U.S. Department of
ENERGY

Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) during Fiscal Years 2008 and 2009

Second Biennial Report to Congress
October 2011

United States Department of Energy
Washington, DC 20585

Message from the Secretary

This is our second biennial report to congress, provided in response to section 807(d)(2) of the Energy Policy Act of 2005 (EPACT), P.L. 109-58, enacted in August 2005. EPACT established HTAC to advise the Department of Energy on programs and activities under EPACT Title VIII, Hydrogen. EPACT states that the committee is to review and make recommendations on: 1) the implementation of programs and activities under Title VIII of EPACT; 2) the safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage or use of hydrogen energy and fuel cells; and 3) the plan called for by section 804 of EPACT, also known as the Hydrogen Posture Plan.

Section 807 of EPACT requires the Department to transmit to Congress, with the budget request, a biennial report responding to the Committee's recommendations. The HTAC held six meetings during Fiscal Years 2008 and 2009. This report presents the recommendations of the HTAC during this time period and DOE's relevant responses, and it is being provided to the following Members of Congress:

- **The Honorable Joseph R. Biden**
  President, United States Senate
- **The Honorable John Boehner**
  Speaker, United States House of Representatives
- **The Honorable Daniel K. Inouye**
  Chairman, Senate Committee on Appropriations
- **The Honorable Dianne Feinstein**
  Chairman, Senate Subcommittee on Energy and Water Development
- **The Honorable Jeff Bingaman**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Harold Rogers**
  Chairman, House Committee on Appropriations
- **The Honorable Rodney P. Frelinghuysen**
  Chairman, House Subcommittee on Energy and Water Development
- **The Honorable Fred Upton**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Ralph M. Hall**
  Chairman, House Committee on Science and Technology

If you have any further questions, please contact me or Ms. Amelia Jenkins, Principal Deputy Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Steven Chu

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Foreword

Section 807(d) of the Energy Policy Act of 2005 (EPAct), P.L. 109-58, states that the Secretary of Energy (Secretary) shall transmit, along with the President's budget proposal, a biennial report to Congress describing any recommendations made by the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC or Committee) since the previous report. EPAct states that the report shall include a description of how the Secretary has implemented or plans to implement the recommendations, or an explanation of the reasons that a recommendation will not be implemented. During fiscal years (FYs) 2008 and 2009, the HTAC provided recommendations to the Secretary in the form of two letters, delivered August of 2008 and March of 2009, a white paper (*Hydrogen and Fuel Cells: Essential Components of the "New Energy Economy"*), and the annual HTAC state-of-the-industry report (*2008 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development)*. These documents are provided in the Appendices to this Report. The HTAC also met three times in FY2008 and three times in FY2009, and held multiple discussions that contributed to the reports and letters to the Department of Energy. Individual members of HTAC have also held two discussions with DOE management: in August 2009 with Undersecretary Kristina Johnson, and in February 2009 with Secretary Steven Chu. This, the *Secretary's Second Biennial Report,* responds to the letters and white paper, and is informed by the HTAC's 2008 report.

HTAC was established under EPAct to advise the Secretary on programs and activities under Title VIII, Hydrogen. The Committee's charter is to review and make recommendations to the Secretary on: 1) the implementation of programs and activities under Title VIII of EPAct; 2) the safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and 3) the plan called for by section 804 of EPAct, also known as the *Hydrogen Posture Plan* (Posture Plan).

The Posture Plan is a high-level document that presents a coordinated plan for research, development, and demonstration (RD&D) programs that directly relate to hydrogen and fuel cells across the Department of Energy (DOE) and portions of the Department of Transportation (DOT). The Posture Plan refers readers to the Multi-Year RD&D Plans prepared by individual DOE or DOT offices, detailing the multi-year program agenda, entities involved, program and subprogram milestones, technical and non-technical challenges, and approaches for addressing those challenges.

As mentioned above, the HTAC held six meetings during FYs 2008 and 2009. During these meetings, the Committee focused on current national and global fuel cell technology advancements and market conditions, as well as element two of its charter, as stated above: reviewing the safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells.

The HTAC white paper commended DOE Hydrogen Program research, development, and demonstration activities for dramatically reducing earlier barriers to commercialization. In the Committee's letters, white paper, and report, HTAC stressed that DOE and industry progress has been noteworthy and that the DOE should "use available resources in the American Recovery and Reinvestment Act (ARRA) and appropriated allocations to implement" the roadmap outlined in the 2008 National Research Council (NRC) study, *Transitions to Alternative Transportation Technologies – a Focus on Hydrogen* (2008 NRC Study).[1]

The body of this report is organized around three topics about which HTAC made recommendations during FY2008 and FY2009. It presents the HTAC recommendations, paraphrased from the source material, followed by DOE's responses to those recommendations.

[1] From HTAC Letter to the Secretary, April, 2009

Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) during Fiscal Years 2008 and 2009

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I. Recommendation 1: Federal Research, Development, and Demonstration (RD&D)

In its white paper released in December 2008, Fuel Cells: Essential Components of the "New Energy Economy" (Appendix C), HTAC stated that, "the 2008 accomplishments in the hydrogen and fuel cell arena are very noteworthy. The independent analyses conducted by a number of highly reputable organizations point to the importance of hydrogen and fuel cells in the 'New Energy Economy' and make it clear that a high priority should be placed on continuing the momentum of 2008 into 2009 and beyond." HTAC recommended, therefore, as it did in its 2007 report, that DOE increase research funding to the level fully authorized in the Energy Policy Act of 2005 (EPAct); this would have been $450 million for FY 2010.

