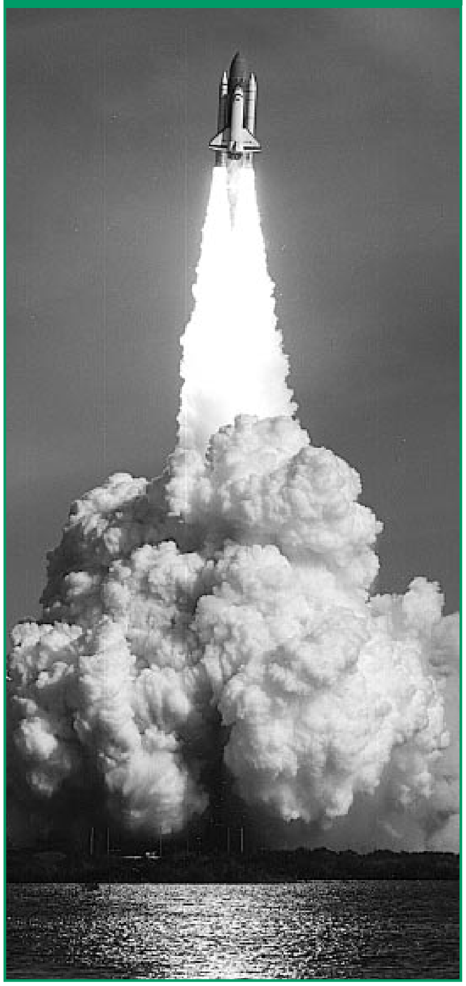
HYDROGEN

The Fuel for The Future



NASA

The hydrogen fuel technology that has boosted NASA's rockets will be available to the rest of America in the near future.

There is an emerging consensus that should global warming manifest itself, the benefits of a hydrogen economy based on clean electricity might well exceed its incremental costs.

With a roar of the engines amid clouds of smoke and steam, the launch of the space shuttle has almost become a commonplace scene for Americans. The liftoff is so precisely timed that we don't think of how much energy it takes to send the mission skyward, or what kind of fuel it takes to operate the space shuttle while in orbit. And very few of us pause to ask how much energy it takes to re-enter the Earth's atmosphere. The fuel of choice for all the space shuttle missions is hydrogen—not a readily available fuel for consumers now, but a viable alternative fuel for the future.

Hydrogen is the simplest, naturally occurring element that can be found in numerous materials—natural gas, methanol, coal, biomass, and water. As an abundantly available fuel that can be produced domestically, it could help the United States decrease its dependence on foreign oil imports.

Hydrogen, an energy carrier, is anticipated to join electricity as the foundation for a globally sustainable energy system using renewable energy. Hydrogen can be made safely, is environmentally friendly, and versatile, and has many potential energy uses, including powering non-polluting vehicles, heating homes and offices, and fueling aircraft.

Interest has been spurred by a growing awareness of burgeoning environmental threats to which hydrogen produced by solar-generated electricity seems the near-perfect solution. The theoretical combination of the two is appealing: electricity generated from the limitless supply of solar energy, then used to produce a flexible, transportable, and easily stored fuel which is virtually non-polluting. Cost remains the largest single obstacle, although there are formidable engineering challenges as well.

An energy carrier, not a source, hydrogen must be manufactured, principally by either splitting water (see box) or by extracting it from natural gas through steam reforming. The major markets for hydrogen are in the petrochemical and fertilizer industries. The National Aeronautics and Space Administration (NASA), in addition to using hydrogen to propel the space shuttle, uses hydrogen to provide all of the shuttles' electric power from on-board fuel cells. Fuel cells combine hydrogen and oxygen to generate electricity; the fuel cells' exhaust—pure water—is used for drinking water by the crew.

Hydrogen From Water

The most widely used method of water splitting is *electrolysis,* in which an electric current is run through water, decomposing it into hydrogen at the negatively charged cathode and oxygen at the positive anode.

A variant is *steam electrolysis*, in which some of the energy needed to split the water is imparted as raw heat rather than electricity, thus making the process more efficient. Other methods of generating hydrogen include:

- *Thermochemical water splitting* in which chemicals such as bromine or iodine, assisted by heat, split the water molecule in several, usually three, steps.
- *Photolysis*, in which the molecule is split by sunlight aided by catalysts in a way that mimics photosynthesis.
- *Biological and photo-biological (sunlight-assisted) water splitting,* in which organisms not only produce hydrogen, but clean up pollution as well.
- A radically different approach that has been investigated in the U.S., Japan, Canada, and France is *thermal watersplitting* using temperatures of up to 3000˚C.

