HyWays - IPHE

Benchmarking of Hydrogen Energy Roadmaps

Summary of the HyWays-IPHE Roadmap Workshop in Brisbane, Australia

Date/Place	05 August 2008, Changsha (HyForum2008)
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Agenda

Session Chairmen: Christoph Stiller (LBST), Ye Wu (Tsinghua University)		
Session I The HyWays IPHE project		
2:00-2:15 pm	Welcome Remarks Introduction: Objectives of the workshop Overview of HyWays IPHE Project	Christoph Stiller Rei Fernandes
2:15-2:45 pm	Benchmarking of European and U.S. Hydrogen Roadmapping Efforts (HyWays-IPHE): Hydrogen Pathway Analysis	Christoph Stiller
2:45-3:10 pm	Benchmarking of European and U.S. hydrogen roadmapping efforts (HyWays-IPHE): Socio-economic modelling and stakeholder involvement	Ingo Bunzeck
3:10-3:30 pm	Summary of roadmapping activities in IPHE countries – the results of a survey	Rei Fernandes
3:30-3:45 pm	Coffee Break	
Session II Road mapping activities in China		
3:45-4:10 pm	Feasibility study on Bohaiwan hydrogen corridor	Zongqiang Mao
4:10-4:35 pm	R&D and Demo of key technologies on hydrogen storage and supply for FCVs in Shanghai	Jianxin Ma
4:35-5:00 pm	Study on hydrogen infrastructure planning in China	Zheng Li
Session III Structured Discussion		
5:00-6:00 pm	1. Factors influencing approach to modelling in different IPHE countries. 2. Discussion (based on section I/II) on: a. Different Drivers – What is/was the main motivation for the roadmap exercise b. Different Objectives - What is/was the main objectives of the roadmap exercise c. Different Approaches – Highlight of the different methodologies used in the roadmap exercise (shown in the previous presentations) - - discuss pros and cons. - compare and contrast. 3. General discussion on: a. Appropriated Models -	Rei Fernandes Paul Leiby Ye Wu

Note: All presentations can be downloaded at www.hyways-iphe.de

Session I - The HyWays IPHE project

Ye Wu, Christoph Stiller and Rei Fernandes welcomed the participants and presented an overview of the HyWays-IPHE project.

The objective of the workshop was to disseminate the results of the project to and collect feedback from a wide range of experts. Furthermore the project consortium wants to learn about further roadmap activities and the views of the experts on different drivers, objectives and approaches. Therefore the discussion is an important part of the workshop.

Overview of HyWays IPHE Project

HyWays-IPHE is an EU project receiving funds from the European Commission, the US Department of Energy and the industry partners. The project aims at comparing hydrogen roadmaps, with the goal to improve understanding about the ongoing activities and therewith support the roadmapping process in further IPHE countries, particularly in Asia. Within the project a multi-national group of institutes compared models and approaches applied for hydrogen roadmaps in Europe and the U.S. Its duration is 24 months, ending in September 2008. Beside the coordination work package (WP1), the project contains three topical workpackages, one on comparison of hydrogen energy pathway analyses in Europe and the U.S. (WP2), one on further comparisons of other roadmapping elements such as socio-economic modelling and stakeholder involvement (WP3) and one on dissemination and comparison with further IPHE countries (WP4).

Hydrogen Pathway Analysis

Christoph Stiller presented the findings of the comparison of hydrogen energy pathway analysis (work package 2). Nine hydrogen energy pathways (production / delivery / distribution) were assessed with regard to costs, energy use and well-to-wheels emissions. Both regions used similar methodology to estimate the technical potential of hydrogen pathways but modelling philosophies and terminology sometimes differed. In the US, three models were used. They were connected to form pathways that could be compared to pathway results generated by European analysts in a single tool. Because the methodologies were similar, parameters in the various tools could be compared. The US focused on business-cases and required a greater rate-of-return than Europe. European analysts assumed vehicles would be smaller and have greater fuel efficiency than US analysts. European energy-price projections are significantly higher than the US projections. Both sides also used similar methodologies for uncertainty analysis.

The question was raised why these pathways were selected. Christoph explained that the number of pathways to be compared had to be limited, and it was tried to cover a wide range of different technologies. The coal pathways do not necessarily indicate the “long term” preference of pathways but were rather chosen as long term since CCS was not expected to become available before 2020 but all other technologies were.

