Building the Hydrogen Economy:
Enabling Infrastructure Development

Part II: Sharing the European Vision

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I. Acknowledgements

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II. Foreword

The IEA Secretariat hosted the second International Energy Agency (IEA) / International Partnership for the Hydrogen Economy (IPHE) workshop "Building the Hydrogen Economy: Enabling Infrastructure Development/ Part II: Sharing the European Vision" in Paris, 11-12 July, 2007. This was the second of a series of three workshops. The first took place in Detroit in April, 2007, and the third will follow in Shanghai in October, 2007. We welcome the cooperation with the IPHE which enables us to organize these workshops. As an important international forum for advancing the hydrogen economy, the IPHE has been a very reliable and inspiring partner in this endeavor.

The broad objectives of the workshop were to:

1) 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

2) Inform policymakers on opportunities to accelerate these transition plans through policy instruments.

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. 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.

We have seen great R&D strides with hydrogen and fuel cells technologies. Hydrogen production costs have dropped, we have new opportunities to store and transport hydrogen and fuel cell costs continue to decline. Although cost-effectiveness is still a distant objective, we need to plan for R&D success, including the consideration of various scenarios of hydrogen infrastructure development.

I am pleased that participants in this workshop built upon prior analysis, such as the Detroit workshop key messages and conclusions, and appreciated the support of the IEA Ministerial and the G8 Summit in Heiligendamm, Germany, to the objectives of this project. I hope that work will continue to progress, and visions of the hydrogen economy will be realized.

Claude Mandil
Executive Director

III. 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.

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 (see 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 that 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 United States. Analytical activities in Japan have led to development of technology roadmaps and strategic plans to advance 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 United States. Complementary activities have been developed by European Commission and individual member states. 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.

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. The second workshop in Paris, July 10-12, 2007, will particularly focus on Sharing the European Vision of hydrogen. 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 Paris 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 analyse 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.

IV. Hydrogen and The European Vision

The European Union (EU) has a deep and broad commitment to developing the hydrogen economy. Individual member states and the European Commission have been active contributors to global and regional hydrogen and fuel cell research and development activities. Strategic policy drivers for European hydrogen and fuel cell technology investments include security of energy supply, mitigation of greenhouse gas emissions and local pollutants, and economic competitiveness. The European Hydrogen and Fuel Cell Technology Platform was established several years ago and a Strategic Research Agenda, Deployment Strategy and Implementation Plan Status Report were published in 2005, 2005 and 2006, respectively. Hydrogen and fuel cell research, development, deployment and demonstration projects funded by the European Commission (EC) totaled almost 300 million Euros between 2002 and 2006. Key EC projects that contribute to development of a hydrogen economy infrastructure include: HyWays---a harmonized European roadmap for hydrogen energy development, HyLights---lighthouse transport projects that include HyFLEET:CUTE, ZERO REGIO and HyChain, and Roads2HyCom project that brings together mapping of infrastructure and community development. In the 7th EU Framework Programme a Joint Technology Initiative (JTI) is proposed. The JTI is a research, development and deployment programme that addresses: hydrogen vehicles and refueling infrastructure, sustainable hydrogen production and supply, fuel cells for combined heat and power systems, and fuel cells for early markets. Public-private partnerships will be a key ingredient of JTI. Both the EC and member states have been active in IEA and IPHE research and development cooperation projects.

European investments in the hydrogen economy complement those made by African and Middle Eastern neighbors. Rapidly expanding hydrogen development programs in South Africa, Egypt, Morocco, Libya and Turkey light the pathway forward for development of clean energy technologies in developing countries. The UN Industrial Development Organization (UNIDO) recently established the International Centre for Hydrogen Energy Technologies (ICHET) in Turkey. The mission of ICHET is to provide technical and financial assistance to developing countries as they advance their portfolios of hydrogen and fuel cell technologies.

V. Summary of Workshop Presentations

The Workshop agenda can be found in Appendix B.
Plenary presentation slides are available online:
http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=311

Welcome Address
Mr. Claude Mandil, Executive Director, IEA

Mr. Claude Mandil, Executive Director of the IEA, opened the workshop plenary session by welcoming participants to the IEA Headquarters in Paris for the second workshop in the IEA/ IPHE project: “Building the Hydrogen Economy: An Infrastructure Strategy.” Mandil summarized the objectives of the workshop series, and re-emphasized his support of the successful IEA/IPHE partnership. He thanked all participants for contributing their expertise to achieving the goals of the workshop, and for helping to build sustainable energy systems for the future, in which hydrogen will play a part. Mandil noted the current achievements in hydrogen and fuel cell R&D, and encouraged participants to plan for the success of these technologies. Mandil recognized the IEA Ministerial and the G8 Summit support of the project objectives and deliverables. Mandil invited participants to engage with one another, and to formulate conclusions and questions in these dialogues.

Workshop Goals: The Road from Detroit to Shanghai

Dr. Robert K. Dixon, Head, Energy Technology Policy Division, IEA

Dr. Robert Dixon, Head of the Energy Technology Policy Division at the IEA, followed Mandil with an overview of the Workshop Goals. Dixon presented several key points that will drive a transition to a hydrogen economy. He summarized the current energy demands and the high costs of sustaining current fossil fuel energy. Hydrogen is a possible key to creating a secure and clean energy future by fulfilling three important criteria. Hydrogen is: 1) secure, 2) environmentally green, and 3) economically competitive. There has been considerable progress made in hydrogen technologies and policies in the past decade, such as large scale RD&D programs and the adoption of hydrogen roadmaps in several countries and regions. Dixon proposed that if strong CO_2 policies are adopted worldwide and hydrogen technology continue to develop, hydrogen powered vehicles could gain up to 30% of the market share by 2050.

However, there are several challenges that must be overcome in the near and long-term planning process. Dixon encouraged all participants to focus on infrastructure and investment strategies over the course of the workshop, and to contribute to the advancement of a hydrogen economy. He emphasized that workshop outcomes would include a detailed workshop information proceedings which will be circulated to a wide international audience, particularly G8 leaders and policymakers.

Session I: Sharing the European Vision

The Hydrogen Strategy of the EU Technology Platform

Dr. Bernard Frois, ANR – National Research Agency, France

Mr. Bernard Frois, Chairman of the HFP Mirror Group, offered a strong introduction to the workshop theme of the European Perspective in his presentation “The Strategy of the European Hydrogen and Fuel Cell Technology Platform.” There is a vision for the Hydrogen Economy in Europe, with over 80 projects underway in the FP6 program. Frois highlighted the HYCHAIN project, a partnership of 26 actors coordinated by AirLiquide to deploy hydrogen small vehicle fleets in Europe in the period 2006-2010. The driving forces for hydrogen in the EU directly relate to addressing three EU Energy Policy Goals:

Security of Supply, Climate Change, and EU Competitiveness. Frois outlined the existing EU policy framework, called the European Strategic Energy Technology Platform (HFP). There is an Energy Package under this HFP umbrella which addresses sustainability, internal market, and external relations issues.

The HFP Strategy for realizing the hydrogen vision operates under market penetration phases, market enabling factors, and a critical joint public-private partnership. The Joint Technology Initiative working group and the Implementation Panel comprise the Advisory Council to the HFP to ensure successful deployment. Frois provided a summary of the Implementation Panel members, publications, and plan. The European roadmap categorizes priorities into four main innovation and development actions leading up to 2015: 1) Vehicles and refueling stations; 2) Sustainable H2 supply; 3) Fuel cells for CHP and power generation; and 4) Fuel cells for early markets. Frois summarized the key goals of this roadmap, and gave a snapshot of market penetration success in 2020 within each category. The Industry Groupingcomprises 45 companies and a board of six elected members, and will lead together with the European Commission the EC-funded Joint Technology Initiative on fuel cells and hydrogen (JTI). The JTI aims to achieve several goals, such as building industry and public confidence through shared commitment and investment, and encouraging public-private partnerships to move forward. International players, such as U.S. Department of Energy, China, Japan and the IPHE, support and work with the JTI. Frois concluded by emphasizing the importance of the JTI as one of the most important steps in the right direction to realizing a hydrogen vision.

HyWays - The European Hydrogen Energy Roadmap - Final Results

Mr. Reinhold Wurster, Senior Project Manager - Hydrogen,
Ludwig-Bolkow Systemtechnik (HyWays coordination office)

Mr. Reinhold Wurster, the Senior Project Manager with the Ludwig-Bolkow Systemtechnik HyWays team, summarized conclusions and recommendations from his work with the project. HyWays is a European public-private partnership formed by several international companies and organizations, and 10 member state partners. HyWays has created a European-specific roadmap for building the hydrogen market through state-supported RD&D and public-private partnerships. HyWays promotes the economic and employment benefits of hydrogen technologies and infrastructure development to drive progress in member states. The partnerships work to scale-up the current series' of hydrogen vehicles, and to push the commercialization of hydrogen technologies for the consumer. Wurster explained the highly cost effective benefits of hydrogen in reducing CO_2 emissions by 2050 and he underlined the market and employment opportunities and the fossil fuel energy independence hydrogen will provide. The HyWays project promotes hydrogen as a strong pathway to a sustainable energy future, but the success of this opportunity requires immediate action to overcome the initial investment and construction barriers. Wurster underscored the success of Joint Technology Initiatives as a sustainable framework for public-private cooperation. The HyWays model provides an advanced and positive vision for realizing a hydrogen economy through immediate investments and technologies.

EU-funded Initiatives for Hydrogen Infrastructure Development:
Current Status and Future Prospects

Ms. Beatrice Coda, Scientific Officer, European Commission

Ms. Beatrice Coda, Scientific Officer of the Research Directorate General at the European Commission, re-emphasized the theme of the workshop in her presentation "EU Funded initiatives for H2 infrastructure development: status and prospects." Her summary of the European Hydrogen and Fuel Cell Technology Platform provided a relevant overview to participants unfamiliar with the European perspective, and followed-up on Frois' introduction to the platform. The platform aims to implement the development and deployment of a range of hydrogen technologies in two phases before 2015. Coda also discussed the hydrogen programs such as WETO modeling, HyWays, HyLights, Roads2HyCom, and HY-CO underway in Europe. The 7th EU Framework Program (FP7) has developed a Joint Technology Initiative in which public and private interests are aligned to manage an EU-funded research program. The JTI for Hydrogen Fuel Cells aims to put Europe at the forefront of fuel cell and hydrogen technologies. This initiative will involve strong industry commitment and invite additional national and regional support to achieve four "Innovation and Development Actions." At this point, Coda explained that and the legislative proposal is in the final stages. Coda stated that the European Commission is willing to work together with the IEA/ IPHE and other international parties to ensure a consistency of approach, and to share regional insights in the future of the hydrogen economy.

