Testimony of Jerome Hinkle
House Committee on Science
Subcommittee on Energy

ASSESSING PROGRESS in ADVANCED TECHNOLOGIES for VEHICLES and FUELS

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Chairman Biggert, Ranking Member Honda, Representative Lipinski and guests, good morning. The National Hydrogen Association welcomes the opportunity to discuss progress toward building the Hydrogen Economy. We would like to focus on those technical and policy challenges that will be most important to transforming our energy systems. Under your leadership, the Science Committee continues to help guide our country's search for critical energy alternatives — we hope today's hearing will provide some insight gain in several key areas.

For 17 years, the National Hydrogen Association has promoted a transition to a hydrogen economy through its extensive work in codes and standards, education and outreach, and policy advocacy. Its 103 members represent considerable diversity: large energy and automobile firms, utilities, equipment manufacturers, small businesses, transportation agencies, national laboratories, universities and research institutions. In partnership with the U.S government and each other, we are the wave front of technical and economic action on hydrogen in the U.S. and abroad — these are the people and organizations that are making great progress along a broad technical front, and will have a key role in implementing these technologies (please see the attached slides about the NHA).

Hydrogen is our Nation's premier energy destination. We'll need an army of dedicated and talented people to solve all the technical and market-building challenges along the way. The stakes are high, and we've got a lot of tough homework to do.

The Committee has requested our views in several areas. We will comment on some of the key technical and deployment issues, and relate these to important provisions of the Energy Policy Act of 2005.

Energy Policy Act of 2005 (P.L. 109-58) and Fiscal Year 2007, 2008 Budget Action

Many of the provisions in EPAct 05 originated in S. 665, the *Hydrogen and Fuel Cell Technology Act of 2005,* introduced on March 17, 2005. Written in concert with industry and the Senate's Hydrogen and Fuel Cell Caucus, it became the heart of the Hydrogen Title (VIII) in the Senate's Energy Bill, S. 10, and subsequently a substantial part of the hydrogen language negotiated in the Conference Committee. It was signed into law by the President on August 8, 2005. Significant sections of the Act's Vehicle and Fuels Title (VII) also deal with early market transition for hydrogen and fuel cells.

Section 802 of the Act establishes the purposes of the Hydrogen Title:

- Enable and promote comprehensive development, demonstration and commercialization in partnership with industry
- Make critical public investments that build links to industry and the research community
- Build a mature hydrogen economy that creates fuel diversity in the massive U.S. transportation sector
- Create, strengthen and protect a sustainable energy economy.

In Titles VII and VIII, the Act clearly intends to accelerate the research, development and demonstration programs in DoE, makes the Government a more durable partner in its industry relationships, gives permanent authorization to the hydrogen programs in DoE, broadens the Secretary of Energy's authorities and provides more than triple the resources to accomplish this. It builds on the strong foundations of DOE's prior work on hydrogen and the President's Hydrogen Fuel Initiative, which has planned to devote $1.2 billion to this work from 2004 through 2008. The EPAct 05 authorizes $3.73 billion over Fiscal Years 2006 through 2011, and "such sums as are necessary" through 2020 (please see the attached slides about the EPAct 05).

The House recently passed H.R. 5427, the *Energy and Water Development Appropriations Act for Fiscal Year 2007*. It mirrors DoE's Budget Request for hydrogen — $246 million for those programs included in Titles VII and VIII (under the Energy Efficiency and Renewable Energy and Science offices of DoE).

RD&D activity in the Government is fueled by these public investments. The level of funding requested by DoE is on a path established by the Hydrogen Fuel Initiative in early 2003. Much has changed since — by February 2003, we had already seen energy prices beginning their rise — the average world oil price was about $28/barrel, but by the end of May 2006 that price was nearly $64/b. The President and Congress have anticipated the need to seriously search for transportation fuel alternatives, but there is a policy lag in the hydrogen program — less than half (47.5% -- $246 million) of the EPAct 05's authorized funding level of $518 million has been requested by DoE for FY 2007.

