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The Barometer

William G. Collins

THE BAROMETER

The Editor
Naval War College Review

Sir,

I was both interested in and disturbed by the article entitled "Energy Security and the Hydrogen Economy" by Harvey B. Silverstein, in the September-October 1980 issue of the Review.

I was interested because of my own professional and civic concern for energy production, conversion, transmission and utilization. I have for some years been following rhe development of techniques for producing and storing hydrogen fuel. It seems clear to me that hydrogen must become a major means of storing and transmitting energy in the next century as fossil fuel reserves, particularly liquid petroleum and natural gas, are depleted.

However, I was disturbed by Dr. Silverstein's treatment of hydrogen as an energy "source." The chemical burning of hydrogen is no more a "source" of energy than is electricity; like electricity, hydrogen must be produced by processes that involve the consumption of some primary source of energy, whether nuclear energy, a fossil fuel or some form of solar energy (in which category I include hydroelectric and wind energy, as well as biomass conversion, direct solar heating, Ocean Thermal Energy Conversion (OTEC) and photovoltaic conversion). Hydrogen is well suited for storing and transmitting the energy produced by these sources, but is not itself a source.

To be sure, Dr. Silverstein talks about methods of producing hydrogen. However, he implies, and as regards hydrogen production from nuclear and hydroelectric energy explicitly states, that hydrogen could be produced with little or no increase in primary source consumption. To quote:

> Consequently, a significant portion of the nuclear fuel rods are "burning" and water is going over the dam (in some cases) without doing any useful work. Most of the remaining 30-60 percent of energy now being wasted could be converted directly into hydrogen *with no increased fuel consumption within the system*. Therefore, total energy outputs from nuclear and hydroelectric plants could be increased significantly without additional fuel inputs and cost of additional fuel purchases.

The foregoing statements are wrong. Since they underlie several of Dr. Silverstein's points, they render the article rather misleading.

The rate at which nuclear fuel undergoes fission (is "burned" in Dr. Silverstein's term) in a reactor is simply proportional to the power demand on the plant. When the power demand is less than the peak capacity of the plant, the fission rate is less than the full power fission rate in the same proportion. Hence, no more fuel is "burned" in the reactor than is required to produce the power demanded of the plant. Likewise, hydroelectric dams are usually (but not always, to be sure) operated such that water is only released as fast as required to meet the power demand of the generators.

What is gained by using hydrogen production for load peak shaving (the context in which the above quoted statements appear) is *not* an increase in energy production for the fuel consumed, as Dr. Silverstein asserts, but rather an increase in the utilization of the generating equipment, hence a more rapid payback on the capital investment in that equipment, and therefore a reduction in the total cost of power generation.

As fossil fuels become increasingly scarce, nuclear fission, and ultimately nuclear fusion, along with solar radiation and perhaps geothermal heat must become the prime sources of energy. Hydrogen (as a chemical, not as fusion reactor fuel) is admirably suited, as Dr. Silverstein points out, for storing and transporting a portion of the energy generated by these sources. As he also points out, it can serve as a substitute for petroleum based vehicle fuels. A "source" of energy, however, it is not.

Unfortunately, Dr. Silverstein's inaccurate perception regarding the true energy cost of producing hydrogen makes his impassioned call for immediate national commitment to develop a hydrogen economy quite exaggerated. Because of his fundamental error regarding hydrogen production, he seems to disassociate the cost of hydrogen from the cost of basic fuels, and argues that use of hydrogen *now* as a vehicle and heating fuel would be desirable.

The table entitled "Energy Output Comparison" and the accompanying discussion of relative costs of various types of energy clearly suffer from this misconception. The table and the discussion imply that the cost of hydrogen, and the cost of electricity, are somehow independent of the cost of coal, natural gas, and oil. On the contrary, as long as a substantial fraction of electrical power is generated by the burning of fossil fuels, the cost of hydrogen and electricity will both be linked directly to the cost of those fuels. At present, most of the world's electrical power is generated by fossil fuel combustion; this will remain true until nuclear and solar generation become the predominant sources of electricity, a prospect many years away.