Renewable & Hydrogen Activities

Mr. Gijs van Breda Vriesman, GM Hydrogen Europe, Shell

"Maximizing Hydrogen's Value in a Carbon Constrained World," presented by Mr. Gijs van Breda Vriesman, offered an industry perspective on a transition to a hydrogen economy. Vriesman, General Manager of Shell Hydrogen Europe, explained the IPCC and the Stern Review predictions about climate change must be immediately addressed by governments and industries. Shell is "learning by doing," for example, implementing hydrogen projects in seven cities and supporting academia, government and the market by stimulating RD&D. Vriesman explained the high costs and unsure outcomes are averting the OEM investment necessary to move forward with vehicle deployment and infrastructure build out. Shell is researching LNG re-gasification and low CO_2 footprint technologies to manufacturing hydrogen, as well as clean coal gasification, CCS and syngas technologies for power. Vriesman concluded by inviting the workshop participants to create partnerships across multiple sectors, focusing on CO_2 reductions as the main driver for this coordination and planning.

Urban Hydrogen Projects; Finding your Way in European Town Halls

Ms. Marieke Reijalt, Executive Director, European Hydrogen Association, Belgium

Ms. Marieke Reijalt, Executive Director of the European Hydrogen Association (EHA), outlined the framework and projects of the EHA by describing the official and un-official accounts of local hydrogen developments in Europe. The EHA, a structure of 13 national associations and several major hydrogen production and distribution corporations, aims to "foster the development of hydrogen technologies and their use in industrial, commercial and consumer applications by collecting local insights and supporting community projects." Reijalt presented the four categories of community selection by the EHA for its hydrogen projects, and the six critical local success factors identified. Reijalt also described three examples of current activities in Germany, Italy, and Poland to show "un-official" accounts of how hydrogen applications can be implemented in local communities. In Hamburg, Germany, hydrogen applications have been integrated into city planning, and the hydrogen bus initiative underway there has inspired a similar project in Milan. Despite a lack of integration in urban strategy similar to Hamburg, Milan is beginning work to develop public-private partnerships that will drive a hydrogen infrastructure transition. In Jelenia Gora, Poland, the community is fully accepting of a HyApproval project, and several local actors are determined for the project to succeed. Reijalt was positive about several levels of political and institutional support hydrogen receives there. The conditions are ideal for the project to proceed. Reijalt closed by explaining that there is not a predefined pattern for urban hydrogen projects, but that coordination among the many actors and levels involved is an urgent task. Finally, she called for an EU Urban Hydrogen Development Watchdog to spread information and awareness of hydrogen technologies and activities to encourage more players and partnerships to get on-board.

Session II: Building Blocks for the Hydrogen Economy

IEA Hydrogen Implementing Agreement (HIA)
Building the Hydrogen Economy through RD&D Cooperation
Mr. Ray Eaton, UK Department for Business, Enterprise & Regulatory Reform

Mr. Ray Eaton presented the IEA Hydrogen Implementing Agreement (HIA) in his work with the program as a member of the UK Department for Business, Enterprise and Regulatory Reform. The HIA is a collaborative research and development program created in 1977 "to accelerate hydrogen implementation and widespread utilization by facilitating, coordinating, and maintaining innovative research, development and demonstration activities through international cooperation and information exchange." The HIA goals are based on advancing science and technology, assessing the market environment, and increasing knowledge and comfort with hydrogen through outreach programs. The current portfolio of work includes over 25 annexes. Eaton described several activities currently supported by the HIA, ranging from hydrogen safety tests to alternative hydrogen production technologies. He concluded by summarizing current proposals to find near-term market routes of hydrogen through co-utilization, and the mass-storage infrastructure required for distribution. The IEA provides a critical factor in the RD&D cooperation that the HIA work requires.

Analysis of the U.S. Market Transition to a Hydrogen Economy
Mr. Fred Joseck, U.S. Department of Energy

Mr. Fred Joseck, a Chief Technology Analyst with the US Department of Energy, summarized the extensive analysis that has been conducted in the US market to encourage a hydrogen infrastructure transition. The case study offered a concrete picture of the measures needed to support and sustain long-term hydrogen infrastructure growth and vehicle deployment. The analysis operates with three timeline scenarios, planning for a vehicle rollout strategy concentrated in California and the Northeast. Hydrogen production and refueling station construction opportunities in these areas were shown to be the most ideal during the early market stage. The costs of infrastructure build out have also been extensively considered in the study, particularly fuel cell vehicle prices modeled on the cost estimates and production volumes by various automotive manufacturers. Joseck concluded by evaluating the policy options available to facilitate the transition. Fuel cell technology success must be parallel with transition policies that enhance the competitive advantages of hydrogen, particularly hydrogen produced from renewables.

The Road to a Full-Scale Hydrogen Economy

Mr. Dan Cicero, Hydrogen Technology Manager, U.S. Department of Energy/NETL

Mr. Dan Cicero, Technology Manager with the US National Energy Technology Laboratory (NETL), introduced hydrogen in the context of the technology status and transition scenarios in the US following Joseck's detailed model analysis. "The Road to a Full Scale Hydrogen Economy" summarized the sources of current energy demands in both the US and Europe, and the predicted increases in these figures over the next two decades. He explained that NETL is working to ensure that alternative energy technologies are available to offset the overwhelming dependence on fossil fuels, emphasized by the models. He explained that a hydrogen transition will occur through multiple pathways, and the majority of hydrogen fuel supply through 2050 will come from fossil fuels in natural gas reforming and coal gasification processes. The FutureGen project, a USD 1.2 billion US Department of Energy public-private partnership, will produce hydrogen from coal and have near-zero emissions. NETL has an active hydrogen energy program and is working to help the transition to a hydrogen economy in both the US and worldwide by supporting IEA and IPHE coordination.

Building the Hydrogen Economy

Dr. Tapan K. Bose, President & CEO, Hydrogen Engine Centre, Canada

Dr. Tapan Bose, President of the Hydrogen Research Institute in Canada, opened his presentation by offering a brief overview of the dominance of fossil fuel in technology and transportation networks despite the current environmental, distribution, and sustainability problems with this system. If our current emissions remain unchecked, the cost of climate change predictions could be as much as 20% of GDP annually. In “Building the Hydrogen Economy: The Canadian Perspective,” Bose outlined the pathways and scenarios of a transition to a clean hydrogen economy. Canada is the largest per capita producer and user of hydrogen in the OECD. He explained that a feasible transition strategy is to use HCNG, a mixture of NG and hydrogen. This alternative would utilize existing internal combustion engine technologies and infrastructure, and more importantly operates with ultra-low exhaust emissions. Bose also presented the opportunities of stationary hydrogen internal combustion engines (HICE) and fuel cells as backup power for industrial and residential use. He explained that renewable hydrogen must be pursued as a long term strategy to combat current energy challenges. However, policy and technologies must be implemented in the near term to drive initial success, and sustain a long-term vision.

Transition Scenario for Hydrogen Infrastructure for Fuel Cell Vehicles in Japan

Mr. Yuichiro Shimura, Mitsubishi Research Institute, Japan

Mr. Yuichiro Shimura with the Mitsubishi Research Institute offered a Japanese perspective in “Transition scenario for hydrogen infrastructure for fuel cell vehicles in Japan.” Shimura explained that Mitsubishi Research Institute work has been supported by the Japanese government’s initiative to reduce CO_2 emissions from the transportation sector by 50% by 2050. His organization’s work focuses on estimating the social costs related to hydrogen infrastructure deployment, to hydrogen fuel cell vehicle diffusion, and to the implementation of codes and standards. The research explores three potential cases for vehicle deployment with variable scales and volumes in a 12 year period to release 10 000 vehicles. The status of the vehicle market in central Tokyo indicates that passenger car and light duty trucks are the main target for initial fuel cell vehicles, with planned expansion of vehicle rollout in other urban areas after 3-5 years. Shimura summarized the detailed case study of Tokyo as an ideal area to deploy initial hydrogen vehicles in the spatial and cost estimations. Hydrogen refueling station issues, such as storage, transportation, and space constraints, must be addressed before further development can proceed. The Mitsubishi Research Institute will continue work to compare costs of hydrogen distribution by factors such as production location and capability, market environments, and delivery locations.

Hydrogen and Fuel Cell Infrastructure Development in Shanghai

Mr. Jianxin Ma, Tonghi University, China

Dr. Jianxin Ma from the BP Clean Energy Automotive Engineering Center at Tongji University presented the "R&D Progress of FCV's and Hydrogen Infrastructure in Shanghai." Three fuel cell car platforms have been in development in the Start Series Fuel Cell Car program since 2003. The program has tested 10 prototype cars in several durability and reliability exercises. The Tongji Start-3 model earned "A" scores in the 2006 Challenge Bibendum in Paris in the Noise, Pollution, Fuel Efficiency, and CO_2 categories. The newest model in the series, the "Shanghai," operated with a new power train system to increase acceleration. Ma explained that by the end of February 2008 43 Shanghai fuel cell cars will be produced. Shanghai is also developing a fuel cell bus fleet and is planning for the construction of hydrogen refueling stations in the work of 4 national and regional partnerships. Testing is underway to determine the effects of hydrogen impurities on fuel cell performance, but the first hydrogen refueling station in Shanghai was commissioned in June 2007 and is already in construction. The hydrogen fuel cell roadmap in Shanghai will enter the second phase this year with the purchase and operations of 3-6 fuel cell buses by July 2008. Twenty fuel cell cars and two refueling stations will be demonstrated during the 2008 Olympics. The 2010 Exposition Park in Shanghai will also feature fuel cell transportation systems. The final workshop in the IEA/ IPHE Workshop series "Building the Hydrogen Economy" will take place in Shanghai with the support of Tongji University in October, 2007.

Hydrogen in the Spanish Energy Framework

Ms. Esther Chacón, National Institute for Aerospace Technology, Spain

Ms. Esther Chacon, the IEA-HIA Spanish representative with the National Institute for Aerospace Technology, summarized Spain's outlook for hydrogen in her presentation "Building the Hydrogen Economy in Spain." Chacon explained that there have been several activities surrounding hydrogen and fuel cell R&D in Spain, supported largely by national and regional R&D energy funding. Public-private partnerships have been created in Spain in other alternative energy projects, such as wind and solar projects. The HyWays project will facilitate the creation of similar partnerships for building the hydrogen infrastructure by providing experience and cost models in development roadmaps. Chacon offered a brief comparison of three schemes for investing and operating the hydrogen infrastructure in Spain up to 2030, as well as a price model comparison of the average hydrogen cost within each scheme. The HyWays model provides a vision for the hydrogen deployment stages in Spain, beginning in five urban regions. The HyWays conclusions comprise the predictions and strategy that will be considered in each stage of construction in Spain. Chacon underscored that a proper policy framework must be in place for hydrogen and fuel cells to succeed, and proposed several measures that will need to be taken, such as implementing codes and standards, adopting a national roadmap for hydrogen infrastructure development, and advancing national R&D investments to diffuse and promote technologies and lighthouse projects.

Supporting Technologies for the Hydrogen Economy

Dr. Eitan Yudilevich, Executive Director, BIRD Foundation

Dr. Eitan Yudilevich, Executive Director of the BIRD Foundation, presented an overview of his organization. BIRD was created to stimulate, promote and support joint partnerships in industrial R&D of mutual benefit to Israel and the United States. In the past thirty years, the organization has granted USD 240 million to 743 approved joint projects. Yudilevich summarized several hydrogen technologies developed in Israel, such as a Solar Driven Hydrogen Production program and high efficiency hydrogen storage technologies, which could become BIRD projects in the near future. Yudilevich also outlined the framework of his organization as an ideal model for supporting R&D and commercializing technologies on the city and regional level. Yudilevich proposed to discuss and further explain these opportunities to participants in later sessions.

