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 Ecosystems

APPENDIX to D4.4 Final Report on WP4

Analysis of Questionnaire:

Comparison of modelling efforts in hydrogen roadmapping activities in IPHE countries

Due date of deliverable: SEP 2008
Actual submission date: 06 OCT 2008

Start date of project: 01 OCT 2006 Duration: 24 Months

Organisation name of lead contractor for this deliverable: IDMEC-IST

Project co-funded by the European Commission within the Sixth Framework Programme		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

The HyWays-IPHE project is a specific support action (SSA) to assess and to compare the development efforts for the European Hydrogen Energy Roadmap prepared by *HyWays* with international roadmapping or comparative activities of IPHE partner countries.

In the first step, an in-depth assessment and comparison of the individual elements of the national/regional strategies, modelling approaches and experiences in the EU and the US was conducted. In the second step, the project aimed at broadening its scope within IPHE by including and involving other IPHE partner countries, allowing for a common language and mutual understanding of the ongoing activities, modelling techniques and approaches applied by the countries and thus nurturing an alignment of international approaches.

The consortium agreed at the meetings in Paris in July 2007 to conduct a brief survey of IPHE countries as a supporting action to the workshops and dissemination activities planned in Work Package 4 *"HyWays-IPHE liaison"* of the project. The purpose was not to do an in depth study of roadmaps in IPHE countries but more to find out which countries have roadmapping activities, the extent of the work performed and the contact persons in order that the EU-US consortium could learn about stakeholder involvement, the models employed and how they are used in IPHE partner countries.

Methodology and scope

A methodology for the questionnaire was devised which involved contributions from the HyWays IPHE consortium via a teleconference followed by the preparation and circulation of a draft questionnaire for further comments and inputs. It was agreed that the International Liaison Committee (ILC) meeting of the IPHE in Essen should be used to find out who the modellers are in countries not represented in the HyWays and HyWays IPHE activities and to do a test run of the draft questionnaire for clarity and completeness. A draft version of the questionnaire was presented at the WP4 kickoff meeting held in Munich on the 24th January 2008 and after some modifications, the questionnaire was presented at an ILC meeting of the IPHE held in Essen, Germany on the 19th February 2008.

It was at the IPHE ILC meeting in Essen that individuals from the partner countries were identified and invited to participate in the survey. For countries that were not represented at the meeting names of potential respondents were obtained from the secretariat and these leads were followed up. After further changes, a revised questionnaire was sent in March 2008 to all 17 partners of the IPHE which included Australia, Brazil, Canada, China, The European Commission, France (HyWays), Germany (HyWays), Iceland, India, Italy (HyWays), Japan, New Zealand, Norway (HyWays), Republic of Korea, Russian Federation, United Kingdom (HyWays) and the United States. Responses from 15 of the 17 partners were obtained during April and May. Details of the persons responding to the questionnaire, their affiliation and position in the institution are given in Table 1.
As a roadmap can mean so many things, it is not an easy task to assess the state of maturity of the systems analyses and roadmapping activities achieved by the different IPHE partners without going into an indepth analysis as was done for the EU-US comparisons. An attempt at such comparisons across all IPHE countries was out of the scope of this task as it might have been affected by the lack of a formal roadmap for certain countries and, where roadmaps do exist, they could pose further challenges for the team if they were in other languages. It was agreed therefore that within the timeframe and the resources allocated to the tasks in this

workpackage a cursory survey of the roadmapping activities would be carried out by means of a structured questionnaire.

This report covers the analysis of the IPHE member countries' responses to the afore-mentioned questionnaire. The analysis is based on the responses of 15 out of the 17 countries addressed and extracts information for comparison. The presentation of the results follows the structure of the questionnaire dealing with the general roadmap overview, tools and models used and the results. In each case the question appears at the beginning of the appropriate section. The main findings are mostly presented in the form of graphs accompanied by brief comments of the features evident from the data. A profile of the hydrogen roadmapping activities of each IPHE country is presented in the form of tables for each country in Annex 1.

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. In some countries where large teams of experts may have been involved in the roadmapping activities, it is possible that the respondent may not have been totally familiar with all aspects of the roadmap. Despite this inherent weakness of the questionnaire, it is believed that the results are of value in establishing the broad pattern of the approach to roadmapping in the various IPHE countries. Nevertheless this potential constraint should be borne in mind when critically evaluating the responses as the answers depend on the personal knowledge and interpretation of the questions by the respective respondents.

Table 1. Information on the person(s) responding to the questionnaire by the individual countries

COUNTRY		Name	Organisation	Position
1	**USA**	Fred Joseck Sunita Satyapal Kristin Deason	US Department of Energy; Sentech, Inc.	Hydrogen System Analysis Lead
2	**EU-10**	Ingo Bunzeck	ECN	Researcher
3	**UK**	Ray Eaton	Dept. of Business, Enterprise and Regulatory Reform	Assistant Director
4	**France**	Jean-Marc Agator	CEA	Project Manager
5	**Germany**	Christoph Stiller	LBS GmbH	Researcher
6	**Italy**	Antonio Mattucci	ENEA	Senior Engineer
7	**Norway**	Christoph Stiller	Norwegian University of Science and Technology	Post-doc Researcher
8	**Iceland**	Ingolfur Thorbjornsson	Iceland Innovation Centre	Managing Director
9	**China**	Kun Yuan	Institute of Nuclear and New Energy Technology, Tsinghua University	Associate Professor
10	**New Zealand**	Anthony H. Clemens	CRL Energy Limited	General Manager - Research
11	**Korea**	Seong-Ahn Hong	National RD&D Organization for Hydrogen and Fuel Cell/KIST (Korean Institute of Science and Technology)	Director
12	**India**	B.M.S. BIST	Ministry of New and Renewable Energy	Advisor/Scientist
13	**Australia**	Rohan Tepper	Dept. of Resources, Energy and Tourism	Senior Policy Officer
14	**Canada**	Annie Desgagne	Industry Canada	Senior Advisor, Hydrogen & FC
15	**Brazil**	Symone Araújo	Departamento De Combustíveis Derivados De Petróleo.	Coordinator-General Natural Gas Department
16	**Japan**	Atsushi Yamamoto	Ministry of Economy, Trade and Industry (METI)	Deputy Director
17	**Russia**	Stanislav Malyshenko	Joint Institute for High Temperatures of Russian Academy of Sciences	Head of laboratory for Hydrogen Energy Technologies

2 RESULTS OF THE QUESTIONNAIRE

The answers to the first question are mostly covered in Table 1. The remaining answers to questions two to four are covered below. Throughout the description and the graphics presented below the countries are referred to by their common abbreviations given in Table 2. In the case of the European Commission that is officially listed as an IPHE partner, the countries represented are the ten countries mapped in the *HyWays* project, collectively referred to as "*HyWays*". The ten countries include Germany, Spain, Finland, France, Greece, Italy, Netherlands, Norway, Poland and the United Kingdom. In addition to being included in the HyWays Project, the UK, France, Germany, Italy and Norway responded to the questionnaire individually on the basis of roadmapping activities being undertaken in the respective countries.

Table 2 Abbreviations used in the report for the individual countries

No.	Country name	Country code	No.	Country name	Country code
1	Australia	AU	12	Italy	IT
2	Brazil	BR	13	Japan	JP
3	Canada	CA	14	South Korea	KR
4	China	CN	15	The Netherlands	NL
5	Germany	DE	16	Norway	NO
6	Spain	ES	17	New Zealand	NZ
7	Finland	FI	18	Poland	PL
8	France	FR	19	Russia	RU
9	Greece	GR	20	Great Britain	UK
10	Iceland	IC	21	United States of America	USA
11	India	IN	22	DE, ES, FI, FR, GR, IT, NL, NO, PL, UK	HyWays

3 ROADMAP OVERVIEW

3.1 Hydrogen roadmaps

(**Q2.1** Has your country prepared a roadmap or other strategic planning document to prepare for the transition to a hydrogen-based energy system?)

The majority of the countries (CA, AU, IN, KR, NZ, CN, IC, NO, DE, HyWays, USA, JP) indicated the existence of a specific programme devoted to the preparation of a "roadmap" for the transition to a hydrogen energy system as demonstrated in Figure 1. However, some countries do not have such a specific activity (UK and IT), and they cover hydrogen roadmap planning within other broad ranging programmes such as the work of the Department of Business, Enterprise and Regulatory Reform (BERR) in the UK and within *HyWays* in France and Italy.

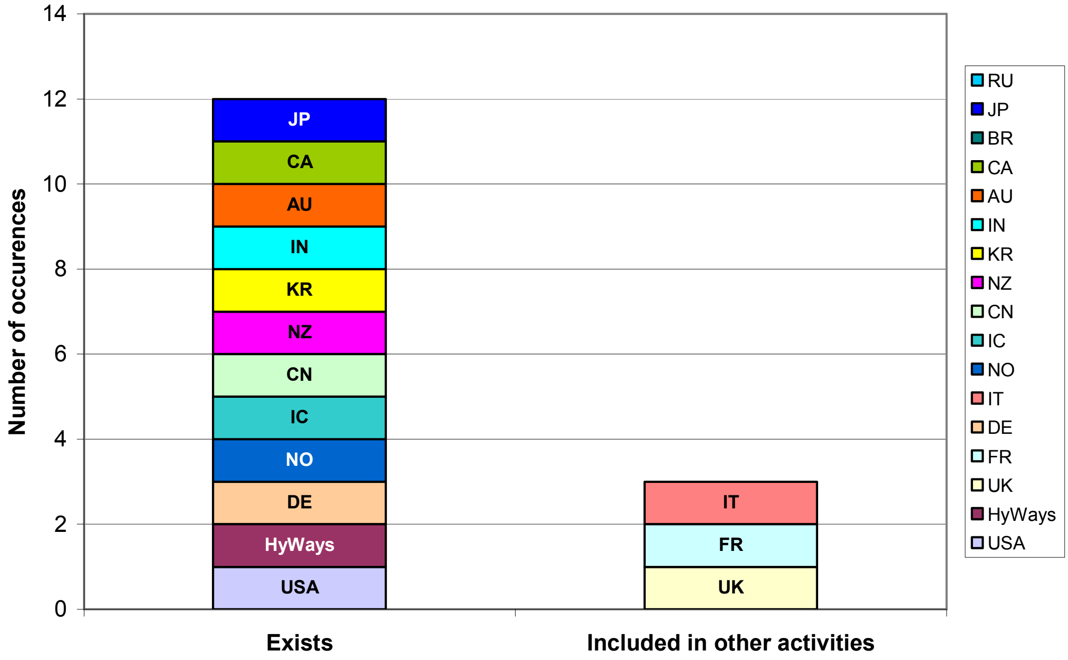

Figure 1 Existence of roadmap programmes

3.2 Status of hydrogen roadmaps

(**Q2.8** What is the status of the roadmap (planned, in progress, completed)? Please include (expected) date of completion.)

As far as the question on the status of the hydrogen roadmap is concerned, most of the respondent countries stated that it had been completed (IN, KR, CN, IC, IT, FR, UK, HyWays, USA), see Figure 2. In the rest of the countries (CA, AU, NZ, NO, DE) the hydrogen roadmap development is in progress and is expected to be completed in the course of 2008, or it is under revision (JP). The countries that prepared their hydrogen roadmap earlier, as is the case of USA (2003) and KR (2005), plan updates of the roadmaps, while the other countries at present do not have clear plans for future updating activities. This can be explained by the fact that they are just about to finish the first roadmaps. Interestingly, CA has already prepared and published two hydrogen roadmaps and the third one is under development. The roadmaps cover 10-year periods and a similar approach is assumed for their update.

