OutPost on the Endless Frontier©

EPRI e-News on Recent Key Developments in Energy Science and Technology
By Paul M. Grant

No. 5, 3 September 1998

Sun, Sea and Sand:
Solar Energy Stored in Hydrogen Controlled by Silicon Semiconductors

California has two excellent university systems. One, the University of California, with campuses at Berkeley, Los Angeles and seven other locations, is famous worldwide for its outstanding scientific and technical research. The other, the California State University system, originally founded to educate teachers and tradesmen, is not so well known outside the state. The CSU system does not award degrees at the doctorate level; however, this does not preclude the existence of a number of research projects at several campuses which rival in excellence and originality those found at UC. In the opinion of *OutPost*, one of these is located at CSU Humboldt in the city of Arcata on the north seacoast of California.[1] It is called the Schatz Solar Hydrogen Project, named after Dr. Louis W. Schatz, a local plastics manufacturer who provided its original endowment. Its purpose is to demonstrate the efficacy of a novel method to combine the merits of photovoltaic conversion of solar energy and hydrogen as fuel for the generation of electricity "off the grid" in those parts of the globe where the usual paradigm of central generation and distribution become impractical. More about the Humboldt project later. First let's review a few general observations on solar power to set the stage.

What happens when the Big Light goes out?

Almost everyone is aware that the major disadvantage of all forms of solar-derived electricity is that it is only directly available during daylight hours and then only optimally in clear weather conditions. A major challenge has been to find a means to effectively store solar electricity during periods of maximum generation under light load demand for higher demand need later, for example, at night. Solar thermal stations, like the Southern California Edison demonstration project with EPRI and DOE in the Mojave desert, use molten salt, taking advantage of its high heat capacity. At night, the salt is used to generate steam fed to conventional turbine generators to provide electricity.

For photovoltaics, most often batteries are used, and there are many examples of solar/battery installations in small remote villages in Latin America beyond the reach of the conventional electric transmission system. However, it has been reported the most frequent causes of failure at these locations have arisen from battery problems, not the associated PV array or power electronics. My colleague, Dr. Terry Peterson of EPRI's renewable energy target in our Energy Conversion Division, tells me batteries are essentially the principal barrier to diffusion of more "standalone" PV power units in developing nations. Batteries 1) have a relatively short lifetime (~5 years), 2) present a disposal/recycle problem, 3) can only increase storage by linearly increasing their number (more about this below), and 4) are heavy. Are there alternative methods of storage? Several have been discussed from time to time, such as superconducting magnetic energy storage, flywheels and pumped hydro or compressed gases, but so far batteries, or electrochemical cells, have remained the technology of choice.

But what about a different kind of electrochemical storage?

Hydrogen: Both fundamental element and fuel

Much has been written about the so-called “hydrogen economy.” The heat released by combusting hydrogen with oxygen is one of the highest of ordinary chemical reactions (after all, both in liquid form comprise rocket propellant), and produces as “exhaust” only water and nothing else, unlike the burning of hydrocarbons. These are the attributes of hydrogen that “fuel” speculation regarding its use to power personal transportation vehicles of the future. Of course, there are challenges – low energy density, safety and distribution infrastructure not the least among them.

There is another way to utilize hydrogen besides direct combustion, and that is in a fuel cell, the inverse electrochemical reaction to a battery, to produce electricity from the H-O reaction directly. In principle, it is possible to achieve very high efficiency conversion of chemical potential energy to electric energy because, unlike heat engines and turbines which are subject to the constraints of the Second Law of Thermodynamics, there is no analogous thermal cycle in the fuel cell. Most schemes to utilize hydrogen as fuel involve fuel cells rather than direct combustion. Although the principle behind fuel cells has been known for more than a century, it was not until their use in the early days of the American space program began to push their development to its current stage of commercial emergence for power generation and transportation.

All well and good, but how do you get hydrogen? The overwhelming present day source of hydrogen, a chemical commodity vital to a myriad of industrial processes, is as a byproduct of petroleum refining or coal gasification, and is likely to remain so for a long time to come. Moreover, the much publicized investment and development activity of major Japanese, American and European automakers in "hybrid" fuel cell powered cars involve on-board reforming of various hydrocarbons -- alcohol, gasoline, methane -- to obtain hydrogen to run the fuel cell. Again, as long as some level of CO_2 emission is permitted, the hydrocarbon reforming approach to locomotion uses of fuel cells will be the technology of choice for the foreseeable future.

