Hydrogen and Fuel Cell Developments in The Netherlands

(2002 - 2003)

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SenterNovem is an agency under the Ministry of Economic Affairs that implements government policy for various ministries, regional governmental bodies and the European Union. The agency specialises in knowledge of innovation, energy, climate, the environment and living conditions. SenterNovem thus contributes towards a stronger position for Dutch industry and a sustainable society that cares for people and the environment.
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Contents

Foreword

SenterNovem has compiled this report at the request of the Ministry of Economic Affairs, as a form of 'hydrogen map' (2002-2003) that includes both national and European hydrogen-based activities. It provides answers to questions such as 'which R&D activities are taking place in which Dutch organisations with respect to hydrogen technologies, and how do these activities relate to those in other countries? The authors have split this question into a number of subsections, and have provided answers based on a large number of data sources, e.g. the SenterNovem project inventory, data from the ACTS Sustainable Hydrogen (NWO, the Netherlands Organisation for Scientific Research), the European Commission's Fifth and Sixth Framework Programmes (FP5 and FP6), and the BSIK (subsidy investment in knowledge infrastructure) programme, as well as the knowledge and experience available within SenterNovem and NWO.

The media regularly publishes articles concerning the opportunities for using hydrogen. Almost all industrialised countries have an active hydrogen policy, including the Ministry of Economic Affairs (EZ) in the Netherlands. This is why the ministry recently requested SenterNovem to conduct an analysis of hydrogen projects, i.e. to provide readers with an overview of hydrogen developments in the Netherlands. This report also makes clear which areas are still unexploited.

Hydrogen as an energy carrier is a 'hot item' in two current policy initiatives by the Ministry of Economic Affairs (EZ): i.e. EOS (energy research strategy) and Energy Transition. The EOS programme emphasises fundamental research, but also includes the application and demonstration of converting hydrocarbons into hydrogen, as well as fuel cell systems such as PEMFC (proton exchange membrane fuel cells) and SOFC (solid oxide fuel cells). Energy transition focuses on a sustainable energy management system through system changes. Five main routes have now been defined. One of these routes (concerning efficient and green gas) concentrates on natural gas and hydrogen. The energy transition programme is supported through subsidies for feasibility and demonstration projects, e.g. OTC (support for transition coalitions) and the UKR (unique opportunities scheme). Both schemes have recently been introduced.

The authors hope that this report meets your expectations, and that it will stimulate the discussion on the future hydrogen policy in the Netherlands. This report was originally written in Dutch. It has been translated and reduced.

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Introduction

There is considerable interest in hydrogen as an energy carrier. This is understandable, as everyone realises that hydrogen can play an important role in a sustainable energy management system. It also offers many commercial opportunities. The interest in hydrogen, by the government, industry and the general public, has increased significantly as a result of the political developments in the Middle East: the small production capacity reserves of crude oil and the uncertainty regarding the size and availability of the extractable oil reserves. During 2002-2003 practically all the major countries (USA, Japan and Canada) plus the European Community have developed active policies regarding hydrogen and fuel cells.

In June 2003 Mr Prodi, former President of the EC, announced the initiative to set up a Technology Platform for hydrogen and fuel cells. Hydrogen is also specifically included in the EU's Sixth Framework Programme (FP6) for which EUR 300 million has been reserved. Europe aims to generate around 22% of the European electricity requirement from renewable sources from 2010 onwards. In the longer term, the EU has set a stepped target for the transition to a hydrogen economy based on renewable energy (around 2050). At national level many Member States have already defined their individual policies. Germany plays the greatest role in Europe.

> *A step-for-step transition to a hydrogen economy based on renewable energy (around 2050).*

The interest in hydrogen is also increasing outside European borders. In his 2003 'State of the Union' speech President Bush presented his plan to invest USD 1.2 billion in research into fuel cells and the use of hydrogen for energy generation and transport purposes. The Americans refer to it as the 'freedom fuel', because it would reduce American dependence on fossil energy from the Middle East and also contribute to the reduction of environmentally damaging emissions. Japan also has hydrogen as a new energy carrier high on its agenda. The government implements an active policy and is well informed of the latest developments (vehicles and consumer appliances). Prime Minister Koizumi stated in 2002 that: 'The fuel cell is the key that will open the door to a hydrogen economy. We plan to be using fuel cells within three years as a power source for vehicles and households.'

