INTERNATIONAL ENERGY AGENCY

HYDROGEN & FUEL CELLS

Review of National R&D Programs

OECD

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six* of the OECD's thirty Member countries. The basic aims of the IEA are:

- to maintain and improve systems for coping with oil supply disruptions;
- to promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- to operate a permanent information system on the international oil market;
- to improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- to assist in the integration of environmental and energy policies.

* *IEA Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. The European Commission also takes part in the work of the IEA.*

ORGANISATION FOR
ECONOMIC CO-OPERATION
AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

With the oil and gas supply security and climate change emerging as high concerns, the need for new technologies to alleviate dependence on hydrocarbons and reduce carbon dioxide (CO_2) emissions is becoming increasingly urgent. In the mid to long term, this will require significant changes in the way the global energy system is managed and the adoption of an array of new technologies which produce and use energy more efficiently and more cleanly than in the past.

IEA countries have been improving the overall efficiency of their energy systems and developing renewable energy sources for many years. More recently, they have also invested considerable effort in making commercially available technologies to separate and store carbon dioxide from fossil fuels, produce hydrogen from fossil, nuclear and renewable energy sources, and develop fuel cells for clean and efficient use of hydrogen. In addition to reducing emissions in power generation, CO_2 capture and storage would enable hydrogen to be produced from natural gas and coal without incurring significant emissions to the atmosphere. Increasing use of the world's abundant coal reserves to produce CO_2-free electricity and hydrogen would both diversify energy supply and mitigate environmental concerns. Clean, CO_2-free hydrogen produced from fossil fuels and – in the longer term – from nuclear and renewable sources could potentially replace oil and reduce emissions in transport. In turn, fuel cells hold the promise to significantly increase the efficiency of the energy system in both stationary and transport applications with reduced or nearly zero emissions.

The development of cost-effective hydrogen and fuel cells technologies and infrastructure requires time, public and private sector investment, and technology breakthroughs to achieve commercial maturity and market penetration. Many IEA Member countries have already embarked on this effort in close co-operation with industry. Many others are in the process of revising and reinforcing their research and development strategies.

This book is a timely attempt to map the many and various governmental research activities and policies for hydrogen and fuel cells. It provides policymakers and managers with the information needed to exploit synergies and maximise the benefits of international co-operative efforts. The book draws primarily on information contributed by IEA governments through the IEA Hydrogen Co-ordination Group. Such cooperation together with concerted government strategies, long-term commitment and public research activities are indispensable for catalysing larger private R&D investment, for building public awareness and for facilitating the penetration of hydrogen and fuel cells technologies in the competitive marketplace.

Claude Mandil
Executive Director

ACKNOWLEDGEMENTS

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Marianne Haug, Director of the IEA Technology Office, provided encouragement and leadership. Carmen Difiglio, Head of the IEA Energy Technology Policy Division, contributed to organise the activities. Giorgio Simbolotti, IEA Energy Technology Collaboration Division, co-ordinated the activities and reviewed the final draft. Jeff Hardy patiently drafted the manuscript and made it a smoothly readable text. Corinne Hayworth, IEA Public Information Office, designed the graphics of the cover page. The work benefited from the financial contribution of the US Department of Energy to support the activities of the Hydrogen Co-ordination Group.

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EXECUTIVE SUMMARY

Technology development and international co-operation are part of the solution to address the energy security and environmental concerns that affect our current energy system. Along with other energy technologies, hydrogen as an energy carrier and fuel cells as a conversion technology are emerging as high-potential options to ensure a CO_2-free, secure energy future. The expectation is that in some decades from now fuel cells and CO_2-free hydrogen produced from fossil, renewable and nuclear energy sources, will be entering the power generation market as well as the transport, industrial and residential sectors, thus playing a significant role in reducing emissions and enhancing global energy security.

This development requires extensive public and private R&D efforts to achieve technology breakthroughs and bring these technologies to commercial maturity. Hydrogen is a well-known industrial gas, used in a number of applications such as refinery, chemical industry, metal manufacturing. As an energy carrier it is flexible and potentially clean. However, its production and use still require energy-consuming and costly processes, and the need for new infrastructure. Similarly, fuel cell performance and cost are far from the economic competitiveness, and their use is currently confined to niche market applications.

