Hydrogen: Solution or Distraction?

A Debate on the "Hydrogen Economy"

For years, talk of the coming hydrogen economy has excited some in the renewable energy movement and irritated others. Will hydrogen be the solution to our energy woes? Or is it a distraction that siphons dollars and attention away from more practical solutions?

Home Power asked Richard Engel, hydrogen promoter, and Dominic Crea, hydrogen critic, to air their views. Each submitted a 1,000 word statement independently, and then had a chance to rebut the other's statement briefly. We hope you enjoy the discussion.

A Renewable Energy Future Needs Hydrogen

Richard Engel

As fossil fuels become scarce, renewable energy is poised to emerge as the best alternative for our future global energy economy. Given the intermittent nature of renewable energy resources, however, some form of energy storage will be a critical element of this new renewables-based economy. Hydrogen is the best all-around energy storage technology identified to date.

Today's household-scale users of renewable energy already know that energy storage—whether it's a bank of batteries or the grid—is essential for any practical system. There are a number of technologies for storing electrical energy, including batteries, superconducting magnets, ultracapacitors, pumped hydroelectric storage, compressed air, thermal storage, and flywheels. Hydrogen beats these other methods in balanced overall analyses considering technical feasibility, cost, wire-to-wire efficiency, lifespan, weight, and volume. Author A. Ter-Gazarian, in the book *Energy Storage for Power Systems*, agrees: "There are major technical problems to be solved in

Drunk on Hydrogen—Some Sobering Facts

Dominic Crea

As a physics teacher, I often study and lecture on renewable energy, and occasionally my calculations uncover some disturbing contradictions. The "hydrogen economy" is just such a case, and I think it's time to point out some reasons why we should be careful about pinning all of our hopes on this technology.

Let's start with the generation of hydrogen. Of the various ways it can be produced, two techniques are being considered—steam reforming of coal and natural gas, and electrolysis of water via renewable energy sources. The reforming process, while technically feasible, leaves much to be desired from an environmental and sustainability perspective. Hydrogen generated in this manner still produces the same, if not more, CO_2 (various proposals for sequestering the CO_2 are speculative). And in the case of natural gas (coal has its own, unique issues), merely shifts our dependency to a commodity whose future supply is in serious question. A fossil-fueled hydrogen economy is a gamble at best and a nightmare at worst.

Richard Engel, continued

the production, utilization, and storage of hydrogen, but, nevertheless, it is the most promising concept for future environmentally benign energy systems."

Batteries are today's most widely used form of energy storage. Off-grid solar electricity users are already aware of batteries' drawbacks. They know that batteries are the weak link in stand-alone renewable energy systems. They incorporate large amounts of hazardous materials, are too heavy and bulky for many portable and transportation applications, and have a relatively high self-discharge rate, making them unsuitable for longer-term seasonal energy storage. Batteries are inappropriate for energy storage on a national or global level. The other storage technologies listed above are limited by high cost or by narrow applicability.

Misdirected Funds

In spite of hydrogen's promise, many environmentalists and advocates of renewable energy are understandably suspicious of all the recent hydrogen happy talk from the White House and Wall Street. Hydrogen can be reformed chemically from any hydrocarbon fuel or split from water using electricity from any source. The nuclear and coal industries are thus latching onto hydrogen as a means to assure their continued dominance of energy markets.

In the public sector, the U.S. federal government has greenwashed itself by increasing spending on hydrogen energy research and development. At the same time, it is shelving policies such as improved auto mileage, building efficiency standards, and deployment of cost-effective renewable energy technologies that could offer greater benefit sooner, and at lower cost.

Hydrogen research and development (R&D) is a great use of tax dollars, but much of the recent federal spending increase is directed at nonrenewable hydrogen technologies. President Bush's fiscal year 2004 budget

The Schatz Solar Hydrogen Project in Trinidad, California, has been generating and using solar hydrogen to help power a marine research laboratory since 1991.

Dominic Crea, continued

Renewable Hydrogen?

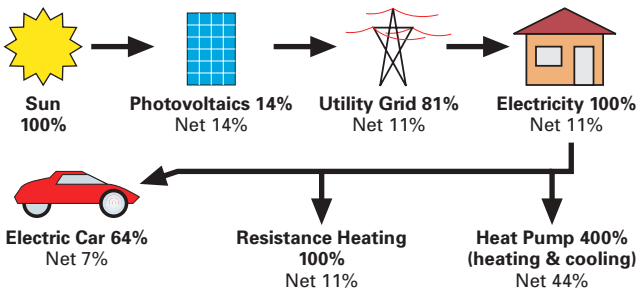
What about a renewably based hydrogen economy? In this scenario, vast arrays of photovoltaic modules and large wind farms will, through electrolysis, split water into hydrogen and oxygen. The hydrogen will be pumped down a pipeline and delivered to homes and industries, where the gas can be used in several ways:

