Building the Hydrogen Economy: Enabling Infrastructure Development

April 2-4, 2007

Detroit, Michigan, USA

Table of Contents

Acknowledgements

This publication was prepared by the International Energy Agency's (IEA) Office of Energy Technology and R&D. The authors of this publication are Dr. Robert K. Dixon, Head, Energy Technology and Policy Division, IEA, Mr. Peter Schniering, Ms. Emily Glenn, Mr. Uwe Remme, (all IEA) and Mr. Richard Scheer and Ms. Shawna McQueen of Energetics Incorporated. The information and ideas contained in this document are based upon the International Partnership for a Hydrogen Economy (IPHE) and IEA joint workshop on April 2-4, 2007 in Detroit, Michigan, USA titled "Building the Hydrogen Economy: Enabling Infrastructure Development."

The authors would like to acknowledge the contributions of Dr. Dolf Gielen, IEA, Mr. Barry Worthington, Mr. Robert Donovan, Ms. Jill Gagnon, Mr. Matthew Gebert, and Mr. Albert Doub, all United States Energy Association. We would also like to acknowledge the contributions of all the speakers and participants who attended the workshop, and who provided their ideas and suggestions that have been summarized in this document. Special thanks to all of the Discussion Leaders, Dr. Robert Dixon, IEA, Mr. Wayne Surdoval, US Department of Energy, Ms. Annie Desgagné, Hydrogen and Fuel Cells Canada, Mr. Richard Scheer, Energetics Incorporated, Dr. Dolf Gielen, IEA, and Dr. David Greene, Oak Ridge National Laboratory, as well as the Rapporteurs, Mr. Michael Mills, US Department of Energy, Ms. Emily Glenn, IEA, Mr. Matthew Gerbert, US Energy Association, Mr. Albert Doub, US Energy Association, and Ms. Shawna McQueen, Energetics Incorporated. Thank you also goes to Mr. Jim Murphy, Mr. Bertrand Sadin, Ms. Virginie Buschini, Mr. Olivier Parada, and the IEA publications team for facilitating the printing of this document. Dr. Dixon and his team are grateful for the support and cooperation of the IEA Committee on Energy Research and Technology (CERT) and the IPHE Steering Committee.

This work was funded in large part by the IEA/IPHE project "Building the Hydrogen Economy: An Infrastructure Strategy," launched in 2007 by Dr. Robert K. Dixon and supporting IEA/ IPHE members.

I. Foreword

Claude Mandil, Executive Director, International Energy Agency

There is a strong and growing global interest in advancing the hydrogen economy to improve energy security, protect the global environment, and improve/ maintain economic prosperity. Emerging IEA analysis suggests that an energy infrastructure that considers hydrogen could contribute to providing clean, clever, and competitive energy in the future. When technical challenges such as cost competitive production, efficient storage systems, and fuel cell reliability are overcome, a well-designed hydrogen infrastructure could provide energy services in the transport and stationary applications. While further work is required to provide sustainable production of hydrogen through renewable energy, nuclear power, or reliable carbon capture and sequestration (CCS).. Many countries and multinational companies are making substantial R&D investments in the hydrogen economy.

The IEA has experience with analysis of hydrogen infrastructure requirements. For example, the IEA Hydrogen Coordination group completed two publications on this topic, titled *Prospects for Hydrogen and Fuel Cells* (2005) and *Hydrogen and Fuel Cells: Review of National R&D Programs* (2004). Moreover, tackling the challenges of a worldwide hydrogen economy is also represented in the IEA's Implementing Agreements.

Considerable progress has been achieved recently through activities in North America, Europe, and Asia, but much more work needs to be done at the local, national and international levels to facilitate significant hydrogen infrastructure investments, and to lay the groundwork for the large scale expansion of this important option in our future energy portfolio. Many uncertainties remain for investors, and fields for further research include equipment safety and the liability and financial attractiveness of such investments.

This report presents the major findings from the first out of three worldwide workshops on such challenges in 'Building the Hydrogen Economy.' Under the leadership of the IEA and the International Partnership for a Hydrogen Economy (IPHE), participants from the corporate, governmental, and research sectors met in Detroit from April 2-4, 2007 to discuss potential pathways for the development of hydrogen energy infrastructure in North America. The workshop included breakout sessions with facilitated discussions on the requirements of stationary and transport applications for hydrogen energy technologies and fuel cells, as well as recent developments and challenges in modeling and analysis of hydrogen energy infrastructure and the market penetration of hydrogen energy systems and equipment.

One of the major workshop findings is the need for government to participate in hydrogen energy infrastructure beyond traditional research and development activities to help speed implementation by sharing lessons learned from hydrogen infrastructure demonstration projects to guide the development of much-needed standards. In addition, government assistance will be needed to help increase public acceptance and understanding of this important technology. Government can also play an important role in addressing a number of the important legal and financial issues which will have to be overcome for the vision of the hydrogen economy to be realised.

I am delighted that IEA continues to provide value to the international hydrogen community, and hope that this latest publication paves the way for future work to improve the investment security for its key technologies.

Claude Mandil
Executive Director

I. Introduction and Overview

Background:

Considerable progress towards the vision of a global hydrogen economy has been achieved in recent years. Large-scale, long-term research, development, demonstration and deployment investments to advance hydrogen and fuel cell technologies have been realized in the public and private sectors (IEA, 2004). Yet, decades of work may remain, including the unfinished business of developing an infrastructure for the hydrogen economy, if the research and development successfully meets consumer demands and makes a business case.

To date, over 400 significant hydrogen and fuel cell technology demonstration and deployment projects in the stationary power and transport sectors have been funded and constructed around the world (IPHE web site). Many of the early transport projects have focused on hydrogen production facilities, hydrogen fueling stations for vehicles, and vehicle/fleet trials. A fair number of hydrogen highway projects have been announced, planned or are under construction in North America, Europe and Japan. An equally robust number of demonstration and deployment projects have been realized in the distributed energy sector, including recent announcements to build 500 MW hydrogen fueled power plants. Public-private partnerships are the foundation for most of these activities.

Most countries who are members of the Organization for Economic Co-operation and Development (OECD) and a handful of developing countries employ hydrogen and fuel cell technology roadmaps to guide their investments. These roadmaps have proven highly valuable in coordinating public and private sector research and development investments in hydrogen and fuel cell technologies. The transition of hydrogen and fuel cell technologies from the laboratory to the marketplace has many barriers. The relatively slow capital stock turnover in the energy sector and the long lead time required for energy sector infrastructure investments requires careful planning. Some countries have begun strategic planning of future hydrogen economy infrastructure investments. Strategic planning for the hydrogen economy seems especially important given current energy security and economic prosperity goals of OECD and non-OECD countries. Strategic planning, via public-private partnerships, can be useful in sending appropriate signals to the marketplace.

This project will build on the solid foundation established by complementary activities in Europe, Japan and the US. For example, HyWays, an integrated project co-funded by public and private sector institutions, links technology databases, socio-economic analysis and stakeholder developed scenarios of future hydrogen systems in Europe. Complementary analytical activities in Japan have led to development of technology roadmaps and strategic plans for development of hydrogen power systems stationary and mobile applications. A preliminary scenario analysis, based on several analytical tools and stakeholder guidance, has been completed for development of transport sector hydrogen and fuel cell technologies for the US. Other IEA and IPHE member countries have also begun making investments in this arena. The challenge ahead is linking these national or regional activities using common methodologies and tools, as well as augmenting the analysis for key developing and OECD countries.

An integrated and comprehensive portfolio of strategies and policy instruments, representing key economies around the world, will help enable an efficient transition to a hydrogen economy. Governments, via public-private partnerships, can play a critical role in nurturing market introduction of new technologies using policy levers to stimulate market entry strategies. This strategy includes developing fuel cell manufacturing technologies, hydrogen and fuel cell market and capital investment analysis, and facilitating early adopters. Early opportunities such as fuel cells for portable applications, forklifts, airport hauling equipment and small stationary applications may be used as stepping stones to encourage large scale manufacturing of fuel cells and other hydrogen energy equipment. Such approaches can help accelerate the learning process about hydrogen energy systems among manufacturers, developers, financiers, code and safety officials, and the general public. The potential of financial incentives, regulatory reforms, and other public policy instruments that can be used to support hydrogen energy technologies and infrastructure development need to be assessed at the local, regional, national, and international levels.

Hydrogen and the Americas:

The Western hemisphere is of particular relevance to the IEA/IPHE project on hydrogen infrastructure development since numerous governments, companies and researchers have initiated important work on hydrogen or other alternative fuel in North and South America. (IEA, 2004)

Apart from having the largest national R&D program on hydrogen (President Bush's 2003 *Hydrogen Fuel Initiative*), the United States hosts other important projects and actors on Hydrogen infrastructure, often in cooperation with other nations. California's Hydrogen Highway on the Western coast (which is complemented by similar activities in the Canadian province of British Columbia) is but one example of several lighthouse projects which could result in a broad dissemination of hydrogen fueling stations first in the metropolitan regions and later across North America. The Western state's slogan "Hydrogen means business in California" grasps the vision of many companies that invest substantially in taking hydrogen technologies to the marketplace. Various automobile companies from the U.S. and abroad have managed to get ten different hydrogen cars from the demonstration phase to the showroom and many public lighthouse projects – such as hydrogen shuttle buses which were delivered to the Canadian parliament recently – help to overcome remaining obstacles on the "road to the hydrogen economy." Thus, government programs team up with key industry support and result in significant developments in the area where most of the world's hydrogen in produced.

Exciting progress on alternative fuels has also been made in South America, where Brazil and Argentina currently run the largest fleet of alternative fuel vehicles – a fact that is often neglected in discussions on the contribution of this region to worldwide development of alternative energy systems. From pioneering efforts by the small town of Pico Truncado in the Southern Patagonian province of Santa Cruz (which initiated local Hydrogen production from renewable energies in 2003) to efforts in South American metropolitan areas, South America is a crucial region for the development and demonstration of alternative fuel technologies. The Detroit workshop on "Building the Hydrogen Economy" reflects the most urgent issues in hydrogen infrastructure development and brings together experts from the Americas to identify promising opportunities and remaining challenges in the transition phase to a hydrogen economy.

Objective:

The overall objective of the project Building the Hydrogen Economy: Enabling Infrastructure Development is to convene public and private sector officials in an international strategic process to evaluate transition planning scenarios for the expansion of infrastructure for the hydrogen economy and to inform policymakers on opportunities to accelerate these transition plans through both public policy instruments and market mechanisms. Common methodologies and tools will be used to link existing analyses, and additional analyses will be undertaken for key economies (e.g., China, Brazil, and India). Specific objectives of the Detroit workshop include:

- Convene public and private sector officials in an international strategic dialogue to refine and evaluate infrastructure transition planning scenarios for building out the hydrogen economy;
- Examine analytical tools that analyze hydrogen economy scenarios and market transformation planning for key countries and the world out to 2050
- Inform policy makers of opportunities to effectively advance these transition scenarios and to plan policy instruments.

Definition:

For the purpose of clarification we employed the following definition of Hydrogen Infrastructure: Hydrogen energy infrastructure comprises the physical, financial, and knowledge-based assets for delivering hydrogen energy services from suppliers to consumers. This includes hydrogen production, storage, and delivery facilities for transportation and electric power applications. It also includes the public policies, market mechanisms, and codes and standards that will be needed to enable hydrogen energy development.

II. Summary of Workshop Presentations

The workshop agenda can be found in Appendix B.

Plenary session presentations and photos are available online at:

http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=299

The workshop Plenary Session opened with a **Welcome Address** given by Mr. Graham Campbell, who is the Chairman of The Committee on Energy Research & Technology CERT at the IEA; the Vice Chair, IPHE Steering Committee; and the Director General of the Office of Energy Research and Development at Natural Resources Canada. Mr. Campbell explained the workshop offered "an excellent opportunity for close collaboration" via the complementary fit of the IEA and IPHE organizations and the workshop participants in attendance. He announced that the workshop conclusions and results would have a great influence on the priorities and messages that the IEA and IPHE provide to their governing bodies.

Dr. Robert K. Dixon, Head of the Energy Technology Policy Division at the IEA, followed Mr. Campbell with an overview of the **Workshop Agenda and Objectives**, emphasising that infrastructure investment and development strategies were key points of workshop discussions and of moving forward with building a hydrogen economy. He noted that one of the premises of the workshop is to assume "R&D success." While recognizing that several of the technical barriers associated with hydrogen energy development still need to be overcome, this workshop was not intended to focus on R&D needs, barriers, or opportunities but on technical, institutional, financial and other issues associated with the infrastructure requirements of the hydrogen economy. This focus on hydrogen energy infrastructure is one of the distinguishing features of this series of workshops.