Once nuclear and solar generation have taken over nearly all electrical power production from the fossil fuels, it will make economic and energy sense to use some of that electricity to produce hydrogen for vehicle fuel, home and industrial heating use, with attendant benefits in load peak shaving and pollution avoidance. Until that time, however, it would not make sense. For example, because the maximum efficiency of a practical heat engine is between 40-50 percent,* it would be wasteful of energy to burn a fossil fuel in a power station, use some of the electricity produced to manufacture hydrogen at, say, 40% efficiency, then turn around and use that hydrogen to either propel a vehicle (with an efficiency of its own of no more than 40%) or heat a house. The overall energy efficiency of these two uses would be at most 16% (.4x.4) for the vehicle propulsion, or 40% for home heating. Far better to use the fossil fuel directly to either propel the vehicle at 40% efficiency or heat the house at near 100% efficiency. (Note: 40% and 100% are higher than efficiencies actually attained in most vehicle propulsion and house heating, but I use the same figures for both hydrogen and fossil fuels, so the comparison is valid.) Please note that this also answers Dr. Silverstein's question related to lack of tax benefits and other incentives for individual use of hydrogen fueled equipment.

Certainly we should be vigorously pursuing development of techniques to produce, transport and use hydrogen, so that we will be able to do those things economically and safely on a large scale when the day comes, not many decades hence, that sees most of the world's energy production taken over by nuclear and solar sources, and fossil hydrocarbons too valuable as chemicals to be burned as fuel!

/s/William G. Collins, Jr.

WILLIAM G. COLLINS, JR.
CDR, USN

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* NOTE—For those readers rusty on thermodynamics, any device which converts heat energy into mechanical (or electrical) energy is called a "heat engine." Heat engines include every such device from gasoline lawnmowers to nuclear power stations. Any heat engine is inherently limited in its efficiency for fundamental physical reasons. In order to get work (mechanical or electrical energy) out of a heat engine, it is necessary to dump a portion of the heat to a low-temperature "sink." This dumped heat does no work, and is, in effect, wasted. In a nuclear power station, the "heat sink" is the condenser of the steam plant, which in turn dumps the heat to a nearby body of water, or, through a cooling tower, to the atmosphere; in the gasoline lawnmower, the heat sink is the engine exhaust to the atmosphere. The efficiency of the heat engine is defined as the ratio of net work output to heat input, that is:

$$\text{efficiency} = \frac{\text{Net Work Output}}{\text{Heat Input}}$$

In the most efficient heat engine conceivable, an imaginary device known as a Carnot Engine, the efficiency simply depends on the absolute temperatures of the heat source (for example, the boiler) and the heat sink, thus:

$$\text{efficiency} = \frac{T_H - T_C}{T_H}$$

where

T_H = the absolute temperature of the heat source

and

T_C = the absolute temperature of the heat sink.

Because practical heat engines are limited by materials and their environment to a heat source temperature not much more than 1000°F (about 1500° Rankine, an absolute temperature scale) and a heat sink temperature not much less than 100°F (about 560° Rankine), the maximum efficiency of a real Carnot Engine, if such a thing could be built, would be about $\frac{1500-560}{1500} = .6 = 60\%$. Real engines are appreciably less efficient than Carnot Engines, hence my statement that the maximum efficiency attainable by a real heat engine is in the range of 40-50 percent, with most still less efficient than that.

Fuel cells, which Dr. Silverstein mentions, are not heat engines and therefore are not subject to the same inherent limitation of efficiency. However, it does not make sense to burn a hydrocarbon fuel to make electricity and therefore hydrogen at 40% efficiency, and then use the hydrogen to power a fuel cell, rather than using the hydrocarbon directly in a suitable fuel cell at much grearer overall efficiency.