Advantages and Opportunities

There are advantages and opportunities to using hydrogen as an alternative fuel.

- The production of hydrogen from renewable electricity and from biomass could reduce our dependence on imported petroleum. If the U.S. Department of Energy (DOE) reaches its goal of hydrogen energy providing 10% of total U.S. energy consumption by 2025, our dependence on oil imports could be reduced by half.
- Hydrogen can be combined with gasoline, ethanol, methanol, or natural gas; just adding 5% hydrogen to the gasoline/air mixture in an internal combustion engine could reduce nitrogen oxide emissions by 30% - 40%. An engine converted to burn pure hydrogen produces only water and minor amounts of nitrogen oxides as exhaust.
- California's new "zero-emission" standard for passenger cars—requiring 2% of new cars sold in the state be non-polluting by 1998—could be met by electric vehicles powered by hydrogen fuel cells (a kind of battery that combines hydrogen and oxygen to produce an electric current), or hybrids powered by hydrogen fueled internal combustion engines and batteries or flywheels. Manufacturing fuel cells to meet the potential demand could add 70,000 new jobs to the state.
- Hydrogen can be produced from a variety of renewable sources and has many uses in our economy. Because of the versatility of production methods and end use, wide-spread hydrogen energy use will create significant benefits to the agricultural, manufacturing, transportation, and service sectors of the U.S. economy.

Technological and economic constraints of hydrogen

If hydrogen has such positive attributes, why isn't being widely used? There are technological and economic constraints that include safety, the form of the fuel, production and storage, and economics. The nation's infrastructure is not geared to a hydrogen-based economy, and hydrogen's basic cost turns out to be higher than that of conventional fuels.

Research through the DOE is addressing these constraints by examining improved fuel cells and storage capabilities.

Fleet vehicles well suited to hydrogen

Hydrogen is being blended with other alternative fuels and used in fleets of buses in a number of cities. In many cases, alternative fuel vehicles whose engines are properly maintained produce fewer polluting emissions than do vehicles using diesel fuel.

In general, bus fleets are well suited to alternative fuels. Buses are used on routes that require a known range per tank of fuel. Buses have well-defined space and weight requirements for accommodating passengers. And transit buses are maintained in a single maintenance facility that can

Warren Gretz, NREL

These light-weight high strength compressed natural gas storage tanks are similar to those needed for compressed hydrogen.

conveniently service alternative fuel vehicles.

Nevertheless, no single engine/fuel combination has yet proven to be the best for all transit applications. Local factors, such as the availability of the alternative fuel, the size of the particular bus fleet, and specific environmental requirements, often help local transit officials determine which clean-air technology is their best choice. In addition, cost and budget factors, availability of refueling stations, maintenance needs, and engine performance must be considered before deciding which new engine/fuel combination is best for each locale.

Hydrogen as a source of power for public utilities

Hydrogen can also supplement other sources of energy to produce electricity. Gaseous hydrogen can be stored like an industrial gas. And—on paper, at least—hydrogen could be shipped in modified natural gas pipelines, thus carrying energy over long distances more economically than high-voltage transmission lines. Some researchers have estimated that it is about one-fourth as expensive to pipe hydrogen across long distances as it is to transmit electricity the same distance.

Energy Supply Potential

Using hydrogen to displace other fuels in the nation's energy supply will require numerous changes in existing infrastructures for storage, distribution and utilization. The journey to a practical system may be a long one. Many different photo-conversion approaches are candidates for future hydrogen production processes, but only a few have been examined through research and development projects. Given the environmental considerations, hydrogen may be a good choice for the United States and other industrial countries.

A new DOE Program Demonstrates Alternative Fuel Buses

DOE is providing cost-sharing funds for local transit authorities and school districts that purchase alternative fuel buses. This $90 million program, created by the Energy Policy Act of 1992, authorizes DOE to provide funds to governments of communities larger than 100,000 people for joint ventures with transit authorities to purchase alternative fuel buses.