In 2002, at the request of the Ministry of Economic Affairs (DG Innovation and DG M&E), Senter conducted an inventory into the Dutch development of hydrogen technology over the period 1997-2001. The knowledge that Senter had built up (through implementing a large number of subsidy schemes and programmes) proved a central factor. These various programmes provided support to companies and organisations with respect to innovation, the environment and energy. In 2003 the ministry requested a follow-up study for the period 2002-2003, plus an overview of the European projects under FP5 (1999-2003). This gave the impression that things within this area of technology have accelerated over the past few years. Questions are regularly received from companies with respect to hydrogen technology. These requests for information concern support, possible partners, technology development and international opportunities.

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In order to compile this overview, the authors have not only taken data from the former Senter organisation, but also those from the former Novem and the ACTS Sustainable Hydrogen Programme initiated by NWO. This report shows the strengths and weaknesses that exist within the Netherlands. The Netherlands has the disadvantage that there is little or no industry to act as organiser or investor for the application of hydrogen technologies for traction applications (e.g. the automotive industry). This overview will allow the Ministry of Economic Affairs to focus on the opportunities that hydrogen can provide for the Netherlands, and the policies necessary to implement this strategy.

The Netherlands has the disadvantage that there is little or no industry to act as organiser or investor for the application of hydrogen technologies for traction applications (e.g. the automotive industry).

This report attempts to provide an up-to-date and complete image of the Dutch activities regarding hydrogen as an energy carrier. Previous research by Senter shows that (groups of) industrial companies are collaborating closely, and that companies are working with knowledge institutes. The latter have a clear specialisation in these subjects and the broad knowledge level within the Netherlands is good. However, the Netherlands has a real disadvantage in that there is little or no industry willing to act as organiser or investor for the application of hydrogen technology for traction applications (e.g. the automotive industry). Interviews with a number of important stakeholders show that they have generally collaborated with foreign companies or knowledge institutes. These stakeholders view the development of hydrogen technology as a global race in which collaboration with foreign parties is extremely important.

Hydrogen technology a global race?

A complete image of this development within the Netherlands can only be given if we take into consideration the role that Dutch stakeholders play in international projects. Following on from the national activities in Part 1, Part 2 outlines these international collaborative projects. For international developments, Dutch participation in the European Framework Programmes and the Eureka network has also been covered in this report. The amount of Dutch participation, compared to that of other countries, indicates the Netherlands' international position. A comparison between the Netherlands and Europe, with respect to technology input and the application orientation of the participation, provides a picture of Dutch expertise, as well as that in other European countries. The assumption is that participation in national and international programmes matches in detail. Part 3 lists the authors' conclusions, and provides a compact image of current trends and future opportunities for everyone involved (either now or in the future) in hydrogen projects.

The central question asked by this report is:

Which R&D activities are taking place in which Dutch organisations with regard to hydrogen technology, and how do these relate to such activities in other countries?

This question has been split into a number of subsections:

- Which Dutch companies and knowledge institutes are actively working on hydrogen technology? Which industrial sectors and categories are involved?
- Which technologies are these stakeholders developing?
- Which applications form the main focus of their R&D efforts?
- How are the projects divided over the innovation chain (from fundamental research to specific applications?
- Which collaborations are currently used to implement the projects?
- Which foreign partners are included in the collaboration efforts?

This report provides answers to these questions.

N.B. In order to avoid misunderstandings, please note the following. In order to indicate the size of the R&D taking place for an area or sub-area of hydrogen technology, this report consistently refers to the total project costs of the relevant hydrogen projects. Therefore the terms R&D size, R&D investments and projectcosts are synonymous. Subsidies or fiscal funding schemes can only finance part of these amounts.

Summary

Hydrogen is seen a main energy carrier of the future: this is increasingly confirmed by the policies of the Ministry of Economic Affairs (EZ). This summary contains the current policy developments and a brief description of the study undertaken with respect to the current hydrogen situation. This means that there is certainly good news, but there are also concerns about the slowness or lack of certain developments.

In the Netherlands, the Ministry of Economic Affairs aims to define an energy policy that contributes to a *sustainable* global energy management system. This means: good security of supply, economically efficient and ecologically maintainable. At the end of 2000 the Directorate-General for Energy (DGE), set up the EOS (energy research strategy) projectgroup in order to develop a strategy for energy research.

The National Environmental Policy Plan (NEPP-4) describes three possible paths that can be taken in order to achieve a sustainable energy management system (energy transition). One of these concerns advanced energy technologies, e.g. using hydrogen as an energy carrier and fossil energy technologies with almost-zero emissions (Clean Fossil).

