Informational Hearing

Select Committee on Air and Water Quality
Assemblymember Fran Pavley, Chair

California's Hydrogen Highways

Testimony By:

Dr. Timothy E. Lipman

Assistant Research Scientist
Energy and Resources Group

and

Assistant Research Engineer
Institute of Transportation Studies

University of California, Berkeley

telipman@socrates.berkeley.edu

Thank you for the opportunity to provide this testimony to the Air and Water Quality Select Committee. I would like to focus my comments on making three broad recommendations for the state to consider as it moves forward in exploring the prospects for this hydrogen highways plan. However I would first like to note that during the years that I have been studying hydrogen and fuel cells for transportation, I have seen great technological progress with regard to the development of fuel cell systems suitable for motor vehicles, and with other important technologies such as hydrogen storage systems and electric motors and power electronics for vehicles. For example, ten years ago we did not know if sufficiently powerful fuel cells could be made compact enough for practical motor vehicles. But now General Motors is on about their 10^{th} generation of automotive fuel cell technology, and has succeeded in increasing fuel cell system power densities to over 2 kilowatts per liter -- more than a tenfold improvement in less than 10 years.

However, despite significant improvements in fuel cell and hydrogen technologies, daunting challenges do remain. These include fuel cell system cost and durability issues, the challenges of safely and practically storing hydrogen onboard vehicles, and of course the challenge of providing adequate refueling infrastructure for hydrogen vehicles used beyond centrally-refueled fleet applications.

To me, these challenges mean that California should carefully consider each step of a hydrogen infrastructure research, development, and deployment plan that is *staged* in some fashion to assure that certain important milestones are met at each stage before proceeding to the next one. I would recommend an overall plan that is bold and that helps to further California's leadership in bringing about the hydrogen economy, but that also includes some flexibility in making

adjustments along the way. New technology paths are usually bumpier than they are smooth, and the challenges in front of us should not be underestimated.

With those general comments, I would now like to make three specific recommendations for the state to consider.

1) The Importance of a Renewable Hydrogen Future

First, I would like to draw attention to the importance of emphasizing a *renewable* hydrogen future. Perhaps *the main* advantage of introducing hydrogen into transportation sector and other markets is that it offers a wide and diverse set of potential benefits. If one only wishes to address air quality improvement, there is probably a cheaper and easier way. If one only wishes to address greenhouse gas emissions, there is probably a cheaper way. And if one only wishes to address petroleum dependency, there is probably a cheaper way. But, if one wishes to address *all* of these important issues – that is where hydrogen may have a strong advantage.

I believe that one of the most important benefits that hydrogen can ultimately offer is its ability to be made from a diverse array of domestic sources, including -- very importantly -- sources that are renewable and sustainable. However, in the early years of the hydrogen transition, natural gas will probably play a key role as a source for hydrogen due to its relatively attractive economics. There are two potential dangers to this, as a natural gas based hydrogen future is at best an incomplete one. First, natural gas is subject to significant price fluctuations, and some experts are predicting the potential for increases in what are already historically high prices over the next several years. These price fluctuations could therefore greatly affect the economics of hydrogen production, and could threaten to "pull the rug out" from under the hydrogen economy just as it is getting started. Second, there is a risk of technological "lock-in" to natural gas based hydrogen production, making it potentially difficult to switch to other more attractive alternatives from a social and environmental perspective.

For these reasons, I think that it is important that the state develop a plan to rely increasingly on renewable sources of hydrogen, as it is only in this way that the benefits of hydrogen can be fully realized. In most people's minds, this means producing hydrogen by electrolysis from wind and solar power because these are the renewable hydrogen options that have received the most attention. However, the costs of electrolysis-derived hydrogen are relatively high, and likely will remain so for some time. Recent research suggests that there are other renewable sources of hydrogen based on biomass sources that can produce delivered hydrogen for less cost, perhaps around $3.00 per kilogram in the medium term. These sources include municipal solid waste, landfill gas, and agricultural and livestock residues, as well as dedicated energy crops. While these sources may ultimately be limited in magnitude, they are potentially attractive options for producing hydrogen cleanly and renewably. Along with the electrolysis-based options, they should be explored with regard to their potential for California.