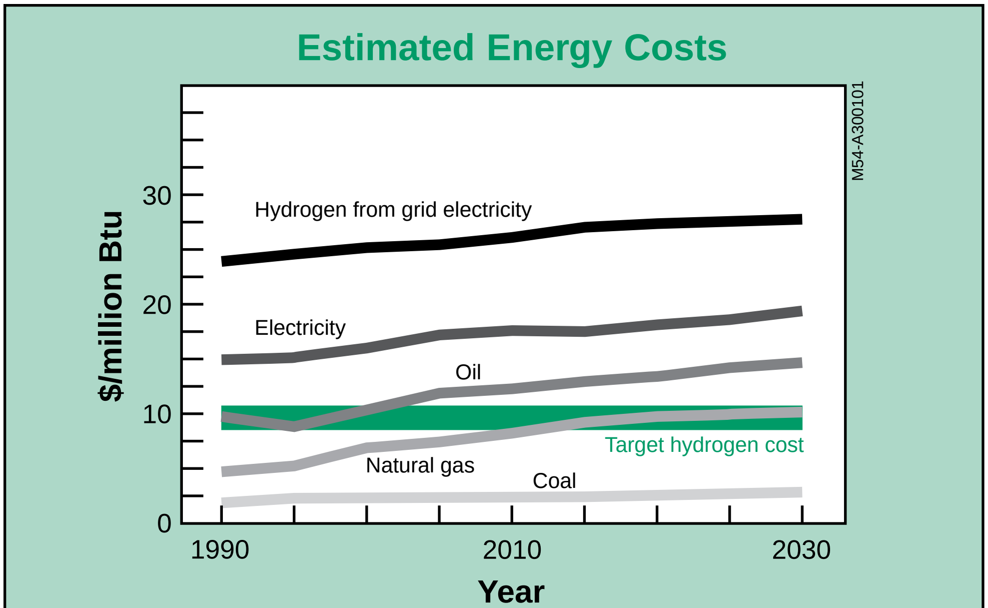
In addition, DOE has a program to help local school districts purchase alternative fuel buses. The purpose of this program is to test the performance of school buses operating on alternative fuels in different climates and operating conditions. Under this program, DOE pays for the difference between the purchase cost of an alternative fuel school bus and that of a conventional bus (i.e., the incremental cost). The program is administered through the state energy offices. For more information, contact your state energy office.

Performance Data are Available

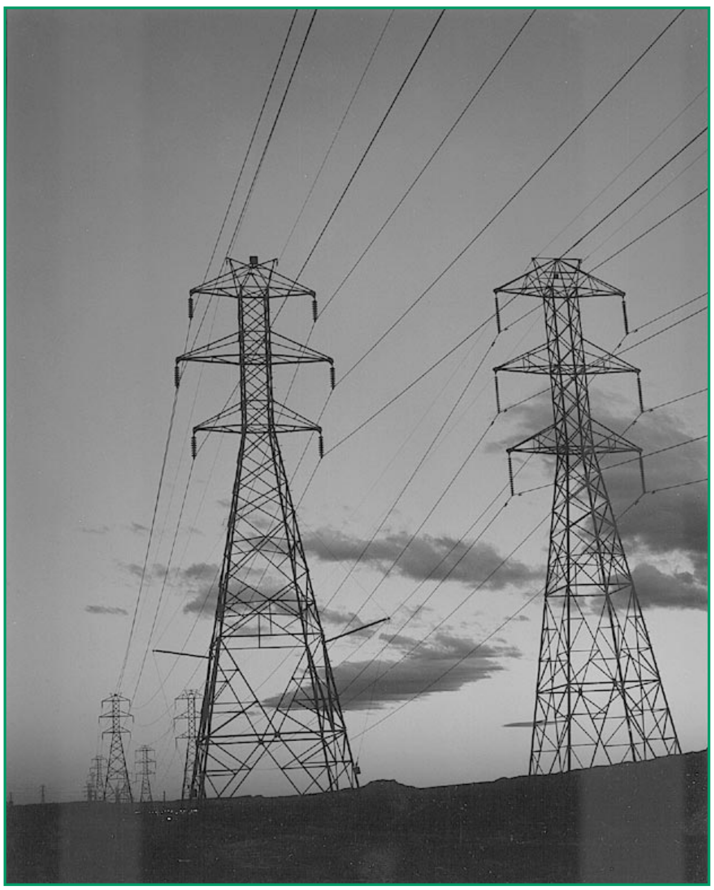
The DOE maintains data on the performance of urban transit buses operating on alternative fuels. Information can be obtained on fuel economy, maintenance costs, and safety requirements necessary for using alternative fuel vehicles. The data are available by calling the National Alternative Fuels Hotline: (800) 423-1DOE.