VI. Discussion Groups: Structure & Summary of Discussions

A. Overview of Discussion Group Structure

The Workshop Plenary Session was followed by a series of facilitated discussions in which up to 20 participants were able to meet and identify technical, institutional, and financial opportunities and challenges for hydrogen infrastructure development in Europe (See Appendix A). The five Discussion Groups were organized according to mobile applications, stationary applications, and modeling and analysis of hydrogen technology and infrastructure development.

Discussion Groups

Subject	**Discussion Leaders**	
Mobile	Dr. Robert K. Dixon	Group 1
Mobile	Mr. Tom Gross	Group 2
Stationary	Mr. Robert Donovan and Mr. Khalid Benhamou	Group 3
Stationary	Mr. Nicolas Lymberopoulos	Group 4
Modeling & Analysis	Dr. Dolf Gielen and Paul Leiby	Group 5

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

<u>Planning and Design</u>

- 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?

<u>Construction and Operations</u>

- What are the most significant technical, financial, and institutional issues and barriers to constructing and operating hydrogen infrastructure?

- What policy and market mechanisms and opportunities can best address construction and operations issues and barriers in building hydrogen infrastructure?

The modeling and analysis Discussion Group addressed a different set of questions, which are presented in Section F.

Each Discussion Group leader consolidated the opinions, suggestions, and questions raised in each session into the following summaries.

B. Group 1: Mobile Applications

Discussion Leader: Dr. Robert K. Dixon, IEA

Rapporteur: Mr. Michael Mills, U.S. Department of Energy

Planning and Design

Mobile Discussion Session 1 identified several pathways for infrastructure development as well as policy factors that could facilitate effective development. The group indicated that industry as a whole would not benefit from scattered development. To maximize market penetration and return on investment, infrastructure development needs to be centralized, including the initial demonstration/deployment activities. The group thought that fueling station infrastructure should be initially located in large cities and other areas of potential high use, and then expand along consumer corridors to connect more cities. The growth of fueling stations and vehicles should be coordinated and consistent with expectations of the scale of use for each new area of expansion. Also, a related factor dealing with scale is the need to directly link the volume of demonstration fleets to the state of the technology – the technology needs to be advanced enough to meet the performance characteristics required of the demonstration fleets. This is critical to a successful technical demonstration and will increase consumer acceptance and promote continued expansion.

What are the likely pathways for hydrogen infrastructure development (e.g. city-wide, intra-regional, inter-regional)?

The session participants discussed various factors that will influence the pathways for hydrogen infrastructure development. They worked under the assumptions that hydrogen will be a mass-market fuel, that the technology will be economically competitive, that OEMs will be able to ramp up production to meet demand, and that political support for hydrogen technologies will be strong. The group also agreed on a general principle that the required infrastructure will depend upon which production and delivery technologies are employed. The end goal is for mass market utilization of hydrogen technologies, not merely a niche use of the technology.

The group felt that niche markets can drive the development of mass market applications by following particular growth strategies. First, hydrogen and fuel cell demonstrations for early market applications could provide a necessary foundation of support for promoting additional hydrogen use. Growth from these early demonstrations could be facilitated by a linear process of sharing the information gathered and incorporating the lessons learned into collaborative analyses on the best means for utilizing hydrogen on a large scale. These findings could then be applied in concentrated lighthouse projects for mass market applications of hydrogen that will lead to infrastructure growth and increased public acceptance.

The niche market applications and large-scale applications would follow a similar development pathway – starting with small fleets in locations with existing infrastructure and consumer demand, and then growing the infrastructure and levels of technology at economically appropriate rates to accommodate large fleets which would eventually join with other areas/regions of infrastructure development. These could be cities or areas with potential for high use that can then expand to neighboring areas as demand grows. The reason for developing this centralized approach is because of the minimal benefit that industry would receive from scattered development. Rather, demonstration and deployment activities will need to be centralized to maximize market penetration and return on investment. A caveat is that there should not necessarily be a complete reliance on centralized growth – if economic characteristics allow for distributed growth in certain areas, then these opportunities should be realized.

This approach will utilize past investments as much as possible while also taking advantage of the local infrastructure, past knowledge, and existing networks. Identifying and engaging local, regional and national champions will be critical to the successful expansion of infrastructure, as will obtaining policy and public support and security of supply. Other factors associated with the speed of development include: balancing growth with boundary conditions, alignment with commercial/economic interests, consumers' ability to relate to the technology (*i.e*. their comfort zone), public buy-in (as opposed to merely funding technology development), and an appropriately high level of coordination among stakeholders, policymakers and consumers.

Other issues discussed by the group include the question of whether and by how much the traditional fossil fuel infrastructure need to transform in order to accommodate hydrogen vehicles. This will likely depend on which technology proves to be most effective and efficient, and thus the most prominent. Also discussed was the anticipation that a small percentage of hydrogen vehicles will initially enter the market, creating a need for sufficient initial fueling infrastructure to guarantee the level of convenience expected by the public. The infrastructure for delivery of hydrogen will also need to account for whatever stationary and transportation applications become predominant.

Finally, the group discussed outreach and education activities that could influence the development of a hydrogen infrastructure. They agreed there is a need to create stakeholder groups that could help shape development programs, and to disseminate information on the hydrogen economy to policy makers. They also determined that education at the university level is an important component of hydrogen outreach because it will drive workforce development and public acceptance.

What policy and market mechanisms and opportunities will have the greatest impact in realizing these pathways?

The group outlined several policy mechanisms that will have the greatest impact on realizing the pathways discussed above. Many of the recommendations included education and outreach. Generally, the group feels it is important to continue educating the public on energy – specifically hydrogen - issues. Sharing knowledge from demonstrations and other experiences will also increase the speed of effective development. Beyond outreach, the group thought that there should be a dedicated policy and regulatory framework that promotes hydrogen use and sustainable energy. In particular, post-niche market incentives are critical to moving beyond small applications and into mass market development.

Several market mechanisms were recommended by the group to stimulate effective infrastructure growth. The group reiterated the need to manage expectations of the public, government and industry to ensure continued growth of the hydrogen economy. As discussed in the first section, the growth of fueling stations and vehicles should be coordinated and consistent with expectation of the scale of use for each new area of expansion. Framing the issue for the public may be important as well - the issue is not that traditional energy sources may run out but that hydrogen offers increased benefits for society such as reduced emissions and a more diversified energy supply.

Another issue is that the development and implementation timeframes may be different for OEMs and energy suppliers. This may result in different timeframes for return on investment which will affect the growth rate of infrastructure. Although the group felt the development will be primarily driven by OEM's, focus should be maintained on how to reduce costs for consumers and industry to facilitate growth.

The group was confident that large numbers of refueling stations are not necessarily needed for public relations, as more effective means for educating the public exist. Because the number of vehicles will likely be small in the near future, fueling stations should be located in areas with the best potential for significant utilization of the station. In other words, it is important to match supply with demand, especially early in the infrastructure development process.

Other factors to consider are the locations of hydrogen production and application requirements. Managers of initial projects should examine all options for delivery of hydrogen to the project, and should not just consider opportunities where the production of hydrogen can be co-located with the demonstration or fleet site. Regarding applications, two drivers for infrastructure development will be the need for hydrogen quality and the need for available storage technologies. Various applications will have different needs and thus require differing infrastructures, for example, cars vs. laptops, stationary applications, etc.

Some opportunities discussed by the group include the following:

- Penetration of hydrogen technology is not necessarily dependent on population size, but the values embodied by the population/consumers in a given area. Proponents of hydrogen can promote the value and benefits of hydrogen to drive interest and use. This needs to be balanced with the possible public expectation of "green" hydrogen and the reality that most hydrogen today is produced from fossil fuels.
- Hydrogen is not the only infrastructure that will be built so there may be opportunities for synergistic development with other technologies.
- Hydrogen has many drivers, and as a result there is flexibility for development means and mechanisms from region to region.
- Customer expectations today are very different from when automobiles were first introduced for personal transport. Hydrogen can accommodate the advanced expectations for both individual and mass transportation.

Construction and Operations

The area of greatest concern for the group in the area of construction and operations is regulations, codes and standards (RCS). Because there are different approaches in different countries, it is difficult to generalize on how to approach RCS development, harmonization and dissemination. The group agreed that there may be a need for localized RCS development - bringing labor, safety, fire, police, etc. together via workshops to let them exchange information and experiences. One avenue for efficiency in RCS development is to combine vehicle and stations RCS processes. Other issues discussed by the group include insurance and liability, development of a technically skilled workforce, a supply base, and public-private partnerships.

What are the most significant technical, financial, and institutional issues and barriers to constructing and operating hydrogen infrastructure?

The most significant issue and barrier to constructing and operating hydrogen infrastructure was regulations, codes and standards. The group recommended that RCS should be developed specifically for hydrogen instead of attempting to use RCS intended for other technologies. There are many different approaches used by countries to develop, implement and enforce RCS, which makes it hard to develop a generalized approach to RCS development and harmonization. One approach may be to facilitate local RCS development that brings together the various stakeholders, such as labor groups, safety officials, fire departments and the police, for workshops where they can exchange information and experiences. This approach should help with the problem of local jurisdictions having different RCS, requirements and processes. One way to help with this problem is to combine the development of stationary and vehicle RCS into the same process since many of the issues apply to both applications.

Other factors discussed by the group relate to workforce development, finances, development and outreach. The participants reiterated the need for intensive skill development in the education and technical schools. This will serve to enhance public education/acceptance for hydrogen as well as develop the skilled work force needed to operate hydrogen equipment.

In terms of finances, the group discussed the need for attracting financing for what is expected to encompass large-scale, high-cost development projects. Venture capitalists are aware of hydrogen technology applications for addressing energy issues, but this type of investment does not currently offer an attractive timeframe for return on investment. The group anticipated that the venture capitalist community will invest only when they can get a return on investment within a reasonable timeframe, although cultivating successful venture capitalist champions could lead to increased investment. Other factors that could influence investment in infrastructure include uncertainty regarding methods of production and delivery, requirements for hydrogen quality (relates to storage, compression mechanisms), insurance and liability concerns, and overall cost competitiveness of the technology in the market.

Other factors discussed include the need to balance long-term needs/issues with the short-term policy outlook. An investment in the common good can be difficult to justify without short-term needs. Although we may be approaching this situation, the group felt we are not quite there yet. If we apply the lessons learned from other alternative fuels, as well as failures, we can justify the needed investment to properly develop the supply base that will feed a growing demand. It is also hoped that, as demand grows, the public's definition of affordability will shift based on the need to address our energy and environmental problems.

What policy and market mechanisms and opportunities can best address construction and operations issues and barriers in building hydrogen infrastructure?