2) The Possibility of Combining Hydrogen Infrastructure with Distributed Power Generation

Second, I would like to mention the interesting prospect for combining hydrogen production for motor vehicles with the production of electricity using distributed power generating systems. Concepts such as "hydrogen energy stations" that would co-produce hydrogen for vehicles and

electricity for local building loads and/or utility grids have the potential for more attractive overall costs than dedicated hydrogen generating and dispensing facilities. These stations would use stationary fuel cells or other hydrogen-based electricity generating systems, and while they would require some decreases in stationary fuel cell costs to become fully economic, decreases on the order of twofold may be sufficient in this regard and these may be expected in the medium term, if not the near term. The obvious attractiveness of this type of scheme is that two important problems can be addressed simultaneously. First, the issue of developing cost effective hydrogen infrastructure for vehicles, particularly in early years when the number of vehicles refueled at each facility is low. Second, the need to meet growing demand for electricity given the difficulties in siting new central power stations and long-distance transmission lines. There are many different potential technologies and designs for theses types of energy stations, and we have only begun to analyze their potential costs and benefits.

3) The Potential Importance of Hybrid Electric and Hydrogen Combustion Vehicles

Third, I would like to again highlight the fact that key technological issues remain for the introduction of fuel cell vehicles. While I believe these vehicles have great promise, I know of no one who can yet see a "clear path" to the manufacture and sale of fuel cell vehicles that would be cost-competitive with conventional vehicles. For this reason, it is important for California to not "put all of its eggs in one basket" with regard to fuel cell vehicles, and to recognize that at least two other advanced vehicle types have the potential for near-term environmental and energy benefits and – importantly – could actually assist with the development and introduction of fuel cell vehicles.

These vehicle types include hybrid electric vehicles, and hydrogen combustion engine vehicles. Hybrid EVs use many of the same electrical drivetrain components that would be used for fuel cell vehicles, such as electric motors, motor controllers, and high-power battery systems. Continued development of hybrid EVs can thus contribute directly to the development of fuel cell vehicles. And hydrogen combustion vehicles such as those being pursued by Ford and BMW can potentially allow hydrogen to be introduced as a vehicle fuel more quickly and in a bigger way, as these vehicles may be commercially attractive sooner than vehicles powered by fuel cell technology. Developments with these other hydrogen vehicles would assist in addressing issues associated with the onboard storage of hydrogen, and would provide additional demand for hydrogen that could be crucial to the economics of hydrogen as a vehicle fuel in California.

In addition to these general recommendations, I would like to make the following more specific ones:

1) The numbers of hydrogen-powered vehicles called for in the ZEV mandate are insufficient to justify a widespread hydrogen infrastructure in the 2010 timeframe. Additional efforts should focus on increasing the number of hydrogen vehicles in the state, through government purchase programs, other fleet requirements, and greater incentives to include hydrogen vehicles in private fleets. Hydrogen combustion vehicles should be included as well as fuel cell vehicles as a means of generating greater demand for hydrogen fuel.

2) Under the Pavley Bill, a credit scheme for vehicle-related greenhouse gas emission reductions should be developed. This should include the full fuel cycle emissions of greenhouse gases, including as many different types of greenhouse gases as possible. This could provide an important stimulus for hydrogen as a vehicle fuel.

3) Tax incentive schemes should be developed for businesses that invest in hydrogen refueling infrastructure, and hydrogen vehicles in their fleets.

4) California should consider some form of carbon tax to incentivize hydrogen as a fuel, efficiency-improving technologies, and other low-carbon energy systems. This could provide significant benefits to efforts to introduce hydrogen as a fuel for transportation and in other sectors.

I close my testimony with these recommendations, and again thank you for the opportunity to provide this testimony. At UC Berkeley we look forward to working with the state in any way that we can as it pursues this important strategy for reducing the environmental and human health impacts of transportation and electricity sector energy use.

Biographical Information

Timothy E. Lipman

Dr. Timothy E. Lipman is an Assistant Research Scientist with the Energy and Resources Group (ERG) and an Assistant Research Engineer with the Institute of Transportation Studies at UC Berkeley. He also has an affiliation with the Institute of Transportation Studies at UC Davis (ITS-Davis) where he is a research track director for the Hydrogen Pathways Program.

