An Opinion/White Paper

# Nuclear Energy and The Future
# The Hydrogen Economy or the Electricity Economy?

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## Executive Summary

The intended audience for this paper is the US nuclear energy community. Hydrogen and the "hydrogen economy" are of particular interest to us because of their potential to steer next generation reactor design decisions to meet a presumed niche opportunity for hydrogen production via high-temperature thermo-chemical processes or high-temperature electrolysis. We should, therefore, seriously consider the future hydrogen market and understand the source for the momentum to develop the hydrogen economy.

Many groups have joined the hydrogen discussion, each bringing a different set of assumptions and a different definition of what the hydrogen economy means to them. Therefore, it is useful to review nuclear energy's strengths and define what the "hydrogen economy" means to us to set the stage for cataloging which sub-topics ought to be discussed. Nuclear energy is mankind's only non-greenhouse-gas-emitting, 'round-the-clock, regardless-of-the-weather, stationary energy source. Nuclear energy is particularly adept at making electricity. The "hydrogen economy" means carrying our stationary-source energy to the transportation sector, presumably, as the title implies, by using hydrogen as the energy carrier in replacement of the transportation sector's present energy source, petroleum.

To discuss the transportation sector at all, we must discuss the supply, demand and cost trends for petroleum. Economics, national security and energy independence are paramount. The state of hydrogen technologies and some consideration of why hydrogen might or might not be a worthy heir-apparent for transportation are discussed, as are some noteworthy energy-carrying alternatives and related opportunities. These issues are considered in the context of nuclear power's role in the overall national energy budget and unavoidable global energy issues.

This paper reaches two conclusions of relevance to the US nuclear energy community. First, hydrogen has a critical inefficiency problem that is rooted in thermodynamics, that is essentially unsolvable and that renders hydrogen impractical as either an energy carrier or an energy storage tool (page 3). Second, economics, technical practicality and the urgency of strengthened national security through energy independence all overwhelmingly favor electricity as the energy carrier that will be carrying stationary-source energy to the transportation sector in the 21st Century. Electric transportation is already less expensive than petroleum and it will always be much less expensive than hydrogen. Gas-electric hybrid vehicles are maturing to include a plug-in capability for overnight charging and increased emphasis of all-electric mode. Long before hydrogen becomes feasible, the less-expensive energy carrier — electricity — will have already captured much of the US transportation market (page 6). Therefore, the US nuclear energy community might be well advised to sidestep hydrogen and focus, over the next several critical decades of nuclear renewal, on our fundamental issues — passive safety, proliferation resistance and closing the fuel cycle — to ensure that nuclear energy continues to be available, viable and sustainable as the lowest-cost provider of grid-distributed electricity.

## Introduction: Hydrogen and Transportation

The "hydrogen economy" is understood to imply a reconfiguration of the US transportation system into one based on hydrogen as the fuel. The hydrogen fuel, it is further understood, will be the energy carrier by which stationary-source energy is carried to the transportation sector. Since transportation accounts for a full third of the US's annual energy consumption, it is only reasonable that all stationary energy source communities should want to realistically survey the issues that will effect the possibility and timing of an opportunity to broadly extend their stationary-source energy to the transportation sector.

Currently, hydrogen is used by many industries ranging from fertilizer to metallurgy. Hydrogen's largest use, however, is in the refinement of crude oil into the gasoline that fuels our present system of mobile transportation. Hydrogen is both incorporated into the gasoline product through the hydro-cracking of long-chained molecules and applied to the removal of impurities as hydrides. It should be noted that the present hydrogen industry is a relatively trivial sliver of the overall national energy budget. Capturing the present hydrogen market is certainly not the big hydrogen opportunity that would justify the investment to develop dedicated nuclear heat-based hydrogen production plants. As long as transportation continues to be based on petroleum, there is no big hydrogen opportunity worthy of a dedicated plant level of focus.

