



Building the Hydrogen Economy: Enabling Infrastructure Development

Summary of Workshops

Detroit, United States • Paris, France • Shanghai, China



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Executive Summary

In 2007, the “Building the Hydrogen Economy: An Infrastructure Strategy” project was jointly sponsored by the International Energy Agency (IEA) and the International Partnership for the Hydrogen Economy (IPHE) to promote a strategic, global dialogue regarding the development of a sustainable, hydrogen-based energy infrastructure. The widespread commercialization of hydrogen and fuel cell technologies can potentially offer emissions-free power for both stationary and mobile applications in diverse geographic regions. To this end, workshops were conducted on three different continents to facilitate discussions among experts and stakeholders around the world. The first, held in Detroit, Michigan, United States (US), focused on the Americas (2-4 April 2007); the second, in Paris, France, focused on Europe (10-12 July 2007); and the third in Shanghai, China, focused on the Asia-Pacific region (22-24 October 2007).

The workshops concentrated on the technical, institutional, financial, and other issues associated with the infrastructure requirements of hydrogen technologies. Hydrogen infrastructure was defined as encompassing the physical, financial, and knowledge-based assets for delivering hydrogen energy services from suppliers to consumers; including hydrogen production, storage, and delivery facilities for transportation and electric power applications as well as public policies, market mechanisms, regulatory codes, and industry standards needed to enable hydrogen energy development. For both mobile and stationary applications, discussions about infrastructure focused on three primary themes: (1) planning and design, (2) construction and engineering, and (3) operations and maintenance.

Workshop participants included public and private sector officials who engaged in discussions to refine and evaluate possible transition scenarios. Public policies and incentives to advance the hydrogen economy were explored. Attendees also examined the modeling tools used to analyze hydrogen economy scenarios and market transformation planning for key countries and the world to the year 2050.

Workshop participants concluded that the advancement of a hydrogen economy will continue to pose numerous challenges and opportunities. Diverse hydrogen-related technologies will need to be developed, and willing, informed investors will be needed to fund them. Successful implementation cannot be achieved by a single plan, because infrastructure planning and design possibilities must consider regional, economic, and political contexts. Rather, a wide range of stakeholders must be involved in the planning process, including local, state, and national

government agencies, automakers, hydrogen equipment manufacturers, financial and insurance institutions, industry, utilities, and policy makers. As the work started at this series of meetings continues, international organizations like IEA and IPHE are poised to facilitate the communication, coordination, and cooperation needed to realize the proposed next steps outlined below:

- Continuing to convene stakeholders to identify and discuss technical, institutional, financial, and other issues associated with the infrastructure requirements of the hydrogen economy
- Promoting development of technology roadmaps and strategic plans for development of hydrogen power systems in both mobile and stationary applications
- Linking national and regional activities using common methodologies and tools
- Informing policy makers of opportunities to effectively advance transition scenarios through public policy instruments
- Establishing an international modeling forum to examine analytical tools for hydrogen economy scenario and market transformation planning for key countries and the world out to 2050.
- Initiating a joint annex between IPHE and IEA to study codes and standards, reporting findings to the stakeholders
- Facilitating dialogue that will promote international cooperation, strategic planning, and consistency of approach
- Supporting public education efforts to promote hydrogen as a viable energy alternative
- Creating partnerships across multiple sectors focusing on CO₂ reductions as the main driver for coordination and planning

IEA and IPHE plan to work with workshop attendees and other stakeholders to implement these next steps in an effort to ensure that planning and development of a hydrogen infrastructure continues as a collaborative, coordinated international effort that incorporate input from a wide variety of stakeholders.

Introduction

Over 400 significant hydrogen and fuel cell technology demonstration and deployment projects are currently underway around the world, and hydrogen highway projects are planned or are under construction in North America, Europe, and Japan. Public-private partnerships are providing the foundation for most development activities, with technology roadmaps guiding investments for most member countries of the Organization for Economic Co-operation and Development (OECD) as well as a handful of key developing countries. These activities are part of a global effort to increase energy security, environmental protection, and economic prosperity by commercializing hydrogen and fuel cell technologies.

