Hydrogen and Fuel Cells – Refining the Message
Initiating a national dialogue and educational agenda

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The first step, in any program of self-improvement, is admitting you have a problem. My friends and colleagues, I would like to talk to you today about two big problems. We have a communication problem—communicating with our fellow citizens whose political, economic, and moral support we will need to achieve our transportation energy goals. We have an education problem—educating the professionals with the knowledge required to understand these goals and create the necessary technologies and strategies to achieve them.

1. Initiating a National Dialogue

I'll start with the communication problem.

Hydrogen and fuel cells have now enjoyed over a decade of increasing and generally positive support. However, while this support continues to be quite broad, spanning multiple industries and political affiliations, it is not deep. Already we are starting to see cracks developing within this support. We see cracks of skepticism, which I would argue is generally healthy, because skepticism represents a need for more detailed information, more discussion and more dialogue[i]. However, we also see cracks of cynicism, which is not healthy, as cynicism is generally a sign of suspicion and distrust, especially distrust of those carrying the message.

Hydrogen, as we all know, is an energy carrier, not an energy source. A fuel cell is simply an electrochemical device to efficiently and cleanly convert this energy carrier into electricity, to be used for whatever purpose we deem necessary. In this sense, both hydrogen and fuel cells are merely pieces of our larger energy system. Which is why, when we talk about hydrogen and fuel cells, we must talk about them in the context of these broader transportation and energy systems.

So let's take a moment to talk about the primary goals of the broader transportation energy system. We might consider these to be the 'usual suspects of transportation and energy goals' -- I think you will recognize them:

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[1] This paper is an expanded version of a talk that was given in the closing plenary of the NHA conference.

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1. Provide affordable, safe, and desirable **mobility** to consumers. We sometimes forget this one but from the consumer's perspective, it may be the most important, but more on that in a moment.
2. Reduce/minimize the **local** environmental externalities of transportation energy (sometimes associated with 'criteria pollutants', oil spills, drilling in ecologically sensitive areas, etc.)
3. Reduce/minimize the **global** environmental externalities of transportation energy (sometimes called 'climate change')
4. Reduce/minimize the **political and economic** externalities of transportation energy (sometimes called 'energy security', 'petroleum dependency', 'trade imbalance', etc.)

Where should we—who believe that hydrogen and fuel cells represent a potential pathway to achieve these four goals—start? The first thing we need to do is to give people a reason to care. If we propose hydrogen and fuel cells as a potential enabler to realize the above mentioned goals, then consumers and the general public have to understand and care about all of these goals and understand how they can link their mobility choices to the other three goals.

There has been some progress in informing people on these issues over the last decade (including the efforts by many of you in this room). We believe much more is needed. I would also argue that the US, which has the largest economy in the world, uses more petroleum than any other country, produces the most greenhouse gases, and has the highest level of mobility in the world, has a special obligation to initiate a serious national and even international dialogue on these issues. Unfortunately, we do not believe this has happened yet.

To demonstrate to people why they should care, we need to talk about hydrogen and fuel cell vehicles in the context of all four goals. In order to do this, I suggest we should talk about hydrogen and fuel cells with the following four concepts in mind:

1. **Magnitude**
2. **Timing**
3. **Relativity**
4. **Value**

Magnitude

Magnitude has to do with the scale of the global environmental, political, and economic externality issues.

If you believe climate change models of the IPCC are more or less correct, the US will have to reduce its GHG emissions some 50 to 90% over the next century, just to contribute its share towards stabilizing the atmospheric concentration of CO_2 at 450 - 550 ppm (Figure 1). And even 450 - 550 ppm is projected to cause significant ecological and human harm (Figure 2).

This means that gasoline hybrid vehicles, which are an important evolutionary step on the way to fuel cells, are simply not sufficient. In fact, the CO2 and petroleum savings from a dramatic introduction of hybrids will, at best, only keep pace with the rise in travel in the US (Figure 3), and will be utterly swamped by the increase in travel worldwide (Figure 4).

Therefore, while important, it is not enough to focus on encouraging the adoption of efficient gasoline hybrids as the solution to climate change. While important, it is not enough to focus on decarbonizing our stationary power sector as the solution. Further, it is not enough to solely focus on the research, development, and eventual deployment of hydrogen and fuel cells as a potential solution.

