Building the Hydrogen Economy: Enabling Infrastructure Development

Part III: Sharing an Asia-Pacific Vision

October 22-24, 2007

Shanghai, China

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I. Acknowledgements

This publication was prepared by the International Energy Agency's (IEA) Office of Energy Technology and R&D. The authors of this publication are Mr. Graham Campbell, Natural Resources Canada, Ms. Annie Desgagne, Industry Canada, Dr. Robert K. Dixon, IEA , Dr. Dolf Gielen, Energy, IEA, Mr. Lun Jingguang, Tsinghua University, Dr. Paul Leiby, Oak Ridge National Laboratory, Mr. Michael Mills, U.S. Department of Energy, Mr. Wang Shudong, Chinese Academy of Science, Mr. Ren Xiangkun, Shenhua Group, Dr. Ming Yang, IEA, Mr. Xiao Yunhan, Chinese Academy of Science, Mr. Yu Zhuoping, Tongji University and Ms. Simone Brinkmann, IEA. The information and ideas contained in this document are based upon the IEA and the International Partnership for a Hydrogen Economy (IPHE) joint workshop 22-24 October 2007, Shanghai, titled "Building the Hydrogen Economy: Enabling Infrastructure Development/ Part II: Sharing an Asia-Pacific Vision."

The authors would like to acknowledge the contributions of Mr. Neil Hirst, IEA, and Mr. Barry Worthington of the United States Energy Association (USEA). We also acknowledge the contributions of all the speakers and participants who attended the workshop, and who provided their ideas and suggestions that have been summarised in this document. Special thanks to the Session Discussion Leaders: Mr. Graham Campbell, Ms. Annie Desgagne, Dr. Robert Dixon, Mr. Michael Mills and Dr. Dolf Gielen. Thanks to the Discussion Session Rapporteurs: Mr. Lun Jingguang, Tsinghua University, Dr. Paul Leiby, Oak Ridge National Laboratory, Mr. Wang Shudong, Chinese Academy of Science, Mr. Ren Xiangkun, Shenhua Group, Mr. Xiao Yunhan, Chinese Academy of Science, and Mr. Yu Zhuoping, Tongji University.

Dr. Ming Yang played an important role in developing and organising the workshop. We offer special thanks to our Chinese hosts including the Ministry of Science and Technology of the People's Republic of China, Tongji University and Shanghai Centre for Scientific & Technological Exchange with Foreign Countries (SSTEC). The Chinese Academy of Science and Tsinghua University also put significant efforts to this workshop. General Motors provided a financial contribution to the workshop. We acknowledge the contributions of Mr Ma Jian Xin of Tongji University and Ms Milly Liu Tingting of SSTEC for their logistic arrangements for the workshop.

We are grateful to the IEA web and publications teams for facilitating the workshop and preparing the workshop deliverables. Dr. Dixon and his team are grateful for the support and cooperation of the IEA Committee on Energy Research and Technology (CERT) and the IPHE Steering Committee.

This work was funded in large part by the IEA/IPHE project "Building the Hydrogen Economy: An Infrastructure Strategy," launched in 2007 by Dr. Robert K. Dixon and supporting IEA/ IPHE members. Voluntary contribution for this project and workshop were provided by Australia, the United Kingdom and the United States.

II. Foreword

Nobuo Tanaka, Executive Director, International Energy Agency

The IEA Secretariat and the Ministry of Science and Technology of the People's Republic of China and Tongji University of China co-hosted the third International Energy Agency (IEA) / International Partnership for the Hydrogen Economy (IPHE) workshop "Building the Hydrogen Economy: Enabling Infrastructure Development, Sharing an Asia-Pacific Vision" 22-24 October 2007, Shanghai, China. This was the third of a series of three workshops. The first took place in Detroit, Michigan, USA, April, 2007 and the second in Paris, France, July 2007. We welcome the cooperation with the IPHE which enables us to organise these workshops. As an important international forum for advancing the hydrogen economy, the IPHE has been a very reliable and inspiring partner in this endeavour.

The broad objectives of the workshop were to:

1) Convene public and private sector officials from the Asia-Pacific region 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 and Paris workshop key messages and conclusions, and appreciate 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 realised.

Nobuo Tanaka
IEA 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 realised 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 fuelling stations for vehicles, and vehicle/fleet trials. A fair number of hydrogen highway projects have been announced, planned or are under construction in Europe, Japan and North America. An equally robust number of demonstration and deployment projects have been realised in the distributed energy sector, including recent announcements to build 500 MW hydrogen fuelled power plants. Public-private partnerships are the foundation for most of these activities.

Most member countries of the Organisation for Economic Co-operation and Development (OECD) and some 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, Asia and North America. For example, 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.

Goals and Objectives

The overall goals of the project Building the Hydrogen Economy are to: (1) to convene public and private sector officials in an international strategic process to evaluate transition planning scenarios for the expansion of infrastructure development for the hydrogen economy; and (2) inform policymakers on opportunities to accelerate these transition plans through both public policy instruments and market mechanisms. Three workshops were convened in the process:

April 2007, Detroit, Michigan, July 2007, Paris, France and the subject workshop. The 22-24 October 2007, Shanghai, China workshop focused on Sharing an Asia-Pacific Vision. Common methodologies and tools will be used to link existing analyses, and additional analyses will be undertaken for key developing economies (e.g. China, Brazil, and India). Specific objectives of the Shanghai workshop include:

- Convene public and private sector officials from the Asia-Pacific region 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 and
- 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. The Asia-Pacific Vision for Hydrogen and Fuel Cell Technologies and Policies

The Asia-Pacific region has a deep and broad commitment to developing the hydrogen economy. Nations across the region have been active contributors to global and regional hydrogen and fuel cell research and development activities. Strategic policy drivers for Asia-Pacific hydrogen and fuel cell technology investments include security of energy supply, mitigation of greenhouse gas emissions and local pollutants, and economic competitiveness.