The group discussed various policy issues relating to the construction and operation of hydrogen infrastructure. They agreed that an effective approach would be to develop simple natural-resources based policies that clearly express consistent, continuous government support for developing solutions to energy and environmental issues through advanced technologies. Some means include policies targeted at certain sectors (urban vs. rural and regional differences), tax incentives (credits, carbon taxes, gas taxes, etc.); policies that facilitate and support transparent, open, long-term public-private partnerships; public procurement policies to stimulate demand; and development of internationally accepted means for certifying all types of fuels based on their GHG intensity and other costs associated (spills, wars, etc).

The group discussed several factors that affect the market for these technologies. These included: voter distribution driving technology use (rural vs. urban interests), education of the public on the technology, relative prices shaping consumer choices, the institution of an effective, reliable carbon pricing system, and continued promotion of hydrogen as a solution for sustainable mobility.

Finally, the group discussed some opportunities in the construction and operation of a hydrogen infrastructure. They focused on the opportunity for international agencies to help construct platforms that will prompt public acceptance and behavior change and also ensure that policy makers understand hydrogen is a solution to a broad problem. Also, there is an opportunity to take advantage of other alternative technologies and products to promote to the need for sustainable energy.

Suggestions:

- Refine product after the meeting, building to final workshop in Shanghai.
- Spell out implications of differing approaches
  i.e.: Auto OEMs probably not supportive of just niches due to fact that they cannot scale to levels that are profitable.
- Define infrastructure in this context.
- Move step-by-step focusing on how we transition from demonstration to fleets to mass markets?

C. Group 2: Mobile Applications

Discussion Leader: Mr. Thomas Gross, IF, LLC.

Rapporteur: Ms. Jill Gagnon, US Energy Association

Planning and Design

Question 1: What are the likely pathways for hydrogen infrastructure development (e.g., city-wide, intra-regional, inter-regional)?

Multiple perspectives were provided in response to this question. Comments offered addressed the following considerations related to pathways for the development of hydrogen infrastructure.

- Centralized versus decentralized production.
- Fossil pathways.
- Renewable pathways.
- Delivery options, *e.g.*, pipeline versus truck or rail.
- Urban buses as early competitive applications for hydrogen.
- Dual sources of hydrogen as a means to assure reliability of supply.
- RD&D success as a critical element of the pathway to hydrogen.

Cost, and the potential for cost reduction, is a key factor in determining the relative merits of pathways characterized by centralized and decentralized production of hydrogen. Points were made that the evolution of electricity prices, the cost of fossil fuel technologies, and the availability of electricity are linked directly to decisions regarding hydrogen. Indeed, cost is a major consideration in the evolution of any hydrogen pathway. However, it is not necessarily the determining consideration.

- While centralized production of hydrogen from fossil sources is currently less expensive, the benefits are offset due to the lack of carbon capture and storage technology.
- While pipelines are the least expensive way to transport hydrogen, low demand and other factors must be considered.
- Local and regional hydrogen infrastructure development projects are already underway.
- The ability to store hydrogen is an important factor.
- The safety of handling, dispensing and using hydrogen must be considered.
- Cost and efficiency of fuel cells, of various types and sizes, are important elements of the overall hydrogen system.
- Hydrogen does not need to be moved as elemental hydrogen. Alternative methods to transport hydrogen, *e.g.*, methanol or ammonia, can be considered.

As a practical matter, regional and local projects and initiatives are already driving the process of infrastructure development forward. It was noted that this is the case in Europe. Demonstration projects, which are important as precursors for infrastructure development, are underway in urban areas in Europe and elsewhere. These projects are important for public education and overcoming skepticism regarding hydrogen. Ultimately, however, the building out of infrastructure beyond demonstration facilities will depend on:

- Success in achieving research and development goals.
- The assignment of value by national governments to drivers such as energy security, environmental quality and greenhouse gas reduction. It was stated that the primary driver in Europe's large cities has been local and regional air quality, and that other drivers are not playing a role yet in demonstration projects. EU policy is pointing to the importance of sustainability, competitiveness and security of supply.
- The passage and implementation of policies that reflect valuation of these drivers.

A key conclusion was that hydrogen planning and design must be consistent with policy. While the importance of national policies as a determinant of infrastructure evolution was noted and discussed, a question was also raised about whether too much central planning could be counterproductive, particularly during a period when the results of research and development activities are not yet known.

Question 2. What policy and market mechanisms and opportunities will have the greatest impact in realizing these pathways?

Multiple policy goals were cited as important for the development of hydrogen as an energy carrier, and thus for investment in hydrogen infrastructure. These included:

- National security. It was noted that, unless national security is viewed as a related issue, governments will not seriously pursue a "hydrogen economy". Some group members pointed out that energy security is not yet a well-accepted driver for hydrogen, but there should be a good fit in the longer term.
- Greenhouse gas emission reduction. It was stated that carbon reduction policies will have the greatest impact on use of hydrogen. Conversely, others said that hydrogen is a questionable response to policies having an objective of reducing carbon.
- Air quality improvement. In a scenario in which policy is focused primarily on reduction of air pollutants, this can be an important driver for the use of hydrogen, particularly in the short term.
- Short term policies that facilitate hydrogen demonstration projects.
- Increased use of renewable energy sources. It was noted that there is good synergy of hydrogen with renewable energy, and hydrogen demonstration initiatives which advance hydrogen from renewables should be promoted.

Governments must realize that energy is a national security issue. In market-based economies, lack of energy can lead to serious market failures. To be effective, policy has to result from a joint effort of government and private companies. It was noted that different policies would favor different energy pathways, and that there will be winners and losers. However, there was general support for policies that are market-based, technology neutral and broadly implemented, *e.g.* a global price for carbon.

Mobile Applications Group 2 had difficulty accepting the assumption of successful research and development. **Its most clear and broadly supported message was that policies of robust,**

continued support for research and development are critical to hydrogen making a serious contribution to meeting future energy demands. R&D is necessary for cost reduction, and to provide assurance of equipment and infrastructure that have required characteristics such as durability, reliability and safety. Without successful hydrogen R&D, the ability of any reasonable policy to result in acceptance of hydrogen is questionable. For example, a long-term policy to reduce carbon emissions would likely not favor hydrogen. Opinions were offered that, first and foremost, hydrogen R&D budgets should be increased.

A statement was made that Europe needs a "confrontation" of hydrogen with other technologies based on facts. "Well-to-wheels" analyses are important. More definitive data on hydrogen, and other energy solutions, must be developed to perform an integrated and consistent assessment of energy technologies. It is also needed to further evaluate the contribution of hydrogen, in particular in the European context of 20 20 20 scenario which promotes the renewable energy sources. The point was made, however, that other countries don't necessarily view hydrogen and related issues in the same way Europe does. Nevertheless, there was general agreement that policy goals should highlight and underscore the need for a clean, clever and competitive hydrogen infrastructure. The achievement of such an infrastructure, however, remains dependent on successful R&D, and convincing a variety of interested parties that hydrogen is a viable and competitive option.

Construction and Operations

Question 3. What are the most significant technical, financial, and institutional issues and barriers to constructing and operating hydrogen infrastructure?

Assuming success of hydrogen research and development, **the most significant issue associated with constructing and operating hydrogen infrastructure is education and training**. Consensus among members of Mobile Applications Group 2 was achieved for this statement more than any other throughout the session. In Europe, the market will provide the technical and financial solutions when and if cost-competitive, reliable technology is available. However, programs must be undertaken to interest, educate and train the following people and organizations.

- The public generally, to reduce skepticism and improve acceptance of hydrogen.
- The workforce required to handle the technical jobs which accompany the building of a hydrogen economy, e.g., engineers and maintenance personnel.
- Companies and their leaders.

The point was made repeatedly that creating the "human capital" needed is vitally important and will be difficult. Finding adequate engineering and scientific talent is already a problem generally. Training sufficient numbers of skilled people to deal with the emerging hydrogen-related technologies will increase the magnitude of the challenge. A European study has been done on the need for technical training. It was noted that training could benefit poverty reduction efforts in developing countries.

Other issues and barriers presented and discussed were:

- Availability of capital for investment.
- Failure of the public and government leaders to account properly for all the costs of energy.
- Environmental impacts associated with infrastructure construction.
- Hydrogen quality.
- The separation between primary energy supply decisions and the end use energy consumers.

Most of the group concurred with the view that, given R&D success and competitive technology, investment capital would flow to hydrogen projects. While accepting the assumption of research and development success at this stage of the discussion, the group continued to comment on the importance of continued support for technology development. Issues such as fuel cell reliability and durability, warranties for equipment and facilities, and the need for significant cost reduction were mentioned.

There was also general acceptance of the notion that economic externalities are not sufficiently accounted for in decision-making. Impacts of energy production, delivery and use on health and national security are not factored into energy costs. It was noted that the European Union is attempting to deal with such "market failures" in its formulation of policy. Mention was also made that European consumers are gaining more choice in energy suppliers, *e.g.* they can choose a supplier of energy from renewable sources.

Question 4. What policy and market mechanisms and opportunities can best address construction and operations issues and barriers in building hydrogen infrastructure?

A key to addressing issues and barriers associated with hydrogen infrastructure is education. Most important is education of the public and its political leaders regarding energy issues generally. Creation of a vision about the "right way" to go on energy matters is a precursor to leadership.

Carbon taxes and taxing of local air emissions will increase the sustainability of the transportation sector. 80% of Europeans live in urban areas; air quality is a problem. However, it was noted again that policies to reduce emissions, whether related to climate change or air quality, will not be particularly helpful in advancing investment in and use of hydrogen. It is not clear that there are specific policies and actions that can or should be taken to increase the use of hydrogen for transportation, at least in the short term before more R&D is accomplished. Group members reiterated that hydrogen policies beyond R&D support are premature.

With respect to training for hydrogen-related jobs (see response to question 3), it was noted that timing is important. Caution was urged with regard to training people specifically for such jobs before there is more assurance that the work will be available.

The preference for technology-neutral energy policy instruments was reiterated, along with support for hydrogen R&D (see response to question 2). A need for more analysis of the socio-economic costs and benefits of hydrogen was cited. Demonstrations of hydrogen use in fleet vehicles and fueling station technology, funded primarily by government, can be useful for both understanding the state of technology and education of the public.

D. Group 3: Stationary Applications

Discussion Leader: Mr. Khalid Benhamou, Sahara Wind, Inc.
Mr. Robert Donovan, US Energy Association
Rapporteur: Ms. Simone Luft, IEA

<u>Planning and Design</u>

Pathways

Group 3 identified several pathways likely to lead to the development of hydrogen energy infrastructure for stationary power applications.

In order to be viable, a hydrogen economy will have to be energy efficient, environmentally sound or carbon neutral and sustainable in terms of resources. Thus the group has identified two different hydrogen supply pathways that have different characteristics.

Hydrogen from renewable energies presents several advantages besides the fact that the resource cannot be depleted. In as far as renewables such as wind and solar energies are intermittent, hydrogen production processes become in fact ‘enabling technologies’ for integrating larger amounts of renewables into electricity grids. The wind energy business has become a multibillion dollar industry, with a strong social manufacturing base that is growing at a rate of 20% per year. Wind electricity is fairly erratic for grids and it induces significant stability problems. Grid saturation to wind generated electricity currently represents one of the wind energy industry’s main limiting factors. Wind integration into grids can hardly exceed 25% of total electric installed capacities, and major markets such as Denmark, Spain or even Germany are facing difficulties in integrating additional wind turbines into their grids. As both wind and solar energies are intermittent, electrolysis for grid stabilization and subsequent hydrogen energy storage is a possible solution for maximizing wind penetration rates in large or isolated grids.