Hydrogen and Electricity

The energy relationship between hydrogen and electricity is fixed by physical laws. If there were no conversion losses, 1 kWh of electricity would produce 3412 Btu worth of hydrogen (or about 11 ft^3). At $0.05/kWh (today's national average industrial rate) and no conversion losses, 1 million Btu of hydrogen produced from electricity consumes nearly $15 worth of electric energy. When production (electrolyzer) inefficiencies and other handling costs are considered, practical electrolytic hydrogen costs can reach $30/million Btu. In contrast, natural gas costs about $3/million Btu. Gasoline at $1.10/gallon is equivalent to $9/million Btu. Thus, as the diagram illustrates, electrolytically produced hydrogen is likely to continue to be regarded as a premium product, and electrolysis is unlikely to become a predominant method for multiquad production of hydrogen.



Source: National Energy Strategy



However, it is possible that hydrogen fuel could be produced in this fashion. For example, regional imbalances that favor lower cost electricity and higher cost hydrogen could account for more extensive use of this production method. In addition, local electricity demand patterns that resist attempts to level peaks and fill valleys could also result in off-peak electrolytic hydrogen production. Specially designed solar or renewable electricity to hydrogen systems, taking advantage of high local resource levels, could be employed to meet peak hydrogen demands in certain areas. Electrolysis could also be the method of last resort for areas served by electricity but not by regular hydrogen delivery.

Electrolytic production of hydrogen is likely to be employed to serve niche applications in near-term and mid-term markets that are prompted by a variety of influences in addition to economics. The increasing willingness to pay premium costs for environmental, national security, or domestic resource benefits suggests that such demand will grow. Thus, the use of electrolysis for hydrogen manufacture merits consideration in a multiyear hydrogen strategy—not for expectations of great return on R&D investment but rather for supporting trial or transition activities.

Production

The choice of production methods will vary depending on the quantity and desired purity of hydrogen.

➢ *Natural Gas Steam Reforming:*

The first step of this two-step process is to expose natural gas to high-temperature steam to produce hydrogen, carbon monoxide, and carbon dioxide. The second step is to convert the carbon monoxide with steam to produce additional hydrogen and carbon dioxide. Most hydrogen is produced by this process. The yield of hydrogen is approximately 70%–90%.

➢ *Electrolysis:*

Electric energy is used to split water into hydrogen and oxygen gas ($2H_2O$ + electricity → $2H_2 + O_2$). Renewable energy sources of electricity such as solar, wind, and hydropower can be used in this process.

➢ *Photoelectrolysis:*

In a one-step process, sunlight is absorbed in a semiconductor, splitting water into hydrogen and oxygen. (At present, experience in this process is minimal.)

➢ *Biomass Gasification and Pyrolysis:*

The production of hydrogen can result from high-temperature gasifying and low-temperature pyrolysis of biomass (feedstocks include wood chips and forest and agricultural residues). This technology is currently available for fossil fuels.

➢ *Photobiological:*

Certain photosynthetic microbes produce H_2 in their metabolic activities using light energy. Employing catalysts and engineered systems, H_2 production efficiency could reach 24%.

Storage

➢ *Compressed Gas Storage Tanks:*

New materials have permitted storage tanks to be fabricated that can hold hydrogen at extremely high pressures. At present, the costs of the tanks and compression are high, but the technology is available.

➢ *Liquid Hydrogen:*

Condensing hydrogen gas into the more dense liquid form enables a larger quantity of hydrogen to be stored and transported. However, converting hydrogen gas to liquid hydrogen is costly and requires a large input of energy.

➢ *Chemical Hydrides (high and low temperature):*

Various pure or alloyed metals can combine with hydrogen, producing stable metal hydrides. The hydrides decompose when heated, releasing the hydrogen. Hydrogen can be stored in the form of a hydride at higher densities than by simple compression. Using this safe and efficient storage system depends on identifying a metal with sufficient adsorption capacity operating under appropriate temperature ranges.

➢ *Gas-on-Solid Adsorption:*

Adsorption of hydrogen molecules on activated charcoal (carbon) can approach the storage density of liquid hydrogen.

➢ *Microspheres:*

Very small glass spheres can hold hydrogen at high pressures, charged with gas at high temperatures where the gas can pass through the glass wall. At low temperatures the glass is impervious to hydrogen and it is locked in. Customized glass spheres are being developed for this purpose.

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