Critical Issues Forum
Responses to the Hydrogen Economy

Thanks to those who took the time to respond to our premiere Critical Issues Forum (Nov. 2004, pp. 4–6). We have received numerous letters, of which a handful have been printed below. Interestingly, a majority of letters have endorsed Dr. Shinnar's view — one that focuses on the thermodynamic inefficiencies of the hydrogen economy, or as Dr. Shinnar put it, "committing a thermodynamic crime." There appears to be a cognitive dissonance between the view of our profession — a key contributor to the future energy economy — and the view of politicians and change agents who believe we have a "magic bullet" with hydrogen. The question now is, how do we get both groups see eye to eye? And furthermore, how can we educate the general public about the science behind the hydrogen economy? If you have any suggestions, we'd like to hear from you. Please send your comments to cepedit@aiche.org.

The hydrogen economy discussion was very informative and stimulating. The pro-arguments of Dr. Hirsch and the con-arguments of Dr. Shinnar are both cogent and have merit. It appears that automobile manufacturers have recognized that hydrogen is the ultimate transportation fuel by setting a course on developing hydrogen fuel-cell vehicles. It is also true that, currently, electrical energy is worth more than hydrogen energy.

There may be a middle road in fulfilling the two needs. Over 80% of electrical power is generated by coal in the U.S. The cogeneration of electricity with hydrogen employing coal gasification can improve the overall thermal efficiency of coal conversion for the electrical power sector and eventually hydrogen for the transportation sector.

High efficiency is one key element in reducing greenhouse gas emissions (*e.g.*, CO_2). Hydrogen, as a coproduct or as a component of synthetic fuel from coal, is one option to economically reduce our dependence on foreign oil imports. The DOE FutureGen program recognizes these benefits and adds sequestration for zero CO_2 emissions. The integrated coal-gasification combined cycle can yield 55% electrical efficiency, which is nearly 50% higher than the steam-Rankine-cycle plants. Hydrogen fuel cells are limited to about 60% thermal efficiency, but new laboratory work indicates that a direct carbon fuel cell can achieve efficiencies of 80% or higher for electricity production.

Nuclear power is all well and good; however, this country is not yet ready to take the risk. Hydrogen safety pales compared to a nuclear reactor event. Solar energy including wind, will continue to develop slowly. The bottom line is that all these approaches must be continually evaluated and implemented in terms of the environmental and economic benefits, both in the short and long term.

Meyer Steinberg,
Melville, NY

> "The bottom line is that all these approaches [nuclear, solar, wind, hydrogen, etc.] must be continually evaluated and implemented in terms of the environmental and economic benefits, both in the short and long term." — Meyer Steinberg

The perspectives of the hydrogen economy presented by Drs. Hirsch and Shinnar span the range from a challenge to achieve and implement to a waste of research funds. The most important points to be drawn from the discussion are that the long term sources of energy must be sustainable, environmentally sound when used, and as efficient as practicable. A variety of energy sources are likely to contribute to the needs of the economy and, on a policy basis, research and development funds should not be focused on any one alternative to the detriment of other reasonable alternatives. In the long term, fossil fuels will not meet one or more of the three criteria identified above.

From my years of service on the Biomass Research and Development Technical Advisory Committee of the U.S. DOE and USDA, it is apparent that biomass, primarily cellulose, can provide a reasonable portion of future energy needs, particularly for transportation, in the forms of ethanol and biodiesel. Both are liquid fuels that can be compatible with existing distribution and storage systems, are sustainable if the biomass is re-grown, and are not contributors to climate change, as biomass is a product of photosynthesis. Combined with hybrid-vehicle and plug-in-battery technologies, biomass can make a significant contribution to energy supplies, displacing petroleum within a decade or so.

One technology that appears attractive is the hot-water extraction of hemicellulose from wood chips prior to pulping followed by acetic acid separation and fermentation of sugars to ethanol (*Paper Age*, Oct. 2004, p. 16). This opportunity fits into existing infrastructure, is applicable in many parts of the world, and can enhance the pulp-and-paper process. This technology, along with many others based on biomass, can make a significant contribution to the future, and deserves to receive adequate R&D funds.