Hence, hydrogen intraregional pathways are likely to start with renewable energy clusters that will be gradually linked to grids leading to large scale supply infrastructures. Distributed renewable hydrogen solution clusters will contribute to develop this technology enabling sustainable energy systems to be more broadly deployed.

This participants of this group agreed that Hydrogen from fossil fuels will need to incorporate carbon capture systems or at least be carbon neutral in order to prevent greenhouse gases emissions, which constitutes a significant impediment for Hydrogen deployment if CO_2 emissions continued to be released into the atmosphere in its generation process. In fact, the environmental dimension of hydrogen as an emission free fuel may constitute its key asset for ensuring its success and a widespread use.

Regarding hydrogen distribution infrastructures it has been reiterated that existing natural gas pipelines infrastructure could be used to supply up to 30% of capacity for hydrogen, using pipeline coating and gas separation techniques at the point of use. Further, existing hydrogen pipelines for industrial uses may be expanded, whereas ammonia could also be considered for storing and transporting hydrogen.

Energy intensive industries and chemical plants would gain in synergies when integrating hydrogen processes generated through electrolysis. Besides oxygen or other by-products like caustic and chlorine that can be generated and integrated in various chemical processes, electrolyzers stabilize grids enabling higher penetration rates of renewables energies.

Hydrogen released can be used for energy generation and backup through GenSets (hydrogen internal combustion engine), whereas lower investment costs H_2/O_2 steam turbines currently under development are likely to improve grid performance by making it highly responsive.

Finally the group has acknowledged the role hydrogen coupled with renewable energies in improving energy access possibilities for remote communities, highlighting its use particularly for low density distributed energy applications such as telecommunications and other infrastructures.

Policy and Design

Group 3 separated policy mechanism from market mechanism that will have the greatest impact in realizing the pathways towards a hydrogen economy.

Policy Mechanisms

The security of supply and energy diversification from existing fossil fuels and infrastructures such as natural gas remains a fundamental drive towards a hydrogen based economy. The European Union's perspective to focus on renewable generated hydrogen is an example of how strategic, the diversification of supply using hydrogen can become. This could represent a major policy tool likely to act in favor of hydrogen deployment in the future.

Hydrogen could also be supported by policies related to providing energy access in remote areas - a fundamental obligation from the state- where hydrogen technologies can become relevant.

Grid Stability and backup back-up power are very important issues in developing countries, as hydrogen could enhance grid stability. One simple example is the problems of failing power in hospitals where water electrolysis can generate hydrogen for electric backup and oxygen for life support systems. Hydrogen fired internal combustion engines for backups are low cost devices compared to fuel cells and can be deployed easily in many hospitals.

In some European countries (France, Germany, Portugal), new buildings have high environmental quality standards, and hydrogen technologies are likely to contribute to energy efficiency and CO_2 reductions, besides being solely considered as a energy storage mechanisms. Promotion of fuel cells in apartments' buildings in large cities can be easily envisioned, and support mechanisms for risk management regarding hydrogen technologies and their deployment will have to be crafted.

Financial support guarantees, and investment facilities or tax incentives for companies using these technologies should be promoted as has been the case when introducing previous technologies, particularity as these can be considered as enabling technologies for accessing newer resources such as renewables while optimizing current energy mixes. It is important to mention that hidden costs behind fossil fuel supply, technologies and infrastructures that are not yet capable of matching with rising energy demands worldwide have to be integrated when considering the deployment costs of these newer energy technologies. The very same applies to convention electricity grid distribution systems.

Environmental policies are likely to play a significant role as well, and a bottom-up sensitization process to encourage capacity building in education and the mobilization of human resources towards that end is mandatory. The broadening of stakeholder participation which is a key priority in meeting future energy supply and environmental challenges is likely to lead to considering hydrogen options when planning energy demand.

Market Mechanisms

Marketing tools to introduce fuel cells are needed to introduce 2-3 kW small fuel cells usage in the newest condominium in rapidly expanding cities like Shanghai, Tokyo and Singapore (backup power). Expanded range of services through Combined Heat and Power (CHP) by fuel cells in buildings could be considered, with premiums for green power, or green enabling technologies.

Energy access in distributed telecommunication infrastructures or military stand alone remote surveillance systems are likely to be considered fairly early on by technology/ defense industries.

Electric utilities may envision the use of hydrogen coupled with renewables for grid stabilization trough electrolysis as well as energy storage for backup. Before that however, large electricity users such as mining, raw minerals processing and chemical industries, could make use of new processes utilizing hydrogen (direct reduction of iron ore, phosphoric acid production, etc.). The steel industry for instance has shifted to more environmentally friendly and lower investment costs Electric Arc Furnaces in recent years which represents today over 45% of the world’s steel production. Besides oil refining industries for cleaner fuel synthesis, there are many other industries that could find added value possibilities in utilizing hydrogen in industrial processes.

Construction and Operation

Technical, Financial, and Institutional Issues and Barriers

Group 3 separated the aforementioned issues & barriers hampering the deployment of a hydrogen economy into three categories:

Technical Barriers

The storage of hydrogen remains one of the most critical technical barriers that will have to be surmounted for the deployment of hydrogen systems. Safe, efficient and cost competitive storage options need to be developed in order for hydrogen to be widely used in stationary as well as for mobile applications. On the production side, electrolyzers are still “custom made” and expensive types of equipments as are hydrogen fuel cells which can convert stored hydrogen back to electricity. Technology changes will be needed to enable the mass production of these devices and drive down costs. Power conditioning schemes and expanded flexibility ranges for electrolyzers is also necessary for handling intermittent and/or erratic sources of electricity.

Institutional Barriers

The group has clearly identified grid operations, management and the open access to the electricity grid as main prerequisite for distributed generation of hydrogen and electricity via fuel cells. Newer distributed generation systems and hydrogen infrastructures can enter in direct competition with electricity markets on existing grid infrastructures. Rules will have to be introduced to avoid conflicts of interests and enable synergies with grid operators to develop. Hydrogen infrastructures can also be redundant to natural gas networks, and appropriate frameworks will need to be established. Cogeneration processes and the integration of hydrogen related technologies within the industry will require incentives and stimulating measures as well as technical, scientific and financial support schemes. Safety requirements, codes and standards as well as specific construction measures will have to be agreed upon and applied to hydrogen applications and infrastructures. Awareness raising and training to fire brigades will be required in order to get appropriate permission to install these systems.

Energy education centers, university programs, and the need to introduce targeted education at all levels can provide essential training skills for hydrogen to become a widely used element. Raising the awareness for local planners, local communities can be very effective in highlighting the need for environmental products such as hydrogen to be deployed. Target groups can be identified or incentives for regions that would be willing to use such technologies can be made available.

Policy Mechanisms

Opening up completely the approach to energy planning, involving all stakeholders – the more people participate, the better the outcome- has been a unanimous suggestion made by all members of Group 3.

As hydrogen is a new player in well established energy markets, anti-trust regulations and market deregulations to avoid conflict of interests may be required.

The need to develop a long-term strategy from government and keep it open to debate is critical as hydrogen covers energy and environmental aspects where technological options are likely to lead to significant breakthroughs in the way we use energy. Policies ought to be developed to facilitate and even encourage appropriate technology transfer and dissemination of hydrogen related technologies. In order to stimulate creativity however, mechanisms for intellectual property rights protections, ought to be reinforced particularly for small and medium enterprises whose work would be recognized and rewarded accordingly.

The development and harmonization of permitting approaches, codes and certifications is essential for that task. Risks in developing hydrogen technologies need to be reduced, and government have to take a lead in promoting it through incentives. Proactive tax policies, mandates for public good – citizens' – and community interests may be able to foster momentum in overcoming technological complex issues and enable the development of clean, sustainable energy technologies. The introduction of a carbon tax or emission trading could provide further incentives for clean hydrogen production –an efficient energy carrier- as opposed to the inefficient and environmentally harmful burning of fossil fuels.

Market Mechanisms

The group has recognized that generalizing energy access to remote communities could open opportunities in which hydrogen has a crucial role to play. Bottom-up processes in deploying hydrogen technologies would be expanded and involve local expertise. The outreach of IPHE – to introduce hydrogen lighthouse projects in several developing countries would open new perspectives for hydrogen applications. For that matter, consensus building has to be achieved on pre-competitive co-operation, in order to avoid duplication of pilot projects or technologies and highlight instead comparative advantages of different conditions and settings.

A strong emphasis on synergies has to be pursued with hydrogen as an ‘enabling technology’ in a variety of processes (industrial, chemical etc.) and where energy is only indirectly derived. This remains, our workgroup believes, one of the hydrogen economy’s key assets. The building and reinforcing of “hydrogen champions” or large industrial users has to be encouraged to stimulate a hydrogen economy likely to expand beyond its few initial applications.

E. Group 4: Stationary Applications

Discussion Leader: Mr. Nicolas Lymberopoulos, UNIDO-ICHET
Rapporteur: Ms. Emily Glenn, IEA

The group included 7 experts that represented a very international profile, with two coming from Europe and the rest coming from Greenland, Japan, China, Mexico and Israel.

The realisation of “Hydrogen in stationary applications” would provide the means to replace conventional fuels. In the short term fossil-fuelled fuel cells could first be applied in stationary applications, but eventually in the long term these will be hydrogen driven. Even in the short term however there can be niche stationary applications of hydrogen energy technologies.

Planning and Design

Pathways

Participants suggested a number of pathways ranging from centralised hydrogen production to niche distributed systems. It was proposed that the existing hydrogen generation infrastructure for captive or merchant hydrogen could readily be used as a source of hydrogen as an energy carrier. This could then be expanded to coal-fired power plants that would be turned into coal gasification plants, aiming for “polygeneration” of electricity, hydrogen and other products (flexible approach) and could be combined with CCS.

An alternative pathway could be based on demonstration nuclei that would progressively expand into infrastructures. One would be densely populated urban environments, aiming for maximum return, starting by utilizing spare or by-product hydrogen, creating opportunities (e.g. town gas) by exploiting environmental benefits, sponsoring hydrogen vehicle demonstrations at limited outlets and expanding on those. Another type of nuclei would be rural or remote locations where hydrogen could be used to store excess energy produced from renewable energy sources

Another pathway could focus on developing countries, either to help provide electricity (1.6 billion people do not have access to electricity) or in the case of countries with an adequate electricity network but with an electricity deficit, to contribute to the security of supply (*e.g.* China).

The introduction of fuel cells that would in the short to medium-term run on hydrocarbons could be considered an intermediate step to the transition to a full hydrogen infrastructure. Similarly remote relay stations and UPS applications of hydrogen and fuel cells are important niche markets in terms of establishing investments and public acceptance mechanisms.