Dr. Lipman's research focuses on fuel cell systems, combined heat and power (CHP), renewable energy, hydrogen infrastructure, and electric-drive vehicles from an integrated economic, engineering, public policy, and environmental perspective. He currently is helping to lead several research projects, including acting as co-director of the Pacific Region Combined Heat and Power Application Center – a research and outreach effort sponsored by the U.S. Department of Energy and California Energy Commission. Other projects include ongoing collaborative efforts with the Lawrence Berkeley and Sandia National Laboratories for distributed power system modeling, and various studies for the California Air Resources Board (ARB) and the California Energy Commission.

Prior to working with ERG in this recent capacity, Dr. Lipman completed a two-year post-doctoral research fellowship with the ERG's Renewable and Appropriate Energy Lab (RAEL). While working at RAEL, Dr. Lipman led a research program that conducted various projects to examine the economics and environmental impacts of using fuel cells and other clean energy technologies as distributed power-generating resources.[1] Also as part of this post-doctoral fellowship, Dr. Lipman assisted with California, U.S., and international energy policy studies and teaching/outreach efforts, and helped to organize and manage collaborative studies of distributed energy systems and "microgrids" with colleagues at the Lawrence Berkeley National Laboratory.

Dr. Lipman completed a Ph.D. degree in Environmental Policy Analysis with the Graduate Group in Ecology at the University of California at Davis in December of 1999. He then served as Associate Director of the Fuel Cell Vehicle Center at ITS-Davis through August of 2000. Dr. Lipman also completed an M.S. degree in 1998 in the technology track of the UC Davis Graduate Group in Transportation Technology and Policy, with coursework in civil engineering and atmospheric science.

While enrolled as a graduate student, Dr. Lipman worked as a researcher at ITS-Davis on an ARB sponsored electric vehicle cost and performance study and on a CALSTART neighborhood electric vehicle project, as well as participating in various smaller projects. He authored or co-authored several journal articles and ITS-Davis research reports on policies to encourage the production and use of neighborhood electric vehicles, on the potential use of hydrogen as a transportation fuel, on the manufacturing costs of electric vehicle technologies, and on greenhouse gas emissions from transportation fuel cycles. He has authored papers for annual meetings of the Transportation Research Board, the Electric Vehicle Symposium, and the National Association of Environmental Professionals, and has delivered professional talks at various other conferences and technical workshops. These have recently included a series of

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[1] http://socrates.berkeley.edu/~rael/fuelcell.html

talks about the economics of fuel cell systems for use in the transportation and stationary sectors, including an Emirates Center for Strategic Studies and Research conference on "The Future of Oil as an Energy Resource" in Abu Dhabi UAE in 2000, ITS-Davis "Fuel Cell Vehicle Workshops" in Washington, D.C., Sacramento, and Davis in 2001-2002, UCB Haas Business School's 2001 and 2002 "Leading Edge" Technology Conferences, and the Berkeley Lab's Fall 2002 "Distributed Energy Resources Seminar Series."

Dr. Lipman has received several fellowships and awards, including the nationwide Council of University Transportation Centers "Charley Wootan" best transportation policy PhD dissertation award for 1999, a 1998 NSF IGERT teaching fellowship, a 1997 University of California Transportation Center Dissertation Grant, a 1996 ENO Foundation Fellowship, a 1995 University of California Transportation Center Dissertation Grant, and a 1994 Chevron Foundation Fellowship.

Dr. Lipman is also a graduate of Stanford University, where in 1990 he completed a self-designed B.A. in Anthropology, focusing on energy and environmental technology transfer for the developing world. He has previously worked for two years as an environmental analyst and technical writer under a Boeing Aerospace, Inc. contract with the NASA-Ames Research Center in Mountain View, California, and for three months as a policy intern for the Bank Information Center at the International Center for Development Policy in Washington, D.C.

Selected Publications

(from over 40 total; email telipman@socrates.berkeley.edu for complete list)

Lipman, Timothy E., Jennifer L. Edwards, and Daniel M. Kammen (2004), "Fuel Cell System Economics: Comparing the Costs of Generating Power with Stationary and Motor Vehicle PEM Fuel Cell Systems," *Energy Policy* **32**(1): 101-125.

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Lipman, Timothy E. and Mark A. Delucchi (2002), "Emissions of Nitrous Oxide and Methane from Conventional and Alternative Motor Vehicles," *Climatic Change* **53**: 477-516.

Delucchi, Mark A. and Timothy E. Lipman (2001), "An Analysis of the Retail and Lifecycle Cost of Battery-Powered Electric Vehicles," *Transportation Research – D* **6**: 371-404.

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