The Energy Policy Triangle and Molecular Hydrogen

*By James L. Sweeney**

Three fundamental issues are now and have always been explicit or implicit in energy policy – reducing environmental impacts of energy production, distribution, use; providing security against disruption of the supply system; supplying and using plentiful energy at a reasonable cost. These issues together are what I call the *energy policy triangle*.

I would like to make a few observations about the energy policy triangle and then relate my observations to the quest for a new energy carrier: molecular hydrogen, which might take a place comparable to that of electricity.

Environmental Impacts

We have learned or are learning to deal with most of the worst environmental impacts of energy use. In the U.S. we have reduced acid rain precursors from electricity generation and could choose to reduce them further. The allowable criterion pollutants from new automobiles have been reduced by orders of magnitude, so that the biggest problem now is old, super polluting vehicles. We do find environmental problems with emerging technologies, e.g., avian and bat kills from wind turbines, but we are attacking such problems. Air and water pollutants from refineries are tightly controlled.

But there is one problem we have not learned to control – carbon dioxide releases from combustion of fossil fuels. There is basically a one-for-one linkage between the amount of gasoline we use and the carbon dioxide released from combustion of that gasoline. Combustion of coal in electricity generation releases carbon dioxide basically proportional to coal use.

And the evidence is persuasive that the accumulation of atmospheric carbon dioxide can be expected to change the patterns of global heat flow, increase average global temperature, modify rainfall patterns, increase severity of tropical storms, raise ocean levels, sharply disrupt many ecosystems, and accelerate the extinction of species. Scientists have identified other risks, for example, that the ocean "conveyor belt" could be shut down, leading to a sharp decreases in European temperatures.

Internationally we have the Kyoto protocol as a response, but that has not been universally ratified and has been rejected, for good reasons, in the United States, and may not be met in some countries who have ratified the protocol. A problem is that the protocol tells us what commitments are expected by various countries but does not make such changes economically viable. Nor does it assure that the changes will happen. To meet the goals requires not simply institutional and economic changes, it needs technological advances.

Thus, the challenge is to create technologies that allow us to continue supplying plentiful energy at a reasonable cost, while sharply reducing or eliminating carbon dioxide releases into the atmosphere.

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We also have to broaden our focus to include the non-fossil fuel releases of greenhouse gases. We need to seriously think about adaptation to the changing circumstances in parallel to our focus on mitigation. But these are not fundamentally energy issues and I would like to focus here on energy topics.

Security Issues and Associated Disruption of the Energy Supply System

For many of us old-timers, the public policy focus of energy started with security issues. The 1973 war in the middle east, reduction in production of oil by Saudi Arabia and other middle eastern countries, coupled with inventory buildups by oil users led to a rapid jump in world oil prices, which in turn created a world-wide depression and indirectly led to world-wide inflation. Those changes were coupled with an embargo of oil exports against the U.S. and the Netherlands. Although ineffectual, the embargo showed that oil might be used as an economic weapon. The world saw that the entire world economy was vulnerable to oil supply interruptions.

In the United States that led to the call for Project Independence; to creation of the department of Energy. It led to the International Energy Agency. Our very organization – the IAEE – never would have been organized without that energy shock.

Since that time we have come a long ways. Since 1973, oil use has grown little while the world's economic activity soared, so now oil expenditures are a relatively small fraction of world gross product. The strategic petroleum reserve can provide some shock absorber against oil price spikes. Oil is produced in many more areas of the world than in 1973. And during the many years of excess production capacity, OPEC nations deliberately reduced the severity of price jumps, although they have also kept oil prices elevated above competitive levels. Natural gas has grown as an alternative to oil, creating more supply diversity.

But we now must return our attention to oil supply vulnerability. The recent and projected future growth in world oil demand, driven by the recovery in the world economy and in the growth trend of automobiles in China, implies that world oil markets may be tight for decades to come. It is not just that tight oil markets imply higher oil prices. I am more concerned that the tighter the market, the greater the price jump that would stem from an oil supply disruption and the more damaging would be the impacts on the world economy.

Second, I believe that the probability of oil supply disruptions is higher than ever. I no longer expect OPEC countries to use oil as a political weapon. But the growth of world-wide terrorism and the vulnerability of oil infrastructure suggests increasing risk. In Iraq the oil infrastructure has become a target. In Saudi Arabia, once thought to be internally secure, there are now terrorist attacks, some directed toward the oil system and its workers. The weapons of terrorist networks are becoming more powerful and more unpredictable. I personally would not be surprised to see a low-yield nuclear bomb detonated somewhere (and I hope it is low yield). Thus I believe the risk, including the risk of major disruptions to oil supply infrastructure is greater than ever. Now, maybe some of you can show that I am wrong and I fervently hope I am wrong. But, if I am right, then the combination of increased probability of disruptions and a tighter oil market implies that we are back into the high risk area so prevalent in the early 1970s.

