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# The hydrogen economy: age of unlimited energy

by Marsha Freeman

*The following article is part of an ongoing study by* Executive Intelligence Review *of alternative energy resources, to end our dependence on finite and polluting fossil fuels—fuels which are better used for indispensable petrochemical production.*

In the future, the lightest and most abundant element in the universe, hydrogen, will be the fuel for our electricity generating plants and the plasma technologies that the age of fusion power will make available. For the first time in history, the oceans, rivers, and lakes on this planet will produce our major raw materials and energy resources.

Fusion energy, using isotopes of hydrogen for fuel, will make high-density energy available to every nation in the world, regardless of its array of "natural" resources, and will be the propulsion energy for interplanetary travel to move human civilization throughout the solar system and to the stars.

Between today's dependence upon fossil fuels of coal, oil, and natural gas, and the widespread use of fusion, lie advanced nuclear fission and laser technologies that can open the Hydrogen Age. Before hydrogen is used widely in the fusion process to produce energy, it will be a crucial stepping stone to this age of unlimited energy. Developing new techniques to cheaply and abundantly produce hydrogen will bring about new materials necessary to get to fusion. It will replace the finite fossil fuels that now power our industry and transportation.

One most extraordinary feature of hydrogen is that it is completely reversible and recyclable. Large-scale production of hydrogen in the future will be from water. When that hydrogen is burned with oxygen to produce heat, water is the only by-product. If that water can be recaptured, it can be reused, again, and again.

Today our industry depends upon coal for steelmaking, industrial heat, and to produce a major part of our electricity. Petroleum fuels nearly all of our transportation, including automobiles, trucks, railroad locomotives, and aircraft. The only major mode of transportation today where hydrogen has already supplanted fossil fuels is in the manned space program.

Replacing fossil fuels in industry and transportation with hydrogen will allow the widespread use of these precious organic compounds as raw materials for industrial processes that are just now emerging. The production of new refractory materials out of carbon-carbon composite cloth, now used in the thermal protection tiles on the Space Shuttle, will be the basis of new high-temperature industries.

In their most advanced applications, one use of organic compounds will be as a mixture with ceramics to produce non-brittle material with high tensile strength. These new materials will be able to replace steel and metal alloys, in certain applications.

Any significant increase in real economic activity in the United States and the rest of the industrialized sector, plus the rapid agricultural and industrial development of the majority of the underdeveloped nations of the world, would quickly put a strain on our ability to economically mine, transport, and process our fossil reserves. If we are going to be able to fuel the rate of necessary world growth, both the massive introduction of available fission nuclear technology for electricity, and hydrogen for fuel, will be required.

## Advanced energy sources for production

In the aftermath of the 1973 Mideast war and oil embargo, the Nixon administration started a search for technologies that could be developed to take the United States off its dependency on imported oil. Project Independence was formulated to replace oil-burning electric generating capacity with nuclear energy and coal. The fast breeder reactor was given a target date of 1980 for operation, and the fusion program was accelerated.

Early in 1974, the National Aeronautics and Space Administration—the nation's largest user of pure hydrogen—determined that even for their own requirements for the upcoming Space Shuttle program, hydrogen production capabilities had to be analyzed. Since many government agencies were re-examining their energy requirements for the president's Project Independence study, a joint effort was initiated.

At the end of 1975, NASA published its review, titled, "Hydrogen Tomorrow." In that study a scenario was examined that included greatly expanded production and use of hydrogen, based on the accelerated use of nuclear fission. In 1973, the production of hydrogen in the United States was 86.7 billion cubic meters; the NASA study recommended a more than 20-fold increase by the year 2000.

In order to approach that magnitude of increase in hydrogen production, it was clear that completely new technologies would be required. Today, as in 1973, the vast majority of the hydrogen produced is from the reforming of methane, or natural gas. The small percentage of hydrogen which must be absolutely pure for medical, scientific, or space applications, is obtained from the electrolysis of water.