DOE Response 1

The Department of Energy agrees that the accomplishments of government- and industry-funded research were noteworthy in 2008. However, given the urgency of addressing emissions reductions in the near term and the global economic conditions, the DOE's FY 2010 budget request balanced the advanced transportation technology portfolio to prioritize technologies that will have a more immediate energy impact and bring consumers advanced transportation choices sooner. Technologies such as biofuels and plug-in hybrids can achieve benefits 1) sooner, 2) at less cost, and 3) with less technology risk than hydrogen fuel cells. In addition, a number of automakers have begun to bring commercial plug-in hybrid vehicles to the market in the current timeframe. Given the above factors, as well as the recent shift by energy companies to biofuels, DOE's fuel cell activities were refocused to be technology neutral for multiple applications, especially stationary applications that will see commercialization first. However, given feedback from stakeholders and the funds above the FY 2010 request appropriated by Congress in FY 2010 and subsequently in FY 2011 for hydrogen and fuel cell activities, DOE is focusing on spending these funds wisely to ensure near term benefits through early markets in addition to maintaining the hydrogen portfolio of longer term R&D. Future budget requests will be informed by many factors, including the HTAC, stakeholder feedback, technology developments, the status of competing options, and independent reviews.

As noted in the response to recommendation 2 below, $42 million of ARRA funds were focused on near-term fuel cell applications. Furthermore, because fuel cells show promise in the longer term, but are less mature than biofuels and plug-in hybrids, more basic research is required. For this reason, more than $50 million was provided in FY 2010 for relevant basic research such as catalysis, membranes and biological approaches through the Office of Science.

II. Recommendation 2: Vehicle Demonstration Funding

From HTAC Letter to the Secretary, August, 2008: "HTAC is particularly aware that to meet the demand for the thousands of fuel cell vehicles in the market by 2012, the Department would need to include funds in its 2010 budget sufficient to begin installation of 50 to 100 public hydrogen fueling stations in areas where demand would be greatest in this best-case scenario … HTAC recommends, therefore, that the Department include in its FY 2010 Request funds for a substantial hydrogen infrastructure and vehicle deployment program. Federal fuel cell vehicle purchases are mandated by EPAct beginning in 2010, and Section 808 of EPAct authorizes $375 million in 2010 for vehicle and infrastructure deployment."

DOE Response 2

The Department of Energy has already invested approximately $140 million over 8 years for Technology Validation, which includes the deployment and validation of 155 hydrogen fuel cell vehicles and 24 hydrogen stations as part of the National Hydrogen Learning Demonstration. This highly valuable, 50/50 industry cost-shared effort provided real world data and validated performance, demonstrating more than 3 million miles driven with vehicles demonstrating 2,500 hour (~75,000 mile) durability, up to 254 mile driving range, and the fuel cell systems achieving 53-59% efficiencies [2],

The DOE believes that the time is right for some fuel cell product deployment, but that fuel cells should be introduced first in near-term markets, such as materials handling and backup power. There is already a competitive business case in some circumstances for fuel cells in these markets [3], and additional federal funding will help developers reduce costs, create a domestic supply base, and help make fuel cell systems competitive for other applications, such as stationary power as well as transportation in the longer term. To this end, approximately $42 million of ARRA funding has been focused specifically on demonstration of fuel cell technologies in early markets and should help to maintain our competitiveness in this technology.

This funding level is consistent with the DOE's approach to prioritizing technologies that will have a more immediate energy impact. In addition, DOE is exploring approaches such as trigeneration (combined heat, power and hydrogen when needed) which could provide an integrated option for early markets and support both plug-in hybrids and hydrogen vehicles, as well as realize savings in building energy efficiency[4]. Before considering an investment to build

[2] 53-59% covers the full range (lowest to highest recorded) of steady-state efficiencies for second generation fuel cell systems operating within the vehicles at one-quarter net system power
[3] 2007 Fuel Cell Technologies Market Report, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/46023.pdf
[4] http://www.hydrogen.energy.gov/pdfs/review11/tv006_heydorn_2011_o.pdf

50 to 100 public fueling stations, DOE plans to conduct a rigorous analysis of the status of infrastructure technologies, including requirements, costs, and commercial viability. This analysis will include a workshop with stakeholders in California (the California Fuel Cell Partnership, the California Energy Commission, and the California Air Resources Board) – a likely region where infrastructure needs are relatively near term (i.e. ~2012) and will also include global participation, particularly by Germany (which plans to build up to 1000 stations by 2017), Japan, and Korea. Such a workshop will help develop a solid foundation of information and lessons learned to lay the framework for a more thorough and strategic plan for fuel station deployment.

III. Recommendation 3: NRC Study

From HTAC Letter to the Secretary, April, 2009: "Our report is intended to demonstrate that real progress is being made but should not be constituted to mean that there are not continuing issues that must be addressed through federal research, development and demonstration and through financial risk mitigation with substantial federal intervention. The National Research Council study presented the nation with a roadmap for addressing these issues and we would urge the Department of Energy to use available resources in the American Recovery and Reinvestment Act and appropriated allocations to implement that roadmap."

The NRC Study (http://www.nap.edu/catalog.php?record_id=12222) estimates that the maximum practicable number of hydrogen fuel cell vehicles that could be operating in 2020 is 2 million, and states that "substantial government actions and assistance would be needed to support such a transition to HFCVs in the 2020 time frame, even with good technical progress on fuel cell and hydrogen production technologies."

DOE Response 3

The Department of Energy agrees that appropriated allocations, along with the Recovery Act funds, are an important resource that can be leveraged to address the challenges facing commercialization of fuel cell technologies. Along with using annual program funding to support ongoing R&D projects and other activities, DOE has used ARRA funds in several areas to promote growth and development of early fuel cell markets.

ARRA provided $42 million to fund 13 projects deploying more than 1,000 fuel cells in early market applications including backup power and specialty vehicles. This funding has helped achieve near term impact and create jobs in the fuel cell manufacturing, installation, maintenance & support service sectors. Recovery money is also being used to support the building of infrastructure. As part of its $13.2 million Clean Cities award, the Greater New

Haven Clean Cities Coalition is installing a new hydrogen refueling station for transit buses in Hartford, Connecticut.

In addition, the California Energy Commission plans to spend up to $40 million on hydrogen infrastructure,[5] and the Department of Transportation Federal Transit Administration (DOT-FTA) National Fuel Cell Bus Program is demonstrating 12 fuel cell buses with additional buses planned for sites across the United States.