Thus, a challenge is to reduce the vulnerability of our oil supply system. That may mean finding ways of sharply moving away from oil. It may mean hardening soft targets. It may mean development of other shock absorbers in the system. It demands out-of-the box creative thinking followed by policy choices, some of which may be costly.

But issues of security and vulnerability are not limited to the oil system. As we develop international trade in liquified natural gas, we may find that some of the same issues arise. Large concentrations of valuable resources creates economic incentives to gain control of those resources, possibly by military force. If the world economy becomes dependent on natural gas trade for a large share of its energy needs and if LNG supply becomes concentrated in unstable parts of the world, we may face similar vulnerability problems.

On a more local scale, more centralized energy systems, from which more energy must be moved, provide more attractive targets for terrorist attacks. And they can become more vulnerable to inadvertent disruptions, as the power blackout in the U.S. Northeast illustrated.

This issue of energy security will bring me to electricity and hydrogen as two energy carriers that have, in principle, the opportunity of helping to meet these objectives, if managed appropriately.

Two Energy Carriers: Electricity and Hydrogen

Superficially, electricity and molecular hydrogen are very different. First, the form is different – one is moving electrons requiring a circuit for movement, the other is a very simple gaseous molecule. Electricity is produced at the very moment it is used; hydrogen can be produced and stored indefinitely. We have developed ways of using electricity for every generic energy need – heating, cooling, lighting, mobility, communication. Many of these uses are very economical. On the other hand we have found economical ways of using hydrogen only in chemical processes, such as hydro-cracking heavy petroleum and fertilizer manufacture, purposes for which electricity cannot serve.

But at a more abstract level, there are many similarities between electricity and hydrogen. And those similarities underlie my hope in the development of hydrogen as a parallel to electricity for our energy system.

First, as we all know, neither electricity nor molecular hydrogen are primary energy sources, but are produced from primary sources. Thus I will refer to them as energy carriers. This is important: neither are in themselves energy supplies but must be produced from other energy sources.

Second, I believe that electricity and hydrogen could ultimately both be available for virtually all generic energy uses. In this vision, hydrogen and electricity would compete as energy carriers, with their differing physical properties giving one or the other a competitive advantage for particular uses. Market and policy forces would determine where electricity was used and where hydrogen was used.

This <u>does</u> require development of economical hydrogen fuel cells and the improvement of hydrogen storage. But with such fuel cells, we could convert hydrogen to electricity at the point of use. Thus hydrogen could satisfy all uses of electricity. Hydrogen could be stored and used for mobile purposes, particularly transportation. Through fuel cells, we could have rechargeable hydrogen batteries. And, direct combustion of hydrogen could provide uses of hydrogen not feasible for electricity.

There is a third similarity. Neither hydrogen nor electricity lead to emissions of carbon dioxide at the point of use, nor do they release other criterion pollutants. Hydrogen simply releases water and heat after it combines with oxygen; electricity releases heat and possibly light. Thus, at the point of use, both electricity and hydrogen allow energy use without release of pollutants.

Fourth, both electricity and hydrogen can be produced using <u>any</u> primary energy resource. Of course, electricity can be produced using coal, natural gas, oil, hydro-power, nuclear, solar energy, wind, biomass, and geothermal energy. But so can hydrogen. We can gasify coal or biomass to produce hydrogen. We can use a steam shift reforming of natural gas. We may be able to use high-temperature nuclear to dissociate water into hydrogen and oxygen. And, using electrolysis, we can convert electricity, produced using any other resource, including the renewables, into hydrogen. So hydrogen can be produced using any primary energy resource that can be used to produce electricity. Whether this is economical or not, of course, is a different matter.

Thus, both electricity and hydrogen allow the <u>potential</u> for any nation to harness whatever primary energy resources it has available to produce energy for all uses. This may be domestically produced; it may be imported. But since the many different primary energy sources are broadly distributed around the world, either of these energy carriers have the potential of sharply reducing the security risk of highly-geographically concentrated supplies of hydrocarbons.

Although both electricity and hydrogen are carbon-dioxide free at the point of use, they either may or may not be carbon-dioxide free at the point of production. Hydropower, solar, nuclear, and wind are inherently carbon-dioxide free for hydrogen or electricity production. Thus each offers the potential, using either energy carrier, of a complete supply chain free of carbon dioxide emissions. Other primary resources, particularly coal, natural gas, and oil, include carbon. But even for these, there is the potential to separate carbon dioxide from the gas stream and sequester it permanently, in spent oil and gas reservoirs, in coal beds, or in salt water aquifers. And biomass-based hydrogen offers the possibility of fixing carbon dioxide from the atmosphere and then sequestering that carbon dioxide when the biomass is used to produce hydrogen. This would pump carbon dioxide from the atmosphere.