Heating a house or an industrial process by fuel combustion is also free of the efficiency limitations of a heat engine; in principle, up to 100% of the heat liberated by fuel combustion can be captured in the house or industrial process. Hence, direct fuel combustion for space or process heating is far more energy efficient than heating derived from any heat engine conversion process, such as electric heating or heating with hydrogen produced by electrolysis at a power plant.

The Editor
Naval War College Review

Dear Sir:

While I was generally interested in the article "Energy Security and The Hydrogen Economy" by Harvey B. Silverstein, *Naval War College Review* Vol. XXXII, No.5/Sequence 281, Sep-Oct 80, I was appalled at his light-hearted dismissal and treatment of the safety factors involved.

Since I am in the Industrial Gas Business, I do not suffer from the "Hindenberg Syndrome"; instead I suffer from the "Industrial Gas Experience Syndrome" or better from the "Safety Syndrome."

Hydrogen is basically a dangerous gas. It is odorless, colorless and very hard to detect; in addition it is highly flammable and explosive under too many conditions.

While, I, like Mr. Silverstein, would like to see a greater use of hydrogen, I am deeply concerned by the safety factors when hydrogen is available to the average man. I do not believe that hydrogen can be introduced into the natural gas pipeline distribution system we have in this country without increasing hazards. For one thing, hydrogen is a very thin gas and will leak thru joints that will resist leakage of natural gas. Any joint made up of threads and standard pipe compounds will leak hydrogen.

I am glad to see the development of metal hydride as a storage system of hydrogen, but then I am plain scared of the fact that in order to get the hydrogen gas out of solution heat up to 130-deg.F. is required. I can just see some householder leaving the heater on and the pressure of the released gas building up and up until finally there is an explosion and a fine high grade fire.

It is readily agreed that hydrogen has been successfully used by individuals and organizations listed by Mr. Silverstein, but I would point out that the use of hydrogen in brazing operations is marginal, altho it is a cleaner gas to use in critical brazing operations than is acetylene. But the user of indusrrial gases prefers to stay with safer gases than with the highly dangerous hydrogen.

I suggest that we should do what has to be done to make hydrogen a viable fuel system in our economy, but let us not dismiss too light-heartedly the dangers inherent in the widespread use of this interesting and basic gas.

Sincerely,

/s/Herbert T. Johnson

HERBERT T. JOHNSON
Major General, AUS Retired

Editor, *Naval War College Review*

Dear Bill:

One of the most interesting aspects of both Commander Collins's and Major General (Ret) Johnson's letters was that they both focused essentially on technical dimensions of my proposal. Neither responded to my central themes regarding political and economic security aspects of energy policies.

Commander Collins's remarks about my treatment of hydrogen as an energy "source" compelled me to re-read my own article word-by-word—a not inconsequential task. He is absolutely correct, hydrogen is *not* an energy source but is a carrier of energy produced from something else. However, nowhere did I declare, nor did I even mean to imply, that hydrogen was a source of energy. In many public lectures and other published writings I have explicitly made the declaration, and I am happy to repeat here, that hydrogen is not a source but merely a carrier of energy. Confusion may have been created by my use of the term "hydrogen system" which is meant to include an energy source (hydroelectric dam, solar cells, OTEC, etc.) coupled with a hydrogen generator (i.e., water electrolyzer) along with distribution pipes or storage devices as a complete package.

Secondly, Collins challenges my discussion of hydrogen production methods. Conversations with several nuclear engineers have indicated to me that nuclear reactors operate at their highest efficiency and lowest cost per kilowatt-hour when they are going full-bore at close to 100% operating capacity. While it is true that they can be throttled back by lowering control rods into the reactor and slowing down fission reactions, more nuclear fuel per kilowatt-hour of electric output will be burned. Since the operating history of commercial power reactors has yielded an overall average load factor of somewhere between 50-70%, a substantial capacity of high-cost capital investment has not been well utilized. Most economists would agree to the notion that underuse of capital by not running at capacity rather than marginal increase in costs of nuclear fuel assemblies (to run a reactor at 100%) is one of the most significant problems in the economics of nuclear power. Also, reaction time to consumer demands may not be quite as sensitive as with other sources of electrical generation.