Public sector investments by Australia, Canada, China, Japan, Korea and the United States for hydrogen and fuel cell research and development programs constitute some of the largest and most expansive in the world. Hydrogen and fuel cell investments are emerging in Malaysia, Thailand, India, and Indonesia. Each nation, based on its economic structure and natural resource endowments, has its own research, development, demonstration and deployment activities in both stationery and mobile applications. The depth and breadth of these programs are summarized in Appendix C.

The Asia Pacific Economic Cooperation Energy Working Party (APEC EWG) has made the development of hydrogen and fuel cell technologies a recent priority. The APEC EWG has worked cooperatively with the IEA and the IPHE to coordinate and leverage hydrogen and fuel cell activities in the region.

The European Union (EU) works cooperatively with nations of the Asia-Pacific region on a number of projects include the Clean Urban Transport (CUTE) program established hydrogen power transport bus demonstration and deployment trials in key cities across the region. The CUTE trials leverage public and private investments and provide real-time data on performance of hydrogen power vehicles.

Public-private partnerships have stimulated the development and testing of hydrogen fuelling stations in key cities across the Asia-Pacific region. Island states, such as Singapore, are evaluating the suitability of hydrogen as an energy carrier for transport systems.

The UN Industrial Development Organization (UNIDO) recently established the International Centre for Hydrogen Energy Technologies (ICHET). The mission of ICHET is to provide technical and financial assistance to developing countries, including those in the Asia-Pacific region as they advance their portfolios of hydrogen and fuel cell technologies.

In summary, some of the world's largest and fastest growing economies are located in the Asia-Pacific region. Sustainable development and energy security are high on their national agendas. The development of alternative technologies and policies, such as hydrogen and fuel cells, are a significant component of their clean and competitive energy agendas.

V. Discussion Groups: Structure and Summary of Discussions

Group 1: Regulations, Codes and Standards for a Hydrogen Economy

Michael Mills, US Department of Energy and Lun Jingguang, Tsinghua University

Prior workshops addressed planning, design, construction, and operation issues relating to hydrogen and fuel cell infrastructure development. Regulations, Codes and Standards (RCS) were repeatedly identified as key issues. To build on this theme, a workshop session was dedicated to discussing the barriers, opportunities, lessons learned, and best practices for RCS development and implementation. The discussions centred on three main themes: 1) issues relating to RCS development and implementation, 2) lessons learned and best practices and 3) prioritisation of RCS focus areas for international government organisations.

Issues relating to RCS Development and Implementation

Through the course of discussion, the participants quickly identified two fundamental issues with attempting to coordinate internationally to advance the development of RCS in order to promote the widespread use of hydrogen technologies: countries have different terminology and regulatory approaches for developing and implementing RCS. For example, China indicated its RCS are all developed and implemented at the national level while many other countries employ a system whereby regulations are developed at the national level but codes and standards are developed at the regional or city level. To further complicate this difference, the group learned that the terminology of RCS seems to differ across the International Energy Agency (IEA) and International Partnership for the Hydrogen Economy (IPHE) countries.

Additional issues identified through the group dialogue related to the implementation of projects and the RCS barriers. Participants agreed that we are in the middle of a transition phase for development of hydrogen and fuel cell RCS. This results in a bottleneck between existing, feasible technology and its deployment. Part of the delay for establishing RCS may relate to the private sector’s hesitation to share some technical data necessary for applicable entities to move forward with creating RCS. This could be a reason for some temporary standards not making the transition to final standards, which creates an enabling environment for technology deployment. Another barrier identified was that some international standards lack enough specificity to be actionable. Their generality makes them ineffective when used to address local RCS requirements.

Lessons Learned and Best Practices

The participants identified lessons learned and best practices that governments could implement to overcome the barriers to RCS development and implementation. The main unifying theme of the discussion was the value of sharing RCS experiences with similar technologies to ensure that best practices and experiences are transferred to nations, states and local entities engaging in domestic hydrogen infrastructure RCS development. Governments, private sector and other entities involved in RCS development should strive to maximise the dialogue in both bilateral and multilateral forums. Participants provided examples of how sharing information and learning from others work has already helped develop RCS for specific applications. Specifically, the city of Shanghai recently coordinated with Australian cities to transfer their experience with liquefied propane gas (LPG) RCS to the Shanghai LPG taxi program.

The group also identified how national governments may be able to best facilitate the development of RCS for hydrogen and fuel cell infrastructure. First among the suggestions is to address the issues of regulations separately from codes and standards. Another key component is national government-led planning and research activities. National governments should provide leadership by conducting comprehensive strategic planning and coordination to enable a sustained, long-term effort to develop the necessary RCS to address the specific needs for each country. To enable the specific RCS development, national governments can: 1) couple research organisations to appropriate national, local and industry entities to work together to address the priority issues, 2) strive to connect industry project developers with appropriate standards bodies, and 3) organise codes and standards research to facilitate the development of effective regulations. These government and industry collaborations should have a co-benefit of increasing the access to technical data from private industry activities. Finally, all government entities should be the voice of confidence that technical safety issues for hydrogen and fuel cell technology will not be a limiting factor in the development of the hydrogen economy. Focusing on educating safety officials is critical because their perception will be critical to public acceptance.

Prioritisation of RCS Focus Areas for International Organisations

The final discussion focused on topics international organisations could consider to advance RCS development. The group emphasised that the issue of RCS is extremely large and complicated; with no one size fits all approach. To best address this reality, the group recommended addressing RCS issues in phases. In order to ensure all participants have a common understanding of the issues and practices involved, the harmonisation of RCS terminology, definitions and methodologies for research and development should be a priority. The importance of sharing data and experiences was highlighted again in this session because the group feels that international organisations can play a significant facilitation role in creating forums for discussion and exchange, and to ensure appropriate entities are connected. In a related area, the participants felt that international organisations could also be integral in helping resolve RCS issues that apply to large-scale projects involving many networks, institutions and countries. Finally, and continuing the scale-up theme, these organisations may be most effective if they prioritise their activities to address critical RCS issues relating to the development of large-scale commercialisation projects. Successful implementation of initial large-scale projects will create an infrastructure backbone that would facilitate the expansion necessary to meet the needs of the majority of the population.

