

## Hydrogen Technologies – Facts and Myths David L. Block

Good morning ladies and gentlemen. I wish to give my thanks to ASES for allowing me the privilege to address all of you at this year's most exciting ASES Annual Conference. I also want to thank Frank Vignola for the kind introductory remarks. Before I start, I want to say that David Garman's presentation is always a tough act to follow, but I hope that I am up to the challenge this morning.

My talk: Hydrogen Technologies – Facts and Myths, is a technology area that I have been following for more than 20 years.

In this morning's talk, I am going to assume that you, the audience, understand some of the basic aspects of hydrogen. That leaves me free to talk about the problems, opportunities and challenges.

Six months ago, I was fully immersed in hydrogen research and was the strongest advocate of hydrogen you could ever meet. Today, I am still a strong advocate of the technology, but the use of hydrogen has become far more controversial these days. Let me take a few minutes to set this background.

As all of you know, President Bush talked about hydrogen in his 2003 State of the Union address. This brief mention set a ball rolling which everyone is still trying to catch.

But a year and a half later, the picture has unfortunately become fuzzier instead of clearer, and there are a lot of notable people asking questions and raising issues that should be addressed.

### What are these people asking?

They are asking questions about production, costs, infrastructure and DOE priorities. The concerns raised by these individuals are real, and I will address them today. However, I am still positive that we have to move forward on hydrogen.

There is simply no other answer.

Why are we interested in hydrogen? The answer is that hydrogen is the perfect fuel.

- It is abundant and can be produced locally
- It satisfies all our energy needs – from transportation to electric power generation
- It is least polluting, as its combustion produces water.

Finally, what I consider to be most important:

- Hydrogen is the perfect partner for solar in that it affords solar a storage medium and solar supplies hydrogen.

If all of these great facts are true – and indeed, they are -- then why do we not use hydrogen today? The answer is simply that it must be produced. Let's talk about this issue in some detail.

There are three, and only three, energy sources available to us to use on earth. These are fossil fuels, renewables and nuclear. All the energy we use must originate from these three main sources.

The next fact about hydrogen is that it is extremely reactive and does not exist in free form at ambient conditions. It is always combined with another element such as oxygen in water or carbon in natural gas. This leads to the first and what I consider to be the foremost, technical problem with hydrogen; it must be produced. Or in other words, it must be extracted from the compound in which it is contained, and then stored.

Let me now add one additional statement to this comment that I think you'll all agree with. For a practical and real future in hydrogen, it must be produced from renewable resources.

In fact, in my estimation, if hydrogen is to be produced from fossil fuels, as it is done today, the hydrogen economy that we hope for the future is doomed. A couple of facts lead me to this conclusion. In any technology discussion, cost will and must enter into the picture. In fact, if you leave this session with nothing more today than the next few statements on cost, I will be happy.

What are some good values for the cost of hydrogen?

Today, about 95 percent of the hydrogen we use is produced from steam reformation of natural gas and other fossil fuels.

Hydrogen produced by steam reformation costs three times the cost of the natural gas. This means that if natural gas costs \$4/million BTU, then hydrogen will be \$12/million BTU. The other fact about hydrogen production is that hydrogen produced from electrolysis with electricity at 5 cents/kWh will cost \$28/million BTU -- about two to three times the cost of hydrogen from natural gas.

Note also that the cost of hydrogen production from electricity is a linear function of electricity costs, so electricity at 15/cents kWh means that hydrogen will cost \$84/million BTU. Today, photovoltaic power costs about 15 cents/kWh, which means hydrogen from PV electrolysis is about seven times the cost of hydrogen from natural gas.

Now let's talk about applying some practical engineering sense to this problem. If I am going to use hydrogen to power an automobile, and its cost is three times the cost of natural gas, it really makes no economic sense to use hydrogen. I should just use natural gas. Thus, I will only use hydrogen because of its environmental benefits, which today, nobody is willing to pay for. This is a place where politics enter into the picture --and let me say no more.

