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.

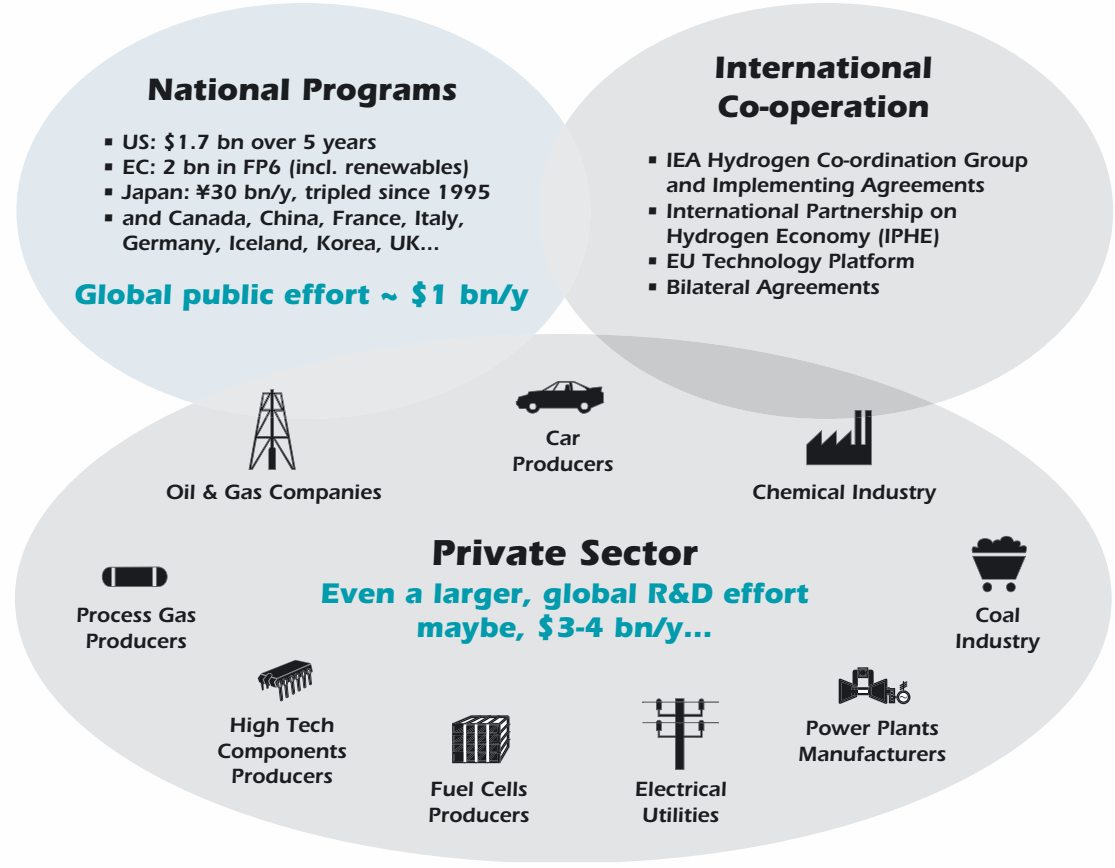
The *Review* comprises two parts. In the first, the huge number of ongoing, national activities and projects are presented in a thematic, cross-country overview reflecting the vast array of technologies, logistics and policy issues required to build a hydrogen-based energy system. Individual country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