It was also declared that in the analysis, the U.S. models used 350 bar refuelling also for long-term. This has, however, been changed with the last HDSAM update.

Socio-economic modelling and stakeholder involvement

Ingo Bunzeck (ECN) presented the results of work package 3 where stakeholder involvement, regional infrastructure build-up analyses, energy system modelling and energy price assumptions, modelling of economic impacts and vehicle cost analyses were assessed quantitatively and qualitatively.

In both regions, stakeholders hold a strong although different input into the programs. Existing models used to analyze regional infrastructure build-up scenarios were mapped with respect to objectives, spatial detail, spatial extent and data handling. An extensive toolbox is available, however lacking models with imperfect foresight and detailed global interactions. The set of used models was consistent although the assumptions and approaches varied. Energy system models were similar but the prices assumed exogenously for fossil energy sources (oil, natural gas, coal) were much higher in the European model than the endogenous US price estimates. In addition, the European model was constrained in choice of primary energy according to stakeholder input leading to high diversity, while the US model was not constrained. Employment effects were modelled on a disaggregated level similarly in both regions. Also vehicle costs are comparable, however based on different assumptions on components and cost reduction. Both sides did produce a number of publicly available documents such as roadmaps and actions plans directed to policy makers.

The key differences in assumptions and results found are summarised in the following figure.

KEY DIFFERENCES:	EU	US
ECONOMIC CALCULATIONS	Macro-economic view: simple approach; lower interest rates	Investor's view: detailed financial and cost calculations; taxes, high rates of return
ENERGY PRICE PROJECTIONS	Higher natural gas, biomass and coal prices	Lower natural gas, biomass and coal prices
KEY ENERGY SCENARIO INPUTS	H_2 vehicle penetration; bounds of H_2 production mix	Resource-cost-curves; technology costs
KEY ENERGY SCENARIO RESULTS	Scenario costs, required infrastructure	H_2 vehicle penetration; least-cost production mix
STAKEHOLDER INVOLVEMENT	Horizontal approach: project and panel level decision making, roadmap tailored to European regions	Vertical approach: Top-down decision making, roadmap (hydrogen energy pathways) by least cost.
LEARNING PROCESS	Learning by doing (global stock)	Three learning mechanisms (domestic stock): searching, manufacturing, doing
INTERLINKAGE OF MODEL TOOLBOX	Socio-economic scope, manual iteration between models+review	Economy and LCA, automated transfers

As much as both approaches are different they are also to a large extent similar.

On top of the differences outlining the variety of approaches and assumptions available, the project has developed recommendations for further roadmapping activities.

A question was asked about the employment modeling and the inclusion of infrastructure in the input-output approach. Ingo answered that in trying to model a most realistic 'hydrogen economy', all relevant value chains regarding fuel cell components, hydrogen production and distribution are taken into account. Those technologies had to be added to the input-output table since new technologies are usually missing from those tables.

Summary of roadmapping activities in IPHE countries – the results of a survey

As the final speaker in the session, Rei Fernandes presented the results of a questionnaire that was composed within work package 4 of HyWays-IPHE and sent to all IPHE countries to find out the status of the roadmap and the approaches employed in each country..

The presentation was based on the analysis of responses from 15 out of the 17 member countries of the IPHE. The results provide a broad qualitative overview rather than a quantitative analysis as they are derived from a short questionnaire covering an overview of the roadmap, the models used and the results obtained. In most cases the answers were provided by individuals from each country who had indicated a willingness to participate in the survey at a previous IPHE meeting.

The survey shows that most IPHE countries have a roadmap although in some cases (IT, FR and UK) it is included as part of another activity. In many cases the roadmap is still in progress or being updated. The roadmaps are mostly government sponsored, with the target audience being both government and industry. Common features in their objectives are the introduction of hydrogen in the energy system and the identification of energy pathways and cost competitive technologies. Additionally IPHE members have country specific objectives. In all cases stakeholder participation is recognised as being important. The majority of the countries use models in the preparation of their roadmaps but some major players do not. The hydrogen production technology selected is dependent on the scenario selected by the country and the time frame of implementation. The impacts considered in the roadmaps are mostly environmental whilst the economic impacts are considered as secondary.