In conclusion, the group identified several recommendations for national and international entities to consider for promoting the development of RCS for hydrogen and fuel cell infrastructure development. The participants emphasised the need to share experience and lessons learned in order to leverage successful efforts and increase the speed and effectiveness of RCS development. They felt that national governments were in a unique position to provide the necessary leadership through strategic priority setting and education on hydrogen and fuel cell safety. Finally, the group thought that international organisations could maximise their influence on RCS development by focusing on harmonising terminology and definitions and focusing on large-scale efforts that will provide the backbone from which the majority of hydrogen and fuel cell infrastructure could be built.

Group 2: Hydrogen Production

Robert K. Dixon, IEA and Xiao Yunhan, Chinese Academy of Science

Approximately 20 technical, policy and finance experts drawn from academia, the private sector and governments convened to consider and explore five questions:

1) What are the likely pathways for the development of hydrogen production infrastructure?
2) What are policy and market mechanisms that could help enable the development of hydrogen production infrastructure?
3) What are the significant technical, financial and institutional barriers to constructing and operating future hydrogen production infrastructure?
4) What are the significant policy and market mechanism barriers to constructing and operating future hydrogen production infrastructure?
5) What are the potential public policy initiatives and market strategy opportunities for making the pathways a reality?

Likely Pathways for the Development of Hydrogen Production Infrastructure

Likely pathways for the development of hydrogen production infrastructure were the first topic explored. It was generally agreed that hydrogen energy should be based upon existing primary energy sources, such as nuclear energy, fossil energy, and renewable energy. In terms of infrastructure, producing, storing, and transporting hydrogen is a multipath, multi-step process, and some participants believed that producing hydrogen near its points of use would be the most viable solution. Others suggested building out from the existing hydrogen supply infrastructure, or building upon the backbone of the natural gas distribution network.

Representatives of China's Bao Steel claimed that plants they are operating in all Chinese provinces produce hydrogen as a by-product of the coking process. Research and development of this hydrogen production technology continues. Bao Steel estimated that if the coking gas-based hydrogen supply is realised at a large scale, it could provide as much as 500 million cubic meters of hydrogen annually.

Large coal deposits are co-located with some of the world's largest economies. Thus, coal to hydrogen production was discussed. Some participants doubted the environmental integrity of this technology as the resulting carbon dioxide emissions are greater than those from any other method of producing hydrogen. Carbon sequestration technologies are relatively new and untested but could become important future component of coal to hydrogen production.

Production of hydrogen from natural gas is a proven low-cost technology. Australia and China both have research and production projects that are exploring the viability of coal gasification. China has plans to develop 20-100 GW of power from Integrated Gasification Combined Cycle power plants by 2020.

Participants considered production of hydrogen from nuclear energy a viable option in countries that accept this technology. The future of nuclear energy technologies is promising but regulatory, policy and finance factors may limit the rapid or efficient expansion of this hydrogen production option.

Renewable energy (e.g., solar, hydro, biomass, geothermal and wind) can also become important contributors to hydrogen production in the future if this technology can be perfected and the installation and operating costs can be reduced. Hydrogen production and storage could become an important ally to the development of distributed energy technologies including renewables.

Policy and Market Mechanisms for the Development of Hydrogen Production Infrastructure

The participants then discussed the policy and market mechanisms that could help enable the development of hydrogen production infrastructure. This free-wheeling discussion topic evoked a long list of public policy and market based mechanisms that could help advance hydrogen production infrastructure. Potential policy levers include: energy and environment regulations, tax codes, infrastructure development incentives, research and development investments, etc.

Representatives from General Motors (GM) offered a list of public policy action items that could be considered by governments. Participants agreed the list identified many important topics. One participant pointed out that the list of action items and requests provided by GM focused almost entirely on socioeconomic and policy challenges. Financial and social constraints, of course, are major obstacles to the development of a hydrogen economy. Policies that nurture or induce a hydrogen economy should be favoured – a revolution will be necessary, rather than an evolution; and this transition would be the largest managed social change ever experienced by OECD countries.

A discussion participant pointed out that short-term political decisions rarely benefit technology development pathways. In order to advance the hydrogen economy, it will also be important to train the next generation of skilled labour, as well as develop sound carbon management policies. Technology research and development policies should stay the course.

Significant Technical, Financial and Institutional Barriers

Session participants then considered significant technical, financial and institutional barriers to constructing and operating future hydrogen production infrastructure. Technical barriers exist for production of hydrogen from fossil, nuclear and renewable energy sources. Most of these technical barriers are being address in research and development programs. Deployment and dissemination of these hydrogen production technologies is emerging as an important consideration. Public and private sector finance is not adequate to develop and deploy hydrogen energy technologies. In some instances, the technologies themselves (both hydrogen and fuel cells) are not yet sufficiently mature and finance of new ventures is considered highly risky.

Public and private institutions to nurture and develop the hydrogen economy, including hydrogen production infrastructure, have not yet fully developed. Hydrogen technologies are relatively unknown and the nascent community leading their development has not matured as an institutional force in academia, the public sector or the private sector.

Hydrogen energy technologies are in their infancy and are not widely known or understood and many barriers impede their deployment and implementation. Informing policy makers and the general public is an important first step to developing the hydrogen economy. For example, formal and informal institutions, such as auto clubs, can be helpful to build-out and operate a hydrogen economy, and the matter of land availability for hydrogen production, storage, and transportation facilities must also be seriously considered. Robust hydrogen and fuel cell regulations, codes and standards will continue to play a central role in addressing technical barriers.