William J. Nicholson
Ross, CA

I was delighted to read Dr. Shinnar's, "Demystifying the Hydrogen Myth." Economics aside, using hydrogen fuel cells for power makes no sense thermodynamically. After deducting the energy required to produce and then distribute the hydrogen from the net usable power, you have to be going backwards from a fuel consumption and emissions standpoint, when comparing to direct combustion. I do think that distributed solar energy cells on individual rooftops have a place, but I agree that the ultimate central power station answer has to be nuclear. Unfortunately, we have the twin problems of spent-fuel disposal and public safety perceptions. Everyone forgets that no one was injured as a result of Three Mile Island. The back-up safety systems prevented the spread of radiation, and only the physical plant was a loss. I agree with Dr. Shinnar that we need to start to solve real problems.

John Kunesh
Red River, NM

On Nov. 11, the *New York Times* had an article with pictures on the first hydrogen fuel station. It was built in Washington, DC, with a statement that there are six vehicles that will require the fuel in the geographic area. It is an indication of how something that sounds too good to be true can take hold, and without technical thinking, become the "in thing."

The Critical Issues Forum that appeared in *CEP* is very timely and brings into perspective the large gap that exists between the fashionable "hydrogen economy" and technical reality. Dr. Hirsch points out the need for a technical solution for the fuel that will replace oil and gas as they peak. He also explains that hydrogen, which requires significant energy to produce, may not be the solution to the expected problem.

Likewise, Dr. Shinnar describes the problem in more detail, but arrives at a very similar conclusion — hydrogen has a low probability of being the solution. He discusses solar and nuclear energy, as well as energy conservation as the most likely approaches to meet the technical challenge of the peaking of oil and gas availability.

I agree with both of these articles, but would like to stress the importance of a very overlooked thermodynamic principle — entropy, which brings temperature into the technical thinking and is not very often used.

A coal-fired power plant is quoted as being 35% efficient in converting fuel to electrical energy. This is a true statement if one uses enthalpy as the efficiency criterion. If one looks at entropic efficiency, the result is much different. This efficiency is only 12%. The coal-fired plant adds large amounts of excess air to keep the temperatures below 950°F. It does not take advantage of the energy that can be gotten from coal's flame temperature with stoichiometric levels of air or oxygen and 950°F.

The combined-cycle gas-fired electrical systems are said to have 55% efficiency of fuel to electrical energy. If one looks at the entropic efficiency, it is around 32%. It declines because of the large excess air needed to keep the turbine operating at 2,000°F, instead of the flame temperature of natural gas.

Nuclear energy uses the steam cycle, and thus does not take advantage of most of the entropic energy in the fuel. The technology of the nuclear industry is a tag on to the coal-fired power plants and not much has been done to tailor an electrical generation system to the atomic fuel source

The difference between the industry efficiency (enthalpy) and thermodynamics (entropy) for both of these systems is not well known, and thus has not been pursued with the same passion as easier understood technologies like clean-coal or hydrogen economies.

The point of this discussion is to stimulate thinking towards capturing more useful energy from the fuels we presently have available. A major step to clearing the thinking would be if entropic efficiency calculations were done on all the existing and potentially new technologies that convert fuel to useful energy.

John Oleson
Midland, MI

"Everyone forgets that no one was injured as a result of Three Mile Island. The back-up safety systems prevented the spread of radiation, and only the physical plant was a loss." — John Kunesh

In general, I agree with Dr. Shinnar, and would like to provide some additional practical and experiential information to his review article.

Hydrogen causes embrittlement of ordinary carbon steel. Chemists say it reacts with the steel, causing the weakening and embrittlement with time. Therefore, more-expensive, higher alloy steels must be used in handling hydrogen, for safety's sake. This single issue alone means that the conversion to higher alloy steels will be an enormous expense issue that I have not seen addressed in any articles.

Also, anybody who has worked with hydrogen knows how difficult it is to make a leak-free system. The degree of difficulty of leak prevention, from a mechanical engineering point of view, emerges as a very large and real practical problem that is a major safety and loss issue.

Elaborating on the safety issue, hydrogen ignites spontaneously in air, producing a nearly invisible flame that can be very dangerous to people and other equipment around it. Some people actually walk around facilities with oil soaked brooms and waive them around in order to find a leak and to protect themselves from burns.

Finally, I am interested in knowing other professionals' calculations on the size and pressure of the onboard hydrogen container for a passenger car that has sensible range and power. I calculate that for 10 ft^3, about 100,000 psi gas pressure is necessary, insofaras hydrogen is non-compressible. If you consider the problems described above, this is another very expensive, unsafe operating condition.

