Alternative Fuels and Vehicles: What’s the Selling Point?

Government regulations on alternative fuels and vehicles haven’t succeeded in making them popular. Is there anything that will? Wolf H. Koch, PhD reports on where the issue is today.

Fossil fuels in the lead for the primary fuel source
In 1998, in two columns in PE&T (September and December), Wolf Koch discussed the status of alternative transportation fuels in terms of the US national energy policy and various legislative activities such as the 1990 Clean Air Act Amendments, the Energy Policy Act of 1992 and the Transportation Equity Act for the 21st century. He also described various state activities, especially California’s redefinition of zero-emission vehicle requirements, which were adopted by the California Air Resources Board in November 1998. In this article, Wolf Koch discusses the use of conventional alternative transporation fuels: compressed natural gas, liquified petroleum gas, alcohols and electricity. He also describes current projects using natural gas and discusses future alternative fuels, such as advanced battery technology, hybrid vehicles and fuel cells.

Photo 1: The Chicago Transit Authority (CTA) has the world’s first zero-emission, fuel cell buses in service. These buses are powered by compressed hydrogen gas. Photo courtesy of the CTA

What is the US policy on alternative fuels today? Thus far, all US legislative initiatives have focused on one of two areas: increasing our energy self-sufficiency and decreasing transportation-related emissions. In view of the continuing low prices of oil, annual energy imports have increased. At the same time, the current administration has not implemented key provisions in the Energy Policy Act of 1992 (EPACT), even though the Act itself is old enough to be attending grammar school.

Legal loopholes

In fact, our dependency on foreign energy has increased steadily since EPACT became law—to a large extent because of a loophole in the law that requires the acquisition of alternative fuel vehicles, but not the use of alternative transportation fuels (ATFs). Fleet operators can purchase alternative fuel/gasoline vehicles, operate them on just gasoline and meet the legal requirements of EPACT. While EPACT originally claimed that light-duty vehicle fuel consumption would consist of 10 percent ATFs by 2000 and 30 percent by 2010, the General Accounting Office recently estimated that the ATF portion of fuel consumption will be 0.4 percent by next year and only 3.2 percent by 2010 (GAO/RCED-98-268).

On the environmental side, there has been much rhetoric about improving air quality, but little discussion as to the actual effects of large-scale alternative fuels implementation on our volatile organic compound (VOC) inventory. The 1990 Clean Air Act Amendments called for a 15 to 25 percent reduction in VOCs and air toxics. However, a report entitled Commentary on Alternative Transportation Fuels, released by the American Institute of Chemical Engineers (AIChE) in September of 1997, claims that vehicles and other mobile sources contribute only about 25 percent of the total VOCs and air toxics, while stationary and natural sources contribute the rest.

Of the mobile emissions, 15 percent are evaporative and 10 percent are from vehicle tailpipes. The latter 10 percent are split 60/40 between unregulated heavy-duty vehicles and regulated automobiles and light trucks. Significant VOC reductions can only be achieved by reducing evaporative losses, yet most regulatory initiatives tend to focus on the four percent total of VOC losses resulting from regulated tail pipe emissions.

In all fairness, I must mention that a number of ATF initiatives are directed at the unregulated heavy-duty market: for instance, as discussed on page 36, a number of local requirements have significantly increased the use of compressed natural gas (CNG) and liquified natural gas (LNG) in municipal bus fleets and other vehicles.

Photo 2:
Conventional fuel systems are normally underground, whereas CNG systems are almost always aboveground. This brings up additional concerns for the proper management of a CNG facility. Photo courtesy of Shell Oil

Conventional ATFs

The AIChE study represents one of the most comprehensive recent comparisons of conventional fuel alternatives. Gasoline and reformulated gasoline (RFG) were compared to ethanol, methanol, electric, CNG and liquid propane gas (LPG).

This comparison was done on the basis of economic and environmental factors, energy dependence and efficiency, as well as infrastructure requirements and driveability. The study did not address hybrid vehicles, fuel cells or LNG. In addition, the analysis of electric vehicles is based on lead-acid battery technology.