Now what about hydrogen from electricity?

The first problem is cost which I have already given you some numbers on. But the second one is just as important, and that is --

Why use electricity, a very efficient energy carrier, to create hydrogen and then turn it back into electricity? In other words, electricity is so valuable as electricity, our most excellent energy carrier, we may not want to use it for anything other than that. This statement is especially true when the electricity is made from solar energy, such as photovoltaics.

Photovoltaics as an energy source matches the air conditioning peak load of all of our country's utilities. We will have to use PV electricity as electricity -- it is too valuable to use otherwise.

I do want to note at this point that off-peak electric power from nuclear is a definite option for producing hydrogen. Also, any solar processes which do not match the electric utility profile are strong candidates for hydrogen production. Examples are wind, hydro, geothermal and OTEC.

If we can't beat the cost of hydrogen produced from natural gas and the use of electricity for hydrogen production is questionable, then how should we produce hydrogen? The answer is both simple and complex, and the answer sheds light on the heart of the hydrogen economy and much of the aforementioned controversy. The simple answer is that hydrogen must be produced from direct solar or nuclear power. I am going to ignore the nuclear option here, but let me caution all of you that whether we like it or not, hydrogen may be the rebirth of the so-called "third generation," high-temperature gas-cooled helium nuclear reactor.

Today, let us concentrate on what all of us really feel is the only viable and environmentally acceptable option – direct solar. In using solar and meeting the challenge, I caution you that we must always consider both cost and efficiency.

One way to categorize solar hydrogen production is to separate the processes into three areas – electrolytic processes, indirect solar processes and direct solar processes. Almost everyone talks about electrolysis and the use of PV to supply the direct current electricity. This process works. In fact, we demonstrated it at FSEC more than 20 years ago in 1983.

But I question and do not believe that PV electrolysis can ever become cost competitive because of the value of PV electricity as already mentioned. I will quit this discussion here.

Indirect solar processes is the area where I put biomass gasification which, in time, will be one of the future important hydrogen production processes.

These thoughts lead me to the third and the most critical area which must be developed and is our challenge – producing hydrogen by direct solar processes.

I list three examples here –

- photo electro chemical water splitting using non-photovoltaic means,
- photo biological processes and
- high temperature thermochemical processes.

All three of these direct processes have been under development and all three have major hurdles to overcome. The direct solar processes are long term and are in the earliest R & D stage.

The photo electrochemical and photo biological processes are the ones that our future is betting on. However, they need orders of magnitude improvements in their process efficiency and costs.

Today's systems are less than 1% efficient and they need to get somewhere around 10%. High temperature thermochemical cycles have good efficiencies, but suffer from cost impediments of producing the high temperatures of greater than 800° C.

It is interesting to note that DOE is putting more dollars in to high temperature hydrogen production than in the photo production processes. Why? Because high temperature hydrogen production

supports work in the nuclear power industry. This point is the major issue that has been raised by former ASES Chair, Mike Nicklas, and I completely agree with him.

In other words, we as a nation and we as the world will eventually have to develop direct solar photo processes to split water – we have no other choice. This is the challenge to the world, to the nation, to DOE and to us.

Let me finish production by saying that today there is no clear winner in what will be the final solar hydrogen production process. R & D must be continued with the objective of trying to identify this winner. This is our future challenge.

The next area I want to address is storage. Many technology people, including those at DOE, feel that hydrogen storage could be the show-stopper.

I, personally, am not a member of this group. But storage is a problem, and it is a problem that has to be solved. Hydrogen has very high specific energy, but very low energy density. Can we ever store hydrogen as efficiently as gasoline? No, we can't.

I believe that some form of solid or complex hydride storage will be the end winner because of its ease of use and safety considerations. I see breakthrough research in producing new materials with the ability to absorb and desorb large amounts of hydrogen, and I am confident, in time, the storage problem is solvable.

I also want to say that DOE is directing a major part of its effort on storage and the DOE management is most definitely on the right track in pursuing the solution to this problem.