In 2007, the “Building the Hydrogen Economy: An Infrastructure Strategy” project was jointly sponsored by the International Energy Agency (IEA) and the International Partnership for the Hydrogen Economy (IPHE) to promote a strategic, global dialogue regarding the development of sustainable, hydrogen-based energy infrastructure. Workshops were conducted on three different continents to facilitate discussions among experts and stakeholders around the world. The first, held in Detroit, Michigan, United States (US), focused on the Americas (2-4 April 2007); the second, in Paris, France, focused on Europe (10-12 July 2007); and the third in Shanghai, China, focused on the Asia-Pacific region (22-24 October 2007).

This project built on complementary activities in Europe, Japan, and the US. The challenge is to link national and regional activities using common methodologies and tools, augmenting analysis for all countries supporting development efforts. An integrated and comprehensive portfolio of strategies and policy instruments representing key economies around the world will help enable an efficient transition to hydrogen technologies. Furthermore, the potential value of various financial incentives, regulatory reforms, and other public policy instruments need to be assessed at the local, regional, national, and international levels.

Regional Progress

The Americas

The US currently supports the largest national R&D program for hydrogen energy technologies and infrastructure development. The state of California’s Hydrogen Highway on the Western coast is but one example of several “lighthouse projects” that begin with development in metropolitan regions with the intention of broad dissemination across larger areas. Likewise, similar activities are being conducted in Canada, including a hydrogen highway in British Columbia and hydrogen shuttle buses at the Canadian parliament. In addition, various US automobile companies are continuing development of hydrogen vehicles with limited public

deployments. As North American governments partner with industry, significant results are being manifested in the area where most of the world's hydrogen is produced.

South America is also an important region for hydrogen technologies. Brazil and Argentina currently run the world's largest fleets of alternative fuel vehicles and therefore have much to contribute regarding the development and demonstration of alternative fuel technologies.

During the Detroit meeting, Dr. Sigmund Gronich of the US Department of Energy (DOE) summarized a major project at DOE. Efforts are underway to develop a set of scenarios characterizing the potential development of hydrogen energy infrastructure and fuel cells in the US and to determine the potential costs and impacts of alternative public policies and market mechanisms. The time-scale and geographic positioning of the scenarios provided a range of potential conditions and possibilities for infrastructure development and raised new considerations for workshop participants.

In addition, Annie Desgagné of Industry Canada described her experiences and successes with "Building the Hydrogen Economy in Canada." She reported that air quality concerns, climate change, energy security, and financial investment opportunities were drivers for the Canadian hydrogen economy. She emphasized the importance of government incentives and also presented the intended path of hydrogen from Canadian sources to distributors and finally to major users.

Europe

Hydrogen and fuel cell research, development, and demonstration projects funded by the European Commission (EC) totaled almost 300 million Euros between 2002 and 2006. Driving forces behind these projects directly relate to the three European Union (EU) energy policy goals: security of supply, climate change, and EU competitiveness. Key EC projects include HyWays, a harmonized European roadmap for hydrogen energy development; HyLights, which includes lighthouse transport projects like HyFLEET: Clean Urban Transport (CUTE), ZERO REGIO, and HyChain; and Roads2HyCom, a project that brings together mapping of infrastructure and community development.

The HyWays project was particularly highlighted during the Paris meeting. This project was undertaken by a European public-private partnership formed by several international companies and organizations with 10 member state partners. A Europe-specific roadmap for building the hydrogen market through state-supported research, development, and deployment (RD&D) and public-private partnerships was developed with the goal of scaling up existing hydrogen technologies and promoting their commercialization. HyWays promotes hydrogen energy as a viable, strong pathway to sustainable energy in the future, but the

success of this opportunity requires immediate action to overcome the initial investment and construction barriers.

From the private sector, Mr. Gijs van Breda Vriesman reported that Shell was implementing hydrogen projects in seven cities and was supporting academia, government, and the market by stimulating RD&D. He explained that high costs and uncertain outcomes were barriers to the OEM investments needed to advance vehicle deployment and infrastructure development. Shell is researching LNG re-gasification and low-CO₂ footprint technologies to manufacture hydrogen, as well as clean coal gasification, carbon capture and sequestration, and syngas technologies for power. Vriesman concluded by inviting participants to create partnerships across multiple sectors, focusing on CO₂ reductions as the main driver for this coordination and planning.

