

BY JEREMY RIFKIN

THE HYDROGEN ECONOMY

After Oil, Clean Energy From a Fuel-Cell-Driven Global Hydrogen Web

More than a year after the terrorist attacks on the World Trade Center Towers and the Pentagon, the world is a more dangerous place than ever before. And, at the heart of our collective fear is the struggle to control oil, the one critical resource without which our global economy and modern society could not exist. Can a combination of technological innovation, global cooperation and strategic thinking take oil off the international chessboard of power politics and replace it with the ultimate energy carrier, lighter-than-air, and potentially non-polluting hydrogen?

ILLUSTRATIONS BY JEM SULLIVAN



THE HYDROGEN ECONOMY (continued)

We heat our homes and businesses, run our factories, power our transportation and light our cities with fossil fuels. We communicate over distances with electricity derived from fossil fuels, grow our food with the help of fossil fuels and produce our clothes and home appliances with petrochemicals. Indeed, virtually every aspect of modern existence is made from, powered with, or affected by fossil fuels.

In recent months U.S. government concern over the availability of oil in the Middle East has intensified because of the escalating violence between Israel and the Palestinians, the prospect of war with Iraq, and the likelihood of more terrorist attacks by the Al Qaeda network. Now, an even deeper worry is beginning to surface.

Experts have been saying that we have another 40 or so years of cheap recoverable crude oil left. Now, however, some of the world's leading petroleum geologists are suggesting that global oil production could peak and begin a steep decline much sooner, as early as the end of this decade, sending oil prices through the roof. Non-OPEC oil-producing countries are already nearing their peak production, leaving most of the remaining reserves in the politically unstable Middle East. Increasing tensions between Islam and the West are likely to further threaten our access to affordable oil. Rising oil prices will assuredly plunge developing countries even further into debt, locking much of the Third World in the throes of poverty for years to come. In desperation, the U.S. and other

but not sure if a system so complex and expansive and so centralized in its command and control mechanisms can ever really be completely secured against terrorist attacks.

Because of all these factors, many, including Christopher Flavin, president of the Washington, D.C.-based Worldwatch Institute, believe that the future belongs to decentralized, renewable energy. Although they acknowledge that fossil fuels will continue to provide energy, and that a transmission and distribution infrastructure will still be necessary to get hydrogen to retail customers, these experts see a renewable future. Flavin points out that the market for oil is growing at less than 1.5 percent per year, while the wind and photovoltaic (PV) markets are now doubling in size every three years.

The "Forever Fuel"

While the fossil-fuel era is entering its sunset years, a new energy regime is being born that has the potential to remake civilization along radical new lines. Hydrogen is the most basic and ubiquitous element in the universe. It is the stuff of stars and, when properly harnessed and made from renewable sources, it is the "forever fuel," notes author and alternative energy proponent Peter Hoffman. It produces no harmful CO₂ emissions when burned; the only byproducts are heat and pure water. We are at the dawn of a new economy, using hydrogen as the energy carrier, which will fundamentally change the nature of our financial markets, political and so-



nations could turn to dirtier fossil fuels—coal, tar sand and heavy oil—which will only worsen global warming and imperil the Earth's already-beleaguered ecosystems.

Rethinking Homeland Security

As horrible as the attacks of September 11, 2001 were, they were symbolic acts on the parts of the perpetrators, designed to destroy the icons of American economic and military power. What has government officials and business leaders in the U.S. and the European Union really worried is the prospect that, next time, Al Qaeda terrorists will strike at the heart of the system, the power grid itself, crippling a large swath of the economy and paralyzing urban society. How justified are the fears?

Unfortunately the power grids in North America and Europe are increasingly vulnerable to disruption by terrorists. Even before the September 11 attacks, government officials worried that American power plants, transmission lines and the telecommunications infrastructure could be targets for terrorists. In 1997, the President's Commission on Critical Infrastructure Protection issued a warning that cyber-terrorists' next target might be the computer programs at the power switching centers that move electricity around the country. Disrupting the electrical grid could wreak havoc on the nation's economic and social infrastructures. Richard A. Clarke, who heads the cyber-terrorism efforts of the Bush administration, warns of an "Electronic Pearl Harbor." A combination of cyber-attacks and physical attacks could lay waste to the nation's oil and gas pipelines, power stations and transmission lines with devastating effects on the economy.

Government officials are well aware of the vulnerabilities,

just as coal and steam power did at the beginning of the Industrial Age.

As Hoffman writes in his book, *Tomorrow's Energy: Hydrogen, Fuel Cells and the Prospects for a Cleaner Planet* (MIT Press), hydrogen can "propel airplanes, cars, trains and ships, run plants, and heat homes, offices, hospitals and schools....As a gas, hydrogen can transport energy over long distances, in pipelines, as cheaply as electricity (under some circumstances, perhaps even more efficiently), driving fuel cells or other power-generating machinery at the consumer end to make electricity and water. As a chemical fuel, hydrogen can be used in a much wider range of energy applications than electricity."

Chemically bound hydrogen is found everywhere on Earth: in water, fossil fuels and all living things. Yet, it rarely exists free floating in nature. Instead, it has to be extracted from water or from hydrocarbons. Today, nearly half the hydrogen produced in the world is derived from natural gas via a steam reforming process. The natural gas reacts with steam in a catalytic converter. The process strips away the hydrogen atoms, leaving carbon dioxide as the byproduct (and, unfortunately, releasing it to the atmosphere as a global warming gas). Coal can also be reformed through gasification to produce hydrogen, but this is more expensive than using natural gas and also releases CO₂, which scientists hope to keep earthbound through a process called "carbon sequestration." Hydrogen can also be processed from gasoline or methanol, though again CO₂ is an unwanted byproduct.

Although using steam to reform natural gas has proven thus far to be the cheapest way to produce commercial hy-

drogen, global production of natural gas is likely to peak sometime between 2020 and 2030, creating a second energy crisis on the heels of the oil crisis.

There is, however, another way to produce hydrogen without using fossil fuels in the process. Renewable sources of energy—PV, wind, hydro, geothermal and biomass—can be harnessed to produce electricity. The electricity, in turn, can be used, in a process called electrolysis, to split water into hydrogen and oxygen. The hydrogen can then be stored and later used in a fuel cell to generate electricity, with heat as a useful byproduct that could be harnessed to heat homes, among other uses. Fuel cells run only on hydrogen, but the gas can be derived from many hydrogen-rich sources, including just about any fossil fuel, but only through the use of renewable resources is the whole process emission-free.