Of particular note in the AIChE results is that a relative ranking of ATF depends heavily on the relative rankings assigned to the various factors, especially environmental and strategic ones. The data presented is extensive (the study is available at the AIChE web site at www.aiche.org) and broken down into a preference for economic, environmental or energy dependence factors. The ranking is shown here in order of preferences, with average ratings on a scale of one (worst) to five (best):

Fuel Perfomance Indices	
CNG	4.1
LPG	4.0
RFG	3.8
Gasoline	3.7
Electric	3.2
Methanol	3.1
Ethanol	2.8

Source: American Institute of Chemical Engineers 1997 Study entitled Alternative Transportation Fuels: A Comparative Analysis

• CNG: Compressed natural gas represents the most promising of the alternatives. It is low in cost and has low emissions. While it requires additional infrastructure and costs for vehicle conversions, those costs are subsidized at the local and federal levels. Natural gas is considered the most important interim ATF. Most ATF scenarios consider natural gas to be phased in as the ATF of choice, to be replaced by other technologies as they mature. Alternatives in the use of natural gas will be discussed later.

• LPG: While liquid propane gas appears to be an attractive ATF, widespread use will surely increase its price. LPG (commonly called propane) represents a valuable feedstock for the petrochemical industry with current supplies and demand in balance. The demand/price scenario of LPG can be seen every cold winter when the price of LPG as a rural heating product increases dramatically. Because of its widespread use in rural heating, LPG has become the preferred fuel for that industry. Current estimates for operational CNG vehicles approach four million worldwide.

• Gasoline: Gasoline and RFG ranked lower than CNG and LPG because of low rankings for environmental and energy dependence factors. They do, however, excel in existing infrastructures.

• Electricity: While electricity was one of the least favored fuels in the AIChE study, its relative ranking compared to alcohols depended on how its environmental benefits were calculated. When emissions were based on average utility emissions, electricity ranked above alcohols. However, when the study considered incremental electricity to be generated from coal, it became last in the overall rankings because of additional emissions.

• Alcohols: Methanol and ethanol have a poor net energy efficiency and lower consumer acceptance ratings. They do, however, provide energy security, but lack infrastructure availability. As MTBE is phased out in some RFG markets (such as California), alcohols may become the preferred oxygenate source and enjoy an increased market share as a blending component rather than a neat fuel.

Figure 1: LNG TO CNG converter. Courtesy of Wolf Koch. US patent number US 5,409,046

Natural gas as an ATF

While the AIChE study considered primarily passenger and light-duty vehicles, natural gas is beginning to make inroads as a fuel for heavy-duty vehicles, both as compressed and liquefied natural gas. The Los Angeles Metropolitan Transportation Authority currently operates 590 CNG buses, has 550 on order and is under court order to purchase 530 additional units. The new Denver airport supports all service functions with natural gas vehicles and operates an impressive array of compressor stations around all airport facilities.

There are currently many developmental activities directed towards reducing the cost of compressing and dispensing natural gas, as well as improving vehicle conversions and vehicle fuel storage. Argonne National Laboratory, for instance, is working on a project to reduce the cost of compression by half through the use of novel rotating compressors. Aurora Technology started similar compressor development seven years ago.

For more information on conventional CNG fueling technology, read Shell Oil's Glen Marshall's two-part article in PE&T in the July and August 1998 issues.

LNG demonstration projects have been started in virtually every country. Such projects cover trucks, buses, locomotives and even an experimental project for aircraft fuel use in Russia. The transfer of techological information from these efforts may affect future domestic projects.

A recent study by the Department of Energy (DOE) and the Brookhaven National Laboratory (BNL) concluded that the key to making LNG a viable alternative to diesel fuel is the development of more efficient liquefiers. An increase in overall efficiency of five percent is projected to provide LNG at a competitive price of about $0.40 per gallon (SAE Paper No. 981919, The Clean Fuels Report, Nov. 1998). DOE and BNL are coordinating a large scale demonstration project with 123 heavy-duty LNG vehicles operated by the US Postal Service in Texas.

The main advantage of LNG over CNG is transportability and higher energy content per volume. Liquefaction to LNG is one method of utilizing remote natural gas at oil fields or land fills. This gas may be used to generate electric power, if the power grid infrastructure exists; otherwise the gas is often flared (burned).

To be used as a fuel, LNG may be vaporized and dispensed into vehicles as CNG. A typical vaporization train, described in US Patent 5,409,046, is shown in Figure 1 (page 33).

Alternatively, LNG may be transferred to cryogenic fuel tanks on the vehicle or locomotive and vaporized prior to injection into the engine cylinders.

Figure 2: A hybrid electric vehicle with a parallel or "power assist" configuration

Battery-powered vehicles

Battery-powered vehicles have been available longer than gasoline-powered ones. However, two disadvantages have kept them from having the market penetration of their competitors: (1) a short driving range and (2) significant reduction in battery power output at cold temperatures.