Significant Policy and Market Mechanism Barriers

Participants also address the question: what are the significant policy and market mechanism barriers to constructing and operating future hydrogen production infrastructure? Participants all agreed continued support for hydrogen technology research, development, deployment and dissemination is essential. While hydrogen technologies are in their infancy governments can play a key role by advancing financial incentives such as tax breaks and subsidies, as well as the international harmonisation of regulations, codes, and standards will all play a critical role in the development an international hydrogen economy.

In terms of market-related mechanisms, the interoperability of technical components (e.g. in automobiles), the development of niche markets (forklifts, cycles), the education and training of the labour force, and demonstration programmes should all be promoted. Also, it is important to get the price signal right for these technologies, and public expectations must be managed to avoid disappointments.

Group 3: Stationary and Mobile Applications

Graham Campbell, Natural Resources Canada and Wang Shudong, Chinese Academy of Science

Approximately 20 experts, researchers and private sector representatives participated in the break-out group on the infrastructure aspects of stationary and mobile applications for fuel cells. The group considered five questions, and then exchanged views on aspects of the future of fuel cells.

1. What are the recent developments of stationary and mobile applications for hydrogen in the Asia-Pacific region and what is their relevance for the evolution of a future hydrogen infrastructure?
2. What are the likely pathways for hydrogen infrastructure development in the Asia-Pacific region?
3. In reference to the likely pathways, what are the major remaining opportunities and challenges, of a technical, institutional and financial nature, for hydrogen production facilities, delivery systems, fuel cell systems, and fuelling stations?
4. What are the most significant barriers to making these pathways a reality, of a technical, financial and institutional nature, both to constructing the pathways and to operating them?
5. What are the potential public policy initiatives and market strategy opportunities for making the pathways a reality?

The comments on each question made by the participants are summarised as follows:

Recent Developments of Stationary and Mobile Applications

The group recognised the rapid progress in Combined Heat and Power (CHP) applications, highlighted by 1 200+ installations in Japan’s household CHP program.

Blended natural gas and hydrogen fuel is becoming more interesting for transportation and stationary power applications, since only limited modifications to pipeline systems and engines are required. There are many upcoming flagship projects where hydrogen and fuel cell applications will receive international attention – Beijing 2008 Olympics, Shanghai 2010 World Expo, 2010 Winter Olympics in Whistler, Canada, and the 2012 Summer Olympics in London.

The group emphasised that hydrogen production must come from emissions-free sources, since hydrogen production from fossil fuels without CO_2 capture could increase emissions.

A general observation was the growing sense of divergence between the rapid technical progress in fuel cells and the slower pace of developments in the area of hydrogen supply. There is more work to be done to determine the optimum storage pressure, taking account of safety, costs of pressurisation, etc. High capacity storage using 70 MPa tanks are a promising possibility.

Hydrogen is seen by some as the ultimate fuel, since it can be sourced from a variety of resources – coal, wind, biomass, photovoltaic's (PV) – although such applications are generally not yet financially and economically viable. Hydrogen can offer the renewables industry a means to store energy and thereby avoid the problem of intermittency, but costs are seen to be high in most places. Hydrogen produced from nuclear reactors can be stored for later use when peak power is needed. This arrangement allows a nuclear-based system to provide peaking power.

Possible Hydrogen Pathways

The group identified a wide range of pathways for the future evolution of the hydrogen economy. "niche" markets exist now such as local fleets, fuel cells for forklift trucks, "back up" power for remote mobile phone stations, and emissions-free underground mining equipment.

Initially, hydrogen supply could be provided by capturing waste hydrogen from industrial plants, coke ovens or refineries. The practicality is limited by the costs and emissions arising from transporting the hydrogen from the source to the point of use; 35 km was the reported maximum distance. A more practical application is fuel cells installed at a plant where waste hydrogen is available from industrial processes. This application could be the basis for claiming carbon dioxide ($CO_{2)}$ offsets by the plant owner.

There will be applications for hydrogen in remote electricity grids where population density is low and where the operating margins for power suppliers are limited, since it's difficult and costly to extend transmission and distribution capacity to remote areas. Hydrogen systems offer a promising solution in the form of off grid generation and storage which may include wind-hydrogen or PV-hydrogen with battery back-up.

Since there is only limited demand at present from the transportation sector, fuelling stations dedicated to transportation applications will be uneconomic. Local demand in the vicinity of vehicle fuelling stations could be increased by connections to fuel cells in residences and industry, along with the vehicle fuelling stations.

Oil refineries are not interested in hydrogen capture now due to the high costs, but their processes can be changed to capture the hydrogen readily. A historic example of industry's response to a regulation is the elimination of lead from gasoline.

Challenges and Opportunities

The group then turned to a discussion on the many challenges which confront widespread development of the hydrogen economy which included the following comments.

Project financing costs are higher for hydrogen projects than for conventional energy projects due to the lender's concern about risks associated with a new technology. One estimate is a premium of 20% for hydrogen projects in the European Union (EU). Perceptions of public concern also lead to higher lending rates.

The hydrogen economy is not becoming a practical reality as quickly as expected, and as a result some hydrogen/fuel cell companies are down-sizing and investment is becoming harder to find. This observation underlines the importance of continued investment by government to keep moving the technology ahead, based on the view that hydrogen offers a promising solution for clean energy in the future.

There is a perception that there are many barriers to widespread use of hydrogen, which leads to a reluctance to make the initial investments to get a market started. The “chicken and egg” problem is well-known. There is a recognised need to install large-scale infrastructure in order to get the hydrogen market moving.

Another paradox is that the technology knowledge is generally held in major developed countries (Japan, USA, EU) whereas the major large-scale market opportunities are in rapidly developing countries. The perceived lack of IP protection in some rapidly developing countries acts as a barrier to investment and partnerships.