People often ask: Why generate electricity twice, first to produce electricity for the process of electrolytic hydrogen and then again to produce electricity and heat in a fuel cell? The reason is that electricity can be stored only in batteries, which are cumbersome to transport and slow to recharge, while hydrogen can be stored at much lower cost. Internal-combustion engines capture only 15 to 20 percent of the energy in gasoline, and the conventional electric power grid is only 33 percent efficient. But as Amory Lovins' Rocky Mountain Institute (RMI) points out, "Fuel cells can convert 40 to 65 percent of hydrogen's energy into electricity."

The real question, then, is one of costs.

Wind, hydropower and biomass (generating power by burning plant material such as wood waste and agricultural residue) are already cost competitive in many parts of the world and can be used to generate electricity for the electrolysis process. Wind power, for instance, is now the fastest growing new source of energy; it averages six to eight cents per kilowatt-hour at the wind generator, down from 40 cents in the early 1980s, though collection and transmission costs must be added. PV and ge-

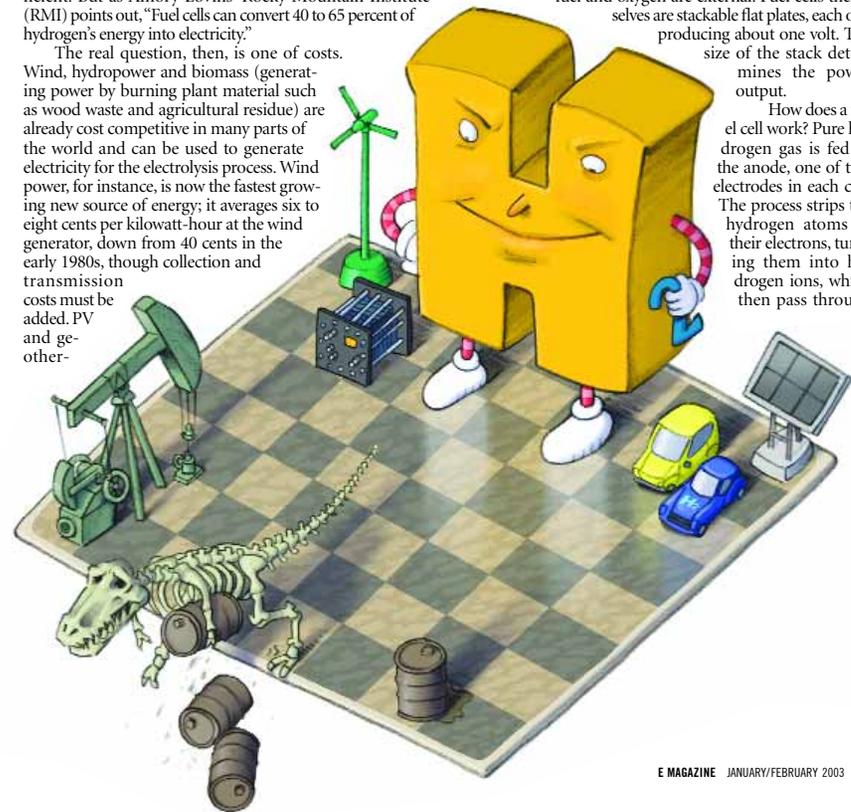
thermal costs, however, are still high and will need to come down considerably to make the process competitive with the natural gas steam reforming process now used most often in the production of hydrogen.

Origins of the Fuel Cell

Hydrogen fuel cells were invented by Sir William Robert Grove (1811-1896), a larger-than-life figure of the type that proliferated in 19th century England. Grove proved that his fuel cells worked, but as he had no entrepreneurial inclinations, and there was no practical use for them at that time, the invention slumbered for over 130 years. It came to life again in the 1960s, when General Electric developed workable proton-exchange membrane cells for use as power supplies in the Apollo and Gemini space missions. The cells were big and very expensive, but they performed faultlessly, delivering an unwavering supply of current as well as a very useful byproduct in space, drinkable fresh water.

Fuel-cell technology can be compared to that of a car battery, in that hydrogen and oxygen are combined to produce electricity. But while batteries store both their fuel and their oxidizer internally, meaning they have to be periodically recharged, the fuel cell can run continuously because its fuel and oxygen are external. Fuel cells themselves are stackable flat plates, each one producing about one volt. The size of the stack determines the power output.

How does a fuel cell work? Pure hydrogen gas is fed to the anode, one of two electrodes in each cell. The process strips the hydrogen atoms of their electrons, turning them into hydrogen ions, which then pass through



THE HYDROGEN ECONOMY (continued)

an electrolyte (which, depending on the type of fuel cell, can be phosphoric acid, molten carbonate or another substance) to the second electrode, known as the cathode. This electron movement produces electric current, the intensity of which is decided by the size of the electrodes. At the cathode, the electrons are brought back together with their ions and combined with oxygen to produce one of the fuel cell's major byproducts, water. The other byproduct is heat, which can be captured and reused in a cogeneration process.

Peer-to-Peer Energy Sharing

Commercial fuel cells powered by hydrogen are just now being introduced into the market for home, office and industrial use. The major automakers have spent over \$2 billion developing hydrogen cars, buses and trucks, and the first mass-produced vehicles are expected to be on the road beginning in 2003.

The hydrogen economy makes possible a vast redistribution of electricity, with far-reaching consequences for soci-

ety. Today's centralized, top-down flow of energy, controlled by global oil companies and utilities, can become obsolete. In the new era, every human being with access to renewable energy sources could become a *producer* as well as a consumer—using so-called “distributed generation.” When millions of end-users connect their fuel cells powered by renewables into local, regional and national publicly owned hydrogen energy webs (HEWs), they can begin to share energy—peer-to-peer—creating a new decentralized form of energy generation and use.

In the new hydrogen fuel-cell era, even the automobile itself is a “power station on wheels” with a generating capacity of 20 kilowatts. Since the average car is parked about 96 percent of the time, it can be plugged in, during non-use hours, to the home, office or the main interactive electricity network, providing premium electricity back to the grid. As hydrogen visionary Amory Lovins explains, “Once you put a fuel cell in an ultralight car, you then have a 20- to 25-kilowatt power station

on wheels. So why not lease those fuel-cell cars to people who work in buildings where you've installed fuel cells?”

It would work like this: Commuters drive their cars to work, then plug them into the hydrogen line coming out of the natural gas reformer installed as part of the building's fuel cell. While they worked, their cars would produce electricity, which they could then sell back to the grid. The car, instead of simply occupying space, would become a profit center. “It does not take many people doing this to put the rest of the coal and nuclear plants out of business,” says Lovins, who's been trying to do just that for decades. “The hypercar fleet will eventually have five to six times the generating capacity of the national grid.”