The first large-scale commerical battery-powered car was General Motors' EV-1. Available in 1997 in California and Arizona on a $500/month, three-year lease (with no purchase options), EV-1 is a capable two-passenger vehicle, exhibiting outstanding performance and comfort, with a 70-90 mile driving range.

PE&T columnist Ed Hasselmann provided me with a much appreciated ride in his EV-1 in early 1997. He mentioned that the EV-1 was significantly more economical than a similar battery-powered car. At a cost of 6 cents/kwhr, an electric car should operate at an equivalent gasoline price of about 45 cents/gallon. Unfortunately lead-acid batteries have power limitations at low temperatures and a 70-mile range requires frequent recharging.

In the long term, several promising technologies may prove to be commercially viable. Mercedes is currently testing their sodium-nickel-chloride Zebra battery, operating with an energy density of double that of lead-acid batteries. Another important feature of the Mercedes battery is that it operates around 300 degrees C and requires cooling; thus it is unaffected by ambient temperature fluctuations. A test vehicle has logged almost 70,000 miles over three years. The battery is designed for a service life of 100,000 miles over 10 years. Installed in an A-Class subcompact, the battery provides a top speed of 77 miles per hour and a range of 120 miles.

Photo 3: In its fuel cell car Necar 3, Mercedes uses methanol as its source for hydrogen for the fuel cell. Photo courtesy of Mercedes Benz

Another interesting, but yet uneconomical, development is the use of a lithium-ion battery in a Nissan Altra. The energy density of lithium-ion batteries is three times that of lead-acid. Since Nissan is testing the vehicle in Japan, it plans a limited introduction there but has not announced a price.

Henry Oman has made an interesting analysis of potential infrastructure requirements for electric cars: living in a society that thrives on instant gratification, he assumed that electric vehicle “filling stations” needed to charge batteries in about five minutes. A car with 100 ampere-hour 312-volt batteries would require 374 kw of power. Six cars charging simultaneously would need more than two Megawatts of power (IEEE AES Systems magazine, April 1999). Two Megawatts of power are comparable to the power requirements for 100 families, operating at maximum load.

Like most things in life, battery recharging will have to be a compromise. Off-peak slow charging will most likely prove to be the most economical alternative.

Figure 3: A hybrid electric vehicle with a series or “range extender” configuration

Hybrid electric vehicles

These vehicles, as the name implies, are not true electric vehicles. Generally, they combine a complex drive train that includes:

• a small engine to charge batteries and provide peak power;
• an electric motor to provide low speed power and assist during peak power requirements; and
• regenerative braking, which also generates electric power to charge batteries.

While these vehicles are not zero emissions vehicles, most will be able to exceed ultra low emissions vehicle standards. Two types of power trains are being commercialized. The parallel version has a direct mechanical connection between the engine and the wheels as well as the electric motors and the wheels. Series systems have no link between wheels and engine and are propelled by electric motors only. **(See Figures 2 and 3.)**

Several manufacturers have announced commercial passenger hybrids during the 2000 model year. In addition, there are many pilot demonstration projects on light- and heavy-duty trucks and buses using diesel, CNG and LPG as fuel in combination with electric propulsion.

Toyota and Honda have both announced plans for a US introduction this fall. For Toyota, it is the Prius, a five-passenger vehicle based on the 1.5 liter Tercel engine. For Honda, it is a parallel two-passenger car using a one-liter, three-cylinder VTEC engine. Both vehicles will use nickel-metal-hydride batteries. Toyota has already been marketing the Prius in Japan, where 10,000 units have sold for under $20,000 each. Both vehicles are claiming performances similar to other subcompacts. Toyota claims fuel consumption of 66 miles/gallon; Honda claims 70 miles/gallon. Toyota expects to sell about 20,000 hybrids outside Japan next year. Audi has also announced a two-door parallel hybrid version of its A-4 model, powered by a diesel engine.

Fuel cell vehicles

Fuel cell technology is already more than 100 years old. However, commercial uses were first developed by NASA for space applications.

Several years ago, Ballard Power Systems was one of the first pioneers to reduce this expensive space technology to everyday applications. Mercedes Benz, and later Ford, made major investments in Ballard and have promised to introduce significant numbers of fuel cell vehicles into the market by 2005.