Nearly all hydrogen in use today is, itself, being "produced" by stripping hydrogen from natural gas through steam reformation of methane. There is no technical advantage to reforming methane in preference to electrolysis of water, there is only a price advantage of about a factor of two. Today, natural gas is trading with a floor price of about 5 USDollars/MBtu. That price will need to rise permanently above 9 USD/MBtu before methane reformation will quantitatively yield the hydrogen supply market to electrolysis using electricity costing 4 ¢/kWh (all figures based on 2004 valuations). Less-expensive off-peak electricity may find limited opportunity in hydrogen production if the price of natural gas approaches the break point. Readers should be aware that the natural gas industry, itself, does not think the recent runup in natural gas prices represents a continuing trend or that 9 USD/MBtu (2004) will be approached through its present planning period of two decades (Balancing Natural Gas Policy — Fueling the Demands of a Growing Economy, National Petroleum Council, September 25, 2003).

## Hydrogen Facts & Economics

Hydrogen's one attribute is that it produces only water at the endpoint of use. This gives the impression that it is a "clean," environment-friendly fuel. As it is an energy carrier, hydrogen can be produced by electrolyzing water with any domestic electricity source or it can be stripped from any fossil fuel. Anything that has hydrogen can be stripped of its hydrogen. This has the appearance of promoting national security through domestic source versatility. The truth, however, about whether hydrogen best serves our national security and energy independence goals depends upon how its burden of application weighs on the national economy in comparison to other options. Similarly, the truth about its supposed cleanliness depends upon its production heritage. A hydrogen auto using hydrogen derived from coal-fired electricity is actually several times more polluting than a gasoline-powered auto. Surprisingly, many conversations with attendees at the 2004 meeting of the National Hydrogen Association and much of the present literature reveal that many hydrogen enthusiasts don't make the distinction between energy carrier versus energy source or know to ask questions about the energy source behind the hydrogen. Entirely absent from hydrogen economy promotion is serious analysis of market economics or consideration of fundamental thermodynamic practicalities.

Among hydrogen's deficits are that it is a low-energy-density gas (at standard conditions) with significant handling and containment problems. It is the smallest and leakiest of gas molecules (i.e., four times smaller and leakier than methane). It embrittles both metals and plastics. Its low normal energy density requires that it be compressed or liquefied to force it into a state of having a reasonable effective energy density for a fuel. The act of compressing or liquefying it consumes ten to thirty percent of its energy value. Simply transporting the compressed or liquefied hydrogen from points of production to fueling stations is estimated to cost fifteen times more than room-temperature liquid distribution simply due to physical volume issues associated with reinforced, high-pressure-gas tanks or insulated, liquefied-gas tanks.

The American Physical Society's March 2004 assessment of the present state of hydrogen vehicle technology is that a factor of ten to one hundred improvement in cost and performance is needed in order for hydrogen vehicles to become competitive. The hydrogen community's reply to that challenge includes an assumed reconfiguration of automobile manufacturing to lighter, carbon fiber-reinforced, thermoplastic vehicles, assumed improvements in fuel cell efficiencies, assumed resolution of storage and materials issues, general denial of the magnitude of capital infrastructure costs and heavy emphasis of the endpoint energy use efficiency of electric drive systems relative to internal combustion engines (ICEs). Much of the competitiveness gap lies with the core hydrogen technologies, the storage system and the fuel cells. At present, these account for a quarter of a million dollar competitiveness gap for an average family sedan or minivan. Of course, every manner of efficiency gain proposed by the hydrogen community can and will first be applied to petroleum vehicles thus eliminating non-hydrogen-based factors as tools to help close the gap. Finally, when hydrogen has taken every possible step to improve itself, there still remains one critical, unsolvable barrier between hydrogen and a legitimate chance at economic viability for the masses.

Hydrogen's coup de grace is its terrible inefficiency relative to our other energy carrier — electricity. Any serious attempt at a hydrogen economy would promptly overwhelm methane resources and necessarily have to be supplied with electricity-derived hydrogen. And, of course, hydrogen use ends with electricity coming out of a fuel cell. So, hydrogen use is really a loop that starts and ends with electricity. Unfortunately, the efficiency of that electricity to hydrogen to electricity loop is only twenty-five percent (see, for example, Bossel's thermodynamics analyses at http://www.efcf.com/reports/ or the CATO Institute's Briefing Paper No. 90, Hydrogen's Empty Environmental Promise, by Anthrop). Basic conversion and handling losses waste most of the energy. The result is that for every four power plants making electricity, only one plant's electrical output actually ends up being productively used. Three power plants' output is lost simply because hydrogen was part of the process. That level of waste is unacceptable in any situation, particularly so at a time of global energy-related challenges. This problem is essentially unsolvable because it is rooted in the thermodynamics of irreversible losses. If hydrogen were extremely convenient or otherwise cost-effective or particularly safe, we might choose to overlook its terrible inefficiency. But hydrogen has none of those attributes either. Inefficiency — particularly hydrogen's inefficiency relative to the direct use of electricity — is the critical, fundamental, unsolvable show-stopper for hydrogen.