The Honorable Robert Walker, a former United States Congressman from Pennsylvania and Chairman of Wexler & Walker Public Policy Associates, gave the **Keynote Address** to participants. Congressman Walker elaborated on his passion for developing hydrogen as an important component of future energy scenarios. He explained his background in public policy, particularly in developing the US Hydrogen Economy Vision Statement at a similar public-private convention. Congressman Walker framed his message to inspire and motivate the workshop participants in addressing pathways to realise the hydrogen economy. He offered two public policy strategies as starting points for the dialogue that would be required to move development forward. His address outlined the universal benefits that are possible with the adoption of hydrogen infrastructure, and offered crucial conclusions from his experience to all participants. *(Full text of Congressman Walker's speech in Appendix D).*

Dr. Sigmund Gronich, Team Leader in Hydrogen, Fuel Cells and Infrastructure Technologies at the U.S. Department of Energy (DOE) in the Office of Energy Efficiency and Renewable Energy, gave the first plenary presentation, **Building H2 Infrastructure for US Highway System**. Dr. Gronich summarized a major project at DOE to develop a set of scenarios on the potential development of hydrogen energy infrastructure and fuel cell vehicles in the U.S., and determine the potential costs and impacts of alternative public policies and market mechanisms. The time-scale and geographic positioning of the infrastructure scenarios provided a range of potential conditions and possibilities for hydrogen energy infrastructure development in the U.S. and raised new considerations for the workshop participants.

Dr. Ming-shan Jeng, Senior Researcher, Energy & Environment Laboratories, Industrial Technology Research Institute (ITRI), Taiwan, explained the status of hydrogen technologies and policies in his presentation: **Perspectives on a Hydrogen Economy in Taiwan.** Dr. Jeng reviewed several important considerations, such as the energy challenges in Taiwan, the Hydrogen Subsidy Program under development by the Taiwanese government, and the current investments in developing a hydrogen infrastructure made by both industry and government. The current goals of his organization's work focus on finalizing a roadmap for the hydrogen economy transition.

Dr. Christoph Stiller, an expert from Ludwig-Bölkow-Systemtechnik and member of the German HyWays program, presented the development and status of his program leading the creation of a hydrogen roadmap for Europe**. HyWays - the European hydrogen energy roadmap: Current status,** outlined the goals, assumptions, costs, and plans of action for deploying hydrogen energy infrastructure in Europe. Dr. Stiller explained that the project had completed all modeling and deliverables that were proposed, and had organized approximately 50 workshops in member countries. HyWays was now focusing on preparing an action plan and national follow-up projects.

Dr. Thorsteinn Sigfusson, Professor and Entrepreneur, Iceland New Energy offered a summary of his experience with **Building the Hydrogen Economy in Iceland.** In his presentation, Dr. Sigfusson explained the unique situation of Iceland as a country with both limited access to biomass resources and large levels of fuel imports. Iceland has focused its efforts on using its geothermal resources for the renewable production of hydrogen and accomplishing the transition to the hydrogen economy while scaling up the existing infrastructure. He predicted hydrogen vehicles were going to be deployed in 2010-2015, in large part due to support from Iceland's government for those willing to adopt the new technology.

Mr. David Haberman, President, IF, LLC spoke about **Building the Hydrogen Economy in an Energy Poor Country.** He invited the IEA, IPHE, and participants to collaborate by sharing lessons and strategies from their diverse array of experiences. He stated that the IEA and IPHE can hasten hydrogen infrastructure development, particularly in the case of Israel, by recognizing hydrogen as a safe, cost-effective, and secure energy carrier.

Ms. Annie Desgagné, a Senior Advisor for Hydrogen & Fuel Cells, Resource Processing Industries Branch, Industry Canada presented her experiences and successes with **Building the Hydrogen Economy in Canada.** Ms. Desgagné described the drivers for the Canadian hydrogen economy, such as the concerns with air quality, climate change, energy security, and the possibilities for wealth generation from investments. She emphasized the importance of government incentives during the early phases of hydrogen energy development and the role of government in encouraging the adoption of hydrogen technology and infrastructure development. Ms. Desgagné presented the clear path of hydrogen from Canadian sources to distributors and finally to major users.

Dr. Bernard Frois, the Director New Technologies of the French National Research Center (CEA) presented various **Perspectives on Nuclear Energy and the Hydrogen Economy.** Dr. Frois summarized the key points of similarity between the development of nuclear technology and energy distribution systems in France and the development of hydrogen energy infrastructure. He emphasized that labor force requirements and long-term viability must be included in hydrogen energy infrastructure roadmaps. Dr. Frois concluded by outlining alternative perspectives on hydrogen technologies and strategies, such as a making a more clear distinction between hydrogen energy development and the development of fuel cells, and on the need for sustainable sources of hydrogen production.

Dr. Christine Sloane, the Global Lead for Hydrogen and Fuel Cell Vehicle Safety, Codes & Standards from General Motors Corporation (GM) provided perspectives on the future of the automobile market, and GM's goals for meeting the increasing demand with zero-emission vehicles. Dr. Sloane, by describing **GM Perspectives on the Hydrogen Economy,** underlined the need for early capital and investment as the major hurdle facing most private partners for the hydrogen economy. She described potential commercialization pathways, examined the possibilities for exponential decline of hydrogen vehicle costs over a ten-year period, and emphasized the pressing need to fund primary technology and infrastructure development efforts and to assume long-term success.

III. Breakout Groups: Summary of Discussions

A. Overview of Breakout Group Structure

The Workshop Plenary Session was followed by a series of facilitated breakout group discussions in which up to 20 participants were able to discuss and identify technical, institutional, and financial opportunities and challenges for hydrogen infrastructure development in North America (See Appendix B). The five Breakout Groups were organized according to mobile applications, stationary applications, and modeling and analysis of hydrogen technology and infrastructure development. Three parallel sessions addressed the mobile applications subject area, since the majority of the participants had particular expertise in this area.

Breakout Groups

Subject	Discussion Leaders	Code
Stationary	Mr. Wayne Surdoval	BREAKOUT GROUP 1
Mobile	Dr. Robert K. Dixon	BREAKOUT GROUP 2
Mobile	Ms. Annie Desgagne	BREAKOUT GROUP 3
Mobile	Mr. Richard Scheer	BREAKOUT GROUP 4
Modeling & Analysis	Drs. Dolf Gielen and David Greene	BREAKOUT GROUP 5

Participants in the mobile and stationary sessions discussed hydrogen energy infrastructure development focusing on three primary themes:

- Planning and Design

  What are the likely pathways for hydrogen infrastructure development (e.g. city-wide, intra-regional, inter-regional)? What policy and market mechanisms and opportunities will have the greatest impact in realizing these pathways?

- Construction and Engineering

  What are the most significant technical, financial, and institutional issues and barriers to engineering and construction of H2 infrastructure? What policy and market mechanisms and opportunities can best address engineering and construction issues and barriers in building H2 infrastructure?

- Operations and Maintenance

Assuming hydrogen infrastructure build-out proceeds, what are the most significant foreseen and unforeseen challenges to operating and maintaining hydrogen infrastructure? What are the prospective policy, market, and technological solutions (including RD&D) to operating and maintaining hydrogen infrastructure?

The modeling and analysis breakout group addressed a different set of questions, which are presented in Section 3.5. The following sections summarize the discussion of the breakout groups.

B. BREAKOUT GROUP 1: Stationary Applications

1. Planning and Design

a) Pathways

BREAKOUT GROUP 1 addressed many of the themes that will likely be important factors in the development of hydrogen energy infrastructure for stationary power applications.

Participants emphasised the view that sustainable energy resource development will be one of the key drivers in the development of the hydrogen economy. Issues such as climate change, energy security and fuel price volatility are likely to advance the transition to alternative energy sources. Participants also noted that measures that facilitate development of other alternative energy sources for electric power generation, such as carbon taxes, carbon capture and storage, and higher energy costs, could also contribute to the development and deployment of hydrogen energy technologies ands infrastructure.

Group 1 participants agreed that distribution and storage issues for hydrogen must be resolved before additional development can proceed. The delivery and supply of hydrogen will also be critical to achieve strong city-wide, regional, or national infrastructure systems. The electric power sector could be essential in assembling the critical mass of investment that will be necessary to finance hydrogen infrastructure development. However, several participants noted that the partnership between the various players involved in hydrogen development must be strengthened, including more extensive involvement from the electric power industry. For example, utility companies must be engaged in this partnership to a greater extent, possibly through the use of financial incentives. Investment in hydrogen infrastructure can provide power companies with opportunities to generate revenues by using off-peak power to make hydrogen and to distribute hydrogen energy through the existing electric grid – e.g., "hydrogen-by-wire." In addition, the regulatory system governing electric power generation and delivery can be modified to provide incentives to engage utilities in hydrogen energy infrastructure development. Increasing levels of electricity demand in developing countries can be another source of revenues and market opportunities for power industry engagement and support. Additionally, developing countries have keen environmental protection and development needs.

b) Policy and Market Mechanisms and Opportunities

BREAKOUT GROUP 1 identified several policy and market mechanisms to help promote the paths to hydrogen energy infrastructure development. The policy and market mechanisms focused particularly on financial and regulatory incentives.

Developing a plan for the hydrogen infrastructure can be a valuable tool as a crisis aversion measure (i.e. oil price spikes). However, there must be further incentives provided to both the suppliers and consumers of hydrogen power generation. Government actions that can function as these measures include, for example, mandates for renewable or alternative energy portfolio standards, subsidies for hydrogen power consumers (i.e. tax rebates or direct price subsidies), and carbon taxes. Policy makers can consider using corn-based ethanol subsidies as a model for hydrogen energy production incentives. Another potential model is the United States' Price-Anderson Act, which is a law that limits liability for private owners of nuclear power facilities. This, or other measures to limit potential liabilities associated with hydrogen energy infrastructure, could be used to mitigate financial risks. Another possibility is the use of loan guarantees for hydrogen energy infrastructure or deployment projects to reduce the potential financial risks to industry.

Public education to address concerns about hydrogen safety is paramount so as to avoid the problems that occurred in the 1970's when public fears about nuclear safety affected siting, permitting, and financing nuclear power plants in the U.S. Public education and outreach campaigns could be a strong influence in raising awareness and building confidence in the benefits offered by hydrogen energy development.

2. Engineering and Construction

a) Technical, Financial, and Institutional Issues and Barriers

BREAKOUT GROUP 1 pointed out that public acceptance of safety issues related to hydrogen pipelines could be tackled through vigorous public acceptance and first responder programs. Moreover, the lack of established financial and insurance industry interest, due to diligence criteria and equipment warranties, imposes constraints on the evolvement of the hydrogen infrastructure.

There are also significant financial issues and constraints associated with the construction of pipelines and other potential hydrogen infrastructure investments based on a variety of risks, uncertainties, and unknown technical issues. For example, the global financial community has little or no experience in underwriting major hydrogen energy projects, in characterizing investment cash-flows, amortization periods, and actuarial tables for major financial risks. In addition, the cost and volatility of natural gas due to the unreliability of pipeline deliveries, liquid natural gas imports, and the 18 month time lag between filing and protection of intellectual property rights, both pose barriers to hydrogen energy development in the U.S.

Another engineering and construction issue is an insufficient industrial supply base, due to the infancy of the supply chain for hydrogen energy, and in need for greater standardization of products. There will be significant requirements for qualified codes and standards, as well as needs for skilled tradesmen and craftsmen. BREAKOUT GROUP1 summarized the conclusions on these barriers with the popular saying that while “…rising tides lift all ships; one bad apple can wreck an entire barrel of market goodwill…”

b) Policy and Market Mechanisms and Opportunities

BREAKOUT GROUP 1 identified several policy and market mechanisms which could serve to address the barriers to the engineering and construction of hydrogen energy infrastructure. One mechanism includes refinement of current market structure. To wit, is there a lack of transparency in electric power markets, and is the current structure dominated by a relatively small number of large companies that are able to exert market power? It is important to address these questions, and there is also a need to explore policies and legislation that address market power and anti-competitive practices in electric power markets, if such are determined to exist.

Participants also expressed concerns regarding legislation that regulates portfolios of feedstocks for hydrogen production (e.g., natural gas for making hydrogen). There need to be efforts for streamlining state/local approvals for hydrogen infrastructure and facilities (and possibly federal back-stop authority for national security or environmental purposes) and potential needs for federal, state, and local investment in hydrogen infrastructure, as well as access to state funds. These efforts could also address the current lack of demand for hydrogen energy production by driving the demand side. In this context, government agencies could play a critical role in market development by serving as a lead adopter.