Policy and Market Mechanisms

The need to reduce CO_2 emissions was considered to be an important driver for the transition to a hydrogen-inclusive economy. New regulations or policies that would lead to a carbon tax or that would make CO_2 capture mandatory could foster the earlier introduction of concepts like the gasification of hydrocarbons and the production of hydrogen for energy use. This could be seen as a policy intervention in order to avoid a market failure of hydrogen end fuel cell technologies due to their present high cost.

At an international level, treaties, protocols and directives related to energy saving and environmental protection could support the introduction of hydrogen and fuel cells and could lead to the provision of funding for developing countries. At a national level, tax incentives and favourable tariffs stemming from national policies related to energy security or environmental protection could similarly help push hydrogen and fuel cells into major demonstrations, like in the case of Japan. At a city or community level, such policies could stem from a clean air act.

A policy of supporting further R&D in order to reduce the costs of hydrogen and fuel cell technologies was also recommended, along with the need to educate the policy makers and the public. The need to elaborate unified codes and standards should also be covered by respective policies.

Construction and Operations

Issues and Barriers

Participants considered that cost, reliability and complexity are the most important barriers. Progress to overcome these barriers through R&D has been slow in relation to available funding. The power industry has been slow to adopt related technologies, while in order to overcome these barriers there is a need to standardise and develop “plug and play” products.

Another barrier is hydrogen purity. Hydrogen production through reforming is well established today, but not at the purity levels required for energy applications, especially for the case of fuel cells. Similarly, for the case of electrolysis, the integration of electrolysers with intermittent renewable energy sources could affect the hydrogen purity.

The storage of hydrogen in low cost and energy dense ways is a major issue, even for stationary applications, although it is of paramount importance for transport applications.

In terms of using hydrogen, fuel cells are not yet reliable and thus other technologies like engines could be considered in the medium term, with the efficiency and emission drawbacks that this solution implies.

The lack of uniform codes and standards was another issue identified, along with safety regulations and simplified technical specifications. The public misunderstanding due to lack of knowledge and the lack of a skilled workforce for installing, operating and maintaining related equipment were barriers also to be addressed.

Policy and Market Mechanisms

Funding of further R&D in the field was identified as one of the mechanisms that would address the barriers previously mentioned, aiming to reduce costs and improve reliability and efficiency.

The successful example of realising wind energy and solar PV technologies where favourable subsidies and tariffs helped create a healthy industry and market is considered as an example that could be applied to hydrogen and fuel cell technologies as well. Enforcing the hybridisation of renewable energy installations with energy storage technologies (one of which is the hydrogen-FCs option) aiming for minimum guaranteed power, would increase the confidence of the power industry to stochastic renewable energy sources and would create market opportunities for hydrogen and fuel tell technologies.

The experts suggested that niche market opportunities should be identified and should be supported as a priority:

- Island/ remote community applications
- Capitalize on Green tourism to showcase technologies
- Guaranteed power for vital applications (hospitals, airports, banks, data handling centres)
- Fuel Cells running on hydrocarbons as a transition step
- Complete domestic or neighbourhood systems

Education and training schemes should also be launched for the benefit of policy makers, the public and the technical labour force.

F. GROUP 5 Modeling and Analysis Discussion Session

Discussion Leaders: Dr. Dolf Gielen, IEA &
Dr. Paul Leiby, ORNL, US Department of Energy

Overview of the Session

In the July 2007 Paris meeting, the modeling and analysis Discussion Group again began with presentations on current modeling and analysis activities. This time, in keeping with the conference theme of “Sharing the European Vision,” there was greater emphasis of European modeling approaches, and how they contrast with those in North America. The group then turned to the task of carrying forward the work started in Detroit, by considering the following pre-identified objectives:

- Continue discussion of the “modeling gaps” and missing elements identified in Detroit;
- Discuss and determine how to link, or best use, several of the available models;
- Address practical matters for model utilization, including conditions and resources needed for “Modeling/Analysis Toolbox” use.

Recognizing that any modeling development or application should begin with a clear goal in mind, the group defined the following modeling goal, for discussion purposes: “To answer, to the extent practical within 12 months, ‘what policies are efficient and effective to enable a transition to hydrogen by 2050?’”

Introductory Presentations

The session began with four presentations, one recapping the progress made at the Detroit meeting and three providing brief overviews of current hydrogen infrastructure and transition modeling activities. The presentations were:

- *Progress Report April 4-7 Detroit Modeling Session,* Dr. Dolf Gielen, Senior Analyst, Energy Technology Policy Division, International Energy Agency (IEA)
- *The MoMo Model,* Pierpaolo Cazzola and Michael Taylor, Energy Technology Office, International Energy Agency (IEA)
- *MOREHyS H_2GIS Model for Optimization of Regional Hydrogen Supply - Model Update,* Philipp Seydel (Fraunhofer Institute Systems and Innovation Research ISI); Christoph Stiller (LBST)
- *HyWays-IPHE: Comparing Hydrogen Analyses,* Mark Ruth (NREL/SI), presenter), Christoph Stiller (LBST), Michael Wang (ANL), Darlene Steward (NREL)

Details on these presentations are available separately.

The progress made in the April Detroit Workshop, summarized in Gielen's presentation, included:

- Identifying the important policy modeling questions related to infrastructure development and hydrogen transition,
- Highlighting issues inadequately addressed by the existing models and analysis; and
- Proposing development of a "Tool box" of models and compiling an initial model list.

The presentations on the MoMo Model (described by Cazzola and Taylor, IEA) and the HyWays/MOREHys/H_2GIS system (Seydel and Stiller, Fh-ISI and LBST) expanded the "Model Toolbox" to include two European modeling initiatives. MoMo was described as a "real-world tool" in use by industry, comprising a spreadsheet model of global transport, energy and materials use and emissions. The HyWays/MOREHys/H_2GIS system exemplifies a coupled system of three EU hydrogen infrastructure models each with a different level of detail and focus. The resulting system, a case study in model integration, allows a high degree of regional disaggregation and site specificity in a consistent overall framework of national-level or higher scope.

The HyWays-IPHE project (Ruth, Stiller, Wang and Steward presentation) compared modeling approaches and assumptions for hydrogen production, delivery and distribution chains in two models: EU E3Database model and the United States system of H_2A/HDSAM/GREET components (linked by a framework called MSM). The study revealed commonalities and differences in production and delivery assumptions. More broadly, however, it uncovered important differences in definition, cost accounting methods, representation of technology change, and modeling philosophy. While the pathway costs from the U.S. framework were typically higher, its focus was on defining a business case for hydrogen while the EU framework primarily characterized a policy-support case. Overall, the HyWays/IPHE project offered a valuable case study on the challenges of, and rewarding insights that can be gained from, hydrogen model validation and comparison.

Discussion Topics

Value of Diverse Model Set: A continuing consensus theme was that no single model is or will be able to address all different questions relevant for the transition to a hydrogen economy. Different models from North America, the EU, and elsewhere each address the key modeling gaps to varying degrees, providing special insights. Each also represents particular regional conditions and planning philosophies. For these reasons there was interest in the coordinated, complementary use of multiple approaches. It is critical to develop and select the right set of models. The following section summarizes the group's discussion of the focus questions listed in Section 1.

Group Discussion Summary

Completing the Gaps in Modeling the Transition and Hydrogen Infrastructure Development

Four principal categories of modeling gaps had been identified: better-characterizing baseline technologies and technology change; modeling risk and uncertainty; improved modeling of individual and firm behavior; and accounting for broader systems issues (such as sectoral interactions, competing demands for resources, and interacting policy goals). Participants emphasized that identifying modeling gaps is important not simply as an academic exercise, but crucial for understanding the limitations and determinants of current analyses. It can also guide priorities for the next stage of model development.

Geographical Scope: It became clear that substantial challenges remain in reconciling their diverse geographical scopes of the available models. Model scopes range from the detailed representation of an individual city to regional, national, and multi-country levels. There is a common desire for both finer spatial detail/specificity *and* expanded scope to larger, even global levels. Recognizing this tension, discussants noted that the different model scopes typically answer different questions and important roles will remain for each. Highly detailed spatial Geographic Information System (GIS) models at the urban or regional level can provide realistic insights on the pattern and cost of infrastructure evolution, or the development of local markets, typically assuming some scenario for hydrogen penetration. It is generally hoped that these insights can be generalized for use in the larger geographical scale, more aggregated models. In turn, the wider-scoped more aggregate models can enable the assessment of economy-wide system connections, sectoral interactions, competing demands for resources, and overall technological progress at the national and international scale. An important challenge for the current state of the art is the appropriately coordinated use of models of different geographical scope, such as was pursued in the EU with the HyWays/MOREHys/H_2GIS system, and in the U.S. with DOE's Transition Scenario study.

Additional Gaps in Current Models and Analyses: In the course of discussion, participants identified the following general topics as additional gaps in current modeling and understanding:

- Macroeconomic effects of hydrogen infrastructure development and transition;
- Implications of, and possible limitations to, international trade in fuels and technology;
- A focus on the roles of regulatory frameworks for hydrogen infrastructure development;
- Validation from other examples of technological change (unleaded gasoline, ethanol in Brazil, introduction of other new vehicle technologies) *recognizing* limits to the analogies and the special technological cost and infrastructure challenges of hydrogen;
- Consideration of sustainability issues;
- A prioritization of model development (gap completion"). There was a call for a clear linkage between model development and gap-completion priorities to the policy driving forces.

Improving Understanding of Current Models: Apart from the acknowledged gaps in model coverage, discussants emphasized that there are still important gaps in *understanding* the current models. There was a call for more effort to examine the major existing models to clarify:

What they tell us now (perhaps summarized by their inputs, outputs, and main implications);

The basic constraints included (*e.g.*, limits on expansion rates);

Their known limitations;

Their fundamental philosophy and assumptions; and

The key value added (“5 key insights”).

Participants agreed on the merits of a careful poll of modelers to begin filling out this information. This would also help better define the component of the current “model toolbox.”

Linking or using several of the Available Models to provide Insight

The discussion explored the main issues for hydrogen model use and reconciliation. The current models typically stand alone, and much work remains to compare them, reconcile their approaches and driving assumptions, and use them in concert. Nonetheless participants strongly emphasized that some progress has been made in reconciliation or harmonization. There has been progress in baseline technology characterization. For example, the technical data behind the representation of hydrogen supply (production and delivery) is similar in many cases. Also emissions data are similar. The HyWays-IPHE comparison project went a long way toward revealing the commonalities and differences of hydrogen pathway models. An important conclusion from that work and from the discussion at the workshop is that, in hydrogen models, “one size does not fit all.” There are important differences between countries and regions regarding resources, policies, vehicle stocks and choices, and planning issues. To a large extent the important differences among models from North America and Europe reflect these differences in regional conditions and objectives.

Practical Steps Necessary to operate and coordinate the available Models

The discussion reached broad conclusions regarding a promising strategy for linking and using the available models in concert. For the near-term objective of gaining insight on efficient and effective policies to enable a transition to hydrogen, no hard linking of models and no single overarching model is anticipated or recommended. Still, there is much to be gained by “soft linking” the models: running selected *established* regional models in concert, under comparable assumptions and conditions, and exchanging data and results in a manual or semi-automated manner.