The Next Great Economic and Social Revolution

This clean fuel could make obsolete our big-scale, polluting oil network through a locally based system. The first thing to keep in mind is that with distributed generation, every fami-

ly, business, neighborhood and community is potentially consumer, producer and vendor of hydrogen and electricity. Because fuel cells are located physically at the sites where the hydrogen and electricity are going to be produced and partially consumed, with surplus hydrogen sold as fuel and surplus electricity sent back onto the energy network, the ability to aggregate large numbers of producer/users into associations is critical to energy empowerment and the advancing of the vision of democratic energy.

Empowering people and democratizing energy will require that public institutions and nonprofit organizations—local governments, cooperatives, community development corporations, credit unions and the like—jump in at the beginning of the new energy revolution and help establish distributed generation associations in every country.

Eventually, the end users' combined generating power via the energy web will exceed the power generated by the utility

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CONVERSATIONS

Amory B. Lovins: Building the Hydrogen Economy



Amory B. Lovins: A great deal. In 1999, Brett Williams and I presented a paper at the National Hydrogen Association called “Strategy for the Hydrogen Transition,” in which we showed how to get there step by step. And the reaction was, “Oh! That's how these pieces fit together!” Since then, as many as five automakers and suppliers have set up businesses implementing that approach and so have a number of major energy companies.

It's noteworthy that at least eight major automakers will be introducing early low-volume fuel-cell cars from this year through 2005. I am also encouraged by the Department of Energy's (DOE) leadership on hydrogen; for a variety of reasons, Energy Secretary Spencer Abraham has become enthusiastic about it. The DOE's FreedomCAR program with the Big Three automakers is still a blank slate, so it could go either way. It could be a flop if they simply drop fuel cells into inefficient cars. It could be a triumphant leapfrog for national competitiveness if they build on the best of what has already been worked out. Third parties like Hypercar® designed in 2000 the vehicle that FreedomCAR wants to spend the next 10 or 20 years designing.

Do you have a timetable attached for automotive fuel cells?

The cars have to be ready for the hydrogen, meaning that they're made so efficient that they need only a third the normal amount of power. Therefore, the fuel cell is small enough to be affordable even at early prices and the compressed hydrogen tanks are

small enough to fit conveniently. That's what Hypercar® vehicles do. And those kinds of cars are making steady progress toward the markets, but I would like it to happen faster. They have been somewhat delayed by a combination of the collapsing private equity market in the last two years and the usual cultural problems in very large automaking organizations.

Aren't most fuel-cell cars on the road today using pre-existing chassis and platforms with fuel cells stuffed into them?

It's a bad design because it makes the fuel cell too big to afford and the tanks too big to package. If you stuff them in, you compromise interior space or performance, and you pay extra cost. Or you're driven to converting fossil fuels through an expensive, bulky on-board chemical reformer.

I do have the sense that the auto industry has finally abandoned the idea of the reformer, or they're getting to that point.

Most oil and car companies have noticeably cooled on their initial enthusiasm for on-board reformers. It turns out to be a very hard thing to do. And it gives up most of the reasons for wanting the fuel cell in the first place. By the time you're done, your gasoline-to-wheels efficiency is comparable to that of a good combustion engine.

Do you think the hydrogen economy is becoming even more inevitable?

In fact there are several new important discoveries. One, from work by C. E. “Sandy”

Thomas, president of Virginia-based H2Gen, is that the capital costs of a national hydrogen fueling infrastructure based on miniature natural gas reformers will be less than that of sustaining the existing gasoline fueling structure. That was quite a revelation to many people who assumed hydrogen would be too expensive. Secondly, General Motors believes that such a strategy would actually reduce national consumption of natural gas. That's because the extra gas that you turn into hydrogen to run vehicles can be offset, or more, by the gas you save in power plants, furnaces and boilers by integrating deployment of fuel cells in vehicles and buildings.

It's starting to seem—and this is counter to what a lot of people have been told over the years—that we will see the cars before we see the residential fuel cells or the battery replacements.

I think that we'll see commercial and industrial fuel cells first. There are many applications where these cells make sense right now. We now understand better the hidden economic benefits of decentralized electric production. My colleague Joel Swisher, published a paper called *Cleaner Energy Greener Profits* applying some of the most important distributed benefits to fuel cells and showing that they're now cost effective if applied properly.

Jeremy Rifkin is of the opinion that the end game is locally generated networks producing hydrogen from renewables.

I think that's a plausible scenario. In brief, the

hydrogen transition strategy we set out starts by making hydrogen mainly from natural gas in buildings. Then we sell surplus hydrogen from buildings to cars parked nearby. We then put the miniature gas reformers and electrolyzers, as they get cheaper with volume, out into filling stations and elsewhere. That helps create a large hydrogen market, which would make practical and possibly cheaper the centralized production of hydrogen from either planet-safe electricity or reformed natural gas with carbon sequestration or possibly other methods.

What is the oil company strategy for hydrogen energy?

They're realizing that they can actually be better off in the hydrogen business than in the oil business. This is very interesting for them, and it changes the politics. All the major oil companies I work with have put substantial efforts in this direction. It's been obvious for a long time that hydrogen is a good play for the natural gas industry. But it wasn't widely accepted until recently that it can also be very good for the oil industry.

Another revolution has not yet happened, but it shows promise. That's the work at the Princeton Climate Mitigation Center making a plausible *prima-facie* case that it may be cheaper in the long run to make hydrogen out of coal than out of natural gas, with carbon sequestration in both cases. There's less hydrogen in coal than in natural gas, and it's harder to get at, but the coal is so much cheaper that it may compensate. So, if the carbon se-

questration works as well as hoped, this could provide an even larger fossil fuel option for making climate-safe hydrogen.

Another potential revolutionary notion is that hydrogen can greatly improve the economics of renewable electricity. A fuel cell is several times as efficient as a gasoline engine in converting fuel energy into traction in a vehicle. So instead of selling electrons as a raw commodity, you make it into a value-added product by attaching a proton to each electron at the wind farm or hydro-dam or solar cell. The extra price it fetches more than pays for that conversion and you end up making more money than you did selling electricity.

The Bush administration's hydrogen plans include using it to jump-start the moribund nuclear industry.

That's to be expected from an administration that's enthusiastic about nuclear power. But it doesn't change the economic unattractiveness of building any more nuclear plants. You may have noticed that no investors showed up at the American Nuclear Society's “Sustaining the Nuclear Revival” conference this year, and there are very good reasons for that. There are at least three technologies abundantly available that beat nuclear plants by a factor of at least three to five in cost, and more are on the way. So this is the future technology that time has passed. CONTACT: Rocky Mountain Institute, (970) 927-3851, www.rmi.org. **E**

INTERVIEWED BY JIM MOTAVALLI

Amory B. Lovins co-founded the Colorado-based Rocky Mountain Institute (RMI) in 1982, and it has grown from a small energy-related think tank into a major global research institution with more than 45 full-time staff. The peripatetic and multiple-award-winning Lovins travels the world spreading his visions of a sustainable future, and is a principal proponent of the hydrogen energy economy. With Paul Hawken and RMI co-founder L. Hunter Lovins, he is the author most recently of *Natural Capitalism* (Back Bay Books).