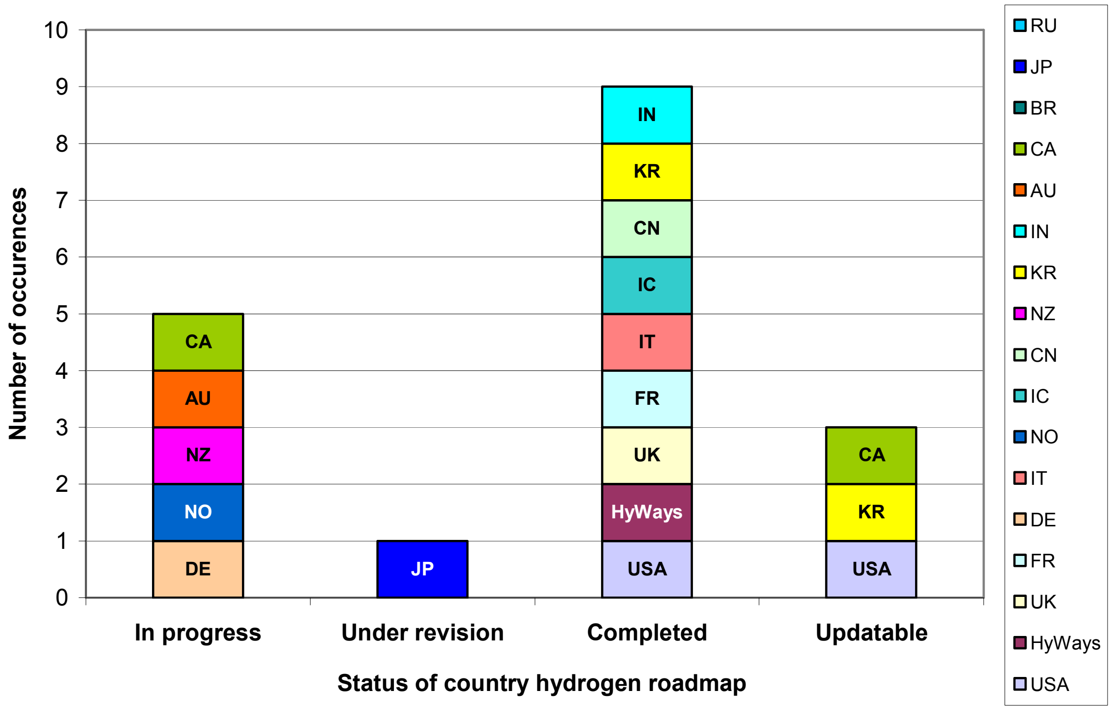

Figure 2 Status of country hydrogen roadmap

Links to the countries' hydrogen roadmaps can be found in Annex 2.

3.3 Philosophy of the roadmap and expected achievements

(**Q2.5** What is the purpose or philosophy of this roadmap? What do you aim to achieve?)

The countries presented quite a wide range of objectives and expected outcomes of the hydrogen roadmapping exercise. Introduction of H_2 to energy systems, identification of viable H_2 energy pathways and cost-competitive / low cost technologies were common answers amongst others. The set objectives per country can be consulted in Annex 3.

3.4 Roadmap programmes funding sources

(**Q2.6** Who is the roadmap funded by?)

In most of the countries the roadmap programmes are funded by government (AU, IN, KR, NZ, CN, IC, IT, DE, FR, UK, USA, JP) as shown in Figure 3. In HyWays and NO co-funding by governmental institutions and industry is reported, and only CA stated that its roadmap development is funded only by industry.

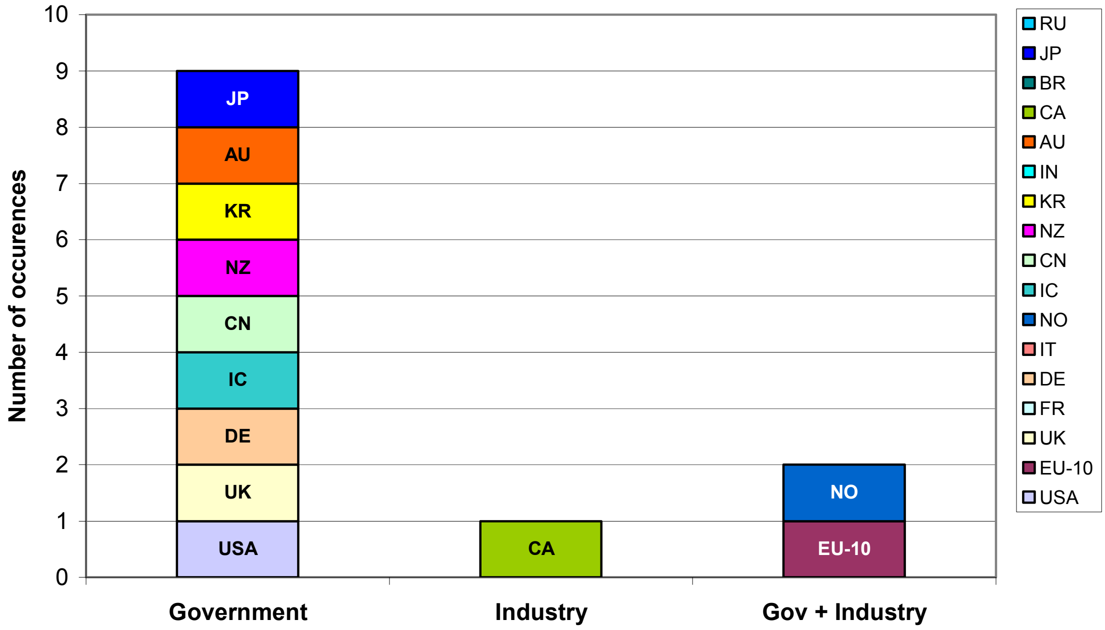

Figure 3 Roadmap funding sources

3.5 Roadmap timeframe

(**Q2.11** What is the timeframe considered in the roadmap (e.g. 2005-2050)?)

As demonstrated in Figure 4, the roadmap timeframes of the various countries differ. While several countries considered a 2003(5/6/8)-2050 time-span (USA, AU, CN, NO, DE, FR, UK), others used 2005-2030 (JP), 2010-2050 (DE and FR), or applied the range 2020-2050 (HyWays and IT). Some countries considered an even much shorter timeframe in their roadmaps (IN and CA). The Indian hydrogen roadmap does not go beyond 2020, and Canadian roadmap covers a 10-year period (2006-2016).

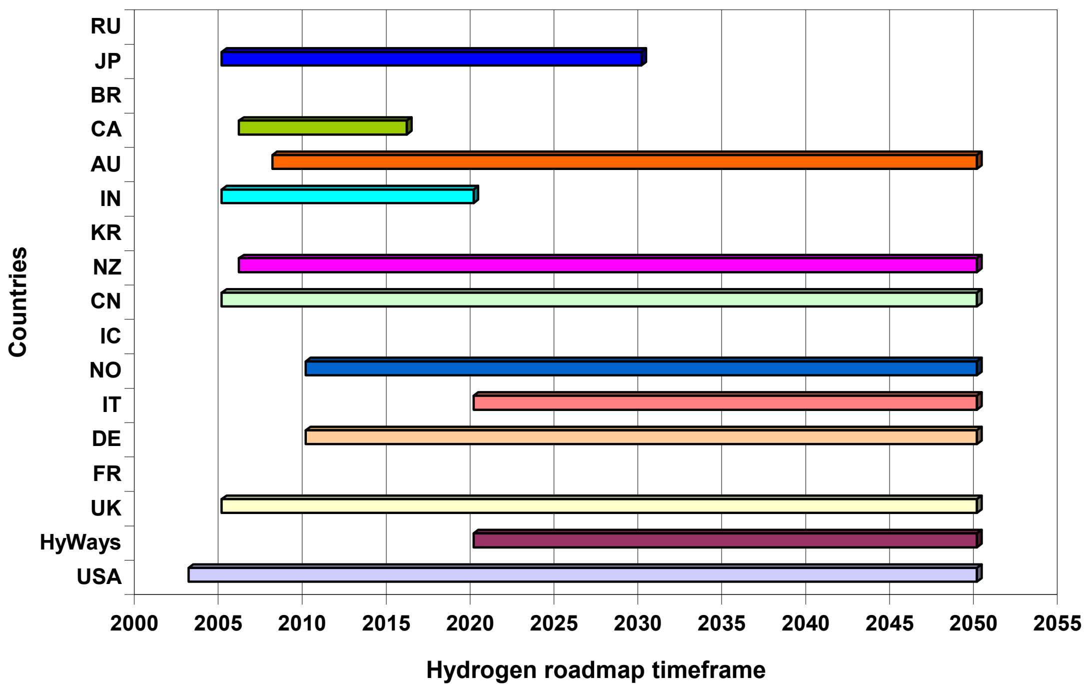

Figure 4 Timeframe covered by country hydrogen roadmap

3.6 Stakeholders' involvement

(**Q2.9** Where any stakeholder groups or stakeholders involved in the development of your roadmap?)

As far as stakeholders' involvement in the process of hydrogen roadmapping is concerned, all the countries that responded to this question mentioned participation of stakeholders. In the majority of cases the stakeholders covered a wide spectrum from *government, academia/research, industry to public* (IC and CA), *government, academia/research and industry* (NZ, KR and IN), or *academia/research, industry and public* (USA and AU). In CN and NO only *industrial* stakeholders were involved, and in DE, besides *governmental institutions and organisations*, there was no direct involvement of other stakeholders at this stage of hydrogen roadmapping development.

3.7 Types of stakeholders' inputs

(**Q2.10** If stakeholders were involved, how did they provide input?)

Various forms of the stakeholders' participation during the hydrogen roadmap development process, or at least at some stages, were reported in the responses as illustrated in Figure 5. The stakeholders were invited for broad discussions on the relevant issues through workshops and meetings. They were contacted for interviews, giving feedback, or they were asked to provide technical data, visions and opinions. In the evaluations stakeholders participated by reviewing and making comments on the results obtained. In some cases the stakeholders' groups had their representatives in the steering committee for the hydrogen roadmap development.

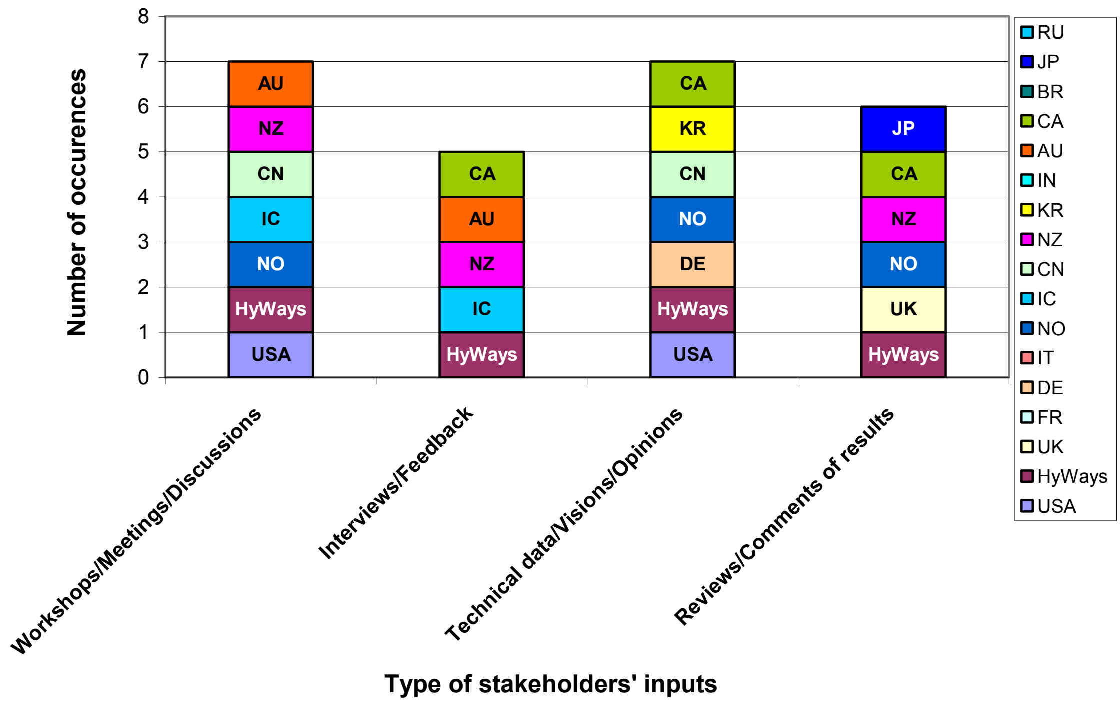

Figure 5 Stakeholders' inputs to hydrogen roadmapping

3.8 Roadmap target groups

(**Q2.12** Who is the target audience for this roadmap?)

Government and *industry* were stated as target groups of the hydrogen roadmap exercise by a majority of the respondents (CA, AU, KR, NZ, CN, NO, DE, UK, USA, HyWays), followed by *academia* (KR, DE, UK, USA) and *public* (KR, CN, JP), as depicted in Figure 6. Some countries also aimed at addressing all stakeholders in general (AU and IC), or presenting results to international audience as in the case of CA.