In the following, the general use of models was discussed. Models need inputs from industry but these are difficult to obtain. The HyWays-IPHE partners agreed that if industrial stakeholders were integrated early enough in the process it was possible to exchange data – directly or indirectly. Data may have to remain confidential.

In general it is important to note that model results must be used with care – drawing wrong or invalid conclusions must be omitted.

Session II - Road- mapping activities in IPHE countries

Feasibility study on Bohaiwan hydrogen corridor

Prof. Zongqiang Mao (Tsinghua University) presented a study on a hydrogen corridor in the pan-Bohai region in China where 260 million people are living. Hydrogen pathway cost analyses were performed with industry data – NGSMR+pipeline came out to be cheapest.

Beside FCV and FC-Buses, HCNG buses and HICEV are proposed. Targets for 2020 are – 2 mill cars and 2500 fuelling stations. Mother/son fuelling station concepts have been evaluated where the mother supplies hydrogen to the son.

Barriers for the development of the project are understanding of the problem, technology problems, RCS, economic problems (hydrogen from NG not economic) and government concert (no agreement on future fuel strategy)

With respect to the solutions, Prof. Mao remarks that the Chinese Government is powerful, if high level is influenced. Decision making in government affected by technology experts, and foreign governments and experts. The economic burdens might be taken since energy is an important topic for the nation.

Being asked for his outlook on hydrogen production pathways, Prof. Mao answers that H2 in 2020 can be from industrial byproduct. After that, he sees an interesting option in coal to hydrogen (in-situ), with pipeline supply.

R&D and Demo of key technologies on hydrogen storage and supply for FCVs in Shanghai

Prof. Jianxing Ma from Tongji University reported on FCV demonstration in Shanghai. He presented development strategies for hydrogen supply and fuelling stations.

A fleet demo project is under planning where in total 1000 EVs are to be used (including H2 vehicles). H2 sources in Shanghai (very limited primary energy resources) can be byproduct, biogas reformation, off peak and renewable electrolysis. Biogas resources in Shanghai would be enough for 1,000,000 FCV. H2 from electrolysis (off-peak) could costs 15 RMB/kg H2, which is cheaper than gasoline.

A quality standard for hydrogen for FC is needed. Based on durability measurements on single fuel cells, FC stacks, and FC cars, a fuel quality index has been established.

Development of mobile refuelling station dispensing 350 bar gaseous hydrogen has been started. Details about the Anting fuelling station were presented: 20 MPA tube trailer, + buffer storage. Diaphragm compressor + 35 MPa dispenser. A daughter station shall receive 450 bar storage vessels from Anting, which are used to fuel cars and buses. Further fuelling stations in the Shanghai region are to be developed in Pudong (EXPO) and Chongming Eco-Island.

Study on hydrogen infrastructure planning in China

As final speaker for this session, Prof. Zheng Li from Tsingua University presented a study on hydrogen infrastructure planning for China.

The challenges connected to energy China is facing today are rising demand, pollution, energy prices, and GHG emissions. A first priority should lie on alternative energy and energy saving, then possibly large-scale H2 production from coal with CCS.

Nine static hydrogen energy pathways were analysed – beside the ones analyses in HyWays-IPHE also a coal-to-methanol-to-hydrogen chain was included. Methanol as an intermediate product can be transported easily and reformed to hydrogen on-site the fuelling station (using palladium membranes). The outcome is that hydrogen transport by methanol is cheaper than piped hydrogen from ~200 km for coal-based feedstock. Generally, NG-SMR seems to be cheapest and water electrolysis needs technologic breakthroughs to become economically interesting in China, and environmentally (through high coal power share in electricity mix).

Dynamic modelling of H2 infrastructure was performed based on these static results. Multi-objective optimization based on costs (NPV) and environment (GHG emissions) was performed, calculating the Pareto optimum for five time frames. The highest benefit results from coal gasification, while the highest GHG saving resuls if biomass gasification and pipeline delivery are chosen. The optimum is depending on the environmental requirements, i.e. a policy on the relationship between greenhouse gas emissions and costs.

The infrastructure model used was a point-to-point model (plant to city gate), and then distribution within the city based on typical delivery distances (analogous to HDSAM).

CCS cost are not included in this study, but will be in a future study.