We will need to do all of these, if we are to have any hope of stabilizing the atmospheric concentration of greenhouse gases. Simply put, in order to achieve GHG reductions on this scale will require nearly a complete de-carbonization of both our stationary and our transportation energy sectors.

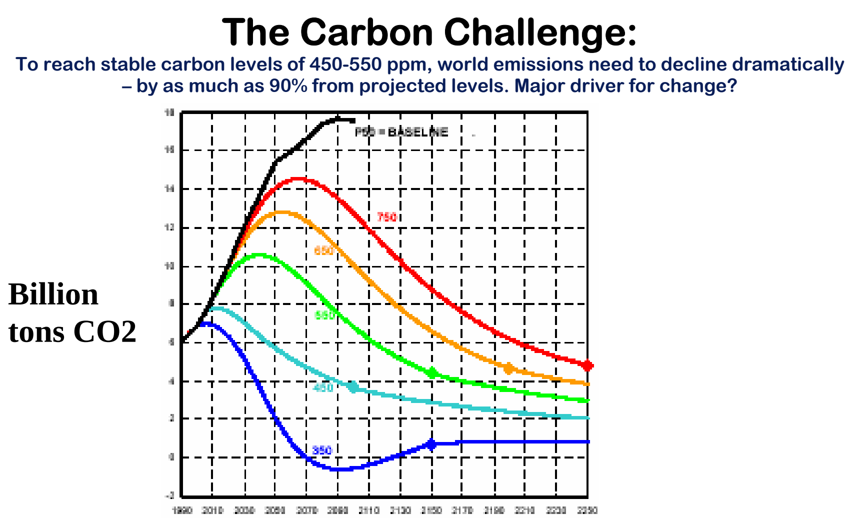

Figure 1: The Carbon Challenge (Source: IPCC TAR, 2001)

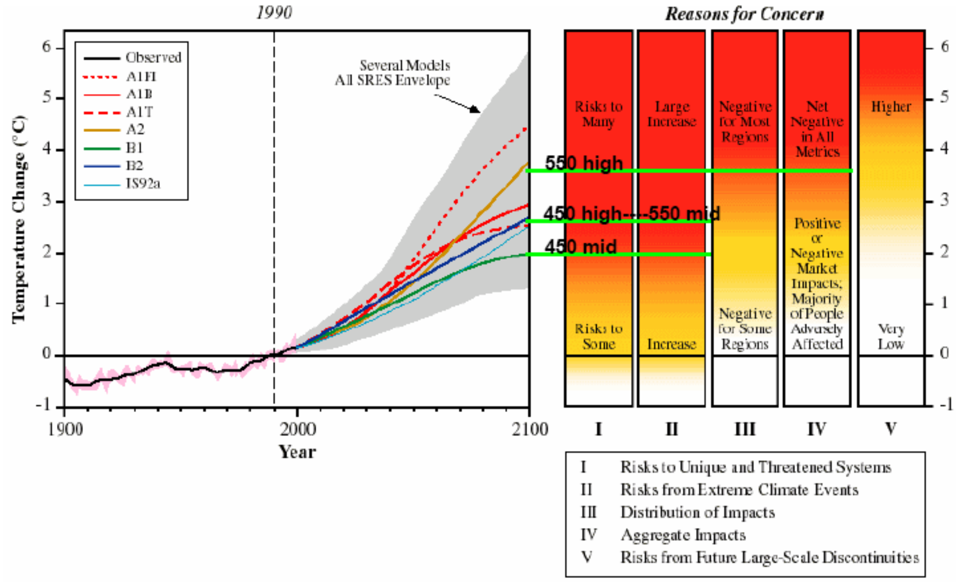

Figure 2: Carbon Consequences (Source: IPCC TAR, 2001)

