used in Europe. Diesel engines achieve about 30 percent better fuel economy than gasoline engines. More than half of all passenger vehicles sold in Europe this year likely will be diesel-powered.[26] Two new technologies for lowering diesel emissions further are under development, one by U.S. and European manufacturers, and the other by Honda. Vehicles featuring these new diesel technologies are planned for introduction to the U.S. market by the end of this decade.[27]

CONCLUSION

Attaining energy independence and a clean environment are critical objectives for policymakers. Several competing technological paths could take us there. The automotive industry finds itself in a state not unlike that of its early days. In 1906, electric vehicles powered by lead-acid batteries outsold vehicles with combustion engines, and gasoline competed neck and neck with ethanol. Once again, the race is on among different technologies and the outcome is unpredictable. Many fuels are technically viable alternatives to gasoline and diesel. More than theoretical substitutes, several alternative fuels have proven real world applications: racecars use ethanol and methanol; significant numbers of cars and buses powered by gaseous fuel are in daily operation; mining truck and train engines employ electric power; and hundreds of thousands of hybrid electric vehicles with electric drive trains are on the roads. In addition, research and development is taking place that has the potential to deliver breakthroughs in a number of technologies.

The effort necessary to develop alternative energy sources is sometimes compared to the government-led drive that brought success in the Manhattan Project and the Moon Landing. However, these were engineering challenges, not resource allocation challenges. The fuel question presents us with many technological options, and relative cost matters greatly for long-term success. Some countries have mandated adoption of a certain path, but they have not inspired much imitation. South Africa makes synthetic

[25] "Impacts on U.S. Energy Expenditures of Increasing Renewable Energy Use," by Mark A. Bernstein, Jay Griffin, and Robert Lempert, RAND Corporation, 2006.
[26] Matt Vella, "Diesels We Want But Can't Get," *BusinessWeek* online, http://www.businessweek.com/print/autos/contentapr2006/bw20060427_580559.htm.
[27] Norihiko Shirouzu, "Honda to Pitch Diesel to Americans," *Wall Street Journal*, September 25, 2006. Interestingly, Honda also is a leading producer of gasoline-electric hybrids and recently announced major improvements in its fuel cell technology; see "Honda Shows Off Fuel Cell, Diesel, Ethanol," MSNBC.com; http://msnbc.msn.com/id/14999781/print/1/displaymode/1098/. For new low-sulfur diesel models by Mercedes and Volkswagen, see Gina Chon and Stephen Power, "Cleaning Up Diesel's Image," *Wall Street Journal*, November 29, 2006; and J.P. Vettraino, "The Day After," *Autoweek*, November 20, 2006.

diesel from coal, Brazil ethanol from sugar cane.[28] Sweden now requires many of its gas stations to offer ethanol (imported mostly from Brazil). Countries that mandate a particular fuel substitute risk missing the benefits of experimentation and competition. They may appear to gain an advantage initially, but also may prove to be on a detour from the path to an optimal mix of technologies and fuels.

The experience of the telecommunications industry illustrates this point. Since the break-up of the Bell System in 1982, the industry has developed on multiple fronts and formed a new information processing and transmission sector vastly superior to the old telephone network. Though the alternative technologies all existed prior to 1982, no one could foresee at the time how they would develop and combine to bring the multitude of new services and enormous efficiency gains we now enjoy. It took competition among different technologies, visions, and business models to form the digital information age we now live in. It will take a similar process to bring us the new automotive age.

Theodore W. Boll
Senior Economist

[28] Brazil's pro-ethanol policies were first instituted 30 years ago. Ethanol pumps were mandated after the oil price spike of 1979. Brazil's progress toward energy independence, however, is based mainly on its increased domestic crude oil production. See "Country Analysis Briefs—Brazil," Energy Information Administration, August 2006, and "Considering Brazil's Energy Independence," by Jaclyn Fichera and Jeff Kueter, George C. Marshall Institute, September 2006.