Driven by recent technical advances and the increasing needs for diversified and sustainable technologies, in particular in the oil-consuming transport sector, the OECD governments have recently intensified their R&D efforts on hydrogen and fuel cells. A number of new initiatives have significantly increased the global governmental R&D investment to some US$ 1 billion a year. They are equally distributed in the three OECD areas, Asia-Pacific, Europe and North America. Fuel cells absorb more than half this global effort. The rest is invested in technologies to produce, store, transport, and use hydrogen including non-fuel-cell technologies such as hydrogen-fuelled internal combustion engines and gas turbines.

The global spending on hydrogen and fuel cells does not fully emerge in the current statistics for public sector R&D investment in energy technologies. The R&D efforts to produce hydrogen from fossil, nuclear and renewable energy sources are accounted for as spending on advanced fossil, nuclear and renewable technology, respectively, and fuel cell R&D is included in the efforts to improve the efficiency of the end-use technologies and the overall energy system.

Although governmental research is indispensable for catalysing the development process, it is not the dominant part of the current, global R&D effort on hydrogen and fuel cells. Considerably larger – and hardly assessable – is the total R&D investment of the private sector, including major oil & gas companies, vehicle producers, electrical utilities, power plant constructors, and a number of major and small players in the current hydrogen and fuel cell market.

This global effort is expected to continue over the next years as major countries have planned multi-annual investment. This includes: $ 1.7 billion over 5 years in the United States; up to € 2 billion, including renewable energy, in the 6th Framework Program of the European Union; more than ¥ 30 billion a year in Japan; and multi-annual programs in place in other countries such as Canada, Germany, Italy.

Governmental R&D efforts and long-term commitments are complemented by three major international co-operation initiatives.

- In April 2003, twenty-four Member countries of the International Energy Agency accepted the IEA Executive Director's invitation to establish the IEA Hydrogen Co-ordination Group (HCG) to enhance co-ordination among national R&D programs and policy strategies. Under the guidance of the IEA Committee for Energy Research and Technology (CERT), the HCG builds on the IEA international co-operation framework for energy technologies. This includes relevant R&D co-operation projects, such as the IEA Implementing Agreements on Hydrogen, Advanced Fuel Cells, the Greenhouse Gas R&D Program, and other Agreements with interest in specific hydrogen and fuel cell topics (Clean Coal Centre, Bio-Energy, Advanced Motor Fuels, Hybrid Vehicles, Energy Technology System Analysis Project).
- In November 2003, sixteen countries including non-OECD countries such as Brazil, China, India and Russia, joined the International Partnership for Hydrogen Economy (IPHE), a global, high-level political interface proposed by the United Stated to foster public and private co-operation on hydrogen and fuel cells.
- In January 2004, the European Commission established the European Technology Platform for Hydrogen and Fuel Cells, a cluster of public/private R&D initiatives within the Commission's Framework Programs.

The Figure 1 shows a schematic of the global hydrogen and fuel cell R&D effort, and ongoing international co-operation initiatives.

This review of the R&D programs and policy strategies in Member countries maps the national, governmental efforts to research, develop and deploy the interlocking elements that constitute a hydrogen-based energy system, including CO_2 capture and storage when hydrogen is produced using fossil fuels. It is a first-of-kind attempt at providing an overview of what is being done, by whom and in which country, for each R&D and policy topic. The information contained in the report can be collectively considered up-to-date as of August 2004. Given the complexity of the matter and the quickly evolving context – many countries are currently revising their R&D strategies and activities, and a number of new projects are underway – the publication is non-exhaustive. It reflects primarily governmental R&D efforts. Private sector activities are only reflected to the extent that they are conducted in partnership with public organisations. Nevertheless, the *Review* highlights potential international co-operation and is intended to support the work of policy makers and R&D experts in the public and private sectors.