The reforming of methane, however, is clearly not a long-term or even medium-term option for large increases in hydrogen production, since this raw material is needed for fertilizer and as a chemical feedstock. Recognizing this, the government began a series of research efforts in the mid-1970s, to develop technologies for separating the hydrogen from the oxygen in water, as the basis for a virtually inexhaustible source of this fuel.

Over the last decade, designs and hardware have been produced to increase the efficiency, and lower the cost, of producing hydrogen from water. At a temperature of approximately 3000 degrees Celsius, it is possible to "thermally crack" water, or split it to liberate the hydrogen with no other energy input than heat.

Today, however, there are no materials that could withstand that thermal-cracking tempereature, nor is there a nuclear energy heat source of that quality. The amount of electricity needed in water electrolysis is directly proportional to the amount of thermal or heat-energy input. Raising the temperature at which the water splitting is accomplished, will reduce the amount of electricity required by the same amount.

Therefore, higher-temperature electrolysis is one promising technique for producing hydrogen in the future. Researchers at Brookhaven National Laboratory in New York have been developing a high temperature electrolysis design, where steam at about 1,500 degrees would be transferred from a fusion reactor and pumped through electrolyzer tubes. Lower temperature systems, which are still significant improvements over today's near-ambient electrolysis techniques, could be designed for high temperature gas-cooled nuclear reactors.

In the near term, available electrical energy capacity could be used on off-peak hours to produce hydrogen, using currently available low-temperature electrolysis technology. Power plants that cannot run at full throttle during nighttime drops in demand, because electricity cannot be economically stored, could be producing hydrogen at night. Unlike electricity, hydrogen is a storable energy source.

The hydrogen produced at night could be used later onsite to generate electricity when it is needed for peak demand, to fuel a steel or other metals-producing plant nearby, or to be put in a pipeline for delivery anywhere in the country. It could be mixed with the natural gas already being transported by pipeline for home and industrial use.

In addition to using this already-existing electric capacity for hydrogen production, next-generation nuclear power plants, operating at higher temperatures, could be designed for transferring some of their heat to hydrogen-producing electrolyzers. New materials development has led to the possibility of using ceramic crystals as an electrolyte to enhance the splitting of water.

With fusion, the plasma torch will enable the use of coherent energy produced in the fusion process for many kinds of materials processing, including hydrogen production. One design, suggested in 1971 by Bernard Eastlund, is to "tune" the plasma and produce ultraviolet radiation to separate out the hydrogen in water. Many variations will be available with fusion plasma technologies.

## Hydrogen today

As these production problems are solved, there will be myriad uses for this recyclable energy source. The production of ammonia for fertilizer will increase, as we move toward order-of-magnitude increases in world food production. The use of other industrial chemicals will likewise increase. The hydrogen used today in the metals industry, for heat treating and annealing, the reduction of non-ferrous matals, hydrogen plasma arc welding, and in powdered metallurgy, will also grow as industry starts a necessary period of rapid growth.

Other small users of hydrogen today include the electronics industry and the space program. Both will see dramatic growth rates in the next decade. The more frequent Space Shuttle flights will require increases in production of pure hydrogen for propellant. Even the next-generation space propulsion technologies, such as nuclear and laser systems which will not burn liquid hydrogen with oxygen, will most likely use hydrogen as a propellant, which is expelled from the rocket to provide the thrust.

But more dramatic than increases in the use of hydrogen where it is already used, will be the completely new applications of hydrogen fuel and technology, in transportation, ore reduction, and even residential uses.

## Hydrogen tomorrow

The most important basic industry for an industrial economy today is its capacity to make steel, other ferrous metals and non-ferrous materials. For most nations in the world, the coking coal that is required for today's blast furnace, which produces pig iron then turned into steel in the basic oxygen furnace, has to be transported from another part of the world, and imported.