Steps to accelerate the maturation of technology are vital, and neutral agencies might be best suited to take on the lead role in standardization and certification. The Society of Automotive Engineers (SAE), The American Society of Mechanical Engineers (ASME), Underwriters Laboratories (UL), or The International Code Council (ICC) were mentioned among the most likely candidates.

3. Operations and Maintenance

a) Foreseen and Unforeseen Challenges

BREAKOUT GROUP 1 addressed many of the potential challenges that could arise in maintaining and operating the hydrogen infrastructure for stationary power applications. Participants considered a variety of issues, including the potential for key materials shortages (i.e. platinum), disposal methods for potentially hazardous materials, and strategies to secure hydrogen energy systems from acts of terrorism, or weather-related supply disruptions.

There is no long-term track record or experience base with the operations and maintenance of hydrogen energy infrastructure so it is difficult to anticipate the exact costs involved and all the issues and problems that could arise for hydrogen demand, distribution and production. In addition, this operations and maintenance phase could be 20-40 years in the future. Energy economy developments could occur over that time that could impact hydrogen energy infrastructure in a host of unforeseen ways.

There are liability and security issues to address for all parties involved. Not only will pipeline and station maintenance be a cost, but the development of unforeseen technologies posing as competition or disruption to the market, such as nontoxic batteries, or fusion energy systems, will also create added costs for hydrogen producers and distributors.

Furthermore, the environmental and social risks linked with stationary hydrogen applications are likely to involve potential challenges to overcome. One approach would be to establish direct ownership of materials and operations to cover the unforeseen costs of these occurrences.

It is important to establish a skilled and informed labor force for dealing with operations and maintenance. There is a need to ensure the system meets codes and standards as well. The pipeline and station upkeep must be reliable, and will require a new model of insurance for utilities and providers.

b) Prospective Policy, Market, and Technological Solutions

BREAKOUT GROUP 1 identified a mix of potential policy, market and technological solutions. There are several important methods which could be utilized to ensure long-term sustainability and cost-effectiveness.

First and foremost is the need for profitable business models, with well understood economic and business implications, for owning and operating hydrogen energy distribution systems. There are several incentives which could serve to bolster the long-term maintenance and profitability of operating and maintaining hydrogen infrastructure for stationary power applications. One possibility involves modifying federal and state tax codes to include accelerated depreciation schedules for hydrogen infrastructure facilities and equipment to encourage initial investors and early adopters. In order to maintain the profit from investments, federal and state government agencies could regulate and enforce intellectual property patents for hydrogen infrastructure and technologies, particularly in international markets. One can also apply business case studies (such as those with LED lights) to the hydrogen system in order to develop a crisis response plan, and aid in refining the insurance policies.

Governments can also provide incentives for inspection methods and regulations for the long-term functioning of the system. It is important to determine the scope and goals for the stationary hydrogen economy, however, so that the capabilities of the government and industrial players are not stretched too thin.

The group concluded that it will be beneficial to adopt a new view concerning hydrogen technology and its opportunities and possibilities. Overwhelming challenges can easily deter investors and skeptics from buying-in, but we must stop looking for the 100% solution – or, as participants summarized: “Better is the enemy of good enough”

C. BREAKOUT GROUP 2: Mobile Applications

1. Planning and Design

a) Pathways

BREAKOUT GROUP 2 identified several priority pathways that will facilitate hydrogen infrastructure development. These observations and recommendations were based on the caveat high level of uncertainty about future conditions and possibilities in energy markets, and the long time-frame involved. Indeed it is difficult to determine exactly how hydrogen energy infrastructure development will occur. There is no definite solution to the question of hydrogen economy development pathways.

Future energy sector uncertainty is based on several points. Since infrastructure development relates to the timing and and readiness of technologies for hydrogen applications, it is difficult to state a single, all-encompassing scenario to follow in planning and designing the system. In fact, it may be premature to define specific infrastructure development pathways as this approach might deter new and creative thinking and ideas to emerge and discourage new entrants from taking part in the market. It is important for those already interested and knowledgeable about the hydrogen technologies to maintain the image of an open market for development to invite new players to enter, spurring innovation, growth, and competition.

It may not be useful to “fine-tune” the infrastructure planning process too early. Early critiques or overly detailed planning could result in stalled or slow construction. And, because “one size does not fit all” concerning infrastructure planning and design, it is important to consider all regional, economic and political differences.

Nevertheless, there are several potential pathways of hydrogen economy infrastructure development to consider. One pathway involves the “Lighthouse” approach which involves the concentrated development of hydrogen energy infrastructure as a precursor to expanded corridor development, and leading to increased consumer demand for hydrogen vehicles through incentives for early adopters. A Lighthouse Project is defined as the approach focusing hydrogen applications on urban centers, with emphasis on municipal bus fleets, taxis and mass-transportation systems to reduce the cost of initial investment and to incorporate flex-fuel technologies to the greatest extent possible. Eventually, further subsidies and incentives would be needed to encourage market development of personal vehicle applications and begin the process of shifting the market away from urban core and cluster settings, and to facilitate greater competition and market development.

It is critical for personal vehicles to be part of the market development strategy as quickly as possible to build the level of potential revenues that automakers need to scale up for mass markets. This is essential for establishing consumer trust and encouraging infrastructure development.

The planning process to create an infrastructure strategy must involve a range of actors (i.e., local and state government agencies, auto makers and hydrogen equipment manufacturers, financial and insurance institutions, and other industry players). These parties need to commence a dialogue to ensure collaboration and coordination of the stakeholders involved in planning and design for the large-scale investment required. There is also a need to consider new approaches including strategies such as joint ventures for sharing investment responsibility among the firms involved in planning, designing, engineering, constructing, operating, and maintaining the infrastructure. Auto makers and hydrogen energy suppliers will be particularly important to this partnership.

It is also necessary to focus on the need for regulations, codes and standards (such as those concerning hydrogen purity) and to set these as soon as possible to stimulate development. The regulations, codes, and standards will establish stability in the market.

Concepts to consider for planning and design include:

- Original equipment manufacture rollout strategies for hydrogen internal combustion engine and FC vehicles
- Hythane as a bridge technology
- Government subsidies for construction to encourage customer acceptance and demand
- Consideration of economic and safety issues with hydrogen delivery
- Education to increase consumer acceptance (Iceland model)
- Develop profitable business models and pathways
- Consider production locations in the context of consumer location to determine best transportation method
- Consider local training needs (i.e., safety officials, consumers, and technicians)
- Flex fuel internal combustion engine vehicles (ICE) / gasoline vehicles
- On-site hydrogen production to reduce transportation issues and lessen carbon footprints

b) Policy and Market Mechanisms and Opportunities

There are several policy and market mechanisms and opportunities that can provide pathways for hydrogen energy infrastructure development. The development of regulations, codes and standards are needed immediately, well in advance of infrastructure engineering and construction, to establish a predictable market environment. There is also a need to ensure consistent government policies. These policies must be developed in a manner where there is not frequent adjustment for political purposes. Nurturing policies must provide stability over time to attract long-term investment.

Policies to consider include various tax mechanisms that can serve as strong drivers to encourage development, but which must be designed in accordance with the maturity of the technologies, regional differences, and public acceptance issues. Tax policies can be implemented to drive the demand for hydrogen as well, such as increases in taxes on traditional fuels, and tax breaks for alternative fuels, including hydrogen. Other mechanisms, such as subsidies, voluntary programs, and rebates, should also be considered to drive demand.

However, there is an important role for government that does not involve tax policies or subsidies. Government agencies can spur development by becoming first-adopters of hydrogen applications. This will occur only if policy-makers and the public are convinced that hydrogen energy development is critically important for the future, and this requires clear and simple messages that explain the technology and infrastructure goals.

It might also be valuable to expand the existing analysis of hydrogen, energy markets, renewable energy possibilities, and environmental strategies that outline the relative merits of alternative pathways and the financial implications of alternative courses of action. This would help educate policy makers and the public, and draw attention to the complexities and trade-offs of actions for hydrogen infrastructure. The use of long-term contracts, such as those found in natural gas markets, should be explored by hydrogen providers and infrastructure developers to build confidence and encourage the investment community to get involved.

There can be no question regarding the importance of focused and aggressive government involvement, and the implementation of specific and effective public policy mechanisms in hydrogen infrastructure planning and design for the eventual build-out to occur.

2. Engineering and Construction

a) Technical, Financial, and Institutional Issues and Barriers

There are a number of technical, institutional and financial barriers facing the construction of hydrogen energy infrastructure for mobile applications. There is a critical need for “price, schedule and performance certainty” to attract private investment in new technologies and long-term infrastructure facilities. Risks associated with the high up-front costs of construction, materials, and human resources can be mitigated with clear and available information.

There is also the problem that existing codes and standards will limit construction if they are not modified. Regulations, codes and standards must be harmonized across regions to encourage consumer confidence, to regulate new technologies, to overcome barriers to the siting and footprints of stations, and to educate local leaders about the technical and social issues associated with the engineering and construction of the hydrogen infrastructure. Labour force issues must also be addressed to ensure there is a cadre of trained technicians and construction personnel to meet long-term demands. Another issue to be considered is the attitude of consumers who often are apprehensive about new technologies and argue against new facilities and construction near where they live (i.e, “not in my backyard”problems).

The existing suite of hydrogen technologies are, for the most part, not ready for mass production and development. To scale-up the production and bring costs down for devices such as hydrogen compressors and on-board vehicle storage devices, these technologies must become more advanced, reliable, and cost-effective.

There are also issues that the automakers need to address. These firms must balance a variety of technical and marketing factors in designing hydrogen vehicles, and bringing them to market in the face of substantial uncertainty about fuelling station locations, capabilities, and costs. They must also determine how hydrogen vehicles will fit in their production and marketing strategies along with conventional vehicles and new designs such as hybrids, plug-ins, and biofuel vehicles. Other business issues include managing supply chains, and addressing the needs of existing subsystem and component suppliers, who are dependent on current offerings and practices.

Other engineering and construction considerations include:

- Acceptance that hydrogen fuel cell vehicles are important to the future of
- transportation technologies
- Right-sizing the facilities and components
- Liability issues
- Not considering all or total costs; costs of equipment, fuel production, storage, safety
- issues, rare metal materials, recycling etc. may be more than anticipated.
- Hydrogen leak detection – odorizing may not work for hydrogen due to fuel cell degradation issues
- Adequacy of capital markets to make investments needed to build hydrogen market

b) Policy and Market Mechanisms and Opportunities

There are several policy and market mechanisms that can be used to address the challenges of engineering and constructing the hydrogen infrastructure. In this early stage there is a continuing need for incentives to stimulate more research and development and equipment testing, industry collaboration, and workforce development. The interaction of these activities can help encourage the development of hydrogen systems. An example of an incentive for stimulating hydrogen and fuel cell vehicle demand would be granting special parking rights in urban areas to owners and operators of hydrogen vehicles and equipment.

Once again there is an ongoing need to coordinate and educate safety officials to standardize and enforce the regulations, codes and standards framework through a nationalized mechanism (such as the system developed for the United States National Fire Protection Association). Not only do regulations, codes and standards need to be consistent, but the process for determining, developing and maintaining fuelling sites must also be standardized across regions to encourage market demand and growth.

As the technologies and labour force matures, it will be important to encourage financiers and investors in the infrastructure by fostering greater certainty in the cost of hydrogen. This information is particularly relevant in assisting policy makers and business decision makers to make choices among competing traditional and alternative fuels in the marketplace.

Other considerations include:

- Setting infrastructure requirements to facilitate, and not inhibit, development
- Recognizing the key drivers of hydrogen development (i.e., price of gasoline, environment concerns, public health, energy security)
- Utilizing the facilities that currently produce large amounts of hydrogen (i.e., refineries and chemical manufacturers) to supply certain amounts to encourage local hydrogen development projects

3. Operations and Maintenance

a) Foreseen and Unforeseen Challenges

There are a number of foreseen and unforeseen future challenges that will be involved in operating and maintaining hydrogen energy infrastructure. There are four primary areas where awareness and planning could avert serious problems.

Highest priority need is workforce development and continuity to ensure there are trained and capable officials to operate and maintain hydrogen infrastructure. Officials will need an intimate understanding of regulations, codes and standards.

Second is the issue of addressing the various aspects of safety that will be critical for ensuring the long-term viability of hydrogen in mobile applications in the market. Crisis management, safety protocols, pipeline and station up-keep, security of facilities against acts of terrorism, and tube trailer safety issues will all be important to consider in operating and maintaining the hydrogen infrastructure. The set of safety protocols that are currently used in natural gas could serve as a reference model for operating hydrogen energy infrastructure.

