Hydrogen, electricity, and nuclear power

BY CHARLES W. FORSBERG

There is a set of asymmetric factors that may ultimately encourage the use of nuclear energy for hydrogen production (assuming the technology is developed) rather than the production of electricity.

THE NUCLEAR INDUSTRY has historically assumed that electricity is the primary energy carrier in an industrial society and that electricity should be the primary product from a nuclear power plant. However, these assumptions may not be true in the future. Hydrogen, not electricity, may be the largest long-distance energy carrier by 2050. If the nuclear industry wants to be the energy source of the future, it must prepare for this alternative future.

Hydrogen futures

World hydrogen consumption for fertilizer production and oil refining is about 50 million metric tons per year, with growth rates estimated at between 4 and 10 percent per year. Most of the growth in hydrogen demand is to convert heavy crude oils to gasoline and jet fuel. Light crude oils can be converted to gasoline without the use of hydrogen; however, we are rapidly exhausting supplies of such crude oils. Heavy crude oils, including Canadian tar sands and Venezuelan crude oils, are abundant but require large quantities of hydrogen for conversion to clean gasoline.

Within decades, the energy that will be required to produce hydrogen for use in refineries and other facilities will likely exceed the energy output of the existing nuclear plants in the United States. This growing "business-as-usual" worldwide market would justify the development of nuclear energy systems specifically for hydrogen production.

The resource limitations of light crude oil and concerns about greenhouse effects have resulted in consideration of "carbon saver" gasoline and other fuels. In these fuels, the hydrogen content is maximized—resulting in about 15 percent more gasoline produced per barrel of crude oil. The hydrogen requirements are equal to about 15 percent of the energy content of the liquid fuels. Hydrogen represents a large untapped market that depends on the relative costs of crude oil versus hydrogen and the incentives to avoid oil imports.

The world's auto manufacturers are entering a race to develop fuel cells for cars. If they (and the more recent Presidential Freedom Car initiative) are successful, fuel cells will begin to appear in cars for mass-market sales by 2010. Fuel cells, which use hydrogen, are significantly more efficient than internal combustion engines and produce much less pollution. Technical revolutions (horses to cars, oil lamps to light bulbs, etc.) typically require 30 to 40 years. If the auto companies succeed, the nation's transportation system may be based on hydrogen before 2050, a development that has several other implications:

- *Stationary applications*—If hydrogen is used in transportation, it will introduce a second hydrogen era for stationary applications. In the first hydrogen era from the late 19th century until the mid-20th century, most major cities used town gas (a mixture of hydrogen, carbon monoxide, and other gases) for lighting, cooking, hot water, and other purposes. When the technology for long-distance pipelines was developed, natural gas ultimately replaced town gas. Pure hydrogen is cleaner, much safer, and more versatile than town gas.
- *Peak electric demand*—If fuel cells become economically viable in cars, hydrogen will become the largest long-distance energy carrier. Like natural gas, hydrogen can be economically stored in large quantities. Current electric power-peaking plants cost hundreds of dollars per kilowatt, whereas a competitive fuel cell in a car must cost less than $100 per kW. If Detroit is successful in deploying fuel cells, the capital cost should ensure that fuel cells become the preferred method to meet electrical demand beyond that supplied by electricity plants operating at their maximum capacity. The energy content of transport fuels and the energy required to produce electricity are about equal. Hydrogen for transportation implies that hydrogen (not electricity) becomes the largest long-distance energy carrier because it replaces liquid fuels (gasoline, jet fuel, diesel) and provides the fuel to meet peak electric demands.
- *Renewable energy sources*—The potential viability of renewable energy resources to make a significant contribution to electricity demand is significantly improved. Most renewable energy resources (1) provide electricity that varies with time and (2) have high capital costs. For such systems to be viable, they must operate at near their maximum output at all times, although the output varies with wind speed, solar flux, or other variables. Because electrical demand does not match production from renewable energy sources, backup electric generating capacity is required. The large-

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scale economic viability of renewable energy resources is directly tied to the cost of the backup generating capacity. Lower cost backup capacity would allow larger use of renewable energy resources. Low-cost fuel cells, with a reliable hydrogen source, would enable larger-scale use of renewable energy resources in electric markets. Thus, nuclear energy may be the enabling technology for large-scale renewables.