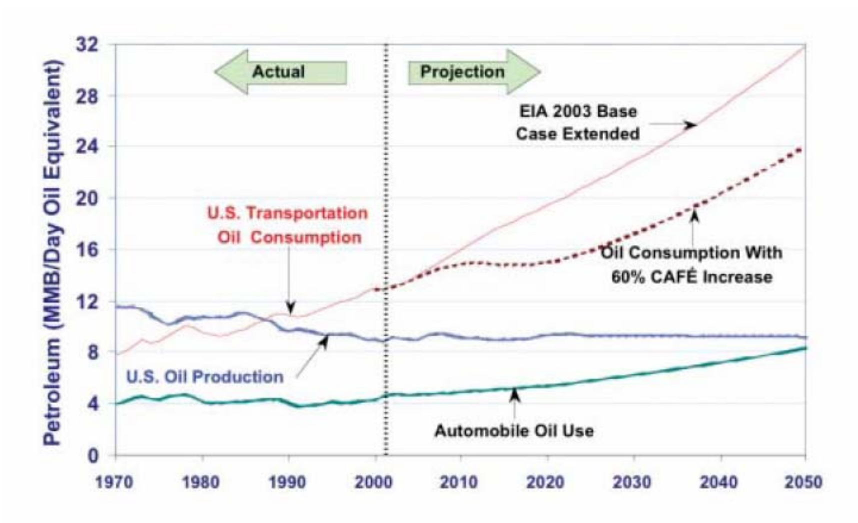

Figure 3: US Oil Use for Transportation (DOE 2003 Projections)

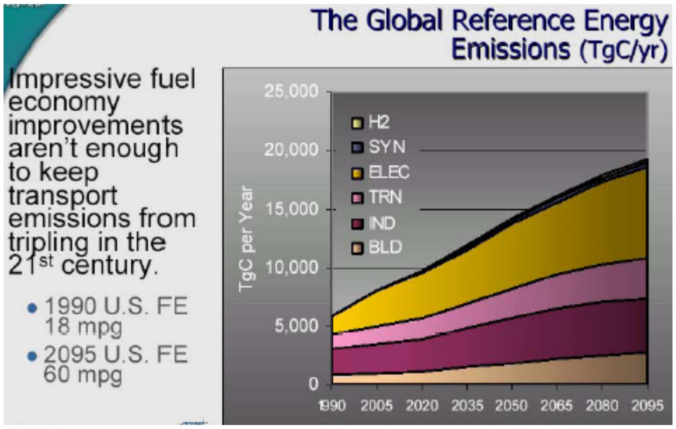

Figure 4: The Carbon Challenge (Global Energy Technology Strategy 2003)

On the issue of the magnitude of the petroleum dependency issue: It is widely accepted by virtually everyone that **conventional** oil production will peak in the next several decades. It is also widely accepted that **unconventional** sources such as tar sands, FT GTL, heavy oils, etc., are already starting to fill the gap, and within a few decades could constitute half or more of our global oil supply. So an important question is whether unconventional supplies can come on fast enough to avert supply and price crises.

There are many ways to look at the dependency issue. To start, I would recommend reading an excellent 2000 report from Nataliya I. Tishchishyna and David Greene from ORNL[ii] titled the "Cost of Oil Dependence". David and Natiliya estimate, using fairly standard neoclassical macroeconomics a cost of oil dependency to the US economy over the last 30 years of \$1.7 to 7.1 Trillion (with a base case of \$3.4T). This is just the estimated value of wealth transfer, loss of GDP, and macroeconomic adjustment losses due to the inefficiencies of the petroleum market. It does not include any of the more difficult to measure political costs such as military or diplomatic costs. Here I would recommend a reading of one of our own ITS Davis researchers Mark Delucchi[iii,iv].

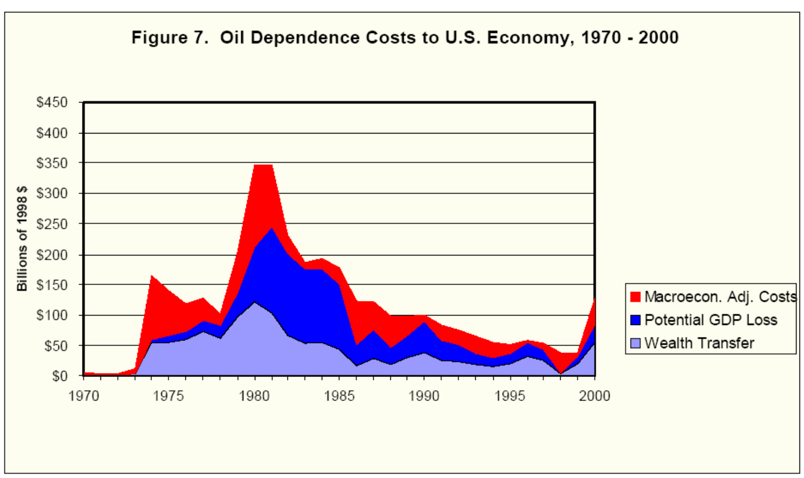

Figure 5: Cost of Oil Dependency (Greene and Tishchishyna, 2000)