Appendices

Appendix A: August 2008 Letter

Appendix B: March 2009 Letter

Appendix C: White Paper: *Hydrogen and Fuel Cells: Essential Components of the "New Energy Economy"*

Appendix D: *2008 ANNUAL REPORT of the Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development*

[5] http://www.energy.ca.gov/2009publications/CEC-600-2009-008/CEC-600-2009-008-CTF.PDF

Appendix A

August 2008 Letter

Exec-2008-010080

August 25,2008

The Honorable Samuel W. Bodman
Secretary of Energy
7A-257 Forrestal Building
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Secretary:

The National Research Council (NRC) has just completed a Congressionally directed analysis of the potential market penetration of hydrogen fuel cell vehicles (HFCVs) over the next several decades, and the public- and private-sector investment needed to achieve their full marketplace potential. The NRC analysis offers useful and timely guidance to the Department as you develop your 2010 budget submission over the next several weeks.

The NRC study concluded that 5 million fuel cell passenger cars could be on the road in 2023, and 25 million by 2030 (in the "maximum practicable case"). By 2023, the NRC estimates that consumers could save $17 billion on fuel costs, and fuel cell vehicles could be fully cost competitive.

Perhaps best of all from the perspective of the Department's mission, a combination of biofuels, improvement in the fuel economy of conventional vehicles, hybrids, and hydrogen fuel cells could ***reduce*** to ***zero*** the demand for motor gasoline from the light duty sector, perhaps as early as 2050, with more than an 80 percent reduction in light duty greenhouse gas emissions.

These results will not occur automatically. They will depend on continued technical progress and on wise and consistent policies from you, your department, and the federal government.

Federal R&D

To achieve these results, the NRC study suggested that an additional $5 billion in federal support will be needed by 2023 for fuel cell and hydrogen research, development, and demonstration, with approximately $350 million needed annually over the next five years. By comparison, the Department's FY 2009 total request for fuel cell and hydrogen research was $266 million. The federal program would complement an estimated $11 billion in private-sector R&D spending, for an R&D total investment of $16 billion (or more) by 2023.

In our September 10,2007, letter to you, the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) recommended increasing research funding to the level fully authorized in the Energy Policy Act of 2005 (EPACT); this would be $450 million for

FY 2010. The Committee continues to believe that $450 million is the minimum amount necessary, and a level more than amply justified by national need.

Hydrogen Infrastructure

The NRC study estimated that the federal investment necessary to deploy sufficient hydrogen fueling infrastructure by 2023 will be $8 billion, at which time NRC estimates vehicle sales and infrastructure will be competitive in this "maximum practicable case." This is an extraordinarily encouraging number.

The $8 billion in public funds would share with industry the cost of deploying the infrastructure needed to fuel the anticipated 5 million fuel cell vehicles on the road. The private sector will need to invest 50 times that amount in later decades, but a consistent national program alongside the competitiveness of the hydrogen fuel cell path will encourage industry to make these investments in the normal course of business.

Vehicle Deployment

The NRC study concluded that "lower-cost, durable fuel cell systems for light-duty vehicles are likely to be available in a growing number of vehicles over the next 5-10 years" [page S-4], but that maximizing deployment will require federal support. The NRC study estimated that covering the incremental cost of 5 million fuel cell vehicles would require $40 billion, but some of this support could come in the form of vehicle purchases for federal fleets. To put the $40 billion in perspective, total US sales of passenger cars over the next 15 years will exceed $5 trillion.

Need For Consistency

With projections of 280 million passenger vehicles in the U.S. fleet by 2020, the NRC study recognized that it will take decades for any advanced technology option to achieve significant market penetration. For this reason, the NRC concluded that "Policies designed to accelerate the penetration of HFCVs... ***must be durable over the transition time frame"*** [S-14; our emphasis] and tied to technology and market progress. In 2002, President Bush recognized this need for consistent long-term policies when he announced his 10-year research program for HFCVs. The U.S. Congress established a 16-year authorization in Title VIII of EPACT in 2005.

What remains is a commitment of funds that lives up to these promises, and enactment of substantial and durable follow-on policies and resources to go from research and development to successful commercialization.

The NRC study also concluded that a technology portfolio approach is the best strategy for addressing our country's future energy needs. A portfolio approach recognizes that technological and marketplace risks remain for all technology pathways. This is fully consistent with the Department's current strategy. Assuming success in cellulosic biomass commercialization, and steady increases in fuel economy through improved

conventional vehicles and hybridization, these technologies could provide significant benefits over the next 20 years. But the NRC study added,

> the longer-term benefits of such approaches [as biofuels and advanced combustion engines] were likely to grow at a smaller rate thereafter, even with continued technological improvements, whereas hydrogen offers greater longer-term potential. Thus, as estimated by the committee, the greatest benefits will come from a portfolio of **R&D** technologies that would allow the United States to achieve deep reductions in oil use, nearly 100 percent by 2050 for the light-duty vehicle fleet. [Abs-2]

Reasons for Optimism

The NRC study noted that federal and private research have produced "impressive technical progress" in the years since the President's decision to increase funding for hydrogen fuel cell vehicles, and "paths forward have been identified for further reducing hydrogen fuel cell costs while increasing durability and fuel economy." [S-4] In his preface, Chair Michael P. **Ramage** stated,

> industry- and government-sponsored research programs have made very impressive technical progress over the past several years, and several companies are currently introducing pre-commercial vehicles and hydrogen fueling stations in limited markets. The introduction of fuel cell vehicles into the light-duty vehicle fleet is much closer to reality than when the National Research Council (NRC) last examined the technology in 2004. [p. ix]

The NRC study noted dramatic reductions in fuel cell system costs and efficiency and improvements in system durability. NRC estimated that the Department's goal of $3 per gallon of gasoline-equivalent hydrogen has been met with natural gas (if produced in high volume), and progress is being made toward achieving the $3 goal with coal- (with sequestration) and biomass-based systems. (Because fuel cell vehicles are at least twice as **efficient** as conventional vehicles, **$3** per gallon hydrogen equivalent is comparable to gasoline at $1.50 per gallon.) Yet there is more to do:

> To achieve wide hydrogen vehicle penetration, further technological advances are required for commercial viability, and vehicle manufacturer and hydrogen supplier activities must be coordinated. In particular, costs must be reduced, new automotive manufacturing technologies commercialized, and adequate supplies of hydrogen produced and made available to motorists. [**Ramage** Preface, p. ix]

This task, and this opportunity, falls to you and your Department, Mr. Secretary. Given the nation's anxiety over energy prices and security of supply, and the concurrent need for environmental security, now is the time to seize the initiative on fuel cells and hydrogen. The NRC study is not a prediction, but an outline of

one possible future. Achieving these results over the next 15 to 20 years requires action this year and a consistent commitment in every future year.