In such a future, electricity drives the world (cars and industry); hydrogen, however, becomes the largest long-distance energy carrier from primary sources of energy (fission, fossil fuels, etc.) to near the user (vehicle or stationary fuel cell). There are alternative hydrogen futures, including those that use internal combustion engines. A successful fuel cell, however, has larger implications on the energy system because it (1) potentially creates a strong economic driver for rapid conversion to a hydrogen economy and (2) has a large impact on the electric system.

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Hydrogen and nuclear power

The central energy-related issues for industrial societies today are (1) climatic change and (2) security of energy supplies from the Mideast, Russia, and other locations. *How hydrogen is made determines if these issues are successfully addressed.* Most hydrogen today is made by steam reforming of natural gas. Research is under way to store hydrogen onboard vehicles or convert gasoline to hydrogen onboard the vehicles. Alternatively, nuclear energy can be used to make hydrogen. Significant R&D programs in Japan and expanding programs in the United States and Europe are developing the technology to use nuclear energy to produce hydrogen. Such a strategy would use nuclear energy to directly solve the central environmental and national security issues of our times—global warming and energy independence. Existing hydrogen plants are built on hydrogen pipeline systems that connect merchant hydrogen plants, refineries, and other hydrogen customers.

Looking to the future, however, the intrinsic characteristics of nuclear power would be compatible with hydrogen production. The newest plants being built to convert natural gas to hydrogen will produce 200 million ft^3/d. If a high-temperature reactor were coupled to a 50 percent efficient heat-to-hydrogen thermochemical cycle, this would be equivalent to a 1600-MWt nuclear power plant.

There is a set of asymmetric factors that may ultimately encourage the use of nuclear energy for hydrogen production (assuming the technology is developed) rather than the production of electricity:

■ *Transmission and siting*—Security requirements, the use of common facilities, and other factors encourage locating multiple reactors at each site. Hydrogen production is intrinsically more suitable than electricity for locating large numbers of reactors at a limited number of remote sites. It is easier to transport large quantities of energy in the form of hydrogen in a few pipelines to urban areas than to construct large numbers of power lines. Large electrical transmission lines carry about 2 GW. Large hydrogen pipelines, similar in size to the proposed Alaskan pipeline, would carry the equivalent of over 20 GW.

Because of recent technical developments, the construction of a hydrogen trunk pipeline system may be significantly simpler than the construction of the early natural gas pipelines. Half of the world's population lives within about 200 km of the coast. The development of a hydrogen economy would likely see the construction of large hydrogen pipelines off each coast with smaller trunk lines into major urban centers. An increasing number of pipelines are located offshore on the seabed because of the ease of finding rights-of-way and the advances in automated pipeline assembly onboard pipeline-laying ships. If nuclear energy is used for a hydrogen future, the long-distance hydrogen pipelines would be far shorter than those used with the current natural gas system because hydrogen would be shipped hundreds of kilometers, rather than thousands of kilometers across continents between natural gas deposits and urban areas.

■ *Time-of-day demand*—A large-scale hydrogen system, like the existing natural gas system, will have a large storage capacity. This allows hydrogen, unlike electricity, to be produced at a constant rate with the storage system handling daily variations in demand. Such production is better matched to the characteristics of nuclear power (low operating cost and high capital cost) than to the variable production required to match electrical demand.

■ *Competitive advantage*—The production of electricity from a wide variety of heat, chemical, and light sources is relatively simple. Solid-state electronics makes it easy to convert electricity with variable current and voltage into a form acceptable to the electrical grid. In contrast, the process of producing, purifying, and pressurizing hydrogen to match pipeline requirements is a complicated task that is inexpensive on a large scale but expensive on a smaller scale. The current evidence also indicates that hydrogen storage is inexpensive on a large scale (similar to natural gas) but expensive on a small scale. Nuclear energy may ultimately be more competitive in the hydrogen market than the electric market.

Futures

There are two credible energy futures for 2050: Electricity is the largest long-distance energy carrier, or hydrogen is the largest long-distance energy carrier. At this time, we cannot predict which direction the world will take or when it will make that choice. The decision depends on both the success of scientists and engineers and institutional factors. If the nuclear industry wants to assure itself a major role in any future, however, it must be prepared for either alternative.

Development of economic hydrogen production methods using nuclear power is a major technical challenge.

If the nuclear industry chooses to address global warming and energy independence, methods to make hydrogen economical using nuclear energy must be created. Development of economic hydrogen production methods using nuclear power is a major technical challenge that should not be underestimated. Such a path forward provides a powerful vision for the future, however, with nuclear energy being used to address the major issues of industrial societies.

Reference

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