It was recommended that representative models or model suites be selected from each of the major global regions. Lead candidates included HyWays for Europe, and the U.S. suite of DOE models. It remains to be determined whether a formal model or scenario planning tool is available for Asian regions at present. It is most practical to undertake a set of coordinated model runs, each model operated by its expert users, using common assumptions. In this soft-linked process, coordinated by IEA/IPHE, the model information flow is bidirectional. Each regional model provides regional outcomes and different insights. It is anticipated that collectively the model results can be used to

- Identify bottleneck issues
- Explore expected impact of policies in different major global regions; and
- Reveal *region specific* patterns of infrastructure

The overall global framework can be managed by IEA, passing information back to the regional models by soft links. The crucial global links to be established across the separate models include:

- Global vehicle and fuel market interactions (including economies of production scale and levels of technological progress)
- Major oil/gas market impacts

The discussants agreed that such a modeling process would be well-worthwhile.

Next Steps for Modeling Discussion and Application

It was proposed that for the next workshop in Shanghai in October 2007, IEA/IPHE will

- Extend the forum for sharing *local* perspectives on modeling hydrogen infrastructure development and transition
- Emphasize discussion of Asian approaches and progress, and seek Asian participation in the coordinated global modeling initiative.
- Finalize plans for the coordinated use of regional hydrogen infrastructure and transition models.

Model Type	**Model Name**	**Model Developer (Institution)**	**Developer (Individual Contact)**
Supply chain pathways and tradeoffs	H_2A	U.S. DOE/ANL, NREL	M. Paster
	HDSAM	U.S. DOE/ANL, NREL	M. Paster
	E3 Database	LBST	
	GREET WTW Emissions	U.S. DOE/ANL	M. Wang
	HyPro	U.S. DOE/Directed Technologies Incorporated	B. James/J. Perez
	MSM 0.5	U.S. DOE/NREL	M. Ruth
	HyDive	NREL	C. Welch
Integrated economic systems	ETP (Global)	IEA	
	Markal	ETSAP	
	MoMo	IEA	P. Cazzola & M. Taylor
Country/region economic systems	HyTrans V. 2.70	U.S. DOE/ORNL	D. Greene & P. Leiby
	H_2CAS	U.S. DOE/ANL	M. Mintz?
	HyWays/MOREHys/ H_2GIS	Fh-ISI, LBST	P. Seydel & C. Stiller
	NEMS	EIA	
	NEMS-H_2	DOE/EERE	F.Wood OnLocation
	Idealized City Model	UC Davis	J. Ogden
	HIT– H_2 Infrastructure Transition Model	UC Davis	D. Lin
	Ohio Case Study	UC Davis	
	Hydra	NREL	J. Levene
	H_2M SEI-US	US.DOE NREL	
	CA Rice Straw Study	UC Davis	UC Davis
Environmental models (local pollutants)	?	?	?

VII. Key Messages and Next Steps

The key messages in this section are derived on the basis of the presentations of the participants and the group discussions on the key issues that are related to planning, design, engineering, construction, operations and maintenance of hydrogen technologies. A number of future steps are also suggested for action.

Key Messages from Presentations:

- The IEA Ministerial and G8 Summit support the objectives and deliverables of the project: "Building the Hydrogen Economy: An Infrastructure Strategy" (Mandil C.);
- Because of three advantages: secure, environmentally green and economically competitive, hydrogen powered vehicles could gain a large portion of market share by 2050 (Dixon R.)
- In Europe, there are over 80 projects underway in the FP6 program. A partnership of 26 actors is coordinated by AirLiquide to deploy hydrogen small vehicle fleets in Europe during the period 2006-2010 (Frois B).
- Public-private partnership formed by international companies and organizations, such as the one formed in Europe with 10 member state partners is a good model to build the hydrogen market (Wurster R.).
- A European Joint Technology Initiative (JTI) on fuel cells and hydrogen technologies, ensuring consistency of public and the private interests in hydrogen technology R&D , and driven by commercial goals, is on the way to be estabilished. -This initiative, funded by the European Commission under the 7th Framework Programme, will involve in strong industry commitmentand it is expected that additional national and regional supports will contribute to the JTI to achieve the commercial goals highlighted in the four "Innovation and Development Actions" of European Technology Platform " Implementation Plan" The European Commission is willing to support the IEA/IPHE initiative to work together to ensure a consistency of approaches, and to share regional insights in the future of the hydrogen economy (Coda B.).
- Shell is implementing hydrogen projects in seven cities to stimulate RD&D, and researching on LNG re-gasification and low CO_2 footprint technologies to produce hydrogen (Vriesman G. van B.).
- The European Hydrogen Association, with 13 national members is fostering the development and use of hydrogen technologies in the industrial and commercial sectors.

Information and awareness campaign on hydrogen technologies and activities to encourage more players and partnerships is necessary to get more actors on-board (Reijalt M.).

- The IEA Hydrogen Implementation Agreement (HIA) is currently supporting a number of projects ranging from hydrogen safety tests to alternative hydrogen production technologies. Mass-storage infrastructure for storage and distribution for hydrogen is a key to expand the market of hydrogen technology deployment. The IEA provides the HIA with a critical factor in the RD&D cooperation (Eaton R.).
- Fuel cell technology success must be parallel with transition policies that enhance the competitive advantages of hydrogen, particularly hydrogen produced from renewables (Joseck F.).
- The majority of hydrogen fuel supply through 2050 will come from fossil fuels. The FutureGen project, a USD 1.2 billion US Department of Energy public-private partnership, will produce hydrogen from coal and have near-zero emissions (Cicero D.).
- In short term, a mixture of natural gas and hydrogen is an alternative fuel with ultra-low exhaust emissions that would utilize existing internal combustion engine technologies and infrastructure. In long term, renewable hydrogen must be pursued to combat current energy challenges (Bose T.).
- The Mitsubishi Research Institute of Japan is working on estimating the social costs related to hydrogen infrastructure deployment, to hydrogen fuel cell vehicle diffusion, and to the implementation of codes and standards. The research explores the deployment of 10 000 hydrogen vehicles in the next 12 year (Shimura Y.).
- Three fuel cell car platforms have been in development in Shanghai China since 2003. Ten hydrogen prototype cars were tested. By the end of February 2008, 43 Shanghai fuel cell cars will be produced, and 3-6 fuel cell buses will be in operation by July 2008. Twenty fuel cell cars and two refueling stations will be demonstrated during the 2008 Olympics (Ma J.).
- The hydrogen deployment will take place in five urban regions in Spain. A proper policy framework must be in place for hydrogen and fuel cells to succeed. It is necessary to develop codes and standards, adopt a national roadmap for hydrogen infrastructure development. (Chacon E.).

- The BIRD Foundation has granted USD 240 million to 743 approved joint projects. Solar driven hydrogen production program and high efficiency hydrogen storage technologies were in the scope of the Foundation (Yudilevich E.).

Key Messages and Next Steps from Planning and Design:

The key pathways for hydrogen infrastructure development include:

1. Cutting down the overnight investment costs by mass production either by centralized or decentralized production. In particular, the reduction of fuel cell production and the increase of fuel cell efficiency are the most important elements of the overall hydrogen energy system. A number of pathways to cut the costs were suggested. Turning a coal-fired power plant into a coal gasification plant aiming at polygeneration of electricity and hydrogen supported by CCS is proposed as an example.
2. Handing, dispensing and using hydrogen safely. Standards and codes are needed to ensue the safety of hydrogen use by the both the hydrogen developers and the public.
3. Increasing air quality in cities. The primary drive of the development of hydrogen technologies in Europe's largest cities has been local and regional air quality.

Other messages from planning and design include:

- It is necessary that government policies of robust, continued support for research, development and deployment are critical to the success of hydrogen technology.
- The development and deployment of hydrogen technology should be linked to national security policy.
- Government carbon reduction policy may have an impact on the deployment of hydrogen technologies. In long term, hydrogen should be produced by using clean energy technology in order to make the use of hydrogen technology comply with government climate change policy.
- The integration of renewables with hydrogen technology can be a win-win situation. For example, wind integration into grids can hardly exceed 25% of total electric installed capacities, and major markets such as Denmark, Spain or even Germany are facing difficulties in integrating additional wind turbines into their grids. As both wind and solar energies are intermittent, electrolysis for grid stabilization and subsequent hydrogen energy storage is a possible solution for maximizing wind penetration rates in large or isolated grids.

- Since hydrogen is a new player in well established energy markets, anti-trust regulations and market deregulations to avoid conflict of interests may be required. In order to stimulate creativity however, mechanisms for intellectual property rights protections, ought to be reinforced particularly for small and medium enterprises whose work would be recognized and rewarded accordingly.
- Risks in developing hydrogen technologies need to be reduced by government incentives.

Key Messages and Next Steps from Group on Engineering and Construction:

The most significant technical, financial, and institutional barriers to hydrogen infrastructure include:

1. Educating the public generally, to reduce skepticism and improve acceptance of hydrogen. Training the workforce and other hydrogen technology stakeholders who will handle the technical management jobs for the building of a hydrogen economy. Energy education centers, university programs, and the need to introduce targeted education at all levels can provide essential training skills for hydrogen to become a widely used element.
2. Convincing the public and the government in accounting all the social and environment costs in fossil energy use against renewable hydrogen energy use. The European Union will take a leader in correcting such market failures.
3. Reducing costs and increasing reliability for fuel cells are very important for constructing hydrogen economy in a large scale.
4. Hydrogen purity. Hydrogen production through reforming is well established today, but not at the purity levels required for energy applications, especially for the case of fuel cells. Similarly, for the case of electrolysis, the integration of electrolysers with intermittent renewable energy sources could affect the hydrogen purity.

Other key messages on Engineering and Construction include:

- Regarding the construction of hydrogen distribution infrastructures, it has been reiterated that existing natural gas pipelines infrastructure could be used to supply up to 30% of capacity for hydrogen.
- Energy intensive industries and chemical plants would gain in synergies when integrating hydrogen processes generated through electrolysis.

- Hydrogen fired internal combustion engines for backups are low cost devices compared to fuel cells and can be deployed easily in many places where hydrogen is a by-product in an oxygen production process.
- Small fuel cells (2-3 kW) in apartment buildings in large cities may be deployed in the near future to meet high energy efficiency and carbon emission standards and to backup power loss.
- Energy access in distributed telecommunication infrastructures or military stand alone remote surveillance systems are likely to be considered fairly early on by technology/ defense industries.

Other key messages on policy, market mechanisms and opportunities:

1. The most important issue is education of the public and its political leaders regarding energy issues generally.
2. Carbon taxes and taxing of local air emissions will facilitate hydrogen technologies.
3. More detailed analysis of the socio-economic costs and benefits of hydrogen is needed
4. A demonstration of hydrogen use in fleet vehicles and fueling station technology, funded primarily by government, can be useful for both understanding the state of technology and education of the public.
5. Cutting down the overnight investment costs by mass production either by centralized or decentralized production. In particular, the reduction of fuel cell production and the increase of fuel cell efficiency are the most important elements of the overall hydrogen energy system.
6. Handing, dispensing and using hydrogen safely. Standards and codes are needed to ensue the safety of hydrogen use by the both the hydrogen developers and the public.
7. Increasing air quality in cities. The primary drive of the development of hydrogen technologies in Europe’s largest cities has been local and regional air quality.

