Why a Hydrogen Economy Based on Renewable Energy is Potentially Cost Effective

-Ben Luce, Ph.D.,
NMSEA Policy Liaison,
Chair, Coalition for Clean Affordable Energy

Note: The following is a draft article written in response to coverage of hydrogen by the Santa Fe New Mexican in its Sunday, April 24^{th}, 2005 edition. My purpose here is to rapidly convey some basic calculations about hydrogen. I intend to develop this in time into a more complete article, including the addition of references and additional information. I welcome feedback on this article at lucien@cybermesa.com.

When the cost of hydrogen is compared to fossil fuels, its important to look at the costs of the entire fuel cycle from "well to wheels", as people say, or in the case of hydrogen generated using wind power, from "turbine to wheels". Hydrogen costs can appear deceptively high when this not done, because, for example, the conversion of hydrogen to mechanical power can be accomplished in an hydrogen "hybrid" vehicle, or a fuel cell vehicle, at a relatively high efficiency compared to today's typical internal combustion engine. If one leaves that fact out, that is, if one doesn't compare what is actually delivered at the drive shaft, then hydrogen can seem relatively expensive.

There are similar issues when different sources of hydrogen are compared. For example, it might seem very economical to produce hydrogen from a fossil fuel source, such as coal or natural gas. But if one is really interested in lowering greenhouse gas emissions, one needs to take into account the cost per unit of avoided carbon dioxide emission, as opposed to cost per gallon gasoline equivalent from a power standpoint, and this depends on such things as how much carbon the fuel contains (coal has more relative to natural gas), how efficient the conversion process is, and finally, what, if anything, is done with the carbon left over when hydrogen is produced from a fossil fuels. For example, the costs of "sequestering" the carbon underground needs to be added, as well as the cost of having to pipe hydrogen over long distances from a coal plant where the sequestration can be accomplished. These latter costs are very uncertain, and those arguing in favor of fossil fuels often, in my opinion, underestimate these costs, or underestimate the undesirability of having lower reductions in carbon emissions.

Fortunately, though, its possible to get a basic idea of the potential cost of carbon free hydrogen, generated from renewable sources, relative to the use of gasoline in typical vehicles today, without getting bogged down in these other issues.

To do this, one first needs to know how much energy a gallon of gasoline contains. It turns out that, in electrical energy terms (which we use because we are going to connect this figure with wind generated electricity), a gallon of gasoline contains about 34 "kilowatt – hours" of energy (in chemical form). A kilowatt-hour is the unit that the electric company uses to bill you for the electrical energy you consume (at a price that's usually around 8-10 cents per kilowatt-hour). 34 kilowatt-hours, that is, one gallon of gasoline's worth of energy, is equivalent to the heat produced by, say, a 1000 watt hair dryer that runs for 34 hours, or run 340 one hundred watt light bulbs for an hour. That's a lot of energy!

Now suppose we have a source of wind power at the bulk electricity rates that many large businesses enjoy today, say, at $.05/kWh (where "kWh" stands for kilowatt-hour). We'll eventually use this assumption to estimate how much it costs to make an amount of hydrogen that can accomplish what a gallon of gasoline does in a typical car.

But first, is this figure for a cost of renewable electricity a reasonable assumption? The (unsubsidized) wholesale cost of wind power is currently a little less than this, about $.04/kWh, which is a little more expensive than coal-fired electricity and cheaper than much electricity produced from natural gas today. The Department of Energy has projected, in its long-term technology projections for wind power, that wind will likely approach $.015/kWh in a decade or so. Because wind is already in the range of what conventional sources cost, and the DOE projects it will become even much lower, I think it is quite reasonable to suppose that wind power can reach a bulk rate this low generally, especially by the end of the decade. Its even likely that some utilities could offer this price today at least on a conditional basis, during, say, periods when their wind farms are producing more power than they need (at say, off peak times).

Before we can calculate the effective cost of hydrogen, we next need a few key conversion efficiency figures. Electrolyzers, that is, devices that literally split water molecules into hydrogen and oxygen, can convert electrical energy into hydrogen (chemical) energy with an efficiency of at least 70%. Higher efficiencies might be achievable, and have been claimed in some cases, but this figure is generally used by many analysts these days as a conservative assumption.

As an aside, some might argue at this point that it doesn't matter if the electrolyzer has 100% efficiency – the device is so costly that it makes hydrogen too expensive! Well, its true that electrolyzers generally *are* expensive today. But that's not because of any fundamental difficulty in making electrolyzers. Very few are made today, and hydrogen, as dangerous as it is, means that you can't just slap something together willy nilly. But the truth is, *I* can make a simple electrolyzer in my garage using potassium hydroxide mixed with water as an electrolyte, and probably make as much hydrogen as I could consume. Of course, I'd probably blow myself up because I don't know what I'm doing (just as I wouldn't know how to refine gasoline safely in my garage)! But if electrolyzers were refined and mass produced, there is no fundamental reason they wouldn't become affordable, just like the many other high tech products we deal with routinely today.

Next, we need to know the efficiency with which hydrogen can be compressed to a density and volume which is adequate for long distance transportation applications. The pressure that one needs to have to achieve 300 miles in say, a hydrogen hybrid vehicle, is about 10,000 psi. That may sound high, but companies such as Quantum and Dynetek have *already* developed small, relatively inexpensive hydrogen tanks for vehicles that achieve this, and these are already certified in Germany, and in US as well (up to 3000 psi in the US). We may see better forms of hydrogen storage emerge over time, but at least we already have something that does the job.

It turns out that one needs to expend an amount of energy equal to about 5-10% of the chemical energy of the hydrogen to compress it to 10,000 psi in actual practice. We will assume this represents a 10% loss in the overall efficiency of the system, or, to put another way, a storage efficiency of 90%.

Finally, we need to know with what efficiency a hydrogen vehicle can convert hydrogen energy into mechanical energy (drive shaft power!). Both hydrogen hybrids, which could be built *today* at a reasonable cost, and fuel cell vehicles, which may not be cost effective for another 10 years or even longer, can attain efficiencies of at least 40%, and probably higher with refinement. By contrast, a *typical* internal combustion engine (not a hybrid) has a typical efficiency today of between 12% to 20% - pretty darn low. So we can safely assume that the efficiency of a hydrogen vehicle will be at least twice that of a typical vehicle today.

We can now put it all together: Knowing that a gallon of gasoline contains 34 kWh of chemical energy, and assuming a source of wind power at $.05/kWh, an electrolyzer conversion efficiency of 70%, a hydrogen storage efficiency of 90%, and a mechanical reconversion efficieny of twice that of today's typical internal combustion engine, we find the effective cost of "renewable hydrogen", relative to a gallon of gasoline in today's cars, to be:

$.05/kWh x 34 kWh/gal / (.7 x .9 x 2) = $1.35/gal.

Here, .7 represents the 70% electrolyzer efficiency, the .9 represents the 90% storage efficiency, and the factor of 2 represents the relative efficiency of a hydrogen vehicle to the typical internal combustion engine. Note that the latter roughly cancels the losses represented by the former terms: the higher conversion efficiency at the end balances the losses in hydrogen production and storage. Overall, the calculation demonstrates concretely that renewable hydrogen is a potentially economic clean energy storage medium.

The result is also an example of the more general principle that renewables and efficiency can go hand in hand to make clean energy affordable without diminishing quality of life. Solar electricity, for example, can be quite affordable today, if one first cuts one's usage of electricity in half by increasing one's energy efficiency.