HTAC is particularly aware that to meet the demand for the thousands of fuel cell vehicles in the market by 2012, the Department would need to include funds in its 2010 budget sufficient to begin installation of 50 to 100 public hydrogen fueling stations in areas where demand would be greatest in this best-case scenario. This investment is a down payment on our hydrogen future. HTAC recommends, therefore, that the Department include in its FY 2010 request funds for a substantial hydrogen infrastructure and vehicle deployment program. Federal fuel cell vehicle purchases are mandated by EPACT beginning in 2010, and Section 808 of EPACT authorizes $375 million in 2010 for vehicle and infrastructure deployment.

We encourage you to fully examine the NRC study. It provides excellent guidance for your FY 2010 budget.

Sincerely,

Dr. Alan C. Lloyd
HTAC Chair (2006-2008)
and
President
International Council on Clean Transportation

Honorable Robert S. Walker
HTAC Vice-Chair (2006-2008)
and
Chairman
Wexler & Walker Public Policy Associates

Appendix B

March 2009 Letter

March 12, 2009

The Honorable Steven Chu
Secretary
Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Secretary Chu,

On behalf of the members of your Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), I am herewith submitting to you our annual report on the progress made globally during the past year toward making hydrogen and fuel cells a commercially viable part of a restructured energy economy.

We believe that hydrogen and fuel cells offer the Obama Administration a significant pathway to meet its energy and environmental goals. Hydrogen competes successfully with all other technologies on economics, environment and energy security. The Administration has set ambitious goals for reducing dependence on foreign supplies of energy while at the same time addressing the issue of climate change. According to a 2008 National Research Council study (Transition to Alternative Transportation Technologies – A Focus on Hydrogen), hydrogen represents the only clear path to attaining those goals simultaneously by 2050. We are confident that the HTAC annual report demonstrates that commercialization has begun and significant progress has been made toward broad deployment (within five years) of this primary technology.

Our report makes clear that hydrogen and fuel cells hold great promise. If we are to create hundreds of thousands of new jobs in a much more environmentally sensitive economic climate, we must pursue technologies that utilize the broad base of available domestic energy resources including wind, solar, biomass, geothermal, nuclear, coal and natural gas. Our report demonstrates that activity in all these areas is underway and that hydrogen represents a strategy for unifying the variety of clean technologies into a diversified yet common infrastructure. No other energy solution has this unifying characteristic and no other energy solution can so substantially reduce the impact of greenhouse gases.

Furthermore, our report makes clear that significant progress is being made by our international competition in both hydrogen utilization and fuel cell technology. We are convinced that there must be significant government and private sector investment in this arena if the United States is to create and maintain a leadership position. Failure to do so could result in the loss of leadership and lost opportunities for new domestic industries and jobs. Already in Europe and Asia there are private-public partnerships in place that will permit the rapid deployment of hydrogen and fuel cell technology. Our own activity can keep us competitive, but only if we continue to invest in its future.

Our report is intended to demonstrate that real progress is being made but should not be constituted to mean that there are not continuing issues that must be addressed through federal research, development and demonstration and through financial risk mitigation with substantial federal intervention. The National Research Council study presented the nation with a roadmap for addressing these issues and we would urge the Department of Energy to use available resources in the American Recovery and Reinvestment Act and appropriated allocations to implement that roadmap.

We will appreciate your attention to our annual report and look forward to your response.

Sincerely,

Honorable Robert S. Walker
Chairman
Hydrogen and Fuel Cell Technical Advisory Committee

Appendix C

White Paper: *Hydrogen and Fuel Cells: Essential Components of the "New Energy Economy:*

Hydrogen and Fuel Cells:

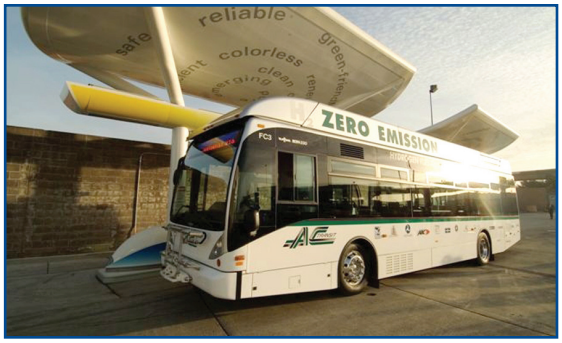
Essential Components of the "New Energy Economy"

Hydrogen has a remarkable ability to integrate all the elements of the "New Energy Economy." Hydrogen enables continuous use of energy from intermittent renewables; it can replace oil and natural gas in many applications; it can be produced using a wide variety of energy resources; and, as a recent landmark National Academy analysis[1] has shown, it is vitally important in reducing CO_2 emissions and eliminating our dependence on foreign oil.

U.S. leadership in the commercial application of clean hydrogen technology will strengthen our economy and create large numbers of high quality "Green Jobs."[2] Other nations are aggressively pursuing hydrogen and fuel cell technologies; we need to act quickly to *ensure a U.S. leadership position.* Fuel cell technology in vehicle applications, for example, can help rejuvenate and transform our automobile industry and create many hundreds of thousands of "Green Collar Jobs."

Hydrogen is a widely used commodity in our economy today. Hydrogen is used in making gasoline and diesel fuel, food products, chemicals, semiconductors, metals, and more. It is safely transported by pipelines and trucks all around the nation every day.