The public expectation is that fuel cells will provide equivalent performance and convenience from the outset in comparison to conventional engines. New hydrogen technologies will experience start-up problems, which is typical for all new technologies.

The current practice of ignoring the environmental consequences of energy activities should be replaced with a proper “full cycle” accounting. Energy has been seen as being cheap to this point, in part because the emissions and effluents have not been properly accounted for. The government should educate the customers about the overall benefits including environmental benefits, arising from new hydrogen technology. If this was done, then hydrogen would compare more favourably with conventional fuels.

Are we sure that hydrogen is always the best answer, or do we need to also consider alternative technologies? This is a critically important consideration for those providing advice to governments.

The hydrogen economy is not becoming a practical reality as quickly as expected, and as a result some hydrogen/fuel cell companies are down-sizing and investment is becoming harder to find. This observation underlines the importance of continued investment by government to keep moving the technology ahead, based on the view that hydrogen offers a promising solution for clean energy in the future.

Without a “cost of carbon” policy instrument, there is little incentive to replace polluting technologies with new clean technologies. Hydrogen is suffering from this situation now.

Public Policy Initiatives

A number of promising ideas were identified, based on the Group's earlier discussion on opportunities and challenges.

One recommendation is to make use of a suite of well-known policy measures – carbon taxes, incentives for hydrogen development, tax exemptions for hydrogen equipment, government procurement, for example.

Another recommendation is to explore the possibility of finding ways for countries with fuel cell technologies to deploy their technologies in rapidly developing countries. Large-scale deployment will likely take place first in those countries. However, industry support for encouraging early widespread development in rapidly growing economies will depend on provisions for protection of IP.

A third recommendation is to proceed aggressively with work on codes and standards, including participation in the work of ISO and other standard-setting organisations.

Finally, the group recommended better public information flow through frequent and properly worded communications to describe hydrogen, its advantages and related issues to the public in a fully objective manner.

China's Perspectives on Hydrogen and Fuel Cells

The group discussed how other countries could assist China to become more involved in hydrogen? Even if the cost of fuel cells was acceptable, and the public policy was in place, issues remain which need attention. Two issues mentioned in the discussion were:

Need for a commercially-successful demonstration project, which demonstrates that the technologies work well and that the investment is profitable. Some technical problems have been recognised, for example, the reliability of fuel cells which operate in applications where they are subject to frequent "on-off" cycles. The group indicated that much more discussion is needed to develop these ideas further.

Group 4: China World Exposition in Shanghai 2010

Annie Desgagne, Industry Canada and Yu Zhuoping, Tongji University

The session focused on opportunities to integrate hydrogen and fuel cell technologies in the operation and exhibits of the World Expo 2010 to be held in Shanghai. Expo aims to promote the exchange of ideas and development of the world economy, culture, science and technology, to allow exhibitors to publicise and display their achievements and improve international relationships. 2010 World Expo will be held from May 1st to October 31st, 2010, in Shanghai, at the Waterfront of the Huangpu River between Nanpu Bridge and Lupu Bridge, downtown Shanghai, a defined area of 3.28 square kilometres. The goal is to have area is a zero emission fairground which offers opportunities for showcasing leading edge clean technologies.

Expo 2010 Shanghai China will explore the full potential of urban life in the 21st century and a significant period in urban evolution. Fifty-five percent of the world population is expected to live in cities by the year 2010. The prospect of future urban life, a subject of global interest, concerns all nations, developed or less developed, and their people. Focused on the theme "Better City, Better Life", Expo 2010 Shanghai China will centre on innovation and interaction. It is expected to bring together 200 nations and international organisations to take part in the exhibition as well as 70 million visitors from home and abroad. The venue will leave a legacy of urban development to people throughout the world.

Mr. Qian Wei, Deputy Director of the Transportation Management Department, Bureau of Shanghai World Expo Coordination, presented the Expo 2010 team Clean Transportation Strategy which includes railways, ferries, buses, micro vans, and personal cars. Technologies to be showcased include electric, battery powered + super caps, fuel cells and hydrogen technologies.

Clean Transportation Strategy Proposed Fleet

- 150 Buses (new energy resources including up to 10 fuel cell buses, hybrid electric, battery electric and super-caps)
- Vehicles for senior officials

    - 10 fuel cell mini buses
    - 40 fuel cell cars
- 60 fuel cells sightseeing vehicles (micro-vans) running on a circular route in the Expo Park
- Possibility of having fuel cell vans and/or super-capacitor electric vans for transportation within the park

The Hydrogen fleet is to be supported by two re-fuelling stations, one mobile and one stationary. The mobile re-fuelling solution will be provided by Xin Ao Jiu Huan in cooperation with Tongji University.

Partnerships

The partnership team plan will be made up of representatives from the Shanghai municipal government, private industry and academic partners to implement this plan. Key partnerships are as follows:

Government Clean Energy Team:

- Shanghai Scientific Committee
- Shanghai Construction and Transportation Committee
- Bureau of Shanghai World Expo Coordination
- Shanghai New Energy Vehicle Promotion Office
- Shanghai Fire Fighting Bureau
- Shanghai Quarantine and Quality Inspection Bureau
- Shanghai Safety Inspection Bureau

Private-Public Partnerships:

- Including General Motors, SAIC, Shanghai Fuel Cell Vehicle Powertrain Corp., Shen Li, Tongji University, Shanghai Jiaotong University
- Refuelling provision to include Xin Ao Jiu Huan in cooperation with Tongji University. Others still to be confirmed.

Key Messages to be communicated during the Expo were developed during the session and are as follows:

- Hydrogen and fuel cell technologies are real. Fuel cell cars are relatively near-term.
- Vehicles can be easily re-fuelled and cars are comparable in handing similar to ICE cars on the road today.
- Hydrogen is safe.
- China Government leadership to find solutions for GHG emission reductions.
- H_2 is an important part of the regional clean transportation strategies and is being demonstrated at Expo 2010.
- Highlight national and international government-industry partnerships in finding new solutions.

