The Hydrogen Economy – Energy and Economic Black Hole

Contributed by Alice Friedemann
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Editor's note: Wonder why you're hearing much more about biofuels than hydrogen fuel these days? It's because the "Hydrogen Economy" has been found to be unrealistic. It so happens our author has been a main factor in sinking the technofix illusion of hydrogen. Alice Friedemann's next report is on biofuels, and it ought to accomplish the same thing.

This report was first published on Culture Change as a draft two years ago. A revision appeared in various publications, helping to burst the hydrogen bubble as promoted by George W. Bush, Jeremy Rifkin and Arnold Schwartzenegger. You are looking at the very latest edition. - JL

The energy-literate scoff at perpetual motion, free energy, and cold fusion, but what about the hydrogen economy? Before we invest trillions of dollars, let’s take a hydrogen car out for a spin. You will discover that hydrogen is the least likely of all the alternative energies to solve our transportation problems. Hydrogen uses more energy than you get out of it. The only winners in the hydrogen scam are large auto companies receiving billions of dollars via the FreedomCAR Initiative to build hydrogen vehicles.

Most importantly perhaps, the real problem that needs to be solved is how to build hydrogen trucks, so we can plant, harvest, and deliver food and other goods. However, hydrogen trucks are completely impractical, as we shall see in this report.

Making it

Hydrogen isn’t an energy source – it’s an energy carrier, like a battery. You have to make it and put energy into it, both of which take energy. Hydrogen has been used commercially for decades, so at least we don't have to figure out how to do this, or what the cheapest, most efficient method is.

Ninety-six percent of hydrogen is made from fossil fuels, mainly to refine oil and hydrogenate vegetable oil--the kind that gives you heart attacks (1). In the United States, ninety percent of hydrogen is made from natural gas, with an efficiency of 72% (2). Efficiency is how much energy you get back compared with how much energy you started out with. So an efficiency of seventy-two percent means you've lost 28% of the energy contained in the natural gas to make hydrogen. And that doesn’t count the energy it took to extract and deliver the natural gas to the hydrogen plant.

Only four percent of hydrogen is made from water. This is done with electricity, in a process called electrolysis. Hydrogen is only made from water when the hydrogen must be extremely pure. Most electricity is generated from fossil fuel driven plants that are, on average, 30% efficient. Where does the other seventy percent of the energy go? Most is lost as heat, and some is lost as it travels through the power grid.

Electrolysis is 70% efficient. To calculate the overall efficiency of making hydrogen from water, the standard equation is to multiply the efficiency of each step. In this case you would multiply the 30% efficient power plant times the 70% efficient electrolysis to get an overall efficiency of 20%. This means you have used four units of energy to create one unit of hydrogen energy (3).

Obtaining hydrogen from fossil fuels as a feedstock or an energy source is a bit perverse, since the whole point is to avoid using fossil fuels. The goal is to use renewable energy to make hydrogen from water via electrolysis.

Current wind turbines can generate electricity at 30-40% efficiency, producing hydrogen at an overall 25% efficiency (.35 wind electricity * .70 electrolysis of water), or 3 units of wind energy to get 1 unit of hydrogen energy. When the wind is blowing, that is.

The best solar cells available on a large scale have an efficiency of ten percent when the sun is shining, or nine units of energy to get 1 hydrogen unit of energy (.10 * .70). But that's not bad compared to biological hydrogen. If you use algae that make hydrogen as a byproduct, the efficiency is about .1%, or more than 99 units of energy to get one hydrogen unit of energy (4).

No matter how you look at it, producing hydrogen from water is an energy sink. If you don't understand this concept, please mail me ten dollars and I'll send you back a dollar.

Hydrogen can be made from biomass, but then these problems arise (5):

- Biomass is very seasonal

- Contains a lot of moisture, requiring energy to store and then dry it before gasification

- There are limited supplies

- The quantities are not large or consistent enough for large-scale hydrogen production.

- A huge amount of land would be required, since even cultivated biomass in good soil has a low yield -- 10 tons of biomass per 2.4 acres

- The soil will be degraded from erosion and loss of fertility if stripped of biomass

- Any energy put into the land to grow the biomass, such as fertilizers, planting, and harvesting will add to the energy costs

- Energy and costs to deliver biomass to the central power plant

- It's not suitable for pure hydrogen production

One of the main reasons for switching to hydrogen is to prevent the global warming caused by fossil fuels. When hydrogen is made from natural gas, nitrogen oxides are released, which are 58 times more effective in trapping heat than carbon dioxide (6). Coal releases large amounts of CO_2 and mercury. Oil is too powerful and useful to waste on hydrogen–it's concentrated sunshine brewed over hundreds of millions of years. A gallon of gas represents about 196,000 pounds of fossil plants, the amount in 40 acres of wheat (7).