## One Alternative to Pure Hydrogen "Fuel" — Synthetic Methanol

One candidate for a post-petroleum "fuel" is methanol (methyl alcohol, MeOH, $CH_3OH$). Methanol is a room-temperature liquid that can be produced from any number of carbon sources in a long-term (i.e., post-natural gas) scheme ranging from the most-expensive route using carbon dioxide that is harvested from the atmosphere (for a net zero greenhouse gas emission loop) to using coal in a modified coal syngas plant. Both of these production schemes would utilize nuclear/renewable hydrogen. Coal-based methanol production utilizing nuclear hydrogen could easily supply our transportation fuel for centuries. Methanol is a very reasonable and versatile fuel with many advantages over pure hydrogen. As a room-temperature liquid, methanol would be handled and distributed with exactly the same type of infrastructure by which liquid gasoline is distributed today. Thus, it has none of the handling or materials complications that come with a pure hydrogen fuel. Think of methanol as still using hydrogen as the energy carrier, but also choosing to carry the energy carrier on a carbon atom for all the handling and materials benefits that come with a room-temperature liquid.

Methanol can be combusted in high-compression ICEs. Grand Prix/Indy-style race cars already burn pure methanol (called M100 in the racing community) for its safety advantages as a fuel with a lower burn temperature. Methanol can also be converted directly to electricity in direct methanol fuel cells (DMFCs). In fact, DMFCs with small MeOH tanks are already on the market; they are being sold as "disposable batteries" for small electronic applications.

Methanol's largest use today, however and very importantly, is by the petrochemical industry to make countless industrial and consumer products such as synthetic textiles, recyclable plastics, household paints and adhesives. The facts that methanol is a good fuel, that it has the convenience of being a room-temperature liquid, that it can be manufactured domestically by a variety of methods and that it also is an important primary feed material for the petrochemical industry make methanol a more useful post-petroleum commodity than pure hydrogen.

Essentially all methanol production today is, like hydrogen, from natural gas. The common heritage of hydrogen and methanol from natural gas ensures that the plastics industry will also be affected by an eventual rise in natural gas prices. Thus, serious analysis of hydrogen opportunities must also consider the methanol market. In fact, considering hydrogen's unsolvable problem, the methanol market should probably be monitored much more carefully. Decades in the future, a combination of events including escalating natural gas prices, pressure on coal and the importance of methanol as a plastics synthesis feed may have proceeded such that nuclear energy might find justification in considering the application of very high-temperature reactor technology to methanol production on a dedicated plant scale (page 9).

## Petroleum

What about supply? Are we running out of oil? A better question is: are we running out of gasoline feedstock? There is growing realization that Mideast fields of conventional oil are probably being pushed too hard to the ultimate loss of recoverable totals. There is considerable discussion right now about the peaking of oil production world wide. Demand is certainly growing, especially in Asia. Production from all known conventional oil sources is generally believed by industry experts to be peaking sometime in the next couple of decades.

Note, that is peaking in the next couple of decades, not ending in the next couple of decades. There is a very big difference between the two.

More important to this discussion than the production curve for conventional oil through this century is realization that there is much more to the petroleum feedstock picture than just conventional oil, especially from the geographical perspective of the US. There are also the massive tar sands of the Western Hemisphere — the Athabasca Tar Sands in Alberta, Canada and the Orinoco Tar Sands in Venezuela. A full two thirds of the world's known petroleum deposits exist in the Western Hemisphere in the form of bitumens. Two thirds of known petroleum is in the Americas and has hardly been touched. Think energy independence and national security from a strategically convenient, Monroe Doctrinesque Western Hemisphere point of view.