During the second half of 2002 various stakeholders, together with the Ministry of Economic Affairs, made an extensive inventory of good transition initiative opportunities. The report 'Hydrogen map of the Netherlands: 1997-2001' formed part of this inventory. At this point in time, the first projects to prepare for transition experiments have been started via the OTC (support for transition coalitions).

What are these positive developments?

- *Hydrogen research is increasing*. Since 1997 there has been a clear upward curve in investments (by companies and knowledge institutes) with regard to hydrogen technology. During the period 2002-2003, a total of EUR 68.2 million was invested in such projects, which were also supported by EUR 22.5 million in subsidies. The European Framework Programmes (FP5 and the start of FP6) spent EUR 13.7 and EUR 6.6 million respectively. In total, dutch companies and research institutes have spend EUR 83.5 milion (2002-2003) on hydrogen and fuel cell research. Taking the EU Framework Programmes as a basis, the Netherlands takes fifth place (in absolute terms) within Europe. However, when related to GDP (gross domestic product), the Netherlands is actually in second place. This is certainly partly due to the prominent role played by ECN within Europe.
- *We have our own specialisations*. The Netherlands have certain specialisations that differentiate it from the rest of Europe, e.g. the country focuses primarily on *hydrogen production*: (petro-) chemical industry, and local production for micro-cogeneration. Also with respect to *gas transport and distribution* the Netherlands have gained considerable expertise.
- *Increasing attention to storage*. Two years ago there were very few activities within the Netherlands with regard to hydrogen storage. However, via the ACTS Sustainable Hydrogen (NWO) programme, universities and companies have now initiated a number of research projects to redress this problem area.

However, there are a number of concerns relating to:

1. *The narrowness of the fuel cell base*. There are very few Dutch parties focusing on the *use of fuel cells.* ECN and Nedstack are the only organisations found. This is certainly not due to a lack of expertise, but a production increase is not expected in the near future.
2. *The production industry requires more encouragement.* Other countries have found the automotive industry to be an important stimulation for hydrogen technology developments. The Netherlands has little or no such industry therefore the production sector (that can produce parts for the hydrogen chain) plays too small a role in the development of hydrogen technology. The authors' impression is that the German productionindustry has made far better use of this opportunity.
3. *International collaboration is essential*. The USA, Canada and Japan have invested the most money into hydrogen, but Europe has little connection to this knowledge. The government offers little assistance in bringing knowledge from such countries to the Netherlands.

Research method

This section of the report lists the sources on which the research is based and indicates the criteria that were used, e.g. regarding technology areas and applications.

Research sources
SenterNovem has a complete database of all projects that have been submitted for the various subsidy and fiscal funding schemes. A number of specific keywords were used to retrieve the relevant hydrogen technology projects from the database.

The CORDIS (Community Research and Development Information Service) database consists of European projects to which Dutch stakeholders have participated, and this too was consulted, i.e. projects from 2002 and 2003 that were implemented under the Fifth and Sixth Framework Programmes.

The authors have also considered the initial flow of funds, i.e. research undertaken by the Dutch universities. Sources used include: annual reports from the STW (Technical Science Foundation), the Dutch Research Database, plus our own knowledge of the various Dutch university websites.

Four technology areas
The selected projects have been coded using the project title and summary; this section provides further information on this coding.

The projects are split into four technological areas: hydrogen production, storage, transport/distribution and use. These are essential for a hydrogen economy. They are also further split into a number of specific technologies (not to be confused with technology areas). See the following table.

Table of technology areas for hydrogen projects

Hydrogen production	Storage	Transport and distribution	Use
Fossil source	*Liquid*	*Mixed*	*Fuel cells*
From waste / residual products	*Compressed*	*Separate hydrogen network*	*(Petro-)chemical*
Electrolysis	*Chemical-physical form*	*Small system connectors and pipes*	*Boilers and burners*
Biomass (thermal)		*Networks, large infrastructure, distribution points*	*Combustion engines, turbines*
Microbiological			
Hydrogen purification			

Several projects focused on non-technical subjects in relation to the hydrogen economy. These projects cover all types of questions concerning the transition to a hydrogen economy, e.g. social acceptance, legal aspects, legislation and safety.

Where is hydrogen technology used?
The projects are coded according to the application of the technology, and are differentiated into the following applications of hydrogen technology: mobile, stationary, transport/storage, industrial processes and general applications.