Natural gas is too valuable to make hydrogen with. One use of natural gas is to create fertilizer (as both feedstock and energy source). This has led to a many-fold increase in crop production, allowing an additional 4 billion people to exist that otherwise wouldn't be here (8, 9).

We also don't have enough natural gas left to make a hydrogen economy happen. Extraction of natural gas is declining in North America (10). It will take at least a decade to even begin replacing natural gas with imported LNG (liquified natural gas). Making LNG is so energy intensive that it would be economically and environmentally insane to use natural gas as a source of hydrogen (3).

Putting energy into hydrogen

No matter how it's been made, hydrogen has no energy in it. Hydrogen is the lowest energy dense fuel on earth (5). At room temperature and pressure, hydrogen takes up three thousand more times space than gasoline containing an equivalent amount of energy (3). To put energy into hydrogen, it must be compressed or liquefied. To compress hydrogen to 10,000 psi is a multi-stage process that will lose an additional 15% of the energy contained in the hydrogen.

If you liquefy hydrogen, you will be able to get more hydrogen energy into a smaller container, but you will lose 30-40% of the energy in the process. Handling hydrogen requires extreme precautions because hydrogen is so cold – minus 423 F. Fueling is typically done mechanically with a robot arm (3).

Storage

The more you compress hydrogen, the smaller the tank can be. But as you increase the pressure, you also have to increase the thickness of the steel wall, and hence the weight of the tank. Cost increases with pressure. At 2000 psi, it's $400 per kg. At 8000 psi, it's $2100 per kg (5). And the tank will be huge -- at 5000 psi, the tank could take up ten times the volume of a gasoline tank containing the same energy content.

That's why it would be nice to use liquid hydrogen, which allows you to have a much smaller container. But these storage tanks get cold enough to cause plugged valves and other problems. If you add insulation to prevent this, you will increase the weight of an already very heavy storage tank. There are additional components to control the liquid hydrogen which add extra costs and weight (11).

Here's how a hydrogen tank stacks up against a gas tank in a Honda Accord.

Fuel - - - - - - Amount of Fuel - - Weight with fuel - - Driving Range - - Tank Cost

Hydrogen - - - 3 kg @3000 psi - - - 400 kg - - - - - - - - 55 miles (5) - - - - $2000 (5)

Gasoline - - - - 17 gallons - - - - - - - 73 kg - - - - - - - - - 493 miles - - - - - - $100

According to the National Highway Safety Traffic Administration (NHTSA), "Vehicle weight reduction is probably the most powerful technique for improving fuel economy. Each 10 percent reduction in weight improves the fuel economy of a new vehicle design by approximately eight percent".

Fuel cells are also heavy: "A metal hydride storage system that can hold 5 kg of hydrogen, including the alloy, container, and heat exchangers, would weigh approximately 300 kg (661 lbs), which would lower the fuel efficiency of the vehicle," according to Rosa Young, a physicist and vice president of advanced materials development at Energy Conversion Devices in Troy, Michigan (12).

Fuel cells are expensive. In 2003, they cost $1 million or more. At this stage, they have low reliability, need a much less expensive catalyst than platinum, can clog and lose power if there are impurities in the hydrogen, don't last more than 1000 hours, have yet to achieve a driving range of more than 100 miles, and can't compete with electric hybrids like the Toyota Prius, which is already more energy efficient and lower in CO2 generation than projected fuel cells. (3)

Hydrogen is the Houdini of elements. As soon as you've gotten it into a container, it wants to get out, and since it's the lightest of all gases, it takes a lot of effort to keep it from escaping. Storage devices need a complex set of seals, gaskets, and valves. Liquid hydrogen tanks for vehicles boil off at 3-4% per day (3, 13).

Hydrogen also tends to make metal brittle (14). Embrittled metal can create leaks. In a pipeline, it can cause cracking or fissuring, which can result in potentially catastrophic failure (3). Making metal strong enough to withstand hydrogen adds weight and cost.

Leaks also become more likely as the pressure grows higher. It can leak from un-welded connections, fuel lines, and non-metal seals such as gaskets, O-rings, pipe thread compounds, and packings. A heavy-duty fuel cell engine may have thousands of seals (15). Hydrogen has the lowest ignition point of any fuel, 20 times less than gasoline. So if there’s a leak, it can be ignited by a cell phone, a storm miles away (16), or the static from sliding on a car seat.

Leaks and the fires that might result are invisible, and because of the high hydrogen pressure, the fire is like a cutting torch with an invisible flame.   Unless you walk into a hydrogen flame, sometimes the only way to know there’s a leak is poor performance.