Action We don't want to see the many opportunities for enhancing DoE hydrogen technology programs to slip away at a crucial time in their history. Built on program success, Congress has given the Secretary extensive authority in the EPAct 05 to enhance Section 808 demonstration programs, particularly with respect to learning demonstrations, broader vehicle/fuel supply systems (including community systems), and the ability to have results from demonstrations revise the direction of R&D projects. DoE is well into planning for the FY 2008 budget cycle — we would urge their program managers, with the support of the Committee, to utilize a much higher share of their budget authority, which grows from $ 517.5 M in FY 07 to $739. 5 M in FY 08. Nearly 53% of this funding is for R&D, including basic science, which also needs to be expanded beyond its $50 M in the current Energy and Water appropriation. There are also significant opportunities in Title VII (Vehicles and Fuels) to have federal and state agencies take a leadership role in purchasing stationary and portable fuel cells and hydrogen supply systems as early adopters. This could be coupled, for instance, with DoE's Clean Cities program to demonstrate real systems in the urban areas where the first commercial deployments of vehicle fleets is most likely.

Critical Technical and Economic Challenges

In its pacesetting report, *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs* (April 2004) , the National Academy of Sciences summarized their four most fundamental technological and economic challenges:

- Develop and introduce cost-effective, durable, safe and environmentally desirable fuel cell systems and hydrogen storage systems
- Develop the infrastructure to provide hydrogen for the light duty vehicle user
- Reduce sharply the costs of hydrogen production from renewable energy sources, over a time frame of decades
- Capture and store the carbon dioxide byproduct of hydrogen production from coal.

Storage As the Committee has noted, adequate on board storage is widely agreed to be a fundamental necessity for a successful light duty vehicle. Stationary storage can be just as important for the fueling stations supplying the vehicles. Much progress has been made on defining and resolving some of the storage issues since the Committee's last field hearing in 2002. Both onboard and stationary storage have seen considerable improvement, especially in concert with the industry/DoE Technology Validation program.

GM and Ballard, for instance, have greatly improved fuel cell power density — GM by a factor of seven in the last six years, while enhancing efficiency and durability and reducing the stack size. Ballard reduced the cost in four years by 80% to $103/kW, still about three times the DoE's 2010 goal of $30/kW to be competitive with current ICE powered cars, but on a path to achieve that goal. Durability increased ten-fold. Their work continues at an urgent pace.

DoE and Department of Defense work, the President's Hydrogen Fuel Initiative of February 2003, and its support by industry and the Congress —

all have led to more orderly program planning that identifies a wide range of alternative approaches to the materials and methods that could be used to store hydrogen. Improving the program management has led to measurable gains in storage performance (a summary description of the progress for 2005 is available on DoE's web site, www.hydrogen.energy.gov – the *Annual Progress Report*, pp 459-462; see, also www.er.doe.gov for the DoE Science program, which has considerable work underway on fundamental science with regard to hydrogen storage).

(Note: please see the attached slide from DoE comparing the relative performance of several storage methods: *Hydrogen Storage Technologies,* which shows storage capacity and costs.)

From the graphs, it is clear that by the end of 2005, volumetric capacity (volume storage effectiveness) and gravimetric capacity (storage by weight) do not yet match the goals DoE has set for 2010 and 2015. Neither has system cost reached the targets, but all the 2010 goals are being approached in steady fashion. Can progress toward these goals be reached more quickly? **We see real progress in storage, but believe that smart, full use of the increased resources for Fuel Cell Technologies (Sec. 805) included in the EPAct 05 could definitely improve program performance. We urge DoE to request full funding in their FY 2008 budget.**

Associated graphs show how the cost curve for proton exchange membrane fuel cells is dropping with steady research effort, and also how hydrogen cost goals for fuel cell vehicles relate to gasoline/electric hybrids and gasoline/internal combustion engines, taking into account their relative efficiencies.

Something missing from DoE's planning is direct combustion of hydrogen in advanced piston engines. This is a conscious program resources decision to focus on what they see as the highest payoff efforts. Two NHA members, BMW and Ford, have done considerable work with a variety of engines running on hydrogen. BMW plans to introduce a 7 Series with a V-12 bi-fuel engine, perhaps before the end of the year. It has remarkable emissions, and excellent performance. We would like to see DoE devote some funding to direct combustion, as it offers much earlier market introduction and a bridge to the hydrogen economy through the establishment of hydrogen supply stations for a wider variety of vehicles and collocated stationary fuel cells for electrical power.

A systems view Focusing on storage and achieving a 300 mile range as if they were separate from other vehicle design parameters may limit the search for solutions within a whole vehicle context. It is important to remember that a modern gasoline-fueled automobile only utilizes less than 1.5% of the fuel's energy to propel the vehicle's payload. This leaves considerable room for improvement.

Extra mass is just ballast. With more intensive application of modern aerospace composite materials and high strength, lightweight steels and alloys, coupled to the new flexibility in vehicle design that fuel cells and electric drive subsystems offer, a much more efficient vehicle package can be designed. Aircraft designers have been coping with these problems for a hundred years. A personal vehicle, however must be much cheaper and simpler.