Now, because of the availability of the unconventional sources, we know we are not going to “run-out of oil”, however we need to ask ourselves if we feel comfortable with this transition. It implies a ***re-carbonizing*** of our energy system. FT fuels and other GTL fuels result in a slight increase in GHGs (per gallon/BTU), heavy oil from Venezuela and elsewhere involves a moderate increase, tar sands of Alberta about 30-50% increase (depending whether in situ or surface mines), and oil shale and coal liquids even more. If the world follows this path, the magnitude of our climate problem will be that much worse.

Now why is hydrogen a compelling idea in relation to the magnitude of these issues? Because not only does hydrogen allow us to modestly reduce greenhouse gases and in the mid-term, even when produced from hydrocarbons such as natural gas[v][vi][vii], but it is one of the **only** energy carriers for transportation that enables us in the long term to de-carbonize our transportation energy production system **worldwide**, and do so with a broad array of globally distributed feedstocks (including hydrocarbons with sequestration). Now, understandably, it will take us some time to de-carbonize our transportation energy system, which brings me to the next point.

Timing

The next concept is timing. We have started to notice a slight confusion in the popular media – one of the groups with whom it is especially important that we effectively communicate to -- about the timing of two significant milestones.

The first milestone has to do with the time necessary to develop a cost-competitive and production-ready fuel cell vehicle. This is largely dependant on progress made in the R&D facilities of automakers, fuel cell system, hydrogen storage component suppliers, national labs, and universities. It is extremely difficult to predict when this will occur because it is difficult to predict technological progress. The good news is that if you track the publicly available technical literature, as well as the press releases of GM, Honda, Toyota and others, the technological progress that has been made over the last 10 years on automotive fuel cell systems is really quite astounding. We have made an order of magnitude improvement in critical metrics such as power density, cost, and durability and it does not seem to be slowing down. Still, transportation fuel cells are in relative infancy, and the point in time when the cost and durability of fuel cell systems, and the hydrogen storage and packaging issues will be solved sufficiently for a commercial ready vehicle is at this point unknown. It could be 5 years, it could be longer. What we do know is that unless all of the major players keep up their rapid and promising pace of research and development, it will never happen.

The second milestone is when fuel cell vehicles will have a significant impact on the four sets of goals we mentioned earlier. Due to the long lead times associated with investments in automotive tooling, customer fleet turnover, and the time required to invest in and build a hydrogen infrastructure, we can safely say that the impact on mobility, pollution, GHG emissions and petroleum usage will not be large for another 20-30 years **after** the introduction of the first commercially viable fuel cell vehicle. This is the simple reality that we all must confront. The transformation of our automotive industry and transportation energy system must be considered on a time scale of decades[viii]. This is true of nearly all proposed vehicle technology and energy options. Consider hybrids, which many would argue have been highly successful and require no energy infrastructure change, and which have only reached a market share of less than 1/10 of 1% seven years after their first commercial introduction. This is not to suggest that we should throw up our hands in despair. It is a reason that we must continue to aggressively pursue all promising options, including hydrogen and fuel cells, and we must do so starting today. As others have stated, this must be treated as a marathon, not a sprint. And given the urgent need to make substantial cuts in carbon emissions and the cumulative effect of such emissions, it is a marathon we must run quickly.

Relativity

The next concept is relativity and here I am not talking about Einstein, but about analyzing and discussing hydrogen and fuel cells relative to alternatives, including the existing petroleum/ICE path.

Unfortunately, people do not normally think about energy or incorporate it into their daily decisions. When people hear about the promise of hydrogen they initially get excited. Then they start to hear about all of the issues and problems associated with hydrogen. This may lead to disillusionment. What they often fail to realize, when they hear about issues such as cost, safety, and timing, is the myriad of similar issues associated with maintaining and expanding our existing petroleum system.

For example, some estimates of the cost of a national hydrogen infrastructure suggest it will cost $100B or more in the US. This sounds like a lot of money, but is it? What is the cost of maintaining, upgrading and expanding the existing petroleum system? How would this be different in developing countries? Most importantly, can the investment be made profitable and what are the risks? I should mention that these are not easy questions to answer, but they are very important to our understanding.