Storage leads to the next area of concern – utilization. Utilization is the area of most interest to the public. It is the sexy area with automobile manufacturers introducing new hydrogen-fueled vehicles every month or so.

We now have at least six auto companies, and maybe more like eight, that have either a fuel cell or internal combustion engine powered by hydrogen.

In reality, the fuel cell just replaces the batteries in an electric vehicle. Fuel cells do not produce mechanical power, they produce direct current electricity.

The decision as to whether or not the final automobile product will be a fuel cell and electric motor or internal combustion engine powered vehicle is yet to be determined. Fuel cells, given consideration for hydrogen production or reforming, have better efficiency – 2 to 3 times those for an internal combustion engine, but cost is the barrier.

Fuel cells cost \$3,000/kW as compared to \$50/kW for an internal combustion engine – a 60 fold price differential to overcome. In comparison, PV costs are only 2 to 3 times the cost of electricity from the grid.

There are also other problem areas, such as infrastructure, safety and codes, but again these problems are man-made and can be solved by reasonable effort and reasonable people.

Let me now list the critical elements for your consideration. These are the R & D challenges that we must meet to make a future hydrogen economy successful.

1. Hydrogen must be produced by direct or indirect solar processes with the emphasis on direct solar processes. Photo electrochemical and photo biological are the best candidates for which extensive long-term R & D is needed. In the interim, the production of hydrogen from fossil resources will require the economic solution of large scale carbon sequestering or processing in the form of solid carbon instead of CO<sub>2</sub>. DOE priorities must emphasize renewables over fossil and nuclear
2. The storage problem is the second critical challenge. It will most likely be solved by using new solid materials or by improvement of cryogenic storage due to zero boil-off systems and greatly improved liquefaction processes.
3. For automobiles, whether to use the fuel cell and electric motor or remain with the internal combustion engine powered by hydrogen is not yet clear. DOE has put its emphasis on fuel cells, but BMW believes the internal combustion engine is the answer. The cost problem with fuel cells may give internal combustion engines the upper hand and this is the fuel cell challenge. For fuel cells, the concept of using a methanol or natural gas fuel cell as a transition is also a part of this issue.
4. The development of the appropriate infrastructure to support the hydrogen economy is another issue and I do not see major technical show-stoppers in this area. However, the economics are a big concern. Exxon-Mobil has estimated \$1trillion will be needed to replace the existing U.S. fueling infrastructure. Infrastructure will happen if we have the will.
5. Finally, safety, handling and building codes are critical challenges and major concerns. They must be aggressively addressed, but I'm confident they can be solved.

Let me end by posing two challenges to all of us. The first challenge is that even though hydrogen is a perfect fuel, it does not offer high "added value" to the individual consumer. Gasoline can do everything as well or better. Hydrogen's only added value, at present, is its environmental benefit.

We must work to sell and develop hydrogen as a value-added product. In other words, we have to add value to hydrogen as an energy carrier. A very good example of this concept is what we did with electricity in the all-electric home of the past. We must find and develop devices, other than just fuel cells, that utilize hydrogen and produce useful effects.

We want to continue our expansion of value added by using fuel cells, but we need more.

An example is hydrogen's use in spacecraft and for propulsion. Hydrogen provides the highest specific impulse of any fuel. These are the value-added applications – we need this "market pull."

The second challenge – and what I see as the most important – is that we need a hydrogen vision.

President Kennedy gave the nation a vision with the man-on-the-moon effort of the 1960s. President Bush's space vision – going to the "moon, mars and beyond" – is a start.

In other words, the realization of our conquest of the final frontiers of space is really tied to the realization of the hydrogen economy.

Hydrogen is the only medium that can take us to a fossil-free world and space at the same time. Space-ward expansion will be realized only with hydrogen.

In conclusion, we must work politically to step up and set this hydrogen vision, because, in the end, no technology holds greater promise for the future than the technology that can replace fossil fuels and that technology is hydrogen. Hydrogen from solar is our future.

Thank you.

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