E: How much of what is happening now represents the vision you had when you published your “Reinventing the Wheels” piece in *Atlantic Monthly* in 1995?

POWER PLAYS

Fuel Cells are Reaching the Market, in What Could be a \$100 Billion Industry

By Jim Motavalli

Depending on whom you talk to, the fuel-cell revolution is either 20 years down the road or right around the corner. In a sense, both views are correct. Fuel cells are no longer tomorrow's technology, the stuff of science fiction and space travel. Annual investment in fuel-cell research tops \$1 billion per year. Within the next two years, the first fuel-cell cars will be on the road, fuel-cell power plants large and small will become commonplace, tiny cells will begin to replace batteries in many household uses, and a start will have been made on creating a global hydrogen-fueling infrastructure. J.P. Morgan Securities estimates that the consumer market for fuel cells could reach \$100 billion by 2020.

All that progress can present a misleading picture, because most experts agree that it will take until at least 2010 or 2015 before the much-touted "hydrogen energy economy" can be even partially realized. What takes time is not so much the fuel cell itself, but the consumer acceptance and support structure to make hydrogen as familiar a commodity as gasoline is today. Among other things, we need to agree on standards for the production of environmentally friendly, low cost and easily deliverable hydrogen; gas stations have to be turned incrementally into hydrogen stations; reliability standards must be established and cost goals met for fuel-cell battery replacements; and fuel-cell vehicles must become affordable, with a range, reliability and cold-starting performance that exceeds their internal-combustion counterparts.

All these things are proceeding, though on widely varying timetables.



A fleet of DaimlerChrysler Citaro fuel-cell buses will be on European roads this year. Below, a General Motors Hy-Wire fuel-cell prototype.

FUEL-CELL VEHICLES

There is a neck-and-neck race underway between Japanese, American and German carmakers to get a fuel-cell car on the road, with a number of manufacturers planning to launch small test fleets this year. This doesn't mean that consumers will be able to buy fuel-cell cars anytime soon, or that obituaries should be written for the internal-combustion engine.

According to the Japan Automobile Manufacturers Association, Toyota and Honda will sell or lease fuel-cell vehicles in the U.S. and Japan in early 2003. Toyota's fuel-cell car is based on the Highlander, a small sport-utility vehicle (SUV). Honda's small FCX, which has a top speed of 90 miles per hour and can travel 220 miles between hydrogen gas fill-ups, became the first fuel-cell vehicle in the world to receive government certification from the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB). Honda plans to have

30 fuel-cell vehicles (FCVs) on the road in the U.S. and Japan by 2005. Nissan is also fielding a fuel-cell vehicle in 2003.

Many of the early hydrogen-powered cars will be equipped with fuel cells from leading automotive fuel cell provider Ballard Power Systems. According to a spokesperson, the company's products are in some 38 vehicles, including 25 cars and 13 buses. That number is likely to increase dramatically, as 60 Ballard-powered DaimlerChrysler FCVs will also appear in 2003, based on small Mercedes A-Class vehicles. Ford's FCV, based on the Focus, has a range of 200 miles and will be entering test fleets in Europe and California in 2004; it is slated to reach the public by 2008.

General Motors (GM) has emerged as a major U.S. fuel-cell player. The Hy-Wire sedan it recently unveiled on the auto show circuit is a refinement of its earlier skateboard-shaped AUTONOMY FCV chassis, which was designed to accommodate several body types. Not only does the Hy-Wire use space-age drive-by-wire steering electronics, but it also incorporates a high-pressure 5,000-pound per-square-inch (psi) hydrogen tank that allows it to travel 300 miles on a fill-up of gaseous hydrogen. What's more, GM is experimenting with 10,000-psi tanks that, if safety questions can be addressed, would put range questions completely to rest.

In a major switch, almost all of the world's carmakers are now focusing on direct storage of hydrogen gas on board the vehicle. GM and DaimlerChrysler

had earlier championed the concept of extracting hydrogen from methanol or gasoline, which would have required the use of an expensive, bulky on-board chemical "reformer."

Direct hydrogen fueling is only possible with a global network of hydrogen filling stations, which fossil fuel critics claim is a \$400 billion proposition. But C.E. "Sandy" Thomas, president of H2Gen Innovations and a former consultant to Ford, points out that switching to a hydrogen-based system would actually save \$840 billion to \$1.1 trillion over the next 40 years when the cost of maintaining the current oil-based grid is fully considered. H2Gen is developing a \$375,000 gas station-based hydrogen generator and pump that will use steam reformation of natural gas. Thomas estimates that 10 percent of U.S. gas stations can be equipped with hydrogen pumping units for a relatively modest \$2 billion.

RESIDENTIAL POWER

In 1998, when it was commonly believed that residential fuel cells would take large numbers of electricity consumers off the grid before the first FCV car was on the road, a New York-based company named Plug Power took journalists on tours of its demonstration house, a brick-faced ranch connected to a seven-kilowatt natural gas-powered fuel cell. The unit, about the size of a copy machine, was able to keep up with an average residential load. The cell promised trouble-free electrical power by 2001 at a price that would beat the utilities at their own game. Plug Power believed that 25

million American households with high-priced electricity or no access to the grid could benefit from fuel-cell energy.

Four years later, despite some new testing programs at U.S. military bases and in 10 California homes, residential fuel cells remain a dream. Plug Power signed a much-ballyhooed distribution deal with General Electric (once itself a fuel cell pioneer) in 1999, but several dates for the cells' launch have come and gone. A major obstacle is reducing costs, including that of expensive platinum catalysts. Unless utility rates spike upwards, natural gas comes down and fuel cell efficiencies and costs improve, residential units aren't likely to become competitive with the grid.

Peter Bos, a Pacific Palisades fuel-cell analyst, predicts that conditions will soon become more favorable. He estimates that one percent of U.S. homes will have residential fuel cells between 2006 and 2010. When cell prices fall



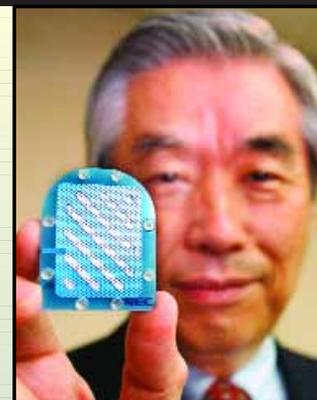
Home-based hydrogen generating appliances, such as the Avance Hydrofiller 50, will make it possible to refuel your fuel-cell vehicle.

more a few years later, the units will be in half of all homes, he says. And by 2031 we'll all be off the grid.