For the amount of steel that needs to be produced worldwide, it is also vitally important that new, more productive methods for producing steel and other metals be developed. One method for next-generation steelmaking was designed by Sven Eketorp from Sweden, in 1974. Rather than using the carbon from coal, (which has had to go through baking in an oven to become coke) as a reducing agent to release the oxygen from iron ore, hydrogen could be used as that reductant. A single Eketorp furnace replaces coking ovens, blast furnaces and the basic oxygen process, or BOP furnace. A blast of high-temperature hydrogen, at about 1000 degrees, through a bath of molten iron, would "blow off" the oxygen in the ore put into the bath. Reduced iron would be continually removed from the bath, along with the steam that is produced in the hydrogen-oxygen combination. One benefit would be greatly reduced capital requirements.

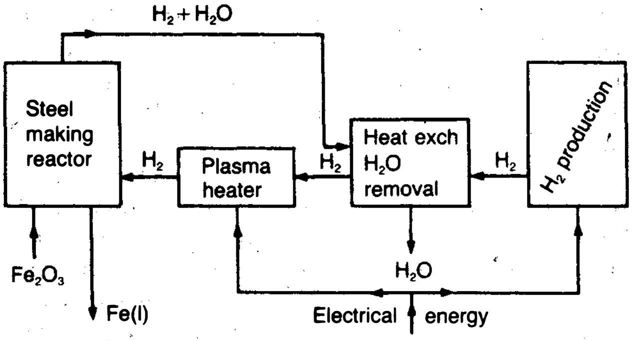
A furnace about the size of a small BOP would be the entire capital required, because the Eketorp process does not require producing coking coal, blast furnaces, "cooking" the iron for any period of time in the BOP, or stopping the furance to empty it out. A smaller furnace would produce the same output per hour as a huge BOP.

Productivity, or production per man-hour, would be between 10-50 times greater than with today's basic oxygen technology. The carbon that is "saved" by eliminating the coking process, could be used to produce the carbon-carbon composite material that would be an excellent lining for the furnace itself.

Hydrogen-reducing steel furnaces could be built anywhere in the world where there is water, an electric power plant, and iron ore. The power plant would produce the hydrogen on site using electrolysis, and feed it directly to the steel mill (see diagram). This integrated production would greatly enhance the overall productivity and efficiency of steelmaking.

The greatest consumer of liquid petroleum fuels in the industrialized countries is transportation. Gasoline and similar fuels power our automobiles, trucks, railroads, and aircraft. The problem in using hydrogen in these transportation applications is not only the current unavailability of economical fuel, but also its safe handling and storage.

FIGURE 1



*Eketorp Furnace: This furnace designed by Sven Eketorp in 1974, uses a hydrogen plasma for the reduction of iron ore without using coal. Electricity produces the hydrogen, and heats it to a plasma. The hydrogen plasma is then injected into the steel making reactor, where it combines with the oxygen in the ore, and is expelled as steam, and some hydrogen. The reduced iron, or Fe, is removed in a continuous reduction process.*

Unlike gasoline, hydrogen is not just flammable, it is explosive. This does not mean it cannot be handled safely—NASA has been doing that for 20 years. It simply means that it

control.

Because hydrogen is a gas at room temperature, unlike petroleum, it takes much more space to store. For example, storage of 1 kilogram of hydrogen at room temperature, which would give you an energy equivalent of 146 megajoules, would require a storage volume of 12,350 liters. To store the same amount of energy potential would require 2.88 kilograms of gasoline, which would occupy only 4.1 liters.

If the pressure of the hydrogen were increased to 400 times atmospheric pressure, the volume for the storage container would be 30 liters, which is still an order of magnitude higher than gasoline. Bringing the hydrogen gas down to only 20° above absolute zero will bring it into the liquid state. In this form, that same amount of stored energy in 1 kilogram of hydrogen will now need 14.3 liters for containment—much closer to gasoline, but much more difficult to keep cryogenically cold.

Researchers have been investigating ways of storing hydrogen, as a gas, in metal hydrides. In this system, the hydrogen is released when the temperature rises, such as in an automobile engine. For the system to be efficient, the density of the hydrogen in the hydride must be high. Otherwise you are carrying around a lot of weight for a small amount of fuel.