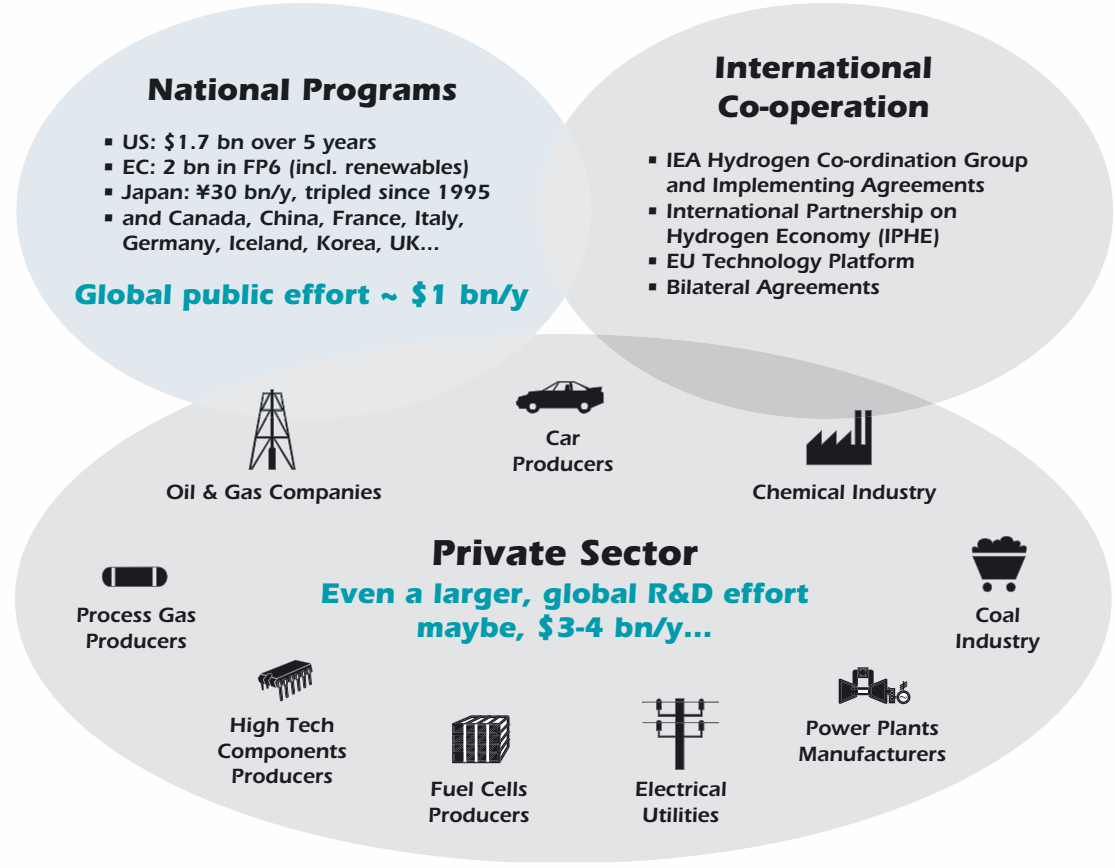
The *Review* comprises two parts. In the first, the huge number of ongoing, national activities and projects are presented in a thematic, cross-country overview reflecting the vast array of technologies, logistics and policy issues required to build a hydrogen-based energy system. Individual country profiles are given in the second section for twenty-three IEA countries.

In the thematic overview the information is organised into six sections. In each section, a brief introduction is provided for each technology, its state of development and important research objectives. Fuel Cells are taken up in Section 1 which includes a review of government work as it relates to each fuel cell type, basic R&D programmes, and fuel cell demonstration projects for both stationary and automotive applications. Hydrogen production is the focus of Section 2, beginning with efforts by type of production method, e.g., production from fossil fuels, renewable and nuclear energy. Since CO_2 capture and storage is considered to be an essential aspect of hydrogen production from fossil fuels, information relating to these R&D programs is also included in this section. Hydrogen

storage, transportation and distribution are covered in Section 3, focusing on activities being undertaken for each of the main storage and transportation technologies. Section 4 provides a synthesis of the activities reported in the areas of hydrogen safety, codes and standards. Section 5 reviews policy studies and delineates policy targets. Section 6 offers some elements of the ongoing efforts to build public awareness and education on hydrogen and fuel cells.