Tar sand bitumens were once considered impossible to recover profitably. It is true, bitumen is closer to asphalt than oil. However, in-situ extraction technologies like steam-assisted gravity drainage coupled with lateral drilling techniques have improved to the point that impressive levels of recovery are now possible. Tar sand deposits in Canada and Venezuela are now being extracted and processed into gasoline, profitably. Athabasca-derived fuels now comprise more than half of Canada's annual petroleum production. As conventional oil depletes, Canadian and Venezuelan bitumens will fill the void. We should anticipate an entirely natural market supply-side transition from gasoline derived from easily extracted conventional oil to gasoline derived from tar sand bitumens with continued petroleum availability through this century. Neither our generation nor the next several generations will be forced into drastic transportation changes because of a lack of traditional supply.

There is a caveat to that favorable supply news — the price is going up. Gasoline derived from tar sands is more expensive than gasoline derived from Saudi Light. Tar sand-derived gasoline will continue to increase in price as more-difficult portions of the deposits are extracted. In addition to increasing recovery costs, bitumen-derived gasoline is also more expensive to process. The Canadians are discussing a couple of new CANDUs or hydro projects (note: a couple, not scores) to meet this additional energy need in Athabasca processing.

If we were to attempt any greater level of speculation regarding petroleum through most of this century — other than the observations that it won't be depleted and that prices will continue to rise — we might also reasonably expect to see increased use of diesel fuel, both for its efficiency and because heavier diesel is a more easily and less expensively reached endpoint for bitumen processing than higher grades of gasoline. There may be more diesel-electric hybrids than gas-electric hybrids on our roads in 2050.

A major change in how we transport ourselves is not being forced upon us through a failure of petroleum reserves, though increasing costs will bring voluntary changes. Petroleum-based transportation will continue to be part of the transportation mix through this century. Since petroleum fuel costs will be increasing, we can anticipate that market responses, including increased efficiency (e.g., lighter, carbon fiber-reinforced, thermoplastic vehicles), more hybridization, greater utilization of electricity in hybrids and, of course, mass transit, will dampen the rate of price increases and serve to extend petroleum resources even further.

## Will the Real Energy Carrier Please Stand Up?

There is only one transportation alternative relevant to this discussion that is less expensive than petroleum. Most people don't realize it, but electric transportation is already, today, less expensive per mile driven than gasoline-based transportation. While hydrogen needs a few miracles and several decades — as well as severe petroleum price escalation — to hope to approach some manner of competitiveness relative to petroleum, electricity is already cheaper. Improvements in battery energy densities have essentially solved the perceived range problem. One quarter ton mass of today's battery technology gives an average metal-chassis car about one hundred miles of range and allows one to run errands around town for about half the cost of powering the same vehicle with gasoline (Advanced Batteries for Electric Drive Vehicles, EPRI 1009299, May 2004). A large fraction of our routine personal transportation can be comfortably met with today's electricity storage and drive technology. This doesn't mean every car will or must or should become all-electric. Rather, petroleum fuels will continue to be produced and available and gasoline-emphasized cars will also continue to be produced, owned by individuals and available from rental car agencies. Nonetheless, a large fraction of the US transportation market can, today, be transferred from petroleum to electricity.

We are already seeing a rapid embrace of hybridization by auto makers and consumers. We will soon start to see the gasoline versus electric ratio shifting in favor of electricity in some models. Adding battery capacity and plug-in capability for overnight charging are simple modifications to an already-hybridized vehicle. In fact, hybrid owners are already making these modifications (e.g., http://www.calcars.org/priusplus.html ) and the manufacturers have indicated that Plug-in Hybrid Electric Vehicles (PHEVs) may be manufactured as soon as the 2007 model year. Some models of hybrids will evolve from being gasoline-based with electric assistance into being electricity-based with relatively minor gasoline backup. Long before petroleum depletes and future generations are considering a replacement "fuel," electricity will have already captured a vast portion of the transportation market through a very simple and predictable maturation of today's hybrid technology. Why will this happen? Because electricity is cheaper.