In addition, the 7th EU Framework Program has developed a Joint Technology Initiative in which public and private interests are aligned to manage an EU-funded research program with the aim of putting Europe at the forefront on fuel cell and hydrogen technologies. Ms. Beatrice Coda, Scientific Officer at the European Commission, indicated to participants in Paris that the EC is willing to work together with other international parties and with IEA/IPHE initiative in order to ensure a consistency of approach and to share regional insights.

Asia-Pacific Region

Public sector investments by China, Japan, and Korea for hydrogen and fuel cell research and development programs are among the largest and most expansive in the world. Additional investments are also emerging in Australia, Malaysia, Thailand, India, and Indonesia. Each nation, based on its economic structure and natural resource endowments, has its RD&D activities in both stationary and mobile applications. Furthermore, public-private partnerships have stimulated the development and testing of hydrogen fueling 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 Asia Pacific Economic Cooperation Energy Working Party has made the development of hydrogen and fuel cell technologies a recent priority. This group has worked cooperatively with IEA and IPHE to coordinate and leverage hydrogen and fuel cell activities in the region. Likewise, the European Union (EU) has worked collaboratively with nations of the Asia-Pacific region on a number of projects including CUTE, which established hydrogen power transport bus demonstration and deployment trials in key cities across the region. These trials leverage public and private investments and provide real-time data on the performance of hydrogen vehicles.

In addition, the United Nations Industrial Development Organization recently established the International Centre for Hydrogen Energy Technologies (ICHET) in Istanbul, 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. This type of aid is particularly applicable to the Asia-Pacific region where some of the world's largest and fastest growing economies are located. Sustainable development and energy security issues rank at the top of national agendas, and hydrogen energy technology offers potential alternative energy solutions.

Thematic Discussions

Current Technologies

Diverse markets, resources, and needs drive current hydrogen energy research, development, and deployment (RD&D) efforts in several directions concurrently. This diversity is exemplified by the variations seen in mobile versus stationary applications, centralized versus distributed development approaches, niche versus large-scale markets, and fossil versus renewable hydrogen production. Coordinated planning and consensus can assist in efforts to cull options and bring strategic to focus each of these areas.

Producing, storing, and transporting hydrogen is a multi-path, multi-step process, and some participants believed that producing hydrogen near its point of use would be the most viable solution. 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 is difficult and costly to extend transmission and distribution capacity to remote areas. Hydrogen systems offer a potential solution in the form of off-grid generation storage which may include wind-hydrogen or PV-hydrogen with battery back-up.

On the other hand, mobile applications seem to favor a "lighthouse approach," with small fleets in locations with existing hydrogen infrastructure (or along the natural gas distribution network) and consumer demand, then growing the infrastructure at economically appropriate rates to accommodate large fleets which would eventually join with other areas/regions of development. This type of centralized approach was believed by some participants to better benefit industry than a distributed approach. Market penetration and return on investment (ROI) can be maximized with this strategy.

Although hydrogen is perhaps most viable and promising as a clean energy alternative to conventional energy, participants generally agreed that hydrogen energy technology development should be based upon existing, primary energy sources, including fossil fuels. Coal-to-hydrogen production received due consideration since large coal deposits are co-located with some of the world's largest economies, and hydrogen from natural gas was cited

as a proven, low cost technology. In addition, China reported a feasible and affordable methanol-to-hydrogen reforming pathway. Participants also agreed, however, that production methods will need to incorporate carbon capture systems, or at least be carbon-neutral, in order to prevent greenhouse gas emissions and promote long-term acceptance.

Renewable resources for the production of hydrogen were preferred in the interest of achieving long-term sustainability. Where renewables such as wind and solar energies are intermittent, hydrogen production processes become enabling technologies for integrating larger amounts of renewables into electricity grids. Hydrogen produced by nuclear reactors can also be stored to provide peaking power; however, regulatory, policy, and cost factors will limit this option in many countries.