FUEL CELLS AS BATTERIES

Tired of laptop computer batteries that fade after three hours of use? Does 20 hours sound better? That's the promise of the miniaturized fuel cell, which could end the long run of the storage battery. Like the residential fuel cell, the battery replacements were supposed to be a vanguard product in the hydrogen revolution. But while the first products are imminent, rechargeable alkaline, lithium and nickel-metal-hydrate batteries (currently a \$5 billion annual business) will remain on the shelf for the foreseeable future.

Smart Fuel Cell began production of its 25-watt Remote Power System in 2002, and it is already powering traffic systems and camping equipment. The next product to hit the market will likely be the Coleman Powermate's 1.2-kilowatt, \$8,000 AirGen fuel-cell generator, **Firoz Rasul of Ballard Power Systems with its AirGen fuel-cell generator.**



This tiny NEC methanol-powered fuel cell could be the next generation of computer battery.

a portable unit running on bottled hydrogen without the noise and pollution of traditional generators. The Ballard-powered unit, intended to provide backup power, can run a computer, phone, fax machine and lamp for about eight to 10 hours before a \$100 refueling. Licensing and distribution issues have delayed the launch.

Other fuel-cell battery players include Motorola, Samsung, NEC, Toshiba (which plans a cell-powered notebook computer by 2004) and Manhattan Scientific, and they envision a thriving market by 2007. Early products could serve as backup power for existing batteries, or as built-in rechargers. Startup companies are also vying to get into the battery replacement market, including Seattle-based Neah Power Systems.

There is widespread agreement that standard lithium ion and nickel-metal-hydrate batteries have reached their limits and that fuel cells represent the future. Methanol, for instance, a common hydrogen source for small fuel cells, has 10 times the energy potential of lithium ion batteries. Chris Dyer, a fuel cell analyst and former Motorola executive, recently told the Grove Fuel Cell Symposium in London that fuel cells could replace batteries in most applications by 2006. CONTACT: Ballard Power Systems, (604)412-4740, www.ballard.com; Plug Power, (518) 782-7700, www.plugpower.com. **E**

JIM MOTAVALLI is editor of **E** and the author of *Breaking Gridlock: Moving Toward Transportation That Works* (Sierra Club Books).

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companies at their own central plants. When that happens, it will constitute a revolution in the way energy is produced and distributed. Once the customer, the end user, becomes the producer and supplier of energy, power companies around the world will be forced to redefine their role if they are to survive. A few power companies are already beginning to explore a new role as bundler of energy services and coordinator of energy activity on the energy web that is forming. In the new scheme of things, power companies would become "virtual utilities," assisting end users by connecting them with one another and helping them share their energy surplus profitably and efficiently. Coordinating content rather than producing it becomes the mantra for power companies in the era of distributed generation.

Utility companies, interestingly enough, serve to gain—at least in the short run—from distributed generation; though, until recently, many have fought the development. Because distributed generation is targeted to the very specific energy requirements of the end user, it is less costly and a more efficient way to provide additional power than is relying on a centralized power source. It costs a utility company between \$365 and \$1,100 per kilowatt to install a six-mile power line to a three-megawatt residential customer. A distributed generation system based on renewable energy can meet the same electricity requirements at a cost between \$500 and \$1,000 per kilowatt. Generating the electricity at or near the end users' location also reduces the amount of energy used because between five and eight percent of the energy transported over long distance lines is

lost in the transmission.

U.S. power companies are reluctant to make large financial investments in capital expansion because, under the new utility restructuring laws, they can no longer pass the costs of new capacity investment onto their customers. And because the field is now very competitive, power companies are reluctant to take funds from their reserves to finance new capacities. The result is that they put stress on existing plants beyond their ability to keep up with demand, leading to more frequent breakdowns and power outages. That is why a number of power companies are looking to distributed generation as a way to meet the growing commercial and consumer demand for electricity while limiting their financial exposure.

The energy revolution will advance on several fronts simultaneously. Before the hydrogen network can be fully realized, changes in the existing electricity grid will have to be made to assure both easy access to the web and a smooth flow of energy services over the web. That's where the software and communication revolution comes in. Connecting thousands and then millions of fuel cells to main grids will require sophisticated dispatch and control mechanisms to route energy traffic during peak and non-peak periods. The Windsor, Colorado-based Encorp has already developed a software program for remote monitoring and control that would automatically switch local generators onto the main grid during peak loads when more auxiliary energy was required. Retrofitting existing systems are estimated to run about \$100 per kilowatt, which is still less costly than build-

ing new capacity.

The integration of state-of-the-art computer technologies transforms the centralized grid into a fully interactive intelligent energy network. Sensors and intelligent agents embedded throughout the system can provide up-to-the-moment information on energy conditions, allowing current to flow exactly where and when it is needed and at the cheapest price. Sage Systems, for example, has built a software program that allows utilities to set back thousands of customers' thermostats by two degrees with a single command over the Internet if the system is at peak and over-stressed.

Hydrogen Safety

The issue of hydrogen safety inevitably arises, largely because of the spectacular fire that killed 36 people and destroyed the German dirigible *Hindenburg*. That 1937 disaster put an immediate end to zeppelin travel and saddled hydrogen with a nasty reputation it still carries with it today.

However, *The Hindenburg* was actually not hydrogen-fueled. The buoyant gas, used because helium was not available to the increasingly bellicose Nazi regime (the famous German airship bore a swastika on each side of its tail), filled 16 cells in the airship's body and gave it lift. Was the hydrogen on board *The Hindenburg* responsible for the fire? Conventional history has made that case, but retired NASA engineer Addison Bain, a hydrogen specialist, thinks otherwise. After several years of research that included tracking

down surviving pieces of the *Hindenburg's* cotton skin, Bain says that the on-board hydrogen certainly fueled the fire, but played no role in igniting it. The culprit, he says, was the highly flammable cellulose-doping compound used to coat the fabric covering and make it taut.

Nonetheless, there are some who speculate that hydrogen is simply too dangerous to ever be safely used for cars. Peter Voyentzie of Danbury, Connecticut's Energy Research Corporation, which makes large stationary fuel cell power plants, is skeptical about automotive applications. "Hydrogen is a strange beast," he says. "It's the smallest molecule, and it leaks out of everything. You also can't see it burn. In a car, it has to remain stable through collisions and constant agitation. That's a lot to expect."

But hydrogen may still be safer than gasoline. When spilled, it simply escapes upward instead of puddling and presenting an ignition hazard. It's odorless, its flame is invisible, and it emits very little radiant heat. People standing next to a hydrogen fire might not even be aware it's there. Even in diluted form, hydrogen will burn easily, but unless you're in physical contact with the fire, it won't hurt you. Remember, too, that fuel cell cars don't burn the fuel, though a spark generated in a crash could set it off.