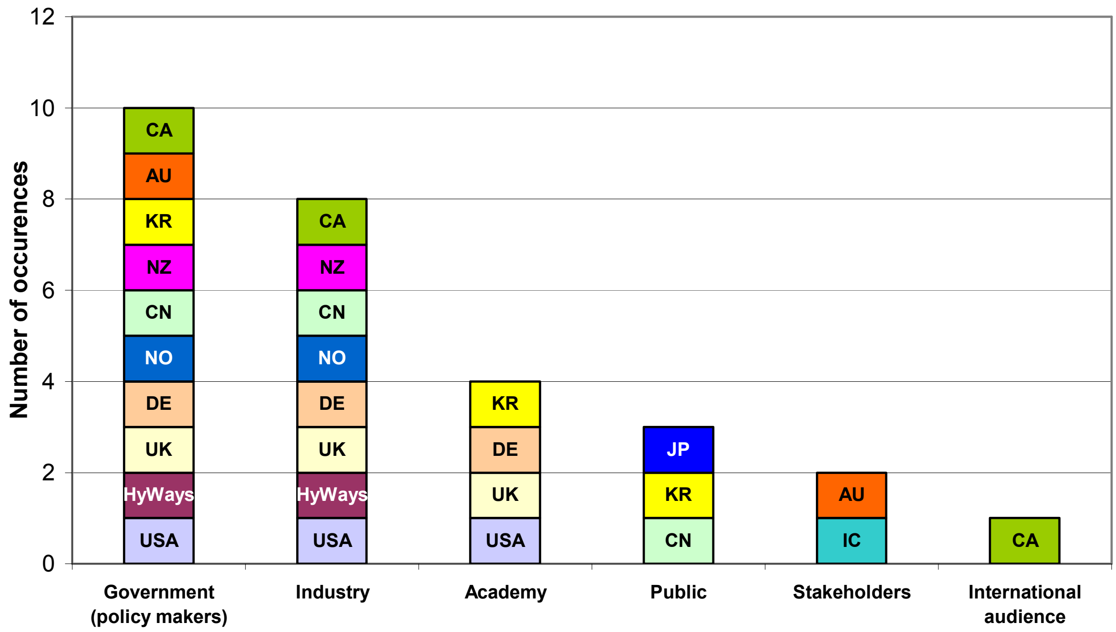

Figure 6 Roadmap target groups

3.9 Roadmap drivers

(**Q2.13** What are the main issues driving the roadmapping initiative (e.g. energy shortage, CO_2 emission reductions, energy security, etc.)?)

Greenhouse gases (GHG) abatement along with security of supply were indicated as the more common drivers for the roadmapping activities (CA, IN, KR, NZ, CN, NO, IT, DE, FR, UK, HyWays, USA), Figure 7, which confirms the concern of the countries towards the commitments made in Kyoto and also towards the need to ensure a secure energy supply. Furthermore, the shortage of fossil energy or sustainable use of fossil fuels (HyWays and DE), use of environmental friendly energy (IC), energy policy (UK) and economic benefits (USA) have also been listed. The key driving issue for Australia was to establish a clear understanding of the areas of hydrogen technology in which Australia had research capabilities and strengths as compared to countries overseas. This information was needed to define goals and milestones for further research and hydrogen development. Japan has a broader range of drivers as indicated in Figure 7.

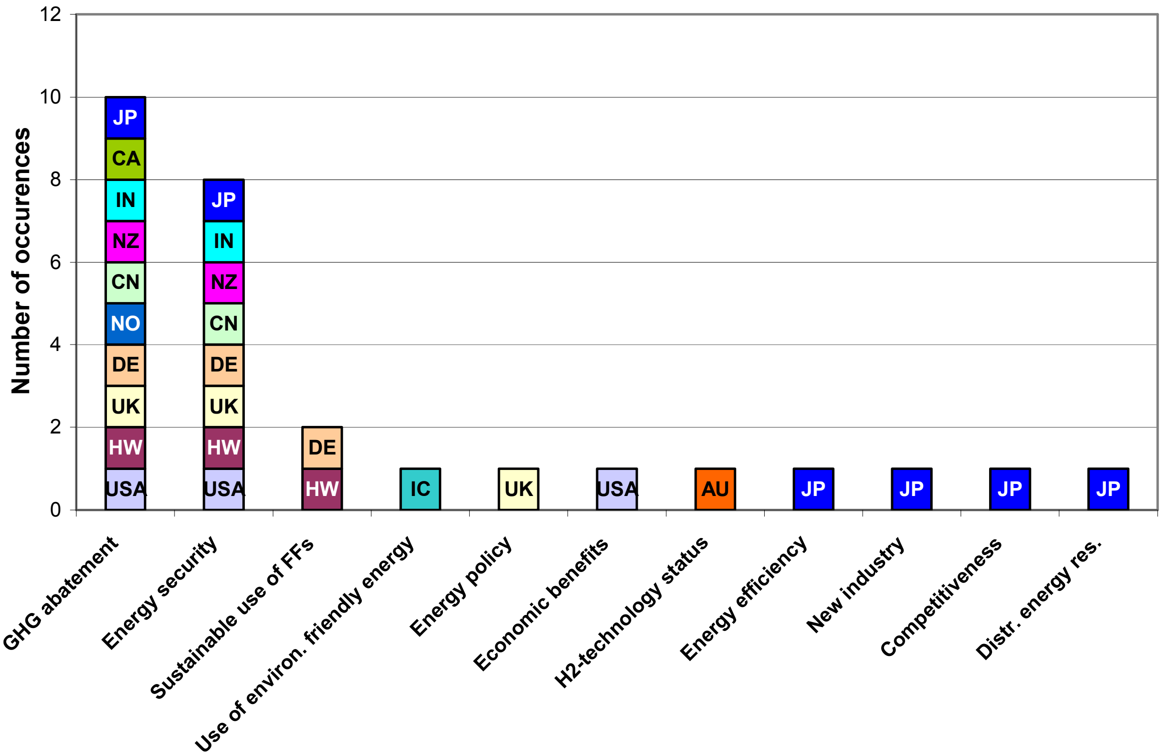

Figure 7 Roadmap drivers

3.10 Challenges faced during the development of the roadmap

(**Q2.14** What challenges did you face in carrying out the roadmap?)

The different countries have faced different types of challenges during the process of developing their hydrogen roadmaps which can be summarised as follows: very tight timeframe for the roadmap completion, or coordination of inputs, organisation of activities and completion of tasks; lack of or conflicting data, difficulties in acquiring hard data from industry; coming to consensus of all stakeholders on the role of H_2, alignment of diverging hydrogen interests; considering all aspects of the H_2 economy, technological barriers, product performance, life and costs.

3.11 Issues that remained unresolved

(**Q2.15** Did any issues remain unresolved? If so, what were they?)
As the majority of the respondent countries have already completed their hydrogen roadmaps they did not specify issues that remained unresolved. However, among some mentioned were difficulties in obtaining hard data from industry (CA), the potential of hydrogen for stationary applications (power/CHP/heat) in specific situations of isolated communities (UK), or insufficient opportunity to discuss the barriers for the introduction of hydrogen FC technology among various stakeholders due to limitations of the available budget (HyWays).

3.12 Plans for further hydrogen roadmapping activities

(**Q2.16** Are there plans for any further roadmapping activities? If so, what are they?)
As the hydrogen roadmaps have already been completed in the majority of countries, at present there are no plans for further roadmapping activities except in the case of the USA, Canada and Japan who plan to update the roadmap or to revise activities in the near future. Germany considers the possibility that the hydrogen roadmap will be evolved further with the formation of a general advisory consortium for the government during the national innovation programme lifetime (up to 2016).

3.13 Plans for the hydrogen roadmap implementation

(**Q2.17** Are there plans for implementing the roadmap? If so, what are they?)
In terms of the implementation of hydrogen roadmaps it is evident that for some countries although the plans for the implementation of the hydrogen roadmap are not yet specified it is likely to be considered in the near future (IC, NZ, IN and AU) as the roadmaps are in the final phase of preparation. However some countries already foresee concrete applications for the outcomes of the roadmaps such as: contributing to a part of the national development programmes (CN), a decision supporting tool for national innovation plans (DE), or incorporation in to national policies (UK and JP), a guide for activities of the relevant governmental institutions (USA), and a base for the hydrogen action plan (HyWays).

4 MODELS & TOOLS

4.1 Use of models in roadmap preparation

(**Q3.1** Were any tools or models used in your energy strategy planning process?)
Most of the countries that responded indicated that they had used some modelling tools in the hydrogen roadmapping activities, AU, NZ, NO, IT, DE, FR, UK, HyWays and USA. employing various models. However, more than one third of the countries with a roadmap did not apply any models, Figure 8. In the case of Japan, their hydrogen roadmapping was based on empirical assumptions, whereas Iceland and Korea based their analyses on existing roadmaps of other countries. Canada has been examining the existing models of HyWays and USA to adapt them for its own approach.

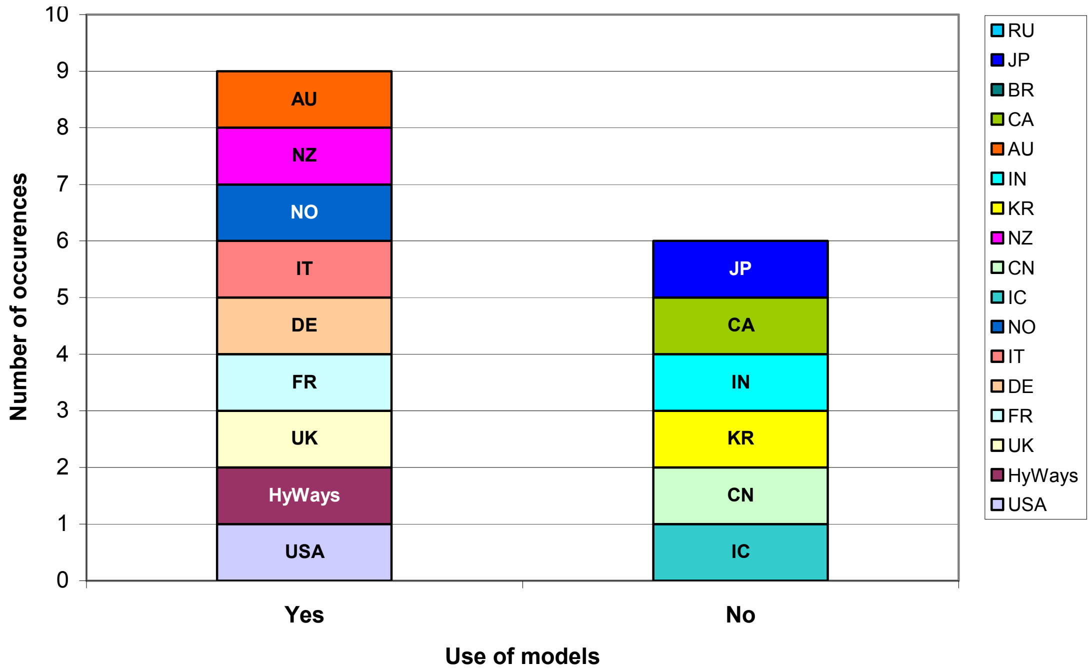

Figure 8 Use of models in roadmap preparation

4.2 Models and tools used

(**Q3.2** If yes, please describe the tools and models used.)

A summary of the models and tools used for the development of a hydrogen roadmap by the various countries is given in Table 3. Some of them are known models whereas others were developed at national level. It appears that a very limited number of models have been in use in the IPHE countries. The most commonly reported model in use is the Markal family of models which includes Times. Both the US and the HyWays project use the greatest number of models in their respective roadmaps.