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IX. Appendix A

IEA/ IPHE Workshop Participants, July 10-12, 2007

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X. Appendix B

IEA/IPHE Workshop Agenda, July 10-12 2007

Tuesday, July 10, 2007

Discussion Group Planning Meeting *(IEA, Room 250)*

Group Discussion Leaders and Rapporteurs only

Welcome Reception

Wednesday, July 11, 2007

Plenary Session (IEA Conference Room 1)

Welcome

Mr. Claude Mandil, Executive Director, International Energy Agency

Building the Hydrogen Economy: Enabling Infrastructure Development

Dr. Robert K. Dixon, Head, Energy Technology Policy Division, International Energy Agency

Session I: Sharing the European Vision

The Hydrogen Strategy of the EU Technology Platform

Dr. Bernard Frois, ANR – National Research Agency, France

HyWays - The European Hydrogen Energy Roadmap - Final Results

Mr. Reinhold Wurster, Senior Project Manager - Hydrogen,
Ludwig-Bolkow Systemtechnik (HyWays coordination office)

EU-funded Initiatives for Hydrogen Infrastructure Development:
Current Status and Future Prospects

Ms. Beatrice Coda, Scientific Officer, European Commission

Renewables & Hydrogen Activities

Mr. Gijs van Breda Vriesman, GM Hydrogen Europe, Shell

Urban hydrogen projects; finding your way in European Townhalls

Ms. Marieke Reijalt**,** Executive Director, European Hydrogen Association, Belgium

Session II: Building Blocks for the Hydrogen Economy

IEA Hydrogen Implementing Agreement (HIA)

Building the Hydrogen Economy Through R,D&D Cooperation

Mr. Ray Eaton, UK Department for Business, Enterprise & Regulatory Reform

Analysis of the U.S. Market Transition to a Hydrogen Economy

Mr. Fred Joseck, U.S. Department of Energy

The Road to a Full-Scale Hydrogen Economy

Mr. Dan Cicero, Hydrogen Technology Manager, U.S. Department of Energy

Building the Hydrogen Economy

Dr. Tapan K. Bose, President & CEO, Hydrogen Engine Centre, Canada

Transition Scenario for Hydrogen Infrastructure for Fuel Cell Vehicles in Japan

Mr. Yuichiro Shimura, Mitsubishi Research Institute, Japan

Hydrogen and Fuel Cell Infrastructure Development in Shanghai

Mr. Jianxin Ma, Tonghi University, China

Hydrogen in the Spanish Energy Framework

Ms. Esther Chacón, National Institute for Aerospace Technology, Spain

Supporting Technologies for the Hydrogen Economy

Dr. Eitan Yudilevich, Executive Director, BIRD Foundation, Israel

Session Instructions

Mr. Richard Scheer, Energetics, Incorporated

Lunch

Facilitated Discussion Sessions

All participants proceed to respective session rooms. Participant session assignments will be provided at registration, and will be posted outside each session meeting room.

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 and challenges for hydrogen production facilities, delivery systems, fuel cell systems, and fueling stations; and potential public policy and market strategy opportunities for addressing these questions and challenges.

Session 1: Mobile Applications
Discussion Leader: Dr. Robert K. Dixon, IEA
Rapporteur: Mr. Michael Mills, U.S. Department of Energy

Session 2: Mobile Applications
Discussion Leader: Mr. Thomas Gross, IF, LLC
Rapporteur: Ms. Jill Gagnon, U.S. Energy Association

Session 3: Stationary Applications
Discussion Leader: Mr. Robert Donovan, U.S. Energy Association
Mr. Khalid Benhamou, Sahara Wind, Inc.
Rapporteur: Ms. Simone Luft, IEA

Session 4: Stationary Applications
Discussion Leader: Dr. Nicolas Lymberopoulos, UN Industrial Development Organization
Rapporteur: Ms. Emily Glenn, IEA

Session 5 *will focus on modeling, analysis, and scenario development issues. The discussion will begin with a series of short presentations to offer various perspectives about modeling hydrogen infrastructure implementation. The following discussion will consider fuel diversity, international cooperation, policy tools, case studies, and industry transitions.*

Session 5: Modeling & Analysis

Discussion Leaders: Dr. Dolf Gielen, IEA
Dr. Paul Leiby, ORNL, U.S. Department of Energy

Reception

Thursday, July 12, 2007

Discussions *(Same rooms as previous day)*

The facilitated group discussions will continue until 10:15 on Thursday morning for participants to review and finalize the previous day's discussions, and to prepare an oral report of the group's key findings and results. Participants will reconvene in the final plenary session at 10:30 to present oral reports from each group, and to participate in a facilitated discussion of cross-cutting themes, information gaps, and remaining issues. ***Goal:*** *Summarize Wednesday and Thursday discussions and identify major themes and other issues for analysis.*

Finalize Group Oral Reports

Final Plenary Session

Reports from the Groups & Discussion

Chair: Mr. Richard Scheer, Energetics Incorporated

Panelists: Group Discussion Leaders

Closing Remarks

Ms. Sara Filbee, Industry Canada

Adjourn

XI. Appendix C

Key Note Address by Mr. Claude Mandil, Executive Director, IEA

Ladies and Gentlemen:

It is my pleasure to welcome you to this second IEA/IPHE workshop on “Building the Hydrogen Economy” at the IEA headquarters in Paris. The broad objectives of this workshop are

3) 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

4) to inform policymakers on opportunities to accelerate these transition plans through policy instruments

This is the second of a series of three workshops. The first took place in Detroit in April, and the third will follow in Shanghai in October. We welcome the cooperation with IPHE which enables us to organize these workshops.

Let me personally thank you for your contribution to the efforts of the IPHE and the IEA when it comes to identifying potential pathways towards a future hydrogen economy. It is your expertise that will help to recognize the challenges and opportunities of transforming current energy systems to more sustainable approaches in the coming decades. In this context, hydrogen can play a major role.

I would also like to thank the IPHE for its great support to this project. As the most important international forum for advancing the hydrogen economy, it has been a very reliable and inspiring partner in this endeavor.

We have seen great R&D strides with hydrogen and fuel cells technologies. For example, hydrogen production costs have dropped, we have new opportunities to store and transport hydrogen and fuel cell costs continue to decline. We need to plan for R&D success, including the consideration of various scenarios of hydrogen infrastructure development.

Moreover, we would like to thank the IEA hydrogen coordination group which has produced three important reports on the potential of hydrogen fuel within the last couple of years. These include

1. Hydrogen and Fuel Cells: Review of National R&D Programs

2. Prospects for Hydrogen and Fuel Cells

3. Hydrogen Production and Storage: R&D Priorities and Gaps

You have made an important contribution to objectives which are also addressed by this workshop.

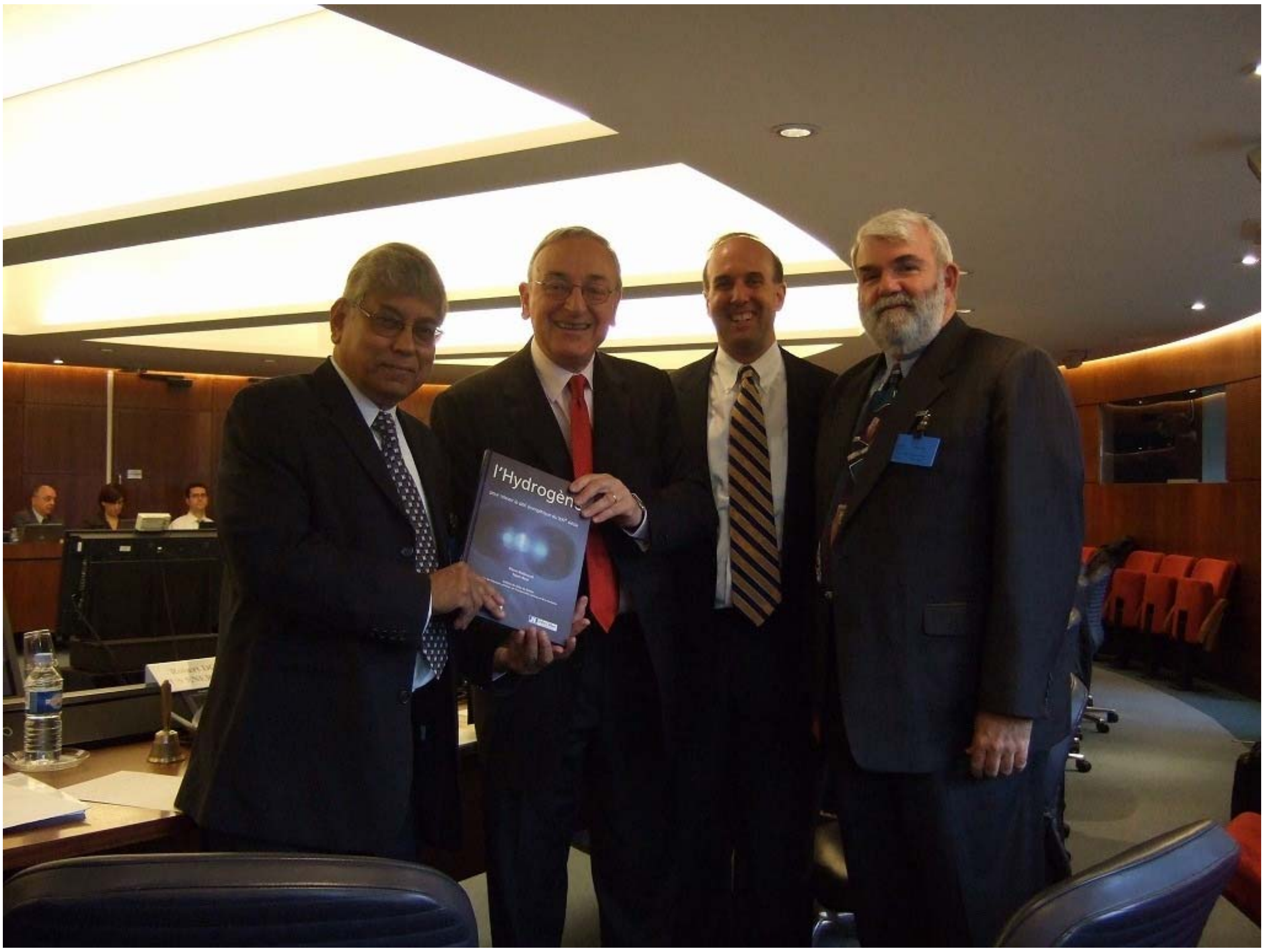
We are pleased that the efforts of participants to this workshop will build upon such prior analysis and have appreciated the support of the IEA ministerial and the G 8 summit in Heiligendamm to the objectives of this project. Hydrogen and fuel cell technologies in transport and stationary applications received attention in both communiqués.

Let me conclude my introductory remarks by wishing you all a productive meeting and many interesting discussions with fellow experts from all over the world.

We are pleased to have you here and please do not hesitate to contact IEA staff if you are in need of any support.
Thank you

Claude Mandil
Executive Director

XII. Appendix D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