HyWays - IPHE

Benchmarking of Hydrogen Energy Roadmaps

# SES6 038965

# HyWays-IPHE

# Benchmarking of the European Hydrogen Energy Road-map HyWays with International Partners

## Specific Support Action

## Priority [1.6] Sustainable Development, Global Change and Eco-systems

### Publishable Final Activity Report

Period covered: from 01 Oct. 2006 to 30 Sept 2008 Date of preparation: 13 Feb. 2009

Start date of contract: 01 Oct. 2006 Duration: 24 months

Project coordinator name: Reinhold Wurster

Project coordinator organisation name: Ludwig-Bölkow-Systemtechnik

# Table of Contents

# 1. Project execution

## Project objectives

The HyWays-IPHE project compares roadmapping and systems analysis activities in Europe and the USA, two major IPHE partners, and plans to get other IPHE partner countries with roadmapping activities in the field of hydrogen engaged in discussions and exchanges of experience between the regions as well as implementing institutional and personal exchanges in this field the under the patronage of IPHE.

Thereby the understanding about the ongoing activities should be improved among the partners to find to a common language and mutual understanding and thus nurturing an alignment of international approaches.

Key assumptions adopted in the HyWays project as well as conclusions drawn are cornerstones around which to compare the different modelling approaches, infrastructure analysis and stakeholder consultation efforts and the scenarios and roadmap drafts developed.

The project is structured in three main work packages (WP2, WP3 and WP4) which are timely phased. In WP2, model methodologies, modelling assumptions for E3database in Europe and for H2A and GREET in the U.S. are being compared during months 1 through 12. Benchmarking runs of the models have been performed.

In WP3, running from months 10 through 18, a comparison of further models and approaches will be performed, among others taking into account infrastructure/ resource analysis, macro-systems models, in-depth technology analysis/ assessment, and stakeholder consultation in roadmapping processes.

In WP4, active between months 16 and 24, the jointly developed understanding on modelling techniques and approaches as well as on stakeholder interactions will be presented to and exchanged with other IPHE member countries in workshops. The implementation of institutional and personal exchange under the patronage of IPHE is one of the expected outcomes of this work package.

## Contractors involved

Acciona Biocombustibles (E), Daimler (D), EC-JRC (NL), ECN (NL), FhG-ISI (D), GE Nuovo Pignone (I), IDMEC-IST (P), Midwest Research Institute (MRI)* (USA), LBST (D), Total (F)

Further, Argonnne National Laboratory (ANL) (USA) and Oak Ridge National Laboratory (ORNL) (USA) were invited to contribute to the project, without being formal contractors.

* Midwest Reseach Institute is the formal contractor, but the project contributions were all performed by National Renewable Energy Laboratory (NREL) which is an entity of MRI.

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## Work performed and results achieved: WP2 (Building a common understanding on modelling approaches)

The objective of this work package was to benchmark the different methodologic approaches and generic data input for energy pathway analyses of the U.S. and EU to identify the major differences and need for further developments.

**Approaches and methodology**

- Development of an approach for comparison of well-to-tank energy pathways
- Benchmarking comparison of 9 chosen well-to-tank pathways in U.S. and EU models. Discussion and interpretation of the results, preparation of an extensive report
- Glossary of terms in use for mutual understanding
- Evaluation of options for continuation into the next work packages
- Personal exchange between LBST, MRI, and ANL

**Main results achieved**

- Generally, the results with respect to costs, energy use and emissions are similar from both sides
- Some significant techno-economic differences could be found (e.g. biomass gasification efficiency, pipeline configuration)
- Different modelling philosophies for economic analysis was observed (micro- vs. macro-economic)
- Regional differences became visible (fuel economy, taxes)
- The energy price forecasts used by the DOE and in HyWays differ significantly
- Based on the found differences in approaches and results, a list of recommendations for model reviews and updates has been compiled which is available in the WP2 report (www.hyways-iphe.org).

The WP2 report has been downloaded 253 times by October 2008.

