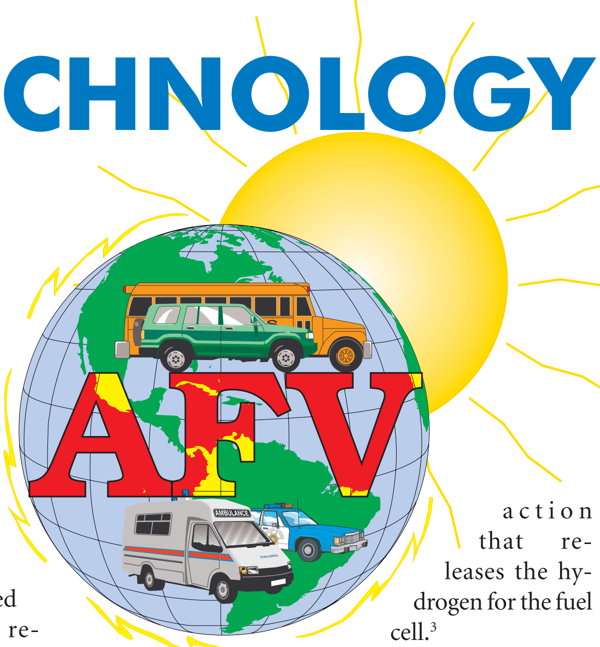
ALTERNATE FUEL TECHNOLOGY

Hydrogen: The Ultimate Alternate?



In the previous *ASE Tech News* (Winter 2001) we discussed fuel cells and fuel cell hybrid-electric vehicles (FCVs), but FCVs can't be driven without fuel. Considering our nation's energy concerns, now's a good time to learn more about the benefits of hydrogen. The conversion to hydrogen for powering both on and non-road transportation is said to be our nation's "ace-in-the-hole."

Like natural gas, pure hydrogen is being burned in internal combustion engines (ICE). Hydrogen can also be mixed with natural gas (methane) to create Hythane® fuel for improved ICE clean-air benefits. Some say that many different hydrogen engines will be in use in the future, but hydrogen's motorfuel attributes are best realized when "reacted" in the fuel cell engine.

A Hydrogen Infrastructure

How and where will motorists be able to find a hydrogen "gas" station? Options include:

A. Produce gaseous hydrogen (H_2) or liquefied hydrogen (called LH_2) fuel from hydrogen-rich materials (feedstocks) off-board at centralized locations or at the refueling site; store pure gaseous or liquefied hydrogen *on-board* the vehicle

B. Ship hydrogen-rich feedstock(s) to refueling sites; store feedstock(s) on-board the vehicle for use in a "reformer" to extract hydrogen fuel as needed

C. Ship/store pure hydrogen on-board within a variety of non-conventional media

To avoid contamination, most fuel cell stacks must use pure hydrogen (see Winter 2001 *Tech News*).

Sunline is road testing this ZE Bus (zero emissions) powered by a hydrogen fuel cell electric engine. Other companies are running similar tests around the country.

Delivering pure hydrogen (option A) requires an entirely new hydrogen infrastructure. Presently, 95% of our nation's hydrogen is extracted by industry from natural gas (CH_4) through steam "reforming" (or other means) for private use. For vehicle use, hydrogen could be similarly produced and shipped using pipelines, railcars and trucks for storage in high-pressure tanks at refueling sites. Already, several private pure-hydrogen producing/dispensing "gas stations" have been built. As with natural gas, gaseous hydrogen can be compressed and stored for fast-fill or timed-fill dispensing.

Reforming

Gasoline or diesel fuel could be used to produce hydrogen at refueling sites. Those against the idea of reforming fossil fuels say it creates pollution and that supplies are limited and expensive to produce and protect. Also, impurities like sulfur and carbon must be completely removed during reforming or the fuel cell stack will be ruined. Other hydrogen-rich feedstocks (natural gas, propane, ethanol/methanol, gasoline/diesel, coal, ammonia, synthetic gas and others) are suitable for reforming but would require new distribution channels. Alcohol-based feedstocks like ethanol or methanol are easier to reform into hydrogen. Plus, such feedstocks — being made from corn, cellular waste products or energy crops, sewage, landfill and municipal waste, etc., —are renewable.