There is a significant interaction between mass and the size of the fuel cell, the amount of hydrogen stored on board, and range. Although DoE has advanced materials, vehicles and manufacturing projects, it is unclear whether these have achieved a high level of integration. Hence Section 808 (b) of the EPAct 05, *Systems Demonstrations*, that specifically combine learning demonstrations with optimized advanced composite vehicle design. DoE already plans for second generation vehicles in their Technology Validation learning demonstrations. Again, this is a real opportunity for DoE to utilize some of their new authority and resources in advancing the art of whole vehicle design. General Motors, for instance, has built several vehicles that incorporate not only advanced hydrogen fuel cell electric drive systems, but totally different platforms. As Amory Lovins has remarked, "Why waste a fuel cell on a primitive platform?"

(Note: please see the attached charts from General Motors, which highlight what they see as the key goals and challenges.)

Of some note is the GM chart encouraging DoE to strengthen their hydrogen program, a "bold new approach". By simply ratcheting up Corporate Average Fuel Economy standards, and achieving this through the use of hybrids of various types we do save oil, but only delay solving the critical transportation fuel diversity/security problem. The conclusion here is that we already know enough about the potential of a hydrogen economy, and the stakes are so high that we need to focus on total solutions rather than partial ones.

Technical barriers in production and distribution — where will the H2 Economy get built?

The Committee is concerned about the technical barriers in production and distribution that would need to be overcome to permit hydrogen to fuel a quarter of the cars on the highway. With about 220 million cars registered in the U.S., and about 17 million sold per year, it would take several years after a competitive vehicle was available for 25% of the existing fleet to be replaced. Since many owners have more than one registered vehicle, and there are somewhat fewer drivers than the entire vehicle stock, significant operational oil savings would occur well before 25% replacement. The National Academy study "upper bound" market penetration case assumes that competitive fuel cell vehicles enter the market in 2015 as part of the mix of hybrids and conventional internal combustion engine (ICE) powered vehicles. They estimate that 25% of the fleet would be replaced within 12 years, or by 2027.

GM and others see that within 20 years the entire fleet could turn over with a superior group of products, which makes it possible to evolve hydrogen supply infrastructure along with vehicle production. In testimony before the Senate last July, GM, Shell and Ballard all concurred that we could see a manufacturable fuel cell vehicle by 2010-2012 that would be competitive with those cars then for sale. GM's urgent target is to validate a fuel cell propulsion system by 2010 that has the cost, durability and performance of a mass produced internal combustion system.

GM and others have estimated that an infrastructure for the first million vehicles could be created in the U.S. for $10-$15 billion, making hydrogen available within two miles for 70% of the U.S. population, and connecting the 100 largest U.S. cities with a fueling station every 25 miles. Others see broader deployment costing nearer $20 billion, not appreciably more than what the industry reportedly spends each year to simply maintain its current gasoline supply system.

Substantial oil savings would result when 25% of the fleet is replaced, resulting in lessening peak refinery capacity needs, as gasoline demand begins to shrink. Since much of the current industrial hydrogen production is utilized by oil refineries in making modern gasolines, some of this could now become merchant hydrogen supply. The attached Shell Hydrogen slides are suggestive.

The first of these shows a satellite picture of the U.S. at night, overlaid by 100 km circles surrounding today's refinery production sites for hydrogen. These are also the major urban, higher density gasoline demand areas — over 100 of them — meaning that at some 60% of the U.S. population is within 100 km of a major source of hydrogen today. And these are where the introduction of hydrogen fuel cell vehicles would likely be focused — starting with fleets of municipal and commercial buses and delivery vehicles, and then evolving to fleets of cars and light trucks, and finally to consumers. We would expect stationary and portable fuel cells to lead these transitions in providing high quality supplemental and distributed power to businesses and municipalities, and the early establishment of hydrogen supply networks.

Shell's next few slides discuss how a transition needs to be managed — in terms of key "Lighthouse" projects — those sized correctly and smart enough to provide a beacon to lead the way to something larger. A critical component is the quality of public/private partnerships — something the EPAct 05 stresses. The coordination of "Infrastructure Rollout" is a critical aspect — if it is uncoordinated, excess retail and manufacturing capacity outruns demand, leading to high costs for hydrogen that further dampen demand and shrink profitability. They see that an excellent match between the rates of demand and supply growth optimizes investment in capacity, and a more orderly and rapid transition. Lighthouse Projects are the harbingers of commercial success, and primary showcases for how well public and private institutions cooperate in establishing the climate for growth — whether it be in North America, Europe or Asia.

