R&D expenditure for H_2 and FC as indicator for political will

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Acknowledgement/Preface

This study in the framework of the 'Roads2Hycom' project of the EU presents an overview of data on R&D expenditures on hydrogen and fuel cells compared to other energy options, viz. biomass, photovoltaic, and nuclear power, and draws conclusions about the priority that countries give to a more sustainable energy development based on, e.g. hydrogen and fuel cells. The project is registered at ECN under project number 7.7710.

Abstract

This study aims to provide insight into the political will to switch to sustainable energy and especially hydrogen and fuel cells, by reviewing public R&D support from 1993 until 2004 in the EU compared to other major economies. It is assumed that R&D expenditures on a specific subject are an expression of the political will to enhance the role of a particular energy source or to change the energy structure in a specific direction. Comparing public R&D expenditures for hydrogen and fuel cells to those for biomass, photovoltaics (PV), wind energy, and nuclear energy, indicates the relative emphasis placed on these technologies by political will. This pertains to countries of interest, viz. the EU and the European Commission, and other IEA countries.

In this study, the global public expenditures on hydrogen and fuel cells are estimated at approximately $1040 mln (€833 mln) per year (2003-2005), of which 30% by Japan, 32% by the EU-25, and 24% by the USA. It is concluded that public R&D programmes for hydrogen and fuel cells tend to be linked to the envisioned position of fuel cells (on hydrogen) in transportation and -to a lesser extent- in stationary power generation.

With respect to R&D on biomass, the budget is fairly constant over the years. Published public R&D expenditures on biomass amounted approximately $230 mln in 2003 ($70 mln in 1993). R&D policies for PV are already coupled to market stimulation policies, e.g., in Germany and Japan. This means most countries that perform high with regard to R&D spending also host manufacturers of PV cells or panels and enable market growth for PV. Total public R&D on PV are estimated at about $290 mln in 2003 ($160 mln in 1993). IEA countries that perform high in the top of R&D spending on wind energy - the USA, Germany, Japan, Netherlands, Denmark, Sweden, but also the UK and Spain - are well known from their progressive policies to increase the share of wind energy. In 2003, public R&D expenditures amounted to an estimated $120 mln ($70 mln in 1993).

Compared to renewable options like PV, wind energy, and biomass, nuclear power is an established power generation option. The amount of public R&D for 'conventional' nuclear energy has been declining for more than a decade, but R&D of fusion power show a constant budget the past decades. In a decade, nuclear R&D expenditures declined by 12% from $4.8 billion ($\$_{2004}$) to $4.3 billion (1993-2003) and even by 20% in the period 1993-2004. The extent of nuclear R&D commitment depends inter alia on the (envisaged) position of nuclear power in the generation mix of a specific country.

Concluding, Hydrogen and Fuel Cell R&D appears to enjoy strong support within the EU and other global economies, and funding is rising faster than in other new energy technologies. The magnitude of R&D support for hydrogen and fuel cells in some countries (e.g. Japan) may be an expression of determination to force a specific market penetration for fuel cell vehicles. The proposed JTI on Fuel Cells and Hydrogen could place the EU in a strong position regarding Demonstration budgets.

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Summary

This study is part of a package of work aimed at characterising the "state of the art" in European technology development in the field of Hydrogen and Fuel Cells. Complementing a review of the "Technical State of the Art" in the elements of Hydrogen and Fuel Cell technology, it aims to provide insight into the "political will" to switch to sustainable energy and especially hydrogen and fuel cells, by reviewing the public research & development (R&D) support for the topic. Another aim is to compare public R&D expenditures for hydrogen and fuel cells on the one hand to those for biomass, photovoltaic power (PV), wind, and nuclear power on the other hand. This pertains to countries of interest, viz. the EU and the European Commission (EC) and other IEA countries. It is assumed that R&D expenditures on a specific subject are an indication of the political will to enhance the role of a particular energy source or to change the energy structure in a specific direction.

In this study, the global public expenditures on hydrogen and fuel cells are estimated at approximately $1040 mln (€833 mln) per year (2003-2005), of which 30% by Japan, 32% by the EU-25, and 24% by the USA. Taking into account the larger population of the EU, one of the literature sources concludes that Western Europe trails the United States and Japan in R&D expenditures. It is noteworthy that this is an instantaneous exposure. The USA shows a rather steady R&D budget, with a growing share for PEM fuel cells (for mobile applications). Expenditures in Japan increase rapidly and focus more on PEM fuel cells for transportation than on stationary fuel cells (MCFC, SOFC). Noteworthy is the countries which host car manufacturers have high R&D expenditure in the hydrogen and fuel cell field.

Although EU countries in total do not seem to support R&D on hydrogen and fuel cells as vigorously as the United States and Japan, it is too early to present definite conclusions on the political will. This is due to the methodology chosen. By looking at the R&D budgets the political will in the early stage of technology development is outlined, but the next phase – the demonstration phase – usually is even more costly. Then the political will and thus the (demonstration) budgets have to get higher and a different picture may arise. With the proposed European "Joint Technology Initiative" a higher degree of investment budget is suggested for demonstration activities, but at the time it remains unclear what the exact budget will be.

One of the R&D options to which hydrogen and fuel cells are compared is biomass. Published public R&D expenditures on biomass amounted approximately $230 mln in 2003 ($70 mln in 1993). Three countries stand out, viz. the USA, Sweden, and Germany. These countries are considered as willing to spend a considerable amount of public money on biomass R&D in order to enhance the share of biomass in their energy use. Other countries are also willing to invest in biomass R&D, which is witnessed by their ranking -Denmark, Switzerland- or their recent interest in biomass R&D (Japan, the Netherlands). Ranking of R&D expenditures has to be used with care when drawing conclusions with regard to the willingness of countries to increase the share of biomass. Especially for the European countries the EU directive has to be taken into account. The EU directive (2003/30/EC) obligates 5.75% of biofuel has to be blended to the transportation fuels by 2010.

Another R&D option for comparison is photovoltaics (PV). Total public R&D are estimated at about $290 mln in 2003 ($160 mln in 1993). IEA and EU countries performing well with regard to R&D spending -Japan, the USA, Germany, Italy, the Netherlands, and Switzerland- are known for their high quality of R&D on PV. In addition, Germany and Japan are also vigorously developing a domestic and an export market for PV. Other countries -France and Spain- became interested in developing their R&D potential and PV market in a later stage. The quan-

tity and quality of R&D is not directly related to the creation of a domestic market. Some countries have difficulty to develop a domestic market because their climate is not so favourable.

A third energy option to which H_2 and fuel cell research is compared is wind energy. In 2003, public R&D expenditures amounted to an estimated \$120 mln (\$70 mln in 1993). IEA and EU countries that perform high with regard to R&D spending -the USA, Germany, Japan, Netherlands, Denmark, Sweden, but also the UK and Spain- are well known from their aggressive policies to increase the share of wind energy. The countries with the largest domestic wind capacities -Germany, Spain, the USA, and Denmark- also host the largest manufacturers of wind turbines. Other countries, e.g., the UK and the Netherlands, have not been very successful in creating a significant wind turbine manufacturing industry.

Nuclear R&D policies are generally intimately linked with the position of nuclear power in the (envisioned) generating mix. Some countries -the UK, the USA, and to a lesser extent France and Germany- are considered as the cradle of the modern nuclear power plant. Other countries are reputed because they have large nuclear capacities installed (Japan, Germany, Canada) and/or are highly dependent on nuclear power (France, Switzerland, Sweden, Belgium). A phenomenon that is relevant to nuclear energy R&D is the combined effect of development of an advanced high technology industrial base and environmental protection. In the case of the Republic of Korea, high first-of-a-kind nuclear power costs were accepted as part of a long-term national energy strategy that anticipated (and subsequently realised) both eventual cost reductions from 'technology learning' and spin-off economic benefits from developing the country's high technology sector. A recent study estimated these economic spin-off benefits from nuclear power at about 2% of the country's GDP.

In a decade, nuclear R&D expenditures declined by 12% from \$4.8 billion ($\$_{2004}$) to \$4.3 billion (1993-2003) and even by 20% in the period 1993-2004. Public R&D expenditures are generally a minor fraction of GDP. The only exception seems to be nuclear R&D in Japan, accounting for 0.6‰ of its GDP. This is about seven times higher than nuclear R&D in OECD Europe as a fraction of its GDP. It is noteworthy, however, that the nuclear R&D budgets are generally declining whereas those for, e.g., hydrogen and fuel cells are increasing.

Based on the data gathered for R&D expenditures on hydrogen and fuel cells (an average of 2003-2005), and on biomass, photovoltaics, wind, and nuclear energy (IEA data of 2004 and similar IEA publications of years before 2004), a top-seven countries with the highest (absolute) expenditures has been drawn up for each of the R&D categories (Table S.1).

Table S.1 *Top-seven countries ranked with regard to R&D expenditures in five categories*

	H_2 & fuel cells	Biomass	Photovoltaics	Wind	Nuclear
1.	Japan	USA	Japan	USA	Japan
2.	USA	Japan	USA	Germany	France
3.	Germany	Netherlands	Germany	Japan	USA
4.	Italy	Sweden	Netherlands	Netherlands	Germany
5.	UK	Canada	Italy	Denmark	Italy
6.	Canada	Germany	Switzerland	Spain	Canada
7.	France	Finland	Spain/France	Sweden/UK	Switzerland

These rankings should be regarded with care because of lack of data for specific years. However, in each of the R&D they give an expression of the political will of the countries involved to switch to some extent to a specific 'deemed sustainable' energy source.

The R&D budgets for biomass, PV, wind, and nuclear energy are based on the same literature sources, viz. (IEA, 2005) and earlier editions. Thus, these budgets may be compared in a straightforward way (Figure 8.1). In a period of about a decade, nuclear R&D expenditures declined by 20% from US$4.8 billion ($_{2004}$) in 1993 to $3.8 billion in 2004. The estimates of R&D expenditures for H_2 and fuel cells show that they exceed those for biomass, PV, and wind. Although nuclear R&D budgets are still much higher than for H_2 and fuel cells, the former are declining while the latter are increasing. Figure 8.1 shows that R&D on H_2 and fuel cells amounts to approximately $1 billion in 2004. Earlier data are generally lacking. Therefore, as R&D on H_2 and fuel cells 'took off' around 2000, a 'wedge' stretches from 2000 to 2004.

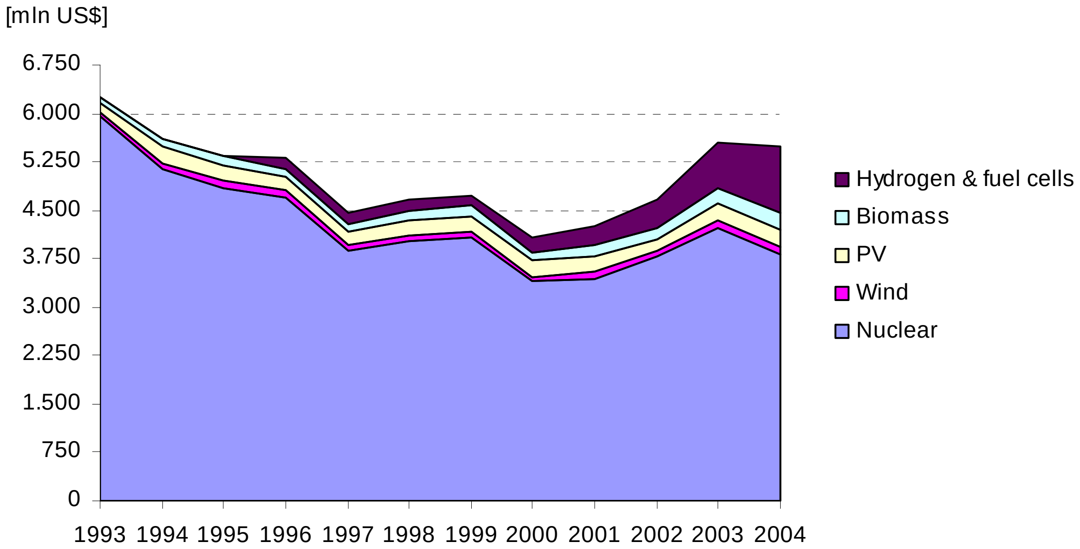

Figure S.1 *R&D expenditures for nuclear, PV, and biomass (and H_2 & FC) in the IEA*
Note: The 'wedge' for H_2 & FC is indicative of lack of historical data for this category of R&D.

Summarising, it appears that R&D in the fields of hydrogen and fuel cells is well supported compared to other new energy technologies, indicating strong political will. Public R&D programmes for hydrogen and fuel cells tend to be linked to the envisioned position of fuel cells in transportation and -to a lesser extent- in stationary power generation. Several countries adopt road maps for hydrogen and fuel cells. The R&D expenditure for biomass is fairly constant over the last years, this could be due to the fact EU countries have to comply with a EU directive obligating to blend in 5.75% of biofuel to the transportation fuels by 2010. R&D policies for PV are already coupled to market stimulation, e.g., in Germany and Japan. Countries with the largest domestic wind capacities -Germany, Spain, the USA, India, and Denmark- also host the largest manufacturers of wind turbines, which evidences the close relationship between R&D budgets on the one hand and market stimulation policies on the other hand.

Concluding, Hydrogen and Fuel Cell R&D appears to enjoy strong support within the EU and other global economies, and funding is rising faster than in other new energy technologies. The magnitude of R&D support for hydrogen and fuel cells in some countries (e.g. Japan) may be an expression of determination to force a specific market penetration for fuel cell vehicles. The proposed Joint Technology Initiative (JTI) on Fuel Cells and Hydrogen could place the EU in a strong position regarding Demonstration budgets.

1. Introduction

Roads2HyCom is a project to assess and monitor Hydrogen and Fuel Cell technology for stationary and mobile energy applications by considering what the technology is capable of, relative to current and future Hydrogen infrastructure and energy resources, and the needs of communities that may be early adopters of the technology.

This study is part of a package of work aimed at characterising the "state of the art" in European technology development in the field of Hydrogen and Fuel Cells. Complementing a review of the "Technical State of the Art" in the elements of Hydrogen and Fuel Cell technology, it aims to provide insight into the "political will" to switch to sustainable energy and especially hydrogen and fuel cells, by reviewing the public research & development (R&D) support for the topic.

Historically, our energy system is mainly based on fossil fuels, and electricity is mainly generated from fossil fuels like coal and natural gas or based on nuclear energy (uranium). In recent years policy makers emphasise the importance of security of supply, reducing the oil dependency by diversifying the fuel mix and decreasing greenhouse gas (GHG) emissions. The advancement of electricity production from renewable energy sources like wind, photovoltaics (PV) and biomass during the last decades underlines this development, although today renewable electricity only provides a fraction of the total power production. The advancement of biofuels and hydrogen for transportation purposes has just started, but also helps the policy makers to reach their goals.

In order to put the R&D efforts in perspective, Figure 1.1 shows the transition of a complex technology from the laboratory to full deployment a few decades later (Curtis, 2003).

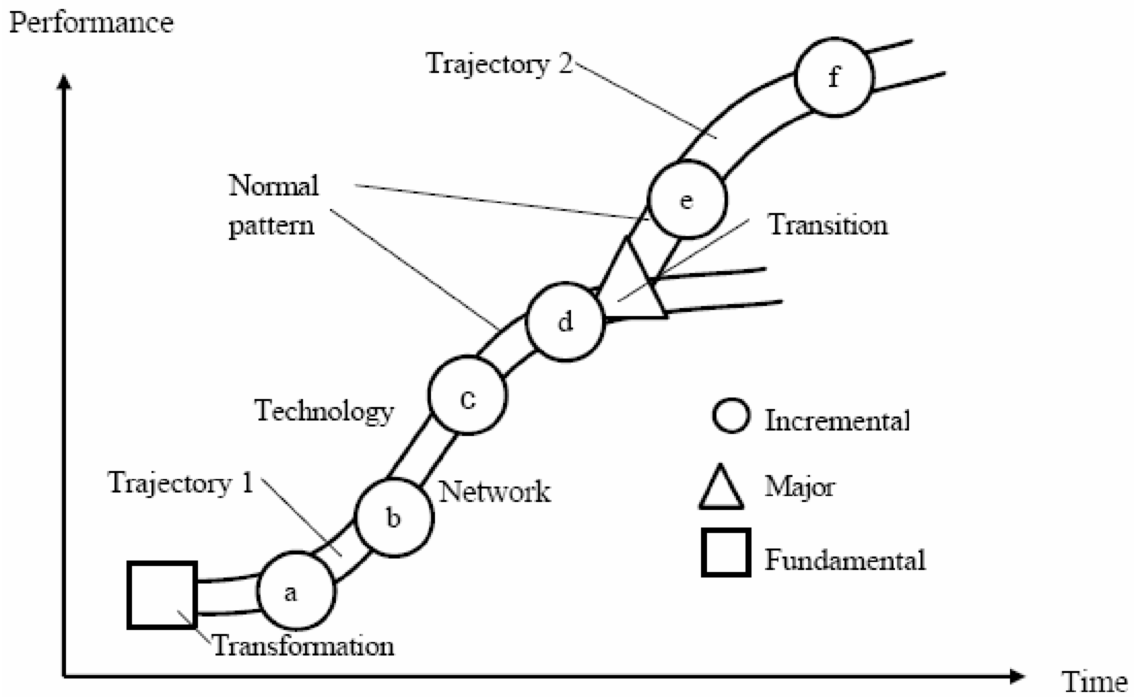

Figure 1.1 *Patterns of innovation of complex technologies*
Source: Curtis, 2003 (based on Rycroft, R.W., and D.E. Kash: The Complexity Challenge - Technological Innovation for the 21st Century. London, Pinter, 1999, p.180).

The political will to switch from conventional energy sources (like oil, gas, coal, and nuclear) to a sustainable energy source can be described by looking at a number of measures and activities:

- The number and extent of regulations that government bodies ratify and initiate, see for example the Kyoto protocol, the EU biofuels directive (2003/30/EC), the EU renewable energy directive (2001/77/EC), etc.
- The number of speeches of high political officials at conferences.
- Financial support for R&D on sustainable or renewable energy options.