A third consideration involves the technical issues in operating and maintaining new hydrogen technology and applications en masse. Problems could arise in the short and long term, and measures must be identified in advance to ensure long-term reliability and resiliency of operations. Potential measures include: leak detection sensors and analyzers, system calibration, compressor maintenance, long-term availability of materials and parts, and local maintenance personnel.

And fourth are risk, liability and insurance policies concerning hydrogen infrastructure operations. This is an area that warrants expanded research and analysis. There is a current lack of experience with the various hydrogen and infrastructure technologies, and it is difficult to asses the full range of financial and physical risks that may be associated with expanded market and infrastructure development.

b) Prospective Policy, Market, and Technological Solutions

There are policy and market strategies that can be used to address these short and long-term risks. Effort is needed now that is aimed at addressing workforce issues, including the design of curricula for engineers, technicians, and code and safety officials. There is also a need to engage insurance providers and explore possibilities for addressing foreseen and unforeseen risks, both physical and financial. Expanded analysis and development of potential business cases for hydrogen infrastructure development can help in this regard. Such analysis should consider a variety of factors, scenarios, conditions, and possibilities.

While hydrogen energy infrastructure operations and maintenance involves thinking about the long term, there are also near term issues to consider with the emerging infrastructure that is being built to support demonstrations, trials, and field tests. For example, it is important to consider other pathways and infrastructure requirements that involve niche applications (i.e., long haul trailers, mining vehicles, airport vehicles, and fishing fleets). It is also important for developers and planners to consider the differing infrastructure requirements for both hydrogen fuel cell vehicles and hydrogen internal combustion engine vehicles as part of the transition to the hydrogen economy in mobile applications.

D. BREAKOUT GROUP 3: Mobile Applications

1. Planning and Design

a) Pathways

There are various strategies concerning the pathways for hydrogen infrastructure development. One area of emphasis is the need for strong and continued public-private partnerships. Governments are well equipped and positioned to provide incentives, investments and interventions to drive industry and the market, and to help create the conditions for long-term profitability and sustainability of investments. However, government cannot do it alone; both industry and consumers are critical partners in the process. Current hydrogen companies are operating on thin margins and many are having difficulty sustaining business operations and making profits during the research and development phase. Consumers are not yet engaged to large extent, but preparations for their involvement must begin as soon as possible to build market pull and create the conditions for changing existing buying habits, existing consumption patterns, and shifting to encourage new investment. Government needs to provide a strong influence in creating the long-term drivers for the hydrogen infrastructure development.

One of the more promising approaches to planning and design is the “Lighthouse” concept, or other regional approaches, that provide potentially cost-effective paths for building-out the hydrogen infrastructure. This strategy has the potential to not over-tax hydrogen energy providers or auto manufacturers during the market entry phase. It can also accelerate the diffusion of the new technologies and the creation of new hubs, but it is important that infrastructure build out not get too far ahead of market demand at the risk of “stranding” assets.

Another planning and design consideration for the market entry phase of development is the application of mobile hydrogen vehicles in fleets (i.e.., municipal bus fleets, government fleets, corporate fleets, airport vehicles, and industrial equipment such as forklifts). This approach can help to promote consumer acceptance, prove technological viability, and increase awareness. The knowledge gained from these “niche” applications can be converted in the future to personal vehicle markets, where the large volumes that will be needed to support large-scale infrastructure development can be found. However, it is important to ensure that the transition from fleets to individuals occurs in a smooth manner, and that the mistakes made from experiences in trying to do this with natural gas vehicles not be replicated, where the technologies implemented in buses and fleets never made the transition to auto markets, at least not in the U.S.

In addition, during the planning and design phase, it is important for auto manufacturers, hydrogen energy suppliers, and fuel cell and hydrogen equipment makers to develop plans, and make as much of them as public as possible, to coordinate investments and goals, and provide a firm foundation for public-private partnerships of operate effectively. The plans need to focus on both technical specifications for key components such as hydrogen storage (i.e. 350 or 700 bar) as well as identify cost-effective implementation solutions for long-term.

b) Policy and Market Mechanisms and Opportunities

There are several public policies and market mechanisms for strengthening public-private partnerships for hydrogen energy development. For example, governments can help drive consumer demand for hydrogen energy with a mix of policy tools, such as tax incentives, hydrogen fuel price subsidies, carbon taxes, and regulations. Each of the policy tools have unique implications for the various players potentially involved in planning and designing hydrogen energy infrastructure. However, the first step to success is a dedication to consistent and sustained messaging and policies from government. Governments' role is not to force demand; but to drive down consumer costs, to highlight safety, to set codes and standards, and to facilitate technology development.

Incentives and regulations are two important tools that need to be further researched in order to most effectively accelerate the growth of hydrogen infrastructure. Incentives encourage the development of technology in the commercial setting by creating the potential for profit. Codes and standards should be used to create guidelines in the development of new technologies to balance the risks and returns of investment since the infrastructure and market of hydrogen applications involves the collaboration of energy providers and vehicle companies. This guideline must be developed with both government and private sector coordination.

Government agencies can also work to signal a definitive and long-term dedication to hydrogen energy development. Not only is government support needed in procuring and promoting hydrogen applications, but government programs can also help build public trust in institutions to increase understanding and acceptance of the new technologies among the various stakeholders and market participants. Government effort will be needed for training "First Responders" and educating key audiences about the various aspects of hydrogen equipment such as energy and environmental regulators, and siting and code officials. Government can assist by placing greater emphasis on energy and hydrogen education programs to build comfort and awareness in the general public. However, it will be important to address potential public concerns about government spending on major new initiatives, particularly during the early phases where private investment may not be visible to the public.

Engineering and Construction

c) Technical, Financial, and Institutional Issues and Barriers

There are many challenges to address during the engineering and construction phases of hydrogen infrastructure development. Prominent challenges include both financial and technical considerations.

One challenge involves the high initial cost of building hydrogen infrastructure and producing new hydrogen vehicles, and the multi-year period that will be needed to achieve return on this investment. Furthermore, proper codes and standards are not yet in place to ensure that storage facilities, siting design, footprints and liability will be cost-effective investments for these firms.

Major components of these high initial costs include the high cost of hydrogen storage systems and on-site production facilities. These have a very high initial cost of investment, and are more expensive due to the size and pressure regulations limiting the scaling-up of off-board storage.

Another challenge involves the need for consistency in insurance and liability agreements between hydrogen energy and vehicle providers. These businesses have different incentives and therefore different strategies for development. Hydrogen infrastructure development will involve a high and unprecedented degree of integration, coordination, and collaboration between vehicle manufacturers and fueling station developers. It is not clear how these partnerships will develop, or what policies can be used to encourage them.

Hydrogen storage technologies are a major piece of the puzzle for infrastructure engineering and construction. Problems range from uncertainties about the size, type, and cost of storage systems, to questions about the footprint, siting criteria, and safety issues, particularly when ultra-high pressure systems are used.

d) Policy and Market Mechanisms and Opportunities

Despite the challenges of hydrogen energy infrastructure engineering and construction, there are many policy and market opportunities that will help to overcome these challenges.

Government investment in developing effective and consistent codes and standards will help decrease the long term costs for many actors involved in construction. There are several models of successful codes and standards development processes that can serve as examples for hydrogen energy infrastructure development (e.g., the Canadian Hydrogen Installation Code.)

For example, it could be valuable for the IEA/ IPHE to initiate a joint annex to study codes and standards, and report their findings to the hydrogen energy community. This could enable and encourage a stronger dialogue between the industries involved in planning and construction by coordinating the various activities of all involved. The collaboration of industry, government and policy activities will lead to an accelerated and more effective infrastructure development effort and a potentially smoother transition to the hydrogen economy.

A prominent example of the need to discuss codes and standards is that of fuel purity guidelines so that providers and suppliers can coordinate their products. A sampling protocol could be devised to ease the problem of liability, and to specify consistent hydrogen standards that can apply throughout the entire hydrogen infrastructure.

Insurance firms are other important players that must be engaged in the dialogue to coordinate activities on hydrogen infrastructure design, planning, engineering, and construction. Insurers need to be more thoroughly educated about hydrogen risks and mitigation procedures so that they can develop policies for the firms who enter the market. Insurance policies and practices for hydrogen energy systems will help to engage existing firms to invest in the new market since they are currently competing with mature technologies for which such policies and practices exist, and they need to establish business models that work and can survive a period where margins will be low and financial returns will occur in the long-term. During the engineering and construction phase, there is a strong need for effective business models, which will depend on customer demand and provider supply being aligned and profitable. The problem of profitable business models is a primary challenge that will need to be overcome.

These business models will involve shifts in existing paradigms and ways of doing business. Public-private partnerships are a key part of the equation. Effective government policies that are consistent over the long term are essential for attracting private capital. But industry and consumers need to be integral players in the process as well. One of the key questions is: The group posed the question: Is the IEA/ IPHE project exploring hydrogen infrastructure development equipped to undertake research and analysis with the goal of developing new model(s) to guide the commercial launch and adoption of hydrogen in the public and private spheres? Such analysis can be highly beneficial in effecting a cost effective transition, and accelerating the process of hydrogen infrastructure development.

2. Operations and Maintenance

a) Foreseen and Unforeseen Challenges

The financial success of infrastructure operators is important to ensuring continued investment and growth in hydrogen energy products and services. Logistically, fuel station operators must consider several factors, such as maintaining fuel quality, location of the storage facilities, form of storage, limiting the up-time at stations and through-put time to cut down waiting periods, interacting with the electricity grid, and ensuring an experienced and skilled workforce.

Transport and pipeline issues are challenges that will need to be addressed. In the future, there needs to be a focus on the best way to transition from a trucking to pipeline distribution system. Trucking poses problems due to regulations from the transportation sectors, such as: limits across statelines and international borders, details of gaseous transport codes, parking, ferries, and safety on the road. However, the technical specifications of pipeline infrastructures, such as lifetime, survival, contamination to hydrogen, vacuum and ultra-vacuum differences, leakage, embrittlement, inspection points, detection, infrastructure, urban construction, and the right of eminent domain are all critical considerations in determining the best method of long term distribution. On-site production is a possible alternative to this dilemma but the costs and benefits of this approach have not been fully demonstrated. While all of the potential problems of operating and maintaining the infrastructure are not predictable, the best time to prepare for long-term operations is now.

b) Prospective Policy, Market, and Technological Solutions

Codes, standards, and regulations need to be developed and implemented to ensure long term operational and maintenance success. There is need to address interstate and border distribution laws, as well as North American treaties, to standardize distribution problems and reduce inefficiencies.

Fueling stations must also be standardized to encourage consumer acceptance and understanding, as well as to facilitate the spread of the infrastructure. There is need to develop a common interface for each platform similar to the existing fueling system. This would require the same level of effort and intuition from the user as the current models.

Hydrogen pipelines should have a systematized protocol for function testing and review. This procedure could be accelerated by hydrogen energy suppliers by entering into a dialogue with code and safety standards officials to implement appropriate testing protocols. Road transport systems should also develop similar protocols, especially high pressure systems.

E. BREAKOUT GROUP 4: Mobile Applications

1. Planning and Design

a) Pathways

There are five key pathways in planning and designing the hydrogen energy infrastructure for mobile applications:

- Hydrogen feedstocks;
- Hydrogen production;
- Market development;
- Fueling stations; and
- Hydrogen transport

With respect to hydrogen feedstocks, natural gas and biomass approaches using distributed steam methane reforming (SMR) are the most likely near term pathways, particularly in the absence of carbon management policies. In addition, utilizing waste hydrogen streams - such as those from electrochemical processes and plastics manufacturing plants - is likely to play a role. In those cases where local renewable resources (such as hydro, geothermal, wind, solar thermo-chemical, tidal or other) offer advantages, electrolysis will be applied. Production form existing industrial gas and hydrogen production facilities will be utilized to the fullest cost effective extent.

With respect to hydrogen production, centralized production in large scale facilities located about 30-60 miles from the city boundary is also a potential near and long term pathway. In addition, small scale facilities could make possible distributed production at fueling stations.

With respect to market development, central fleet applications (e.g., municipal bus systems, government vehicles, and corporate fleets) are a likely near term pathway. Over the longer term, for hydrogen infrastructure requirements to reach regional or national proportions, automakers will have to decide whether or not and how to scale up production to produce thousands and millions of personal vehicles. To accomplish this, government, consumers, and many other companies and partners will have to be involved. This could be achieved by with both FC and/or ICE vehicles.

With respect to fueling stations, the infrastructure will likely be built up around fleet applications, at least at first. It is important for these stations to be as open as possible for public access to lay the groundwork for the personal vehicle pathway that will follow. Urban networks of stations will make it more and more convenient for all types of consumers to fuel their fuel cell or internal combustion engine vehicles. It seems desirable to locate hydrogen fueling stations at or close to existing stations.