Being asked about the benefits of the methanol pathways, Prof. Li mentions that there were different aspects. Energy efficiency is low (two conversions), and CO2 emissions high. But economics is the best.

Session III - Structured Discussion

After commenting briefly on the content of the three Chinese presentations Paul Leiby called for free discussion noting that the purpose of the session was to gain an understanding of the different ways to analyse the problem of hydrogen and to learn from the experiences presented and also to consider the challenges posed and the next steps in providing the answers. The research of the Chinese Professors had not yet been presented to the newly created Bureau of Energy.

Questioned by a researcher from the Chinese Academy of Science about the efficiency of transporting hydrogen as methanol, Prof. Li responded that the economics of transport and onsite reforming of methanol work out better than transporting liquid or gaseous hydrogen, as the absolute amount transported is much higher even though methanol contained only 12% hydrogen.

Prof. Mao, referring to the statement that some countries, including China, already have a hydrogen roadmap, noted that it was not really a roadmap accepted by Government but the result of particular research groups. Rei Fernandes reminded the audience of the broad definition of a roadmap used in this context and asked what it would take to arrive at a roadmap for China, quoting Paul Leiby´s remarks of “Where to from here? What next?” There was agreement that what has been presented as a roadmap for China may not actually constitute a roadmap in the eyes of many stakeholders and Government.

A question was posed as to whether hydrogen has a chance to be developed as an energy carrier and at what level of the oil price does it become economic to replace the infrastructure. This question had a bearing on the issue of risks of stranded assets and infrastructure already in place as raised also in Australia. In response Christoph noted that in HyWays the threshold oil price used was $60 – $80 per barrel and calculations based on these values indicated that it would be feasible to introduce hydrogen, but nevertheless there are still investment risks – for example at the moment, even though there are opportunities for off-shore wind farms in the North Sea, there are insufficient resources to start the deploymen, partly due to the application of the required drilling equipment to finding more oil. Prof. Li commented however, that the figure stated was too low according to his opinion and that the cost of the infrastructure required had been underestimated as some existing infrastructure would have to be abandoned whilst new ones would need to be built, implying double costs. Referring to the example of wind power, it was noted that there were less problems here as wind power was compatible with the existing infrastructure.

Paul Leiby concurred that in many of these models including the system of models used in the US and some of the models used in the HyWays project, there could be an underestimation of cost due to the difficulty in properly sequencing these large investments and recognising that you may leave capital behind.

The question of how to prepare a roadmap depends on the understanding of the concept of a roadmap. Questioning what the roadmap tries to answer could raise much interest as it did in the US. However the US had the advantage that they were asked to do a roadmap by the National Academy of Science. Government felt that if they were considering hydrogen they should have a careful analysis and plan of how it might work by examining a complete and coherent picture of fuel infrastructure (fuel production and delivery) taking into account also the vehicle side, the consumer side and how all this will evolve over time.

Another important question raised in the US related to the support for R&D to understand the science. If ambitious goals were set, for example for density of storage of hydrogen, lifetime of fuel cells, and for the costs of all of these components, and all of these goals were met, would that be enough? This approach was found to be helpful to think about the problem and might help to motivate leaders to support such analysis and assess whether we are doing the right things now in the research that we are doing. There is a need to understand the end result and the consequent impacts upon CO_2 and energy security.

Julie Cairns of CSA, one of the stakeholders in the US, added that roadmapping is a way to help all stakeholders because there is a lot of chaos. She encouraged the early consideration of standards and the development of standardisation for the performance of the products early on in the research phase because that will help transfer the technology into commercialisation.

A doctorate candidate from the Institute of Chemistry, Chinese Academy of Science questioned the production of hydrogen through chemical processes as they also produce CO_2, suggesting that the focus should be on bio hydrogen production as the process was more acceptable. In response Prof. Mao said that the focus depended on the motivations for the promotion of hydrogen. Apart from energy security and CO_2 emissions China & developing countries were concerned about air quality and pollutant emissions. These motivations would lead to different pathways, for example the use of methanol may be cost effective but may not be good in terms of CO_2 and pollutants as there may be some emissions upstream.