Figure 1

Hydrogen and Fuel Cells – National R&D Efforts and International Co-operation



Taken as a whole, the *Review* draws heavily and primarily upon information contributed by the IEA governments participating in the HCG, submitting responses to a survey questionnaire, and providing feedback through the several review and editing rounds. In the course of the work, HCG representatives were also encouraged to provide additions as appropriate to reflect new developments in their country.

Substantial amounts of information were drawn from presentations and papers provided by governments at various HCG meetings and international conferences over the last year. In many cases, these primary sources of information have been complemented by national reports and official governmental web sites. To the extent that the IEA has produced this report from the large pool of information provided primarily by HCG delegates, it relies on delegates for the accuracy and currency of the findings.

In virtually all the IEA countries, R&D and policy efforts on hydrogen and fuel cells are expanding, ranging from fully integrated, government-funded programs to strategies spread in multiple public and private initiatives. Virtually all of the IEA countries indicate that research into hydrogen and fuel cells is an important element of their programs to develop and deploy advanced, clean energy technologies

Japan and the United States provide examples of fully-integrated, highly-funded programs. In Japan, the New Hydrogen Project (NHP) extends the work initiated during the seminal, 10-year, WE-NET program, which initially focused R&D on technologies necessary for establishing a hydrogen infrastructure (e.g., electrolysis, liquefaction, storage) and later on the utilisation of hydrogen and construction of fuelling stations. Japan not only develops hydrogen technologies, but it also is a leading country in fuel cell development with a strong involvement of the private sector. Under the guidance of the Ministry for Economy, Trade and Industry (METI), the NHP integrates fuel cell development, hydrogen production, transportation and storage technologies concurrently with the implementation of demonstration programs, vehicle sales, construction of refuelling infrastructure, establishment of codes and standards, and a general push to enlarge the consumer market for both stationary and automotive fuel cells.

The U.S. conducts the vast majority of its R&D on hydrogen and fuel cells under the "Hydrogen, Fuel Cells and Infrastructure Technologies Program," which funds research, development, and validation activities linked to public-private partnerships. The program is led by the US Department of Energy (DOE) and integrates the activities of a number of US government agencies, including the Department of Defence, the Department of Transportation and the Environmental Protection Agency.

The government's current role is to focus funding on high-risk, applied research in the early phases of development to the point where the private sector can make informed decisions on whether or not, and how best to commercialise these technologies. With two pillar-initiatives such as the *Hydrogen Fuel Initiative* (US$ 1.2 billion over 5 years) and the *FreedomCar* initiative, the US program seeks to implement the recommendations in the President's National Energy Policy, the DOE Strategic Plan, the National Hydrogen Energy Vision and Roadmap, and the Hydrogen Posture Plan.

Australia's 2003 national hydrogen study recognised the long term potential of hydrogen and fuel cells in relation to transport, portable appliances and distributed generation in remote areas, and the need for Australia to be involved in the development of appropriate international codes and standards for hydrogen and fuel cell use. At national level, Australia's principal public research institution – the Commonwealth Scientific and Industrial Research Organisation, CSIRO – and a number of universities are active in hydrogen R&D. A review of national relevant projects is currently being compiled by CSIRO. Hydrogen research is also an element of the COAL21 program, which includes hydrogen production from coal with carbon sequestration.

Canada's R&D program has been managed by Natural Resources Canada since 1985 and is largely based on a public-private partnership to develop fuel cells and hydrogen technologies with short-to-medium term commercial potential. Proton Exchange Membrane fuel cells developed by Canada are currently fuelling a number of demonstration buses in European and North America cities, testimony to the success of the Canadian program. An important element is also the development of codes and standards for safe use and commercialisation of hydrogen and fuel cells. The Canadian effort has recently been strengthened by the "Climate Change Plan for Canada," which allocates C$130 million to developing a hydrogen economy in Canada, and further C$85 million allocated within the Industry Portfolio to support hydrogen/fuel cell RD&D.