Other studies within Roads2HyCom have already indicated that much investment in Fuel Cell and Hydrogen technology remains at the "pre-commercialisation" stage, with relatively small investments by a large number of organisations, many of them non-commercial, and with a high usage of public funding (Roads2HyCom, 2006). Therefore, it is assumed that R&D expenditures are a robust expression of the political will to enhance the role of these technologies. This study aims to provide more insight into the political will to switch to sustainable energy technologies and especially hydrogen and fuel cells, by reviewing the public R&D support. The main question to be answered is, ***what can be said concerning the political will based on the R&D expenditure for hydrogen and fuel cells?***

In order to answer this question, insights have been gathered on public support - in terms of million US$ or € - on R&D for hydrogen (H_2) and fuel cells the over last decades (1990-2005). To give some perspective to the R&D support of H_2 and fuel cells, the same data have been gathered for biomass, photovoltaic power (PV), wind energy, and nuclear energy R&D support. By reviewing these numbers for the EU, Japan, and the USA, an international comparison can be made. Because we are especially interested in H_2 and fuel cells, an attempt will be made to distinguish the expenditure between mobile and stationary use. Also, political statements of high government officials are mentioned to indicate their interest in the field of H_2 and fuel cells.

This report starts with an overview of R&D expenditures for hydrogen and fuel cells in Chapter 3, followed by a short overview of R&D expenditures for biomass in Chapter 4, photovoltaics (PV) in Chapter 5, wind energy in Chapter 6, and nuclear power in Chapter 7. Chapter 8 provides a comparison of R&D budgets for the technologies in the preceding chapters. Finally, Chapter 9 presents a number of conclusions.

2. Methodology

With disruptive technologies support is necessary to drive the technology into the commercial market, especially in the early stages of technology development. Political support is an important factor for stimulating organisations to start developing and demonstrating new technologies. With radical innovations it is of great importance for the government to show commitment, because the developing of new technologies is a big investment for organisations and it is unclear whether the new technology will generate profits or not. If eventually it turns out the new technology does make profit these are generated in the long run except on the short term. Therefore it is important for the government to show political will and commitment in the early stages of technology development.

Political will can be given by politicians in speeches in which they address the potential of a new technology or their vision of the future, but that are just words trying to stimulate organisations to explore new fields. Nowadays for new technologies roadmaps arise outlining future steps towards market implementation. These give insight into future plans of industry and government, but do not really show political will. A more tangible commitment can be made by providing policy support mechanisms, like R&D funds, feed-in tariffs or obligations. These support mechanisms and their budgets, timeframe, etc. have to be decided upon by politicians. So, by reviewing policy support mechanisms in the field of new technologies more insight can be gathered in the political will. This of course may differ between technologies, between development stages of a technology, countries and in time.

Hydrogen and fuel cells are an example of new disruptive technologies on the verge of demonstration. To address the political will in this field some quotes of politicians are used to give an indication of the political will. By also reviewing the R&D budgets of the countries/continents these politicians work for their political will to push hydrogen and fuel cells into the market place is validated. The focus on the R&D budgets and not on other policy support mechanisms is because for hydrogen and fuel cell technology there are no or very few other policy support mechanisms.

By assessing R&D budgets for other renewable energy technologies some perspective can be given on the amounts of support. Herewith, the validity of the ambition of Europe to compete with the US and Japan can be reviewed as well. Reviewing the R&D budgets in time can give insight into if the political will is growing or declining.

Comparing the R&D budgets between different renewable energy technologies has to be done with caution. Not all renewable energy technologies are in the same phase of technology development. Keep in mind by comparing for instance wind energy budgets with hydrogen and fuel cell budgets a comparison is made between a technology which is entering the commercial market (wind energy) with a technology still mainly in the research and demonstration phase (hydrogen and fuel cell technology). Technologies in the R&D phase need even higher budgets in the next phase of technology development, the demonstration phase. This means the wind energy budgets may be higher, not (only) because the political will is higher, but also because the budgets need to be higher because the demonstration of this technology tends to be more costly.

A second note has to be made. There may be a difference between the budget a country announces it will spend on R&D and the actual amounts spend. This research uses figures of actual amounts sped, but the quotes of politicians with future plans include future budgets. Only time can tell if these budgets are actually going to be spend.

3. Hydrogen and fuel cell R&D

3.1 Drivers for hydrogen and fuel cell R&D

The drivers for hydrogen (H_2) and fuel cell R&D (Research, Development, and Demonstration)[1] are divers, ranging from greenhouse gas (GHG) emissions reduction to security of energy supply. Figure 3.1 shows in a nutshell the drivers in different world regions (Jollie et al., 2006). In Europe, the driver is GHG emissions reduction, mainly because Europe ratified the Kyoto Protocol[2]. In the USA and Australia, energy security and availability of indigenous coal are the main drivers. In New Zealand, a main issue is the 92% dependency on foreign oil, most of which is used for transport. Interestingly though research into fuel cells and H_2 for transport applications is limited and most of the work is for distributed generation (Fuel Cell Today, 2005a). Japan, which is even more dependent on foreign oil, recently decided to reduce the reliance of the transport sector on (foreign) oil from 98% in 2000 to 80% in 2030 (METI, 2006).

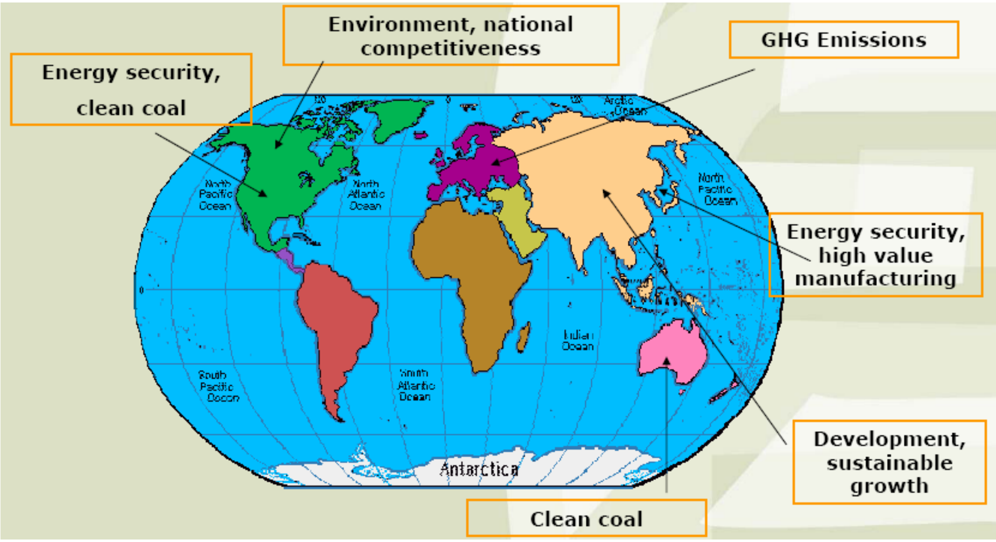

Figure 3.1 *Drivers for hydrogen and fuel cell R&D*
Source: Jollie et al., 2006.

Industry and government are also driven by the novelty of hydrogen and fuel cells (Nail et al., 2005). According to (PWC, 2002), the global demand for fuel cell products in portable, stationary and transport power applications would be \$46 billion per year by 2011 and more than \$2.5 trillion per year in 2021. Therefore, support for H_2 and fuel cell R&D may have an economic component. R&D on H_2 and fuel cells is mainly limited to the OECD and the EU. According to (ESTO, 2005) Japan, the USA, and the EU dominate R&D on stationary fuel cells (Table 3.1). Thus, the focus is on R&D in IEA and EU countries, with scanty reference to other countries.

1 See Appendix A for Acronyms and Abbreviations.
2 For the protocol to come into force, it must be ratified by more than 55 countries, including those responsible for 55% of the emissions of developed countries. The United States, which accounts for 36 percent of these emissions, hasn't ratified the protocol, though 97 countries have.

Table 3.1 *Overview of numbers of stationary fuel cell power units by world region (2005)*

		North America	EU	Japan	Rest of world
2000 up to 5 kW	[%]	40	30	30	Minimal
650 > 5 kW	[%]	45	20	30	5
3000 portable etc	[%]	55	25	20	Minimal
Total capacity	[MW]	40	12	n/a	Minimal

Source: ESTO, 2005 (Based on Fuel Cells Today).

Furthermore, R&D is characterised by the R&D field experiment cycle. Appendix B shows this R&D field experiment cycle for R&D on H_2 and fuel cells under US conditions, where 'demonstration' is called 'field experiment'. According to (DoE, 2003), timing is critical. 'Due diligence' to evaluate economic and technical barriers would be essential prior to and after each R&D and demonstration phase.

3.2 Review of policies and programmes of IEA countries

3.2.1 Introduction

Most IEA and most EU countries are more or less involved in hydrogen and fuel cell R&D. Figure 3.2 gives a view of the structure of national R&D programs (Jollie et al., 2006).

Paragraph 3.2.2 reviews R&D programmes of IEA countries, largely based on (IEA, 2004a). Paragraph 3.2.3 summarises the R&D budgets of these countries. R&D programs rarely provide details about specific end-uses for fuel cell R&D, e.g., mobile or stationary applications (DoC, 2003). Yet, Paragraph 3.2.4 analyses budgets as a function of time and the split between hydrogen, mobile, and stationary fuel cells. The only country outside the OECD that has been taken into account is China.

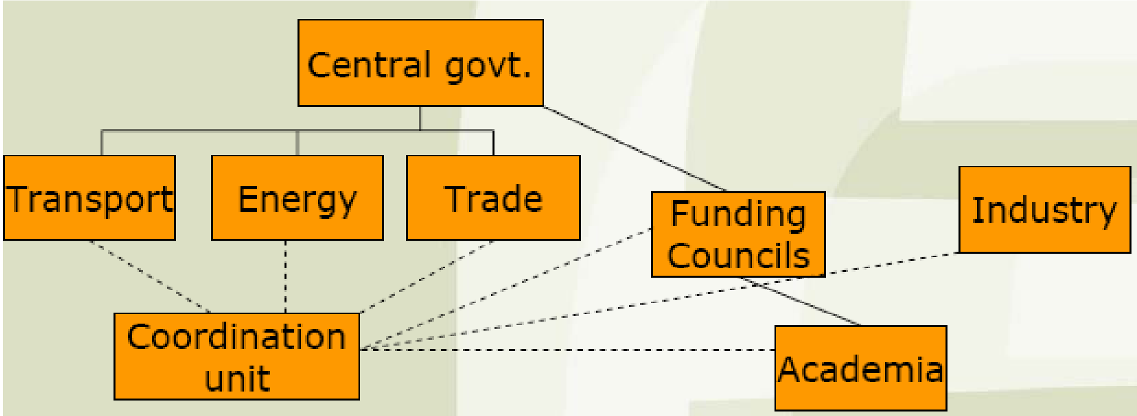

Figure 3.2 *Typical structure of national hydrogen and fuel cell R&D*
Source: Jollie et al., 2006.

3.2.2 Hydrogen and fuel cell R&D programmes of IEA countries and EU

Australia

The Australian government holds the view that the market will determine how and when hydrogen will enter the energy mix. The main potential end uses for H_2 are deemed to be in road transport, portable electrical appliances and distributed generation. In 2004, a demonstration trial in the framework of the HyFLEET:CUTE project[3] (Internet Source 1) of three H_2 fuel cell-powered buses started in Perth. The program is funded at 10.72 mln Australian $ (currency code AUD, shortly A$). In addition, the University of Queensland is developing the 'ultra-commuter', an ultra lightweight hybrid electric commuter vehicle suitable for Australian driving conditions. It will be partially powered by on-board solar cells, and a 10 kW PEM fuel cell (see Appendix A for acronyms and abbreviations).

There is substantially more activity in hydrogen than fuel cells. Data indicate a 70/30 split, in terms of active organisations (Fuel Cell Today, 2005a). Active (R&D) organisations are CSIRO (Commonwealth Scientific & Industrial Research Organisation) and Holden (programme Energy Transformed), Ceramic Fuel Cells Limited, and Zero Emission Coal Gasification.

Austria

Austrian research institutions are mainly interested in hydrogen production from renewable energy sources. The focus is on fuel cells and H_2 for automotive applications, but Austria has experience with stationary fuel cells - a 200 kW PAFC system. The Austrian 'Advanced Automotive Applications', or A3 program, includes PEM and hybrid vehicle demonstrations, environmentally friendly urban bus, and product delivery traffic systems. Austria aims to establish 'centres of excellence' concentrating on PEM, fuel cells with circulating electrolytes and SOFC. Institutions and companies active in hydrogen and fuel cell R&D are, e.g. TU Graz, and ECHEM. The annual budget for hydrogen and fuel cell R&D is €7.5 mln.

Belgium

Belgium is exploring the potential of hydrogen and fuel cells. Parties active in H_2 and fuel cell (PEM, SOFC) R&D are Vito and University Liege. Collaboration between industry and research organisations was set up to enhance the fuel cell research within the Flemish region. The R&D budget is €7.6 mln, of which €3.4 mln for hydrogen and €4.2 mln for fuel cells.

Canada

Canada has a longstanding involvement in the development of hydrogen and fuel cell technologies with government investment of some C$200 mln since the early 1980s. Canada's hydrogen and fuel cell R&D program refers to three phases:

- Phase 1: R&D and Early Deployment (0-5 years)
- Phase 2: Broad Based Deployment (5-10 years)
- Phase 3: Market Expansion (10-20 years)

[3] The HyFLEET:CUTE project is a European demonstration program for hydrogen-fuelled fuel cell buses, with participation from transport companies, bus and car manufacturers, oil companies and utilities, universities and consultants, and government organisations.

“The Government of Canada, in the recent Speech from the Throne, restated its commitment to supporting the development of innovative environmental technologies,” said Minister Robillard. “Through this investment, we are not only helping our environment, but we are also creating a strong and vibrant economy for years to come.’

“This is the type of creative and innovative solution we need to meet our targets within the Climate Change Plan for Canada,” said Minister Guarnieri. “Canada has become a world leader in the development of hydrogen technologies. This industry will be a major component in our reduction of emissions under the Plan.”

“This type of technology will play an important role in enabling more long-term uses of hydrogen, such as the fuel cell and large-scale power generation,” said Alan Lloyd, Member of the Canadian Hydrogen Technology Advisory Group and 2003 Chairman of the California Fuel Cell Partnership. “Not only will this kind of technology contribute to important environmental improvements, but it will also help establish an infrastructure that will benefit the entire hydrogen industry now and into the future.”

(March 8, 2004)
Source: Internet Source 2

The Canadian government and industry is interested in both transportation and stationary applications of hydrogen and fuel cells. The Canadian ‘Transportation Fuel Cell Alliance’ initiative focuses on demonstrating different combinations of fuels and fuelling systems for light, medium and heavy-duty vehicles. Canada’s hydrogen transport and distribution infrastructure program comprises refuelling stations and includes work on large-scale water electrolysers, hydrogen compressors up to 700 bar, hydrogen dispensers, controls, and codes and standards. Stationary demonstrations include a Siemens Westinghouse SOFC prototype of 250 kW (CHP) and a BCHydro/Ballard Airgen PEM backup power system of 1.2 kW. Also, Canada is developing an H_2 Roadmap, considering the role that H_2, fuel cells and related technologies may play in the short, medium, and long term. The process will seek to build consensus between industry, government and other stakeholders on the ways to encourage the strategic development and use of hydrogen in Canada. Hydrogen and fuel cell companies include Ballard Power Systems, Hydrogenics Corporation, and IFCI Vancouver.

Yearly spending by the Canadian government on R&D is approximately C$20 mln (€12.6 mln) through ‘Natural Resources Canada’ and the ‘National Research Council’. Additional support of approximately C$13 mln (€8.2 mln) is provided to the hydrogen and fuel cell industry through other innovation and climate change programs. In October 2003, a C$215 mln (€138 mln) investment was announced that capitalises on the use of hydrogen and fuel cells. Also, the government has made new investments totalling C$28.3 mln (€17.9 mln) through ‘Technology Partnerships Canada’ (TPC) with three innovative British Columbia small and medium sized enterprises. Two investments by the TPC will promote hydrogen fuel cell technology research projects with the potential to advance the hydrogen economy, leading to reduced GHG emissions and contributing to a sustainable environment (CFEVR, 2005a). According to (ESTO, 2005), the total governmental funding for H_2 and fuel cell R&D amounts to C$215 mln or €138 mln for the period 2000-2006, which is on average €23 mln per year[4].

China
Since about 1999, the Chinese government has extended the electric vehicle R&D investment towards Fuel Cell Vehicles (FCVs). With regard to research and development on H_2 and fuel cells, there are two programmes and three research areas:

[4] It is very difficult to delineate total funding: the years are overlapping as are some of the programs (ESTO, 2005).

- Programme 'I', start date March 1997
  1. Fundamentals of Large-scale Production, Storage and Transportation of Hydrogen and the related Fuel Cells
     The period stretches from April 2000 to March 2005. The budget is RMB 30 mln (5 years).
  2. Basic Research of Hydrogen Production in Scale Using Solar Energy
     The period considered is December 2003- November 2008, and the budget is RMB 30 mln (five years).
- Programme 'II', start date March 1986
  During the 10th five-year plan (2001-2005) China's Ministry of Science and Technology (MOST) approved an RMB 880 mln (US$106 mln) R&D program to develop advanced hydrogen technology, hybrid-electric drive and fuel cell vehicles.

China has a five-year demonstration programme for hydrogen buses and fuelling stations. The Ministry of Science and Technology (MOST) is undertaking a project with the Global Environmental Facility (GEF) and the United Nations Development Program (UNDP). This US$32 mln co-funded project is intended to catalyse the cost-reduction of fuel-cell buses (FCBs) for public transit applications in Chinese cities and stimulate technology transfer activities by supporting significant parallel demonstrations of FCBs and their hydrogen fueling infrastructures in Beijing and Shanghai. Its long-term objective is to reduce air pollution and GHG emissions through widespread commercial introduction of FCBs in urban areas of China (IPHE, 2004).

Finally, Shanghai Automotive Industry Corp (SAIC), one of China's biggest automakers, on Friday unveiled its plans for new-energy-powered vehicles over the next three to five years. The company, a partner of Volkswagen and General Motors (GM) in China, plans to begin experimental production of hybrid-powered cars and buses under its own and foreign brands before 2008, SAIC said in a statement. According to Zhu Xiangjun, a spokesperson for SAIC, the annual output of hybrid-powered vehicles will be 'several thousand units' during the period and will increase to 'tens of thousands' before 2010 (Internet Source 3).

It is assumed that 50% of the 1st research area of the Programme 'I' is related to hydrogen and 50% to mobile FCs, and that the whole 2nd research area is related to H_2. Also, 50% of the Programme 'II' s assumed related to H_2 and fuel cells for FCVs (in equal amounts) and the remainder to hybrid-electric vehicles. The average annual R&D budget is $22.5 mln (RMB 186.4 mln).