- Direct burning, as in a furnace, to provide for heat, hot water, and cooking
- In a fuel cell, to generate electricity for residential and industrial use
- In fuel cell powered cars, boats, or lawnmowers

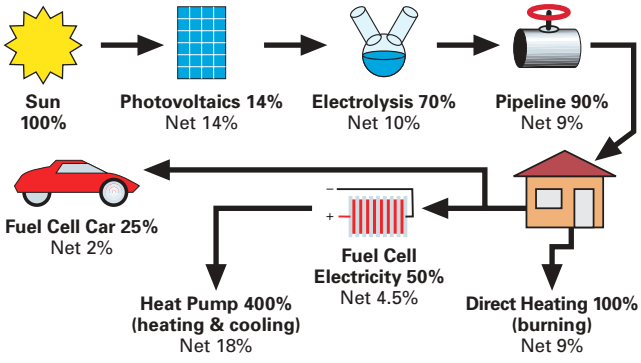
Superficially, these ideas seem palatable, and could in theory reduce or even eliminate our dependency on fossil fuels. But let's examine these claims in greater detail, starting with the pipeline. It doesn't exist. Nor, for that matter, does the rest of the hydrogen infrastructure, the total cost of which is open to debate. Moreover, we already have a proven system that can, and does, deliver energy to us with great efficiency—the utility grid.

The diagram below illustrates the two pathways—the hydrogen pipeline vs. the electricity grid—and displays how much of the original energy is left (net energy) after it is converted (net energy x conversion efficiency). Both systems assume the use of photovoltaic electricity. Remarkably, the hydrogen route wastes twice as much energy as the utility grid pathway!

Distributed Electricity Efficiencies



Distributed Hydrogen Efficiencies



Richard Engel, continued

proposal to Congress earmarked US$22 million for research related to generating hydrogen from coal, natural gas, and nuclear power, with just US$17 million for renewable hydrogen R&D. Both of these figures are dwarfed by the US$62 million Bush earmarked for research on carbon sequestration, without which coal-to-hydrogen is a worthless concept. The same budget reduced overall funding for renewables and energy efficiency by US$86 million.

Spending decisions like these may help to explain why some renewable energy advocates are looking askance at hydrogen. But we need to remember that hydrogen and renewables are natural allies. Let's not be lured into fighting each other over scraps while the oil, coal, and nukes gang stays firmly in control of our energy policy.

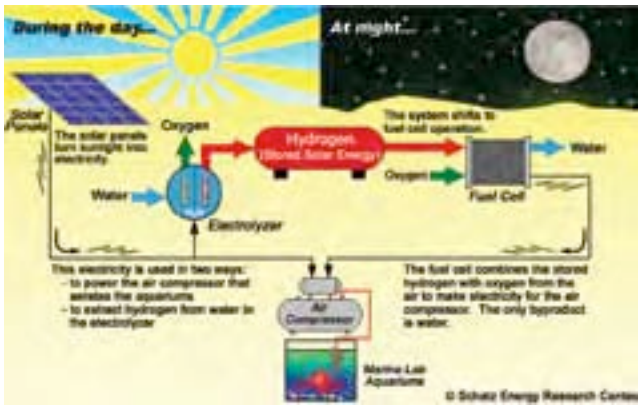
Fuel Cells Work

As manufacturers repeatedly push back release dates for their products, people are starting to ask whether fuel cells really work. At the Schatz Energy Research Center, we know that they do. Like many renewable energy technologies a few decades ago, fuel cells today are still in their infancy. But hundreds of real-life installations worldwide are proving that this clean, quiet, and efficient technology is ready to play an important role. Our work at the Schatz lab continues to improve the reliability, longevity, and cost of fuel cells to make them more acceptable to consumers.

Perhaps an excess of hype has made us all a bit impatient. Bragi Arnason, one of the creators of Iceland's national plan to switch to hydrogen power, notes, "If you look back in history, it has usually taken half a century to change from one type of energy to another—from wood to coal to oil. My generation will see the first steps."

Even more urgent than the need for technological advances, however, is the need to educate the public about hydrogen and fuel cells. Providing this understanding is another role that our research center plays every day.

This diagram is posted at the Schatz Solar Hydrogen Project to help visitors understand how a renewable hydrogen cycle works.