With respect to hydrogen transport, existing natural gas pipelines offer potentially promising pathways if the technical issues can be addressed. One problem is that while pipelines may be useful to have in the early stages of infrastructure development, the costs could be too high for the early market participants.

b) Policy and Market Mechanisms and Opportunities

There are five categories of policy and market mechanisms to focus on to address the primary pathways for hydrogen infrastructure development:

- Carbon policies;
- Incentives for automakers;

- Incentives for consumers;
- Incentives for hydrogen producers;
- Other policies

Carbon policies will be critical and necessary for mass markets and large scale infrastructure development to occur. A big advantage is that these policies can be used to tie in with incentives for automakers and buyers through mechanisms such as tradable credits.

Incentives for automakers are also expected to play an important role as well. One approach for automakers is to limit the number of hydrogen vehicle platforms that they offer to consumers to keep the costs down, and thus reduce the amount of incentives needed from government. For this approach to work, however, it will probably be necessary to use the limited number of platforms in a creative manner to give consumers choices and alternatives, satisfy consumer expectations, and sell vehicles. To reach this end there is a need to incentivize the automakers to take risks. One approach is to provide offsets to Corporate Average Fuel Economy (CAFE) standards for production of hydrogen vehicles. A crucial component is that there needs to be a larger number of suppliers to encourage competition in designs and market entry strategies.

In addition to incentives for automakers there also needs to be incentives for consumers. One way would be to subsidize vehicle costs through financial mechanisms such as tax credits and rebates. Another way would be to subsidize hydrogen fuel costs through similar instruments. Finally, lawmakers could consider imposing fees on non-hydrogen cars and rebates to subsidize hydrogen vehicle costs.

Other Policies could include cost sharing initiatives for large scale demonstration projects involving thousands of vehicles for 3 years after the US Department of Energy's hydrogen technology goals are met in 2015. An important commitment would be to change government fleets at the federal, state, and provincial level even though these measures would have limited ability to change markets.

2. Engineering and Construction

a) Technical, Financial, and Institutional Issues and Barriers

There are three major areas of potential barriers:

- Technical;
- Financial; and
- Institutional

With respect to technical barriers there is a high level of uncertainty regarding the costs, performance, and durability of hydrogen storage technologies. Stationary storage systems, for instance, could turn out to be very large, and there remains the uncertainty of the durability and embrittlement of materials. A key issue would therefore be to focus on hydrogen compression and transportation technologies.

With respect to financial barriers there are a number of liability and insurance issues to consider. At this point, it is unclear how insurance firms will develop and provide policies to hydrogen infrastructure developers. Particularly unsure are the cost structures of these policies. There is little experience upon which to base premiums and no actuarial tables to draw upon. Moreover, the costs for the compression and liquefaction of hydrogen gas are not known and the size of the equipment and the amount of energy required to do the compression could be prohibitive. It will take a significant profit opportunity for developers to take large financial risks given uncertain markets, regulations, and customer preferences. The cost of transporting hydrogen is an additional issue, as is finding and financing real estate acquisitions at convenient sites for fueling stations that are available to consumers.

One of the significant institutional barriers is the lack of codes and standards – particularly for retail applications – and the lack of understanding and variability among the code and permitting officials. These deficiencies could especially aggravate the acceptability and siting of hydrogen pipelines in urban areas. Moreover, the “not in my backyard” phenomenon (NIMBY) is another important barrier to the construction of a substantial hydrogen infrastructure. And, there is a lack of standard measurement devices for volume and quality of gaseous hydrogen fuels.

b) Policy and Market Mechanisms and Opportunities

There are four major categories of policy and market mechanisms:

- Codes and standards;
- Government actions;
- Education and outreach; and,
- Financial incentives.

A top priority is to develop and consolidate codes and standards for retail applications. There is the need to harmonize codes and standards across states, regions, and provinces and between countries to encourage deployment. There are a variety of efforts underway to do this including those of ASME, FreedomCar, ISO, and the Society of Automotive Engineers (SAE). Government Actions could include the expropriation of land for siting and building pipelines along major thoroughfares, as well as the guaranteed purchase and usage of hydrogen fuel to ensure an adequate market. It might be useful to explore the creation of quasi-governmental organizations charged with linking manufacturers and consumers, and to develop a 10-year commitment for sustained policies to promote hydrogen energy and infrastructure development by federal, state and provincial governments.

Education and outreach efforts could serve to overcome some of the above identified barriers. This could be facilitated through permitting officials, rewarding first responders and informing the general public about the environmental and energy security benefits of hydrogen.

Amongst the potential financial incentives could be fuel tax credits for buyers and sellers, loan guarantees and accelerated depreciation provisions, as well as flow through tax credits for investors. Liability concerns for hydrogen fuels could be of the same order of magnitude as those for gasoline. Mechanisms such as liability limits or caps have been used for other energy sources and could be developed and applied to hydrogen.

3. Operations and Maintenance

a) Foreseen and Unforeseen Challenges

Some of the key challenges for operations and maintenance include:

- Safety;
- Workforce;
- Capital equipment; and,
- Institutional.

To address safety concerns, a concrete goal should be established stating that no significant hydrogen events should result in the loss of life. It will be necessary to establish procedures for dealing with vandalism, mis-use, terrorism and other threats that could lead to potential safety related events. In addition, technologies and strategies for hydrogen leak detection need to be developed and incorporated into the safety framework.

Workforce requirements are a significant issue and there will need to be well-trained and skilled technicians as well as service infrastructure personnel and a sufficient number of installation contractors.

A potentially unforeseen challenge is the reliability of hydrogen infrastructure equipment and the potential need for redundancy to ensure reliable supplies. A potential problem could be that city gate facilities may need to be relocated as populations grow. Over time there may be a need to make hydrogen delivery infrastructure compatible with the electric grid, and to possibly co-locate hydrogen pipelines and transport along existing rights-of-way.

An institutional challenge is the issue of weights and measures, and the need for accurate mass flow devices for fueling. Besides this there was a continual need for education over decades as the infrastructure expands. Education and training efforts will have to include for example: rural areas, operational sectors, customers, and first responders.

b) Prospective Policy, Market, and Technological Solutions

There is a need for programs for training technicians, service people, and installers. There is a need to develop testing procedures and certification protocols for producing, testing and evaluating equipment for operation and maintenance. There is a continuing need for government and industrial research and development to provide more reliable pumps, compressors, and other delivery equipment. Efforts need to continue or increase for government research and development for advanced materials for hydrogen storage, pipeline, and delivery equipment. In addition, there is a need to develop cost effective purity verification equipment and procedures.

F. BREAKOUT GROUP 5: Modelling and Analysis Breakout Session

1. Overview of the session

The modelling and analysis breakout group identified the following objectives for the discussion session:

- Exchange information on the latest methodologies and insights from hydrogen infrastructure development and transition modelling activities;
- Identify key questions related to modelling transition policy and technology options and evaluate whether the existing models can answer these questions;
- Brainstorm options to improve the models;
- Evaluate strengths and weaknesses of various modelling approaches; and,
- Explore the value of developing a “model toolbox” for policy maker support, and how such a toolbox could be organized in practice.

2. Introductory Presentations

The breakout session began with six presentations that provided brief overviews of current hydrogen infrastructure and transition modelling activities.

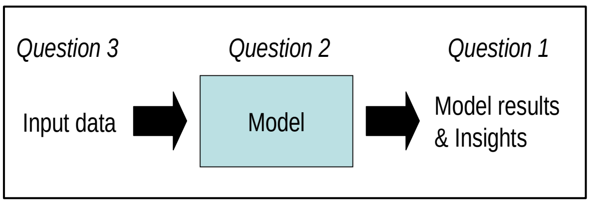
- *Issues in Integrated Market Modelling of the Hydrogen Transition*
  Dr. David Greene, Corporate Fellow, Oak Ridge National Laboratory
- *Building the Hydrogen Economy: Modelling Issues*
  Dr. Dolf Gielen, Senior Analyst, Energy Technology Policy Division, International Energy Agency (IEA) Dr. Uwe Remme, Visiting Analyst, Energy Technology Policy Division, International Energy Agency (IEA)

- *Regional Hydrogen Energy Transition Modelling*
  Dr. Marc Melaina, Project Scientist, Institute of Transportation Studies, University of California at Davis
- *Modelling Infrastructure Expansion and H2A Delivery Pathways*
  Ms. Marianne Mintz, Energy Systems Analyst, Argonne National Laboratory
- *HyWAYS-IPHE: Comparing Hydrogen Analyses*
  Mr. William Borthwick, European Commission, Mr. Fred Joseck, Chief Technology Analyst, Hydrogen Program, US Department of Energy, Mr. Mark Ruth, Macro-Systems Model Engineer, Systems Integration, National Renewable Energy Laboratory, Mr. Christoph Stiller, Ludwig-Bölkow-Systemtechnik GmbH
- *Life-Cycle Analysis of Vehicle/Fuel Systems with the GREET Model*
  Dr. Ye Wu, Assistant Analyst, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory

3. Discussion Topics

The following focus questions were posed to the group for discussion:

- What are the most important policy modelling questions regarding the transition and H2 infrastructure development?
- What questions or issues are not addressed adequately by existing models and analysis?
- What can be done to strengthen data validation and the credibility of inputs for scenario analysis?
- What are the next steps in developing a tool box for modelling and analysis?



The questions were designed to address the different steps of modelling and analysis, including input data and assumptions, the capabilities and shortcomings of the models themselves, and the outputs that are generated. Since a single model is not able to address all different questions relevant for the transition to a hydrogen economy, the last question introduced the idea of creating a tool box of models with different features in terms of methodology as well as regional and sectoral scope. The following section summarizes the group's discussion of these four focus questions.

4. Group Discussion Summary

a) Important policy modelling questions regarding the transition and hydrogen infrastructure development

Participants identified a number of modelling questions and issues which were grouped into the following six categories, as presented below: 1) Technology policy, 2) Consumer behaviour, 3) Current vs. long term policy, 4) Policy strategy/robustness, 5) System and spatial analysis/Interdependencies with other sectors, and 6) Envisioning/Measuring the transition.

b) Technology policy

- Is there a need for bridging technologies (e.g., PHEV, hydrogen internal combustion engine) to compensate for the delay between the development of hydrogen supply infrastructure and cost-competitive fuel cell vehicle production?
    - How (if and when) do advanced alternatives to fuel cell vehicles fit in?
- Should we model the current idea of what a vehicle "is" or should we model new ideas of vehicle utility, symbolic value, performance, etc?
- Under what conditions is a sustainable transition to a hydrogen-powered transportation system achievable?
- How much and for how long is research and development investment and deployment support needed?
- What is the probable (not optimum) total expense above business-as-usual required to make a hydrogen economy self-sustaining?

c) Consumer behaviour

- How are successful market scenarios affected by different assumptions about the behavior of consumers?
    - Will projected technology use accurately match up with actual technology use (e.g. charging of plug-in hybrid electric vehicles during the day and not the night)

- How do we take into account shifting societal values over time within a particular culture and differences between cultures (e.g., importance of personal mobility, consumer behaviors)
- How might the distribution and demographics of urban populations change in the future?

d) Current vs. long-term policy

- What is the most reasonable strategy for near-term next steps (while considering long-term perspective)?
- Based on the modeling results, should I act now or wait?
- Should polices be set in a time-staged (phased) approach?

e) Policy strategy/robustness

- What is the best balance among research, demonstration, and subsidy programs and policies for most efficiently and effectively meeting overall goals?
- What are the key barriers on the demand and supply sides and what type of government intervention is needed to remove the barriers?
- Can we model the potential for policies to unintentionally lock-in specific technologies while blocking the entry of better technologies in the future?
- The “right answer” may not be hydrogen fuel cell vehicles, and other options may be more successful at meeting the objectives
- How robust are different policies under different future conditions, such as:
    - platinum cost and availability
    - failure to fully meet technical goals (something short of failure)
    - cost of hydrogen v gasoline
    - hydrogen feedstock supply costs and availability
    - water supply and availability
    - catastrophic events that cause major global disruptions
- What are some non-conventional policies that might be considered (e.g., scrapping of internal combustion engine vehicles)
- What is the role of niche markets both in and outside of the transportation sector?

f) System and spatial analysis/Interdependencies with other sectors

Ability to simulate and compare scenarios differing in the transportation fuel mix (e.g., hydrogen-based system versus electricity-based system)
How does the spatial (local, regional, national, multi-national) distribution of resources affect the economics of supplying hydrogen and the entire delivery pathway?
Modeling emission reduction targets across regions and within the same region
Are there obvious niche markets where one fuel or another has an obvious advantage?
How will local and national policies affect regional hydrogen feedstock supply and infrastructure technology choices?

g) Envisioning/measuring the transition

- What will the benefits and impacts of the hydrogen transition be (positive and negative), compared to a business-as-usual future (e.g., GHG emissions, other pollutants, energy consumption, etc.)?
    - Implications of a hydrogen economy versus others for sustainability
- What will the policy support cost?

h) Questions or issues that are not addressed adequately by existing models and analysis

The breakout group members identified a number of different gaps in existing models and analysis. These were grouped into four broad categories: 1) Baseline technology characterization and modelling technology progress and change; 2) Modelling risk and uncertainty; 3) Modelling consumer, government and supplier behaviour; and 4) Broader system issues. The key issues identified in each of these areas are described below.