Denmark

Denmark is interested in transportation and stationary applications of hydrogen and fuel cells, with an involvement of Danish industry (DEA, 2005). Parties active in the field of H_2 and fuel cell R&D are Technical University of Denmark, Haldor Topsøe A/S, IRD Fuel Cells A/S, and Risøe National Laboratory. The Research Council supports a centre of excellence on catalysis, storage and demonstration of small energy units. In 2003, €18 mln was spent on H_2 and fuel cell R&D, of which €11 mln on SOFC and €7 mln on PEM R&D. According to (ESTO, 2005), Denmark spent €40.9 mln on 'various H_2 and fuel cell R&D programmes' in the period 1998-2003, which is on average €5 mln per year. Thus, an average of €11.5 mln is used in Table 3.6.

Finland

Finland is engaged in fuel cell R&D, in particular with regard to PEM and SOFC fuel cells. A PEM module for micro CHP (1.5 kW) has been built. Institutions and companies involved are, e.g., Wärtsilä (SOFC), Helsinki University of Technology (HUT) and Research Centre of Finland (VTT). In 2003, the budget for fuel cell R&D was €4 mln, and for hydrogen R&D €1.4 mln. According to (ESTO, 2005), €18.3 mln was spent on 'various H_2 and fuel cell R&D programmes' in the period 1998-2003.

France

In France, fuel cell activities are concentrated in two main areas: PEM and SOFC technologies. Numerous public organisations participate in the finance, research and development of H_2 and fuel cells in France, using their own resources or resources either from industry or from EU programs. Key players are the so-called 'PACo fuel cells network', CNRS, CEA (Atomic Energy Agency), IFP (French Petroleum Institute) and ADEME. In the period 1999-2002, public funding for the PACo network ranged from €6.0 to €9.6 mln per year (LEPII, 2004). According to (ESTO, 2005), the French government spends about €20 mln annually on PEM, SOFC, and H_2 production and storage, of which €10 mln for the PACo network. (IEA, 2004a) presents a figure of €40 mln for the total funding provided by public entities in 2002, including subsidies provided in France by the EU for 'hydrogen and fuel cells' work as part of the FP5 program. The 'Clean vehicles' plan should lead to additional support of €40 mln over a period of 5 years. The figure of €20 mln from (ESTO, 2005) has been retained in Table 3.6.

According to (HY-CO, 2006), €600 mln is available for H_2 and FC research, demonstration and deployment for six years, based on an agreement at the highest government level with the support of the National Research Agency (NRA) and the Industrial Innovation Agency (IIA).

Germany

Germany is one of the world leaders on hydrogen and fuel cell R&D. The R&D on fuel cells refers to all types, viz. PEM, MCFC, and SOFC. Companies engaged are, e.g., Vaillant, Viesmann, MTU CFC, Siemens Westinghouse, and Linde. Besides, vehicle manufacturers like Volkswagen and DaimlerChrysler are engaged in fuel cell R&D. All fuel cell technologies have to be taken into consideration in the R&D programme. The main goals are cost reduction, increased lifetime and better reliability for the crucial components and systems. Public federal funding of hydrogen and fuel cell R&D amounts to €8-10 mln annually. Within the programme 'Programme on Investment into the Future', an additional €15 mln per year have been granted for fuel cell projects during the period 2001-2003. Basic research on fuel cells in the Helmholtz research centres is supported by the Ministry of Research and Education, which amounts to €15 mln per year. The 'Clean Energy Partnership' was initiated in 2004, with a total budget of €33 mln, in addition to €5 mln in funding from the German Federal Government.

Based on (IEA, 2004a), R&D spending of the federal government is estimated at €57 mln. (ESTO, 2005) estimates that €10 mln was spent on H_2 and €126 mln on all types of fuel cells and basic research in the period 2000-2006. The reported budget of approximately €25 mln per year seems to be an underestimation[5], as it is stated that 'Germany exemplifies the strengths required to build a competitive industry' indicating that public R&D expenditures are sufficient (ESTO, 2005). Thus, the figure of €57 mln per year for federal funding is used in Table 3.6.

Recently (March 15th 2006), the German federal Minister of transport, building and urban affairs, Wolfgang Tiefensee, announced a National Hydrogen and Fuel Cell Innovation Program, to strengthen federal commitment with an extra €500 mln ($610 mln) in R&D funding over the next ten years.

[5] (ESTO, 2005) presents in Annex I a figure of €100 mln for the period 2001-2003 as the budget of the Federal Ministry of Economics and Labour, Federal Environment Ministry, and Federal Ministry of Education and Research. This budget pertains to fuel cell development and demonstration projects, including small stationary, large stationary and transport applications, and education and public awareness projects, focused on DMFC, MCFC, PEM and SOFC technologies. It is expected that Länder (States) also made funding available (IEA estimates €150 mln for 1997 – 2003). Therefore federal R&D is probably to the tune of €57 mln (Table 3.66) per year (IEA, 2004b).

On 7th November 2000 the German Chancellor Gerhard Schröder gave strong support to Daimler Benz's latest fuel cell car, Necar 5, by personally presenting the prototype to the media and the general public.

Source: Internet Source 4

On 18 September 2004 Chancellor Schröder received the car from DaimlerChrysler and praised the efforts of the company to develop more environmentally friendly vehicles, especially at a time of increased oil prices and concerns over the effects of CO_2 emissions in relation to climate change.

"This shows that we are on the right track," the chancellor said, running an impressed eye over his new loan car. (the chancellor will have (had) one year to test the car).

Source: Internet Source 5

Greece

The activities with regard to hydrogen and fuel cell R&D in Greece are mainly related to similar programmes in the EU. Institutions and companies engaged are, e.g., HELBIO, CRES, and National Technical University of Athens (NTUA). The total annual budget of hydrogen and fuel cell R&D is greater than €5 mln.

Italy

Italy has a rather broad hydrogen and fuel cell R&D program, including PEM, MCFC, and SOFC fuel cells. Also, a number of demonstration projects both with regard to transportation and stationary power have been realised. Parties engaged are, e.g., Arctronics, Nuvera, Ansaldo, and ENEA. Over the last three years, national funding amounted to €90 mln (€30mln) per year, of which €51 mln (€17 mln) for hydrogen and €39 mln (€13 mln) for fuel cell development and deployment. ESTO (2005) confirms the total budget of €90 mln in the period 2003-2006.

Japan

The Ministry of Economy, Trade, and Industry (METI) has set targets for the introduction of Fuel Cell Vehicles (FCVs) and stationary fuel cells in 2010 and 2020 (Table 3.2). In the 'dawn' period, practically only buses and fleet cars with fuel cells are introduced. Only a small number of FCVs will be introduced by then, but they will require many fuelling stations. One station will be needed to cover the fuel requirement of 100 vehicles by 2010, meaning that at least 500 fuelling stations are needed in the dawn period. The introduction period refers to introduction of fuel cells in business cars. At the end of that period, 5 mln FCVs are assumed to be on the roads. The price of FCVs will decrease during this period, but will still be higher than conventional vehicles. A tax system could be put in place as an incentive to purchase FCVs. The 'penetration' period assumes application of fuel cells in all cars and buses. If the targets are met, hydrogen demand for FCVs in Japan will reach 17.0 billion m^3 by 2030 (CFEVR, 2005b). Table 3.2 also shows Japan's targets with regard to stationary power generation based on fuel cells.

Prime Minister Koizumi:

"The fuel cell is the key to opening the doors to a hydrogen economy."

"We will aim to achieve its practical use as a power source for vehicles and households within three years."

"Fuel cell vehicles have come to market in Japan earlier than anywhere in the world."

"I hope that Japan can be said to have succeeded both harmonious coexistence with nature and economic growth, with continuous technological development."

(February, 2003)
Source: Internet Source 6

Table 3.2 *Penetration of Fuel Cell Vehicles (FCVs) and fuel cell based power in Japan*

Period		2005-2010	2010-2020	2020-2030
Categorisation		'Dawn'	'Introduction'	'Penetration'
FCVs	Nr (at end period)	50,000	5,000,000	15,000,000
Fuelling stations	Nr (at end period)	500	n/a	n/a
FCVs/fuelling station	Nr (at end period)	100	n/a	n/a
Stationary fuel cells	[MW]	2,100	10,000	n/a

Sources: CFEVR, 2005b; ESTO, 2005.

In order to put Japan's 500 H_2-fuelling stations by 2010 in perspective, Figure 3.3 shows the worldwide number of fuelling stations, with projections for 2005-2006 (Fuel Cell Today, 2006).

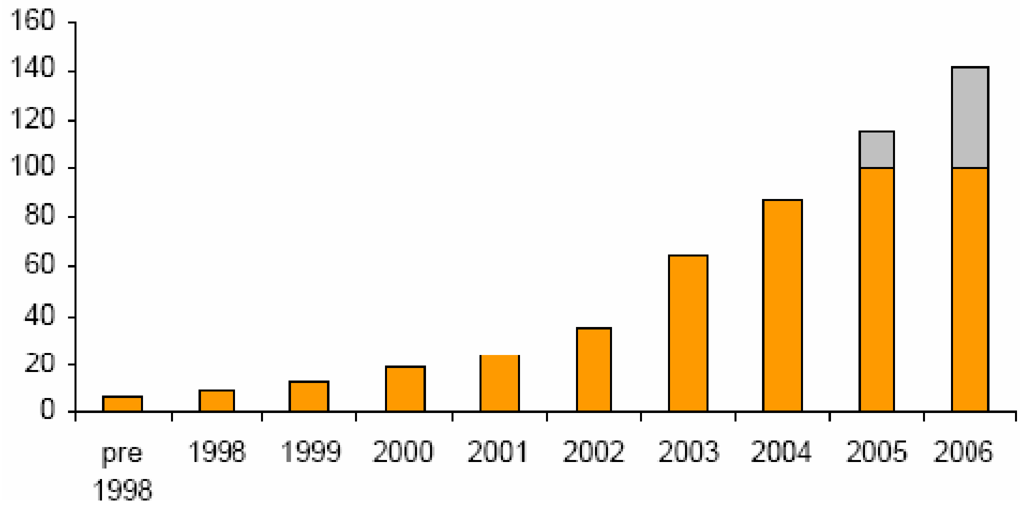

Figure 3.3 *Cumulative number of hydrogen fuelling stations in the world*
Note: Gray area is forecast.
Source: Fuel Cell Today, 2006.

An example of R&D activities on stationary fuel cells is a field test of LPG-based micro CHP: Cosmo Oil Company started this field test with a fuel cell system generating 700 W with an electrical efficiency in excess of 30% based on the higher heating value of LPG (CFEVR, 2005c). R&D applies to all types of fuel cells. Organisations engaged in H_2 and fuel cell R&D are, e.g., the auto industry, the Electric Power Development Co., and NEDO. In 2003, the R&D budget amounted to ¥31 billion, or €237 mln. This is almost double the budget of 2002 (€163 mln) according to (DoE, 2004). Some 85% was related to fuel cell R&D. (ESTO, 2005) presents a breakdown of R&D by fuel cell types for 2002:

- ¥8.4 billion (€64 mln) for PEM fuel cells;
- ¥1.8 billion (€14 mln) for MCFC fuel cells; and
- ¥1.7 billion (€13 mln) for SOFC fuel cells.

The emphasis on PEM fuel cell R&D is mainly driven by the strong industrial interest from Japan's domestic automotive industry. Recently, (Jollie et al., 2006) presented an estimate of the Japanese 2005 budget of $300 mln, but in (EHFC, 2005) it is estimated at €250 mln. The latter figure has been used in Table 3.6, that conveys all expenditures in US$ (in €'s in Appendix C).

The ambitious targets for Fuel Cell Vehicles (FCVs), fuelling stations, and stationary FC (Table 3.2), have inspired the European Commission. According to (EC, 2003): 'Europe can only meet this global challenge with similar total levels of investment from individual states and the EU.'

South Korea

The Korean government has selected fuel cell technology as a key technology requiring its full support since 1990. It seeks to attain a hydrogen economy by 2040, with fuel cells powering a significant portion of the country's transportation and electricity needs. R&D applies to all types of fuel cells (PEM, MCFC, SOFC). Historically, fuel cell research has focused on MCFC and PAFC for large stationary applications (Fuel Cell Today, 2005b). Institutions and companies engaged are CETI (Clean Energy Technologies, Inc.), KEPCO (Korean Electric Power Corporation), KEPRI (Korean Electric Power Research Institute), KIER (Korean Institute of Energy Research), KIST (Korean Institute of Science and Technology), KOGAS (Korean Gas Corporation), KERI (Korean Electro-technology Research Institute), Hyosung, and Samsung.

From 1988 to 2002, $34.7 mln was invested in fuel cell R&D (OECD, 2003), and $5 mln in H_2 R&D (Fuel Cell Today, 2005b). The budget for H_2 and fuel cell R&D has been significantly increased. The budget is estimated at $586 mln or €488 mln from 2004 to 2011, i.e. €70 mln per year. Yet, (Jollie *et al*., 2006) puts it at $115 mln per year.

Netherlands

R&D activities on hydrogen and fuel cells in the Netherlands are mainly focused on PEM and SOFC fuel cell technology. Also, (SOFC) fuel cell technology for stationary power and PEM fuel cell buses is demonstrated. Institutions and companies engaged in hydrogen and fuel cell R&D include NedStack, HYGEAR, ECN, Shell, Hoek Loos (a Linde company), and Air Products (US company). The R&D budget is €7 mln (HY-CO, 2006).

New Zealand

New Zealand has one major hydrogen project underway, aiming to demonstrate electricity production from indigenous coal by the development of an integrated gasification, syngas cleanup, fuel cell package. The New Zealand Government, through the Foundation for Research Science and Technology, is funding the six-year project. Another coal gasification project aims to integrate an air-blown coal gasifier (later to be converted to an oxygen-blown system) with an alkaline fuel cell system. Three technical centres are involved in hydrogen research. The Government has allocated $8 mln over a six-year period for research on developing fuel cell grade hydrogen from coal (IPHE, 2005), equivalent to $1.3 mln per year.

Norway
The hydrogen and fuel cell related activities in Norway have mostly been parts of larger R&D programs within the field of renewable sources of energy. The government established a national 'Hydrogen Commission' to define national targets to develop hydrogen as energy carrier, identify means and instruments for added value and better environment, and necessary funding for a national H_2 program. Institutions and companies engaged in hydrogen and fuel cell R&D are, e.g., Norwegian University of Science and Technology (NTNU) and Norsk Hydro (electrolysis). The budget amounts to €10.2 mln, of which €0.5 mln for fuel cell R&D (in particular PEM fuel cells). According to (ESTO, 2005), the Norwegian government spent €27.6 mln on 'various H_2 and fuel cell R&D programmes' in the period 1998-2003, which is on average €5.5 mln per year.

Portugal
Portugal has relatively modest R&D activities related to hydrogen and fuel cells. One of the institutes engaged in this R&D is the INETI National Institute. Most of the R&D is part of the EU wide R&D activities on hydrogen and fuel cells.

Spain
Spain initiated activities in hydrogen and fuel cell R&D in the early 1990s, and continues to focus its work in the areas of hydrogen production and storage, and the development of components for different types of fuel cells. The annual R&D budget is approximately €10 mln.

Sweden
The Swedish National Energy Agency is the main governmental actor for hydrogen and fuel cell work. Although a number of initiatives have been taken, there is no national program or strategy for hydrogen related activities in Sweden. Institutions and companies engaged in hydrogen and fuel cell R&D include Elforsk, University of Lund, Chalmers University of Technology, and Royal Institute of Technology Stockholm. The R&D budget is €4.0 mln (IEA, 2004a). (ESTO, 2005) reports a budget of €34.7 mln on 'various H_2 and fuel cell R&D programmes' in the period 1998-2003 (€7 mln per year). The average of both studies of €5.5 mln is used in Table 3.6.

Switzerland
In the Swiss National Energy Research and Development Programme, hydrogen is considered one of the most important future secondary energy carriers. R&D has been focused on hydrogen production and storage and fuel cells (PEM, SOFC). Institutions and companies engaged are, e.g., Elektra Birseck (PEM), Sulzer Hexis (SOFC), Linde (German), Paul-Scherrer-Institute, and the Federal Institute of Technology Zürich. The R&D budget is estimated at €4.0 mln. According to (ESTO, 2005), the Swiss government spent €38.7 mln on innovative materials, components and cell design, demonstration of fuel cell systems for transportation, stationary power generation and portable units in the period 2003-2006, which is on average €13 mln per year. Therefore, an average €8.5 mln based on both studies has been used in Table 3.6.

Turkey
Turkey has engaged in a limited work on hydrogen and fuel cells, e.g., through TUBITAK. Recently, the 'National Research and Development Foresight' (Vision 2023) was announced, but there is no dedicated program for hydrogen and fuel cell development. The annual R&D budget amounts to €2.0 mln, of which €1.8 mln for fuel cell R&D.

United Kingdom
The UK has a strong research base in the fields of, e.g., material science and catalysis. Several universities have been involved, apart from DTI (Department of Trade and Industry). Companies engaged in hydrogen and fuel cell R&D include Rolls Royce (SOFC), EPSRC, BP, Johnson Matthey Fuel Cells, Intelligent Energy, Voller CERES Power and the so-called Low Carbon Vehicle Partnership. The *R&D budget* is €2.9 mln. Recently, the UK embarked on a 'Carbon

Abatement Technology' (CAT) strategy, technologies related to decarbonisation of the energy system, by substituting old inefficient fossil fuel based power plants by modern highly efficient ones, by co-firing (5-10%) biomass, or by CO_2 Capture and Storage (CCS). This strategy requires a specific industry-led R&D programme. Commercial organisations are invited to bid for Government support to undertake projects, possibly in collaboration with universities and other R&D organisations (DTI, 2005). The Government will provide £ 40 mln (€59 mln) over four years commencing in 2006/07 for *demonstrations* of CATs, hydrogen, and fuel cells; £ 25 mln (€37 mln) is expected to be dedicated to CATs with the balance split approximately 50:50 between hydrogen and fuel cells. So, the *budget for demonstrations* is €22 mln (£ 15 mln).

Based on (IEA, 2004a), spending from the UK government is estimated at €25 mln per year, of which €14 mln for fuel cells. According to (ESTO, 2005), €8.1 mln is spent on SUPERGEN Hydrogen and Fuel Cells Consortia in the period 2003-2008, and €110 mln on general energy R&D programmes that feed into both fuel cell and hydrogen technology development.