In Germany, the Federal Ministry of Economy and Labour (BMWA) supports research and demonstration of fuel cells and hydrogen within the "Federal Programme for Energy Research and Technologies." Intensive RD&D on hydrogen technologies started in Germany in 1988 and focused on electrolysis, hydrogen storage and larger projects to demonstrate the complete chain of solar hydrogen energy production (HYSOLAR and the Solar-Hydrogen-Bavaria Project BAYSOLAR). This work ended in 1995/1999 with the conclusion that main components were developed and functioning but commercial viability was not proved. As a consequence, since 1995 RD&D efforts were concentrated on fuel cells projects focused on new materials, improved components, and system integration. The "Program on Investment into the Future" (ZIP) includes some 40 projects related to hydrogen technology and demonstration of infrastructure for fuel cell buses. Significant programs are also being conducted at regional levels in Bavaria, Baden-Wurttemberg and North-Rhine Westphalia.

Most of the other R&D programs elsewhere in the OECD are not as integrated as those mentioned above. For example, some 40 Austrian organisations are involved in 50 ongoing hydrogen and/or fuel cell projects. Denmark's strategy during the period 1998-2002 focused on small fuel cells for stationary power as a part of some 34 different projects. Greece is conducting a number of activities in the context of national or EC co-funded projects focusing on islands as an early entry for renewable-based hydrogen technologies. The Netherlands have no hydrogen program but all aspects of hydrogen technology are being investigated, and in 2003 the "Sustainable Hydrogen" project has been launched to stimulate hydrogen related research.

In conclusion, while the book provides a realistic picture of the range of R&D initiatives and projects to develop hydrogen and fuel cells, the high number of technology options under consideration points out that such an effort is only the beginning of a several-decades journey toward a radically changed, sustainable energy system.

INTRODUCTION

Prospects for commercial applications of fuel cells are slowly gaining momentum, largely driven by significant technological advances and expectations. This enables governments to consider turning to hydrogen and fuel cells as a practical foundation for implementing public policies responding to growing environmental concerns and uncertainties about the security and long-term price of oil. With the expectation that fuel cells and hydrogen can play a significant role in the global energy economy, governments are increasing funds for research, development and demonstration of hydrogen and fuel cells and to create programs and enabling conditions to support their use.

The challenge is that most of the required new hydrogen and fuel cell technologies are still in their infancy – compared with the existing conventional energy infrastructure – and major investments, both public and private, will be needed to commercialise the production of hydrogen for energy use.

IEA member governments, as well as non-member governments, recognise that this long-term RD&D effort is required to realise the significant technological potential of hydrogen and fuel cells; and that cooperative efforts among nations can help speed effective progress towards these goals. Auspiciously, the pre-commercial stage of much hydrogen production and fuel cell technology RD&D makes it well suited to collaboration although proprietary issues are associated with pre-commercial technologies.

The objective of this *Review of National R&D Programs* is to assess the current state of play and forward plans by IEA member governments to research, develop and deploy the interlocking pieces of what could become the *hydrogen economy*. The objective is to identify which efforts have been undertaken and where work is currently being done. By beginning to tie together the pieces of the complicated and sprawling hydrogen economy, the IEA aims to exploit the benefits of collaboration among member and non-member governments in the development and commercialisation of hydrogen and fuel cell technologies.

Methodology

This Review of National R&D Programs on hydrogen and fuel cells (HFC) reflects the governmental R&D activities carried out in the IEA countries which are members of the IEA Hydrogen Co-ordination Group (HCG). It is comprised of two parts: (1) a thematic review of hydrogen and fuel cell technologies and related research, development and demonstration projects across the IEA region; and (2) a country-by-country summary of hydrogen and fuel cell R&D efforts in the HCG Member countries.

The basic information for this report was collected using a questionnaire which was completed by the country representatives in the IEA HCG. The results from the questionnaire were used to first produce a country-by-country summary of national hydrogen and fuel cell programmes. Country profiles were reviewed and updated by the HCG delegates. A thematic overview of HFC developments across countries was then prepared to provide readers with an overview of what is going on in any particular area of research, development, demonstration or policy. We have tried to make this thematic summary readable and interesting while still providing a complete picture.

Taken as a whole, the *Review* draws heavily and primarily upon information contributed by the IEA governments participating in the HCG, submitting responses to the survey questionnaire, and providing feedback through the several review and editing rounds. In the course of the work, experts from the HCG were also encouraged to provide additions as necessary to reflect new developments in their country. Substantial amounts of information were also drawn from presentations, speeches and papers provided by governments at various HCG meetings and international conferences over the last year. In many cases, these primary sources of information have been augmented with documentation publicly available from national governments and various program websites.