Another example is safety. When we talk about safety we must talk about hydrogen relative to other fuels. And I commend the good work of NHA, USFCC who maintain that hydrogen can be as safe, and in some cases safer, than gasoline.

Finally, with respect to relativity, we must ask the question: If not hydrogen, then what? We must compare all of our potential options fairly against each other, and not just with our favorite metric, whether efficiency, environmental friendliness, cost, and even value to the customer. We must take all of these factors into account and only when we do this, can we understand why hydrogen holds the potential it does.

Value

The next concept is Value, and this gets back to our first goal of affordable, safe and compelling mobility.

If hydrogen vehicles are to be successful, they must provide value to the customer. And for hydrogen vehicles, or any new vehicles for that matter, to displace the highly successful gasoline internal combustion vehicles, they will have to provide benefits above and beyond the societal goals of reduced pollution, greenhouse gas emissions, and petroleum dependency mentioned earlier. There are numerous historical examples of new vehicles and fuels that had substantial societal benefits but failed, often because they provided nothing new to the customer. There is one simple reason that automakers are investing so heavily in fuel cell vehicles – they truly believe it can be a better car for them and their customers - with increased design flexibility, competitive performance, and offering new attributes not currently available. This potential has been demonstrated, at least in concept form, by GM's Sequel, Toyota's Fine-S, and others.

So, when we talk about our future transportation and energy options, we must consider the ultimate determinant of whether products succeed or fail and that is value proposition to the customer. But is this the entire value story? Perhaps we are missing new, possibly crucial, value propositions if we think such propositions are only marketed as attributes of products. Humans express deeply held values everyday. They express their values around dining room tables, in schools, in churches, synagogues, mosques, and temples. They express them in their choice of housing, friends, jobs, clothes, and yes, even automobiles.

We may have an opportunity to attach powerful new meanings to automobiles; to differentiate automobiles according to their ability to compete on new values and services. One refrain we have heard from early buyers HEVs, is "I never want to go back."[ix] The image of a better future is compelling. We argue that our first challenge—the challenge for those who look to advance a hydrogen future—is to make this image visible and viable to all our fellow citizens, not just for a few visionaries. A vision of a world in which we have increased our human potential by limiting deleterious health impacts, global ecological threats, and dangerous and dispiriting political and economic pacts for energy does not guarantee the success of hydrogen, but it does give it a venue in which to compete.

We argue that the initiation of a national conversation requires two things. One, it requires that political leaders start today to increase the frequency and profile of public comments about why a transition away from carbon-based fuels is necessary. Two, education and outreach activities—indeed the entire idea of a transition—require deeper strategic thinking. To this end, we propose that a long-term education and outreach plan that is situated within the ideas of social marketing. The practice of social marketing has its roots primarily in the fields of education and health behaviors. We argue for its extension to market transactions involving significant collective benefits—benefits no consumer or citizen can obtain unless acting in concert with large majorities of relevant social groups.[x] Based on a social marketing approach, education and outreach actions would be linked to achievements in knowledge, policy, technology, and markets. These achievements would signify important benchmarks in the overall transition to hydrogen. Within such a strategic plan, we would be able to ask and answer questions such as the following: What should the goals be (at any point in the transition process) of education and outreach? To whom should education and outreach next be targeted? What messages, media, and distribution channels are most effective for these goals and these people? What is the effectiveness both of this specific activity and in terms of progress toward the next transitional goal?

Recasting education and outreach brings me to the second problem.

2. A new educational agenda

Many of you are familiar with the following questions: Where will the hydrogen come from? When will fuel cells vehicles make a difference in pollution, climate change, and petroleum dependency? How much will the vehicle cost? How about the fuel?

To fully and honestly answer these questions requires a complex knowledge of science, economics, and perhaps more significantly, business strategy and policy. And to be completely honest, we don't really yet know many of the answers to some of the more challenging questions.