Table 3 Overview of models and tools used by the individual countries

MODELS & TOOLS	GENERAL COVERAGE	USA	HyWays	UK	FR	DE	IT	NO	IC	CN	NZ	KR	IN	AU	CA	BR	JP	RU
H2A	H_2 Cost analysis																	
GREET	GHGs and petroleum use																	
HyTrans model	Consumer choice & vehicle penetration impacts on H_2 use, vehicle & infrastructure costs																	
E^3database	Pathway costs; energy requirements; GHGs																	
MARKAL	Energy system modelling: Bottom-up optimisation																	
MoreHys	Energy system modelling: Regional bottom-up optimisation																	
COPERT	Non-CO_2 emissions																	
Pace-T	Production & consumption elasticities																	
ISIS	Import/Export modelling																	
CONCAWE	BCF hydrocarbon database of the oil companies' European Association for Environmental, Health and Safety in Refining and Distribution																	
POLES	Simulation and economic analysis of sectoral impacts of climate change mitigation strategies																	
Unnamed model	Energy system model as the link and collecting vessel for all assumptions (H_2 infrastructure analysis; energy demand and availability; conversion processes; cost and CO_2 emissions)																	
TIMES	MARKAL family optimisation model																	
STELLA (SU)	Energy economy modelling-system dynamics model																	
Unnamed model	Long-run electricity generation costs																	
Unnamed model	H_2 production cost																	

Used models — Without use of models — Not specified

4.3 Key modelling assumptions

(**Q3.3** What are the key modelling assumptions used in your roadmap (e.g. vehicle costs, technologies & learning, CO_2 caps/taxes, etc.)?)

4.4 Energy price assumptions, price levels

(**Q3.4** What energy prices assumptions were used and what were the price levels?)

4.5 Trends for energy demand

(**Q3.5** How was the trend for energy demand assessed?)

Questions Q3.3 to Q3.5 sought specific information which in many cases did not exist and hence the responses were rather sparse for many countries. However for the comparison of the US and EU roadmapping and systems analysis activities these questions have been addressed by the team in workpackages two and three and the detailed results are given in the respective final reports. The key differences between the EU and the US are summarized in the HyWays IPHE brochure. The assumptions made in all the countries are summarized in Annex 4.

In terms of the key modelling assumptions such as vehicle costs, technologies and learning the questionnaire did not yield any additional information from the IPHE countries outside Europe and the US. On the issue of CO_2 and taxes the values reported for the cost per ton of CO_2 and the caps are mostly within the range of the HyWays assumptions. In the case of Norway, values of up to €100/ton were used for sensitivity analyses. New Zealand reported using charges of NZ$25 to 150 per ton.

There is a wide range of variation in the assumptions for oil prices made by the IPHE countries. In the UK the price of $25 per barrel were based on the Energy White Paper of 2003 with a values of $50 being used for a sensitivity analysis.

The assumptions for the price of oil vary from $25 per barrel (used in the UK on the basis of Energy White Paper of 2003) to $250 per barrel in 2020 in the “Limited Resources Scenario” of Germany, see Annex 4.

5 RESULTS OF HYDROGEN ROADMAPPING EXERCISE

5.1 Hydrogen production mix

(**Q4.1** What was your projected hydrogen production mix (e.g. 40% centralised electrolysis, 60% SMR)?)
The projected hydrogen production by the different countries is illustrated in Figure 9.

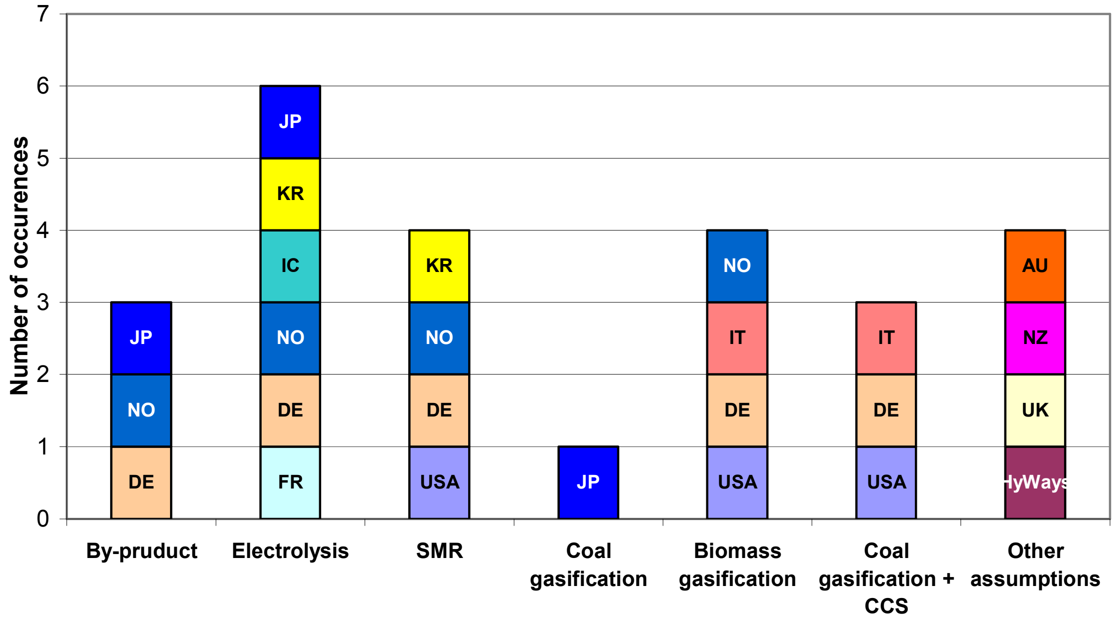

Figure 9 Hydrogen production mix

In fact, when projected, some of the respondent countries assumed different production technology mix used in different time periods (e.g. early stage, medium or transition period and long term) as was the case of USA, DE, NO, KR, IT, FR and JP. However, there were also countries (HyWays, NZ, UK and AU) which applied different approaches. HyWays analysed hydrogen production pathways, which were selected by the stakeholders of the member states. Among common production chains that considered fitting best to their current and future energy systems were included. Thus, hydrogen production mix varies from member state to member state and there is not a common one. Similarly, NZ established 9 supply chains to be needed to meet the identified energy scenarios and, then, the projected production mix varied related to each scenario analysed. UK aimed at identifying options instead to predict hydrogen production scenarios, and AU did not do any projection of mix of production technologies but rather focused on determination under which conditions hydrogen production would be economic.

IC stated hydrogen production applying centralised electrolysis. IN indicated envisaged centralised hydrogen production as well as on-site applications without mentioning a certain hydrogen production technology mix considered. Finally, CN and CA reported no quantitative results to this issue.

In relation to afore-mentioned responses on the implementation timeframe of different hydrogen production technologies, it is summarised in Figure 10.

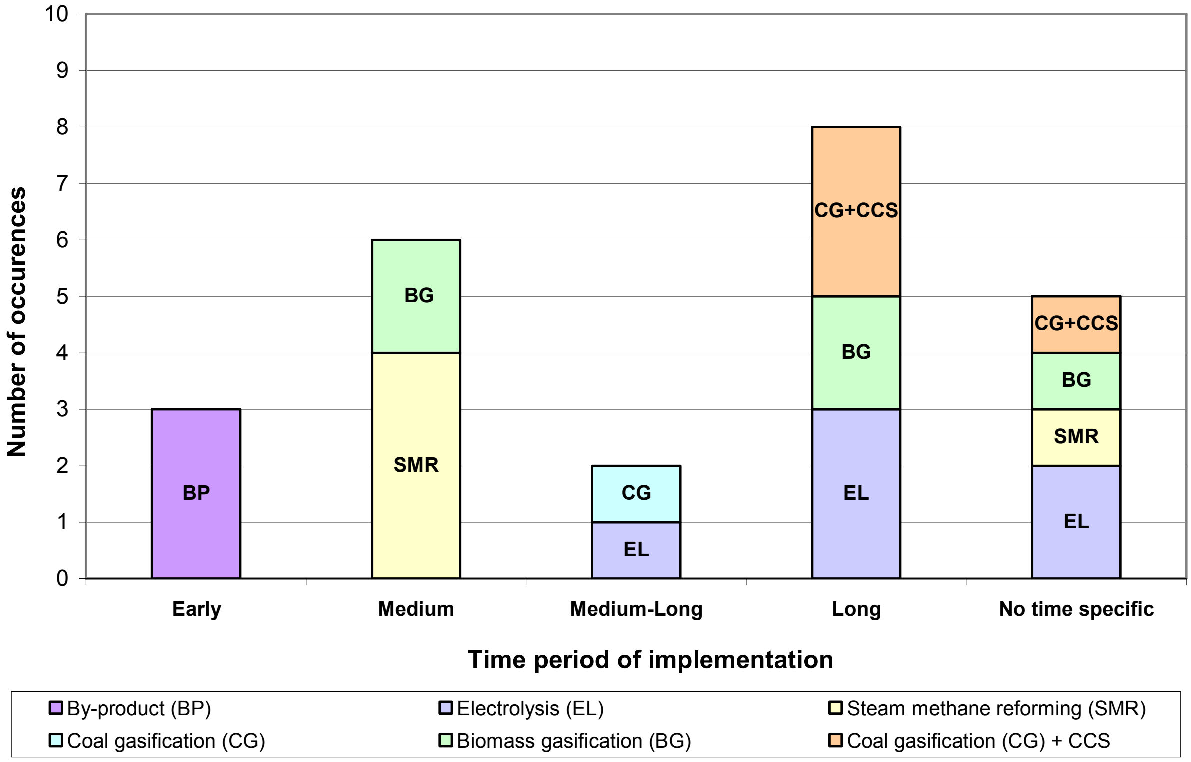

Figure 10 Time period of hydrogen production technology implementation

As can be seen, in the near-term hydrogen availability as *by-product* was assumed (DE, NO and JP). *Steam reforming of methane - SMR* was stated as the technology favoured for hydrogen production in the medium-term (KR, NO, USA and DE) together with *biomass gasification* considered already by some countries (NO and DE), while hydrogen production by electrolysis (JP, KR, FR and DE), *coal gasification* (JP), *coal gasification with CCS* (IT, USA and DE) and *biomass gasification* (IT and USA) are technologies assumed to be ready for hydrogen production in the medium-long or long-term.

5.2 Hydrogen use

(**Q4.2** What hydrogen uses were included in your roadmap (e.g. stationary, transportation, industry, etc.)?)

In relation to hydrogen use, *stationary* energy production (including applications in buildings) and *transportation* were the most considered applications (CA, IN, KR, NZ, CN, IT, JP, DE, FR, NO, HyWays, USA) as shown in Figure 11. *Industrial* application of hydrogen in refineries (IT) and hydrogen *export* (NO) were also pointed. UK and IC considered all potential uses.

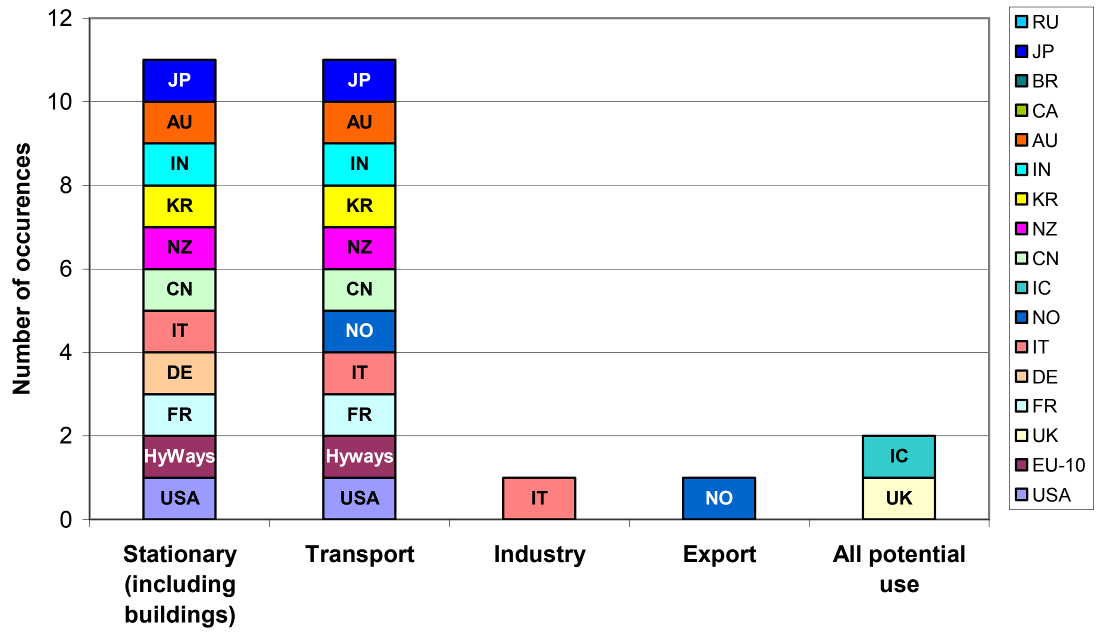

Figure 11 Hydrogen use

5.3 Hydrogen infrastructure

(**Q4.3** What hydrogen infrastructure was considered (e.g. pipelines or hydrogen trucks)?)