Rather than reforming to H_2 at refueling sites, some favor on-board reforming (option B). Those opposed to reforming point out that an on-board reformer adds weight, bulk, complexity and expense to each vehicle. Proponents of reforming say the near-term introduction of reformate H_2 can pave the way for pure hydrogen FCVs once a refueling infrastructure is in place. GM, Toyota, Renault, VW, BMW and others seem to lean towards reforming of gasoline; DaimlerChrysler, Ford, Nissan and others are trying methanol. Some carmakers have tried compressed or liquefied H_2. At present it seems none have locked-in on any one H_2 storage and delivery method.

Synthetic fuels may also be used for producing hydrogen for fuel cells: economic production of H_2 might be accomplished through the photosynthesis of green algae, which can then be stored in carbon nanotubes built into the automobile. One company has announced the success of using aluminum oxide for FCs with reportedly superior energy output compared to pure hydrogen.

Electrolyzing Water

Where economical, an electrolyzer can be used to split fresh water (H_2O) into hydrogen and oxygen. Electrolyzing typically takes a lot of energy, so it's preferably done where sustainable electric power (from hydro, solar, or wind turbines etc.) is available. At Sunline Transit and at Honda in Southern California, solar arrays provide the needed energy for producing and compressing hydrogen.[1] Another company claims to use tap water or salt water, requiring only modest amounts of electricity, and says the process can be made portable.

From this …

… to this!

Sunline Transit uses solar panels and an electrolyzer to split water (H_2O) into hydrogen and oxygen. The hydrogen fuels Sunline's fuel cell and Hythane® buses.

Direct Methanol Fuel Cells

Direct fuel cells may use methanol (or ammonia, or other feedstocks) introduced directly into the fuel cell stack, thus allowing liquid-fuel tanks on-board instead of bulky/heavy hydrogen tanks or reforming apparatus. Direct methanol fuel cells are costly and are not as efficient as pure hydrogen FCs, but are still considered emission free engines.

On-Board Pure Hydrogen Storage

Gaseous hydrogen can be stored on-board in tanks. Some decry the idea as a serious public safety hazard, citing the infamous Hindenburg incident.[2] In truth, gasoline is perhaps more dangerous. Hydrogen is the simplest element (one proton and one electron) yet powerful, burns colorless, and has a *wide* range of flammability (3–78%). Hydrogen gas dissipates quickly into the atmosphere, rather than "puddling" as do gasoline vapors. Pure hydrogen is admittedly difficult to store because its tiny molecules weep through normal materials and escape, and over time hydrogen can crystallize metal. Yet today, gaseous hydrogen can be stored at pressures of 10,000 psi, providing an acceptable vehicle range of around 400 miles. Conformable composite H_2 cylinders have evolved from years of research and development, and manufacturers have a proven safety record.

Instead of high-pressure gaseous storage, hydrogen may be chilled to ~minus 423 degrees F as a liquid (known as LH_2) for storage in insulated tanks similar to those used for liquefied natural gas. H_2 is very dense, and is especially suited for high mileage routes where trucks, buses, etc. are likely to use the fuel before it warms up and boils off.

Other H_2 Storage Methods

Hydrogen may be stored in "containers" (option C), such as metal hydrides or in carbon nanofibers. While such media are said to allow for dense storage of hydrogen at reduced pressures (for increased vehicle range and safety), further R&D is required before these media are practical for automotive use. Another option involves containing hydrogen in ping-pong ball sized pellets, which are stored in on-board water tanks. When H_2 is needed, one or more pellets are sliced open starting a chemical reaction that releases the hydrogen for the fuel cell.[3]

Hydrogen for fuel cells may soon be produced at home from natural gas or propane for primary or standby power needs, or for powering buildings in remote or inaccessible areas. Homeowner co-ops will sell electricity back to the grid, and we'll possibly refuel our FCVs at home. As with CNG vehicles, sev-

(continued on page 6)

1. *Sunline Transit: www.sunline.org*
2. *Actually it wasn't the hydrogen, but the Hindenburg's "gunpowder/rocket fuel" based paint, which was ignited by static electricity.*
3. *Powerball technologies Inc: www.powerball.net*