With regard to **technology characterization and forecasting,** participants identified a lack of readily available, accurate data on key inputs such as the costs of fuel cells and components of the hydrogen infrastructure. There is also a need to improve the methods and data available for representing learning in models, especially global learning and interactions. In general, improved methods are needed for modelling technology change, especially for competing and interrelated technologies, taking into account the uncertainty of technical success.

Modelling risk and uncertainty is a key challenge. Better methods for modelling technical and financial risk are needed, including a better understanding of what risk levels the different stakeholders are willing to accept. Participants also noted that current models do not do a good job of modelling the impacts of unexpected events or 'showstoppers.' More analysis is also needed to identify the key uncertainties or sensitivities in the system and what interactions may be critical to achieving different outcomes.

Another key challenge for modellers is to improve the understanding of the **behaviour and preferences** of consumers, industry and government, and develop better ways to accurately represent these behaviours in the models, including the effects of *changing* behaviours and preferences. These efforts should include *all* actors, e.g., OEMs, electric utilities, oil and gas companies, investors, etc., including their different goals, attitude towards risk, and business models.

Participants also identified a number of **broader systems issues** that create or rely on interdependencies with other sectors outside of the hydrogen infrastructure. It was suggested that more focus on the hydrogen demand side is needed, in order to better understand and represent the impacts of industrial and non fuel-cell uses of hydrogen on the development of hydrogen markets. The probability and impacts of major global disruptions is another area that needs to be incorporated into modelling efforts. Better methods for modelling the cross-sectoral impacts of the pathways are also needed (e.g., impact on agriculture of biofuels, impact on global supply of raw materials). The impacts of the different infrastructure pathways on resource infrastructure must also be taken into account. Improved modelling is needed to estimate impacts on resource infrastructure, such as water resources, pipelines, sewers, roads, land resources, land use patterns, etc.

Improved methods are also needed for deriving strategies that simultaneously accomplish multiple policy goals (e.g., minimizing transition costs, GHG emissions and local pollutants) or for identifying policy priorities through multi-criteria analysis. In addition, participants questioned whether any of the models adequately addresses the "Sustainability" (with a capital "S") of hydrogen, i.e., with respect to all key sustainability factors (equity, environment, and economics).

To strengthen the understanding of the models and the model results, the group developed a number of suggestions, including:

- Enhance the representation and explanation of interactions within the model caused by changes in the input assumptions, especially to stakeholders outside the modelling community
- Improve our ability to understand and communicate differences in *valid* results obtained from different models (e.g., due to regional disparities, policy assumptions, underlying methodologies, etc.)
- Develop and provide information on the pros and cons of each model and the limitations of each model's abilities

i) Strengthening data validation and credibility of inputs

The breakout group participants developed several suggestions on how the **exchange and comparison of input data** used by different modelling teams for different world regions could be promoted. Their recommendations focused first on transparency: All assumptions and key parameters should be clear and well-documented. Models should also be transparent with regard to scope, objectives, and methodologies and clearly describe the underlying storyline (e.g., assumptions about social trends, demographics, land use, etc.). Standardization of input and output formats would also be helpful. **Modelling forums** (such as the Global Energy Demand Collaborative) are especially useful for bringing analysts together to compare data, assumptions, methodologies and results. **Independent reviews of data and models** (like HyWays/IPHE) could also be used to compare the inputs and results from different modelling efforts in different countries and regions. Participants suggested that it is important to prioritize data needs, so that the areas of highest priority (e.g., data needed for sensitivity analysis) are developed first. Other suggestions included fostering **closer linkages between modellers and technology developers/experts** in industry to improve data sets and definitions, and testing input data by **back-casting** exercises.

j) Tool box of models

As a final point of discussion, the concept of creating a tool box of models was presented to the members of the breakout group. The idea behind such a tool box is that no single model is suitable for analysing all aspects of transitioning to a hydrogen economy. Rather, a comprehensive analysis of infrastructure development for a hydrogen economy would be facilitated by the application and (ideally) linkage of different models that address different policy questions.

After briefly considering the question of whether such a toolbox is needed and how it should be developed, participants requested more time to discuss the primary goals of the tool box, its functionality, and which models (including databases) should be included in the tool box.

Based on the group's knowledge of ongoing modelling efforts, the participants compiled a preliminary list of models currently available for use in analysing hydrogen infrastructure development and the transition to a hydrogen economy (see table below). This represents an initial cut at a comprehensive list of all the models that are currently available for this purpose. Participants suggested that this list be expanded to include all models available worldwide.

Model Type	**Model Name**	**Model Developer (Institution/Modeler(s))**
Supply chain pathways and tradeoffs	H2A	U.S. DOE/ANL, NREL
	HDSAM	U.S. DOE/ANL, NREL
	E3 Database	LBST
	GREET WTW Emissions	U.S. DOE/ANL
	HyPro	U.S. DOE/Directed Technologies Incorporated
	MSM	U.S. DOE/NREL
Integrated economic systems	ETP (Global)	IEA
	Markal	ETSAP
Country/region economic systems	HyTrans	U.S. DOE/ORNL
	H2CAS	U.S. DOE/ANL
	NEMS	EIA
	Idealized City Model	UC Davis
	HIT	UC Davis
	Ohio Case Study	UC Davis
	Hydra	?
	H2M SEI-US	US.D.o.E. NREL
	CA Rice Straw Study	UC Davis

Environmental models (local pollutants)	?	?

For a deeper discussion on the subject of a modelling tool box, it was agreed that the next workshop in Paris on July 10-12, IEA/IPHE will expand on the list of available models, and develop a list of the types of models that should ideally be included in such a tool box.

IV. Key Messages and Next Steps

The key messages of the workshop are based on the common issues, opportunities, and themes across the breakout groups with respect to planning and design, engineering and construction, and operations and maintenance of hydrogen energy infrastructure. The major findings include:

Planning and Design:

- Sustainable production of hydrogen is essential
- There is no unique pathway for hydrogen infrastructure development so planning and design needs to take local, state, provincial, and regional demographics, economics, and resource endowments into account. For example, the Lighthouse concept involves focus on clusters of hydrogen fueling stations in urban areas, serving at first corporate and government hydrogen vehicle fleets, then expanding to hydrogen corridors within regions, and ultimately inter-regional infrastructure development to serve thousands and then millions of personal hydrogen vehicles. The Distributed Generation concept involves deploying hydrogen fuel cells for stationary power applications on-site or nearby the electric loads that they serve.
- For planning and design of hydrogen energy infrastructure to begin in earnest there needs to be stable, consistent, and effective government policies in place that provide the private sector with guidelines and incentives that can attract private capital without excessive burdens on taxpayers. These policies can form the basis for long term public-private partnerships for infrastructure development, under which codes, standards, and favorable regulatory mechanisms can be developed and implemented.

Engineering and Construction:

- There are significant challenges that need to be addressed before engineering and construction can occur. Public acceptance will be one of the keys and there is a great deal of ignorance, misconception, and fear to overcome. Not-in-my-backyard is a barrier today for energy facilities and is likely to be a significant issue for hydrogen energy infrastructure as well. In addition, the costs of construction will be significant, if large scale development occurs, and attracting sufficient public and private capital will not be easy, especially given the competing needs in energy and other sectors of the economy. Determination of liability and the availability of insurance to mitigate technical and financial risks will also need to be addressed.

- A portfolio of public policy and market mechanisms will need to be implemented to address these challenges. For example, public education campaigns will need to be developed and implemented to equip consumers with the information they need to participate effectively in siting and permitting of hydrogen infrastructure and facilities. Profitable business models will need to emerge for hydrogen infrastructure projects and there will likely need to be a panoply of financial incentives from government agencies, and ultimately taxpayers, to make infrastructure development financially attractive to investors. Consistent, enduring, and stable public policies, and a comprehensive regime of safety codes and product standards, will help enable streamlined siting and permitting processes to be implemented.

Operations and Maintenance:

- While the challenges involved in operating and maintaining hydrogen energy infrastructure are many years away, it is important to get started now to anticipate problems and devise solutions before they occur. Having skilled personnel, technicians, and repair crews available will be critical. While many aspects of operating and maintaining hydrogen energy infrastructure will resemble what is currently done with existing energy assets, there are unique features such as high pressure storage, low temperature liquefaction, and materials embrittlement for which special training and skilled professionals will be needed. The need to ensure the public of safe operations could mean that hydrogen infrastructure will need to be operated even more safely than the natural gas infrastructure since hydrogen is a new entrant and may be held by the public to a higher standard.
- The potential solutions to these issues involve planning and research and development in several areas. One involves the development of training programs and curricula for universities, community colleges, and technical schools. These will be needed to build a skilled workforce and also to educate code officials, inspectors, and safety engineers. Research and development is needed to focus on improving the safe operations of pumps, compressors, storage devices, and liquefaction equipment, and to develop leak detection, remote monitoring, and repair technologies.

The next steps involve two more workshops, one in Paris, France and the other in Shanghai, China. These workshops need to be designed to build on the results of the Detroit workshop while at the same time developing a consistent set of information about hydrogen infrastructure planning, design, engineering, construction, operation, and maintenance so that regional similarities and differences can be assessed. Specific suggestions from the participants for improving future workshops include:

- Better define and articulate the specific problem statement and ultimate goals for the total effort (e.g., reducing GHG emissions; reducing the transportation sector's dependence on oil; etc.)
- Provide a forum for sharing *local* perspectives on funding hydrogen energy projects as an economic development tool.
- Engage more people from the business community who will make decisions on investing in hydrogen production infrastructure. Get utility companies involved in the workshops (the U.S.-based "Hydrogen Utility Group" is one source of invitees). Invite stakeholders from the financial community, such as venture capitalists, private equity providers, and insurers; and increase efforts to get more energy companies to attend, including nuclear and renewable energy providers, and industrial gas companies.

V. Literature Cited

Abraham, S.: 2004, 'The Bush administration's approach to climate change.' *Science* **305**, 616-617.

Anonymous: 2004, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. National Academies Press, Washington.

Anonymous: 2002, National Hydrogen Energy Roadmap. U.S. Department of Energy, Washington.

Caldeira, K., Jain, A.K. and Hoffert, M.I.: 2003. 'Climate sensitivity uncertainty and the need for energy without CO2 emission,' *Science* **299**, 2052-2054.

California Hydrogen Highway Project, available at: http://www.hydrogenhighway.ca.gov/

Chandler, W., Schaeffer, R. Dadi, Z., Shukla, P.R., Tudela, F., Davidson, O. and Alpan-Atamer, S.: 2002. *Climate Change Mitigation in Developing Countries*. Pew Center for Global Climate Change, Washington.

Cho, A.: 2004, 'Fire and ICE: Revving up for Hydrogen'. *Science* **305**, 964-965.

Clausson, E.: 2004, 'An effective approach to climate change'. *Science* **306**, 816.

Curtis, S.: 2004, 'Fuel cells: Heading for the battlefield?' *Fuel Cell Review* 1, 29-30.

Demirdoven, N. and Deutch, J.: 2004, 'Hybrid cars now, fuel cell cars later'. *Science* **305**, 974-975.

Friedmann, S.J. and Homer-Dixon, T.: 2004, 'Out of the energy box', *Foreign Affairs* **83**, 72-83.

Grant, P.: 2003. ‘The hydrogen economy: Nuclear renaissance?’ *Nature* **424,** 124-130.

Harris, R., Book, D., Anderson, P. and Edwards, P.: 2004, ‘Hydrogen storage, the grand challenge’. *Fuel Cell Review* 1, 17-23.

Hoffert, M.I. et al.: 2002, ‘Advanced technology paths to global climate stability: Energy for a greenhouse planet’. *Science* **298**, 981-987.

IEA. 2004. *Hydrogen and Fuel Cells: Review of National R&D Programs*. IEA, Paris, France.

IEA. 2005. *Prospects for Hydrogen and Fuel Cells*. IEA, Paris, France.

Kates, R.W. et al.: 2001, ‘Sustainability science’, *Science* **292**, 641-642.

Keith, D.W. and Farrell: 2003, ‘Rethinking hydrogen cars’, *Science* **301**, 315-316.