It was noted that Hydrogen cars are not currently approved to travel on public roads in Shanghai area and that there is an opportunity to benchmark what other nations/municipalities are doing in the area of safety, codes and standards. This item was further discussed in the Codes and Standards session. The idea of supporting the demonstration with a showroom on hydrogen safety featuring presentations made up of materials for automotive manufactures and others was also brought up by the group.

Key Actions

A number of new initiatives were discussed and brought forward for consideration. Potential new initiatives for consideration included:

1. Additional vehicles: Opportunity for fuel cell vehicles for catering/distribution of goods, fuel cell powered forklifts to help with goal of zero emission fair ground. The Bureau of Shanghai World Expo Coordination indicated they would take this idea under consideration. This may present potential opportunities to partner with Canada and other nations.
2. Power Generation: Opportunity for stationary/back-up power was also to be taken back to the Bureau of Shanghai World Expo Coordination.

3. Education and Awareness: All players should work together to promote and educate public.
4. One particular recommendation was put forward to the IEA/IPHE for consideration. The Shanghai stakeholders asked the IEA/IPHE to work with them to seek out an international body to set up a booth on the hydrogen economy at the Shanghai Expo. The World Bank, UN, and Professional Engineering Institutions were mentioned as possible entities. The entity would require the capability to present large scale and special lighthouse projects. The Showcase could include education materials, and technologies from Chinese and other manufacturers around the world. The objective would be to promote awareness of environmental issues, the role of hydrogen and fuel cells in sustainable development strategies. This could also be a good way to engage the Chinese Ministry of Science and Technology.

Group 5: Modelling the Hydrogen Economy in the Asia-Pacific Region

Dolf Gielen, IEA, Paul Leiby, Oak Ridge National Laboratory, and Ren Xiangkun, Shenhua Group

Broad Topics of Prior Discussions:

Key modelling issues identified at prior workshops in Detroit and Paris were the basis for the modelling discussion that focused on the use and development of a tool box for H_2 Infrastructure/Transition Analysis. Five topics were discussed:

1. Important questions models are to address regarding H_2 transition and infrastructure development;
2. Identifying gaps in current models and analyses;
3. Developing a model "Toolbox for H_2 Transition Analysis"
   Beginning an inventory;
4. Issues for Model Use, Validation and Reconciliation
   Better understanding of the purpose of various models;
   How to link several models; and,
5. A future International Modelling Forum on H_2 Infrastructure Development.

Policy Modelling Questions

The following key modelling questions were identified and considered:

- How to model the impact of technology policy?
- How to model consumer behaviour?
- Short term vs. long term policy?
- How can policy strategy/robustness be evaluated?
- How can the system and spatial analysis be improved and interdependencies with other sectors be assessed?
- How can the transition be envisions and measures, notably the cost and financing aspects?

Gaps in Current Models and Analysis

A number of important gaps in current models and analysis were discussed:

- Baseline technology characterisation and modelling technology change;
- Modelling risk and uncertainty;
- Modelling individual and firm behaviour;
- Broader systems issues; and,
- Sector interactions, resource use, policy goals.

The main interest regarding different modelling methodologies is not their importance as academic question, but for understanding limitations (or determinants) of scenarios and analyses. Important challenges exist in reconciling analyses with a different geographical scope (regional, country, multi-country). While a common desire and pressure exists to expand/include more into existing models, development of a toolbox seems a more productive way ahead as different models can answer different questions

Important gaps remain in the understanding of current models in terms of what they tell us now (inputs, outputs, insights) and their limitations. A summary characterisation of existing models was established. It was suggested to poll the modellers for the key value added ("5 key insights") and underlying philosophy of their tools.

Model Type	Model Name	Model Developer
Supply chain pathways and tradeoffs	H2A	U.S. DOE/ANL, NREL
	HDSAM	U.S. DOE/ANL, NREL
	E3 Database	LBST
	GREET WTW Emissions	U.S. DOE/ANL

	HyPro	U.S. DOE/Directed Technologies
	MSM	U.S. DOE/NREL
Integrated economic systems	ETP (Global)	IEA
	Markal	ETSAP
Country/region economic systems	HyTrans	U.S. DOE/ORNL
	H2CAS	U.S. DOE/ANL
	NEMS	EIA
	Idealised City Model	UC Davis
	HIT	UC Davis
	Ohio Case Study	UC Davis
	Hydra	?
	H2M SEI-US	US.DOE, NREL
	CA Rice Straw Study	UC Davis
Environmental models (local pollutants)	?	?

Hydrogen Economy Modelling Toolbox: Preliminary Inventory and Characterisation

Issues for H_2 Model Use and Reconciliation

Some progress has been made in reconciliation and harmonisation of modelling assumptions, for example with regard to technical data for H_2 supply, emissions data, etc. However in models "one size does not fit all". It is important to account for regional/country differences regarding resources, policy, vehicle sets, planning issues. Important model differences can be explained by their different objectives. Business and policy problems require a different modelling approach.

Conclusions Regarding Linking and Using the Models:

- No hard linking of models is anticipated;
- Still, important insights can be gained by "soft linking";
- A "global" model that can answer all questions is not a very likely outcome;
- It is better to use insights from established regional models, instead of building new ones;
- Models can be used to identify bottleneck issues;
- Explore expected impact of policies in different major global regions; and,
- Reveal region specific infrastructure patterns.