Prof. Mao commented that a lot had been learnt from the US and European models. As China was weak in this respect he asked about possibilities for future collaboration in modelling as many universities and research institutes realised this shortcoming. Paul Leiby noted that there are models that can be downloaded, but this is not the kind of problem that can be solved by as single model alone. A suite of models had been used carefully with one another because of the need to understand the problem at the detailed spatial level as Prof. Mao had demonstrated with individual filling stations, but it is not practical to do that for all the cities for every year. There should be a national or international perspective and a dynamic analysis, like Prof. Li showed but that requires a different type of model. Paul Leiby reminded the audience that the HyWays IPHE brochure handed out to the participants had a discussion of the types of models that were used in the HyWays project and the US project and other models that were encountered. Those who are interested in modelling may learn something from the brochure and could offer some feedback by way of valuable insights. Presently there is nothing “off the shelf” on offer but there is significant expertise that has been developed. There was interest in working with the panel and with other distinguished researcher present who want to take up this challenge of roadmapping and hydrogen transition analysis.

Prof. Mao noted that there are many models and almost all of the models involve the use of a large database with some real industrial data and some real process data. He cautioned Chinese researchers to be very careful when using these models, as it was not correct to just simply acquire these models and run some simulations. The key to these models is the real data for each specific region, so Prof. Mao proposed that Chinese users should try to learn the models and the key parameters in the database and try to use actual Chinese research data for their applications.

Christoph Stiller explained that there are different levels of models. The infrastructure analysis model was used to evaluate every possible connection. In each of about 25 regions analysed in each country in HyWays there were a number of fuelling stations and a number of possible production methods depending on the availability of coal, wind and so on. The model itself would optimise where to produce hydrogen, from which source, where to deliver it and by which mode - so it was analysed in an integrated way.

To further clarify the discussion on modelling, reference was made to the HyWays IPHE brochure where the models were classified into five different categories:-

1. Life Cycle Analysis - typically the GREET or E3database model.
2. Technology development and costs of technology – H2A and HDSAM in concert with GREET, or E3database.
3. Regional hydrogen infrastructure development – to make the results regionally more specific – for example starting with a map of say 1000 fuelling stations the model can calculate and optimise how each one is supplied.

4. Market development and transition - not only hydrogen infrastructure but other aspects like where to sell the cars – how does that evolve and the transition from conventional or fossil fuels to hydrogen or other alternative fuels.
5. Energy system modelling - the highest or most comprehensive level - typically Markal studies looking not only at hydrogen but at hydrogen in the total energy system where heat, electricity and other fuels are also supplied.

A question pertaining to the same matter was whether the models had embedded data. Christoph Stiller noted that for HyWays the road distances were calculated using a factor, but since then a model has been developed where actual road distances are used for truck transport. In response to a question on the availability of the databases, it was noted that there were separate databases in the US for the individual production, delivery and retail technologies, and all these were downloadable. In HyWays a fair amount of data is available in datasheets that can also be downloaded. With these data it was possible to develop specific Markal models for the EU and the US. China could indeed do the same although Markal is very data intensive.

As China does not have an official roadmap the question of the importance of the modelling tools was raised, noting that the situation was different in China due to the absence of foreign auto and energy companies that actively promote hydrogen and fuel cells.

Paul Leiby responded that there were two clear conclusions

1. modelling is an important part – using not a single model but many types of models, some readily available, some harder to use and requiring more direct communication with those who developed them, but they are an essential way to pull the pieces together and have confidence that all the assumptions are consistent.
2. Stakeholder involvement was important in a profound way because it was critical to learn about technology costs. Once stakeholders felt part of the process they provided proprietary information about their estimates of the costs of producing vehicles and how they might change over time as they learned and increased the scale. From fuel producers they learnt important things about the trade-off between the distribution infrastructure and the costs of having an extensive one *versus* the benefit of concentrating infrastructure in just a few places to satisfy small markets. This led to the concept of how the transition might take place –the lighthouse concept where you target the most important cities first. This provided valuable information on how the analysis might be done and how the transition might take place, resulting in a report that had greater credibility.

In answer to the statement that China is different, it was noted roadmapping is an international problem and we need to do better in connecting with other countries and regions who were working on introducing hydrogen so that compatible assumptions about the size of the industry and how quickly these vehicles might be introduced can be made. Therefore even though things are different, there are opportunities for people here to communicate with manufacturers elsewhere.