A strong emphasis on synergies has to be pursued with hydrogen as an enabling technology in a variety of processes (industrial and chemical) and where energy is only indirectly derived. This was put forth as one key asset of hydrogen energy. The building and reinforcing of hydrogen champions or large industrial users must be encouraged to stimulate a hydrogen economy likely to expand beyond its few initial applications. Likewise, to derive peaking benefits, utility companies must be engaged to a greater extent in order to assemble the critical mass of investment that will be necessary to finance hydrogen infrastructure development.

Continued Research & Development

In general, the existing suite of hydrogen energy technologies is not yet ready for mass production and development. Further research and development (R&D) is needed to advance the most promising options, making them more reliable and cost-effective. For example, there are potentially numerous nascent technologies associated with each production pathway. In addition, many hydrogen storage challenges hinder infrastructure engineering and construction efforts. Problems range from uncertainties about the size, type, and cost of storage systems to questions about footprint, siting criteria, and the safety requirements for high pressure systems. Furthermore, the mass operation and maintenance of hydrogen technologies and infrastructure will necessitate additional technical advancements.

In Europe, the building out of hydrogen infrastructure beyond the current demonstration projects will largely depend on R&D success. Participants in Paris believed that hydrogen R&D budgets should be increased, but it was noted that definitive data on hydrogen technologies should be used to allow fair comparisons with other potentially viable energy technologies.

In Shanghai, participants asserted that current R&D programs are addressing most barriers to the production of hydrogen from fossil fuels, nuclear power, and renewable energy sources. They noted that short-term political decisions rarely benefit technology pathways, so it is important for R&D policies and funding to “stay the course.”

Financial & Legal Liabilities

A menagerie of risks, uncertainties, and unknown technical issues currently hinder the early capital investments needed to fund primary hydrogen technologies and infrastructure development efforts. Relatively slow capital stock turnover in the energy sector and long lead times required for infrastructure development necessitate careful planning on the part of investors, but the global financial community has virtually no experience in underwriting major hydrogen energy projects. Subsequently, there is no good basis by which to characterize investment cash flows, amortization periods, and actuarial tables for all the related financial risks.

Successful business models for various hydrogen energy applications will be needed to demonstrate the long-term viability of a hydrogen economy. In Shanghai, participants indicated that some hydrogen and fuel cell companies were actually downsizing, with investments waning due to the delay in significant, tangible development advancements. Participants in the other meetings noted that, where there is potential, existing infrastructures and networks should be leveraged. Joint ventures could also allow the sharing of investment responsibility among various entities involved in the planning, designing, engineering, construction, operation, and maintenance of infrastructure and/or large-scale projects; however, such partnerships are currently thwarted, at least in part, due to concerns over intellectual property (IP) protection. This barrier is particularly significant given that the technology know-how is primarily held in heavily developed, industrialized regions such as the European Union, Japan, and United States, while the large-scale market opportunities are in rapidly developing countries such as India and China where IP is less secure.

Government Roles & Policies

Since the commitment of private investors to major projects has been tenuous, proponents of the hydrogen economy have largely depended upon the public sector to stimulate the funding, development, and markets required to advance hydrogen infrastructure development. In fact, government involvement was pivotal to virtually every facet of hydrogen energy discussed during the meetings: regional planning; development of public-private partnerships; R&D funding; market incentives; regulations, codes, and standards development; siting and distribution permits; early adoption in fleets; workforce development; and public education.

Participants generally believed that public policies promoting environmental stewardship and/or penalizing reliance on non-renewable energy sources would be the most influential in promoting hydrogen as an accepted, and perhaps even favored, alternative energy source. Dr. Robert Dixon, Head of the IEA Energy Technology Policy Division, stated that if strong CO₂ policies are adopted worldwide and hydrogen technology continues to develop, hydrogen powered vehicles could gain up to 30 percent of the market share by 2050. Hydrogen might

also benefit from various other initiatives designed with the intent of diversifying energy supply, providing energy access in remote areas, promoting grid stability and back-up power in developing countries, or improving environmental quality standards in buildings.