In West Germany, liquid hydrogen-burning auto engines have been developed and are in use experimentally. For the consumer to "tank up" with liquid hydrogen at his neighborhood filling station, a considerably safer and more complex station than operates today with gasoline, would have to be designed. In the United States, researchers at the University of Miami have completed work for the Department of Energy, which included building and testing 19 hydrogen-burning auto engines.

According to the researchers, no major technology issues were found to be outstanding, and auto manufacturers could begin the building of a prototype engine, to be tested and readied for mass production, perhaps over the next decade.

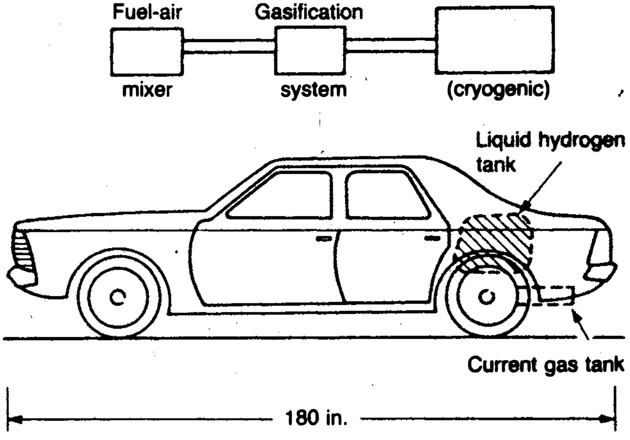
Another possibility is the use of hydrogen in fuel cells to produce electric power for cars. This is the same as running the electrolyzer cell in reverse—instead of using water and electricity to separate the oxygen and hydrogen, hydrogen and oxygen are combined to produce an electrical current. Fuel cells are used by NASA to produce electricity for the spacecraft's systems, and use by the crew.

For a number of years, the Lockheed Corporation has proposed the use of liquid hydrogen for sub-, super-, and hypersonic aircraft. Lockheed engineers proposed that for subsonic aircraft, and for supersonic planes (at least 760 miles per hour, the speed of sound), the liquefaction, handling, and storage technology already developed by NASA for the space program could be used.

FIGURE 2

### Hydrogen powered automobile

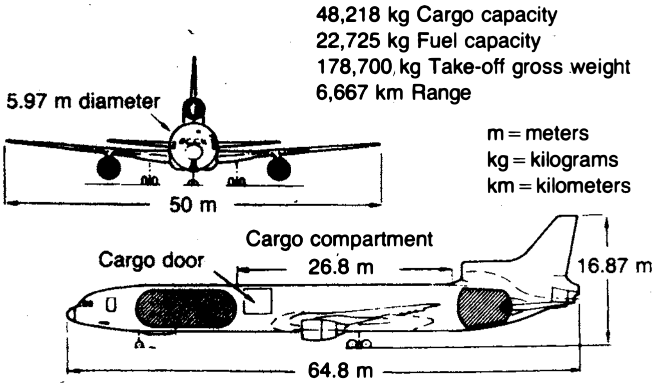
Conversion of the automobile to hydrogen hardware development required



| | Gasoline | Hydrogen |
|---|---|---|
| Range | 650 km (400 miles) | 650 km (400 miles) |
| Tank size | 80 liters (21 gallons) | 312 liters (83 gallons) |
| Fuel weight | 56 kilograms (123 lbs) | 21.8 kilograms (48 lbs) |
| Fuel consumption rate | 8.1 kilometers/liter<br>11.6 kilometers/kilogram | 2.1 kilometers/liter<br>30 kilometers/kilogram |

FIGURE 3

### Experimental liquid hydrogen aircraft



But hypersonic planes, travelling at about five times the speed of sound, (Los Angeles to Tokyo in 2.3 hours), would be subject to air resistance that would create a serious heating problem for the aircraft. The Lockheed design would use the liquid hydrogen fuel to cool the outer surface of the plane. The warmed-up hydrogen would then be used as a gas in the engine.