## Work performed and results achieved: WP3 (Extension of comparison of modelling approaches)

The objective of this work package was to extend the comparison of models and approaches started in WP2 to identify the major differences and to develop a concept for further model improvements and process improvements for stakeholder integration.

**Approaches and methodology**

- Selection of further tasks for extension of bilateral benchmarking comparison, and definition of the scope of each comparison task
- Quantitative and qualitative assessment of stakeholder involvement, regional infrastructure build-up analyses, energy system modelling and energy price assumptions, modelling of economic impacts and vehicle cost analyses, preparation of an extensive report
- Extension of the glossary of terms in use for mutual understanding
- Personal exchange between all involved institutes

**Main results achieved**

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. 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 similarly in both regions. Also vehicle costs are comparable, however based on different assumptions on components and cost reduction.
The WP3 report has been downloaded 121 times by October 2008.

## Work performed and results achieved: WP4 (HyWays-IPHE liaison)

The objective of this work package was to disseminate the results of the project to a wider group of experts, and to collect their feedback and gain insights in roadmapping activities in other countries.

**Approaches and methodology**

- A questionnaire has been created and circulated to IPHE members, interrogating details on key drivers for application of hydrogen / setting up a hydrogen roadmap, methodologies used for the roadmap, players involved, assumptions taken (e.g. energy price development), and results of the hydrogen roadmaps.
- A flyer and poster has been designed and printed to disseminate the high level results to a broader community.
- Two dissemination workshops have been organised and conducted to disseminate the project results, to learn about other activities for hydrogen roadmapping, and to discuss with the participants about roadmapping methodologies and activities.
- A plan for further collaboration beyond the HyWays-IPHE project has been drafted jointly.

**Main results achieved**

- Most IPHE country roadmaps are government sponsored, targeting Government & Industry
- Stakeholders involvement recognised as important
- Majority use models
- H2 production technology depends on scenarios and time frame of implementation
- End-use predominantly transport & stationary
- Impacts considered in roadmaps are firstly environmental, secondary economic

## Degree to which the objectives were reached and impact of the project

The project was the first of its kind to compare modelling activities in the field of hydrogen energy systems; therefore no state-of-the-art exists here.

Two exhaustive reports were written on the comparison of roadmapping and systems analysis in Europe and the USA, and other IPHE partner countries were involved through a survey of roadmapping activities, and partially through discussion in the dissemination workshops.

Institutional and personal exchanges were implemented, first of all bilaterally through visits among the HyWays-IPHE institutes and the task teams formed for the comparisons, and furthermore through the discussions with external experts at the dissemination workshops.

A glossary of terms in use was developed throughout the project to improve mutual understanding and to find a common language (see Annex to WP3 report).

Key successes of the project as collected from the partners were:

- Hydrogen pathway analysis – we developed a methodology and results that many can use
- Verification/Validation of all US models (H2A, HDSAM, GREET) with E3database

- Development of model categories as a basis for discussion
- Establishment of an international analysis team
- Beginning of understanding many countries roadmapping activities and differences in thinking about/modeling technology change and how that affects portfolio evolution

The project results were disseminated in different ways. An exhaustive slide collection was prepared summarising all main results from the previous WPs, and an 8-page flyer with aggregated results and messages for high-level dissemination was printed. The flyer was distributed to all participants of the WHEC 17 conference in Brisbane/Australia and the HyForum 2008 in Changsha/China. At both these events, 3-4 hour HyWays-IPHE roadmapping workshops were held to disseminate the findings of the project and discuss about roadmapping methodologies and activities. In addition, a total of 8 conference presentations were performed, and 2 posters were created for exhibition at public events.

To summarise, we believe that we have reached all the key objectives of the project and created a lot of robust and useful results that can be used by other researchers working in that area. We have dissemintated through all foreseen and appropriate channels and believe that we have reached the majority of people in need of such analyses. By this, we have contributed to an alignment of international approaches, and to some extent may have paved the way for a global roadmap. However, we do not recommend a global roadmap, due to the high complexity of such a task in view of huge regional differences in geologic, developmental, and political premises.

### Proposal for further collaboration

A concept for further exchange after the end of the project was developed.