Today we are facing a significant problem associated with a lack of infrastructure. I am not talking about hydrogen infrastructure; I am talking about human infrastructure. If there is one thing that many of us in the hydrogen and fuel cell community can agree upon, it is that there is a considerable need for more basic science and engineering to solve the difficult technical issues associated with fuel cell vehicles and clean, sustainable hydrogen production. Additionally, in order to answer the broader transportation energy questions there is a considerable need for more interdisciplinary research and training involving the integration of engineering, economics, social science, and business. Because it is at the intersection of these disciplines where we will find the insights necessary to fully understand how hydrogen and fuel cells will evolve to fit into our broader energy picture.

A recent report from the Council on Competitiveness called "Innovate America" [xi], which is signed by many CEO's and senior leaders from industry and academia agrees:

“The changing nature of innovation demands new knowledge and learning networks that can facilitate communications and collaboration at the frontiers of many disciplines and that can cross organizational boundaries between academia, industry and government.”

Unfortunately, we as a country are failing in our responsibility to build this human infrastructure. According to data recently compiled by the NSF, the enrollment in undergraduate and graduate engineering and physical sciences has been decreasing[xii] (see Figure 6). This is partially a pipeline problem. Less than 15 percent of U.S. high school graduates even have the prerequisites necessary to pursue scientific/technical degrees in college. And of those that do eventually go on to graduate work, the percentage studying advanced transportation and energy technologies such as fuel cells and hydrogen are woefully inadequate[xiii].

And while we stagnate the rest of the world is not standing still, with advanced degrees, publications and patents, especially in the physical sciences accelerating at a much more rapid pace than here (see Figure 7). This international competition is a good thing, and it should inspire us all to do better, but we must take it seriously.

Again, from the “Innovate” report:

“An innovation economy that drives economic growth and job creation will be fueled by new ideas – and those will start from curiosity based research, then move to application and finally to commercial exploitation. America must certainly retain and enhance its research at the frontiers. But it must also improve the processes that evolve these ideas into new products, new services or new solutions to pressing societal problems.

Universities have always protected and encouraged inspired individuals to expand and share humankind’s basic scientific knowledge base. Their ideas represent some of our strongest national assets, and we must safeguard the mechanisms that fund and promote them.”

Put simply, we face many complex energy, environmental and mobility problems, and we have ideas as to how to tackle them, but we lack the educational resources to do so… and time is running out. There is a need to dramatically increase both the size and number of research and training programs focused on advanced transportation energy technology (not just fuel cells) if we are to successfully produce the future scientist, engineers, business and policy makers with the necessary complex knowledge to make the appropriate decisions for our energy future.