We should also appreciate that electricity is very unlikely to relinquish transportation market share once it has gained it. Electricity is clean, efficient, safe, familiar and cost-effective. Can you imagine us inventing a new energy carrier that will be any more clean, efficient, safe, familiar or cost-effective? If you're thinking people might resist a change from quick fueling at the gas station to overnight charging, think again. A 2001 EPRI study found just the opposite — that the majority of people surveyed preferred plugging in a vehicle to fueling at the gas station (Comparing the Benefits and Impacts of Hybrid Electric Vehicles, EPRI 1000349, July 2001). A final thought is that overnight charging perfectly fits our present grid functioning which tends to be electricity rich during night-time, off-peak hours.

After having been battled at every turn though our entire history, the US nuclear energy community might have trouble believing that something may actually go well for us. Nonetheless, we are perfectly poised for the only legitimate opportunity to extend stationary-source energy to the transportation sector this century. Rather than speculating on a revolution in transportation based on a thermodynamically inefficient fuel and an altogether new infrastructure, perhaps we should notice that the transportation evolution — based on a familiar energy carrier and existing technology — has already begun.

## The Hydrogen Economy: Roots in Renewable Energy

The strength of the relationship between the "hydrogen economy" and renewables can not possibly be overstated. The wind doesn't always blow and sunlight isn't always striking every solar panel. Renewable energy desperately needs a very big battery, a load leveler. Without some form of energy storage, renewables are physically limited to less than a twenty percent share of the grid. At twenty percent, renewables are more of a headache than a resource for a grid manager. Electricity storage tools are expensive. Very expensive. Too expensive to justify on their own or at societal scale. But, maybe one can assemble enough little problems, like load leveling and urban air pollution and energy independence, into something that looks like one big problem worthy of one big predetermined solution . . .

You don't have to dig too deeply into the hydrogen literature before you encounter discussions of "hydricity." Imagine all energy in a society as a flowing energy commodity that is readily and repeatedly being converted between two carriers, electricity and hydrogen, as needed, in real time, to meet all the energy needs of society — energize the grid, provide all mobile transportation fuel, provide energy storage and load leveling. Clean and instantaneous. The renewable vision is that hydrogen will be the renewable society's electricity storage tool, load leveler and transportation fuel. In such a vision, we would no longer think of electricity or hydrogen or conversion efficiencies. All energy just becomes hydricity. The collective capacity of every car's hydrogen tank is society's energy storage reservoir. Parked cars are not just connected to the grid, they become part of the grid. The lean grid is automatically supported from the huge resource of all parked cars' fuel cells tapping hydrogen from their tanks. And vice versa, replenishing all cars' hydrogen tanks when the grid is rich. Never mind that an electricity to hydrogen to electricity loop delivers only one fourth of the original usable electricity. Apparently conversion efficiencies don't matter. Renewables are, after all, renewable.

For those who have been wondering why this initiative is being called the hydrogen "economy" rather than the hydrogen "transportation system," here is your answer. For those who have been wondering why there is a focus on developing energy independence through hydrogen transportation when electricity is obviously already much more capable, efficient and cost effective, here is your answer. The "hydrogen economy" is not really about energy security or clean air. The "hydrogen economy" is a backdoor attempt to integrate renewable energy's desperately needed load leveler into general commerce.

My sincere advice to fellow greens of the renewable energy community is as follows: recognize that the twenty five percent loop efficiency problem with hydrogen is essentially unsolvable because it is rooted in thermodynamics — hydrogen is a lousy load leveler; instead work to minimize the weather-dependent grid limitation problem of renewables by focusing on improvement of the North American grid infrastructure and encouraging utilization of more-efficient electricity storage tools like vanadium redox flow batteries.

## Climate Change, Coal and Fifty Percent of the US Grid

What about the big environmental issue, global warming? Even the milder predictions (i.e., 1.4 EC temperature increase and 0.5 m ocean rise by 2100) suggest that climate change will become the dominant issue guiding global energy policy before the end of this century.

When priorities shift, surveys of the US energy consumption spectrum seeking the greatest decrease in greenhouse gas (GHG) emissions for the invested dollar will invariably point to the coal-fired power plants on the grid. Coal's carbon-to-hydrogen ratio (as bad as 2.7:1 for anthracite) coupled with the Rankine Cycle make coal one of the worst carbon dioxide emitters per unit of endpoint energy use. Coal is also one of the easiest carbon dioxide emitters to replace because the plant is independent of the distribution network. It is quite a different matter for hydrogen as a tool to reduce GHGs in transportation.