International collaboration on systems analysis has shown to be beneficial to improve socio-economic models by understanding other regions' initiatives, plans and research directions. In addition, evaluating potential development of fuel cell and hydrogen markets requires knowledge of global trends and markets. The HyWays-IPHE project has successfully initiated an international collaboration on hydrogen and fuel cell systems analysis which now needs to be intensified.

Leading hydrogen infrastructure and transition models should be benchmarked and a common approach found on assessment of policy measures, global market interactions (e.g. raw material availability, technology learning) and synergies between transportation sector and other hydrogen and fuel cell applications. With the improved models, policy options shall be tested to determine their effects on hydrogen markets. Key aspects of this work are to identify the most important hydrogen technologies and to develop portfolios of policy options to support the transition from demonstration to early market commercialization. The end product will be identification of potential business cases and an improved comprehension of role of technology, policies and economics in the transition between demonstration and early commercial markets.

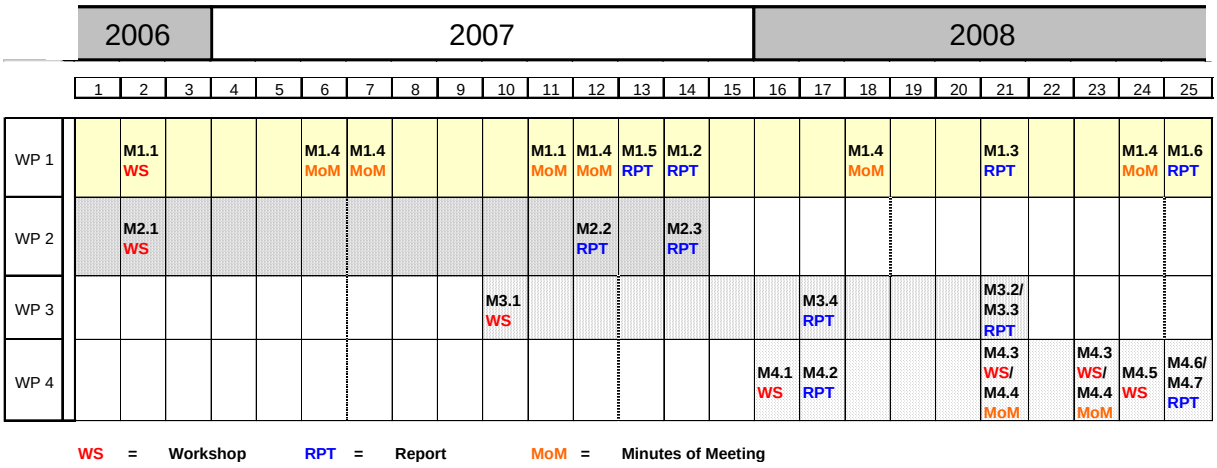
### HyWays-IPHE Logo and website

HyWays - IPHE

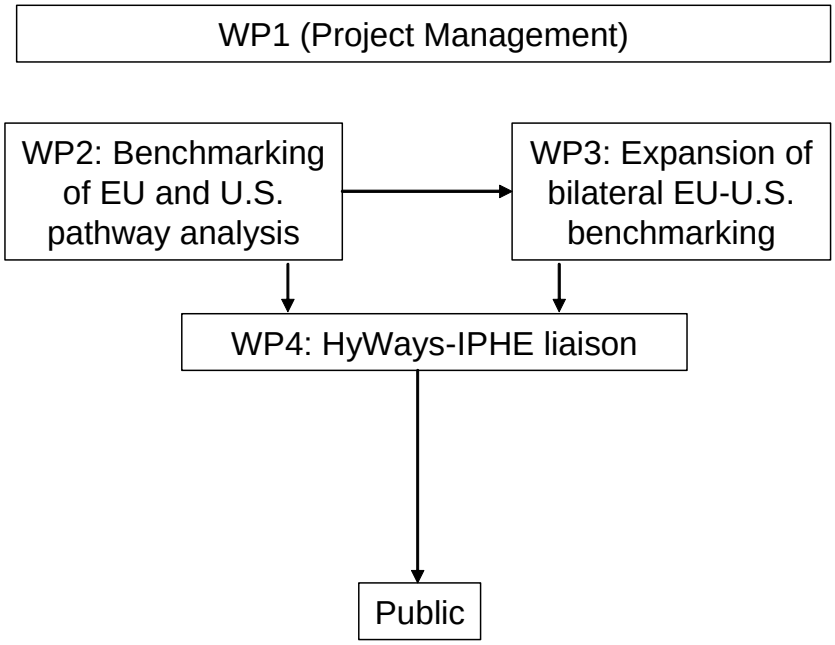
Benchmarking of Hydrogen Energy Roadmaps