European Union

The expenses of the European Commission (EC) on hydrogen and fuel cells are estimated as follows (Table 3.3). The 6th European Framework Programme (FP6) is in place.

Table 3.3 *R&D expenses on H_2 and fuel cells of the European Commission*

Programme	Period	Budget [mln €]
Second Framework Programme	1986/1990	8
Third Framework Programme	1990/1994	32
Fourth Framework Programme	1994/1998	58
Fifth Framework Programme	1998/2002	145
Sixth Framework Programme	2002/2006	300

The EU fuel cell program has several technological focus areas including (Runci et al., 2004):

- Development of low-cost, competitive, high-temperature fuel cells for decentralised power generation. Research aims to develop cost-effective, safe, and reliable fuel cell systems for electricity production covering power ranges from 0.5 MW to 5 MW, with an installed cost of less than €1000/kW and service life of more than 40,000 hours.
- Development of PEM fuel cells and components for stationary and transportation applications. The main research goal is to enable production of PEM fuel cells with a cost of less than €100/kW for stationary and €50/kW for transportation applications, with service life of 30,000 and 5,000 hours, respectively. Research integrates modelling, materials, catalysis, on-board fuel processors, energy/environmental life cycle analyses and policy analysis in the effort to develop fuel cell energy systems.
- Development of new knowledge, materials, processes, and components for PEM and direct methanol fuel cells (DMFCs). The objective is to advance knowledge of related materials physics, electro-chemistry, and economic analyses to eliminate barriers to the mass production and wide deployment of low-temperature fuel cells.
- Development of fuel cells for small, portable applications. This research programme aims to develop safe, clean, and reliable fuel cells of a few hundred W to power small, portable devices.
- Development and validation of 'next generation' computational and simulation tools for fuel cell systems analysis. Efforts focus on the continued advancement of analytical support tools focusing on thermodynamics, reactor performance, heat integration, etc. and particularly on industrial applications.
- Consultation with a Community of Experts on Fuel Cells and Hydrogen. In addition to its R&D activities, the Commission has formed a 'High Level Group for Hydrogen and Fuel Cells' (HLG) consisting of experts and key stakeholders from government, industry and

academia to explore the potential for, and challenges to, the development of European leadership in the production and adoption of fuel cells and related technologies. The group's main objective is to produce a 'foresight' report on hydrogen and fuel cells as a bridge to sustainable energy systems, including scenarios, technology road-mapping, and deployment strategies.

Figure 3.4 shows the main themes of FP6 with regard to hydrogen and fuel cells. The major share of funding of the EC goes to H_2 production and large technology validation and demonstration projects. This latter may imply the EC is focussing on demonstrating hydrogen and fuel cell technologies, trying to push H_2 and fuel cell technology into the market. However it is unclear how the budget can be divided between R&D and deployment, for instance is the area H_2 production funding for demonstration of production or R&D of H_2 production or both.

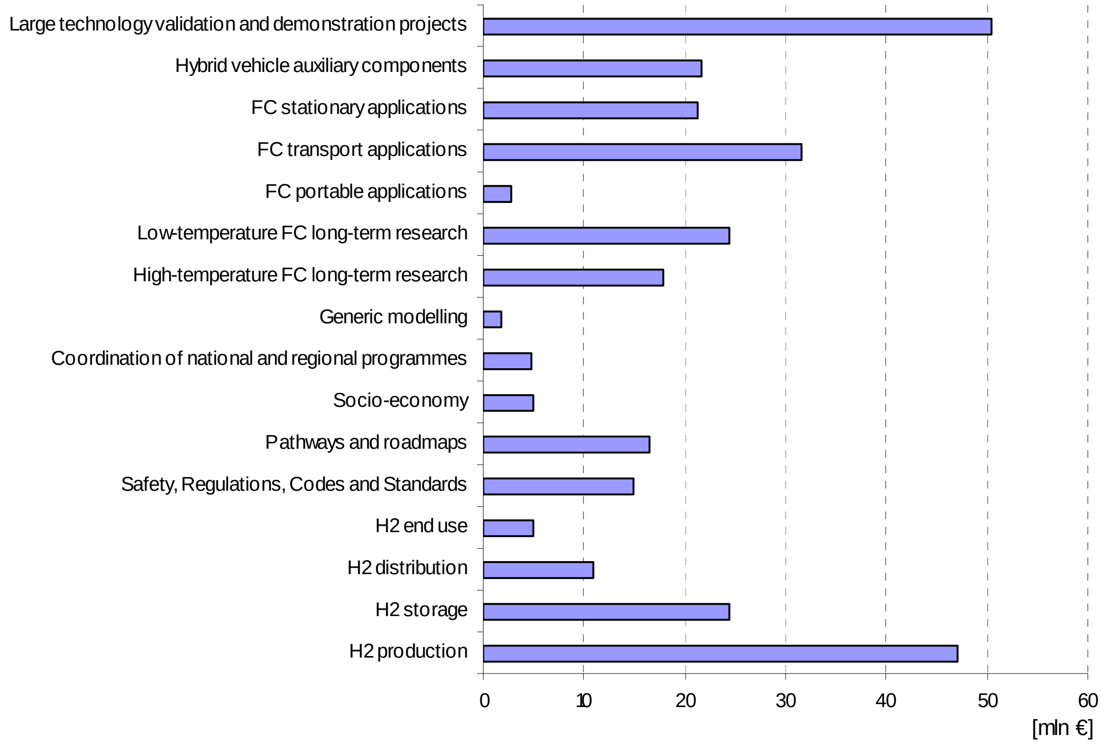

Figure 3.4 *Overview of EC funding in separate areas for FP6*

Besides funding, the EC involves stakeholders in the H_2 and FC field. On October 10th 2002, the aforementioned platform 'HLG' was formally launched in Brussels, by the Vice President of the EC, Loyola de Palacio, responsible for Energy and Transport, and Research Commissioner Philippe Busquin, with the support of President Romano Prodi. It brings together top-level stakeholders from across Europe, with the aim of formulating an integrated EU vision on the possible role that hydrogen and fuel cells could play in achieving sustainable energy. It has provided recommendations to policy makers addressing what would be required to achieve global leadership in this field in the next 20 to 30 years. Recently, the HLG was renamed into the 'European Hydrogen and Fuel Cell Technology Platform' (HFP). This HFP will stimulate the development of public-private partnership to implement its research agenda and deployment strategy, representing new opportunities for research and demonstration of H_2 energy systems. In this context, the Growth Initiative presented by the EC in November 2003 has identified two possible 'Quick Start' initiatives in the field of H_2 focussing in its clean production and its use in communities, and representing a total investment of €2.8 billion.

The FP7 programme will again include fuel cell development with the overall emphasis of the scheme being on R&D and probably more than €68 mln labelled for R&D on H_2 and fuel cells in seven years (Fuel Cell Today, 2005c).

EC President Romano Prodi:

Announced a goal of ‘achieving a step-by-step shift towards a fully integrated hydrogen economy, based on renewable energy sources, by the middle of this century.’

‘Hydrogen and fuel cell technology represents a strategic choice for Europe. Within the next 20 to 30 years it will change considerably our society and economic growth patterns, by bringing about a decentralised and cleaner model of energy production and distribution.’

Commissioner de Palacio added: ‘Hydrogen and fuel cells can potentially reduce the European Union’s dependence on oil while at the same time contributing to sustainable development. They are key to achieving the EU objective of replacing 20% of vehicle fuels with alternative fuels by 2020, including hydrogen.’

EU Research Commissioner Philippe Busquin said: ‘Today, hydrogen and fuel cells are too expensive, and research efforts in this field are scattered. We need a consistent approach at European level to reach a technological and economic breakeven point in hydrogen take-up. A strong partnership between industrialists, researchers, users and policy makers is therefore needed to ensure Europe leads the drive towards the hydrogen economy.’

Source: The Hydrogen Economy, a bridge to sustainable energy” conference (16^{th} June 2003).

USA

According to (Jollie et al., 2006), R&D in the USA may be characterised as follows:

- Focus on economic benefits and manufacturing.
- Funding from State and federal level but not well integrated: target-based.
- Some major programmes and large earmarks.
- Demonstration almost solely at State level.
- Military is important with regard to funding and acts as early adopter.
- Challenge for small companies to grow.

President George W. Bush:

“In this century, the greatest environmental progress will come about … through technology and innovation. Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles.”

“… With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.”

“Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy.”

Source: State of Union, January 28, 2003.

Table 3.4 gives an overview of R&D expenditures of the federal government on H_2 and fuel cells.

Table 3.4 *Federal funding of transportation and total fuel cells FY 1990-2005 and 1996-2005*

Fiscal Year (FY)	Federal PEM Transportation Fuel Cell R&D [current $]	Federal fuel cells R&D [current $]
1992	9.5	n/a
1993	12.0	n/a
1994	19.5	n/a
1995	22.2	n/a
1996	21.5	114
1997	21.1	101
1998	23.5	98
1999	33.7	115
2000	37.0	115
2001	41.5	145
2002	41.2	159
2003	48.0	157 (est.)
2004	65.2	156
2005	77.5	225
2006 (budget request)	*n/a*	*259.5*
Total (1992-2005 or 1996-2005)	473[a]	1,385[a]

a Cumulative federal funding 1990-2005; 2003 estimated (by interpolation).
Source: NRC, 2001; BTI, 2003; DoE, 2005; Miller, 2005.

It is estimated that, if the government would not have supported R&D on PEM fuel cells for transportation, the performance of the technology would be set back approximately 10 years, significantly delaying the introduction of the technology into early market areas such as portable and stationary power and subsequently delaying the emergence in the automotive application.

As fuel cells in vehicles etc. are not yet commercialised, there are no realised benefits yet. Also, because fuel cell systems are still undergoing intensive R&D, the technology is not yet available commercially. Therefore, there are no option benefits at this stage. This is the current development stage, despite the fact that fuel cell-powered buses are demonstrated, there are (experimental) fuel cell cars, and stationary sources are tested. The benefits are classified as knowledge benefits.

In a similar way, the National Research Council evaluated the R&D efforts for stationary fuel cells. The Office of Fossil Energy spent $1167 mln on stationary fuel cell activities from Fiscal Year (FY) 1978 through FY 2000. The Office of Energy Efficiency and Renewable Energy has spent $22 mln to support PEM stationary fuel cell R&D since FY 2000. The total funding for PAFC, MCFC, and SOFC stationary fuel cells has been as follows (Table 3.5).

Table 3.5 *US federal funding for stationary fuel cells R&D Fiscal Year 1978 through 2000*

	R&D budget [mln $$_{1999}$]	R&D stage
PAFC	410.8	Applied R&D
MCFC	406.9	Applied R&D
SOFC	198.0	Applied R&D
Fuel cell systems	114.2	Applied R&D
Multi-layer ceramic technology	3.7	Applied R&D
Advanced research	33.7	Basic and applied R&D
Total	1,167.2	

Source: NRC, 2001.

The R&D effort on low-temperature (~200°C) PAFC fuel cells was terminated in 2000. PAFC fuel cells, while possessing attractive operational characteristics, have never been developed to a commercial scale. With regard to MCFC and SOFC, support is continuing and DoE is claiming the possibility of commercial entry in niche markets. It is questioned whether the goals with regard to MCFC and SOFC commercialisation can be achieved on DoE's stated timeline. Institutions and companies engaged in hydrogen and fuel cell R&D are, e.g., GE Energy (SOFC), car manufacturers, and Air Products.

Since the early 1980s, federal expenditures on energy R&D dropped from $6 billion in 1980 to $1.5 billion in 2001 (in constant $\$_{1996}$). This trend may be changing particularly in the area of fuel cells, which President Bush has specifically targeted for a $1.7 billion increase in research funds for the next five years (Nail et al., 2005). In 2005, the federal budget for hydrogen and fuel cell R&D was approximately $225 mln (€181 mln). In July 2005, the US Congress passed a five-year Energy Policy bill, laying out the government's energy programs, funding priorities and tax policies for fiscal years 2006 through 2010. For projects and activities relating to hydrogen production, storage, distribution and dispensing, transport, education and coordination, and technology transfer, the energy bill provides a total of $1.06 billion for five years, and for fuel cell technology projects and activities $860 mln.

3.2.3 Summary of R&D budgets

Table 3.6 summarises R&D budgets of the countries. Total public expenditures on H_2 and fuel cells amount to approximately $1,060 mln (€850 mln) per year, 29% of which by Japan, 32% by the EU countries and EC, and 23% by the USA (Appendix C shows € instead of $). Table 3.6 makes a distinction (as far as possible) between hydrogen, and mobile and stationary fuel cells.

Table 3.6 *H_2 and fuel cell R&D budgets of IEA and EU countries (average for 2003-2005)*

	PEM	MCFC	SOFC	H_2 & fuel cells	Fuel cells	Mobile fuel cells	Stationary fuel cells	Notes
Currency: US$[a]	[mln $]	[mln $]	[mln $]	[mln $]	[mln $]	[mln $]	[mln $]	
Australia	×		×					Not available
Austria[a]	×		×	~9.3	~6.2	~3.1	~3.1	Mobile and stat.
Belgium[b]	×		×	~9.5	~5.2	~2.6	~2.6	H_2 & fuel cells
Canada[b]	×			~28.6	~19.9	~10.0	~10.0	H_2 & fuel cells
China	~5.7			~22.5	~5.7	~5.7		H_2 & fuel cells
Cyprus								
Czech Republic								
Denmark	~5.6		~8.7	~14.3	~14.3	~5.6	~8.7	Mobile and stat.
Estonia								
Finland[b]	(×)		×	~6.7	~5.0	~2.5	~2.5	H_2 & stationary
France[b]	×		×	~24.9	~17.4	~8.7	~8.7	Mobile and stat.
Germany[c]	×	×	×	~70.9	~64.7	~39.8	~24.9	
Greece[b]	×		×	~6.2	~4.2	~1.7	~2.5	Focus on stat.
Hungary								
Ireland								
Italy[b]	×	×	×	~37.3	~16.2	~8.1	~8.1	Mobile and stat.
Japan[d]	×	×	×	~311.0	~248.8	~172.9	~75.9	Mainly PEM
Korea[b]	×	×	×	~87.1	~74.6	~37.3	~37.3	Mobile and stat.
Latvia								
Lithuania								
Luxembourg								
Malta								
Netherlands[b]	×		×	~12.4	~8.7	~4.4	~4.4	H_2 & fuel cells
New Zealand				~1.3				H_2 from coal
Norway	×		×	~12.7	~0.6	~0.2	~0.4	Focus on H_2
Poland								
Portugal	×	×						Limited budget
Slovakia								
Slovenia								
Spain[b]	×	×		~12.4	~10.0	~5.0	~5.0	Focus on FCs
Sweden[e]	×	×	×	~6.8	~4.5	~2.2	~2.2	H_2 & fuel cells
Switzerland[f]	×		×	~10.6	~7.0	~3.5	~3.5	H_2 & fuel cells
Turkey	~1.2	~0.9		~2.5	~2.2	~1.2	~0.9	Limited budget
UK[b]	×		×	~31.1	~17.4	~8.7	~8.7	Mobile and stat.
EC	×	×	×	~93.3	~31.0	~15.5	~15.5	Average of FP6
USA	×	×	×	~248.8	~150.5	~104.5	~46.0	Rising budget for PEM FCs
Total (rounded)				~1,060	~714	~443	~271	

a The € is assumed equivalent to 1.2441 US$ (2005).
b The budget is assumed to be evenly distributed between mobile and stationary (and hydrogen if applicable).
c Germany's €57 mln is based on (IEA, 2004a, 2004b) and the ratio H_2 : fuel cells is based on (ESTO, 2005).
d The proportion between mobile and stationary fuel cell R&D is based on data for PEM, MCFC and SOFC fuel cell R&D expenditures for 2002 from (ESTO, 2005).
e Budget Sweden of an estimated €5.5 mln is based on €4 mln in (IEA, 2004a) and €7 mln in (ESTO, 2005).
f Budget Switzerland of approx. €8.5 mln is based on €4 mln in (IEA, 2004a) and €13 mln in (ESTO, 2005).

Based on this Table, a top-seven of countries with the highest R&D expenditures is drawn up:
1. Japan
2. USA
3. Germany
4. Italy
5. UK
6. Canada
7. France

Considering the larger population of the EU-25, (BTI, 2003) concludes: 'While Western Europe makes significant R&D expenditures, its major countries trail the USA and Japan (in R&D budgets)'.

3.2.4 Budgets as a function of time and split between mobile and stationary

Governmental R&D programs rarely specify a specific end-use for their fuel cell R&D, e.g. mobile or stationary applications (DoC, 2003). In this Paragraph, data are presented that shed more light on R&D budgets as a function of time and the split between mobile and stationary.

Table 3.7 shows the expenses on hydrogen and fuel cell R&D for the USA, Japan, and Korea that have readily available data on government funding. Together, these countries account for approximately two-thirds of the R&D funding. Table 3.7 indicates that the growth of R&D funding in the three countries is approximately 13% for the period 1996-2005. The lowest growth (~9%) occurred in the USA (1996-2006), and the highest in Japan and Korea (15-18%).

Table 3.7 *Government funding for hydrogen and fuel cell R&D in Japan, Korea, and the USA*

	1996 [mln $]	1997 [mln $]	1998 [mln $]	1999 [mln $]	2000 [mln $]	2001 [mln $]	2002 [mln $]	2003 [mln $]	2004 [mln $]	2005 [mln $]	Growth [%/a]
Japan	69.9	65.1	58.0	43.8	95.9	135.0	258.2	228.0	237.0	250.0	15[a]
Korea	2.3	3.6	3.8	4.0	3.1	5.6	5.0			83.7[b]	18[b]
USA	114.0	101.0	98.0	115.0	115.0	145.0	159.0	157.4	155.8	224.7	9[c]
Total	186.2	169.8	159.9	162.8	214.0	285.6	422.1			558.0	13[c]

a Data 1995-2005.
b Data 1990-2002; the estimate of $83.7 mln in 2005 for Korea is based on $586 mln for the period 2004-2011; according to (Jollie et al., 2006), the figure would be around $115 mln.
c Data 1996-2005.
Sources: DoC, 2003; OECD, 2003; BTI, 2003; DoE, 2005.

The US federal expenditures on hydrogen and fuel cell R&D give a detailed view of the proportion between mobile and stationary R&D (Figure 3.5).