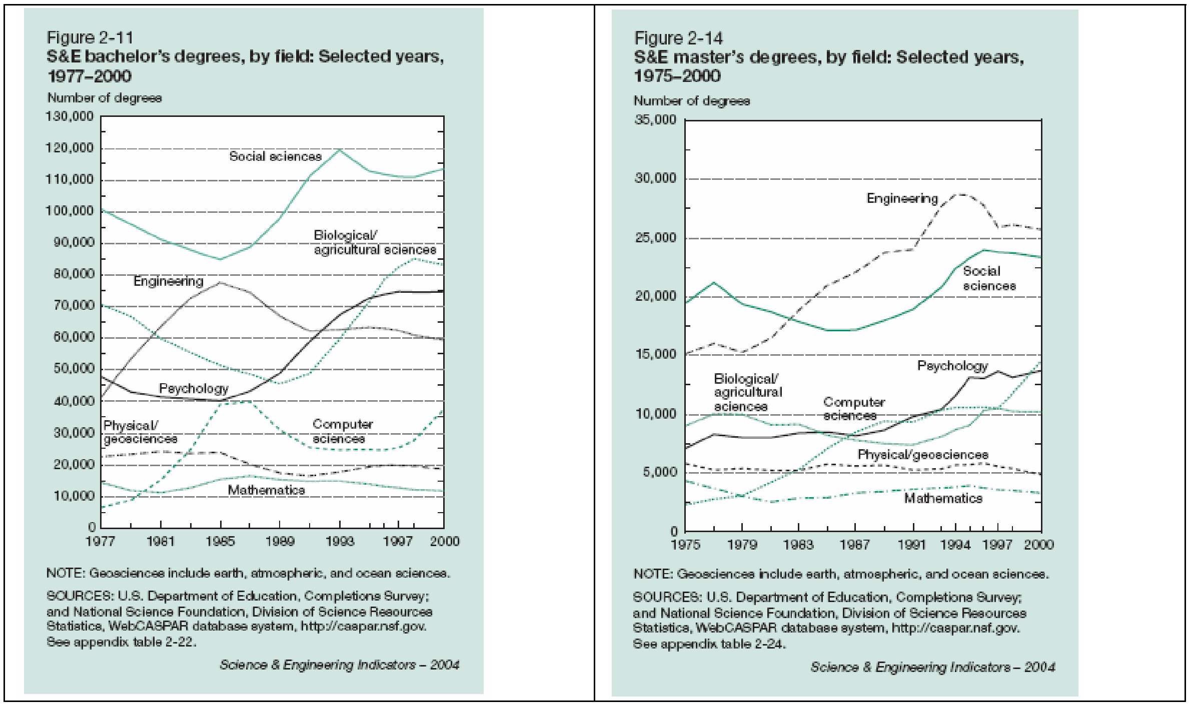

Figure 6: Troubling Trends in Graduate Education (NSF 2004)

Now, I should be clear that this is not a complete story about the key stakeholders that need to learn today about hydrogen and fuel cell technology. There is clearly a strong need for timely and targeted education of permitting officials, emergency response personnel, C&S officials, and others, especially due to the fact that we are now entering a demonstration phase of the technology and these groups must be well informed to proceed. We have already experienced significant challenges in permitting stations, local resistance, and other extremely costly delays primarily due to a lack of adequate education. And while much of this is to be expected with any new technology introduction (and in fact can be considered part of the 'learning process'), it will slow down the progress of those trying to evaluate the performance of their products in the real world.

So how do we propose to address these problems?:

a) Targeted and timely education to the stakeholders that must understand (and in some cases implement) hydrogen and fuel cell technologies today as well as those that require long lead times to develop appropriate policies, codes, standards.
b) We must build the human 'pipeline' by investing in science education with a focus on the environment within the JH-12 grade levels, especially in HS where many young adults begin to contemplate their future careers. This is a very long lead time activity that needs action today.
c) And finally, we must invest in both undergraduate and graduate science, engineering, and interdisciplinary programs with a focus on advanced transportation and energy.

I would like to finish this talk with a short story. Not to long ago, I was recruiting engineers for the emissions and fuel economy group of the Ford Motor Company. Now we always had a problem with hiring engineers to work in our department. The reason we had a problem was because all of these fresh engineers wanted to work only on the Mustang Cobra program, or the F150 lightning or the Ford racing programs. They did not want to work on the emissions and fuel economy programs. Then we began doing something a bit differently and we started targeting students who were working on the DOE's FutureCAR and FutureTruck programs. These are student competitions, research and training programs focused on developing high efficiency, low emissions cars or trucks. And the interesting thing is that these engineers from these programs wanted to work on our emissions programs, and on our hybrid and fuel cell programs, about which they had gained substantial practical knowledge about during school. More importantly, they had also developed a passion for these subjects that they would carry into the job. Through their training they had seen both the problems and the opportunities within the technology, and they were ready to come to industry to help realize those opportunities, perhaps even, to change the world.

So in closing, I would suggest that to effectively communicate about hydrogen we do not need more hydrogen advocates and we certainly do not need more hydrogen cynics. What we need are more hydrogen realists, because that really, is what a credible skeptic is. We need the people who understand the complexities of the problems and are working diligently towards the solutions. And I would suggest that our schools and especially our universities are perfectly positioned to create these hydrogen realists, the future knowledge ambassadors, who will be passionate about realizing our future transportation energy goals.

Thank you very much.

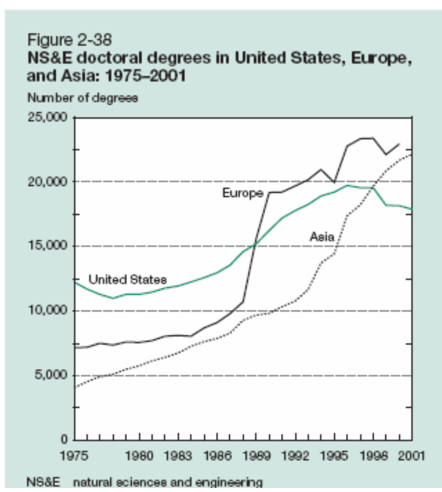

Figure 7: International Competition (NSF 2004)

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