Website: www.HyWays-IPHE.org

## Flow diagram of HyWays project progress




## HyWays-IPHE block diagram on project work structure



# 2. Dissemination and use

### 1. Methodology for benchmarking of hydrogen energy pathway analysis tools

***Result description (product(s) envisaged, functional description, main advantages, innovations)***

A methodology has been developed for benchmarking of hydrogen energy pathway analysis tools comprising techno-economic comparison of hydrogen production plants and delivery scenarios, and well-to-tank energy use and emissions. The methodology was used to compare the U.S. DOE models H2A Production, HDSAM and GREET with the E3database model developed by LBST which was used in major European hydrogen analysis activities. The economic comparison comprises original cases of the pathways (with all financial parameters as used by original analyses with the respective tools), and financially harmonised cases (where all financial parameters, i.e. interest rate, taxes, inflation, etc., have been assimilated). Using this methodology, existing cases can be compared on several levels; differences in assumptions and results for specific components of the energy pathways can be spotted as well as differences in overall costs and financial framework.

***Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)***

The methodology could be used for further comparison of modelling tools supporting hydrogen energy roadmapping of other world regions to the U.S./EU ones in order to investigate how the assumptions there correlate. This may improve understanding of the different roadmaps and differences between them.

***Stage of development (laboratory prototype, demonstrator, industrial product...)***

The methodology has been developed and refined throughout the comparisons between the U.S. and EU. For integrating further models, modification of specific details and improvements can be expected.

***Collaboration sought or offered (manufacturing agreement, financial support or investment, information exchange, training, consultancy, other)***

Collaboration of research and academia is sought for expanding the comparison to further world regions through publicly funded research projects.

***Collaborator details (type of partner sought and task to be performed)***

Research and academia involved into hydrogen energy roadmapping in regions outside the U.S./Europe; expansion of comparison of hydrogen energy pathway models

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## 2. Results of the benchmarking - Differences and recommendations (WP2 report)

***Result description (product(s) envisaged, functional description, main advantages, innovations)***

Using the developed methodology, the U.S. DOE models H2A Production, HDSAM and GREET have been benchmarked with the E3database model developed by LBST which was used in major European hydrogen analysis activities. 9 representative Well-To-Tank pathways have been compared (comprising electrolysis, SMR, CTH; onsite/central, pipeline, trucked-in LH2). Based on the found differences in approaches and results, a list of recommendations for model reviews and updates has been compiled which is available in the WP2 report (www.hyways-iphe.org).

***Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)***

The found differences may be used to refine the involved models, but also to compare the scope of techno-economic assumptions of the U.S./EU models with the ones of further activities. This may lead to a global harmonisation of assumptions (where this is reasonable) for the models supporting hydrogen energy roadmapping activities.

***Stage of development (laboratory prototype, demonstrator, industrial product...)***

An extensive report has been compiled and published at the project website www.hyways-iphe.org

***Collaboration sought or offered (manufacturing agreement, financial support or investment, information exchange, training, consultancy, other)***

Collaboration of research and academia is sought for expanding the comparison to further world regions through publicly funded research projects.

***Collaborator details (type of partner sought and task to be performed)***

Research and academia involved into hydrogen energy roadmapping in regions outside the U.S./Europe; expansion of comparison of hydrogen energy pathway models

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## 4. Definition of categories for roadmapping tools

***Result description (product(s) envisaged, functional description, main advantages, innovations)***

To classify models and tools used to support hydrogen roadmapping activities, the categories “Life Cycle Analyis (LCA)”, “Technology and Engineering Costs (TEC)”, “Regional Hydrogen Infrastructure Development (HID)”, “Market Development and Transition (MT)”, and “Energy System Modelling (ESM)” have been defined, and the available models used in roadmapping processes have been assigned to these categories.

***Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)***

The developed categories and the allocation of models and tools to them define clearly the key approaches and questions addressed by the specific models. They could therefore be useful to facilitate clear communication about models and approaches and help finding the right set of models for application in roadmapping activities.

***Stage of development (laboratory prototype, demonstrator, industrial product...)***

The methodology has been developed and refined throughout the comparisons between the U.S. and EU. An extensive report has been compiled and published at the project website www.hyways-iphe.org (WP3 report).

***Collaboration sought or offered (manufacturing agreement, financial support or investment, information exchange, training, consultancy, other)***

Collaboration is offered to research and academia in utilising the categories to select the right tools and approaches for a hydrogen roadmapping process.

***Collaborator details (type of partner sought and task to be performed)***

Research and academia involved into hydrogen energy roadmapping in regions outside the U.S./Europe; we offer consultancy in setting up hydrogen roadmapping activities.

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## 5. Results of the comparisons of hydrogen roadmapping activities and recommendations for developing a roadmap

***Result description (product(s) envisaged, functional description, main advantages, innovations)***

Different models, assumptions and approaches used by the U.S. DOE and the EC for roadmapping activities have been compared, such as organisation of stakeholder involvement, infrastructure build-up modelling, economic impacts modelling, energy system modelling, energy prices, well-to-wheel sensitivity analyses, hydrogen vehicle costs and cost targets. Based on the found similarities and differences in approaches and results, a list of recommendations for new roadmap activities has been compiled which is available at www.hyways-iphe.org (WP3 report / flyer).

***Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)***

The found differences and recommendations may be used to help new roadmapping activities selecting the right assumptions and support tools and models. This may lead to a global harmonisation of assumptions (where this is reasonable) for the models supporting hydrogen energy roadmapping activities.

***Stage of development (laboratory prototype, demonstrator, industrial product...)***

An extensive report has been compiled and published at the project website www.hyways-iphe.org (WP3 report).

***Collaboration sought or offered (manufacturing agreement, financial support or investment, information exchange, training, consultancy, other)***

Collaboration is offered to research and academia in utilising the results to select the right tools, assumptions, and approaches for a hydrogen roadmapping process.

***Collaborator details (type of partner sought and task to be performed)***

Research and academia involved into hydrogen energy roadmapping in regions outside the U.S./Europe; we offer consultancy in setting up hydrogen roadmapping activities.

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## 6. Results of the questionnaire on worldwide hydrogen roadmapping activities

***Result description (product(s) envisaged, functional description, main advantages, innovations)***

A questionnaire has been created and circulated to IPHE members, interrogating details on key drivers for application of hydrogen / setting up a hydrogen roadmap, methodologies used for the roadmap, players involved, assumptions taken (e.g. energy price development), and results of the hydrogen roadmaps. The evaluation of the questionnaires gives insights into these issues beyond the detailed anaylsis of the U.S. and European hydrogen roadmap. A report is available at www.hyways-iphe.org (WP4 report).

***Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)***

The found differences and recommendations may be used to help new roadmapping activities selecting the right assumptions and support tools and models. This may lead to a global harmonisation of assumptions (where this is reasonable) for the models supporting hydrogen energy roadmapping activities.

***Stage of development (laboratory prototype, demonstrator, industrial product...)***

A report has been compiled and published at the project website www.hyways-iphe.org (WP4 report).

***Collaboration sought or offered (manufacturing agreement, financial support or investment, information exchange, training, consultancy, other)***

Collaboration is offered to research and academia in utilising the categories to select the right tools and approaches for a hydrogen roadmapping process.

***Collaborator details (type of partner sought and task to be performed)***

Research and academia involved into hydrogen energy roadmapping in regions outside the U.S./Europe; we offer consultancy in setting up hydrogen roadmapping activities.

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