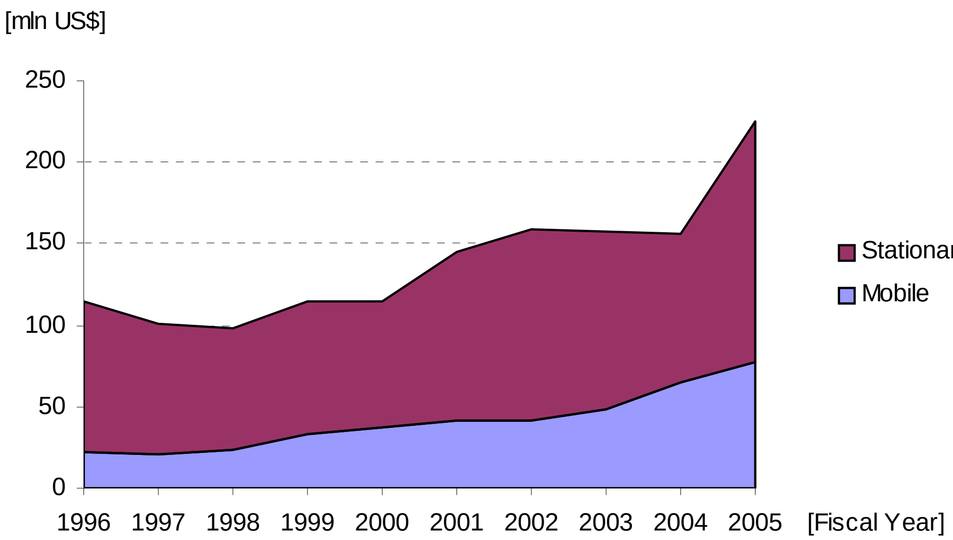

Figure 3.5 *Stationary and mobile H_2 and fuel cell R&D based on U.S. governmental funding*
Note: Based on data from Table 3.4 and Table 3.7 (total R&D budget in 2003 based on interpolation).
Sources: NRC, 2001; BTI, 2003; DoE, 2005.

The data used are based on Table 3.7 (USA), completed for recent years with data from Table 3.4 (rightmost column). Only the total R&D budget for 2003 has been estimated by interpolation. This Figure shows that the budget for PEM fuel cells (mobile applications) increases steadily, whereas the budget for stationary applications remains more or less constant. In the next few years this trend may be expected to continue, as it is advised to discontinue PEM stationary R&D and to reallocate R&D budgets to R&D on Fuel Cell Vehicles (based on PEM FCs).

3.3 Preliminary conclusions

Investment in Hydrogen and Fuel Cell R&D is broadly compatible with the EU's ambition to be a major global player. Although EU countries in total per capita do not seem to support R&D on hydrogen and fuel cells as vigorously as the United States and Japan, this is not necessarily an indication of lesser political will. In particular the next phase - the demonstration phase - is even more costly, and here the aggressive proposals for a Joint Technology Initiative (JTI), which could spend more on demonstration, is ahead of proposals elsewhere in the world.

It appears that R&D in the fields of Hydrogen and Fuel Cells is well supported compared to other "new energy" technologies, indicating strong political will to succeed. Public R&D programmes for hydrogen and fuel cells tend to be linked to the envisioned position of fuel cells in transportation and - to a lesser extent - in stationary power generation. Several countries have adopted road maps for hydrogen and fuel cells, further indicating cohesive political support.

4. R&D related to biomass

4.1 Introduction

One of the R&D subjects to which hydrogen and fuel cell R&D is compared is biomass. Paragraph 4.2 gives a summary of the extent to which IEA and EU countries prioritise biomass R&D. Paragraph 4.3 gives more details about the relationship between biomass R&D on the one hand and H_2 and fuel cell R&D on the other hand. Paragraph 4.4 presents preliminary conclusions regarding political willingness with respect to biomass R&D.

4.2 Priority for biomass R&D in IEA and EU countries

The priority for biomass R&D in IEA and EU countries is qualified by comparing expenditures for R&D in 1994 and 2004. Table 4.1, based on (IEA, 2005a) and earlier editions, shows that:

- In 1994, public R&D expenditures related to biomass were approximately US$131 mln.
- In 2004, these expenditures were (at least) $243 mln (some data for 2004 are lacking).
- Therefore, public R&D expenditures increased by (at least) 85% in ten years.

In order to analyse the development of public (OECD) R&D expenditures in the timeframe considered, a ranking was made for 1994 and 2003-2004. The ranking for 1994 is as follows:

1. USA
2. Sweden
3. Denmark
4. Germany
5. Switzerland
6. Italy
7. UK/Canada

And the ranking for 2003-2004 is:

1. USA
2. Japan
3. The Netherlands
4. Sweden
5. Canada
6. Germany
7. Finland

These rankings should be regarded with care because of lack of data for specific years. For instance, Finland's R&D expenditures of 1994 are lacking, unlike those of 1993 and 1995. Thus, the figure for 1994 may be estimated. Also, R&D expenditures of Austria and Finland in 2004 are not yet available, unlike those of 2003. Furthermore, public R&D expenditures of the UK in 1994 were slightly higher than those of Canada, but Canada ranks higher with regard to the cumulative budget 1993-1995 (and 1993-2004). Therefore, Canada is retained in the top of 1994.

There are three countries in the top 7 ranking of both the years 1994 and 2003-2004, viz.:

- USA
- Sweden
- Germany

Table 4.1 *Public R&D budgets of IEA and EU countries related to biomass*

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993-2004
Australia	[mln $]					2.06						0.00	N/A	2.06
Austria	[mln $]	3.78	3.49	5.89	6.11	4.63	4.89	6.24			6.76	6.70	N/A	48.49
Belgium	[mln $]		1.63	2.43		0.75	0.54	0.05						5.40
Canada	[mln $]	5.27	5.72	5.70	5.65	3.59	4.03	4.15	4.38	5.97	7.84	16.38	14.28	82.96
Cyprus	[mln $]													
Czech Republic	[mln $]													
Denmark	[mln $]	8.02	9.45	7.46	6.73	5.77	5.25	4.39	3.87	5.06	0.81	1.60	4.34	62.75
Estonia	[mln $]													
Finland	[mln $]	7.43	N/A	5.69		10.15	6.32	3.28	7.14	6.45	8.87	8.27	N/A	63.60
France	[mln $]	2.47	1.55	2.03	2.35	0.90	1.67	3.68	0.00	2.30	3.90			20.85
Germany	[mln $]	6.65	7.58	2.02	3.32	2.13	6.62	5.45	6.01	3.83	12.20	9.39	6.34	71.54
Greece	[mln $]	0.32		1.05	0.92	0.59								2.88
Hungary	[mln $]			0.23	0.02					0.68	1.14	1.60	2.52	6.19
Ireland	[mln $]										0.11	0.40	1.41	1.92
Italy	[mln $]		6.57	10.71	10.89	7.80	8.55	0.00	2.01	2.12	2.68	2.93	3.11	57.37
Japan	[mln $]	0.24	5.62	5.33	5.45	4.51	5.06	4.93		15.79		32.81	66.51	146.25
Korea	[mln $]										1.83	2.30	N/A	4.13
Latvia	[mln $]													
Lithuania	[mln $]													
Luxembourg	[mln $]													
Malta	[mln $]													
Netherlands	[mln $]	1.40	1.84	7.11	7.00	5.29	3.80	10.42	13.51	13.40	13.50	29.55	19.88	126.70
New Zealand	[mln $]			0.07	0.21	0.05	0.15	0.20	0.24	0.43	0.33	0.36	0.05	2.09
Norway	[mln $]	1.86	2.11	0.88	0.81	0.92	0.83	0.87	0.87	0.89	0.67	0.56	0.88	12.15
Poland	[mln $]													0.00
Portugal	[mln $]	0.42	0.43	0.06	0.03	0.08	0.07	0.10	0.16	0.09	0.14	0.18	0.00	1.76
Slovakia	[mln $]													
Slovenia	[mln $]													
Spain	[mln $]	8.22	3.92	3.20	3.19	3.35	5.70	1.80	3.40	4.14	3.67	5.24	7.83	53.66
Sweden	[mln $]	6.87	11.48	11.16	5.32	5.37	6.89	6.67		17.40	16.80	14.58	17.52	120.06
Switzerland	[mln $]	5.42	6.88	8.11		6.46		4.34	4.81	4.45	5.26	5.82	6.03	57.58
Turkey	[mln $]	0.00	0.00	0.00	0.00	0.03	0.01	0.26	0.31	0.06	0.08	0.16	0.28	1.19
United Kingdom	[mln $]	4.35	5.76	5.73	5.32	2.37	1.98	3.24	2.51	2.78	2.53	5.61	5.49	47.67
USA	[mln $]	6.50	56.73	60.76	53.20	54.86	98.32	101.33	70.94	87.21	89.12	87.05	86.47	852.49
Total	[mln $]	69.22	130.76	145.62	116.52	121.66	160.68	161.40	120.16	173.05	178.24	231.49	242.94	1,851.74

Source: IEA, 2005a (and similar IEA publications of years before 2004).

These countries are considered as willing to spend a considerable amount of public money on biomass R&D in order to enhance the share of biomass in their energy use. As a matter of fact, Canada, Finland, Sweden, and -to a lesser extent- the USA are countries with a significant share of biomass. Germany is not so familiar from its use of biomass compared to, e.g., Austria, but its aim is to increase the use of biomass and the country does so in a convincing way.

With regard to other countries that ranked high in either 1994 or 2003-2004, observations are that:

- Denmark is well known from its ambitious renewables policy, including biomass. If one takes the cumulative expenditures of the IEA countries as a yardstick, Denmark may be listed at the 8th place. This is indeed a high ranking given its small population size.
- Japan started to become an important player in the field of biomass some five years ago, and its R&D budget has increased since then. Therefore, also Japan may be considered to be willing to increase its biomass use by giving more and more attention to biomass R&D.
- Switzerland has invested significantly in biomass R&D in 1994 and beyond. Their R&D expenditures are of the same order of magnitude as those of their neighbour country Austria. This country has a highly developed biomass R&D infrastructure.
- The Netherlands started to pay much attention to biomass R&D from 1995. Their cumulative R&D expenditures (1993-2004) are almost equal to those of Sweden and not much below those of Japan. Contrary to the five top 7 countries, the share of biomass in the Netherlands is still relatively modest. However, the government and the power generating industry intend and succeed to increase the share of biomass considerably.

In Europe another important factor is the biofuels directive of the European Commission. This directive (2003/30/EC) obligates countries to blend in 5.75% of biofuels with the transportation fuels by 2010. This could cause government budgets to shift from R&D towards deployment.

4.3 Preliminary conclusions

Public R&D expenditures may be used as a yardstick for the willingness of countries to increase the share of biomass in their energy use. IEA countries that perform high in the top 7 of R&D spending - Canada, Finland, Sweden, the USA, and (to a lesser extent) Germany- are well known from the significant share of biomass in their energy use. Other countries -Denmark, Japan, Switzerland, the UK, and the Netherlands - are also willing to invest in biomass R&D, which is witnessed by their ranking - Denmark, Switzerland - or their (recent) interest in biomass R&D (Japan, the UK, the Netherlands). Yet, there are other countries that are reputed for their ambitious biomass policies, which are not explicitly in this section. Therefore, ranking of R&D expenditures has to be used with care when drawing conclusions with regard to the willingness of countries to increase the share of biomass.

5. R&D related to photovoltaics

5.1 Introduction

Another R&D subject to which hydrogen and fuel cell R&D is compared is photovoltaics (PV). Paragraph 5.2 gives a summary of the extent to which IEA and EU countries prioritise PV R&D (see Table 5.1). Paragraph 5.3 presents preliminary conclusions regarding political willingness with respect to PV R&D.

5.2 Priority for photovoltaics R&D in IEA and EU countries

Just like in case of biomass, the priority that IEA and EU countries give to R&D related to photovoltaics (PV) is qualified by making a top seven ranking for the years 1994 and 2003-2004, based on Table 5.1. The ranking for 1994 is as follows:

1. USA
2. Japan
3. Germany
4. Italy
5. Switzerland
6. The Netherlands
7. Belgium

And the ranking for 2003-2004 is:

1. Japan
2. USA
3. Germany
4. The Netherlands
5. Italy
6. Switzerland
7. Spain/France (depending on the year considered)

Contrary to the observation for biomass R&D, the budget for photovoltaics R&D did not increase substantially in the period 1994-2004, taking into account that data for Australia, Austria, Finland and the USA in 2004 are still lacking. However, the trend is surely increasing. There are six countries in the top seven ranking of both the years 1994 and 2003-2004, viz.:

- USA
- Japan
- Germany
- Italy
- Switzerland
- The Netherlands.

These countries are considered as willing to spend a considerable amount of public money on R&D related to PV, as they assume that PV may become an important energy source. As a matter of fact, the USA, Japan, and Germany - and to a much lesser extent Italy, Switzerland, and the Netherlands - are important PV markets from a global perspective. Also, the USA, Japan and Germany host a number of manufacturers of solar cells and panels. Italy, Switzerland, and the Netherlands rank high in PV R&D and also host producers of solar cells or panels.

Table 5.1 *Public R&D budgets of IEA and EU countries related to photovoltaics*

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993-2004
Australia	[mln $]					1.95						3.614	N/A	5.56
Austria	[mln $]	0.80	1.98	1.33	0.90	0.93	1.95	1.00			1.30	1.695	N/A	11.89
Belgium	[mln $]	2.17	5.46	1.14		1.11	0.24	0.05						10.17
Canada	[mln $]	1.63	1.71	1.72	1.48	0.77	1.29	1.99	1.17	2.84	2.48	4.714	6.20	27.99
Cyprus	[mln $]													
Czech Republic	[mln $]													
Denmark	[mln $]	0.31	0.36	0.92	0.34	0.46	0.76	0.53	1.60	3.47		3.797	1.30	13.85
Estonia	[mln $]													
Finland	[mln $]	0.12		0.20		1.19			0.16	0.15	0.36	0.531	N/A	2.71
France	[mln $]	2.17	2.11	1.89	1.66	0.89	1.42	2.83		7.77	14.56	5.763		41.06
Germany	[mln $]	58.68	47.37	38.96	43.76	28.51	37.16	34.02	33.41	27.01	26.92	33.559	30.31	439.67
Greece	[mln $]	0.95		0.24	0.07	0.36								1.62
Hungary	[mln $]				0.02									0.02
Ireland	[mln $]										0.02	0.05	0.05	0.12
Italy	[mln $]		23.30	24.38	21.04	23.41	19.56		12.26	13.51	11.63	13.13	12.80	175.02
Japan	[mln $]	63.72	77.61	69.48	71.73	60.73	78.09	99.66	116.93	79.20		101.4	182.69	1,001.24
Korea	[mln $]										2.73	3.47	2.79	8.99
Latvia	[mln $]													
Lithuania	[mln $]													
Luxembourg	[mln $]													
Malta	[mln $]													
Netherlands	[mln $]	7.48	9.25	8.01	7.89	16.85	10.43	18.52	21.19	16.92	18.70	17.45	17.39	170.08
New Zealand	[mln $]				0.11	0.28	0.09	0.16		0.09	0.18	1.26	1.21	3.38
Norway	[mln $]	0.14	0.29	0.08	0.14	0.39	0.42	0.55	0.63	0.91	1.50	1.56	1.19	7.80
Poland	[mln $]													0.00
Portugal	[mln $]	0.65	0.17	0.04	0.18	0.04	0.03	0.02	0.00	0.04	0.08	0.01	0.01	1.27
Slovakia	[mln $]													
Slovenia	[mln $]													
Spain	[mln $]	4.15	3.49	2.44	2.43	2.24	1.44	1.48	2.86	2.35	3.20	6.55	7.50	40.13
Sweden	[mln $]	0.44	0.47	0.42	0.67	0.45	0.70	0.63		1.23	1.64	3.08	4.43	14.16
Switzerland	[mln $]	11.51	12.89	9.41		10.77		13.08		10.90	12.77	11.136	12.07	104.54
Turkey	[mln $]	0.31	0.00	0.00	0.02	1.43	0.17	0.01	0.01	0.03	0.34	0.06	0.09	2.47
United Kingdom	[mln $]	0.30	0.91	0.89	0.81	0.88	0.97	2.16	1.92	2.78	3.38	7.48	7.33	29.81
USA	[mln $]	2.60	76.15	89.21	61.27	59.79	67.91	74.99	66.02	75.88	72.72	65.7	N/A	712.24
Total	[mln $]	158.13	263.52	250.76	214.52	213.43	222.63	251.68	258.16	245.08	174.51	286.01	287.36	2,825.79

Source: IEA, 2005a (and similar IEA publications of years before 2004).

With regard to the three other countries that ranked high in either 1994 or 2003-2004, the following may be observed:

- Belgium is still promoting R&D of PV, although not to the same extent as in 1994.
- France ranks 7^{th} with regard to cumulative R&D spending. Therefore, it is a top player.
- Spain is becoming a booming market for PV - just like Germany - thanks to favourable feed-in rates for electricity from PV. Also, its public expenditures for PV R&D are rising and Spain hosts several manufacturers of PV cells or panels.

Countries that are not in the top seven of R&D expenditures may also be important from the perspective of future market growth, e.g., the UK and Canada.

5.3 Preliminary conclusions

Public expenditures for photovoltaics (PV) R&D may be used as a yardstick for the willingness to establish a market for PV. IEA and EU countries performing well with regard to R&D spending - Japan, the USA, Germany, Italy, the Netherlands, and Switzerland - are known for their high quality R&D on PV. Also, Germany and Japan are vigorously developing a domestic as well as an export market for PV. Other countries - France and Spain - became interested in developing their R&D potential and PV market in a later stage. The quantity and quality of R&D is not directly related to the creation of a domestic market. Some countries have difficulty to develop a domestic market because their climate is not so favourable. Most countries that perform high with regard to R&D spending also host manufacturers of PV cells or panels and enable market growth for PV. Still, ranking of countries with regard to R&D expenditures should be used with care when drawing conclusions on the willingness to develop a (domestic) market for PV.

6. R&D related to wind energy

6.1 Introduction

The fourth option for R&D to which fuel cell R&D is compared is wind energy. Paragraph 6.2 gives a summary of the extent to which IEA and EU countries prioritise wind energy R&D (see Table 6.1). Paragraph 6.3 presents preliminary conclusions regarding political willingness with respect to wind energy R&D.