Fuel cell forklifts are safely moving goods in airports and distribution centers across America.



This hydrogen fueling station in Oakland, CA fuels both buses and autos.

Hydrogen can become a valuable green energy carrier, complementing green electricity. Producing hydrogen offers an important way to store electric energy generated from intermittent renewable sources such as solar and wind, so the energy can be used later in a variety of applications. It is an enabling technology for renewable energy.

We can domestically produce all the hydrogen we need in a number of ways. Hydrogen can be produced from natural gas, from biomass, from coal with sequestration, and by electrolysis of water with electricity generated from nuclear and renewables. DOE and industry agree hydrogen can be produced and delivered today by distributed natural gas reforming at a cost of $3.00/gallon of gasoline equivalent. Given the high efficiency of fuel cells, that translates to a cost of $1.50/gallon of gasoline on a per mile driven basis for the consumer (see the recent National Academy report[1] for details).

We can use hydrogen either in clean, efficient fuel cells, or wherever oil and natural gas are currently used. Hydrogen fuel cells produce electricity and heat with high efficiency and zero emissions; the only output is pure water. Burning hydrogen instead of fossil fuels in engines, burners, turbines, and furnaces eliminates CO_2 emissions and reduces other emissions.

By using hydrogen and fuel cells in light vehicles we can reduce the fleet's gasoline consumption to nearly zero by 2050 and reduce the CO_2 the fleet generates by 85% from current levels.[1] Hydrogen and fuel cells are clearly key elements of the nation's strategy to cut CO_2 emissions to 80% below 1990 levels by 2050 and secure our energy independence. But we must continue to invest in technology development and begin the commercial deployment of hydrogen vehicles no later than 2015 in order to reach the target CO_2 reduction by 2050 (again see the National Academy report[1]). Similar positive impacts on energy security and climate can be achieved by using hydrogen and fuel cells in other transportation and stationary power applications.

Hydrogen and fuel cell technology is safe and ready for commercial use today. Hydrogen and fuel cells are already being used in special applications: buses and small fleets of cars, back-up power, forklifts, and soon in cell phones and laptops. A broad-based public education program on the benefits and safety of hydrogen applications will help speed the transition to widespread use of hydrogen as an energy carrier.

Huge technical strides have been made over the last few years as a result of both DOE and industry sponsored research, development and demonstration, dramatically reducing earlier barriers to commercialization. While work to lower costs and improve durability continues, today's fuel cell vehicles have largely overcome range and performance barriers and are at least two times more efficient than gasoline cars. Nine automakers have recently toured their latest pre-commercial hydrogen vehicles to 31 cities in 18 states across the country as part of the **Hydrogen Road Tour**. The response from people who saw and drove these hydrogen/fuel cell cars was extraordinarily positive. This is *today's* technology, not some future dream.

But to get hydrogen and fuel cells into millions of cars will cost more than industry alone can afford – substantial and durable government incentives are needed, along with active coordination. The National Academy report[1] estimated the government price tag at $55 billion over a 15 year period (until the whole hydrogen vehicle/infrastructure system becomes cash flow positive in 2023) – less than government has committed to several other energy options. Importantly, the National Academy report estimated that the government's share of infrastructure costs would be only $8 billion of that total – suggesting that building out the needed hydrogen infrastructure is not as challenging a hurdle as some had believed.

The Hydrogen and Fuel Cell Technical Advisory Committee[3] urges national leaders to put a high priority on bringing hydrogen and fuel cells into full commercial use. This clean energy technology must be a critical part of the "New Energy Economy" that will become a legacy of our time.

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[1] *Transitions to Alternative Transportation Technologies—A Focus on Hydrogen*, National Academy of Sciences, National Research Council, Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, July 2008. Available from the National Academies Press: http://www.nap.edu.

[2] In July 2008, the U.S. Department of Energy published a report titled *The Effects of a Transition to a Hydrogen Economy on Employment in the United States*. The study estimated that up to 675,000 new jobs could be generated by 2050. The report is available at http://www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf.

[3] The **Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)** was created by Congress in the Energy Policy Act of 2005. The Committee has adopted a **Vision Statement** that may help guide decision makers as they consider the options for the nation's energy future:

> Our vision of the future is that hydrogen will become a universal and economically competitive energy carrier, progressively substituting for carbon-based fuels over time, to meet the needs of the planet. Hydrogen will be produced from a number of sources, increasingly with the lowest possible carbon impact. To realize this vision, the nation must aggressively bring to the market the hydrogen-based technologies that are available now and those that will be developed in the future. HTAC's role is to aid the nation in developing a policy framework that takes into account the technical, political, social, cultural, environmental and commercial requirements for the hydrogen transition.

Appendix D

2008 ANNUAL REPORT of the Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development

2008 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

The State of Hydrogen and Fuel Cell Commercialization and Technical Development

Hydrogen and fuel cells offer one of the most promising, sustainable, carbon-friendly pathways to achieving the twin goals of national energy security and reduced greenhouse gas emissions. In this first Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) on the State of Hydrogen and Fuel Cell Technical Development and Commercialization, the HTAC summarizes important accomplishments in 2008. Despite the difficult financial climate over the year, the industry continued to meet growing demand for fuel cells in near-term, specialized markets while research and development proceeded on solving technical and institutional challenges in broad-based transportation and stationary fuel cell applications. The progress made confirms that hydrogen and fuel cells offer clear opportunities, both today and in the future, to become a vital part of the "New Energy Economy."

Commercial Installations and Demonstrations in 2008

The industry continued to make important steps toward commercialization of hydrogen and fuel cells. Highlights of commercial and demonstration activities launched in 2008 are summarized below.