In 2002, given the same volume of fuel, a diesel fuel vehicle could go 90 miles, and a hydrogen vehicle at 3600 psi could go 5 miles. But that’s nothing compared to the challenges trucks face. I know we’re just supposed to only driving a hydrogen car, but it’s really hydrogen trucks that are most critical. If we don’t figure out how to make them, we won’t have a way to distribute food and other goods across the country.

A truck can go a thousand miles with two 84 gallon tanks placed under the cab, which takes up 23 cubic feet. But the equivalent amount of hydrogen at 3600 psi would take up almost 14 times as much space as the gas tanks. It is hard to imagine where you could put the two cylindrical, twelve feet long by four feet wide hydrogen tanks. They can’t go in the cargo space because a hydrogen leak in an enclosed area would explode if there were a leak. You can’t put the tanks on top or the truck won’t fit beneath underpasses and make the truck top-heavy.   Nor would these tanks fit beneath the truck. (23).

To redesign trucks and build hundreds of millions of new ones would take too much energy and money. Yet keeping trucks moving after fossil fuels disappear is far more important that figuring out how to keep cars on the road. Trucks deliver food and other essentials we can’t live without.

Batteries are smaller, but they’re very heavy. In 2002, Lithium-Metal Polymer batteries could take a truck 500 miles. They weighed 42,635 pounds, using up 85% of the trucks weight capacity (23).

Transport

Canister trucks ($250,000 each) can carry enough fuel for 60 cars (3, 13). These trucks weigh 40,000 kg but deliver only 400 kg of hydrogen.   For a delivery distance of 150 miles, the delivery energy used is nearly 20% of the usable energy in the hydrogen delivered. At 300 miles 40%. The same size truck carrying gasoline delivers 10,000 gallons of fuel, enough to fill about 800 cars (3).

Another alternative is pipelines. The average cost of a natural gas pipeline is one million dollars per mile, and we have 200,000 miles of natural gas pipeline, which we can’t re-use because they are composed of metal that would become brittle and leak, as well as the incorrect diameter to maximize hydrogen throughput. If we were to build a similar infrastructure to deliver hydrogen it would cost $200 trillion. The major operating cost of hydrogen pipelines is compressor power and maintenance (3). Compressors in the pipeline keep the gas moving, using hydrogen energy to push the gas forward. After 620 miles, 8% of the hydrogen has been used to move it through the pipeline (17).

Conclusion

At some point along the chain of making, putting energy in, storing, and delivering the hydrogen, you've used more energy than you get back, and this doesn't count the energy used to make fuel cells, storage tanks, delivery systems, and vehicles (17).

The laws of physics mean the hydrogen economy will always be an energy sink. Hydrogen's properties require you to spend more energy to do the following than you get out of it later: overcome waters' hydrogen-oxygen bond, to move heavy cars, to prevent leaks and brittle metals, to transport hydrogen to the destination. It doesn't matter if all of the problems are solved, or how much money is spent. You will use more energy to create, store, and transport hydrogen than you will ever get out of it.

The price of oil and natural gas will go up relentlessly due to geological depletion and political crises in extracting countries. Since the hydrogen infrastructure will be built using the existing oil-based infrastructure (i.e. internal combustion engine vehicles, power plants and factories, plastics, etc), the price of hydrogen will go up as well -- it will never be cheaper than fossil fuels. As depletion continues, factories will be driven out of business by high fuel costs (20, 21, 22) and the parts necessary to build the extremely complex storage tanks and fuel cells might become unavailable. In a society that's looking more and more like Terry Gilliam's "Brazil", hydrogen will be too leaky and explosive to handle.

Any diversion of declining fossil fuels to a hydrogen economy subtracts that energy from other possible uses, such as planting, harvesting, delivering, and cooking food, heating homes, and other essential activities. According to Joseph Romm "The energy and environmental problems facing the nation and the world, especially global warming, are far too serious to risk making major policy mistakes that misallocate scarce resources." (3)

When fusion can make cheap hydrogen, and when reliable long-lasting nanotube fuel cells exist, and when light-weight leak-proof carbon-fiber polymer-lined storage tanks/pipelines can be made inexpensively, then let's consider building the hydrogen economy infrastructure. Until then, it's vaporware. All of the technical obstacles must be overcome for any of this to happen (18). Meanwhile, we should stop the FreedomCAR and start setting higher CAFE standards (19).

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Alice Friedemann has completed her new report on biofuels, and it will be in Culture Change soon. The report is based on her 6 years of studying biofuels and 3 years studying soil sciences. In seven parts, it has among its highlights (1) a muckraking section on why soil scientists aren't speaking out on the harm done to soil by harvesting crop residues for cellulosic ethanol; (2) a fresh way of looking at the EROEI (energy efficiency) of ethanol, and (3) it covers challenges with cellulosic ethanol from farm to fuel tank, reported nowhere else. - JL, March 26, 2007

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