6.2 Priority for R&D on wind energy in IEA and EU countries

Just like in case of biomass and photovoltaics (PV), the priority that IEA and EU countries give to R&D related to wind energy is qualified by making a top seven ranking for the years 1994 and 2003-2004, based on Table 6.1 the ranking for 1994 is as follows:

1. USA
2. Germany
3. Japan
4. The Netherlands
5. Denmark
6. UK
7. Sweden

And the ranking for 2003-2004 is:

1. USA
2. Germany
3. Japan
4. The Netherlands
5. Denmark
6. Spain
7. Sweden/UK

Contrary to the observation for biomass R&D, the budget for R&D for wind energy did not increase substantially in the period 1994-2004, taking into account that data for Australia, Austria, and Finland in 2004 are still lacking. However, there is an increasing trend. There are six countries consistently ranking in the top 7 of both the years 1994 and 2003-2004, viz.:

- USA
- Germany
- Japan
- Netherlands
- Denmark
- Sweden

The UK ranks 6th with regard to cumulative R&D spending, and Spain started around 1998.

These countries are considered as willing to spend considerable amounts of public money on R&D related to wind energy, as they (rightly) assume that wind may become an important energy source. Germany, Spain, the USA, India, Denmark - and, to a lesser extent, the UK and the Netherlands - are important wind energy markets: Figure 6.1, based on (BTM, 2006). Also, the five countries mentioned above host the largest wind turbine manufacturers. Other countries, notably the UK and the Netherlands, have not been evenly successful in developing an indigenous wind turbine industry. While wind development in the UK flourishes as never before, manufacturing of turbines and components continues to decline (Windpower Monthly, 2006).

Table 6.1 *Public R&D budgets of IEA and EU countries related to wind energy*

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993-2004
Australia	[mln $]					0.15						1.75	N/A	0.15
Austria	[mln $]	0.07	0.06	0.59	0.4	0.52	0.61	0.31			0.45	1.07	N/A	3.01
Belgium	[mln $]		1.25	0.18		0.97	0.27	0.05						2.72
Canada	[mln $]	1.63	1.04	1.04	1.12	1.65	0.86	1.55	2.65	1.87	1.67	2.91	2.42	15.08
Cyprus	[mln $]													
Czech Republic	[mln $]											0.40	0.25	0.00
Denmark	[mln $]	6.94	7.08	6.65	6.43	8.80	7.58	6.41	5.89	6.47	10.38	9.11	10.27	72.63
Estonia	[mln $]													
Finland	[mln $]	0.61		0.62		0.73	0.97	0.33	0.33	0.68	1.80	2.71	N/A	6.07
France	[mln $]	0.65	0.51	0.36	0.29	0.29	0.41	2.13		2.40	4.59			11.63
Germany	[mln $]	21.78	27.32	26.17	26.02	23.45	21.78	19.23	13.59	16.86	16.08	15.27	11.68	212.28
Greece	[mln $]	1.05		0.91	1.48	2.70								6.14
Hungary	[mln $]										0.29	0.09	0.09	0.29
Ireland	[mln $]										0.23	0.58	0.99	0.23
Italy	[mln $]		0.97	11.07	11.73	6.32	5.87		0.46	0.48	0.58	0.13	0.12	37.48
Japan	[mln $]	8.79	8.57	5.82	5.58	4.27	4.18	4.91	5.12	7.78		13.72	12.44	55.02
Korea	[mln $]										2.31	3.08	2.33	2.31
Latvia	[mln $]													
Lithuania	[mln $]													
Luxembourg	[mln $]													
Malta	[mln $]													
Netherlands	[mln $]	6.35	7.80	6.38	6.29	7.24	6.47	8.44	5.53	13.40	13.67	12.53	13.04	81.57
New Zealand	[mln $]			0.10	0.17	0.13	0.12	0.09	0.10	0.11	0.14			0.96
Norway	[mln $]	0.61	0.39	0.37	0.43	0.52	0.33	0.45	0.90	0.81	0.73	1.18	1.41	5.54
Poland	[mln $]													
Portugal	[mln $]	0.07	0.01	0.01	0.01		0.01	0.03		0.01	0.25	0.16	0.27	0.56
Slovakia	[mln $]													
Slovenia	[mln $]													
Spain	[mln $]	3.45	1.87	0.99	0.99	1.67	8.62	4.37	2.38	2.07	3.59	4.28	6.87	30.00
Sweden	[mln $]	3.56	4.38	2.16	1.55	1.53	3.92	2.87	N/A	3.62	3.50	3.98	5.05	27.09
Switzerland	[mln $]	0.34	0.43	0.73		1.11		0.62	0.60	0.93	1.50	0.83	1.21	6.26
Turkey	[mln $]	0.14	0.08	0.02	0.02	0.01	0.06	0.12	0.05	0.08	0.03	0.07	0.09	0.61
United Kingdom	[mln $]	12.31	4.39	4.36	5.26	2.03	1.65	1.39	1.33	2.17	3.38	4.49	4.40	38.27
USA	[mln $]	1.10	29.58	48.02	31.42	28.93	32.84	35.08	32.45	39.99	38.84	42.50	41.31	318.25
Total	[mln $]	69.45	95.73	116.55	99.19	93.02	96.55	88.38	71.38	99.73	104.01	120.04	113.04	1,167.07

Source: IEA, 2005a (and similar IEA publications of years before 2004).

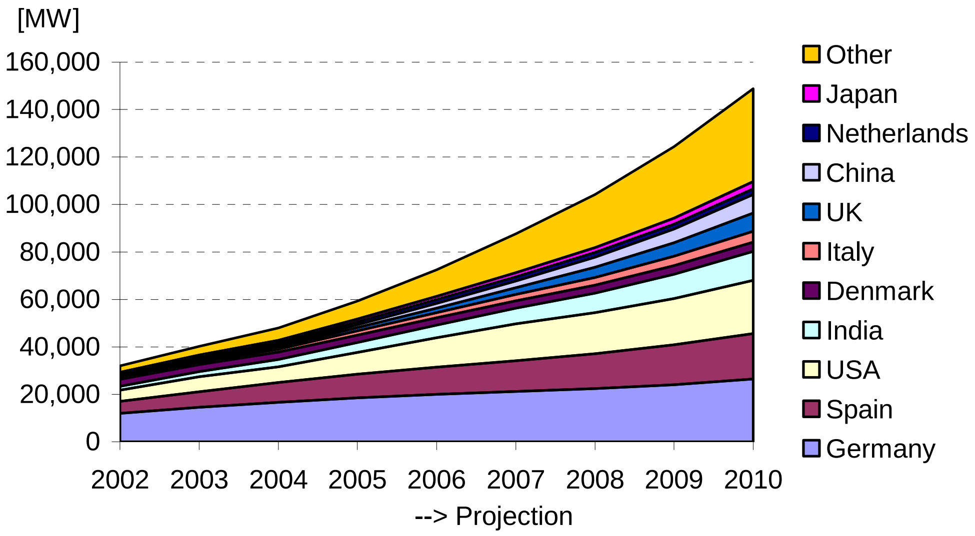

Figure 6.1 *Cumulative wind capacity, realisation 2002-2005 and projection beyond 2005*
Source: BTM, 2006.

6.3 Preliminary conclusions

Public R&D expenditures may be used as a yardstick for the willingness of countries to increase the share of wind energy in their energy use. IEA countries that perform high in the top 7 of R&D spending - the USA, Germany, Japan, Netherlands, Denmark, Sweden, but also the UK and Spain - are well known from their aggressive policies to increase the share of wind energy. The countries with the largest domestic wind capacities - Germany, Spain, the USA, India, and Denmark - also host the largest manufacturers of wind turbines. Other countries, e.g., the UK and the Netherlands, have not been very successful in creating a significant wind turbine manufacturing industry. Therefore, ranking of R&D expenditures has to be used with care when drawing conclusions with regard to the willingness of countries to increase the share of wind energy.

7. R&D related to nuclear energy

7.1 Introduction

Besides biomass and PV, also nuclear energy is compared to hydrogen and fuel cells R&D. Paragraph 7.2 summarises the priority for nuclear R&D. Paragraph 7.3 presents data of the share of nuclear power in electricity generation, and Paragraph 7.4 conclusions on political willingness regarding nuclear power.

7.2 Priority for nuclear R&D in IEA and EU countries

Just like in case of biomass and PV, the priority for nuclear R&D (fission and fusion) is illustrated by ranking IEA countries in 1994 and 2003-2004. Table 7.1 presents data in current US$ (IEA, 2005a). For data in $\$_{2004}$ see Appendix D. Rankings for 1994 and 2003-2004 are quite comparable:

1. Japan
2. France
3. USA
4. Germany
5. Italy
6. Canada
7. UK (1994) and Switzerland (2004)

Except for the UK (1994) and Switzerland (2004), the same countries are in the top lists, signalling their continued priority for nuclear R&D. Contrary to R&D budgets for biomass and PV, Nuclear R&D expenditures declined by 20% from $4.8 billion ($\$_{2004}$) in 1993 to $3.8 billion in 2004 (Figure 7.1, based on Appendix D). Most of the decline is due to budget cuts for breeder and fusion R&D. However, in the last few years a stabilisation may be observed.

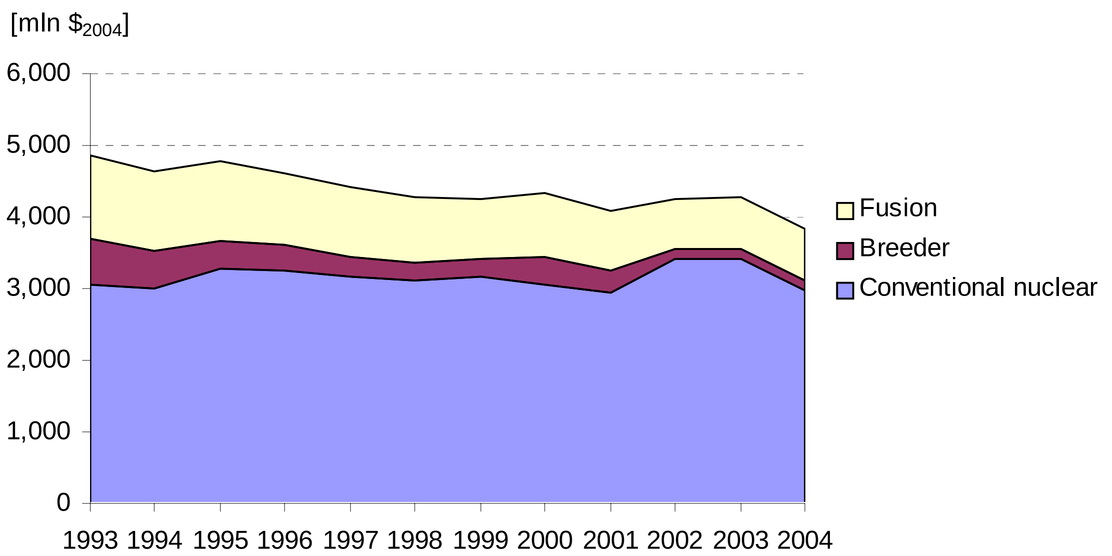

Figure 7.1 *Trend of IEA R&D expenditures on conventional nuclear, breeder, and fusion*
Note: In contrast to Table 7.1 (and similar Tables in this report), data of Figure 7.1 and Figure 7.2 are in constant $\$_{2004}$.
Source: IEA, 2005a.

Table 7.1 *Public R&D budgets of IEA countries related to nuclear energy*

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993-2004
Australia	[mln $]					0.76						1.02		1.8
Austria	[mln $]	2.61	2.19	2.10	1.81	1.89	2.56	2.73			4.00	3.68		23.5
Belgium	[mln $]			32.34		42.16	53.75	38.08						166.3
Canada	[mln $]	121.34	123.68	123.33	121.09	80.63	70.47	54.19	45.96	39.82	46.23	44.05	42.56	922.2
Cyprus	[mln $]													0.0
Czech Republic	[mln $]											3.28	3.72	10.7
Denmark	[mln $]	2.08	0.91	0.62	0.62	0.52	4.78	4.19	4.08	3.51	3.70	3.51	3.19	31.6
Estonia	[mln $]													0.0
Finland	[mln $]	7.83		8.12		8.99	8.55	7.27	6.85	6.64	8.26	5.56		67.3
France	[mln $]	486.55	573.54	604.27	548.87	501.28	523.81	524.45	485.3	352.09	385.86			5,631.0
Germany	[mln $]	240.68	237.15	206.32	184.02	163.65	170.36	164.63	131.43	121.26	133.91	174.59	172.92	2,093.2
Greece	[mln $]	0.02		0.29	0.31	0.23			0.84	0.96	1.28			3.9
Hungary	[mln $]						0.17	0.28			1.10	1.40	1.46	4.4
Ireland	[mln $]													0.0
Italy	[mln $]	131.07	120.84	121.80	125.55	115.26	105.05		97.89	103.24	112.15	115.39	106.21	1,345.7
Japan	[mln $]	3,177.3	3,415.1	3,070.5	3,190.3	2,533.7	2,727.1	2,827.6	2,531.9	2,403.8	2,887.2	2,942.0	2,542.6	32,885.5
Korea	[mln $]										26.28	32.60	33.12	76.1
Latvia	[mln $]													0.0
Lithuania	[mln $]													0.0
Luxembourg	[mln $]													0.0
Malta	[mln $]													0.0
Netherlands	[mln $]	41.45	45.95	45.47	42.47	19.78	19.67	13.05	13.97	21.03	20.93	23.27	22.36	335.2
New Zealand	[mln $]													
Norway	[mln $]	7.61	8.17	8.43	8.05	6.80	7.89	7.65	7.30	7.51	8.72	9.34	10.09	97.5
Poland	[mln $]													0.0
Portugal	[mln $]	1.15	2.45	0.12	0.14	0.07						2.54	2.73	11.3
Slovakia	[mln $]													0.0
Slovenia	[mln $]													363.8
Spain	[mln $]	29.37	38.69	37.62	37.46	32.96	22.23	18.97	22.12	23.79	28.52	32.42	36.80	90.1
Sweden	[mln $]	15.55	17.73	8.68	7.63	5.79	5.63	4.96		4.71	6.26	6.85	6.77	490.9
Switzerland	[mln $]	50.66	58.45	48.93		42.61		27.56	27.08	33.50	37.56	43.69	42.64	7.5
Turkey	[mln $]	1.10	0.97	0.65	0.79	1.26	0.84	0.16	0.09	0.17	0.03	0.34	1.07	418.2
United Kingdom	[mln $]	81.37	40.17	37.20	33.92	30.45	24.76	22.24	25.16	22.63	21.93	30.30	29.41	10,596.2
USA	[mln $]	461.62	441.13	472.34	355.54	278.64	240.53	248.19	279.16	299.04	295.09	378.42	392.55	4,132.7
Total	[mln $]	5,949.90	5,127.07	4,829.12	4,704.32	3,867.43	4,023.21	4,067.67	3,402.72	3,443.78	3,773.01	4,213.15	3,809.09	51,210.5

Source: IEA, 2005a (and similar IEA publications of years before 2004).

The trend of R&D budgets in Figure 7.1 may also be illustrated by the R&D budgets of key IEA countries (Figure 7.2). These countries have large nuclear capacities. Japan accounts for approximately 64% of the cumulative R&D budget of the IEA, France 13%, and the USA 8.5%.

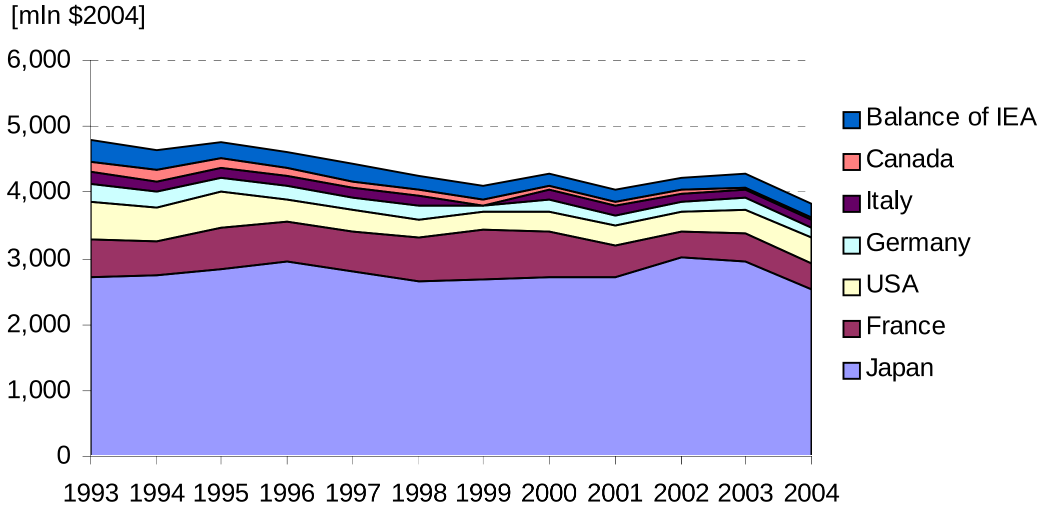

Figure 7.2 *Nuclear R&D budgets in the main IEA countries*
Note: In contrast to Table 7.1 (and similar Tables in this report), data of Figure 7.1 and Figure 7.2 are in constant $\$_{2004}$. Nuclear R&D data for Japan in current and constant $ show significant deviation.
Source: IEA, 2005a.

7.3 Nuclear power's share of electricity generation

Countries with a large stake in nuclear R&D are also often the cradle of nuclear power or have developed into countries that are dependent on nuclear power. Three countries stand out with respect to their nuclear capacities (IAEA, 2006a), viz. the USA, France, and Japan (Table 7.2).

Table 7.2 *Nuclear power generation 2005 (in TWh and as % of total national generation)*

Country	Capacity	Generation		Country	Capacity	Generation	
	[MW]	[TWh]	[% of total]		[MW]	[TWh]	[% of total]
North America				Czech Republic	3,368	23.3	30.5
Canada	12,599	86.8	14.6	Hungary	1,755	13.0	37.2
USA	99,210	780.5	19.3	Lithuania	1,185	10.3	69.6
				Romania	655	5.1	8.6
Latin America				Russian Federation	21,743	137.3	15.8
Argentina	935	6.4	6.9	Slovakia	2,442	16.3	56.1
Brazil	1,901	9.9	2.5	Slovenia	656	5.6	42.4
Mexico	1,310	10.8	5.0	Ukraine	13,107	83.3	48.5
Western Europe				**Africa**			
Belgium	5,801	45.3	55.6	South Africa	1,800	12.2	5.5
Finland	2,676	22.3	32.9				
France	63,363	430.9	78.5	**Middle East and**			
Germany	20,339	154.6	31.0	**South Asia**			
Netherlands	449	3.8	3.9	India	3,040	15.7	2.8
Spain	7,588	54.7	19.6	Pakistan	425	2.4	2.8
Sweden	8,910	69.5	44.9				
Switzerland	3,220	22.1	32.1	**Far East**			
United Kingdom	11,852	75.2	19.9	China	6,572	50.3	2.0
				Japan	45,839	280.7	29.3
Eastern Europe				Korea, Republic of	16,810	139.3	44.7
Armenia	376	2.5	42.7				
Bulgaria	2,722	17.3	44.1	**World**	369,552	2,625.9	15.5

Source: IAEA, 2006a.