As far as hydrogen infrastructure is considered, use of *trucks* followed by *pipeline* distribution were among the most considered applications (AU, KR, NZ, CN, IC, NO, IT, JP, DE, FR, UK, HyWays, USA) as demonstrated in Figure 12. Use of existing natural gas *pipelines* (or their retrofitting) has been considered for the near-term or transition period (CN, FR, USA), too. Some of the countries also stated hydrogen production infrastructure at this point they took into consideration for roadmapping such as *centralised* (IN, UK, USA), *decentralised/on-site* production (AU, UK, USA, IN, DE) (see Figure 12).

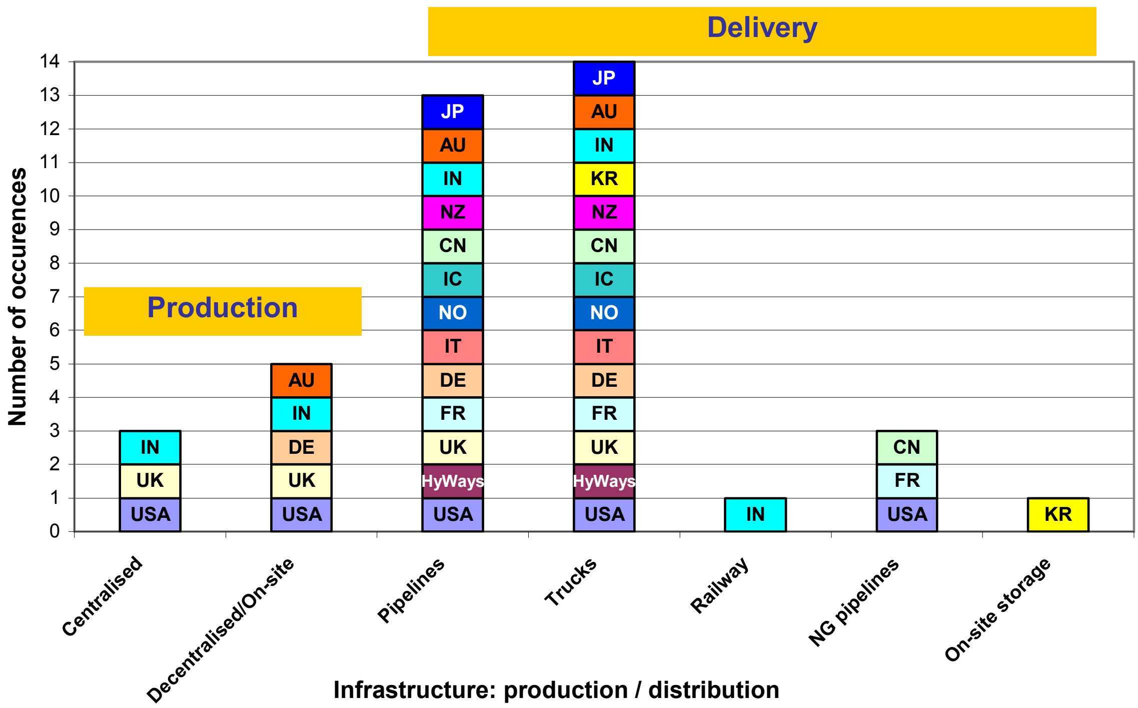

Figure 12 Hydrogen infrastructure

5.4 Assessment of economic & environmental impacts

(**Q4.4** Were economic impacts investigated? If so, what were they (e.g. GDP, employment impacts)?)

(**Q4.5** Were environmental impacts investigated? If so, what were they (e.g. air pollution, GHG emissions, water use)?)

In general, it can be concluded that the majority of the countries did assess economic and environmental impacts associated with the hydrogen economy. However, only few countries made quantitative assessment of the impacts. Other just indicated that consideration was made, made to some extent, as the issues are still subject to lot of uncertainty, or that the focus was on qualitative expression of the impacts. Thus, Figure 13 only illustrates in a general way the positive answer if the respondent countries took into consideration economic and environmental impacts that the hydrogen economy would have.

While, when considered, the indicators of economic impact were not specified, except in the countries of *HyWays* (HyWays and FR) *cash flow* and *employment*, environmental evaluation, again when taken into account, included *GHGs* or *GHGs* and other *air pollutants* (especially transport related air emissions).

Figure 13 Consideration of economic and environmental impact of the hydrogen economy

6 CONCLUSIONS

The survey showed that most IPHE countries do have a roadmap dedicated to the hydrogen economy although in some cases 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.

The main driving forces recognised for the roadmapping process were greenhouse gas abatement and energy security followed by others such as sustainable use of fossil fuels, use of environmentally friendly energy, energy efficiency, distributed energy resources, the status status of hydrogen technologies in the country, energy policy, economic benefits and new industry or competitiveness. Common features in their objectives for hydrogen roadmaps were the introduction of hydrogen in the energy system, the identification of energy pathways and cost competitive technologies. Additionally, IPHE members have country specific objectives including, amongst others, best utilisation of country resources, identification of suitable country regions, niche markets, identification of barriers, gaps and actions to be taken, development of suitable models, recognition of policies required and technical issues to be solved, or links between near-term commercial applications and long-term mass markets.

In all cases stakeholders involvement was recognised as playing an important role, and quite a wide spectrum of stakeholders participated. These often included, beside government and industry, academia and research and the general public. 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 chosen by the country and the time frame of implementation. Transport and stationary application were predominantly considered for hydrogen end-use. The impacts considered in the roadmaps are mostly environmental whilst the economic impacts are considered as secondary. Some of the countries mentioned the challenges they faced during the roadmapping process, which were mostly of an organisational nature with emphasis on the acquisition of data from industry, as well as difficulties to come to a consensus among diverging interests and in setting the scope of the process. One country highlighted the technical challenges that remained to be overcome.

Annex 1 Roadmap survey by country

	Roadmapping	Question	Country: USA
ROADMAP	**Name**	**Q2.2**	Hydrogen Posture Plan
	Status	**Q2.8**	Completed in 2003/next update planned for 2008
	Funded by	**Q2.6**	U.S. Dept. of Energy (DoE)
	Stakeholder involvement	**Q2.9**	Industry; Academy; Public
	Type of Stakeholders input	**Q2.10**	Workshops; Visions/opinions
	Timeframe	**Q2.11**	2003-2050
	Drivers	**Q2.13**	Energy Security; GHG Abatement; Economic Benefits
	Target groups	**Q2.12**	Academy; Industry; Government
	Challenges	**Q2.14**	Coordination of inputs, organisation of activities and completion of tasks
	Issues unresolved	**Q2.15**	N/A
	Plans for further RM activities	**Q2.16**	Updates approximately each 2 years
	Plans for RM implementation	**Q2.17**	Guide for DoE and DoT activities
MODELS	**Name**	**Q3.2**	H2A; GREET
	Key modelling assumptions	**Q3.3**	"AEO 2005 High oil case" for H_2 production and delivery
	Energy price assumptions	**Q3.4**	
	Trend for energy demand	**Q3.5**	Various scenarios-trends from national academies and EIA
RESULTS	**H_2 production mix**	**Q4.1**	Market transformation period (2015-2025): SMR; After 2025: Coal gasification+CCS; Biomass gasification
	H_2 use considered	**Q4.2**	Stationary; Transport
	Infrastructure-production	**Q4.3a**	Centralised; Decentralised; On-site
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks; Natural gas pipelines
	Economic impact	**Q4.4**	The socio-economic impacts on GDP or employment not considered
	Environmental impact	**Q4.5**	investigated
	Technology costs	**Q4.6**	The H_2 cost goal: 2-3 \$/gge (gasoline gallon eq.) independent of production pathway. The R&D target for H2 production technologies established to meet this cost goal.

Roadmapping		Question	Country: HyWays (EU-10)
ROADMAP	**Name**	**Q2.2**	HyWays
	Status	**Q2.8**	Completed
	Funded by	**Q2.6**	Integrated project co-funded be research institutes, Industry and EC under FP6
	Stakeholder involvement	**Q2.9**	Stakeholders from each of the participating countries
	Type of Stakeholders input	**Q2.10**	Workshops, visions/opinion, discussions, providing tech data, reviews, consultations
	Timeframe	**Q2.11**	2020-2050
	Drivers	**Q2.13**	GHG Abatement; Energy Security; Sustainable use of fossil fuels
	Target groups	**Q2.12**	Government; Industry
	Challenges	**Q2.14**	Alignment of diverging hydrogen interests
	Issues unresolved	**Q2.15**	Limitations of discussions on barriers among various stakeholders
	Plans for further RM activities	**Q2.16**	no at European level at the moment
	Plans for RM implementation	**Q2.17**	Through the HyWays action plan
MODELS	**Models used**	**Q3.2**	E^3database (MARKAL, MoreHyS, COPERT, Pace-T, ISIS)
	Key modelling assumptions	**Q3.3**	4 scenarios with the parameters: technological learning, policy support, different starting points of mass production; Vehicle penetration rates defined exogenously; CO_2 caps: A moderate emissions reduction target of -35% for 2050 (compared to 1990) was implemented. As a sensitivity case, a CO_2 reduction scenario of -80% has been analysed.
	Energy price assumptions	**Q3.4**	Energy prices calculated exogenously
	H_2 production mix	**Q3.5**	Sensitivity analysis on the impact of the high energy prices on H_2 production costs carried out
RESULTS	**H_2 use considered**	**Q4.1**	Portfolio of H_2 production pathways selected by stakeholders
	H2 use considered	**Q4.2**	Stationary; Transport
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	A cash flow analysis and analysis of impacts on employment
	Environmental impact	**Q4.5**	GHG emissions from road transport
	Technology costs	**Q4.6**	2020: 4E/kgH2; 100E/kWFC; 10E/kWstorage; 2030: 3E/kgH2; 50E/kWFC; 5E/kWstorage;

Roadmapping		Question	Country: GREAT BRITAIN
ROADMAP	**Name**	**Q2.2**	-
	Status	**Q2.8**	Completed in 2004
	Funded by	**Q2.6**	former Dept. of Trade and Industry (DTI)
	Stakeholder involvement	**Q2.9**	A Refrence Group drawn from the H_2 sector
	Type of Stakeholders input	**Q2.10**	personal contact
	Timeframe	**Q2.11**	2005-2050, with the modelling work focusing on 2030
	Drivers	**Q2.13**	GHG Abatement; Energy Security; Energy Policy
	Target groups	**Q2.12**	Government; Industry; Academy
	Challenges	**Q2.14**	Lack or conflicting data
	Issues unresolved	**Q2.15**	Specific situation of remote and island communities
	Plans for further RM activities	**Q2.16**	No specific plans at this stage
	Plans for RM implementation	**Q2.17**	Hydrogen policy
MODELS	**Models used**	**Q3.2**	MARKAL; CONCAWE
	Key modelling assumptions	**Q3.3**	N/A
	Energy price assumptions	**Q3.4**	The central price assumption of the 2003 Energy White Paper - oil at $25 per barrel was used, together with a sensitivity analysis based on $50 per barrel.
	H_2 production mix	**Q3.5**	IEA data
RESULTS	**H_2 use considered**	**Q4.1**	Aim not to predict a single H_2 production scenario, but to identify options
	H2 use considered	**Q4.2**	All potential uses
	Infrastructure-production	**Q4.3a**	Centralised; Decentralised
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	Mainly qualitative, subject to considerable uncertainty
	Environmental impact	**Q4.5**	investigated
	Technology costs	**Q4.6**	To be cost-competitive by 2030