Using the models in concert, information flows in two directions. It is best to use models run by their expert users, using common assumptions. This could be done in an overall global framework managed by IEA, where each regional model provides regional outcomes and different insights. The participants agreed this would be useful. For example:

- HyWays for Europe
- US Suite of DOE models (H_2A etc.)
- For the Asia-Pacific region, a more thorough inventory is needed

International Modelling Forum on H_2 Infrastructure Development

The participants agreed that it would be a good idea to submit a proposal for an international modelling forum to the IPHE Steering Committee. Provided the IPHE expresses interest the next step would be

- Prepare a framework for integrated model analysis;
- Develop a global outlook vision; and,

- Update and broaden the IEA Prospects for Hydrogen & Fuel Cells publication.

Next Steps

Refine the model characterisation table and present the idea of an international hydrogen transition and modelling forum to the IPHE Steering Committee;

Presentation and Discussion Items

Le Chang (Tsinghua University) presented on behalf of Prof. Zheng Li their work on static and dynamic analysis for hydrogen transitional infrastructure in China. One remarkable feature is that the analysis also includes a methanol pathway (methanol on-board reforming to hydrogen). This option is interesting for China because:

- Methanol is easily available – already introduced today;
- Methanol pathway is the cheapest from 200 km (USD 2.25/kg H_2);
- Methanol pathway will play a key role in China;
- Electrolysis is not acceptable in China;

The methanol model is dynamic in the sense that demand is variable. A key element is a new methanol-to-hydrogen reforming technology (DICP).

VI. Appendix A: Discussion Group Participant List

Group 1: Regulations, Codes and Standards

Discussion Leader and Rapporteur

Michael MILLS
US Department of Energy

Jing-Guang LUN
Tsinghua University, China

Group Participants

Xiao-Wen DAI
Adv Tech Management, GM China

Karine FILMON
ADEME, France

Bemard FROIS
CEA, France

Yong-Pin HOU
Tongji University, China

Cornie HUIZENGA
Clean Air Initiative for Asian Cities Centre, Philippines

Fred JOSECK
US Department of Energy, USA

Jian-Xin MA
Tongji University, China

Wei-Min RUAN
Shanghai Shinoku Ninth Ring Vehicle Energy Ltd., China

Rohan TEPPER
Department of Industry Tourism and Resources, Australia

Yin TIAN
Shanghai Aerospace Energy Co., Ltd., China

Barry WORTHINGTON
US Energy Association, USA

Zhong-Pin XU
Shanghai Fire Brigade, China

Ye YU
Shanghai International Issues Research Center, China

Group 2: Hydrogen Production

Discussion Leader and Rapporteur

Robert K DIXON
International Energy Agency, France

Yun-Han XIAO
The Institute of Engineering Thermo-physics, China

Group Participants

Juan Carlos BOLCICH
Association Argentina Hidrogeno, Argentina

Xiao-Li CUI
Fudan University, China

Andrew DICKS
The University of Queensland, Australia

Jerald FLETCHER
West Virginia University, USA

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Wen-Tao RAO
Baosteel Research Institute, China

Su-Juan WU
Sichuan Ally High-Tech Co. Ltd., China

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Institute of Metal Research, China

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Süd-Chemie Shanghai Office, China

Yu-Wen ZHANG
Shanghai University, China

Zhi-Jie ZHOU
Clean Coal Research Institute, East-China Science and Technology University, China

Sheng-Bao ZHU
GREENGEN Co. Ltd., China

Group 3: Stationary and Mobile Applications

Discussion Leader and Rapporteur

Graham CAMPBELL
Natural Resources Canada, Canada

Shu-Dong WANG
Dalian Chemical Physics Research Institute, China

Group Participants

Hideaki AKAMUTSU
TECHNOVA Inc., Japan

Luke O'DONOGHUE
Western Australian Government, Australia

Takakuni IWASE
Japanese Automobile Research Institute, Japan

Sakib KHAN
Intelligent Energy, South Africa

Zi-Feng MA
Shanghai Jiaotong University, China

Da-Lin SUN
Fudan University, China

Ming YANG
International Energy Agency, France

Ruo-Gu ZHANG
Shanghai Shen-Li High Tech Co., Ltd, China

Group 4: 2010 Shanghai World Expo

Discussion Leader and Rapporteur

Annie Desgagne
Industry Canada, Canada

Zhuo-Ping YU
Tongji University, China

Group Participants

Gerd ARNOLD
GM China & GMDAT, China

Sechaba BAREETSENG
Department of Science and Technology, South Africa

Chung-Hsien CHEN
Ministry of Economic Affairs, Chinese Taipei

Nosisa GARANE
Mintek, South Africa

Jun HU
Shanghai Sunrise Power Co., Ltd., China

Ja-Son JING
United Technologies Research Center Ltd., China

Wei QIAN
Shanghai World Expo Business Coordination Bureau, China

Hao-Hong WU
Shanghai SXinAo Jiuhuang Vehicle Energy Co., Ltd., China

Wei-Hua XIE
Shanghai Aerospace Energy Co., Ltd., China

Feng YU
Shanghai Sunrise Power Co., Ltd., China

Pei-Wen ZHOU
Shell Ltd., China

Group 5: Modelling Hydrogen Economy in Asia

Discussion Leader and Rapporteur

Dolf GIELEN
International Energy Agency, France

Paul LEIBY
Oakridge National Laboratory, USA

Xiankun REN

Group Participants

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Pei CHEN
SAIC Motor Corporation Ltd., China

David P. CHOCK
Ford Research and Advanced Engineering Research and Innovation Centre, USA

Cao JIANG

Titus MATHE
South African National Energy (SANERI), South Africa

Mark RUTH
National Renewable Energy Laboratory (NREL), USA

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Ye WU
Tsinghua University, China

Xiao-Dong HU
Süd-Chemie Shanghai Office, China

VII. Appendix B: Workshop Agenda

Monday, October 22, 2007

Registration and Welcome

Tuesday, October 23, 2007

Plenary Session

Introductions

Mr. Barry Worthington, Executive Director, US Energy Association, Mr. Graham Campbell, Co-chairman IPHE Steering Committee, Mr. Shi Dinghuan, State Counselor, President, China Renewable Energy Society, Ex-Secretary General, MOST and Mr. Niu Xiaoming, Chief Engineer of Science and Technology Commission of Shanghai Municipality