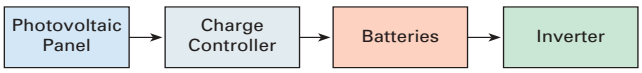


Dominic Crea, continued

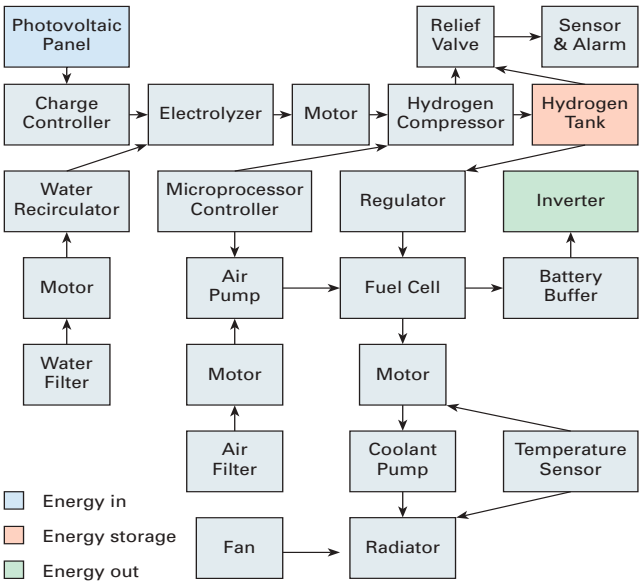
Direct heating with electric or hydrogen combustion at 10 percent net efficiency is dubious too. Even a simple rooftop solar heater (50 percent overall conversion efficiency) can outperform this by many times, and at a fraction of the cost. A case can be made for direct electric heat pumps providing both heating and cooling, but even here, the hydrogen system is still less than half as efficient as the grid system.

Okay, let's say we skip the hydrogen pipeline entirely and consider the most idyllic setting, a totally off-grid home. True, we can generate electricity for our homes and fuel our cars with hydrogen, but we must remember that our photovoltaics ultimately provide the electricity—hydrogen acts simply as a storage medium for that energy. A battery will do the same. Consider the complexity of the hydrogen fuel cell system below, and compare it to the battery storage system. Simplicity speaks volumes.

Battery System Complexity



Fuel Cell System Complexity



Questionable Efficiency

Now, let's examine the fuel cell powered car in greater detail. We'll start with the assumption that the electricity is coming out of a wall socket, and measure efficiencies from that point onward. (The case of pipeline transmission is even worse.)

A fuel cell has an electric conversion efficiency of around 50 percent. The real-world efficiency of PEM fuel cells is different from the theoretical maximum (83 percent). Calculation depends on the terminal voltage of each cell divided by the theoretical separation voltage of

Richard Engel, continued

In our educational outreach, we constantly reinforce the link between hydrogen and renewable energy. We also work to clear up misconceptions, such as the belief that hydrogen is a particularly dangerous fuel, or that hydrogen is a primary energy source we can exploit like oil or sunshine.

We live in a special time of cheap and abundant energy. Despite their potential to pollute air, water, and soil, fossil fuels provide us with cheap, portable, high-density stored energy the likes of which we may never see again. We should use them wisely.

Our Choice

The coming hydrogen energy economy will be what we choose to make it. At its worst, hydrogen could be a launching pad for the return of nuclear power and expanded use of coal, as world oil and natural gas supplies dwindle in coming years. An energy economy built on hydrogen derived from these nonrenewable sources would allow us to carry on with business as usual for a few more decades as our environment continues to deteriorate.

A much better, and I believe realistic, outcome is to build an economy based on renewable electric and thermal energy, incorporating hydrogen where needed to store and transport this energy, and for use as a transportation fuel.

However, there's a big "if" hanging over all our discussions of renewable energy, hydrogen, and sustainability. In the wealthier countries, we cannot keep increasing our energy use, or even maintain our energy use at current levels, under a renewable hydrogen economy. Renewable hydrogen will only prove viable if we greatly improve energy efficiency and, far more important, realign our behavior and expectations with regard to energy. In a steady-state renewable hydrogen economy, we will have to consume less than we do today.

This is not doom and gloom, but rather a necessary coming to terms with planetary resource limits. A renewable energy future will be healthier and more secure than the world we live in today. The path to such a sustainable outcome begins with all of us lobbying political and industry leaders with our votes, our voices, and our consumer dollars to develop clean and renewable energy technologies.

Response from Dominic Crea

I would like to start off by saying that I agree with many of the fine points Richard Engel has raised over such issues as conservation, concern over misuse of research funds, and

Dominic Crea, continued

water (1.23 volts). Typical values for 50 percent loaded cells hover around 0.55 to 0.8 volts.

To that 50 percent number, we must add the inefficiencies of additional components—the inverter at 90 percent, drive motor at 90 percent, electrolyzer at 70 percent, hydrogen storage at 80 percent, O_2 (air compressor) at 80 percent, and finally, the heat management systems at 98 percent. The total efficiency is about 18 percent! A battery electric car has an overall efficiency of about 65 percent—over three times the efficiency of the fuel cell powered car!