Here there appears to be an advantage to hydrogen over electricity. It appears that carbon dioxide separation will be easier and less costly in production of hydrogen than electricity. But technological advances may provide new methods for separation in the process of electricity generation.

In principle, then, with appropriate technological advances, at some future time we potentially could have two competing energy carriers, hydrogen and electricity, each allowing use of a broad variety of primary energy sources, each allowing abundant energy with no carbon-dioxide release at the point of production or the point of energy use. This vision may use little, if any, refined petroleum products as energy carriers.

In this vision, the different physical properties of electricity and hydrogen could help determine which of the two would be used for various energy needs. For example, electricity could be used in all-electric vehicles, but only if battery technology advances greatly. Hydrogen, since it is storable on vehicles and allows for quick refueling, could be the more attractive alternative. For heating and lighting, electricity delivered through the grid is likely to be more economical than hydrogen used to generate electricity on site. But, back up generators based on fuel cells could convert electricity to hydrogen and hydrogen back to electricity when backup power was needed. It is not obvious whether hydrogen based batteries or electrical rechargeable batteries would be more competitive for portable electronic devices.

So what is the problem with this vision? Technology and economics. For hydrogen use, fuel cells are still far too expensive and have too short lives to compete in automobiles with gasoline or diesel fuel. Proton exchange member fuel-cells need too much platinum or other noble metals. Adequate storage of hydrogen on board vehicles is a technological and safety problem. For electricity, battery technology does not yet allow long range for electric vehicles nor quick recharging time. So we still use oil for almost all our light-duty vehicles, in the U.S. and around the world. But changing technologies could make oil the less economical alternative.

I believe that production of hydrogen from biomass is apt to remain too costly, absent technologies not currently envisioned. Land constraints may also make hydrogen from biomass economically not viable. But we have all been surprised with new technologies.

Movement of hydrogen by pipeline or truck is far more expensive than movement of electricity, creating a major disadvantage for hydrogen. But hydrogen production relatively near the point of use could give hydrogen an overall cost advantage in mobile uses, even if electric battery technologies were to advance. Electrolyzers are still very far too costly to economically convert electricity to hydrogen, except for specialized non-energy purposes, but that could change. We know we can sequester carbon dioxide – we do so in the Slepner field – but we don't know whether we can do so on as broad a scale as needed. And we don't know whether we can permanently sequester the carbon dioxide.

Technologies don't just happen. They are created by scientific and engineering advances, by allocation of resources to bring technologies to fruition. By private sector organizations, by government agencies and laboratories, by universities. How we should allocate those science and technology efforts is not obvious, nor is it obvious how much this should be private sector and how much should be public sector.

So what else is the problem? Competition with the other energy carriers, natural gas and refined petroleum products. Technologies for use of these carriers will not remain stagnant. For example, hybrid electric vehicles, now rapidly growing as a technological option, allow better fuel economy and thus lower cost of gasoline than conventional vehicles. And hybrid electric mid-size vehicles and SUVs will soon be available. The greater conversion efficiency of a fuel cell may not be enough to compensate for higher capital costs of vehicles or higher costs of hydrogen, relative to gasoline. If hybrid electric vehicles remain more economically attractive than hydrogen or electric powered vehicles for driving cars and trucks and if natural gas remains more economical for heating homes, then even with technological advances in the hydrogen and electric system, we still will not get the environmental or security benefits, absent policy drivers.

And there are other problems. We need to manage safety risks for hydrogen, including standards for fueling stations, pipelines, ventilation of garages and tunnels. It will be costly to develop the appropriate infrastructure. The problem of having a dual fueling system – gasoline and hydrogen – for decades is clear. Assuring that there is enough local competition among fueling stations that retailers cannot exercise excessive market power will itself increase the cost of the system. Will there be unforeseen consumer acceptance issues – after all the grass is always greener until we get to the other side of the road.

Finally is policy. We have not seriously in the United States imposed carbon constraints or externality prices for carbon. The security costs of a tight oil market are socialized to the entire economy, not integrated into policy instruments that would push energy systems that are less vulnerable. But policy alone cannot be the answer, absent technology. We can set all the security or carbon dioxide policies we want, but without the technological advances, we will not have the two competing energy carriers envisioned here.

In short, we do not know whether we can reach this vision of two competing energy carriers, each carbon-dioxide free, each allowing a multiplicity of different primary energy sources, with sharply lower security risks, providing abundant energy around the world at reasonable costs. If we reach this vision, we do not know how quickly it can be reached. We just know that it will take many decades. Many decades seems like a long time. In some sense it is. But some of us in the room have been involved in energy policy for many decades. And if IAEE is successful as an organization, many of the students here at our conference will themselves be working in the energy field for many decades.

Thus I offer this vision to the distinguished members of the IAEE – especially the students who may well help guide evolution toward such a vision throughout their careers.