The safety of hydrogen storage tanks for cars is also a concern, with regard to auto accidents. Hydrogen's safety problems shouldn't be minimized, but they shouldn't disqualify the fuel from consideration. Like gasoline, hydrogen can be dangerous. And, also like gasoline, we can learn to use it as safely as possible. ▶

CONVERSATIONS

James S. Cannon: *China at the Crossroads*



Cannon heads the Colorado-based Energy Futures, Inc., which publishes the journals *EV News*, *The Clean Fuels and Electric Vehicles Report* and *Hybrid Vehicles*. As a consultant and journalist, Cannon has visited 23 countries.

E: China's car population is growing at 19 percent a year, and the Chinese are dramatically curtailing bicycle use in favor of the private automobile. China has evolved a significantly large middle class that can afford cars, and automakers from all over the world are opening plants there. Aren't we looking at an incredible increase in global warming gas unless the Chinese take a serious look at a hydrogen energy economy?

James S. Cannon: In the U.S. now, American automobiles release about 30 tons of carbon dioxide (CO₂) every second. In China, the figure is much lower, but the projections for the Chinese automobile population have it surpassing the U.S. numbers, 200 million, within 10 to 20 years. At the current pace, you have China quickly becoming a larger CO₂ emitter than the U.S., which is now the world leader. It took the

U.S. a century to get to where it is today, and China only started having private automobiles five or 10 years ago. This is a very large threat to any attempt to mitigate global warming effects around the world.

I know there's a national hydrogen association in China, but are the Chinese really looking seriously at fuel-cell automobiles?

Yes, they are actually making great strides. They only started to work on the issue five to 10 years ago, so they're not yet seriously competitive with Japan, Germany or the U.S. in terms of producing prototype hydrogen-powered vehicles. When I visited China as part of a hydrogen delegation in 1997, we were hard-pressed to find more than just basic research into the chemical and physical properties of hydrogen. But since that time China has made very rapid progress in building a well-coordinated national hydrogen program. China is looking both at hydrogen production and the development of vehicle prototypes to use that hydrogen. There are several fuel-cell cars now, and plans for larger numbers.

Unlike the U.S., China does not have a multi-billion-dollar investment in a fossil fuel infrastructure. Could the Chinese leapfrog over the need to make such an investment and go directly to a hydrogen energy economy?

They could, and it's a very ambitious undertaking. The field is wide open because China doesn't have an integrated transportation system for any fuel today. Hydrogen fuel would be the most cost-effective approach China could take. You can see this now in Beijing. I attended the opening of the first natural gas pipeline in China five years ago, a big event that was not then attached to any transportation purpose. But now China has 5,000 natural gas buses tied in to that pipeline, the largest such fleet in the world. The government has realized some of the energy security issues associated with oil, and they're seriously considering bypassing oil in favor of something better.

China already has some of the world's worst air pollution—even without a big private car fleet.

That's correct. China has always realized that auto pollution was an issue, but a much bigger problem was the massive emissions from coal-burning power plants and uncontrolled industrial operations. Now the statistics show that in urban areas like Shanghai and Beijing, the automobile has emerged as the number one source of air pollution. The percentage of urban pollution from cars is now about the same as in the U.S.

Is China worried about its energy security, as it becomes, like the U.S., a net importer of oil?

The energy issue goes hand-in-hand with the burgeoning demand for vehicles in China. Until 1993, China was self-sufficient in oil. That year, China began to import oil, and it took only three years before the country was importing 20 percent of its petroleum. The U.S. was similarly self-supporting in oil for a significant part of the 20th century, but it took us 20 years to reach 20 percent foreign dependency. Today, China is 32 percent reliant on outside oil, and that is a

critical number because the U.S. was 32 percent dependent at the time of the crippling Arab oil embargo. Until recently, China imported oil from Indonesia and other Pacific Rim nations, but now there's a major reliance on unstable Middle Eastern countries, including Yemen and Iraq.

Are you ultimately optimistic that China will develop a hydrogen energy economy?

Yes, China has become very sensitive about this, and is grappling with it early on. They're hitting some of the dramatic warning signs about oil dependence. It's fortunate that so much is now available in demonstration programs and in the literature about the true potential of the hydrogen economy. So it's happening much quicker than we were thinking 10 or 20 years ago. Between the push and the pull of these issues, China is waking up very quickly. The natural gas bus program is creating the infrastructure for using gaseous fuels, and that could speed up the timetable and accelerate the work on hydrogen. **E**

INTERVIEWED BY JIM MOTAVALLI

Empowering the Poor

Incredibly, 65 percent of the human population has never made a telephone call, and a third of the human race has no access to electricity or any other form of commercial energy. The global average per capita energy use for all countries is only one fifth that of the U.S. The disparity between the connected and the unconnected is deep and threatens to become even more pronounced over the next half century with world population expected to rise from the current 6.2 billion to nine billion people. Most of the population increase is going to take place in the developing world, where the poverty is concentrated.

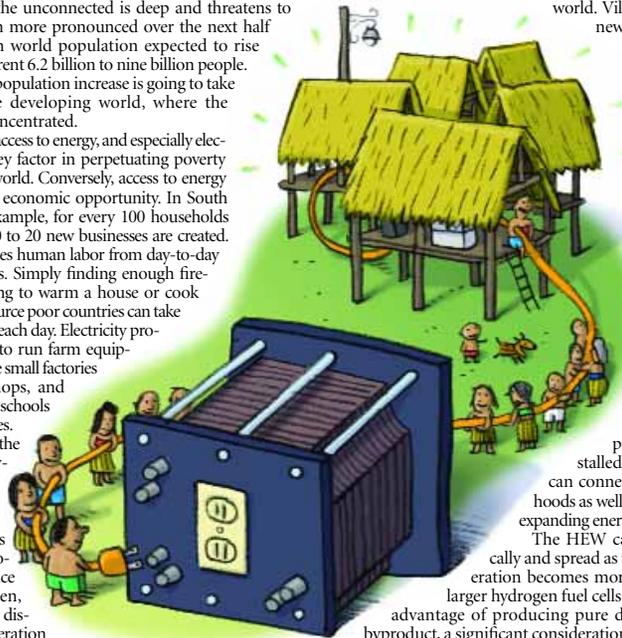
Lack of access to energy, and especially electricity, is a key factor in perpetuating poverty around the world. Conversely, access to energy means more economic opportunity. In South Africa, for example, for every 100 households electrified, 10 to 20 new businesses are created. Electricity frees human labor from day-to-day survival tasks. Simply finding enough firewood or dung to warm a house or cook meals in resource poor countries can take hours out of each day. Electricity provides power to run farm equipment, operate small factories and craft shops, and light homes, schools and businesses.