Although non exhaustive – many IEA countries are currently revising their R&D strategies and programs, and a number of new projects are underway – the information contained in the following pages can be collectively considered as up-to-date as August 2004, and to the extent that the IEA Secretariat has produced this draft from the large pool of information provided primarily by HCG delegates, it relies on delegates to confirm the accuracy and currency of the findings. The report reflects only governmental R&D efforts. Private sector activities are only reflected to the extent that they are conducted in partnership with public organisations.

Information is organized into 6 sections, derived from the primary questions put forth in the questionnaire. Each section features a *chapeau* which provides an introduction to the technology and an overview of its state of development and important research objectives.

Fuel Cells are taken up in Section 1, which begins with a brief overview of fuel cell fundamentals and a synopsis of each of the major fuel cell types. It then provides a review of IEA government work as it relates to each fuel cell type, including R&D efforts directed as specific fuel cell types; a review of programs undertaking basic fuel cell R&D; and, the section concludes with a review of fuel cell demonstrations for transportation and stationary applications.

Hydrogen production is the primary focus of Section 2, starting with a brief overview of hydrogen production techniques and issues. It then delineates IEA government effort by type of production method, e.g., production from fossil fuels. Since CO_2 sequestration is considered to be an essential aspect of hydrogen production techniques which generate CO_2 emissions, information reported by IEA governments is also included in this section.

Hydrogen storage, transportation and distribution are covered in Section 3, focussing on a review of activities being undertaken for each of the main storage technologies. The section also includes a discussion and synthesis of IEA government activities in the area of hydrogen transportation and storage.

Section 4 provides a synthesis of IEA government activities reported in the areas of hydrogen safety and codes and standards. Section 5 reviews policy studies and delineates policy targets for future work. Section 6 offers a brief synthesis of the ongoing efforts to build public awareness and education.

Overview

Virtually all of the IEA countries indicate that research into hydrogen and fuel cells is an important – and in most cases an increasingly important – element of their overall public policy and program planning activities, either as a purposely designed and funded hydrogen and fuel program (HFC),

or an element of an overall energy and environment strategy, or as a specific budget line item found in one or more programs and agencies.

Japan and the United States provide exceptional examples of fully-integrated, highly-funded HFC programs. In Japan, the New Hydrogen Project (NHP) extends the work initiated during the seminal, 10-year, ¥18 billion WE-NET program, which initially focused R&D on core technologies necessary for establishing a hydrogen infrastructure (e.g., electrolysis, liquefaction, storage) and then later on the utilisation of hydrogen and construction of fuelling stations. The NHP, not only ties together a number of METI's ongoing and new programs, but it integrates the development of fuel cell, hydrogen production, and hydrogen transportation and storage technologies concurrently with the implementation of demonstration programs, vehicle sales, construction of refuelling infrastructure, establishment of codes and standards, and a general push to enlarge the consumer market for fuel cells and fuel cell vehicles.

The U.S. conducts the vast majority of its R&D on hydrogen and fuel cells under the "Hydrogen, Fuel Cells and Infrastructure Technologies Program," which funds research, development and validation activities linked to public-private partnerships. The program is led by the US Department of Energy (DOE) and integrates the activities of a number of US government agencies, including the Department of Defence, the Department of Transportation and the Environmental Protection Agency. The government's current role is to concentrate funding on high-risk, applied research in the early phases of development to the point where the private sector can make informed decisions on whether or not, and how best to commercialize these technologies. The program seeks to implement recommendations in the President's National Energy Policy, the DOE Strategic Plan, the National Hydrogen Energy Vision and Roadmap, and the Hydrogen Posture Plan.