Mobile applications
These include all kinds of transport applications whereby hydrogen forms the primary fuel. Projects cover for example fuel cells (the engine), storage systems for hydrogen (gaseous, liquid), control systems, battery systems, DC/AC adaptors and the entire vehicle concept. The system on board the vehicle depends on the type of fuel cell used and, in the end, on the type of fuel in the tank. If 100%

pure hydrogen is used, this requires a storage system for gaseous or liquid hydrogen. If not, e.g. for (fossil) fuels such as petrol, biodiesel, diesel, LPG, natural gas etc. then an *on-board reformer* is required to produce the hydrogen. For mobile applications there is a further split between the following sub-applications: cars, (motor) bikes, shipping, aviation, portable equipment and space travel.

Stationary applications

Fuel cells can be used for the local production of electricity and heat. Portable cogeneration systems usually consist of a *reformer (*to produce hydrogen) and a fuel cell. Fuel cell systems can be used, depending on the scale size and the temperature levels required. Various scale sizes can be identified: small scale (residences) and large scale (apartment buildings, non-residential buildings). Another application consists of the large-scale generation of electricity and heat. This can involve large industrial processes whereby hydrogen is released as residual product. Large-scale fuel cell systems are suitable for contributing to the reserve within the framework of security of supply (short response time). Another application is the *stand-alone* production of electricity for niche markets (luxury vehicles and yachts) or for locations where there is no electricity network available. Stationary applications also include: small-scale generation of electricity and heat (a building or house), large-scale generation of electricity and heat (industrial), and generation for space travel.

Transport and storage

This application concerns the storage of hydrogen by the end-user, or the transport of hydrogen to the end-user. This type of hydrogen storage clearly has a different scale level. There are many developments concerning small-scale storage systems (both lightweight and new materials) as well as developments whereby existing storage tanks are made suitable for higher pressure and better insulation. Both developments are deployed at a filling station.

Large-scale hydrogen transport occurs using cylinder-tank trucks, but ships may also be used in the future. A large new network would be another possibility, but this would require huge investment, and the existing natural gas network (natural gas mixed with several percent hydrogen) is also being considered. The following network applications are considered: networks and distribution, filling stations, large-scale hydrogen transport, storage, small-scale storage in bottles, *packs*, and drums.

Industrial processes

These are mostly large-scale industrial processes that allow the production of hydrogen. There is a differentiation between the chemical industry and other industry. Hydrogen is used in industry for a variety of applications, e.g. to remove sulphur from crude oil, cracking heavy oil components, hardening fats, hardening steel, as well as in the pharmaceutical sector. Which projects are relevant for a hydrogen economy? Relevant projects are those that study new hydrogen production methods, improving existing production processes or managing hydrogen flows. These are therefore included in the analysis. This means that projects whereby hydrogen is one of the reactors during a chemical process do not fall within the scope of this study. These were generally projects from the pharmaceutical sector or projects aimed at developing a catalyst for the production of chemicals.

General applications

There are certain projects where the results can be used for several applications (mobile and stationary). Some projects are not aimed at a specific application. An example is the development of a specific part of a fuel cell that can be used for both stationary and mobile applications. It is therefore not always possible to differentiate based on application alone. The coding used aims to keep this category as small as possible, by taking into consideration the strategy used by the project participants.

Part1 Analysis of Dutch National Hydrogen Projects

Important stakeholders in the field of hydrogen

This chapter provides an overview of the most important stakeholders in the field of hydrogen technology. Section 1.1 includes a list of the most important companies and knowledge institutes. Section 1.2 lists the most important companies and knowledge institutes that specifically focus their research towards a hydrogen economy. Section 1.3 includes the R&D activities concerning hydrogen technology as conducted by the various Dutch universities.

Top-10 in hydrogen technology

The following list includes the Top-10 companies currently conducting research into hydrogen technology. Shell appears to conduct a lot of R&D, followed by the GVB (local authority transport company in Amsterdam) and the smaller organisations such as Nedstack and Jacobs. Shell focuses on reforming liquid hydrocarbons in hydrogen, for which catalysts, reactors and related technologies are being developed. The GVB conducts practical experiments with fuel cell buses in Amsterdam. Nedstack develops fuel cells, and Jacobs focuses on hydrogen purification (in order to produce clean diesel).