Policy, Programme and Activities in H2/FC Sector in China

Mr. Zhang Zhihong, Deputy Director General, Department of High and New Technology Development and Industrialization, Ministry of Science and Technology, China, MOST

Building the Hydrogen Economy: Enabling Infrastructure Development

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

Demonstration Project for Hydrogen Stations and Fuel Cell Vehicles in Japan

Mr. Takakuni Iwase, Japan Automobile Research Institute (JARI), Japan

Planning and Building the Hydrogen Economy in the US

Mr. Fred Joseck, US Department of Energy, USA

Development of Fuel Cell Vehicles and Hydrogen Refueling Stations in China

Prof. Yu Zhuoping, Tongji University, Shanghai, China

Break

Building the Hydrogen Economy in Europe

Dr. Bernard Frois, CEA, Paris and ANR – National Research Agency, France

HYWAYS-IPHE: Comparing EU and US Approaches

Mr. Mark Ruth, European HyWays-IPHE Project, National Renewable Energy Laboratory, Golden, Colorado, USA

Risk and Cost-effectiveness Analysis for Hydrogen Technologies

Dr Ming Yang, International Energy Agency, Paris, France

Development of Hydrogen and Fuel Cell Technology in China

Prof. Wang Shudong, Deputy Director, Experts Panel for National High-Tech Program in Energy Area, DICP, CAS, China

Overview of the Perth, Australia, Fuel Cell Bus Program

Mr. Luke O'Donoghue, Director of Sustainable Transport Energy, Department for Planning and Infrastructure, Western Australia Government

ITRI's Hydrogen and Fuel Cell Research

Mr. Ming-Shan jeng, Senior Researcher, EEL/ITRI, (Industrial Technology Research Institute), Chinese Taipei

GM's Fuel Cell Electric Vehicle Development and Thoughts on Commercialization.

Mr. George Hansen, Director of AP Fuel Cell Commercialisation, General Motors, Shanghai, China

Building the Hydrogen Economy in Australia

Mr. Rohan Tepper, the Department of Industry, Tourism and Resources, Canberra, Australia

Break

Discussion Sessions

All attendees proceed to respective discussion meeting rooms. Participant assignments to specific discussion sessions will be available at registration, as well as posted by the specific discussion meeting rooms.

The discussion sessions consider infrastructure development and transition issues for mobile and stationary hydrogen energy applications. The discussions will identify technical, institutional, financial opportunities and challenges for H2 production facilities, delivery systems, fuel cell systems, and fueling stations; and potential public policy and market strategy opportunities for addressing them.

Session 1: Regulations, Codes and Standards

This discussion session will focus on the institutional, public policy, and business practice aspects of hydrogen energy infrastructure development. The group will discuss the status of these aspects today, as well as future directions and possibilities. The group will consider regulations, codes, and standards in the context of planning and design and construction and operations for hydrogen energy infrastructure.

Discussion Leaders: Mr. Michael Mills and Mr. Lun Jingguang

Session 2: Hydrogen Production

This discussion session will focus on hydrogen production. The group will consider alternatives for the production of hydrogen, the relative merits of alternatives approaches and strategies, the status of hydrogen production today, as well as future directions and possibilities. The group will consider hydrogen production in the context of planning and design and construction and operations for hydrogen energy infrastructure.

Discussion Leaders: Dr. Robert K. Dixon and Mr. Xiao Yunhan

Session 3: Stationary and Mobile Applications

This discussion session will focus on recent developments of stationary and mobile applications for hydrogen. The group will consider these developments and touch upon their relevance for the evolution of a future hydrogen infrastructure. In particular, participants will identify technical, institutional, and financial opportunities and challenges for H_2 *production facilities, delivery systems, fuel cell systems, and fueling stations as well as potential public policy and market strategy opportunities for addressing these questions and challenges.*

Discussion Leaders: Mr. Graham Campbell and Mr. Wang Shudong

Session 4: China World Expo in Shanghai 2010

This discussion session will focus on the hydrogen energy demonstrations planned for the World expo in Shanghai in 2010. The group will discuss these plans and how they can be used to showcase hydrogen energy infrastructure, and educate practitioners around the world about problems and opportunities related to hydrogen energy infrastructure.

Discussion Leaders: Ms. Annie Desgagne and Mr. Yu Zhuoping

Session 5: Modeling Hydrogen Economy in Asia

This discussion session 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.

Discussion Leaders: Dr. Dolf Gielen and Mr. Ren Xiangkun; Co-chair: Mr. Paul Leiby

Wednesday, October 24, 2007

Discussions Continued

The facilitated group discussions will continue until 10:00 to review and finalize the previous day's discussions, and then to prepare an oral report of the key findings and results. The discussion groups will disband and meet together as a large group at 10:45 to present oral reports from each discussion group, and participate in a facilitated discussion of crosscutting themes, gaps, and remaining issues.

Goal: *Summarize prior discussions and identify major themes or other issues for analysis.*

Break

Prepare Oral Reports from Discussion Sessions

All participants return to Plenary Session

Plenary Session: Reports from the Discussion Groups and Discussion of Gaps and Cross-Cutting Themes

Chair: Dr. Robert K. Dixon

Panelists: Group Discussion Leaders

Closing Remarks

Ms. Tan Kerong, Director, Division of Energy and Transport, Department of High and New Technology Development and Industrialization, Ministry of Science and Technology, China and Mr. Graham Campbell, Co-chairman IPHE Steering Committee

VIII. Appendix C: Workshop Photographs

Field Trips

1. Clean Energy Automotive Engineering Center of Tongji University
2. Hydrogen Filling Station in Anting, Jiading District
3. Shanghai Clean Energy Research and Industry Promotion Center