	Roadmapping	Question	Country: FRANCE
ROADMAP	**Name**	**Q2.2**	There is no specific roadmap for H_2, but a country vision through HyWays (HyFrance project)
	Status	**Q2.8**	-
	Funded by	**Q2.6**	-
	Stakeholder involvement	**Q2.9**	-
	Type of Stakeholders input	**Q2.10**	-
	Timeframe	**Q2.11**	-
	Drivers	**Q2.13**	-
	Target groups	**Q2.12**	-
	Challenges	**Q2.14**	-
	Issues unresolved	**Q2.15**	-
	Plans for further RM activities	**Q2.16**	-
	Plans for RM implementation	**Q2.17**	-
MODELS	**Models used**	**Q3.2**	POLES - model for energy sector (other); E3database
	Key modelling assumptions	**Q3.3**	Study PROTEC-H2
	Energy price assumptions	**Q3.4**	2015-2030: 100-150$/barrel; 2030-2050: 100$/barrel
	H_2 production mix	**Q3.5**	Study PROTEC-H2
RESULTS	**H_2 use considered**	**Q4.1**	Electrolysis using nuclear energy (but also possibly wind energy)
	H2 use considered	**Q4.2**	Stationary in buildings; Transport
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks; Natural gas pipelines
	Economic impact	**Q4.4**	a French vision through HyWays
	Environmental impact	**Q4.5**	a French vision through HyWays
	Technology costs	**Q4.6**	a French vision through HyWays

Roadmapping		Question	Country: GERMANY
ROADMAP	**Name**	**Q2.2**	GermanHy
	Status	**Q2.8**	in progress/ to be completed in 2008
	Funded by	**Q2.6**	German Federal Ministry of Transport, Buildings and Urban Affairs
	Stakeholder involvement	**Q2.9**	Apart from Government and the National Organisation for H_2, no stakeholders directly involved
	Type of Stakeholders input	**Q2.10**	Consultations, providing technical data
	Timeframe	**Q2.11**	2010-2050
	Drivers	**Q2.13**	Energy Security; GHG Abatement; Sustainable use of fossil fuels
	Target groups	**Q2.12**	Academy; Industry; Government
	Challenges	**Q2.14**	not yet completed
	Issues unresolved	**Q2.15**	not yet completed
	Plans for further RM activities	**Q2.16**	To form a general and steady advisory consortium for the Government
	Plans for RM implementation	**Q2.17**	Part of National Innovation Programme
MODELS	**Models used**	**Q3.2**	H_2 infrastructure analysis; Energy demand calculation for heat, power & fuel; Energy availability for each primary energy type
	Key modelling assumptions	**Q3.3**	Moderate scenario: moderate oil prices (HyWays II), no hard shortage of fossil energy; Ambitious climate protection scenario: Higher CO2 costs and caps, otherwise based on moderate; Limited resources: strong shortage in fossil energy supplies => higher prices of all energy sources, and less fossil resources, otherwise based on moderate.
	H_2 production mix	**Q3.4**	"Moderate" and "Ambitious climate protection" scenarios: energy prices from HyWays II (WETO-H2): 2050 prices: Oil 110 €/bbl (market price), NG 101 €/boe (market price). For all renewable energies full costs are accounted. "Limited resources" scenario: Oil price goes up to 250 $/bbl in 2020, and then down to 200 $/bbl in 2050. All other energy prices are related to oil and solar energy prices by cross-cutting processes
	H_2 use considered	**Q3.5**	Different energy demand scenarios: Moderate scenario - the transportation energy demand decreased by 10-20% from 2010 to 2050 (total energy demand decreases app. 20%). Scenario with limited primary energy resources - a stronger demand reduction was assumed (no data available to date).
RESULTS	**H2 production mix**	**Q4.1**	By-product; SMR; Biomass gasification; Electrolysis; Coal gasification+CCS
	H2 use considered	**Q4.2**	Transport ONLY
	Infrastructure-production	**Q4.3a**	On-site
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	not considered
	Environmental impact	**Q4.5**	GHG emissions
	Technology costs	**Q4.6**	based on HyWays

	Roadmapping	Question	Country: ITALY
ROADMAP	**Name**	**Q2.2**	There is no specific roadmap for H_2, but a country vision through HyWays
	Status	**Q2.8**	-
	Funded by	**Q2.6**	-
	Stakeholder involvement	**Q2.9**	-
	Type of Stakeholders input	**Q2.10**	-
	Timeframe	**Q2.11**	-
	Drivers	**Q2.13**	-
	Target groups	**Q2.12**	-
	Challenges	**Q2.14**	-
	Issues unresolved	**Q2.15**	-
	Plans for further RM activities	**Q2.16**	under the Italian Hydrogen Platform
	Plans for RM implementation	**Q2.17**	-
MODELS	**Models used**	**Q3.2**	TIMES; MARKAL family model
	Key modelling assumptions	**Q3.3**	Vehicle cost = 20000€; Learning factor: same as HyWays; CO2 tax 50€ at 2030 (30€ at 2020) NOx emission cap: extension and reinforcement of NEC directive limits at 2020 horizon for all end-use sectors.
	Energy price assumptions	**Q3.4**	World Energy Outlook 2008, i.e. considering a price of $58 per oil barrel in 2016 ($ 2006). After 2016, prices increases due to higher demand. In 2030, the average real price of crude oil reaches $72 per oil barrel in 2006 $.
	Trend for energy demand	**Q3.5**	The main aspects considered for the energy scenarios are related to their capability to satisfy the supply security for the country, to provide high diversification for the energy sources, to minimize the energy foreign dependency and to meet the environmental constraints.
RESULTS	**H_2 production mix**	**Q4.1**	Coal gasification+CCS; Biomass gasification
	H_2 use considered	**Q4.2**	Stationary; Transport; Industry
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	not yet investigated
	Environmental impact	**Q4.5**	GHG emissions
	Technology costs	**Q4.6**	Stationary applications: Hydrogen combine cycle turbine plant: size 16.6 MWe, plant cost 20M€ at 2020, efficiency 47% electricity + 35% heat; Transport: Compressed H2 FC cars, from CONCAWE: efficiency 0,26 kWh/km, cost 28.8 k€ at 2010; liquid H2 ICE cars from CONCAWE: efficiency 0,465 kWh/km, cost 24 k€ at 2010; compressed H2 FC bus, from CONCAWE: efficiency 2.86 kWh/km, cost 400 k€ at 2020; liquid H2 ICE bus from CONCAWE: efficiency 4.9 kWh/km, cost 360 k€ at 2020;

Roadmapping		Question	Country: NORWAY
ROADMAP	**Name**	**Q2.2**	NorWays
	Status	**Q2.8**	in progress/planned to be completed in 20082008
	Funded by	**Q2.6**	Research Council of Norway (RENERGI programme); Industry
	Stakeholder involvement	**Q2.9**	ONLY Industry partners
	Type of Stakeholders input	**Q2.10**	Discussions, providing tech data, reviews
	Timeframe	**Q2.11**	2010-2050
	Drivers	**Q2.13**	GHG Abatement
	Target groups	**Q2.12**	Government; Industry
	Challenges	**Q2.14**	Consensus of all stakeholders on role of H_2
	Issues unresolved	**Q2.15**	not yet completed
	Plans for further RM activities	**Q2.16**	not foresen to date
	Plans for RM implementation	**Q2.17**	not known yet
MODELS	**Models used**	**Q3.2**	MARKAL
	Key modelling assumptions	**Q3.3**	Most data taken from the HyWays project; Vehicle costs by the OEMs; Technologies: SMR, biomass gasification (with and without CCS), electrolysis, industrial by-product. Transport: Pipeline and CGH2 trailers (no liquid). Learning by doing of fuelling station equipment and onsite technology. CO2 caps: Reduction of GHGs in transport sector by 60% until 2050 (not implemented directly in the models) CO2 taxes: Baseline 25 €/ton, sensitivities for 50 and 100 €/ton.
	Energy price assumptions	**Q3.4**	Oil and Gas: Deriving from HyWays Phase II. 2050 prices: Oil 110 €/bbl (market price), NG 101 €/boe (market price), 2nd Gen biofuels 180 €/boe (market price), offshore wind 6.4 ct/kWh (full costs), grid mix electricity 7.3 ct/kWh (full costs), domestic biomass: 4.3 ct/kWh (full costs).
	Trend for energy demand	**Q3.5**	steadily increasing
RESULTS	**H_2 production mix**	**Q4.1**	Biomass gasification; SMR; Electrolysis
	H_2 use considered	**Q4.2**	Transport; Export
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	no macro-economic impacts assessed
	Environmental impact	**Q4.5**	ONLY GHG emissions investigated
	Technology costs	**Q4.6**	Deriving from HyWays Phase II - however modified for cheaper batteries (for BEV and PHEV). Prices in Euro, first value 2020, second 2050: H2-ICE; 20308; 19773 H2-ICE Hybrid; 23812; 22448 H2-FC;22609;19782 H2-FC Hybrid; 24863; 21569 Plug-in Hybrid; 27686; 25876 Battery electric vehicle (Full range); 36743 ;32327

Roadmapping		Question	Country: ICELAND
ROADMAP	Name	Q2.2	The Icelandic Hydrogen Energy Roadmap
	Status	Q2.8	Completed
	Funded by	Q2.6	Ministry of Industry
	Stakeholder involvement	Q2.9	All stakeholders
	Type of Stakeholders input	Q2.10	Workshops, discussions
	Timeframe	Q2.11	not specified
	Drivers	Q2.13	Use of environment friendly energy
	Target groups	Q2.12	Stakeholders; International Audience
	Challenges	Q2.14	To ensure all aspects of H_2 economy
	Issues unresolved	Q2.15	no
	Plans for further RM activities	Q2.16	no
	Plans for RM implementation	Q2.17	envisaged
MODELS	Models used	Q3.2	Looking at the other roadmaps available at IPHE level
	Key modelling assumptions	Q3.3	N/A
	Energy price assumptions	Q3.4	no
	Trend for energy demand	Q3.5	no trends for energy assumed
RESULTS	H_2 production mix	Q4.1	Electrolysis
	H_2 use considered	Q4.2	All potential uses
	Infrastructure-production	Q4.3a	-
	Infrastructure-distribution	Q4.3b	Pipelines; Trucks
	Economic impact	Q4.4	considered to some extent
	Environmental impact	Q4.5	considered to some extent
	Technology costs	Q4.6	N/A

Roadmapping		Question	Country: CHINA
ROADMAP	**Name**	**Q2.2**	Vision for Hydrogen Energy
	Status	**Q2.8**	Completed in 2005
	Funded by	**Q2.6**	Ministry of Science and Technology of China
	Stakeholder involvement	**Q2.9**	Industry
	Type of Stakeholders input	**Q2.10**	Workshops, visions/opinions
	Timeframe	**Q2.11**	2005-2050
	Drivers	**Q2.13**	Environmental concern; Climate Change; Energy Security
	Target groups	**Q2.12**	Government; Industry; Public
	Challenges	**Q2.14**	Technological barriers, product performance, life, costs
	Issues unresolved	**Q2.15**	no
	Plans for further RM activities	**Q2.16**	no
	Plans for RM implementation	**Q2.17**	Part of national development plan
MODELS	**Models used**	**Q3.2**	-
	Key modelling assumptions	**Q3.3**	-
	Energy price assumptions	**Q3.4**	-
	Trend for energy demand	**Q3.5**	-
RESULTS	**H_2 production mix**	**Q4.1**	-
	H_2 use considered	**Q4.2**	Stationary; Transport
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks; Natural gas pipelines
	Economic impact	**Q4.4**	no
	Environmental impact	**Q4.5**	no
	Technology costs	**Q4.6**	see website of the roadmap

	Roadmapping	Question	Country: NEW ZEALAND
ROADMAP	**Name**	**Q2.2**	Transitioning to a Hydrogen Economy
	Status	**Q2.8**	in progress/ to be completed in 2008
	Funded by	**Q2.6**	Fundation for Research Science and Technology
	Stakeholder involvement	**Q2.9**	Government; Industry; Research
	Type of Stakeholders input	**Q2.10**	Meetings, reviews, visions/opinions
	Timeframe	**Q2.11**	2006-2050
	Drivers	**Q2.13**	GHG Abatement; Energy Security
	Target groups	**Q2.12**	Government; Industry
	Challenges	**Q2.14**	Tight timeframe, wide range of feedback to analyse
	Issues unresolved	**Q2.15**	no significant
	Plans for further RM activities	**Q2.16**	no
	Plans for RM implementation	**Q2.17**	envisaged
MODELS	**Models used**	**Q3.2**	E^3database; Stella
	Key modelling assumptions	**Q3.3**	Fuel costs, vehicle costs, carbon charges, technology uptake rates, contributions of other vehicle technologies, contributions from biofuels, level of education and public outreach
	Energy price assumptions	**Q3.4**	Carbon charges from $NZ 25 to $150 per tonne, linked oil and gas prices increasing at various rates per annum at different trigger points from a base of $US80/bbl. This led to wholesale electricity prices ranging from 8 c/kWh to 25c/kWh.
	Trend for energy demand	**Q3.5**	Based on continuation of present growth demand rates
RESULTS	**H_2 production mix**	**Q4.1**	SMR; Electrolysis; Coal gasification; Biomass gasification
	H_2 use considered	**Q4.2**	Stationary; Transport
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	no investigated
	Environmental impact	**Q4.5**	GHG emissions investigated
	Technology costs	**Q4.6**	Mainly relating to cost of H_2 vehicles meeting those of alternative options - including ICE and BEV