Australia is an example where HFC R&D is consistent with the government's objective of reducing the greenhouse gas intensity of energy supply and use. HFC work is also an element of Australia's COAL21 program which includes research into hydrogen production by coal gasification (and employing carbon sequestration) as part of the national clean coal strategy. Australia's national hydrogen study, undertaken in 2003, investigated the longer term potential of hydrogen fuel cells in relation to transport, portable appliances and distributed generation, particularly in remote areas, leading to an energy *White Paper* which acknowledged the long-term importance of hydrogen and the need for Australia to be involved in the development and adoption of appropriate international codes and standards. At the national level, research and development into hydrogen is occurring in a number of universities as well as through *Energy Transformed*, a significant, wide-ranging and long-term initiative of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's principal public sector research institution. Through CSIRO, a comprehensive review of Australian hydrogen and fuel cell technology projects is being compiled, and this is expected to be completed before the end of 2004.

Similarly, Canada's HFC R&D work contains various program elements focusing on the development of clean, efficient technologies for the production of hydrogen using renewable or sustainable energy sources. The hydrogen R&D program has been managed by Natural Resources Canada since 1985, and is largely based on cost-shared R&D partnerships with the private sector – focusing primarily on automotive fuel cell technologies, stationary power applications concentrating on Solid Oxide Fuel Cells (SOFC) and portable power using direct methanol fuel cells. Overall, the C$20 million program is oriented toward the development of technologies with short-to-medium term commercial potential. The R&D program focuses on hydrogen production and storage; fuel cell commercialization; and the development of coordinated hydrogen and fuel cell standards that will be required for hydrogen to be a safe and cost-effective energy carrier. Two of Canada's most successful technology

developments have been the Ballard Proton Exchange Membrane fuel cell and the Stuart Energy alkaline water electrolyser. Overall, HFC efforts have recently been strengthened by Canada's C$1 billion "Climate Change Plan for Canada," which allocates C$130 million to developing a hydrogen economy in Canada. A further C$85 million has been re-allocated to support hydrogen/fuel cell RD&D activities.

In Germany, within the Federal Programme for *Energy Research and Energy Technologies* the Federal Ministry of Economics and Labour (BMWA) supports RD&D of fuel cells and hydrogen technologies. Intensive RD&D on hydrogen technologies started in Germany in 1988 and was concentrated on the development of specific technologies like hydrogen production using electrolysis, hydrogen storage and on larger projects to demonstrate the complete supply chain of a solar hydrogen energy economy (HYSOLAR and the Solar-Hydrogen-Bavaria Project BAYSOLAR). This work was concluded in 1995-1999 with the result that in principle the main components of a hydrogen energy system were developed and functioning, however, that commercial viability of a solar hydrogen economy could only be reached in the far future. As a consequence, RD&D was concentrated on fuel cells since 1995 with an annual BMWA budget of €8-10 M per year. Ambitious projects concentrating on new materials, improved components and system integration have been supported. Notably, the *Program on Investment into the Future* (abbreviated "ZIP") includes some 40 projects related to hydrogen technology, such as demonstration of infrastructure for fuel cell buses.

Most of the other HFC programs are not as integrated. For example, despite having no overarching HFC program, some 40 Austrian organizations are involved in 50 ongoing hydrogen and/or fuel cell projects. The Danish fuel cell strategy is oriented towards smaller SOFC and PEMFC stationary power through 34 projects during the period 1998-2002. Greece also does not have a HFC specific program, but conducts a plethora of R&D activities, undertaken by Greek research institutions in the context of national or EC co-funded projects. Islands with isolated electricity grids, for example, have been identified as a case of particular interest for the early entry of renewable-based hydrogen technologies. The French *Reseau Paco* provides and example of a national network developed to promote cooperation between R&D institutes and companies, with the major themes focussed primarily on PEM, SOFC, hydrogen storage and on-board reforming. Additionally, France features innovative research on the development of high-temperature processes for hydrogen production, coupled with future nuclear energy. The Netherlands, like a number of other smaller countries, reports generally that "all aspects of HFC technology are being investigated." As an example of specific, forward-looking projects aimed at bridging renewables to the hydrogen economy, Sweden reports long-term basic research into artificial photosynthesis project using the sunlight directly to produce hydrogen from water.

Regardless of the approach taken on HFC research and development, a vast amount of information was reported in response to the IEA's HCG survey questionnaire. The following pages provide a categorical review of the findings reported to date.

PART 1

THEMATIC OVERVIEW