- **Stationary Fuel Cells**
  - **The number of large (more than 10kW) commercial installations continues to grow.** In 2008, fuel cell manufacturers reported approximately 50 new, large stationary fuel cell installations, providing distributed power to a wide range of operations including communication and data centers, grocery and retail stores, schools, hospitals, office buildings, and wastewater treatment plants. The world's largest fuel cell installation, 4.8 MW of on-site generation capacity in the new World Trade Center towers, will accept delivery of its first fuel cell in early 2009.
  - **Reliability is backed by improved manufacturer warranties.** Stationary phosphoric acid fuel cells are available with an 80,000-hour warranty on the fuel cell stack. Manufacturers of molten carbonate fuel cells report typical operating life of 40,000 hours between major overhauls.
  - **Back-up power provides an important early market.** Fuel cells are beginning to replace batteries in back-up power applications at cell and radio towers, as well as other critical communications facilities. The Federal Aviation Administration and the U.S. Department of Defense announced plans to procure 45 fuel cell back-up power units.
  - **Residential fuel cells are being demonstrated in thousands of Japanese homes.** As part of its "Residential Fuel Cell Extensive Demonstration Project," Japan installed an additional 1,120 polymer electrolyte membrane (PEM) fuel cells to provide electricity and hot water to private homes. Under this program, gas and oil companies have shared the cost to put in more than 3,300 1-kW PEM fuel cell systems in homes throughout Japan since 2005. These systems operate on propane, city gas, or kerosene, and can reportedly reduce a home's primary energy use by 24% and its CO_2 emissions by 39%.
  - **Denmark is demonstrating residential combined heat and power fuel cells.** Denmark launched a residential demonstration in 2008 to evaluate the use of 1-kW solid oxide or PEM fuel cells to provide combined heat and power to homes using either natural gas- or wind-generated hydrogen.

Hydrogen Infrastructure

» **Two major reports project manageable costs to build early hydrogen infrastructure.** In its 2008 report on the hydrogen transition, the National Academy of Sciences estimated the total, cumulative cost of building and operating enough hydrogen infrastructure to support 5.4 million fuel cell vehicles by 2023 would be $16 billion, or less than $2 billion per year (shared 50:50 by fuel suppliers and government). A 2008 study published by Oak Ridge National Laboratory, which modeled early fuel cell vehicle penetration and infrastructure requirements, reached similar conclusions, projecting cumulative costs to the government of between $7 billion and $27 billion, depending on the aggressiveness of the policy scenarios.

» **The number of operating hydrogen fueling stations in the U.S. reaches 58.** During 2008, two new hydrogen fueling stations were installed in the DOE Hydrogen Learning Demonstration, bringing the total number of stations in the DOE-industry partnership to 16. The largest number of U.S. stations (26) are located in California, and the California Fuel Cell Partnership (CaFCP) reports that another 10 have been commissioned.

» **Renewable hydrogen gains ground with two new stations.** In partnership with BP, Ford, and DOE, the Sacramento Municipal Utility District opened the first solar-assisted hydrogen fueling station, which uses solar-generated electricity to electrolyze water. Construction also began in Orange County, California on the first 100% renewable tri-generation (heat, power, and hydrogen fuel) station using biogas from a municipal waste water treatment plant.

» **Experience with hydrogen vehicle refueling grows.** According to a leading U.S. industrial provider of hydrogen, a total of 80,000 hydrogen vehicle refuelings have occurred to date and that number is growing by 30,000/year in 16 countries. Approximately 75% of all refuelings currently occur in the U.S. and hydrogen vehicle users report that the fueling process is not very different than gasoline fueling.

Energy Storage

» **Studies suggest that hydrogen energy storage can be competitive with peak electricity.** Initial economic studies conducted at the National Renewable Energy Laboratory (NREL) suggest that utility-scale hydrogen energy storage systems may offer a competitive alternative to some electric generation peaking resources (if DOE technology targets are achieved).

» **Demonstration project explores potential for hydrogen to enable continuous use of energy from intermittent wind and solar energy resources.** The Wind2H2 project, a joint venture between NREL and Xcel Energy, entered its second year of operation. The project is exploring system integration issues with co-production of renewable power and hydrogen, with the goal of improving the reliability, dispatchability, and economics of renewable energy by storing it as hydrogen during peak power production periods. The hydrogen can then be converted to electricity when needed or used as a vehicle fuel.

Fuel Cell Vehicles (Cars and Buses)

» **Honda and GM vehicles are delivered to consumers.** The latest generation of Honda and GM hydrogen fuel cell vehicles (HFCVs) hit the road as part of limited commercial demonstration programs in 2008:

– General Motors' Project Driveway placed over 100 Chevy Equinox HFCVs with mainstream customers in New York, California, and Washington, D.C. By year end 2008, Chevy's HFCV fleet had passed the 500,000 miles-driven milestone. A similar Project Driveway program was launched in Europe in November.

– Honda introduced its Clarity HFCV in Japan and California, and selected customers to drive these vehicles in daily use. A total of six Clarity vehicles are on the road in California and the plan is to have a total of 200 by the summer of 2011. The Clarity is reported to get 72 miles per gallon of gasoline equivalent (gge).

– Customers are responding favorably to both products, and requests to participate in the programs far exceed the availability of vehicles.

» **Japanese government begins leasing HFCVs.** In September 2008, Toyota announced that it had begun leasing its latest HFCV to the Japanese government for $7,700/month over a 30-month lease. Although not representative of HFCV costs at higher production volumes, this program indicates the willingness of the Japanese government to buy down the early costs of HFCVs.

» **Existing, mixed-generation vehicle fleets continue to perform.** The Ford fleet of 30 Focus HFCVs achieved over 1,000,000 miles of cumulative operation in 2008. By year end, more than 1.5 million miles were logged on first-generation HFCVs in the DOE Learning Demonstration project.

» **Fuel cell buses show pathway for low-emission public transport.** Successful demonstration of hydrogen fuel cell buses at AC Transit in Oakland, CA has shown that early adoption by operators of bus fleets can yield climate benefits and a 66% efficiency improvement over diesel-powered buses. Three fuel cell buses were used to transport high-profile Chinese and international athletes during the 2008 Beijing Olympic Games.

■ **Other Mobile Applications**

» **Fuel cells offer attractive alternative to batteries in operations with intensive material handling needs.** The Defense Logistics Agency initiated efforts to deploy approximately 100 fuel cell forklifts at four large distribution centers. Because of the life-cycle cost and operation benefits, private sector companies with high-volume operations, including grocers, tire manufacturers, and logistics companies, also announced new fuel cell forklift deployments.