These points, and numerous others, are cause for a serious reassessment of the hydrogen economy. At the very least, a renewably based hydrogen economy will require the installation of US$40 trillion worth of photovoltaic panels, of which US$20 trillion is wasted in overcoming the inefficiency of the system—minimum!

In simple terms, the decision to go with a renewably fueled utility grid system, as opposed to the hydrogen system, would save enough money in photovoltaic panels alone to provide every American family with an electric car and the photovoltaic panels to run it. Furthermore, enough would be left over to handle all of the electricity, heating, and cooling needs for the entire house—for free!

Solutions that Deliver

Hydrogen may hold a place in our energy future, but we must remain mindful of its limitations as well as its potential. A headlong rush to develop a hydrogen economy might well distract us from other solutions whose practicality is not in question—conservation, carpooling, public transportation, electric and alcohol fueled cars, biking, walking, telecommuting, online education and shopping, rooftop solar heating and electricity, three and four day optional work weeks, etc. These ideas and many more have proven themselves. Time is running out. Let's make sure that we follow a course that makes sense and does more than promise—let it deliver!

Response from Richard Engel

I agree with Dominic that renewable energy has to be the foundation of our energy future. Our difference of opinion is on how best to store renewable energy to make it portable and to match loads over time.

Wherever possible, renewable energy needs to be used directly at the time and place of generation. This avoids the complexity and inefficiency found in any storage scheme.

Crea Response, cont.

the potential of hydrogen to "greenwash" the American public. Richard and I both feel very strongly that an energy policy based on the use of nonrenewable feed stocks, such as coal and natural gas, has the wrong focus.

That being said, I must point out that we differ in our perception of the likelihood of hydrogen becoming a viable fuel in the near future. While hydrogen arguably has the potential for significant energy storage, it is by no means the only—or even the most desirable—method by which to accomplish this task. At 300 BTUs per cubic foot, hydrogen, even at 400 atmospheres pressure, contains only about one-quarter of the thermal energy of ethanol on a volume basis.

In terms of domestic electricity, it must be remembered that the transmission of hydrogen entails many loss mechanisms, amounting to fully half or more of the original energy contained in the gas. On the other hand, a national grid-intertie system that allows homeowners to dump excess PV electricity back into the grid during daytime hours (when demand is highest) is a proven technology. Likewise, the storage of heat and cold can be accomplished with exceedingly simple, reliable, and above all else, safe heat of fusion chemical systems.

Hydrogen has potential—perhaps in aviation, nautical, and rail vehicles in the form of liquefied gas where destinations and schedules are well known. But it also has some very significant limitations, and we should be mindful of this fact. Hydrogen is being promoted as a panacea for all our energy woes, but we must examine the quantitative realities, not the qualitative promises offered by hydrogen advocates.

It is my belief that we can ill afford to place such emphasis on hydrogen. To do so will divert attention from technologies that are better suited to a national energy policy. As a start, why not use our tax dollars to supply homes with net metered PVs before spending it on hydrogen demonstration filling stations?

Certainly, if hydrogen technologies mature, they will need a renewably based energy source. Let's make sure we put the horse in front of, rather than behind, the cart.

Engel Response, cont.

But where storage or portability is necessary, hydrogen is the best choice. Do we want to keep relying on batteries for all of our energy storage needs?

Like Dominic, I'm a fan of simplicity. But complexity in power and transportation technologies can and does work for us every day. The renewable hydrogen systems we design, build, and operate at Schatz don't even approach the complex synthesis of computer and mechanical technologies under the hood of any new car. For that matter, how simple are the computers on which Dominic and I are composing our debate?

Regarding Dominic's schematic comparison of hydrogen and battery systems, it's unfair to ignore the complexity, cost, and environmental impacts inherent in safely disposing of and replacing batteries every few years.

As for the electrical efficiency of fuel cells, most of their losses, particularly in larger stationary applications, can be recaptured as useful heat energy. Such co-generating fuel cell systems can compete with batteries on overall efficiency. Here are just a few examples of applications where hydrogen energy already makes sense:

Transportation fuel. Battery powered cars will never go far enough or charge fast enough to approach the performance we take for granted today. A gasoline or hydrogen pump transfers energy to a car at a rate of about 10 MW. Battery cars can't come close to matching this.

Seasonal energy storage. Batteries' high self-discharge rates make storing summer solar energy for winter use infeasible. We regularly store hydrogen at pressures of thousands of psi with no measurable loss over months.

Portable energy. On a weight basis, a regenerative fuel cell system (fuel cell, electrolyzer, and storage) offers two to five times the energy storage of the best available batteries.

Direct use of renewable energy is beyond a doubt our best option for the future. Where storage or portability is necessary, hydrogen's abundance, cleanliness, and efficiency make it renewable energy's greatest ally. Combined with efficient and conservative use of energy, renewables and hydrogen can lead us to a healthier and more secure future.

Access
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