Countries like Germany, Canada, and the UK are also characterised by their early adoption of nuclear power or their large nuclear capacity - Germany ranks 5th behind the USA, France, Japan and the Russian Federation. Some of these and other countries are highly dependent on nuclear generation, such as France (78%), Belgium (55%), Sweden (45%), and Switzerland (32%).

A phenomenon that is relevant to nuclear energy R&D is the combined effect of development of an advanced high technology industrial base and environmental protection. In the case of the Republic of Korea, high first-of-a-kind nuclear power costs were accepted as part of a long-term national energy strategy that anticipated (and subsequently realised) both eventual cost reductions from ‘technology learning’ and spin-off economic benefits from developing the country’s high technology sector. A recent study estimated these economic spin-off benefits from nuclear power at about 2% of the country’s GDP (IAEA, 2006b).

7.4 Preliminary conclusions

Countries with a high stake in nuclear R&D are generally important with regard to their nuclear generation. Some countries - the UK, the USA, and to a lesser extent France and Germany - are considered as the cradle of the modern nuclear power plant. Others have developed into countries that have large installed nuclear capacities (Japan, Germany, Canada) or are highly dependent on nuclear power (Switzerland, Sweden, Belgium, and particularly France).

Japan accounts for approximately 64% of the cumulative R&D budget in the IEA, France 13%, and the USA 8.5%. Expenditures for nuclear R&D declined substantially in the period 1993-2004 due to budget cuts for breeder and fusion R&D. However, in the last few years a stabilisation may be observed.

8. Comparison of energy R&D expenditures

8.1 Introduction

In the preceding chapters, R&D expenditures have been presented for hydrogen and fuel cells, biomass, photovoltaics (PV), and nuclear energy. These data may be compared to each other, although this comparison is not easy for the budgets for hydrogen and fuel cells as will be elucidated. Paragraph 8.2 gives a number of key data of energy R&D budgets of the main IEA countries.

8.2 Key data of energy R&D budgets by fuel and region

The R&D budgets for biomass, PV, wind and nuclear power are based on the same literature sources, viz. (IEA, 2005a) and earlier editions. Thus, these budgets may be compared in a straightforward way (Figure 8.1). In a period of about a decade, nuclear R&D expenditures declined by 20% from \$4.8 billion (\$$_{2004}$) in 1993 to \$3.8 billion in 2004 (Appendix D). The estimates of R&D expenditures for H_2 and fuel cells show that they exceed those for biomass, PV, and wind. Although nuclear R&D budgets are still much higher than for H_2 and fuel cells, the former are declining while the latter are increasing. Figure 8.1 shows that R&D on H_2 and fuel cells amounts to approximately \$1 billion in 2004. Earlier data are generally lacking. Therefore, as R&D on H_2 and fuel cells 'took off' around 2000, a 'wedge' stretches from 2000 to 2004.

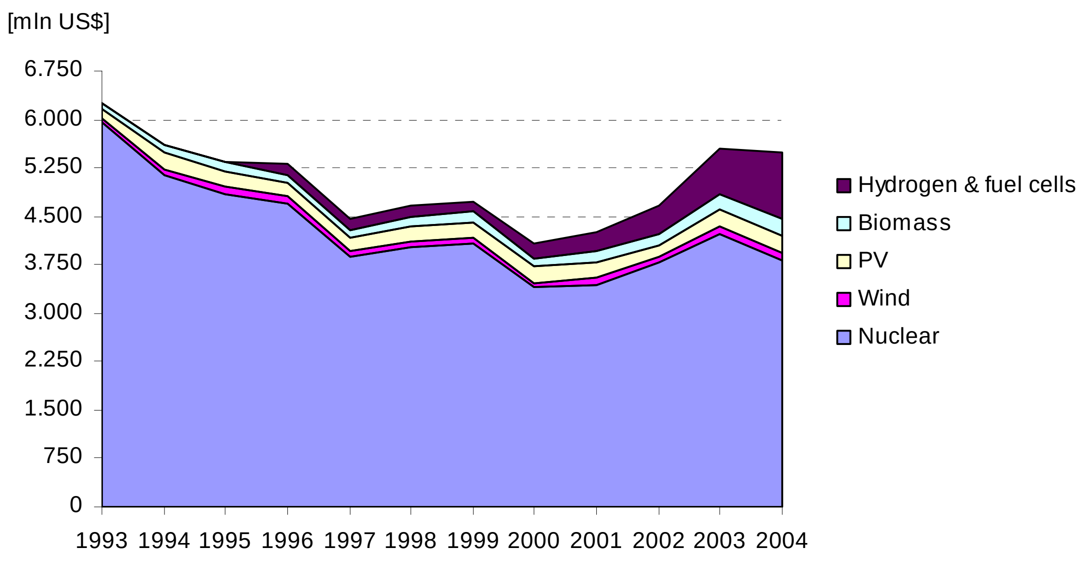

Figure 8.1 *R&D expenditures for nuclear, wind, PV, biomass, and H_2 & FC in the IEA*
Note: The 'wedge' for H_2 & FC is indicative of lack of historical data for this category of R&D.

Another way to compare R&D expenditures is by summarising public R&D expenditures in the USA, Japan, and OECD Europe and relating these expenditures to the Gross Domestic Product (GDP), as elucidated by Table 8.1. The Table shows that public R&D expenditures are, in general, a minor fraction of GDP. The only exception appears to be nuclear R&D in Japan, which accounted for 0.6‰ of its GDP in 2003. This is about seven times higher than the corresponding figure for OECD Europe and four times higher than the average of the IEA countries. It is noteworthy, however, that nuclear R&D in IEA countries is declining, whereas R&D budgets for, e.g., H_2 and fuel cells are increasing. The amount of R&D funding for H_2 and fuel cells is approaching 50 percent of the nuclear R&D funding in EU countries and 25 percent in the OECD.

Table 8.1 *Public R&D expenditures energy sources and technologies and ratio to GDP*

	Public R&D expenditures (absolute)					Public R&D expenditures (relative)				
	H_2 & FC	Biomass	PV	Wind	Nuclear	H_2 & FC	Biomass	PV	Wind	Nuclear
	[mln $] (Average 2003-2005)	[mln $] (2003)	[mln $] (2003)	[mln $] (2003)	[mln $] (2003)	[‰ of GDP]	[‰ of GDP]	[‰ of GDP]	[‰ of GDP]	[‰ of GDP]
OECD Europe	338	86	93	54	762	0.033 [a]	0.008 [a]	0.009 [a]	0.005 [a]	0.075 [a]
Japan	311	33	101	14	2,942	0.060	0.006	0.020	0.003	0.568
USA	249	87	66	42	378	0.022	0.008	0.006	0.004	0.034
Other (OECD)	162	26	26	10	131	-	-	-	-	-
Total	1,060	232	286	120	4,213	0.036 [b]	0.008 [b]	0.010 [b]	0.004 [b]	0.145 [b]

a Public energy R&D expenditures are expressed as a fraction (‰) of GDP of the year 2003 in $US\$_{2004}$; R&D budgets generally refer to EU-25, but GDP to OECD Europe. Thus, the relative values are approximations.

b Total public R&D expenditures refer to IEA countries, except for H2 & FC (including China); expenditures expressed as a fraction (‰) of GDP of 2003 (in $US\$_{2004}$) of the OECD (OECD, 2006; Internet Source 11).

Sources: IEA, 2005a; OECD, 2006; Internet Source 11.

9. Conclusions

One of the aims of this study is to provide insight into the political will to switch to sustainable energy production and use, and especially hydrogen and fuel cells, by reviewing the public R&D support. Another aim is to compare public R&D expenditures for hydrogen and fuel cells to those for biomass, photovoltaic power (PV), wind energy, and nuclear power. This pertains to countries of interest, e.g., EU and IEA countries and the European Union (EC) itself.

The review of public R&D budgets shows that expenditures for hydrogen and fuel cells amount to approximately $1.0 billion (€850 mln) per year, of which Japan accounts for 30%, the combined EU countries and the EC 32%, and the USA 24%. It is noteworthy that this is a crude estimated and an instantaneous exposure. The USA shows a rather steady R&D budget, with a growing share for PEM fuel cells. Expenditures in Japan increase rapidly and focus more on PEM fuel cells for transportation than on stationary fuel cells (MCFC, SOFC).

In one of the referenced publications it is stated: 'While Western Europe makes significant R&D expenditures on hydrogen and fuel cells, its major countries trail the United States and Japan'. This may be a sobering conclusion, but it seems that most countries, also within the EU, are expanding their R&D budgets. Thus, it is too early to present more definite conclusions in this regard. This is due to the methodology chosen. By looking at the R&D budgets the political will in the early stage of technology development is outlined, but the next phase – the demonstration phase – usually is even more costly. Then the political will and thus the demonstration budgets have to get higher.

With respect to R&D on biomass, three countries stand out, viz. the USA, Sweden and Germany. These countries are willing to spend a considerable amount of public money on biomass R&D in order to enhance the share of biomass in their energy use. The total public R&D expenditures of all countries are not as large as for hydrogen and fuel cells ($1.0 billion): in 2003, they amounted to $230 mln. Other countries are also willing to invest in biomass R&D, which is witnessed by their ranking -Denmark, Switzerland- or their recent interest in biomass R&D (Japan, the Netherlands). Keep in mind in Europe the focus may be on the deployment of biofuel because EU countries have to comply with the biofuel directive obligating them to blend in a certain percentage (5.75%) of biofuel with the transportation fuel by 2010.

With respect to R&D expenditures on PV, Japan, the USA, Germany, Italy, the Netherlands, and Switzerland stand out. Germany and Japan are vigorously developing a domestic as well as an export market. Other countries - France and Spain - became interested in developing their R&D potential and PV market in a later stage. The total public R&D expenditures of all countries are not as large as for hydrogen and fuel cells ($1.0 billion): in 2003, they amounted to an estimated $290 mln. The quantity and quality of R&D is not directly related to the creation of a domestic market. Most countries that perform high with regard to R&D spending also host manufacturers of PV cells or panels and enable market growth for PV. Germany and Japan are also vigorously developing a domestic and an export market for PV. Other countries -France and Spain- became interested in developing their R&D potential and PV market in a later stage. Some countries have difficulty to develop a domestic market because their (solar) climate is not so favourable.

IEA countries that perform high in the top of R&D spending on wind energy -the USA, Germany, Japan, Netherlands, Denmark, Sweden, but also the UK and Spain- are well known from their aggressive policies to increase the share of wind energy. The countries with the largest domestic wind capacities -Germany, Spain, the USA, India, and Denmark- also host the largest manufacturers of wind turbines. The total public R&D expenditures are not as large as for hydrogen and fuel cells: in 2003, they amounted to an estimated $120 mln. The countries with the largest domestic wind capacities -Germany, Spain, the USA, India, and Denmark- also host the largest manufacturers of wind turbines. Other countries, e.g., the UK and the Netherlands, have not been very successful in creating a significant wind turbine manufacturing industry.

Nuclear R&D policies are generally intimately linked with the position of nuclear power in the (envisioned) generating mix. Some countries - the UK, the USA, and to a lesser extent France and Germany - are considered as the cradle of the modern nuclear power plant. Others have developed into countries that have large nuclear capacities installed (Japan, Germany, Canada) and/or are highly dependent on nuclear power (Switzerland, Sweden, Belgium and particularly France). In 2003, public R&D expenditures amounted to $4.2 billion ($3.8 billion in 2004). A phenomenon that is relevant to nuclear energy R&D is the combined effect of development of an advanced high technology industrial base and environmental protection. In the case of the Republic of Korea, high first-of-a-kind nuclear power costs were accepted as part of a long-term national energy strategy that anticipated (and subsequently realised) both eventual cost reductions from 'technology learning' and spin-off economic benefits from developing the country's high technology sector.

Based on data gathered for R&D expenditures on hydrogen and fuel cells (average 2003-2005), and on biomass, PV, wind, and nuclear energy (IEA data of 2004 and earlier publications), a top-seven of countries with the largest expenditures has been drawn up for each of the R&D categories (Table 9.1). These rankings should be regarded with care because of lack of data for specific years. However, in each of the R&D they give an expression of the political will of the countries involved to switch to some extent to a specific 'deemed sustainable' energy source.

Table 9.1 *Top-seven countries ranked with regard to R&D expenditures in five categories*

	H_2 & fuel cells	Biomass	Photovoltaics	Wind	Nuclear
1.	Japan	USA	Japan	USA	Japan
2.	USA	Japan	USA	Germany	France
3.	Germany	Netherlands	Germany	Japan	USA
4.	Italy	Sweden	Netherlands	Netherlands	Germany
5.	UK	Canada	Italy	Denmark	Italy
6.	Canada	Germany	Switzerland	Spain	Canada
7.	France	Finland	Spain/France	Sweden/UK	Switzerland

Public R&D expenditures are generally a minor fraction of the GDP. The only exception seems to be nuclear R&D in Japan, which accounts for 0.6‰ of its GDP. This is about seven times higher than the corresponding figure for OECD Europe and four times higher than the average of the IEA countries. It is noteworthy, however, that nuclear R&D in IEA countries is declining, whereas R&D budgets for, e.g., hydrogen and fuel cells are increasing.

Summarising, it is concluded that public R&D programmes for hydrogen and fuel cells tend to be linked to the envisioned position of fuel cells in transportation and -to a lesser extent- in stationary power generation. R&D expenditure for biofuel research remains fairly consistent trough the years, this may be due to the increasing effort which has to be made in Europe to comply with the biofuel directive. R&D policies for PV are already coupled to market stimulation policies, e.g., in Germany and Japan. With regard to wind energy, there appears to be a close relation between R&D budgets on the one hand and market stimulation policy on the other hand, as evidenced by Germany, Spain, and Denmark.

Concluding, Hydrogen and Fuel Cell R&D appears to enjoy strong support within the EU and other global economies, and funding is rising faster than in other new energy technologies. The magnitude of R&D support for hydrogen and fuel cells in some countries (e.g. Japan) may be an expression of determination to force a specific market penetration for fuel cell vehicles. The proposed JTI on Fuel Cells and Hydrogen could place the EU in a strong position regarding Demonstration budgets.

References

Ashworth, J. (2006): *Biomass, Biorefineries, and the Rural Southwest: Innovation for Oklahoma's Future*. National Renewable Energy Laboratory, USA, January 2006. Http://www.greatplainsrcd.org/docs/Ashworth_OK_cellulosic_biomass_Jan_31_2006.pdf?bcsi_scan_5AC5CC8B343D9567=0&bcsi_scan_filename=Ashworth_OK_cellulosic_biomass_Jan_31_2006.pdf.

BTI (2003): *Fuel Cells at the Crossroads*. Breakthrough Technologies Institute, Inc. (BTI), Washington, 2003. Http://www.fuelcells.org/info/charts/economicstudy.pdf.

BTM (2006): *World market update 2005*. BTM Consult ApS, Denmark, March 2006.

CFEVR (2005a): *The Clean Fuels and Electric Vehicles Report* (CFEVR), September 2005, p. 92.

CFEVR (2005b): *The Clean Fuels and Electric Vehicles Report* (CFEVR), March 2005, p. 71.

CFEVR (2005c): *The Clean Fuels and Electric Vehicles Report* (CFEVR), June 2005, p. 30.

Curtis, M.R. (2003): *The Innovation of Energy Technologies and the U.S. National Innovation System - The Case of the Advanced Turbine System*. US Department of Energy (DOE), Office of Policy and International Affairs, Washington, USA, December 2003, p. 13.

DEA (2005): *Hydrogen Technologies - Strategy for Development and Demonstration in Denmark*. Danish Energy Authority, Copenhagen, Denmark, June 2005.

DoC (2003): *Fuel Cell Vehicles: Race to a New Automotive Future*. US Department of Commerce (DoC), Office of Technology Policy, Washington, 2003. Http://www.technology.gov/reports/TechPolicy/CD117a-030129.pdf.

DoC (2005): *Energy Innovation in the United States - Automotive Fuel Cell Applications*. US DoC, Washington, 2005. Http://www.oecd.org/dataoecd/11/48/31968387.pdf

DoE (2003): *Fuel Cell Report to Congress*. US Department of Energy (DoE), Washington, February 2003.

DoE (2004): *Hydrogen Posture Plan: An integrated Research, Development, and Demonstration Plan*. US Department of Energy, Washington, February 2004

DoE (2005): *DOE Hydrogen Program - 2005 Annual Progress Report*. US Department of Energy, Washington, April 2005.

DTI (2005): *A Strategy for developing Carbon Abatement Technologies for Fossil Fuel Use - Carbon Abatement Technologies Programme*. DTI, UK, 2005.

EC (2003): *Hydrogen Energy and Fuel Cells - A vision of our future. Summary report*. High Level Group for Hydrogen and Fuel Cells, European Commission, Brussels, June 2003, p. 6. Http://www.climnet.org/CTAP/h2fc/hlg_summary_vision_report.pdf.

EC (2003): *Directive 2003/30/EC of European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport*, Brussels, May 2003.

EHFC (2005): *Deployment Strategy Progress Report 2005*. European Hydrogen & Fuel Cell (EHFC) Technology Platform, Brussels, October 2005.

ESTO (2005): *Assessing the International Position of EU's Research and Technological Development and Demonstration (RTD&D) on Hydrogen and Fuel Cells*. European

Science and Technology Observatory (ESTO), EC, Brussels, 2005.

Fuel Cell Today (2005a): *Australia and New Zealand – A Survey of Recent Fuel Cell and Hydrogen Development*. Fuel Cell Today, August 2005.

Fuel Cell Today (2005b): *Korean Fuel Cell and Hydrogen R&D Targets and Funding*. Fuel Cell Today, May 2005.

Fuel Cell Today (2005c): *An Overview of the European Fuel Cell Conference*. Fuel Cell Today, December 2005.

Fuel Cell Today (2006): *Fuel Cell Today 2005 Worldwide Survey*. Fuel Cell Today, January 2006.

HY-CO (2006): *Report on analysis of data collected WP2, Deliverable D2.2*. Http://www.hy-co-era.net/datapool/page/18/HY-CO_D2.2_100206_Final_version.pdf

IAEA (2006a): *Energy, electricity and nuclear power estimates for the period up to 2030*. International Atomic Energy Agency (IAEA), Vienna, July 2006.