Making the shift to a hydrogen energy regime, using renewable resources and technologies to produce the hydrogen, and creating distributed generation energy webs that can connect communities all over the world, holds great promise for helping to lift billions of people out of poverty. Narrowing the gap between the haves and have-nots requires, among other things, narrowing the gap between the connected and the unconnected. It also presents a significant challenge: developing and harnessing renewable energy sources for hydrogen in countries with no current infrastructure.

As the price of fuel cells and accompanying appliances continues to plummet with new innovations and economies of scale, they will become far more broadly available, just as was the case with transistor radios, computers and cellular phones. The goal ought to be to provide stationary fuel cells for every neighborhood and village in the developing world. Villages can install renewable energy technologies to produce their own electricity, using some of it to separate hydrogen from water and store it for subsequent use in fuel cells. In rural areas, where commercial power lines have not yet been extended, because it is too expensive, stand-alone fuel cells can provide energy quickly and cheaply. After enough fuel cells have been leased or purchased and installed, mini-energy grids can connect urban neighborhoods as well as rural villages into expanding energy networks.

The HEW can be built organically and spread as the distributed generation becomes more widely used. The larger hydrogen fuel cells have the additional advantage of producing pure drinking water as a byproduct, a significant consideration in village communities around the world where access to clean water is often a critical concern.

Distributed generation associations (DGAs) could be established throughout the developing world. Cooperatives, lending institutions and local governments might then view distributed generation energy webs as a core strategy for building sustainable, self-sufficient communities. Breaking the cycle of dependency and despair, becoming truly "empowered,"



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starts with access to and control over energy.

National governments and world lending institutions need to be pressured to help provide both financial and logistical support for the creation of a hydrogen energy infrastructure. Equally important, new laws will need to be enacted to make it easier to adopt distributed generation. Public and private companies will have to be required to guarantee distributed generation operators access to the main power grid and the right to sell energy back or trade it for other services. And new investment will be needed to confront the remaining technical problems, which are daunting but certainly solvable.

The fossil-fuel era brought with it a highly centralized energy infrastructure, and an accompanying economic infrastructure, that favored the few over the many. Now, on the cusp of the Hydrogen Age, it is possible to imagine a decentralized energy infrastructure, enabling individuals, communities and countries to claim their independence, while accepting responsibility for their interdependence as well.

In the early 1990s, at the dawn of the Internet era, the demand for "universal access" to information and to communications became the rallying cry for a generation of activists, consumers, citizens and public leaders. Today, as we begin our journey into the Hydrogen Era, the demand for universal access to energy ought to inspire a new generation of activists to help lay the groundwork for establishing sustainable communities.

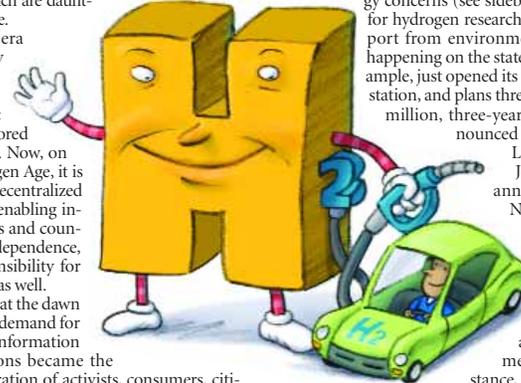
Were all individuals and communities in the world to become the producers of their own energy, the result would be a dramatic shift in the configuration of power. Local peoples would be less subject to the will of far-off centers of power. Communities would be able to produce many of their

own goods and services and consume the fruits of their own labor locally. But, because they would also be connected via the worldwide communications and energy webs, they would be able to share their unique commercial skills, products and services with other communities around the planet.

By redistributing power broadly to everyone, it is possible to establish the conditions for a truly equitable sharing of the Earth's bounty. This is the essence of the politics of re-globalization from the bottom up.

will hydrogen be made? Agreement on the broad outlines of a national and international hydrogen infrastructure is desperately needed. Will the new regime be imposed from the top down, or the bottom up?

The hydrogen economy is within sight. How fast we get there will depend on how committed we are to weaning ourselves off of oil and the other fossil fuels. What are we waiting for? CONTACT: Foundation on Economic Trends, (202) 466-2823, www.foet.org; FreedomCAR, www.ott.doe.gov/freedom_car.shtml.



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A HYDROGEN ECONOMY HAS THE POTENTIAL TO ALLOW A VAST REDISTRIBUTION OF POWER, WITH FAR-REACHING CONSEQUENCES FOR SOCIETY.



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Looking Forward

A more sustainable and equitable future made possible by a worldwide hydrogen web looms on the horizon, but it is as yet woefully unrealized. California, the incubator of the American hydrogen industry, has only two hydrogen filling stations, and there are less than 12 in the entire U.S. There are only a few fuel-cell cars, all million-dollar prototypes. Al-

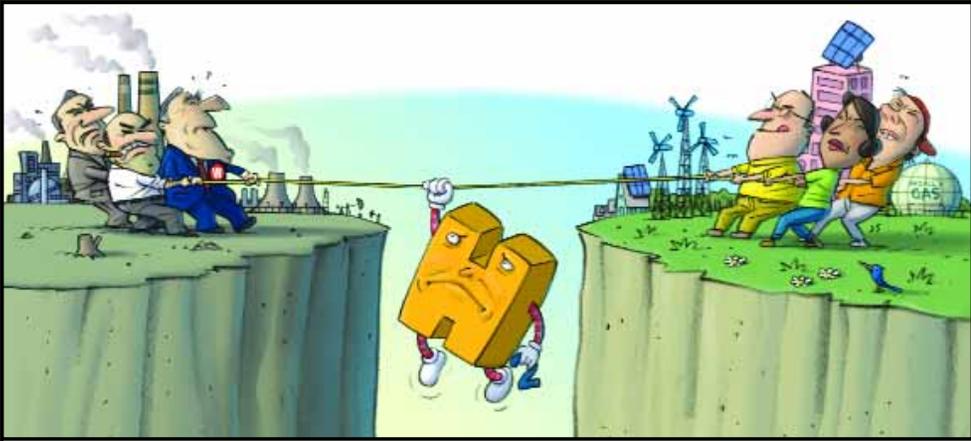
JEREMY RIFKIN is president of the Foundation on Economic Trends and the author of such works as *The End of Work*, *The Biotech Century* and *The Age of Access*. His latest book is *The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth (Tarcher Putnam)*, from which this article is excerpted.

EUROPE'S HYDROGEN INVESTMENT

Romano Prodi, the president of the European Commission, the governing body of the 15-nation European Union (EU), has unveiled the EU's \$2 billion commitment to a renewable hydrogen-based energy economy. Jeremy Rifkin, the author of this piece and an advisor to President Prodi, was the architect of the strategic white paper that launched the initiative.