Some participants in Paris particularly preferred technology-neutral energy policy instruments implemented in conjunction with increased hydrogen R&D. They believed that more R&D, as well as an analysis of the socioeconomic costs and benefits of hydrogen, is needed before specific policies to promote hydrogen can realistically receive further support. Nevertheless, government-funded fleet demonstrations and fueling station technologies were deemed useful for understanding the state of the technology and educating the public. Assuming the success of continued R&D, public education and workforce training will subsequently become the key issue associated with the construction and operation of a hydrogen infrastructure.

In Shanghai, a suite of well-known policy measures was recommended, including carbon taxes, incentives for hydrogen development, tax exemptions for hydrogen equipment and government procurement requirements. Participants recommended that countries work together in deploying hydrogen energy technologies and that they make the necessary provisions for IP protection that would be needed to do so. Government involvement in the alignment of developing codes and standards was strongly supported. Finally, public outreach and education was considered vital to increase awareness, acceptance, and support.

Regulations, Codes & Standards

The importance of regulations, codes, and standards (RCS) in guiding development and ensuring safety was regularly reiterated throughout all three meetings, and a group discussing mobile applications commented that existing codes and standards will limit construction if they are not modified. On the other hand, there was concern that premature definition (and subsequent regulation) of a specific infrastructure might actually limit development options and creativity if formulated and enforced too early, while there is still much potential for new, innovative approaches.

Participants also found RCS development, harmonization, and dissemination difficult to generalize largely due to differences in terminology and regulatory approaches across IEA and IPHE member countries. Both localized and nationalized approaches were suggested during the meetings. Some current international standards were said to lack the necessary specificity to be actionable and were found to be ineffective when used to address local RCS requirements.

The need for regulatory guidance was discussed in the following areas:

- Hydrogen purity, so that providers and suppliers can coordinate their products
- Safety protocols, to ensure long-term viability and public acceptance

- Fueling stations, to facilitate the spread of infrastructure and encourage consumer acceptance
- Hydrogen pipelines, to provide a systematized protocol for function testing and review
- Retail applications, to promote widespread deployment

The development of RCS will not only promote standardized, safe practices but will also go a long way to balance the risks and ROI for high-cost equipment and facilities. The need to develop and consolidate codes and standards for retail applications across states, provinces, countries, and regions is a top priority. A group discussing stationary applications during the Detroit meeting suggested that neutral agencies might be best suited to take on the lead role in standardization and certification. In addition, participants suggested that IEA and IPHE could play a valuable role by initiating a joint annex to study codes and standards, reporting findings to the stakeholders in order to facilitate dialogue. Strong emphasis was given to the value of sharing best practices and experiences across the community of stakeholders.

Modeling & Analysis

All stakeholders will need access to reliable, accurate data in order to effectively advance hydrogen technologies. Modeling and analysis tools can facilitate data-driven decision making, thereby allowing for the mitigation of risk and improving the outlook for investors. Each of the three meetings provided opportunities for participants to collaboratively ascertain the critical questions to be answered by models and to learn about the capabilities of modeling tools currently under development or in use. In Paris, the group devised a goal to focus future modeling efforts: to determine (to the extent possible) what policies would efficiently and effectively enable a transition to a hydrogen economy by 2050.

Also in Paris, the European and North American models were contrasted and their strengths and weaknesses evaluated. This exercise revealed both 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 pathway costs from the US framework were typically higher, its focus was typically on defining a business case for hydrogen while the EU framework primarily characterized a policy-support case.

During the course of all three meetings, participants identified gaps in modeling capabilities and brainstormed improvements. Gaps in existing models were grouped into three broad categories: technology characterization and forecasting, modeling risk and uncertainty, and broader systems issues. Additional needs were subsequently determined; they included consideration of sustainability issues and a call for the clear linkage between model development and gap completion priorities. Suggestions to strengthen model results were also offered. Specifically, the group wanted enhanced representation and explanation of

interactions within each model that are caused by changes in the input assumptions. This improvement would be especially valuable to stakeholders outside the modeling community. Furthermore, there was an expressed desire to improve the group's ability to understand and communicate differences in valid results obtained from different models due to regional disparities, policy assumptions, underlying methodologies, etc. The pros, cons, and limitations of each model's abilities need also to be examined.