Kolbert, E.: 2003, *The Car of Tomorrow*. The New Yorker, August 36-40.

Kreith, F. and West, R.E.: 2003, Gauging efficiency, well to wheel. Mechanical Engineering Power. June

Lackner, K.: 2003, ‘A guide to CO2 sequestration’. *Science* **300**, 1677-1678.

Pacala, S. and Socolow, R.: 2004, ‘Stabilization wedges; Solving the climate problem for the next 50 years with current technologies’. *Science* **305**, 968-972.

Rifkin, J.: 2003, *The Hydrogen Economy*, Penguin Putnam, New York.

Romm J.J.: 2004, *The Hype About Hydrogen*, Island Press, Washington.

Schultz, M.G., Diehl, T. Brasseur, G.P. and Zittel, W.: 2003. ‘Air pollution and climate forcing impacts of a global hydrogen economy’. *Science* **302**, 624-627.

Science and Development Network, Argentina makes push for hydrogen fuel, available at: http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=897&language=1

Service, R.F.: 2004, 'The Hydrogen backlash', *Science* **305**, 958-961.

Sirens, R. and Verhelst, S.: 2001. 'Experimental study of a hydrogen-fuelled engine'. *Journal of Engineering for Gas Turbines and Power* **123**, 211-216.

Sperling, D. and Cannon, J.S.: 2004. The Hydrogen Energy Transition: Moving Toward the Post Petroleum Age in Transportation. Elsevier Academic Press London.

Sperling, D. and Ogden, J.: 2004, The hope for hydrogen. Issues in Science and Technology. Spring, 82-86.

Tromp, T.K. et al.: 2003, 'Potential environmental impact of a hydrogen economy on the stratosphere'. *Science* **300**, 1740-1742.

Turner, J.: 2004. 'Sustainable hydrogen production'. *Science* **205**, 972-976.

Vogel, G.:2004 'Will the future dawn in the north?' *Science* **305**, 966-967.

The White House, Hydrogen Fuel Initiative can make 'Fundamental Difference,' available at: http://www.whitehouse.gov/news/releases/2003/02/20030206-12.html

Wald, J.:2004. 'Questions about a hydrogen economy'. *Scientific American*. May, 68-73.

Weil, K.S.: 2004, 'O fuel cell, where are thou?' *TechComm* **2**, 21-22.

VI. Appendix A

IEA/ IPHE Workshop Participants, April 2-4, 2007

First Name	Last Name	Organization	Country	Group
Thomas	Alfstad	Brookhaven National Laboratory	USA	Modelling
Sheral	Arbuckle	Ford Motor Company	USA	Mobile 3
Nicole	Barber	Chevron	U.S.A.	Mobile 3
Kamel	Bennaceur	Schlumberger	France	Modelling
Pierre	Beuzit	ALPHEA and INEVA	France	
Graham	Campbell	Natural Resources Canada	Canada	Mobile 2
Pierpaolo	Cazzoli	International Energy Agency	France	Modelling
Chung-Hsien	Chen	Bureau of Energy, Ministry of Economic Affairs, Taiwan	Taiwan	
David	Chock	Ford Research & Advanced Engineering	USA	Modelling
Sangjin	Choi	Korea Institute of Energy Research	Republic of Korea	Modelling
Daniel	Cicero	U. S. Dept of Energy -- National Energy Technology Laboratory	USA	Stationary
Robert	Dempsey	The Lincoln Electric Company	USA	Mobile 4
Annie	Desgagné	Industry Canada	Canada	Mobile 3
Robert	Dixon	International Energy Agency	France	Mobile 4
Rob	Donovan	US Energy Association	USA	
Albert	Doub	US Energy Association	USA	Mobile 2
Carmen	Dybwad	Energy Council of Canada	Canada	Mobile 4

Raymond	Eaton	Department of Trade & Industry	U.K.	Stationary
Stuart	Fee	Industry Canada	Canada	Mobile 3
Greg	Frenette	Ford Motor Company	USA	Mobile 4
Paul	Friley	Brookhaven National Laboratory	USA	Stationary
Bernard	Frois	CEA	France	Mobile 3
Richard	Fry	Natural Resources Canada	Canada	Mobile 3
Jill	Gagnon	US Energy Association	USA	
Matthew	Gebert	US Energy Association	USA	Stationary
Dolf	Gielen	International Energy Agency	France	Modelling
John	Ginder	Research and Advanced Engineering, Ford Motor Company	USA	Mobile 2
Emily	Glenn	International Energy Agency	USA	Mobile 3
David	Greene	Oak Ridge National Laboratory	USA	Modelling
Sigmund	Gronich	US Department of Energy	USA	Mobile 2
Thomas	Gross	IF, LLC	USA	Mobile 4
Donyell	Gutter	NYK Logistics & Megacarrier	USA	
David	Haberman	IF, LLC	USA	Stationary
Robert	Hegger	UTC Power	USA	
Kan-Lin	Hsueh	ITRI, Industrial Technology Research Institute	Taiwan	Stationary
Yosuke	Ishikawa	Honda R&D Americas	USA	Mobile 3
Ming-shan	Jeng	Industrial Technology Research Institute	Taiwan	Modelling
Donald	Jones	RCF Economic and Financial Consulting, Inc.	USA	Mobile 2
Fred	Joseck	Department of Energy Hydrogen Program	USA	Modelling
Ryuta	Kawaguchi	Nissan Motor Co., Ltd	USA	Mobile 4

Terry	Kimmel	Canadian Hydrogen Association	Canada	Mobile 4
Sachio	Kobayashi	Mitsui & Co (U.S.A.), Inc.	USA	Modelling
Akiteru	Maruta	Technova, Inc	Japan	Mobile 3
Rod	McMillan	National Research Council	Canada	Stationary
Shawna	McQueen	Energetics Incorporated	USA	Modelling
Mark	Mehall	Ford Motor Co	USA	Mobile 2
Marc	Melaina	Institute of Transportation Studies, University of California at Davis	USA	Modelling
Robert (Bob)	Menard	Power Workers' Union Training Inc.	Canada	
Michael	Mills	U.S. Department of Energy	USA	Mobile 4
Marianne	Mintz	Argonne National Laboratory	USA	Modelling
Paul	Moore	Ford Motor Company	USA	
Kee-Suk	Nahm	Chonbuk National University	Republic of Korea	Mobile 2
Paul	Osborn	Mediateurs	The Netherlands	Modelling
Joseph	Pierre	Siemens Power Generation	USA	Stationary
Attilio	Pigneri	Massey University Centre for Energy Research	New Zealand	Modelling
Uwe	Remme	Energy Technology Policy Division, International Energy Agency	France	Modelling
Jerry	Rogers	General Motors Corp.	USA	Modelling
Andrew	Rosenblatt	Delphi Corporation	USA	Mobile 2
Mark	Ruth	NREL- Systems Integration	USA	Modelling
Chris	Sacré	Sacré-Davey Engineering	Canada	Mobile 4
Ichiro	Sakai	American Honda Motor	USA	Mobile 4

John	Sakioka	Ford Motor Company	USA	Mobile 3
Danilo	Santini	Argonne National Laboratory	USA	Mobile 3
Krishna	Sapru	Energy Conversion Devices, Inc.	USA	
Vesna	Scepanovic	Natural Resources Canada	Canada	Mobile 2
Richard	Scheer	Energetics Incorporated	USA	Mobile 2
Klaus	Scheuerer	BMW AG	Germany	Mobile 4
Mark	Schiller	Proton Energy Systems	USA	Mobile 4
Steven	Schlasner	ConocoPhillips	USA	Mobile 4
Norman	Shilling	GE Energy	USA	Stationary
Thorsteinn	Sigfusson	IPHE Implementation and Liason Committee	Iceland	Mobile 3
Christine	Sloane	General Motors Corp.	USA	Mobile 4
Roger	Smith	Fluor Corporation	USA	Mobile 4
Christoph	Stiller	Ludwig-Bolkow-Systemtechnik GmbH	Germany	Modelling
Kenneth	Stroh	Los Alamos National Laboratory	USA	Mobile 4
Jeroen	Struben	Massachusetts Institute of Technology	USA	Modelling
Wayne	Surdoval	National Energy Technology Laboratory (NETL), DOE	USA	Stationary
Andrés	Svanbjörnsson	Ministry of Industry and Commerce	Iceland	Mobile 4
George	Sverdrup	National Renewable Energy Lab	USA	Mobile 3
James	Van Gilder	Ford Motor Company	USA	Modelling
Florin	Vladu	UNFCCC	Germany	Stationary
Robert	Walker	Wexler & Walker Public Policy Associates	USA	
Justin	Ward	Toyota Motor Engineering and Manufacturing North America	USA	Mobile 2

Robert	Wright	U.S. Department of Energy	USA	Mobile 2
Ye	Wu	Argonne National Laboratory	USA	Modelling
Rosa	Young	Ovonic Hydrogen Systems, LLC	USA	Stationary
Stephen	Zimmer	DaimlerChrysler	USA	Mobile 3

VII. Appendix B

IEA/IPHE Workshop Agenda, April 2-4, 2007

<u>Monday, April 2, 2007</u>

16:00-19:30 Registration

16:00- 17:00 Breakout Group Planning Meeting Breakout Group Discussion Leaders and Rapporteurs only

18:00-19:30 Hospitality Suite

<u>Tuesday, April 3, 2007</u>

7:30 Registration

7:45 Continental Breakfast

8:30 Welcome: Mr. Graham Campbell, Chairman, CERT, IEA; Vice Chair, IPHE Steering Committee; Director General, Office of Energy Research and Development, Natural Resources Canada

8:45 Overview of Workshop Goals: Dr. Robert K. Dixon, Head, Energy Technology Policy Division, International Energy Agency (IEA)

8:55 Keynote Address: The Honorable Robert Walker, Former Congressman from Pennsylvania; Chairman, Wexler & Walker Public Policy Associates

9:25 Building H2 Infrastructure for US Highway System: Dr. Sigmund Gronich, Hydrogen Team Leader, United States, Department of Energy

10:05 Perspectives on a Hydrogen Economy in Taiwan: Dr. Ming-shan Jeng, Senior Researcher, Energy & Environment Laboratories, Industrial Technology Research Institute (ITRI), Taiwan

10:25 Coffee Break

11:00 HyWays - the European hydrogen energy roadmap: Current status: Dr. Christoph Stiller, HyWays; Ludwig-Bölkow-Systemtechnik, Germany

11:20 Building the Hydrogen Economy in Iceland: Dr. Thorsteinn Sigfusson, Professor and Entrepreneur, Iceland New Energy

11:40 Building the Hydrogen Economy in an Energy Poor Country: Mr. David Haberman, President, IF, LLC.

12:00 Building the Hydrogen Economy in Canada: Ms. Annie Desgagné, Senior Advisor, Hydrogen & Fuel Cells, Resource Processing Industries Branch, Industry Canada

12:20 Perspectives on Nuclear Energy and the Hydrogen Economy: Dr. Bernard Frois, Director New Technologies, National Research Center, France

12:40 GM Perspectives on the Hydrogen Economy: Dr. Christine Sloane, Global Lead**,** Hydrogen and Fuel Cell Vehicle Safety, Codes & Standards, General Motors Corp.

`

13:00 Lunch

13:45 Breakout Group Instructions and Overview of the Facilitation Game Plan Mr. Richard Scheer, Vice President, Energetics Incorporated

14:00–17:45 Facilitated Breakout Sessions Organized by Energetics

All attendees proceed to respective breakout session rooms. Participant assignments to specific breakout sessions will be available at registration, as well as posted by the specific breakout meeting rooms Breakout sessions 1-4 will involve group discussions to consider infrastructure development and transition issues for mobile and stationary hydrogen energy applications. The discussions will identify technical, institutional, and financial opportunities, as well as the challenges for hydrogen production facilities, delivery systems, fuel cell systems, and fueling stations. Participants will also discuss the3 potential public policy and market strategy opportunities for addressing these opportunities and challenges.