Christoph Stiller highlighted that the advantage of bringing all the different groups of industry together was that, in the end, they all had a common vision. Each industry commonly tries to promote its own process or product, for example onsite steam methane reforming or coal gasification, without regard to other processes, but by collaboration in HyWays each industry had a certain share and the resulting roadmap was accepted by all the key stakeholders.

In conclusion Prof. Mao suggested that, as there was great interest in preparing a Chinese hydrogen roadmap, a memorandum of understanding should be signed allowing cooperation between the US, Europe and China, with the respective financing bodies providing support for the local research organisations involved. The coordinator of HyWays IPHE agreed that it was a good idea and would be discussed further.

The meeting ended exactly on schedule with Christoph Stiller thanking all the participants for the lively and interesting discussion.

List of participants

NB: This list may not be complete, and does not imply that all delegates participated during the entire programme.

Name	Organization	Country
BOHONG Lin	Tshinghua University	China
BUNZECK Ingo	ECN	NETHERLANDS
BYEONG Soo Oh	Chonnam National University	Korea
CAI Chiliu	Gugang zhou Energy Institut	China
CAIRNS Julie	CSA America	USA
CHANGFENG Yan	Guangchou Institute of Energy Con-version	China
CHEN Zhuan	Tongji University	China
CHUNXIN Ji	General Motros Corp.	USA
COURADE Nicolas	Ambassade de France	France
DAMGON Ye	MBraun	China
DONG-JEN Qian	Fudan	China
FAN Xiulin	Zhejiang University	China
FENG Weizhang	Panasonic Shanghai Labor	China
FERNANDES Rei	IDMEC-IST	Portugal
GAO Dan	Tsinghua Univ.	China
GONG Zhenhua	East China University of Science and Technology	China
GONGXUAN Lu	Lanzhou Institute of chemical physics	China
GU Jun	Nanjing University	China
HANG Zhouming	Zhejiang University	China
HIAO Jangming	Guangzhou Research institute of Nonferrous metals	China
HU Enyuan	Guanghou Inst. of Energy Conver-sion	China

HUA Zhang	Nanjing University of Technology	China
JEN Wei	Chonnam National University	Korea
JIANG Qizhong	Shanghai Jiao Tong University	China
JIANG Ying	Northeast Forest University	China
JIANGUO Liu	Nanjing University	China
JIANLIANG Wei	Xiangtan University	China
JIANXIN Ma	Tongji University	China
JIAO An-Ying	Northeast Forestry University	China
JIE Sun	Institute of chemical Defense	Chian
Jingle Shi	Nanjing University	China
JONG WON Kim	KIER	Korea
KYU-JUN Kim	Sejong Ind.	Korea
LEIBY Paul	CAS ORNL	USA
LI Bing	Tongji University	China
LIANG Zhao	Xianjiaotong University	Chna
LIONG Zhitao	Dalian Institute of chemical physics	China
LIU Binhong	Zhejiang Univ.	China
LUO Maji	Wuhan Univ. of Technology	China
MA Lai-Peng	IMR, CAS	China
NAI-CHIEN Shih	Ming Dao University	Taiwan
OWSTON Rebecca	Purdue University	USA
QUANTI Chen	Xiangtan University	China
SHI Ying	Wuhan University of Technology	China
STILLER Christoph	LBST	Germany
SUN Hong	Shen Yang Jianizhu University	China
TIAN Guangyu	Tsinghua University	China
TSENG Chia-Lin	National Central Universtiy	Taiwan
TSENG Chung-Jen	National Central University	Taiwan
VERFONDERN Karl	Research Center Jülich	Germany
WANSHENG Zhang	Dalian Institute of chemical physics	China

XIAOZI Yuan	Institute for Fuel Cell Innovation	Canada
XICONGLAN Shi	Nantong University	China
XIE Chang-Jun	Wuhan University of Technology	China
XIN Gao	Tongji University	China
YANG Hsiharng	CeTech Co. Ltd.	Taiwan
YANG Ying	Xi'an Jiaotong University	P.R.China
YE Tian Jun	Zhejiang University	China
YE WU	Tshinghua University	China
YUZHI Xie	Nantong University	China
ZHANG Cuninan	Tongji University	China
Zheng Li	Tsinghua University	China
ZHOU Li	Shanghai University	China
ZONG QIANG Mao	CAHE	China