Fuel Cell Vehicles – A Sampling of Prototype Car Models

BMW	750hL (sedan)
DiamlerChrysler	NECAR (models 1 thru 4)
	Jeep Commander
	MB Sprint (van)
Ford	P2000 (sedan)
Ford/Th!nk Technologies	Focus H-FCV
GM	Precept (sedan)
	Zafira/HydroGen I (minivan)
Nissan	Xterra (SUV)
Honda	FCX – V4 (4 passenger vehicle)
Hyundai	Santa Fe Sport (SUV)
Mazda	Demio FCV (SUV)
	Premacy FC-EV (5 pasenger vehicle)
Renault	Leguna Estate FCV
Toyota	FCHV-3 (SUV)
	FCVH-4 (passenger car)
Volkswagen	Bora Hymotion (Jetta - sedan)

More Websites for Hydrogen, Fuel Cell & FC Vehicle Information…

(see also Winter 2001 TechNews)

California Fuel Cell Partnership:	www.fuelcellpartnership.org/
U.S Dept. of Energy:	www.eren.doe.gov/hydrogen/basics.html
Honda:	http://world.honda.com/news/2001/c010904_1.html
HbT:	www.hbti.net/hbt_frames.html
Millenium Cell:	http://www.millenniumcell.com/index.pl
National Hydrogen Association:	http://www.hydrogenus.com/
Powerball Technology:	www.powerball.net
Proton Energy Systems:	www.protonenergy.com
Schatz Energy Research Center:	www.humboldt.edu/~serc/h2fuel.html
Stuart Energy:	www.stuartenergy.com
Sunline Transit:	http://www.sunline.org/clean_fuels_index/cf_index_frameset.html
Xogen Power Inc.:	www.xogen.com

Part of a continuing series on alternate-fuel vehicles and advanced vehicle technology. If you have comments or questions, contact ASE's Bob Rodriguez at brodriguez@asecert.org or 703-669-6634.

Alt Fuels

(continued from page 5)

eral companies offer H_2 "extractors" which run on 220 volts and use CNG or water "from the garden hose" for feedstock.[4] Ultimately, hydrogen will likely be used as a "carrier" (storage media) for electricity.[5] Check the Internet for a wealth of further information.

Where are we now?

NASA's space program demonstrated the practicality (if not the economy) of fuel cells in the 1960s. The cost of platinum (for catalysts) and other material costs must still come down. Technology breakthroughs are needed to make the fuel cell practical for varying climates and vehicle uses. The FC's intolerance to fuel impurities is critical, as is warm-up time; FCVs may have to run on batteries until the FC warms up.

With the aid of government funding, public and private labs, universities, and organizations are all working hard to bring increasingly small, less expensive and more reliable fuel cells and vehicles to market. Gasoline powered hybrid-electric vehicles (Insight and Prius, et al) offer significant fuel savings and serve as bridge-technology for FCVs. But pure hydrogen FCVs do not burn petroleum and are thus zero-emission vehicles (ZEVs). Unfortunately, despite the almost daily announcements of new developments and 2003/2004 launch dates for FCVs, insiders say that given fuel availability, mass commercialization is eight to ten years away. It's said that by 2020 fuel cell vehicles will be the dominant mode of transport, at least in California.

In the much shorter term, expect to see centrally refueled fuel cell hybrid-electric urban transit buses and short-haul trucks on our city streets, and FC powered equipment at airports, parks etc. With only water coming from the tailpipe, they are (as with battery EVs) zero emission vehicles (ZEVs) serving both our on- and non-road transportation needs.

Finally, hydrogen offers us the chance to level the energy/economics playing field. The U.S. now imports 56% of its oil—600,000 barrels of crude a day from Iraq alone—and spends almost *$2 billion dollars each week* on oil imports, mostly for cars and trucks.[6] The widespread use of fuel cells and hybrid-electric FCVs will enhance our nation's energy independence, conserve energy, and provide meaningful clean air benefits...all compelling goals. Hopefully you are now prepared to share the good news about fuel cells, FCVs, and the benefits of moving to hydrogen fuel with others.

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4. *Stuart Energy: www.solar-h.com*
5. *Schatz Research Energy Center: www.humboldt.edu/~serc/h2fuel.html*
6. *According to the DOE's* Clean Cities