Top-10 Companies (amount of R&D)

Top-10 Companies
Shell Nederland
GVB
Nedstack
Jacobs
Hexion
Ballast Nedam
Teesing
Stork
Plug Power Holland

The following list shows the Top-10 knowledge institutes that are currently conducting research into hydrogen technology. ECN undertakes by far the most R&D, followed by the VU (Free University) in Amsterdam and Twente University. ECN studies and develops fuel cells (SOFC, PEMFC) and equipment for producing green gas (from biomass).

Top-10 Knowledge institutes (amount of R&D)

Top-10 Companies
ECN
VU Amsterdam
Twente University
ATO
TU Eindhoven
RU Groningen (RUG)
RU Leiden
TNO
Wageningen University (WUR)
Utrecht University

R&D activities at Dutch universities

General
Dutch universities primarily conduct fundamental research, e.g. into production, storage and usage. Research into hydrogen transport and distribution is usually not included in university studies.

The number of cross-relationships between and within universities is remarkable. Faculties work together on a whole range of subjects. The commitment shown by companies and knowledge institutes is also considerable, particularly by Shell, Gasunie Research and ECN. The projects analysed also included a limited role by TNO. Apparently TNO doesn't use subsidies to finance their hydrogen related research.

Technological research
Compared to the previous Hydrogen Map, the TU Eindhoven now clearly has a wide range of projects focusing on hydrogen production, storage and use (fuel cells and electricity usage). However, other universities also feature prominently: TU Delft, Twente University, Utrecht University, RU Leiden and the VU Amsterdam, which primarily conduct research into production and storage. In addition, Wageningen University is also working on 'biological' hydrogen projects aimed, for example, at biomass conversion and microbiological shift reactions. RU Groningen plays a relatively small part, and primarily works towards usage, i.e. specifically the combustion behaviour of natural gas to which hydrogen has been added ('green gas').

Details per university

TU Delft
This university is the only one to study (together with the Colorado School of Mines) the storage of hydrogen in gas hydrates for use in motorised vehicles. The university also conducts considerable research into monolithic reactors for all kinds of reactions. The TU studies CPO (catalytic partial oxidation) from methane specifically for hydrogen. It is also worth mentioning the research conducted into photocatalysis and hydrogen production from sunlight through photoelectrolysis. The university is also conducting 'beta-gamma' research into the build-up towards a hydrogen economy.

Wageningen University (WUR)
Hydrogen production from biomass forms the main focus for this university, plus desulphurisation of hydrocarbons (e.g. methane) via biological routes.

Rijksuniversiteit (RU) Leiden
Research is conducted into producing hydrogen by oxidising water and modelling the hydrogen storage process in metal hydrides.

TU Eindhoven
This university has a clear specialisation in electrical driving techniques, including research into power converters and induction engines for PEM fuel cells. A study is also being undertaken into storage in metal hydride systems, plus the possibility to operate SOFC fuel cells at low temperatures. Ongoing research is also looking at reforming fuels such as methane and methanol. Finally, researchers are studying the social acceptance of hydrogen as an energy carrier.

Utrecht University
Utrecht does a lot of research into hydrogen storage for vehicles based on metal hydrides on carriers made of plastic nanofibres. The university also studies ceramic membranes for separating hydrogen in a catalytic membrane reactor. There are also a number of ongoing studies into producing hydrogen from biomass (super-critical water environments and ‘steam-iron’ process).

Vrije Universiteit (VU) Amsterdam
Research projects include storage (metal-hydride films), hydrogen sensors and (‘beta-gamma’) research into strategies for implementing the transition to a (sustainable) hydrogen economy.

Rijksuniversiteit (RU) Groningen
The RU focuses on the influence of mixing hydrogen on the combustion behaviour of natural gas. A research project also looks at the consequences of a hydrogen economy for the energy supply at suburb and district levels.

Twente University /MESA+ Institute
Twente studies hydrogen production from biomass, catalytic membrane reactors with ceramic membranes for application in fuel cells, and modelling of lightweight metal hydrides at microscopic level.

Spin-off research
Although in some projects the research is not directly related to the hydrogen economy, there are sometimes useful spin-offs. For example, the TU Eindhoven research into dehydrogenating reactions of alkanes, which aims to increase the efficiency of hydrogen. This research focuses on dehydrogenating, rather than hydrogen production. However, it can produce a spin-off for the hydrogen economy. Wageningen also studies biological desulphurisation cycles for desulphurising gas, for example. The results of this research can be used in hydrogen production systems, e.g. from biomass. Leiden University has considerable knowledge of catalytic processes. Researchers visualise this via scanning tunnelling microscopy. This technique can be useful in researching catalytic behaviour in a reformer or when studying degradation processes of membrane plates in a fuel cell.