Early on, participants determined that no single modeling/analysis tool could accurately characterize hydrogen infrastructure development issues in all represented regions. Alternatively, a "tool box" approach was adopted. The Detroit meeting group began to compile a comprehensive list of models currently under development or in use. As the "value-added" of each model is determined, users will be able to selectively choose and "soft link" the best tools to understand and predict infrastructure development issues corresponding to their specific geographic area.

Participants in the Shanghai meeting decided that it would be helpful for IEA to provide a global framework for a deliberate and coordinated approach to modeling and analysis. Ideally, models would be run by expert users, using common assumptions. Each regional model would provide regional outcomes and different insights that could be instructive to everyone involved. In addition, attendees plan to submit a proposal to the IPHE Steering Committee for the establishment of an international modeling forum.

Education & Outreach

In every meeting, the need for widespread education and outreach was deemed critical to the successful development of hydrogen infrastructure. Awareness and confidence in hydrogen energy technologies will need to be fostered among financial investors and the public in order to allay fears of any inherent financial and safety risks. Public information campaigns were also cited as a means to manage public expectations, to help balance development and supply with demand. Policymakers need to be informed of opportunities to effectively promote hydrogen energy as being beneficial to both environmental and energy security interests. Furthermore, a skilled workforce will need to be trained to manage, build, and maintain hydrogen energy projects and equipment according to the regulations, codes, and standards of their localities and/or regions.

Conclusion

As intended, this series of meetings provided a venue to discuss the future of hydrogen energy on a worldwide scale. North American lighthouse projects and models were presented for examination, and South American successes in building alternative fuel vehicle fleets were considered in the context of hydrogen vehicle deployment plans. European representatives showcased HyWays, a project that developed a Europe-specific roadmap for building the hydrogen market through state-supported research, development, and deployment (RD&D) and public-private partnerships. The implications of rapid economic growth in several countries of the Asia Pacific region were discussed as they relate to hydrogen infrastructure development.

The advancement of a hydrogen economy will continue to pose numerous challenges and opportunities. Diverse hydrogen-related technologies need to be developed, and willing, informed investors are needed to fund them. All infrastructure planning and design possibilities must consider regional, economic, and political contexts, so successful implementation cannot be achieved by a single plan. Rather, a set of modeling tools must be assembled to accurately characterize the possible scenarios to facilitate planning efforts moving forward. Furthermore, a wide range of stakeholders must be involved including local, state, and national government agencies, automakers, hydrogen equipment manufacturers, financial and insurance institutions, industry, utilities, and policy makers.

As the work started at this series of meetings continues, international organizations like IEA and IPHE are poised to facilitate the communication, coordination, and cooperation needed to realize hydrogen as a future, sustainable energy source in a variety of ways:

- Continuing to convene stakeholders to identify and discuss technical, institutional, financial, and other issues associated with the infrastructure requirements of the hydrogen economy
- Promoting development of technology roadmaps and strategic plans for development of hydrogen power systems in both mobile and stationary applications
- Linking national and regional activities using common methodologies and tools
- Informing policy makers of opportunities to effectively advance transition scenarios through public policy instruments
- Establishing an international modeling forum to examine analytical tools for hydrogen economy scenario and market transformation planning for key countries and the world out to 2050. Activities of this forum could include the following activities:

- Determining what policies would efficiently and effectively enable a transition to hydrogen
- Strengthening current model results
- Performing enhanced representation and explanation of interactions within each model caused by changes in input assumptions
- Providing a global framework for a coordinated approach to modeling
- Initiating a joint annex between IPHE and IEA to study codes and standards, reporting findings to the stakeholders
- Facilitating dialogue that will promote international cooperation, strategic planning, and consistency of approach
- Supporting public education efforts to promote hydrogen as a viable energy alternative
- Creating partnerships across multiple sectors focusing on CO₂ reductions as the main driver for coordination and planning

IEA and IPHE plan to work with workshop attendees and other stakeholders to implement these next steps in an effort to ensure that planning and development of a hydrogen infrastructure continues as a collaborative, coordinated international effort that incorporate input from a wide variety of stakeholders.

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Workshop Summary

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