» **German consortium launches world's first hydrogen fuel cell powered passenger ship.** The first "Zemship" (Zero Emission Ship), was launched into regular line service on the Alster Lake in Hamburg, Germany. The Zemship uses two 48-kW maritime fuel cells and a lead-gel battery in a hybrid system for propulsion. The ship can transport 100 passengers while being nearly twice as efficient as a standard diesel ship.

» **Fuel cell auxiliary power unit provides low-emission "hotel power" for tractor trailers.** Delphi Corporation and Peterbilt Motors Company demonstrated a Delphi solid oxide fuel cell (SOFC) auxiliary power unit (APU) that kept the battery of a Peterbilt truck charged while supplying an average of 800 watts of electricity to the cab and sleeper for air-conditioning, communications, and lighting over a 10-hour period (while the diesel engine was turned off).

■ **The 2008 Hydrogen Road Tour**

» **Hydrogen Road Tour makes stops across America.** Nine automotive manufacturers showcased their hydrogen vehicles in a two week, coast-to-coast tour involving stops at 31 locations in 18 states.

– The Road Tour was presented by the Department of Transportation (DOT), CaFCP, DOE, and the National Hydrogen Association in partnership with the automotive and hydrogen supplier participants and host organizations.

– The event reached television audiences of over 8.6 million people and facilitated test drives by over 1,600 citizens, including 40 local, state, and federal officials and members of Congress.

Technology Developments in 2008

Very significant progress was reported on hydrogen and fuel cell technology development during 2008, as a result of initiatives by industry, government and public/private partnerships. Several of the most exciting results are summarized here.

■ **Hydrogen Production and Distribution**

» **Distributed production of hydrogen provides near-term option for cost-competitive hydrogen supply.** Distributed steam methane reforming systems, developed over the last several years to generate small (<500 kg/day) amounts of hydrogen at fueling stations, became commercially available.

These systems are an important step toward scale up to 1,500 kg/day, which would enable hydrogen to be produced at less than $3.00/gge. If the hydrogen is used to power a fuel cell vehicle, this translates to less than $1.50/gge on a miles driven basis – since HFCVs are about twice as efficient as conventional internal combustion engine (ICE) vehicles.

» **Small-scale electrolyzers offer near-term options for producing hydrogen from electricity.** Distributed electrolysis units for producing hydrogen by electrolyzing water also are being introduced commercially. The projected cost from high volume distributed production (1,500 kg/day) is $4.80/gge, or $2.90/gge on a miles driven basis. Longer term, water electrolyzers can be integrated with intermittent renewable energy resources, such as wind and solar power, to produce hydrogen for use in fuel cell vehicles and for use as an energy storage medium to buffer the intermittent energy source.

» **New, lower-cost pipeline materials show promise for carrying large quantities of hydrogen over long distances at low cost.** Fiber-reinforced polymer pipelines (FRPP), now widely used in oil and natural gas operations, have the potential to significantly reduce capital cost for pipeline delivery of hydrogen, compared to standard steel pipeline ($600,000/mile versus $1 million/mile). Tests at Oak Ridge and Savannah River National Laboratories have shown FRPP leakage and permeation rates to be comparable to or better than those for steel pipe.

» **Progress is made on nuclear hydrogen production pathway.** The High Temperature Steam Electrolysis (HTE) process being developed at Idaho National Laboratory achieved 5,000 liters/hour of hydrogen production in initial tests. Early successes on two different thermochemical cycles for producing hydrogen using heat from solar or high temperature nuclear reactors were also reported by groups at Sandia and Savannah River National Laboratories.

■ **Hydrogen Storage**

» **Hydrogen vehicle storage tanks offer competitive range performance to current vehicles.** Major automakers announced their intention to use carbon wound high pressure tanks to store hydrogen on board vehicles at 5,000-10,000 psi -- Toyota claims a range of 472 miles (based on the Japanese JC08 mileage testing cycle) is achievable using 10,000 psi tanks in an SUV prototype without compromising cargo capacity. Honda reports a range of 280 miles (based on the official EPA estimated range) is achievable using 5,000 psi tanks in their sedan prototype while still maintaining 13.1 cubic feet of cargo space and 100 cubic feet of passenger space. Weight, cost and fueling time remain as challenges with tank storage technology.

» **R&D is progressing on novel, high energy density storage materials.** The DOE is supporting a wide range of basic and applied R&D efforts to find novel materials and concepts for storing hydrogen in lower volume/lower mass systems through its National Hydrogen Storage Project. The Center of Excellence teams have produced numerous materials and concepts with higher capacity and more favorable energetics and performance for vehicular applications. Though none of the materials yet meet DOE technical targets, promising examples include high-capacity metal borohydrides, metal hydride nanoconfinement, alane, amine-borane formulations, "hybrid" metal and boron doped sorbents, high surface area metal organic framework materials (MOFs), and new room-temperature sorbents such as metal catalyzed carbons and MOFs.

■ **Fuel Cells**

» **Recent analysis projects vehicle fuel cell system cost of $73/kW.** Research and development led to a decrease in the modeled cost estimate of an 80-kW automotive polymer electrolyte membrane (PEM) fuel cell system. The 2008 modeled cost estimate, projected for a manufacturing volume of 500,000 units per year, dropped from $94/kW in 2007 to $73/kW in 2008. The 2015 cost target is $30/kW.

» **R&D leads to several promising approaches to reduce or eliminate platinum content.** Major players continued to work on lowering platinum (Pt) content to reduce fuel cell cost, and several innovative approaches for significantly reducing total Pt content, or eliminating it altogether, emerged. Though still in the very early stage, these new developments hold promise for significant cost reduction.