In some hydroelectric dams, as Collins concedes, water may be going over the dam without generating electricity. My point here is that there are formidable amounts of potential hydroelectric generating capacity in several parts of the world (equivalent to dozens of 1,000 megawatt reactors). Rather than just producing electricity, which would be an inappropriate and even wasted form of energy for many locales, the conversion of this energy to hydrogen would yield a fuel of significantly more importance. For example, exploitarion of the potential generating capacity of Newfoundland and Labrador to produce hydrogen could make all of Eastern Canada far less dependent upon imported oil at the same time that markets for electricity may already be saturated.

Finally, most of the last 50% of Commander Collins letter seems to be based on a misperception on his part. Nowhere did I advocate the burning of fossil fuels to ultimately produce hydrogen. I agree with him—based on laws of energy conservation and thermodynamics this makes no sense. Today, hydrogen systems can help us to make better use of existing non-fossil fuel sources of energy (hydroelectric, solar cells) and more opportunities for exploitation of future developments (OTEC, nuclear fusion)—let us not wait until our fossil hydrocarbons have all been burned.

The letter from Major General (Ret.) Johnson raises the issue of safety of hydrogen. My response may at first seem to be contradictory: yes, it is dangerous and no, it is safe. I did not intend nor did I perpetuate a "light hearted dismissal of safety" factors. Hydrogen is dangerous just as gasoline, natural gas, and even coal can be dangerous under given conditions. In some situations hydrogen is less dangerous (while stored in a hydride tank, when leaking in an open environment, in an explosion) and in some situations more dangerous (when leaking in an enclosed space, in its enbrittlement of metals) than natural gas or gasoline. The determination of whether or not hydrogen is more or less dangerous than other common everyday substances we willingly expose ourselves to is totally dependent on one's own subjective definition of "dangerous." Extensive evaluations of the dangers of handling hydrogen have been made by the U.S. National Bureau of Standards, the National Aeronautics and Space Administration, and the Institute of Gas Technology. Their analyses have expanded our knowledge on the behavior of hydrogen gas in many applications, and their conclusions suggest that with certain precautions hydrogen can be handled as safely as other volatile substances. There is not space here to detail these precautions or exactly *how* hydrogen is more safe or more dangerous than any other given compound.

I, too, am concerned about use of hydrogen by the "common man" or for that matter "common woman." That is exactly why I did stress the need for education of the public on the use of hydrogen in the original article. The type of educational programs used with the introduction of other new technologies from natural gas burners to microwave ovens would be relevant.

I am pleased to see that Mr. Johnson not only recognizes the problems but also appreciates the benefits of hydrogen systems. A small point but still an important one is his comment regarding pipeline distribution and leakage. Recent research, some mentioned in the article, shows that hydrogen leakage from conventional natural gas pipelines depends upon the percentage mixture of the gas transmitted as well as its transmission pressure. Up to approximately 15% mixtures of hydrogen with natural gas can be safely sent through existing pipelines with little or no change in the pipes, connectors, valves, pumps, etc. Furthermore, some existing networks may be able to transmit pure hydrogen as long as the pressure under which it is transmitted remains fairly low. Mr. Johnson's implication, though, is correct; special materials need to be used because hydrogen does have a higher propensity to leak and does cause the breakdown of certain materials. Safe procedures and combinations of materials for handling hydrogen are fairly well recognized by the growing community of hydrogen users.

I would like to thank both Commander Collins and Major General (Ret.) Johnson for their comments and hope that discussion of the security dimension of hydrogen systems continues within the pages of the *Naval War College Review*.

Sincerely,

/s/Harvey

Harvey B. Silverstein
Visting Associate Professor of
International and Marine Affairs
Dalhousie University

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