It is interesting to speculate on how the industrial base for a hydrogen economy might evolve. As a result of a study called for in Section 1821 of the EPAct 05, *Overall Employment in a Hydrogen Economy,* DoE will soon have underway an economic development analysis that looks at different transitions to varied forms of a hydrogen economy, to accompany other such work on market and technology transitions. It is expected that both new job growth and retention of existing jobs during a transformation like this would center on the supply chain for new vehicles, and much altered refinery and utility operations producing hydrogen. In addition, we would likely see considerable expansion in renewable energy production — both electricity and biofuels — in widely dispersed agricultural regions of the US some distance from urban demand centers.

Also, much of the hydrogen in the early years will likely be produced from widely distributed sources, using electricity off the existing grid or natural gas from the existing pipeline system. These distribution networks are large, reliable and reach all urban areas. The combined electrical grid is connected everywhere — as the Hydrogen Utility Group suggests, "For decades, we have brought electrons to every home and business in the US; why not protons?" Their operations are well understood, and key investments already made. The smoothest stage of the supply transition will be made in this way.

And since hydrogen does not lend itself to worldwide transport like oil and liquefied natural gas, it will not be as fungible internationally as oil — yielding domestic and regional markets where value can be based largely on market fundamentals and cost of production and transportation, unhooked from global volatility. This could also make the tools of government incentives — investment, production and use tax credits, loan guarantees, etc., more effective and predictable. Domestic production of hydrogen is the next wave of products for the energy industry, and promises considerable economic growth opportunities.

Depending upon how existing manufacturing capacity is converted and preserved in traditional areas, the automobile supply chain might have more inherent flexibility in locating new and old operations. The advanced fuel cell vehicle could have only 1/10 as many moving parts as today's cars, SUVs and pickups, and much of the rest of the vehicle would be different. Transformation would happen everywhere. True worldwide markets will evolve for components and vehicles, and manufacturing capacity is more mobile than hydrogen production.

Large export markets are expected to evolve for vehicles and components, and also for the technology surrounding hydrogen production and storage. Due to its particular appeal in improving the efficiency and shrinking the carbon footprint of conventional fuel cycles, hydrogen-related technologies will help create an even wider range of new export opportunities. International competition could be fierce.

Centralized and Distributed Hydrogen Production

As noted above, the U.S. has some of the basic infrastructure already in place that could be utilized in transitioning to a hydrogen economy — plants near oil refineries that manufacture hydrogen from natural gas and some byproduct plant fuel, and the nationwide electric power grid. These are valuable and essential assets, but they will need to be adapted to new business models. Depending upon the highly varied and unique regional mix of generating capacity (coal, hydroelectric, nuclear, renewable), and how effectively they can grow, the relative production efficiencies and carbon footprint of the possible hydrogen fuel cycles will be quite different.

No single production strategy will work for the U.S., and all feasible techniques and sources for making hydrogen will likely be needed — but more uniform emissions, costs and oil savings criteria can be applied. There may be an important new role for the Federal Energy Regulatory Commission (FERC), especially with regard to enabling rulemakings for producing more renewable electricity if a national Renewable Portfolio Standard were to be adopted (in the Senate's Energy Bill, but defeated in the EPAct 05 Conference). Investment decisions selecting between alternative sources of hydrogen could vary considerably, and the Committee needs to encourage R&D investment that can make these distinctions.

In shaping possible regulations for greenhouse gas management in the U.S., emission allowances and credit valuations could be designed to favor system design and technology deployment that minimize carbon emissions across the entire fuel cycle, not just for a particular energy sector. Proposals for investing in advanced low carbon technologies, funded by the sale and trade of carbon credits, might be structured to assist the most promising hydrogen supply and use technologies. The EPAct 05 Hydrogen and Incentives Titles are reasonably clear on the intent to select those public investments in technologies that optimize their carbon footprint. The carbon characteristics of particular projects funded through the Indian Energy Title are likewise important system performance criteria.

Action So, where does the key technical work need to be done, and what is government's role? The above discussion of the EPAct 05 advocates fuller funding in FY 08 of all the key components of the Act with regard to hydrogen and fuel cells for vehicles. The Act attempts to reach forward to give DoE the authorities it needs to be more aggressive in creating more technical solutions more quickly. Besides making the vehicle and drive package lighter, cheaper and more efficient, the supply infrastructure needs equivalent attention, and new legislation might be needed to help.