» **Vehicle fuel cell durability improves toward commercial targets.** A number of fuel cell manufacturers have announced substantial progress in performance lifetime for fuel cells (principally a membrane life issue). Most automotive fuel cell manufacturers are comfortable claiming 2,000 hours for stacks, and some privately say 5,000 hours (equivalent to a 150,000 mile life of a car) is achievable. In 2008, 3M Inc. announced that their membrane electrode assembly, the core component related to stack durability, operated over 7,300 hours with load cycling, and Plug Power announced that it had reached 10,000 hours in field operation of their fuel cell packs designed for forklift duty cycles. These are major steps forward in establishing the commercial feasibility of fuel cells for vehicles.

» **Strategies have been developed for fuel cell vehicle start-up in freezing temperatures.** Nearly every leading fuel cell manufacturer has indicated that the freeze protection and cold-start problems have been successfully addressed. For example, in 2008 Nuvera achieved vehicle startup to 50% power in 30 seconds at -20°C (-4°F).

» **High-temperature membrane R&D provides path for simpler, lower-cost systems.** Progress has been made on high-temperature membranes that allow PEM fuel cells to operate at 120°C, well above the 80°C limit of conventional membranes. High-temperature membranes that can operate in dry conditions can reduce cost by eliminating the need for humidification and allowing easier heat rejection, which leads to reduced cooling system requirements.

■ **Safety/Codes and Standards**

» **Safety of hydrogen for use as a fuel continues to be proven.** Studies in Japan indicated that slow leaks in a hydrogen fueling system pose very little risk of hydrogen ignition. A compressor unit fire at a White Plains, NY hydrogen fueling station demonstrated that safety systems performed as designed to control the fire quickly. There were no personal injuries and minimal property damage.

» **First responder training programs have been developed for incidents involving hydrogen and HFCVs.** More than 7,000 first responders in the United States have been trained on hydrogen safety procedures through industry, state, and federal-sponsored training programs.

» **Significant progress has been made on codes and standards, both in the U.S. and internationally.** For example, the DOT's Pipeline and Hazardous Material Safety Administration (PHMSA) published its final rule allowing transport of fuel cells and a wide range of fuels on board U.S. passenger aircraft as carry-on baggage. This new rule also provides for routine cargo shipment of fuel cells and fuel cell cartridges by road and rail, as well as international ocean shipment in bulk.

The Financial Climate for Hydrogen and Fuel Cells

The climate for investing in innovative hydrogen and fuel cell technology and products became more challenging during the year. The rapid rise in the price of gasoline (and indeed all petroleum products) during the first nine months of 2008 created favorable conditions for financing alternative fuel options such as hydrogen. However, the worldwide economic meltdown in the fourth quarter led to dramatic reductions in fuel prices, which in turn focused attention away from energy issues, at least in the short term. Some indicators for the financial health of the hydrogen and fuel cell industry are:

Negative indicators

■ No Initial Public Offerings (IPO's) of companies occurred in 2008 and a number of small public companies operating in the hydrogen and fuel cell field were facing severe financial pressure. The private equity/venture capital market in the field was virtually shut down.

■ Hard hit by the world financial crisis, automotive companies face an uncertain future for their ambitious HFCV programs.

Positive indicators

■ Partially off-setting the dire news from the financial community was the launch of a new European Fuel Cell and Hydrogen Joint Technology Initiative (JTI). The JTI marks a strong commitment by the

European community to bringing hydrogen and fuel cell technology to market. The funding available through JTI initiatives exceeds 1 billion euros ($1.27 billion). An additional 500 million euros ($637 million) is available through Germany's NOW program.

- In the U.S., the Federal Investment Tax Credit for fuel cell installations was extended to 2016 and increased to $3,000/kW (or 30% of the cost, whichever is less) as part of the Emergency Economic Stabilization Act of 2008.

Major Reports on Hydrogen and Fuel Cell Initiatives

During 2008 a number of important studies led to the publication of landmark reports on the progress and potential of hydrogen and fuel cells, particularly in light vehicle applications. Among them:

- "Transitions to Alternative Transportation Technologies – a Focus on Hydrogen" was published by the National Research Council in response to a congressional mandate in EPACT 2005. The second in a series of two National Academy reports on hydrogen, the 2008 report made a strong case that hydrogen vehicles were an essential element in achieving substantial reductions in CO_2 emissions from, and gasoline use by, the light vehicle fleet. The study also emphasized the importance of "substantial and durable" incentives to ensure that policy objectives are met over time.
- "The Future of Hydrogen: An Alternative Transportation Analysis for the 21st Century," a complementary study conducted by the National Hydrogen Association, arrived at conclusions very similar to those in the National Academy study.
- "Effects of a Transition to a Hydrogen Economy on Employment in the United States," a DOE report to Congress on job creation potential in the field, concluded that up to 675,000 new jobs could be created by 2050 if an aggressive roll-out of hydrogen and fuel cell systems occurred.
- "Hydrogen Fueling Infrastructure Assessment": Late in 2007 GM and Shell together published an insightful analysis of the requirements for a phased roll-out of a national hydrogen infrastructure. This report, which was widely discussed in 2008, made it clear that the

"hydrogen infrastructure problem" was not nearly as daunting as many had assumed.

- "Vision for Roll-Out of Fuel Cell Vehicles and Hydrogen Fuel Stations": This vision paper from the California Fuel Cell Partnership provides a clear roadmap for roll-out of a hydrogen-based transportation system in California.
- "HyWays – the European Hydrogen Roadmap": This influential report, published by the European Commission in February 2008, shows that hydrogen energy could reduce oil consumption in road transport in the EU by 40% by 2050.
- "Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements": This study, published by Oak Ridge National Laboratory, addresses production and deployment of hydrogen-fueled vehicles and the hydrogen production and delivery infrastructure needed to support those vehicles.

In HTAC's view, the 2008 accomplishments in the hydrogen and fuel cell arena are very noteworthy. The independent analyses conducted by a number of highly reputable organizations point to the importance of hydrogen and fuel cells in the "New Energy Economy" and make it clear that a high priority should be placed on continuing the momentum of 2008 into 2009 and beyond.

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under Section 807 of the Energy Policy Act of 2005 to provide technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts. http://www.hydrogen.energy.gov/advisory_htac.html