However, most of us in our high school chemistry days ran a simple experiment whereby water – H_2O – was separated into hydrogen and oxygen between two immersed metal electrodes to which an external voltage was applied, a process called electrolysis. Why not get the required electric potential from a photovoltaic cell, store the resulting hydrogen in a tank for later distribution by "service stations" to supply fuel cell powered vehicles and other industrial and residential needs? Well, there are a number of projects supported by government agencies here and abroad to study just such a possibility. The two best known to *OutPost* are the College of Engineering Center for Environmental Research and Technology (CE-CERT)[2] located at University of California-Riverside, which studies the technical and economic efficacy of PV-generated hydrogen for vehicle power plants, internal combustion mainly, and Solar-Wasserstoff-Bayern (SWB)[3], a joint venture between the State of Bavaria, BMW, Siemens and Linde, to explore similar applications as is UC Riverside. *OutPost* views these efforts as at best realizable on a large scale only in a scenario where fossil fuel supply nears exhaustion (or CO_2 mitigation technology and regulation mitigate its use) and renewal of the nuclear option remains politically unacceptable.

On the other hand, how about considering a smaller scale, standalone, turnkey solar generation plant where hydrogen production, storage and fuel cell oxidation supplants the current role played by batteries? In other words, a "black box" on which the sun shines and electricity comes out -- all the time, even at night.

In the Redwoods by the Pacific

This is exactly the concept the Schatz Solar Hydrogen Project[4] at Humboldt State was designed to investigate. A combined photovoltaic array, electrolyzer, and fuel cell plant was constructed and installed in late 1989 at the university's aquarium within its marine studies laboratory on the coast in Trinidad. Hydrogen is produced during the day by the PV-powered electrolyzer, stored in tanks, recombined with atmospheric oxygen at night in the fuel cell to produce electricity to power the pumps for the aquarium 24 hours a day to aerate its fish tanks. Pretty nifty, in the opinion of *OutPost*. Briefly, the technical details are:

- PV Array Power: 9 kW
- Electrolyzer Load: 7 kW
- Electrolyzer H_2 Production: 20 liters/min
- Proton-exchange Fuel Cell Output: 1.5 kW

The "efficiency" of the operation will require considerable improvement to compete with traditional battery storage. That is, if we ratio fuel cell output to PV power in, we obtain an electrical throughput figure of only about 17% (1.5/9). Actually, this is a rather conservative number as not all the PV produced power goes to run the electrolyzer while the sun is up, but it serves as useful quantity to compare to batteries where the "round trip" efficiency is approximately 75%. On the other hand, suppose we want to double the power output of our solar black box. Unlike batteries, where to double the storage capacity it is necessary to double the number of cells (and hence all the associated problems already alluded to above), an increase in hydrogen storage capacity could be accomplished by higher pressure, or simply a higher volume tank.

It is also worth pointing out that the Trinidad installation was plagued at the beginning by problems with vendor-supplied proton-exchange-membrane (PEM) fuel cell units, and the researchers resorted to building their own. However, *OutPost* sees great opportunity for improvement in this particular component. It is expected that PEM-based fuel cells will improve drastically in cost/performance and reliability as hybrid-powered automobiles emerge into the world market, and the "trickle down" impact on symbiotic applications of PEM units such as this one should be dramatic.

Is the CSU Humboldt/Schatz approach -- the combination of PV generation with hydrogen storage -- the optimum way to engineer a low-cost, highly reliable, self-contained, low maintenance turnkey off-the-grid electricity supply system for the remote communities of the earth (or future moon stations perhaps)? The answer, for the present at least, has to be the old Scottish verdict, "not proven." However, as far as *OutPost* could determine, nowhere else, either in the US or other countries, has this concept received serious attention other than at Humboldt State. We believe it deserves a much closer look by the solar energy R&D community. In that regard, the lyrics of the 60's rock opera *Hair* say it all: "Let the Sun Shine In!"

73

[1]http://www.humboldt.edu
[2]http://www.cert.ucr.edu/index.html
[3]http://www.bayernwerk.de/pages/energie/sonne/solwas.htm *(in German)*
[4]http://www.humboldt.edu/~serc/facilities.html#solar