IAEA (2006b): *Nuclear technology review 2006*. IAEA, Vienna, 2006, pp 43-44.

IEA (2005a): *Energy policies of IEA countries - 2005 review*. IEA, Paris, 2005.

IEA (2005b): *Key world energy statistics 2005*. IEA, Paris, 2005.

IEA (2004a): *Hydrogen & fuel cells - Review of national R&D programs*. IEA, Paris, 2004.

IEA (2004b): *Public Support to Hydrogen and Fuel Cells: An International Perspective.* Presentation of Ms. Haug at the Hydrogen Infrastructure Investment Roundtable III. Chantilly, Virginia, USA, March 17-19, 2004.

IPHE (2005): *IPHE Update*. International Partnership for the Hydrogen Economy (IPHE), Washington, USA. Issue September 2005, p. 2.

IPHE (2004): *IPHE Country Paper - China*. IPHE, Washington, USA, May 18, 2004.

Jollie, D. *et al*. (2006): *Fuel cell and hydrogen activity: Europe and USA*. Fuel Cell Today. FC Expo, Tokyo, Japan, 25th January 2006.

Jörgensen, B.H. (2005): *Key Energy Technologies for Europe*. Risø-R-1533(EN), Denmark, September 2005.

Lasure, L.L., M. Zhang (2003): *Bioconversion and Biorefineries of the Future*. Pacific Northwest National Laboratory and National Renewable Energy Laboratory (NREL). Http://www.pnl.gov/biobased/docs/biorefineries.pdf.

Lehrburger, E. (2005): *Developing Biorefineries to Produce Energy, Ethanol and Other Industrial Products*. Presentation for the Louisiana State University Alternative Energy Conference, Louisiana, USA, March 3, 2005

LEPII (2004): *France - Case Study Fuel Cells*. LEPII/EPE, CNRS, Grenoble, France, March 2004 (Draft version). Http://www.oecd.org/dataoecd/12/45/31964792.pdf.

METI (2006): *New National Energy Strategy (Digest)*. Ministry of Economy, Trade and Industry (METI), Tokyo, Japan, May 2006, p. 19. Http://www.enecho.meti.go.jp/ nglish/newnationalenergystrategy2006.pdf.

Miller, J.F. (2005): *U.S. Hydrogen Fuel Initiative*. Conference Hydrogen Fuel Cells and Alternatives in the Transport Sector: Issues for Developing Countries. Maastricht, Netherlands, November 7-9, 2005. http://www.intech.unu.edu/events/workshops/hfc05/workshop_materials.php.

Milne, T.A., et al (2002): *Hydrogen from Biomass - State of the Art and Research Challenges*. IEA/H2/TR-02/001. NREL, Golden, CO, USA, 2002.

Nail, J.M., et al. (2005): *The Role of the U.S. National Innovation System in the Development of the PEM Stationary Fuel Cell*. National Institute of Standards and Technology (NIST), US Department of Commerce, Washington, February 2005.

NRC (2001): *Energy Research at DOE: was it worth it?* National Research Council (NRC), National Academy Press, Washington, D.C., 2001.

OECD (2003): *Innovation in Fuel cell and Photovoltaic industry in Korea*. OECD, Paris, 2003. Http://www.oecd.org/dataoecd/12/13/31967755.pdf.

OECD (2006): *Main Economic Indicators*. OECD, October 269.

PWC (2002): *Fuel cells: The opportunity for Canada*. PricewaterhouseCoopers, June 2002, p. 68.

REN (2004): *Renewable Energy Newsletter*. EC Community Research, January 2004, p. 6.

Roads2HyCom (2006): *Interim results from the Researchers Questionnaire: Analysis of data collected from the online questionnaire on hydrogen and fuel cell research and technology development*, www.roads2hy.com, R2H1005PU, December 2007

Runci, P., Dooley, J. (2004): *European Union Energy R&D Programs*. Joint Global Change Research Institute, USA, July 2004.

Smith, S.J., et al. (2004): *Near-Term US Biomass Potential: Economics, Land-Use, and Research Opportunities*. Battelle Memorial Institute, Baltimore, USA, January 2004.

Windpower Monthly (2006): Windpower Monthly, October 2006, p. 10.

Internet sources

1. Https://www.hfpeurope.org/uploads/1106/1635/HyFLEET-CUTE_SCHUCKERT_TechDays05_051209_FINAL.pdf.
2. Http://www.industrycanada.ca/cmb/welcomeic.nsf/cdd9dc973c4bf6bc852564ca006418a0/85256a5d006b972085256e4e00720d2e!OpenDocument.
3. Http://www.chinadaily.com.cn/english/doc/2005-08/27/content_472699.htm.
4. Http://www.hydrogen.org/News/arcv400e.html#DaimlerChrysler%20presents%20the%20last%20NECAR%20nov%2000.
5. Http://www.dw-world.de/dw/article/0,2144,1301086,00.html.
6. Http://www.kantei.go.jp/foreign/koizumispeech/2003/01/31sisei_e.html.
7. Http://www.managenergy.net/products/R526.htm.
8. Http://www.whitehouse.gov/news/releases/2003/01/20030128-19.html.
9. Http://www.esv.or.at/esv/fileadmin/opet_res_e/TechPaper3_fuelcells-fin.pdf.
10. Http://www.cordis.europa.eu/fetch?CALLER=MSS_RESU_PL.
11. Http://unstats.un.org/unsd/snaama/downloads/IPD-countries.xls.

Appendix A Acronyms and abbreviations

CAT	Carbon Abatement Technology
CCS	CO_2 Capture and Storage
CHP	Combined Heat and Power
CSIRO	Commonwealth Scientific & Industrial Research Organisation (Australia)
DMFC	Direct Methanol Fuel Cell
DoC	Department of Commerce (USA)
DoE	Department of Energy (USA)
DTI	Department of Trade and Industry (UK)
EC	European Commission
FCV	Fuel Cell Vehicle
FP6	6^{th} (European) Framework Programme
GHG	Greenhouse gas
HFP	(European) Hydrogen and Fuel Cell Technology Platform
HLG	High Level Group for Hydrogen and Fuel Cells (Europe)
MCFC	Molten Carbonate Fuel Cell
METI	Ministry of Economy, Trade and Industry (Japan)
PAFC	Phosphoric Acid Fuel Cell
PEM	Polymer Electrolyte Membrane (Fuel Cell)
PV	Photovoltaics
R&D	Research, Development, and Demonstration
RTD&D	Research and Technological Development and Demonstration
SOFC	Solid Oxide Fuel Cell
TPC	Technology Partnerships Canada

Appendix B R&D field experiment cycle

(DoE, 2003) presents the following R&D field experiment cycle that may apply to R&D on hydrogen and fuel cells (Figure B.1). According to (DoE, 2003), timing is critical. ‘Due diligence’ to evaluate economic and technical barriers would be essential prior to and after each R&D and demonstration phase.

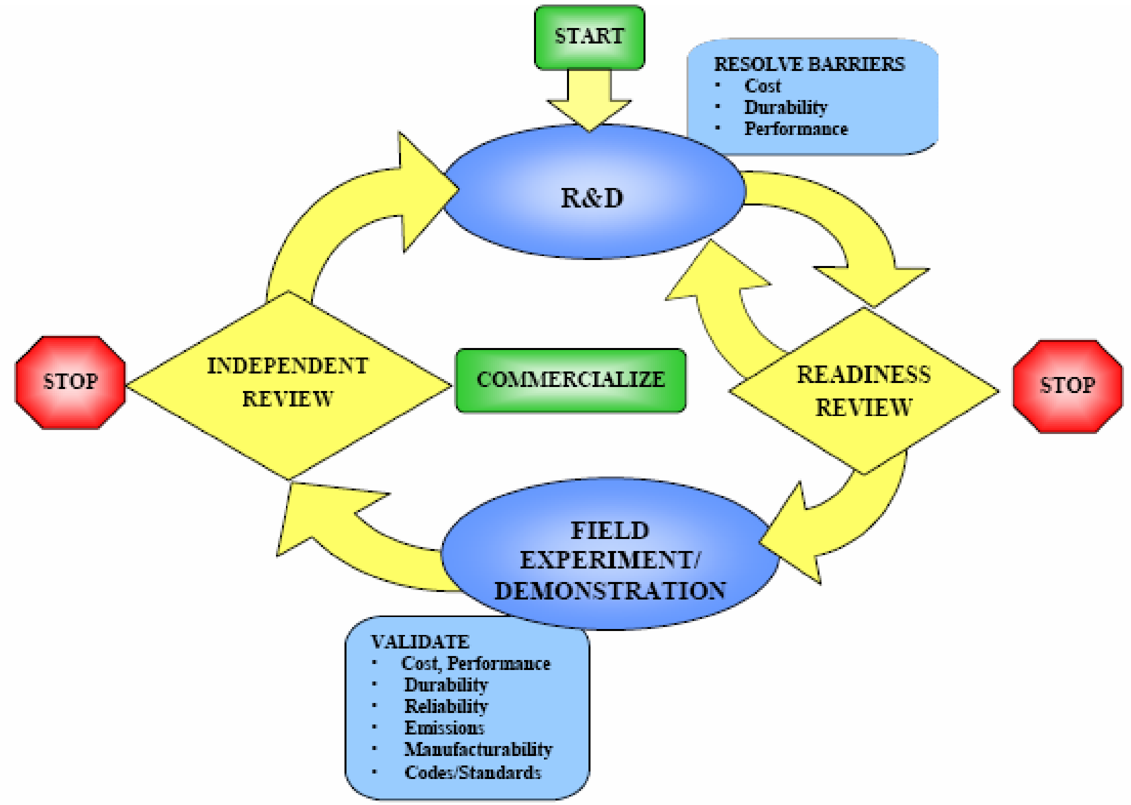

Figure B.1 *R&D field experiment cycle*
Source: DoE, 2003.

Figure B.1 is based on the practice of public/private partnerships in the USA for research, development and demonstration of, e.g., fuel cell vehicles and related hydrogen infrastructure. Continued investments in advanced R&D are needed to support the development and deployment of improvements that address the technical and cost barriers to commercialisation of fuel cells. Advanced R&D should focus on cost reduction and durability improvement for all applications. Hydrogen storage and fuel delivery infrastructure R&D, in particular, would be focused on vehicle applications.

Appendix C R&D budgets hydrogen and fuel cells of IEA countries

Table C.1 gives a summary of hydrogen and fuel cell R&D budgets of IEA and EU countries that is identical to Table 3.6 (Chapter 3), with the exception that budgets are presented in € instead of US$ (footnote Table C.1).

Table C.1 *H_2 and fuel cell R&D budgets of IEA and EU countries (average 2003-2005)*

Country	PEM	MCFC	SOFC	H_2 & fuel cells	Fuel cells	Mobile fuel cells	Stationary fuel cells	Notes
Currency: €[a]	[mln €]	[mln €]	[mln €]	[mln €]	[mln €]	[mln €]	[mln €]	
Australia	×		×					Not available
Austria[b]	×		×	7.5	~5.0	~2.5	~2.5	Mobile and stat.
Belgium[b]	×		×	7.6	4.2	~2.1	~2.1	H_2 & fuel cells
Canada[b]	×			23.0	~16.0	~8.0	~8.0	H_2 & fuel cells
China	~4.6		~4.6	~18.0	~4.6			H_2 & fuel cells
Cyprus								
Czech Republic								
Denmark	~4.5		~7.0	11.5	11.5	~4.5	~7.0	Mobile and stat.
Estonia								
Finland[b]	(×)		×	5.4	4.0	~2.0	~2.0	H_2 & stationary
France[b]	×		×	20.0	~14.0	~7.0	~7.0	Mobile and stat.
Germany[c]	×	×	×	57.0	~52.0	~32.0	~20.0	
Greece[b]	×		×	5.0	~3.4	~1.7	~1.7	Focus on stat.
Hungary								
Ireland								
Italy[b]	×	×	×	30.0	13.0	~6.5	~6.5	Mobile and stat.
Japan[d]	×	×	×	~250.0	~200.0	~139.0	~61.0	Mainly PEM
Korea[b]	×	×	×	~70.0	~60.0	~30.0	~30.0	Mobile and stat.
Latvia								
Lithuania								
Luxembourg								
Malta								
Netherlands[b]	×		×	10.0	~7.0	~3.5	~3.5	H_2 & fuel cells
New Zealand				~1.1				H_2 from coal
Norway	×		×	10.2	0.5	~0.2	~0.3	Focus on H_2
Poland								
Portugal	×	×						Limited budget
Slovakia								
Slovenia								
Spain[b]	×	×		10.0	~8.0	~4.0	~4.0	Focus on FCs
Sweden[e]	×	×	×	5.5	~3.6	~1.8	~1.8	H_2 & fuel cells
Switzerland[f]	×		×	8.5	~5.6	~2.8	~2.8	H_2 & fuel cells
Turkey	1.0	0.7		2.0	1.8	1.0	0.8	Limited budget
UK[b]	×		×	25.0	14.0	~7.0	~7.0	Mobile and stat.
EU	×	×	×	75	~24.9	~12.5	~12.5	Average of FP6
USA	×	×	×	~200.0	121.0	84.0	37.0	Rising budget for PEM FCs
Total (rounded)				~852	~574	~356	~218	

a The € is assumed equivalent to 1.2441 US$ (2005).
b The budget is assumed to be evenly distributed between mobile and stationary (and hydrogen if applicable).
c Germany's €57 mln is based on (IEA, 2004a) and the ratio between H_2 and fuel cells on (ESTO, 2005).
d The proportion between mobile and stationary fuel cell R&D is based on data for PEM, MCFC and SOFC fuel cell R&D expenditures for 2002 from (ESTO, 2005).
e Budget Sweden of an estimated €5.5 mln is based on €4 mln in (IEA, 2004a) and €7 mln in (ESTO, 2005).
f Budget Switzerland of approx. €8.5 mln is based on €4 mln in (IEA, 2004a) and €13 mln in (ESTO, 2005).

Appendix D Nuclear R&D budgets of IEA countries

Table D.1 shows figures of nuclear R&D expenditures of IEA countries in $US\$_{2004}$, based on (IEA, 2005a). These may be compared with figures in current US$ in Table 7.1 (Chapter 7).

Table D.1 *Public R&D budgets of IEA countries related to nuclear energy*

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993-2004
Australia	[mln $_{2004}$]	1.1		7.2		1.0								9.3
Austria	[mln $_{2004}$]	3.0	2.2	2.2	1.9	2.3	3.2	4.0	3.6	4.3	4.4	3.7		34.8
Belgium	[mln $_{2004}$]		34.9	35.1	51.3	52.5	68.8	55.1						297.7
Canada	[mln $_{2004}$]	154.6	154.6	151.3	117.7	105.6	91.5	67.9	60.6	51.0	52.2	44.0	42.5	1,093.5
Cyprus	[mln $_{2004}$]													
Czech Republic	[mln $_{2004}$]											3.3	3.7	7.0
Denmark	[mln $_{2004}$]	2.7	1.0	0.7	0.7	0.6	6.2	6.1	5.9	4.8	4.1	3.5	3.2	39.5
Estonia	[mln $_{2004}$]													
Finland	[mln $_{2004}$]	10.5	9.0	8.8	11.0	10.9	10.6	13.5	9.7	8.8	9.1	5.6		107.5
France	[mln $_{2004}$]	579.1	538.2	638.8	605.5	610.1	659.9	759.5	698.6	482.5	401.7	422.3	372.2	6,768.4
Germany	[mln $_{2004}$]	274.7	232.6	210.4	199.8	192.0	206.2	106.5	189.2	162.7	148.6	174.6	173.0	2,270.3
Greece	[mln $_{2004}$]		0.2	0.3	0.4	0.3								1.2
Hungary	[mln $_{2004}$]						0.3	0.5	1.3	1.3	1.3	1.4	1.5	7.6
Ireland	[mln $_{2004}$]													
Italy	[mln $_{2004}$]	183.6	162.1	148.8	151.6	149.0	139.8		148.5	144.6	126.5	115.4	106.2	1,576.1
Japan	[mln $_{2004}$]	2,722.1	2,731.7	2,833.3	2,963.9	2,802.4	2,665.3	2,675.2	2,705.9	2,704.7	3,005.7	2,942.0	2,542.6	33,294.8
Korea	[mln $_{2004}$]										28.2	32.6	33.1	93.9
Latvia	[mln $_{2004}$]													
Lithuania	[mln $_{2004}$]													
Luxembourg	[mln $_{2004}$]													
Malta	[mln $_{2004}$]													
Netherlands	[mln $_{2004}$]	54.6	69.2	25.8	22.5	26.7	19.8	21.6	31.7	28.8	23.4	23.3	22.3	369.7
New Zealand	[mln $_{2004}$]													
Norway	[mln $_{2004}$]	11.4	10.8	11.0	10.4	10.1	11.4	10.7	9.7	9.4	9.6	9.3	10.1	123.9
Poland	[mln $_{2004}$]													
Portugal	[mln $_{2004}$]	1.8	3.1	0.1	0.2	0.1						2.5	2.7	10.5
Slovakia	[mln $_{2004}$]													
Slovenia	[mln $_{2004}$]													
Spain	[mln $_{2004}$]	42.0	49.4	46.6	46.6	46.1	31.8	30.4	35.3	34.5	32.7	32.4	36.8	464.6
Sweden	[mln $_{2004}$]	19.2	19.4	8.9	7.7	6.8	6.9	6.7	6.6	6.4	6.9	6.8	6.7	109.0
Switzerland	[mln $_{2004}$]	58.8	54.2	51.0	51.2	51.8	45.0	38.8	44.2	42.4	43.8	43.7	42.6	567.5
Turkey	[mln $_{2004}$]	1.6	1.2	0.8	1.0	1.5	1.1	0.2	0.2	0.2		0.3	1.1	9.2
United Kingdom	[mln $_{2004}$]	125.0	59.2	53.8	35.7	39.1	31.6	29.8	34.7	29.2	30.1	30.3	29.4	527.9
USA	[mln $_{2004}$]	553.4	507.9	531.8	320.4	312.9	266.0	268.7	295.4	312.6	301.8	378.4	392.6	4,441.9
Total	[mln $_{2004}$]	4,799.2	4,640.9	4,766.7	4,599.5	4,421.8	4,265.4	4,095.2	4,281.1	4,028.2	4,230.1	4,275.4	3,822.3	52,225.8

Source: IEA, 2005a.