Even though I agree with Professor Shinnar, I think the Robert Hirsches of the world who provide positive articles should be encouraged to keep thinking creatively and be provided with some budget to try to progress their ideas. People who are trying new ideas are known to surprise you — so who really knows for sure?

Arthur Klink
Denver, PA

First, I fully agree with Dr. Shinnar's clear analysis as to why hydrogen, from a simple but immutable energetic standpoint, cannot be a source of basic energy for our future. If we had to make hydrogen by expending some form of energy, we should just use that form of energy directly, and not suffer the loss of energy in going through the processing steps to produce hydrogen in the first place.

Secondly, I am extremely disappointed in Dr. Hirsch's rationale for supporting a vast hydrogen R&D program. To draw an analogy between the unknowable potential of hydrogen with the unknowable prediction for supersonic flight at the time of Wright brothers first flight is wrong and illogical. The immutable, thermodynamic inefficiencies in producing hydrogen from any energy source will not change with time or level of research effort, while there are no such thermodynamic limits to flying at faster speed than the Wright brothers first flight.

I have a positive recommendation to Dr. Hirsch, in his eminent position on various key advisory boards that can shape energy R&D: The one technology that the world needs is a viable and cost-effective means to store electricity on a vast scale — and I mean on the scale of multi-MWHr. We need this technology to even out the diurnal cycles in direct solar conversion to power, and the intermittency of wind power, as we plan ahead to the time of necessary reliance on renewable energy. The flow of electricity is instantaneous now. Unlike natural gas, oil or coal, electricity cannot be stored to provide surge protection, to even out loads, and to make solar or wind power dispatchable. We, in coordination with the world, should launch a long-term R&D effort to develop this technology, whether we use superconductors, magnetic storage, nanotechnology, etc. It is a real challenge for all of us, and I sincerely hope that we can initiate this immediately in our national energy program.

Bernard Lee
Sun Lakes, AZ

I found the article by Dr. Shinnar to be very thought-provoking, despite the fact that the tone of the article was very much shaded by his repeated and unsubstantiated use of negative jargon. In my opinion, Dr. Shinnar is very much on-target by emphasizing the importance of nuclear and thermal solar for our long-term energy needs. For this reason, I am puzzled that he spent so much time using CO_2 emissions from fossil-fuel-based hydrogen production to build his argument that the hydrogen economy makes no sense.

At some point in the future, after the price of fossil fuels has risen, due to shortages or carbon taxes, production of hydrogen from nuclear-generated electricity or nuclear-generated heat, or a combination of both, will likely become cost competitive. Unless high-capacity batteries are made cheaper, lighter, and able to hold more energy, electricity is not the solution for mobile energy consumption. A fuel is needed, and many believe that hydrogen is the ideal fuel for mobile energy consumption. Personally, I am concerned that this may not be the case, due to the problems with distribution and storage on vehicles. Dr. Shinnar astutely points out that a car loaded with hydrogen can be a very effective suicide bomb. For all of these reasons, alternatively converting hydrogen to a liquid fuel such as methanol appears to make a great deal of sense. Otherwise, it must be "stored" in a non-explosive state on a vehicle.

Dr. Shinnar's criticism of DOE is both on-target and unfair. It is on-target, because many of us in the DOE complex get stuck in a rut of trying to develop technology with no possible end customer. But, it is unfair, because much of our mission is to invest in technology development that is so far off from being able to be commercialized that the private sector will not touch it. Once oil production peaks and global warming becomes a worldwide crisis, there will be little time to develop the fundamental science and technology needed for a dramatic change in our energy economy. That is the role I believe that DOE and its national laboratories play — investing in our country's long-term future, albeit with very high-risk research.

I think it is important to listen to the points raised by critics, such as Dr. Shinnar. But in doing so, we must not lose vision of the overall goal. Changing our energy economy is probably the greatest technology challenge that our country has ever faced. It is going to be necessary for critics and advocates to feed off of each other so that we can quickly converge upon practical solutions to this huge problem.

Michael Simpson
Idaho Falls, ID

"Changing our energy economy is probably the greatest technology challenge our country has ever faced. It is going to be necessary for critics and advocates to feed off of each other so that we can quickly converge upon practical solutions to this huge problem." — Michael Simpson