Roadmapping		Question	Country: NORTH KOREA
ROADMAP	**Name**	**Q2.2**	-
	Status	**Q2.8**	1st draft completed in 2005/continual update
	Funded by	**Q2.6**	Government
	Stakeholder involvement	**Q2.9**	Government; Industry; Academy/Research
	Type of Stakeholders input	**Q2.10**	-
	Timeframe	**Q2.11**	-
	Drivers	**Q2.13**	-
	Target groups	**Q2.12**	Government; Academy; Public
	Challenges	**Q2.14**	-
	Issues unresolved	**Q2.15**	-
	Plans for further RM activities	**Q2.16**	-
	Plans for RM implementation	**Q2.17**	-
MODELS	**Models used**	**Q3.2**	Benchmarking and analysis of roadmaps developed in other countries
	Key modelling assumptions	**Q3.3**	FC cost targets comparing to those of the competitive technologies
	Energy price assumptions	**Q3.4**	not defined
	Trend for energy demand	**Q3.5**	-
RESULTS	**H_2 production mix**	**Q4.1**	Temporary period: H_2 production from fossil fuels, especially NG; H2 production from water
	H_2 use considered	**Q4.2**	Transport; Stationary; In buildings
	Infrastructure-production	**Q4.3a**	-
	Infrastructure-distribution	**Q4.3b**	On-site storage; Trucks
	Economic impact	**Q4.4**	considered, but uncertain
	Environmental impact	**Q4.5**	Climate change issues investigated
	Technology costs	**Q4.6**	ONLY vehicles: 2012:300 M Won(0.3 M Dollars) for passenger cars (small scale production) 2015:120 M Won(0.12 M Dollars) for passenger cars (large scale production) 2015: 60 M Won(0.3 M Dollars) for passenger cars (commercial scale production)

Roadmapping		Question	Country: INDIA
ROADMAP	**Name**	**Q2.2**	National Hydrogen Energy Roadmap
	Status	**Q2.8**	-
	Funded by	**Q2.6**	Ministry of New and renewable Energy
	Stakeholder involvement	**Q2.9**	Government; Industry; Academy/Research
	Type of Stakeholders input	**Q2.10**	not specified
	Timeframe	**Q2.11**	2005-2020
	Drivers	**Q2.13**	Energy Security; GHG Abatement
	Target groups	**Q2.12**	All concerned stakeholders
	Challenges	**Q2.14**	no significant
	Issues unresolved	**Q2.15**	not at present
	Plans for further RM activities	**Q2.16**	not at present
	Plans for RM implementation	**Q2.17**	envisaged
MODELS	**Models used**	**Q3.2**	-
	Key modelling assumptions	**Q3.3**	-
	Energy price assumptions	**Q3.4**	-
	H_2 production mix	**Q3.5**	-
RESULTS	**H_2 use considered**	**Q4.1**	-
	H2 use considered	**Q4.2**	Transport; Stationary
	Infrastructure-production	**Q4.3a**	Centralised; On-site
	Infrastructure-distribution	**Q4.3b**	Railway; Trucks; Pipelines
	Economic impact	**Q4.4**	considered, but not quantified
	Environmental impact	**Q4.5**	considered, but not quantified
	Technology costs	**Q4.6**	see website of the roadmap

Roadmapping		Question	Country: AUSTRALIA
ROADMAP	**Name**	**Q2.2**	-
	Status	**Q2.8**	in progress/2008
	Funded by	**Q2.6**	Government for the Council of Australian Governments
	Stakeholder involvement	**Q2.9**	Government; Industry; Academy/Research
	Type of Stakeholders input	**Q2.10**	Workshops, written submissions, interviews
	Timeframe	**Q2.11**	till 2050
	Drivers	**Q2.13**	H2TS
	Target groups	**Q2.12**	Government; other Stakeholders
	Challenges	**Q2.14**	not at this stage
	Issues unresolved	**Q2.15**	not at this stage
	Plans for further RM activities	**Q2.16**	not foreseen
	Plans for RM implementation	**Q2.17**	yet to be considered
MODELS	**Models used**	**Q3.2**	Electricity production cost model; H_2 production cost model (other)
	Key modelling assumptions	**Q3.3**	Capital costs decline at rate of 2% pa, AUD/USD \$0.80, CPI 2.5%. FC capex \$1,000 - \$5,700/kW; H2 capex \$0.5 - \$17 million per tonne H2 per day. AUD
	Energy price assumptions	**Q3.4**	Energy prices based on MMA in house modelling. Electricity prices range from \$40 - \$50 /MWh wholesale to \$140 - \$170/MWh retail in real 2007 AUD gas prices range from \$4/GJ wholesale to \$14 -\$17/GJ retail.
	Trend for energy demand	**Q3.5**	National data resources
RESULTS	**H_2 production mix**	**Q4.1**	No projection of mix production technologies, rather under what conditions H_2 would be economic
	H_2 use considered	**Q4.2**	Stationary; Transport
	Infrastructure-production	**Q4.3a**	Decentralised
	Infrastructure-distribution	**Q4.3b**	Pipelines; Trucks
	Economic impact	**Q4.4**	no macro-economic parameters examined
	Environmental impact	**Q4.5**	GHG emissions reduction
	Technology costs	**Q4.6**	N/A

	Roadmapping	Question	Country: CANADA
ROADMAP	Name	Q2.2	Canadian Fuel Cell Commercialization Roadmap
	Status	Q2.8	in progress/planned to be completed in 2008
	Funded by	Q2.6	Industry
	Stakeholder involvement	Q2.9	All stakeholders
	Type of Stakeholders input	Q2.10	Visions/opinions, interviews, reviews
	Timeframe	Q2.11	10 years
	Drivers	Q2.13	GHG Abatement
	Target groups	Q2.12	Government; Industry; International Audience
	Challenges	Q2.14	Receiving hard data from industry
	Issues unresolved	Q2.15	Receiving hard data from industry
	Plans for further RM activities	Q2.16	updates in 10year-periods
	Plans for RM implementation	Q2.17	implementation done
MODELS	Models used	Q3.2	Currently undertaking a feasibility study to examine existing models, and how they can be adapted for Canadian approach
	Key modelling assumptions	Q3.3	-
	Energy price assumptions	Q3.4	-
	Trend for energy demand	Q3.5	-
RESULTS	H_2 production mix	Q4.1	-
	H_2 use considered	Q4.2	-
	Infrastructure-production	Q4.3a	-
	Infrastructure-distribution	Q4.3b	-
	Economic impact	Q4.4	-
	Environmental impact	Q4.5	-
	Technology costs	Q4.6	-

	Roadmapping	Question	Country: JAPAN
ROADMAP	Name	Q2.2	-
	Status	Q2.8	in progress/under revision
	Funded by	Q2.6	Ministry of Economy, Trade and Industry (METI)
	Stakeholder involvement	Q2.9	The half of the stakeholders is from Industry, 2nd half represents research in the field
	Type of Stakeholders input	Q2.10	Comments
	Timeframe	Q2.11	2005-2030
	Drivers	Q2.13	Energy Efficiency; GHG Abatement; Energy Security; Distributed energy resources; New Industry; Competitiveness
	Target groups	Q2.12	Public
	Challenges	Q2.14	none
	Issues unresolved	Q2.15	Continuous review and revisions of scenarios
	Plans for further RM activities	Q2.16	Yes
	Plans for RM implementation	Q2.17	National policies and programs take into consideration the roadmap results
MODELS	Models used	Q3.2	no - Empirical assumptions and expert's insight applied
	Key modelling assumptions	Q3.3	N/A
	Energy price assumptions	Q3.4	N/A
	Trend for energy demand	Q3.5	N/A
RESULTS	H_2 production mix	Q4.1	Near-term: Industrial By-product; Medium-long-term: Electrolysis using renewable energy, Coal gasification
	H_2 use considered	Q4.2	Transport; Stationary
	Infrastructure-production	Q4.3a	-
	Infrastructure-distribution	Q4.3b	Pipelines; Trucks
	Economic impact	Q4.4	qualitative impacts investigated
	Environmental impact	Q4.5	qualitative impacts investigated
	Technology costs	Q4.6	Cost target for H_2 production: 450 JPY/kgH2

Annex 2. Links to country hydrogen roadmaps (Q2.3)

Table 4 Links to country hydrogen roadmap programmes

Country	Link
USA	Hydrogen Posture Plan http://www.hydrogen.energy.gov
HyWays	HyWays http://www.hyways.de
UK	-
FR	See HyWays
DE	GermanHy http://www.germanhy.de
IT	-
NO	NorWays http://www.ntnu.no/norways
IC	Icelandic Hydrogen Energy Roadmap
CN	Vision for Hydrogen Energy in China http://www.iphe.net/IPHErestrictedarea/Rio%20Dejaneiro%20ILC/ilc%20rio%20pdfs/22_03%20-%20Tuesday/Afternoon/13h30%20-%20China.pdf ; http://www.energetics.com/pdfs/hydrogen/chinavision.pdf
NZ	Transitioning to a Hydrogen Economy
KR	http://www.h2fc.or.kr
IN	National Hydrogen Energy Road Map http://www.mnre.gov.in
AU	-
CA	2003 Commercialization Roadmap http://www.hydrogeneconomy.gc.ca/publications_e.html CHA Hydrogen Systems Roadmap http://www.h2.ca/PDF/HydrogenSystems.pdf
BR	-
JP	http://www.enecho.meti.go.jp/info/committee/nennryoudennchi/040317a.htm
RU	-

Annex 3. Philosophy of the roadmap, expected achievements (Q2.5)

Table 5 Objectives established for hydrogen roadmapping by the individual countries

Country	Objectives
USA	The Hydrogen Posture Plan outlines the activities, milestones, and deliverables that the Department of Energy (DOE) and the Department of Transportation (DOT) must pursue to develop hydrogen energy systems, the key elements of which are: - More compact, lighter weight, lower cost, safe, and efficient storage systems; - Lower cost, more durable materials for advanced conversion technologies, especially fuel cells - Lower cost methods for producing and delivering hydrogen; - Technologies for low cost carbon capture and containment for fossil-based hydrogen production (a separate DOE program coordinated with the Hydrogen Program); - Designs and materials that maximize the safety of hydrogen use. The Hydrogen Posture Plan integrates the planning and budgeting for program activities that will aid in this development. The Plan lays the foundation for a coordinated response, including collaboration with the DOT, to the President's plan for accelerating implementation of hydrogen infrastructure and fuel cell technologies.
HyWays	- To develop a validated and well-accepted roadmap for the introduction of hydrogen in the energy system in Europe. The *HyWays* project combines technology databases and socio-/ techno-/ economic analyses to evaluate selected stakeholder scenarios for future sustainable hydrogen energy systems. Scenarios are based on member states (MS) visions for the introduction of hydrogen technologies with extensive interaction between science and stakeholders involving over 50 workshops. For each country the theoretical economic optimum choice is calculated and evaluated by the member states on an iterative basis. A multinational approach covering, at that time, 80% of the EU land area and over 70% of the population ensures a wide diversity in terms of feedstock, regional & infrastructure-related conditions and preferences.
UK	- To identify the hydrogen energy pathways which have the potential to provide cost-competitive carbon savings by 2030.
FR	Not available
DE	Institute work to show: - why we need hydrogen (only short); - given a certain hydrogen deployment - from which energy will the hydrogen come (under consideration of the whole energy sector, NOT only hydrogen pathways); - special focus on limited energy resources, and connected to that, the need for saving of energy / demand reduction; - evaluation and placement of alternative / supplementary technologies (such as battery electric vehicles, plug-in hybrid vehicles, biofuels).
IT	Not available
NO	The main objective of this project is to provide decision support for introduction of Hydrogen as energy carrier in the Norwegian energy system. This objective is reached through the following sub/goals: - Documenting how introduction of hydrogen as energy carrier in Norway is influenced and restricted by the characteristics of the existing Norwegian energy system; - Developing alternative scenarios and identifying market segments and regions of the Norwegian energy system where hydrogen may play a significant role, with focus on early markets; - Developing suitable, regionalized models for analysing an introduction of hydrogen as energy carrier in competition with other alternatives (natural gas/electricity/district heating/bio-fuels); - Suggesting viable pathways and providing well-founded recommendations for introduction of hydrogen in the Norwegian energy system based on modelling and evaluation (in an iterative process with national stakeholders) of the most relevant scenarios, market segments and regions; - Establishing a common arena for exchange of knowledge and experience with the aim of reaching consensus between Norwegian stakeholders.
IC	- To look to Icelandic conditions and how Icelandic can best make use of its resources to obtain hydrogen economy aiming at strategic planning for both public and private.
CN	- To draft a rough time-table for China's transition toward the hydrogen economy, - To identify possible obstacles or challenges confronting ahead, and - To find out possible political, social and technological solution to tackle the problems.