As for GHG reduction in transportation, the electricity path is straightforward. No new technology, distribution network or infrastructure are needed. Simply build non-GHG power plants rather than new oil refineries, keep electricity economical and clean and let the hybrid evolution run its natural course. The market is more than capable with the right incentives.

Reducing GHG emissions in transportation with hydrogen or methanol, on the other hand, would be much more expensive per unit of GHG reduction. The hydrogen approach also starts with new non-GHG power plants, then multiplies the number of those plants to account for the losses in the inefficient hydrogen loop, then either builds and operates hundreds of centralized production plants along with a hydrogen distribution network or it builds and operates tens of thousands of localized production facilities. Of course, the hydrogen path also includes the ominous task of convincing consumers to pay for all of those additional plants and all that new infrastructure in addition to buying the much more expensive, fuel cell-based vehicles all for the pleasure of getting to use a fuel that is several times more expensive than electricity.

There are two messages here for the US nuclear energy community. First, for GHG emission reduction, coal-fired power plants are the low-hanging fruit. Coal's own estimates are two to three additional cents per kiloWatt-hour to separate carbon dioxide and inject it into subsurface geologic formations[a]. Coal simply doesn't have that price margin relative to nuclear. Regardless of the fact that utilities are right now planning over 100 GWe in new coal plants (http://www.netl.doe.gov/coal/refshelf/New%20Coal%20Plants%20(12-22-04).pdf), when coal's long-enjoyed externalities finally come home to roost the coal industry will not be able to hide the facts that coal is both the dirtiest and the most easily replaced. That's fifty percent of the US grid up for replacement. That most certainly is not a trivial sliver of the overall national energy budget.

The second message is that the most economical, and probably only economically viable, way to reduce GHG emissions (and oil imports) in transportation is to support and encourage the hybrid evolution by providing clean, economical electricity.

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[a] It should be noted that the word "sequestration" was purposefully avoided. Sequestration implies assured longevity of isolation. In truth, it is impossible to either promote carbonate-forming reactions or ensure they have proceeded to completion as would be required to assure isolation of carbon dioxide from the environment for geologic time periods. We, the US nuclear energy community, should engage the "carbon sequestration" discussion and call for parity. Specifically, we are expected to assure isolation in Yucca Mountain for 10,000 years, the coal industry should be required to meet the same standard. Simply pumping it underground does not equate to "sequestration." If they are, in fact, able to satisfactorily prove a 10,000-year isolation of gaseous carbon dioxide by simply injecting it into porous media and capping the wellhead, then we should ask to be allowed to liquefy our waste and inject it underground with their gas. That would certainly be much less expensive than a repository.

## Distant Clues of When Nuclear Might Consider a ~~Hydrogen~~ Methanol Focus

In the very slim chance that electricity hasn't already permanently captured most of the transportation sector by late century, such that there continues to be discussion of opportunities for extending stationary-source energy to transportation by carriers other than electricity and/or if there is a funded industrial interest in methanol for its petrochemical synthesis role, then there are three clues future reactor designers can look for in making a determination of when it might be reasonable to start thinking about pushing core outlet temperatures. The first clue is to be found in the methanol and petrochemical industry: the price of natural gas has already risen sufficiently that methanol production to feed the synthesis industries has shifted or is being shifted from methane to other sources, presumably coal.

The second clue has to do with the rate of climate change awareness steering energy policy: climate change concerns have been driving energy policy for some extended period of time such that new coal plant starts have long since ended and we are well through an economically viable campaign of closing coal-fired power plants and replacing them with non-GHG plants.

The third clue has to do with industrial demand for methanol and/or the relative price of methanol versus bitumen-derived gasoline: pressure on natural gas and coal are forcing the petrochemical industry to seek a new source of methanol and/or the price of tar sand-derived gasoline has permanently exceeded two times the cost of coal-derived methanol.