- **Multiple sources of H2 —** the US has enormous coal reserves, but some reluctance to move quickly on solving its fundamental problems at an equivalent scale. The EPAct 05 has an excellent Coal Title, but little of it has been funded. There needs to be some agreement forged on the scale of public investment, including projects like that in Section 411, which is a regional 200 mW Integrated Gasification Combined Cycle (IGCC) facility that would make hydrogen and electricity, used in a power park setting. Many unused opportunities exist in Title XVII, *Incentives for Innovative* Technologies, (loan guarantees) which could be applied very fruitfully in combination with Title V, *Indian Energy,* (which has its own loan guarantee program) and Title VIII, *Hydrogen*. We need to build flexibly sized, innovative commercial scale plants that match the pace of the hydrogen technology program's accomplishments with vehicles. Additionally, Title XVI, Subtitle A, *National Climate Change Technology Deployment,* could readily be combined with the Coal, Indian Energy, Incentives and Hydrogen Titles to put some key projects in place that would provide substantial learning and commercial possibilities.
- Although there is a uniform strategic plan for the climate program in DoE and other agencies, there are a very wide variety of projects across the government whose effectiveness in actually solving critical problems with coal, for instance, may be unlikely. It is unclear that the degree of fragmenting allows critical focus on solving key public problems, especially since they are located in so many separate agencies. A critical review and redeployment could be useful.
- Very useful R&D can be planned at the front end of a small commercial scale demonstration, encouraging an iterative R&D evolution much like the Learning Demonstrations are employed to revise R&D agendas in the H2 programs. Full scale tests of new materials and processes could speed eventual commercial deployment. We would include consideration of how Title VI, Subtitle C, *Next Generation Nuclear Plant Project,* could be enhanced.
- There are significant opportunities, for instance, for advanced ceramic materials to be used in higher temperature applications for carbon capture from advanced coal gasification processes, and in nuclear hydrogen production. *The American Competitiveness Initiative* in the DoE Science program has an advanced materials program that could contribute fundamental knowledge in these areas.

- DoE has been working to improve the efficiency and durability of electrolyzers, which are a critical component of early distributed generation strategies. More needs to be done in the area of materials, processes, manufacturing and validation.

- **Renewable H2 —** again, less innovative use of the EPAct 05 authority shrinks our horizons. The public investment in wind, biomass and solar production of hydrogen needs to grow, both with regard to fundamental science and learning demonstrations. For those technologies that have true commercial appeal, the suite of authorities in the Incentives, Climate Change, Indian Energy, and Electricity Titles offer some intriguing possibilities for R&D focused on solving real public problems. More exploratory work in the DoE Science program could speed the availability of direct biological and solar hydrogen production, perhaps teamed in their advanced stages in Learning Demonstrations in specific regions and cities.

- **Electrical grid —** sizable renewable resources are often far away from urban load centers, but the Western Area Power Administration (WAPA) could be a key factor in bringing renewable electricity to high growth population centers in the Southwest and California. Significant planning studies have already been done on how to get more wind on the wires so renewable electricity from the Northern Great Plains — where the richest wind resources are — could be moved to high demand areas for hydrogen.
- Important work needs to be done on much more sophisticated control systems, composite materials and processes for enhancing transmission efficiency and high throughputs in corridors where there are significant siting problems. Much could be done to improve the potential for transmitting renewable energy to market.

- **Management organization —** The Committee is considering versions of an ARPA-E bill, based on the quick and flexible management often used in the Department of Defense by the Advanced Research Projects Agency, and placing such an organization within DoE. Working directly under the Secretary of Energy, an ARPA-E would be able to identify promising technologies in an R&D stage, and nurture them through demonstrations and early market acceptance. They would have expedited personnel and procurement authorities, and be able to integrate all their necessary technical authorities into a single management structure. For instance, in the above examples of combining multiple authorities from the EPAct 05, it is unlikely that a traditional Federal agency structure could accomplish blending the necessary functions, because they are often assigned to completely separate programs whose cooperation is incidental.

- Some have described the quest for a hydrogen economy as needing an Apollo or Manhattan Project's urgency — symbolic models for sustained high levels of funding and commitment to results. An ARPA-E for DoE could do that — placing all hydrogen and carbon reduction enabling work under single directorates, and holding them to high standards of performance until critical results are achieved.

We greatly appreciate the opportunity to contribute to a discussion that is critical to our collective future. The National Hydrogen Association looks forward to working with the Committee in shaping and achieving our common goals.