The advantages to using liquid hydrogen are first, that the supply will be unlimited, and second, that in liquid form, it contains three times the energy as the fossil-fuel based alternatives used today, or those produced synthetically. Lockheed proposed that the first fleet of hydrogen airplanes be used only to carry cargo, until the technology is tested and proven. Then, passenger service could be initiated, with the liquid hydrogen produced and stored on site, at the airport.

At the present time, more than one-quarter of the natural gas consumed in the United States is for residential uses. This includes cooking, heating water, and space heating. Heating and cooking could just as easily be done using gaseous hydrogen, that would be delivered from the same pipeline (with some modifications) that now delivers the natural gas to each home or office building.

Appliances put on the market could make use of hydrogen fuel. The only modification, if the burner uses a flame or pilot light, would be that a slight fragrance would have to be added to the odorless hydrogen, so leaks could be detected.

Flameless catalytic heating devices can also be used. In this case a plate coated with a catalyst would have air and hydrogen passed over it. The hydrogen would "burn" or combine with the oxygen when in contact with the catalyst, producing heat, without an open flame. As an intermediate step, natural gas could be "hydrogen enriched" by simply mixing the two gases in the pipeline.

In the energy sector itself, hydrogen can be used as a storage and convertible energy source for utility peaking.

Fuel cells, already described for use in electric cars, could be used on a larger scale for high demand periods. Gas turbines, already used as peaking power, could use hydrogen. And direct conversion cycles, such as magnetohydrodynamics, could use superheated hydrogen as a source of plasma in the production of electricity without using steam turbine generators.

Hydrogen is the perfect fuel and energy source. It is potentially unlimited in availability, reversible in production, use and recycle, and produces only water as a by-product.

Today we use fossil fuels to produce hydrogen. In the far distant future, we may have to use hydrogen to produce our hydrocarbons! Limestone, or even carbon dioxide captured from the air, might be the source of carbon most available in centuries ahead, when fossil fuels have been depleted. Then, hydrogen, which will surely be in bulk use, will be needed to re-create these complex organic molecules for us.

The challenge facing the technical community now, is to develop methods of producing hydrogen from water, making use of the second-generation nuclear fission technologies that should already be available, and the fusion power technologies that will also need hydrogen themselves for the production of unlimited energy.

# Robotics: Germany

### by William Engdahl

The most important area of prospective development in world industrial production today, which is essential for any crash program for the Strategic Defense Initiative, is industrial automated assembly. Industrial robotics is a vastly underutilized component of industrial assembly processes which, if fully realized, would allow exponential increases in productivity for the world's basic engineering industry. Particularly significant is the rapidly growing use of industrial lasers integrated with robots.

Developments of the past decade have placed the Federal Republic of Germany at the forefront of this work. Faced with the global crisis of soaring energy prices and usurious interest rates which began in the 1970s, the West German capital goods industry had two, quite different, responses. On the one side, productive capacities were shrunk, under the dictates of the European Community's infamous Davignon Plan for restricting steel production. Hundreds of thousands of workers were laid off in steel and industries dependent upon it, But some entrepreneurs took a different route: Beginning after the 1974 first "oil shock," a significant portion of the West German engineering industry began to invest heavily in capital-intensive productivity improvements. As a result, the West German machine tool and industrial automation technology is today the world's most advanced, with the possible exception of Japan.

The Federal Republic of Germany is the world's leading exporter of machine tools today, providing approximately 25% of the world market in 1983. Fully two-thirds of West German machine tools are exported. In the past year, the United States has become the largest import market for German engineering products, not merely because of the competitive price advantage from the rising dollar, but because of the quality differential.

Undertaking a broad-based technological investment, the German machine tool industry began 10 years ago to introduce numerically controlled machine tools. The per tool productivity increases, on average, over conventional manually operated machine tools, is 75 to 100% greater, according to the West German Machine Tool Association. Today, more