These events seem unlikely to develop in the first half of this century. Additionally, very-high-temperature reactor designers may have a unique opportunity as these events develop. Specifically, Generation V or VI or VII reactors may very well be able to be the sole energy source in the late-century methanol production plant. If the ceramic-core, very-high-temperature reactor is capable of safe 1000 EC outlet temperatures, then that reactor will be able to provide not only the hydrogen and electricity needed for methanol production, but also most of the direct heat needed for the base process of gas synthesis if coal is the carbon source. This is a late-century maybe. It should be noted that the needs of the petrochemical and synthesis industries for methanol will probably significantly precede any opportunity for methanol in transportation.

## Electricity Will Always Be Nuclear Energy's Primary Mission

Even if there were to be, someday in the distant utopian future, a society so rich and overflowing in clean energy that it could choose to base its transportation system on inefficient hydrogen, such a society would still be making and using more electricity. Regardless of what happens in the transportation sector, regardless of the eventual magnitude of a possible late-century nuclear heat-to-methanol opportunity, the electricity market will always be larger.

Electricity is mankind's cleanest, most-efficient energy carrier.
Nuclear energy is mankind's only non-greenhouse-gas-emitting, 'round-the-clock, regardless-of-the-weather energy source.

There is no conceivable future energy scenario in which nuclear energy will be more heavily used for anything more than it will be used to make electricity for the grid.

## Conclusion

It is usually difficult to predict the future. In this case, however, the economic realities are overwhelming and the hybrid evolution has already begun. Electricity is the energy carrier that will be carrying stationary-source energy to the transportation sector in the 21st Century. That portion of the transportation market not captured by electricity will continue to be met by petroleum-derived fuels through the next several generations' planning horizons.

Affordable PHEVs will begin appearing on dealers' lots in the next few years. Grid-distributed electricity will gain significant US transportation market share because it is a less expensive form of personal transportation. Being clean, efficient, convenient and wholly supportive of our national security and energy independence goals will further solidify its hold. Electricity is simply the best energy carrier value.

So, what about hydrogen? There are significant challenges to a hydrogen energy-carrying scheme including materials development, tremendous cost barriers, infrastructure inadequacies and the very low conversion efficiency. While many of hydrogen's problems could presumably be reduced with enough time and effort, the fact remains that the twenty five percent efficiency problem of the electricity to hydrogen to electricity loop is unsolvable. That kind of waste is simply unworkable in a world that is facing the energy-related challenges our's is facing. Societies around this planet will be struggling this century and beyond just to afford to replace their existing GHG-belching stationary sources with clean, non-GHG sources like nuclear, wind, low-head hydro and solar. There certainly will not be an overabundance of clean energy to squander on an inefficient hydrogen loop, particularly when the same tasks can be accomplished directly with the original electricity. Not this century, anyway.

Not even nuclear energy can turn hydrogen into a winner. Renewable hydrogen is four times the cost of renewable electricity. To be sure, direct heat nuclear can easily beat that — our hydrogen would be only twice as expensive as our electricity. Nuclear easily wins the hydrogen game. That victory in making hydrogen, however, is moot. The hydrogen car costs much more than the PHEV. The new hydrogen distribution infrastructure costs much more than the grid. The cheapest hydrogen still costs more than electricity, always will. Electricity = 3, hydrogen = 0. Nuclear can easily win the hydrogen game, but hydrogen, itself, is a loser.

Because electricity is mankind's best energy carrier, all societies are demanding ever greater amounts of it. Most of this grid growth and coal replacement will go to nuclear if critical mistakes — like seeing our reactors closed because there is no path for large volumes of low-power-density, once-through spent fuel — are avoided. Nuclear growth is inevitable because, very simply, nuclear energy is mankind's only non-greenhouse-gas-emitting, 'round-the-clock, regardless-of-the-weather energy source. Environmental, economic and efficiency factors unanimously call for an electricity economy. Therefore, the US nuclear energy community should ignore the hydrogen red herring and concentrate on our fundamental issues — particularly reversing the mistake of the '70s by redeveloping core skills in waste volume and proliferation risk minimization through closing the fuel cycle — to ensure that nuclear energy continues to be available, viable and sustainable as the lowest-cost provider of electricity.

Commit this to memory: Electricity will always be nuclear energy's primary national mission.