Country	Objectives
NZ	- To identify likely pathways to hydrogen uptake, the critical knowledge gaps associated with those pathways and the role of research investment in filling those gaps. The hydrogen project is being carried out concurrently with programmes looking at the entire energy scene in New Zealand out to 2050 and the findings of the hydrogen project will be incorporated into that bigger picture.
KR	- To provide a direction for national vision aiming H_2 economy and commercialization of H_2 and FCs technologies; - To provide a direction for the development and policy of H2 and FC technologies; - To form the national consensus.
IN	- To suggest pathways for Hydrogen Energy Development in India up to 2020.
AU	- To assess in what areas of hydrogen technology Australia currently has research capabilities and strengths, compared to research overseas; and - To identify what actions Australia should take to prepare for the possible emergence of a hydrogen economy, and the economic case for each of these options.
CA	- To demonstrate progress for the industry as a whole and identify key issues and gaps that companies must overcome to be cash-flow positive in the mid-term. Focus is on progress in niche areas: micro fuel cells, material handling, residential CHP, back-up power, buses and supporting hydrogen infrastructure. - To draw the links between near term commercial applications and longer term mass markets (automotive). Findings will be used as a key input to streamline federal research and development initiatives.
BR	Not available
JP	- To accelerate activities aiming at hydrogen energy society in a medium- and long-term by indicating promising prospect of hydrogen energy society, and by surveying required policies and technical subjects that must be resolved.
RU	Not available

Annex 4. Assumptions (Q3.3 to Q 3.5)

Key modelling assumptions

COUNTRY		Vehicle costs	Technologies & Learning	CO_2 caps/taxes	Other/Comments
1	USA			not considered	"AEO 2005 High oil case" for H_2 production and delivery
2	EU-10	Vehicle penetration rates defined exogenously (rate is NOT a function of the cost-effectiveness of H2 technology)		CO_2 caps: A moderate emissions reduction target of -35% for 2050 (compared to 1990) was implemented. As a sensitivity case, a CO_2 reduction scenario of -80% has been analysed.	4 scenarios with the parameters: technological learning, policy support, different starting points of mass production
3	UK				
4	France				The National research agency is funding the project PROTEC-H2 (2006-2009) which organizes the relevant technical and economic data on hydrogen technologies in order to develop a long term prospective analysis of these technologies in the transport sector, using the energy prospective model POLES
5	Germany	Hydrogen ICE, Fuel cell (data from HyWays), conventional, biofuels, electric vehicles	Based on HyWays data (for onsite SMR and electrolysis, costs have been corrected).	CO_2 caps: 2050 reduction as compared to 1990: -40% (moderate and limited resources scenario); -80% (ambitious climate protection scenario). CO_2 taxes: 2050: 22.5€/ton (moderate and limited resources scenario); 50€/ton (ambitious climate protection scenario). Linear ramp up to 2050 value.	1. moderate scenario: moderate oil prices (HyWays II), no hard shortage of fossil energy 2. ambitious climate protection scenario: Higher CO_2 costs and caps, otherwise based on moderate 3. limited resources: strong shortage in fossil energy supplies => higher prices of all energy sources, and less fossil resources, otherwise based on moderate.
6	Italy	Vehicle cost = 20000€	Learning factor: same as HyWays	CO_2 tax 50€ at 2030 (30€ at 2020) NOx emission cap: extension and reinforcement of NEC directive	

				limits at 2020 horizon for all end-use sectors	
7	**Norway**	Vehicle costs defined by the OEMs	Technologies: SMR, biomass gasification (with and without CCS), electrolysis, industrial byproduct. Transport: Pipeline and CGH2 trailers (no liquid). Learning by doing of fuelling station equipment and onsite technology.	CO_2 caps: Reduction of GHGs in transport sector by 60% until 2050 (not implemented directly in the models) CO_2 taxes: Baseline 25 €/ton, sensitivities for 50 and 100 €/ton.	Most data were taken from the HyWays project
8	**Iceland**				
9	**China**				
10	**New Zealand**			Carbon charges from $NZ 25 to $150 per tonne	Fuel costs, vehicle costs, carbon charges, technology uptake rates, contributions of other vehicle technologies (electric vehicles, improvements to ICE vehicles) contributions from biofuels, level of education and public outreach.
11	**Korea**				The cost targets of FCs as assumptions to buildup the roadmap by comparing to those of the competitive technologies.
12	**India**				
13	**Australia**				Capital costs decline at rate of 2% pa, AUD/USD $0.80, CPI 2.5%. FC capex $1,000 - $5,700/kW, H2 capex $0.5 - $17 million per tonne H2 per day. AUD
14	**Canada**				
15	**Brazil**				
16	**Japan**				

17	**Russia**				

CPI - Consumer Price Index; Capex - Capital Expenditure;

Energy prices assumptions

COUNTRY		Oil price	Gas price	Renewables	Electricity price	Other/Comments
1	**USA**					EIA energy prices from the AEO 2005 High oil case
2	**EU-10**					Energy prices are calculated exogenously. In order to minimise discussions on key scenario parameters, the HyWays consortium decided to base the energy price analysis on a well accepted scenario (exogenously calculated) developed on behalf of the EC ("European Energy and Transport: Trends to 2030"), (more info at http://www.hyways-iphe.org - WP3 report).
3	**UK**	$25 per barrel; a sensitivity analysis based on $50 per barrel				The central price assumption of the 2003 Energy White Paper.
4	**France**	100-150 $/oil barrel between 2015 and 2030; 100 $/b between 2030 and 2050				The most recent French report on energy prospects (October 2007) has adopted new energy price assumptions (http://www.strategie.gouv.fr/article.php3?id_article=682, page 119).
5	**Germany**	"Moderate" and	"Moderate" and	"Moderate" and		"Moderate" and "Ambitious climate protection"

		"Ambitious climate protection" scenarios: 2050 prices: Oil 110 €/bbl (market price). "Limited resources" scenario: Oil price goes up to 250 $/bbl in 2020, and then down to 200 $/bbl in 2050.	"Ambitious climate protection" scenarios: 2050 prices: NG 101 €/boe (market price).	"Ambitious climate protection" scenarios: 2050 prices: all renewable energies full costs		scenarios: energy prices from HyWays phase II (WETO-H2) and "Limited resources" scenario. The reason for the late decrease of oil price is that once solar energy (the most expensive and most abundant energy source) becomes cheaper, the oil price will approach it asymptotically (the consumers will shift to solar energy instead of buying oil at unreasonably high prices). All other energy prices are related to oil and solar energy prices by cross-cutting processes (e.g., the coal price is calculated from the oil price through the efficiency of the CtL process - reasoning "in a balanced market, gasoline from coal will NOT be cheaper than gasoline from oil".
6	**Italy**	$58 per oil barrel in 2016 ($ 2006). After 2016, prices increases due to higher demand. In 2030, the average real price of crude oil reaches $72 per oil barrel in 2006 $				The analyses have been carried out using the same curves adopted for the World Energy Outlook 2008.
7	**Norway**	110 €/bbl (market price)	101 €/boe (market price)	2nd Gen biofuels 180 €/boe (market price), offshore wind 6.4 ct/kWh (full costs), domestic biomass: 4.3 ct/kWh (full costs)	grid mix electricity 7.3 ct/kWh (full costs)	Oil and Gas: Deriving from HyWays Phase II. 2050 prices
8	**Iceland**					
9	**China**					
10	**New Zealand**	oil and gas prices increasing at various rates per annum at different trigger points from a base of			wholesale electricity prices ranging from 8 c/kWh to 25c/kWh	Carbon charges from $NZ 25 to $150 per tonne, linked oil and gas prices increasing at various rates per annum at different trigger points from a base of $US80/bbl.

		$US80/bbl.				
11	**Korea**					It is expected that the final goal will be in the reduction of cost barriers. The R&D of H2 and FCs were primary focused during the fulfillment of the roadmap.
12	**India**					
13	**Australia**		range from $4/GJ wholesale to $14 -$17/GJ retail		range from $40 - $50 /MWh wholesale to $140 - $170/MWh retail in real 2007 AUD	Energy prices based on MMA in house modelling.
14	**Canada**					
15	**Brazil**					
16	**Japan**					
17	**Russia**					

boe - barrel of oil equivalent; bbl - barrel=31.5 gallons;

Technology costs and Cost targets

COUNTRY		H2 production cost targets	Technology targets	Other/Comments
1	**USA**	The hydrogen cost goal for the U.S. is $2.00-3.00/gge, which is independent of production pathway.	The R&D targets for hydrogen production technologies are established to meet this cost goal.	
2	**EU-10**	Snapshot 2020 of the HFP: H2:4€/kg; Snapshot 2030 of the HFP: H2: 3€/kg	Snapshot 2020 of the HFP: FC:100€/kW H2Storage:10€/kW; Snapshot 2030 of the HFP: FC: 50€/kW H2Storage: 5€/kW	

3	**UK**	Cost targets were those required for H2 to be cost-competitive by 2030 (based on US-DoE data).		
4	**France**			HyWays
5	**Germany**			HyWays
6	**Italy**		Stationary applications. Hydrogen combine cycle turbine plant: size 16.6 MWe, plant cost 20M€ at 2020, efficiency 47% electricity + 35% heat Transport. Compressed H2 FC cars, from CONCAWE: efficiency 0,26 kWh/km, cost 28.8 k€ at 2010; liquid H2 ICE cars from CONCAWE: efficiency 0,465 kWh/km, cost 24 k€ at 2010; compressed H2 FC bus, from CONCAWE: efficiency 2.86 kWh/km, cost 400 k€ at 2020; liquid H2 ICE bus from CONCAWE: efficiency 4.9 kWh/km, cost 360 k€ at 2020;	
7	**Norway**		Deriving from HyWays Phase II – however, modified for cheaper batteries (for BEV and PHEV). Prices in Euro for 2020 and 2050, respectively: H2-ICE; 20308; 19773 H2-ICE Hybrid; 23812; 22448 H2-FC;22609;19782 H2-FC Hybrid; 24863; 21569 Plug-in Hybrid; 27686; 25876 Battery electric vehicle (Full range); 36743 ;32327	only vehicles considered
8	**Iceland**			
9	**China**			See website
10	**New Zealand**			Mainly relating to cost of hydrogen vehicles meeting those of alternate options - including ICE and BEV.
11	**Korea**		2012: 300 M Won(0.3 M Dollars) for passenger cars (small scale production) 2015: 120 M Won(0.12 M Dollars) for passenger cars (large scale production) 2015: 60 M Won(0.3 M Dollars) for passenger cars	only vehicles considered

			(commercial scale production)	
12	**India**			See website: Refer the abridged version of National Hydrogen Energy Road Map.
13	**Australia**			
14	**Canada**			
15	**Brazil**			
16	**Japan**	Cost target for hydrogen production was 450 JPY/kg.		
17	**Russia**			

gge - Gasoline Gallon Equivalent; HFP - The European Hydrogen and FC Technology Platform; JPY - Japanese Yen