Many of today's fuel cell vehicles, and most likely those developed over the next two decades, will rely on fossil fuels to generate hydrogen. Hydrogen is then used in a proton exchange membrane fuel cell to generate electricity **(see Figure 4).**

Figure 4: Proton exchange membrane fuel cell diagram

Today's prototype fuel cell projects use natural gas, methanol, gasoline or diesel to generate hydrogen—or, as in the case of the largest fuel cell demonstration project, use compressed hydrogen directly. Fuel cell operations are environmentally benign; hydrogen is combined with oxygen to generate water.

In view of our previous description of hybrid electric vehicles, most future fuel cell vehicles will be hybrids that generate hydrogen from other hydrocarbon fuels through a catalytic reformer. This is a compact, efficient chemical reactor that converts the fuel to hydrogen. Efforts in catalyst and reformer technology development are geared at optimizing hydrogen generation while minimizing emissions.

Daimler-Chrysler has recently unveiled its fourth generation fuel cell car, the Necar 4 (New Electric Car). While the first generation was primarily a prototype, successive developments have logged extensive test mileage: Necar 2 was fueled with compressed hydrogen, stored on the vehicle roof; Necar 3 uses a methanol reformer and has a 240-mile range with an 11-gallon tank (see Photo 3).

The most recent Necar 4, an A-Class subcompact fueled by liquefied hydrogen, is capable of a top speed of 90 miles/hour with 280-mile range.

Every major auto manufacturer has announced similar fuel cell vehicle programs. Developmental costs for these projects are estimated to approach $2-3 billion over the next few years. Daimler-Chrysler has projected fuel cell engines to be competitive with gasoline engines when production levels reach 250,000 units annually.

The most ambitious current demonstration project is underway in both Vancouver and Chicago. Each city has three buses operating on 275-horsepower fuel cells that are fueled via compressed hydrogen cylinders mounted on the bus roofs (see Photo 1 on page 34). The buses have a 240-mile range and will be driven for 1,000 miles without passengers for testing. They will then be integrated into each city's bus fleet.

Prognosis for the future

Two years ago, Peter Schwartz, a strategic planner credited with scenario planning, co-authored a study entitled "The Long Boom" with Peter Leyden (Wired, July 1997). The article draws on past achievements and projects future developments over the next two decades for major industries.

Rather than bore the reader with my personal musings, I want to summarize and paraphrase Peter Schwartz's projections for the transportation sector:

Around the turn of the century, electric hybrids achieving 80 miles/gallon will be introduced by major automakers. By 2005, hybrids using technology from aircraft onboard electric systems burning natural gas will be available. Hydrogen fuel cell hybrids will replace this technology by 2010. Fossil fuels will remain as the primary fuel source for at least 50 years, but by 2020, most new vehicles will use hydrogen- powered hybrid drive trains and have very low emissions.

The most important prognosis from the study is that hybrid vehicles will dominate the future market place—not because of the regulatory environment, but because they will be sporty, fast and fun to drive. Auto companies will build them because they will be profitable. What this prognosis means to the petroleum equipment industry will result in as many opinions as there are debaters. However, with changing automobile technology, the fuel delivery infrastructure will certainly have to undergo changes in the next two decades.

Abbreviations	
AIChE	American Institute of Chemical Engineers
ATF	Alternative Transportation Fuel
BNL	Brookhaven National Laboratory
CNG	Compressed Natural Gas
CTA	Chicago Transit Authority
DOE	Department of Energy
EPACT	Energy Policy Act (1992)
GAO	US General Accounting Office
IEEE	Institute of Electrical and Electronic Engineers
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MTBE	Methyl Tertiary Butyl Ether
NASA	National Aeronotics and Space Administration
RFG	Reformulated Gasoline
SAE	Society of Automotive Engineers
TEA-21	Transportation Equity Act for the 21st Century
ULEV	Ultra Low Emission Vehicle
VOC	Volatile Organic Compounds
ZEV	Zero Emissions Vehicle

Wolf Koch is founder and President of Technology Resources International, Inc. in Sterling, IL. He provides consulting services in technology evaluation, development and testing, and litigation and expert witness support. He managed fuel distribution and service station technology at a major oil company for many years and is an avid motorcyclist and sailor. He is a frequent contributor to Petroleum Equipment & Technology and PE&T online and can be reached at Technology Resources International, Inc. 1314 Mineral Springs Rd. Sterling, IL 61081 Web site: www.t-r-i.com Phone: 815 626 7110 Fax: 815 626 7126