The aim, Prodi said in U.S. remarks that were covered both by the *New York Times* and the *Wall Street Journal*, is to bring industry, the research community and government together to map out the hydrogen future. President Prodi said that the EU's scientific effort will be as important for Europe as the space program was for the United States in the 1960s and 1970s. The EU has already committed itself to producing 22 percent of its electricity from renewable sources by 2010.

—J.M.



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HIJACKING HYDROGEN

Will Big Oil, Coal Interests and the Nuclear Industry Control the Next Energy Revolution?

By Jim Motavalli

Whether or not hydrogen becomes “the people’s energy” depends to a large extent on how it is generated and transported in the current, early stages of development. This sustainable gas can be generated locally via renewables like wind, biomass or solar power, but it could also be a new product for our large-scale, centralized oil and nuclear power industries. Mike Nicklas, chairperson of the American Solar Energy Society (ACES), warns that even though the Bush administration is publicly supporting hydrogen development through its new FreedomCAR program, its vision does not support clean energy technologies for hydrogen production.

“Clean” in this case means coal, nuclear and natural gas,” says Nicklas, who attended the federal National Hydrogen Energy Roadmap Workshop last April. Fossil fuel and nuclear industry representatives dominated the session on hydrogen production, Nicklas observes. “We’re now at the point of making a transition to an entirely new energy paradigm, and we don’t need to be continuing the carbon era by other means.” Nicklas says that ACES is working with other groups, including Worldwatch and the World

Resources Institute, to promote truly renewable hydrogen generation.

In what could be a parallel to its purchase of many solar companies, the oil industry is buying in to hydrogen: Shell established Shell Renewables in 1997 and Shell Hydrogen in 2000, BP/Amoco is investing \$500 million in renewables over three years, and ChevronTexaco has purchased a 20 percent stake in Energy Conversion Devices, a Detroit-based photovoltaic, battery and fuel-cell company.

Large utilities are also interested in generating hydrogen from what they call “clean coal,” coupled with a scheme to “sequester,” or isolate the resulting carbon dioxide emissions to prevent them from entering the atmosphere. According to one scenario, coal would react with steam and oxygen before combustion to produce hydrogen and carbon dioxide, with the carbon dioxide liquefied and stored underground in deep aquifers or other geological formations.

GOING NUCLEAR

At the annual meeting of the World Nuclear Association in London last September, the group’s director general, John Ritch, touted what he called the “hydrogen-nuclear economy.” He

envisions “an entirely clean energy global economy, with nuclear power supplying not only electricity and clean water, but also energizing transport of all kinds.”

There are 400 conventional nuclear plants in the world, generating a sixth of global electricity. While these plants produce no emissions of carbon dioxide, the major global warming gas, they have created an intractable radioactive waste crisis and an ongoing safety debate that has made it extremely difficult to license any new facilities.

Some scientists see the need for large-scale hydrogen production as a way to jumpstart the moribund nuclear industry. Speaking at the International Youth Nuclear Congress in South Korea last April, Dr. Leon Walters, former director of engineering at Argonne National Laboratory, estimated that nuclear power—now just seven percent of U.S. power production—could leap to 50 percent if it were harnessed to produce hydrogen for transportation. He estimates that a transition to a hydrogen-nuclear economy would take 30 years.

General Atomics held a workshop last May on producing hydrogen from both conventional nuclear fission and as-yet unproven nuclear fusion. L.M.

Wagner of Boeing said at the forum that hydrogen could be profitably produced in off-peak hours from fusion reactors. Nuclear fusion, if it were feasible, would produce no radioactive waste or bomb-grade materials, but no practical process for a fusion reactor has yet been demonstrated, despite hundreds of millions of dollars in funding over the past 50 years.

Joan Ogden, a Princeton research scientist, says that the frontrunner for nuclear hydrogen production is a thermochemical heat process. “This is a difficult technology that is much further from commercialization than many other hydrogen production options,” Ogden says. A recent analysis by Ogden’s Princeton colleague, Robert Williams, found that thermochemical nuclear hydrogen would be an expensive and complicated procedure when compared to other methods.

per prepared by DOE energy scientist Samuel Rosenbloom, “Hydrogen Development Program: A Perspective,” is stridently pro-nuke, describing renewable production as “high risk” and “long term.” The proposed goal: “Nuclear-driven hydrogen production demonstration by 2006,” coinciding with the 100th anniversary of Albert Einstein’s relativity theory.

Speaking anonymously, a high-ranking official in DOE’s Office of Hydrogen, Fuel Cells and Infrastructure Technologies said that hydrogen should be generated from “diverse feedstocks [including reformation of fossil fuels, nuclear and electrolysis of water using renewable sources], with some more suited to certain regions than others.” The official said that many DOE scientists had concluded that nuclear generation of hydrogen “is the way to go,” but added, “I per-

sonally don’t think that they’ve addressed the waste issue in a way that alleviates the fears of the public.”

A LEVEL PLAYING FIELD

Thomas Jackson, president of Milford, Connecticut-based Avaleance, which is working on residential hydrogen electrolyzers (essentially, a home-based hydrogen station), worries that federal incentives will go to the nuclear industry and strongly influence what would otherwise be a free market for new technologies. “There needs to be a level playing field that includes all the different approaches,” Jackson says.

Similarly skeptical is C. E. “Sandy” Thomas, president of Virginia-based H2Gen, which is moving rapidly to develop natural gas steam reformation technology to install hydrogen pumps at gas stations around the country by 2004. Thomas, an advocate of direct, renewable-generated hydrogen since his days as an advisor to Ford’s fuel-cell efforts, is very dubious about nuclear fusion, which he notes has yet to reach the break-even point of energy production. Even if a breakthrough did occur, he says, “engineers would still have to design, build and test reactors that could produce a net increase in energy at an af-

fordable cost.” Thomas’ vision calls for localized hydrogen production. “Make the hydrogen where people want it,” he says, “at filling stations, at fleet operators’ garages and even at home. Through economies of mass production, that could be the least costly way to make hydrogen in the long run.” Obviously, the world’s dominant energy industries will not happily go out of business or voluntarily cede market share to renewables, though there is growing evidence that, at least in the long term, solar and wind power could be harnessed to produce a decentralized, completely zero-emission energy loop. Thomas, who champions steam reformation of natural gas as an interim step, advocates a truly spectacular zero emissions end game, in which the fuel is produced from a combination of regionally appropriate photovoltaic collectors,

Will the HYDROGEN FUTURE be driven by big energy companies or done OVER THEIR DEAD BODIES?

JIM MOTAVALLI is the editor of E.