Breakout Session 1: Mobile Applications
Discussion Leader: Dr. Robert K. Dixon, Head, Energy
Technology Policy Division, International Energy Agency (IEA)
Rapporteur: Mr. Michael Mills, Energy Efficiency and Renewable
Energy Office, U.S. Department of Energy
Vignette Speaker: Mr. Thomas Gross, Senior Associate, IF, LLC

Breakout Session 2: Mobile Applications
Discussion Leader: Ms. Annie Desgagné, Senior Advisor, Hydrogen &
Fuel Cells, Resource Processing Industries Branch, Industry Canada
Rapporteur: Ms. Emily Glenn, Energy Technology Policy Division,
International Energy Agency (IEA)
Vignette Speaker: Mr. Richard Fry, Manager, Canadian Transportation
Fuel Cell Alliance, Natural Resources Canada

Breakout Session 3: Mobile Applications
Discussion Leader: Mr. Richard Scheer, Vice President, Energetics
Incorporated
Rapporteur: Mr. Albert Doub, Senior Program Coordinator, U.S.
Energy Association
Vignette Speaker: Dr. Robert Wright, Senior Program Manager,
Hydrogen, Sequestration and Clean Coal Fuels, US Department of Energy

Breakout Session 4: Stationary Applications

Discussion Leader: Mr. Wayne Surdoval, Technology Manager, Fuel Cells National Energy Technology Laboratory, US Department of Energy

Rapporteur: Mr. Matthew Gebert, Program Coordinator, U.S. Energy Association

Vignette Speaker: Dr. Norman Shilling, Product Line Leader, IGCC Power Block, GE Energy

Breakout Session 5: Modelling

Breakout session 5 will focus on modelling, analysis, and scenario development issues. The discussion will begin with a series of 15-20minute presentations to offer various perspectives about modelling hydrogen infrastructure implementation and transition issues. The following discussion will consider the complementarity and integration of various modelling approaches and results, the use of models for policymaking, data validation, international modelling cooperation, use of models for industry and infrastructure planning purposes.

Co- Discussion Leaders: Dr. Dolf Gielen, Senior Analyst, Energy Technology Policy Division, International Energy Agency (IEA)

Dr. David Greene, Corporate Fellow, Oak Ridge National Laboratory

Rapporteur: Ms. Shawna McQueen, Energetics Incorporated

Speakers:

Issues in Integrated Market Modelling of the Hydrogen Transition

Dr. David Greene, Corporate Fellow, Oak Ridge National Laboratory

Building the Hydrogen Economy: Modelling Issues

Dr. Dolf Gielen, Senior Analyst, Energy Technology Policy Division, International Energy Agency (IEA)

Dr. Uwe Remme, Visiting Analyst, Energy Technology Policy Division, International Energy Agency (IEA)

Regional Hydrogen Energy Transition Modelling
Dr. Marc Melaina, Project Scientist, Institute of
Transportation Studies, University of California at Davis

Modelling Infrastructure Expansion and H2A Delivery Pathways
Ms. Marianne Mintz, Energy Systems Analyst, Argonne
National Laboratory

HyWAYS-IPHE: Comparing Hydro gen Analyses
Mr. William Borthwick, European Commission
Mr. Fred Joseck, Chief Technology Analyst, Hydrogen
Program, US Department of Energy
Mr. Mark Ruth, Macro-Systems Model Engineer, Systems
Integration, National Renewable Energy Laboratory
Mr. Christoph Stiller, Ludwig-Bolkow-Systemtechnik

Life-Cycle Analysis of Vehicle/Fuel Systems with the GREET Model
Dr. Ye Wu, Assistant Analyst, Center for Transportation
Research, Energy Systems Division, Argonne National Laboratory

15:30-15:45 Coffee Break

18:00 Reception

<u>Wednesday, April 4, 2007</u>

8:00 Continental Breakfast

8:30 - 10:00 Breakout Discussions Continued

The facilitated breakout group discussions will continue until 10:00 to review and finalize the previous day's discussions. Each group will, prepare an oral report outlining the key findings and results. The breakout groups will reconvene in plenary at 10:45 to present oral reports from each breakout group, and participate in a facilitated discussion of crosscutting themes, gaps, and remaining issues. Goal: Summarize Tuesday discussions and identify major themes or other issues for analysis.

10:00	Coffee Break
10:15	Prepare Oral Reports from Breakout Sessions
10:45	Plenary Session: Reports from the Breakout Groups and Discussion of Gaps and Cross-Cutting Themes Chair: Mr. Richard Scheer, Vice President, Energetics Incorporate Panelists: Breakout Group Discussion Leaders
12:15	Closing Remarks Dr. Robert K. Dixon, Head, Energy Technology Policy Division,International Energy Agency (IEA)
12:30	Adjourn

VIII. Appendix C

Keynote Address

HYDROGEN – THE UNIVERSAL TRUTH

Congressman Robert Walker

In his most recent book, Death by Black Hole, America's best-known astrophysicist, Neil DeGrasse Tyson, makes quite a point about the prevalence of hydrogen in the universe. His book is largely about immutable physical laws of science that dominate our understanding of the universe – universal truths if you will.

One of the items that struck me in Tyson's book was this statement, "Under the right conditions of temperature, density, and pressure, you can use hydrogen and helium to synthesize every other element on the periodic table." So I asked Neil, who happens to be a friend, does the reverse hold true? Can every other element on the periodic table be desynthesized into hydrogen and helium under the right conditions? His answer was yes, but in the case of some elements like iron, it would be very costly. This, of course, is absolutely true.

But it occurs to me as we begin an international meeting on our common energy future and, in particular, how hydrogen can contribute to that future, that relying on a universal truth might be useful. The fundamental scientific fact that hydrogen is the most prevalent element in the universe helped lead me to hydrogen policy in the first place. And I think it has particular relevance to any discussion of where the world should look for its energy solutions.

So welcome workshop participants. You come from over 20 countries representing five continents. As for me, I've been working in this arena for a long time. While serving in the U.S. Congress, I chaired the House Science Committee where we drafted and passed the original enabling legislation for hydrogen research and development activities.

In 2000 and 2001, I worked with Bob Dixon, Rich Scheer and others to develop the first US Hydrogen Economy Vision statement, a statement that was developed through public-private partnerships in a workshop such as this one.

In 2001 and 2002, this same team worked together to develop the first US Hydrogen Technology Roadmap, a seminal document in advancing public and private sector R&D activities across the United States and around the world.

President Bush and his team of advisors, working with Secretary Spence Abraham, used the roadmap to lay out his vision for a hydrogen economy in the 2003 State of the Union Address. He said, "…a child born today will have the opportunity to drive a vehicle powered by hydrogen and pollution free."

By 2004, Secretary Abraham and 15 fellow Energy Ministers formed the International Partnership for the Hydrogen Economy. The Ministers directed their deputies to lead and implement a focused R&D program across 15 countries and the European Union, an effort that has now grown to 18 countries.

Now we are prepared to embark on a new mission, to develop a vision and strategy for building the hydrogen economy.
So let's begin with a look at reality. The 21st Century will see significant increases in demand for energy. The current developed world will require more, probably much more. The developing world will create major new demands for energy supply. And the under-developed world will want to grow their economies with energy being the principal ingredient of that anticipated growth.

Reliance upon energy resources of limited availability or accessibility, of consequential environmental or economic sustainability, or geo-political instability makes little sense as a long-term proposition. Hydrogen, on the other hand, makes sense. It is available in every nation in some form. It is accessible through a variety of technological processes. It is sustainable environmentally leaving a minimal carbon imprint even when obtained from non-renewable resources. It is economically sustainable because the infrastructure needed to support a hydrogen economy can be so broad-based. And its geo-political profile is positive in the extreme because it takes much of the energy equation out of international relations and negotiations.

But to reap the benefits, we must first get there. And the world acting together can contribute significantly to a staged development of the hydrogen economy.

While there is plenty of hydrogen production capability worldwide to provide sufficient supplies for the early transition, most of that capability involves reforming natural gas. There are many nations that could help us move toward renewable supplies and non-carbon intensive production. Countries with wind and solar energy assets could lead the way toward production of hydrogen from those sources. Countries that have large concentrations of nuclear power could use off-peak periods to crack water into hydrogen or even experiment with the more high-tech applications of using nuclear waste heat for production. Countries with massive coal deposits could be in the forefront of converting clean coal to hydrogen. Countries with a history of using biological materials for fuel production could take the next step of creating bio-hydrogen. And throughout the world where land fills produce streams of methane, we could begin the process of converting waste to hydrogen power. One of my favorite ways of getting people to recognize the potential of hydrogen is to tell them that in the hydrogen economy, every waste dump can be a fuel dump. To visualize this kind of worldwide response, think in terms of Iceland. Iceland has stood up to hydrogen leadership by showing how to convert its geothermal resource into hydrogen power. That’s the kind of model I’m talking about.

And there are other opportunities. In the developing world to be followed by the underdeveloped world, new infrastructure must be created to accommodate growth. Insofar as that new infrastructure includes hydrogen capability, or at least, leaves a placeholder for hydrogen, those nations can begin to leap frog the developed world in the same way that economies like China skipped over several generations of telecommunications technology. The developed world has the problem of legacy infrastructure which investors are not willing to leave as stranded assets. Countries just bringing assets on line have the ability to think anew and invest differently.

Unlimited supply and diverse access opens many opportunities for reaping reward from hydrogen. But first there must be some consensus that hydrogen should define the global energy future. After all, competing concepts abound – ethanol, bio-diesel, nuclear, clean coal, natural gas and even vast amounts of known petroleum reserves. So why would the world choose hydrogen?

Let's go back to the universal truth. What we know that many of the world's policy-makers have yet to acknowledge is that all the other potential energy resources can play in the hydrogen economy. Once you commit to the hydrogen matrix – fuel cell vehicles and appliances, distributed power generation and zero-emission capability –all the other sources of energy become contributors. Solar, wind and nuclear can be used to make hydrogen in vast quantities with minimal environmental impact. Ethanol, bio-diesel, clean coal, methane, natural gas and petroleum can all be sources of hydrogen supply, and by adding water to the equation, the energy supply issues facing the world disappear.

It is the unification of resources feeding a common infrastructure that ultimately makes hydrogen so attractive as a global energy solution. But if that's true, then comes the hard work of cooperation toward a common goal.

The International Partnership for the Hydrogen Economy is all about creating that cooperative framework. Hopefully, since the rewards of success are so apparent, we can avoid some of the problems that have plagued other international efforts dealing with energy and environment.

Too often such efforts have come down to heavy doses of political gamesmanship. Energy issues are debated around who has the supplies, who needs the supplies, who benefits from pricing policies, who cannot afford the prices charged and many, many other such matters. Environmental debates get bogged down on who wins and who loses. One of the problems with the Kyoto accord was that the politics of haves vs. have nots became more instrumental in the final product than finding a workable way to reduce carbon emissions.

Perhaps we'll find in the course of this meeting and others that follow an ability to cut through the gamesmanship. The fact we are dealing with a resource where the supply equation changes, where pricing does not have to be dependent on cartels, and where the environmental consequences are relatively benign gives us an opportunity to seek solutions that provide everyone with economic potential. And we can be somewhat comforted in our deliberations that the basis for our conclusions begins not with a computer model, but with a universal truth.

That still leaves plenty to discuss and even debate. Sharing an understanding of the state of hydrogen technology development (non-proprietary, of course) can make us smarter about the right set of policies needed. While there are technical hurdles to be cleared, I worry most about the development of proper market incentives, safety assurances and proper codes and standards. Technology breakthroughs will be static if we do not address the wider issues that demand public policy engagement.

Here are two public policy concepts that I believe would have worldwide impact.
First, we should encourage the development of racing competition with hydrogen-powered vehicles. The origins of racing involved technology validation, increasing safety, and improving the breed. All of these are things that hydrogen development needs and wants. And the additional benefits of demonstrating safety and endurance to consumers all across the globe increases the appeal of this concept even more. Government would have to do little to advance this idea, but would have to be sympathetic in the same way it has been toward solar-powered racers. And governments could even push things further along by providing some sponsorship opportunities.

The second concept involves substantially more government intervention. We should consider for a limited period of time, providing the early adopters of hydrogen vehicle technology with free hydrogen, paid for by governments. My proposal would be for government subsidies of 250 kilograms of hydrogen per year per consumer for 3 years. Everyone purchasing or leasing a hydrogen vehicle would be eligible. By providing free fuel to the consumer, we would do what the hydrogen economy needs most, create consumer demand.

The initial reaction to such a proposal is usually that such a plan is unaffordable. To the contrary, it would appear that in the United States a full five-year program using conservative assumptions would cost about one quarter on this one year's subsidy of ethanol alone. In fact, the money presently spent by the U.S. Government on hydrogen each year would more than cover the first three years of the subsidy. And the result would be a positive opportunity for getting the first 250,000 hydrogen cars on the road in the United States.

My fundamental point is that the hydrogen community needs to begin thinking about what we support in public policy beyond research and development. There is a worldwide cry for a broad-based energy solution that provides both adequate supplies and environmental advantages. We cannot sit on the sidelines doing our R&D when we know that hydrogen is the universal answer with the potential to shape the future. The final words of the final song in the great Broadway musical Les Miserable say, “The future’s what we bring when tomorrow comes.” That’s my challenge to you – when tomorrow comes make hydrogen the universal truth and the universal choice.