Dutch national hydrogen projects

This chapter analyses the content of the nationally supported projects. Most R&D concerns industrial research. There is also quite a lot of fundamental research taking place. This is not so surprising, since hydrogen technology is currently still in the development phase, rather than an application phase.

Innovation path

The hydrogen projects can be split according to their place along the innovation path. Figure 2.1 shows how the total R&D into hydrogen technology is spread over the innovation path. Most R&D concerns industrial research. Around 25% of this is fundamental research. There was only one demonstration project, and that was a trial project with three hydrogen buses in Amsterdam, the so-called CUTE project (Clean Urban Transport for Europe).

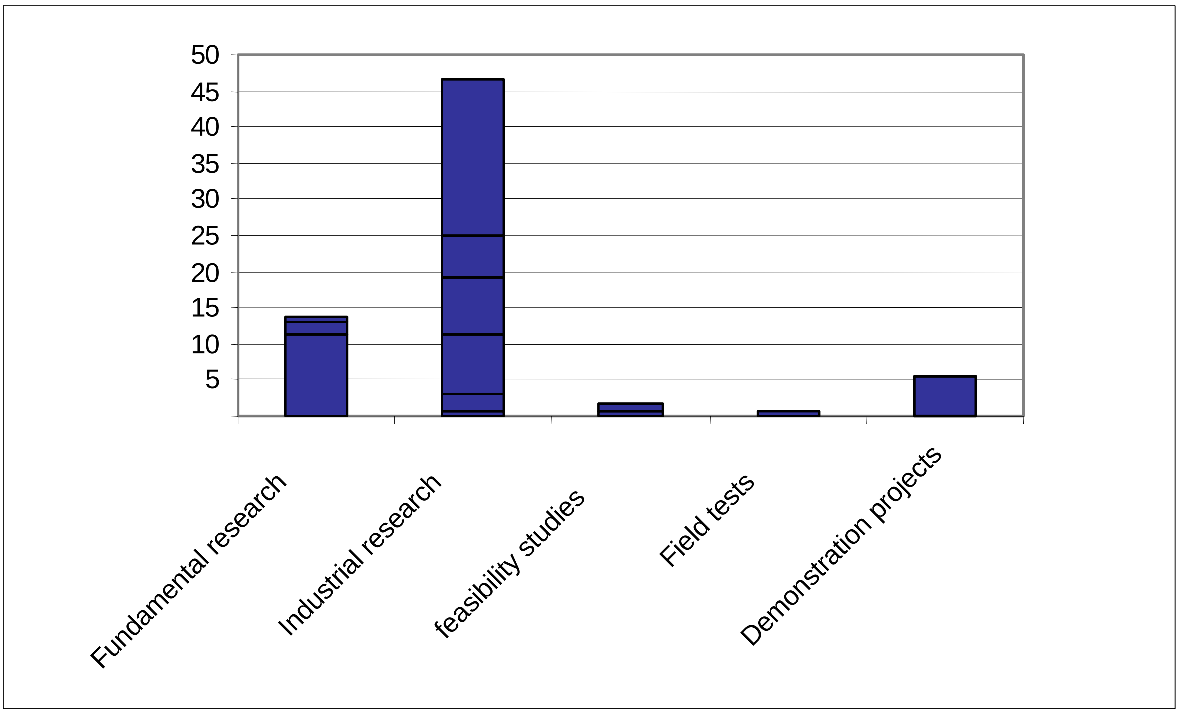


Figure 2.1 Project costs for hydrogen projects over the entire innovation path (mln. EUR)

R&D per sector and category size

The project costs that Dutch stakeholders incur regarding hydrogen research are split according to the relevant industrial sectors. Table 2.1 shows the Top-10 sectors.

Most project costs are incurred in the research sector, i.e. primarily universities and knowledge institutes. The other three large sectors are the gas extraction sector, the machinery and equipment industry, and engineering consultancies.

Table 2.1 Top-10 Total project costs per sector (based on SBI categories)

Sector	Total project costs (EUR mln.)
Research	28.5
Natural gas and oil extraction	10.1
Machinery and equipment industry	9.8
Engineering consultancies	9.0
Land-based transport	5.4
Medical and optical equipment industry	1.1
Energy supply companies	0.9
Other electrical equipment industry	0.6
Chemical industry	0.6
Oil and coal industry	0.5

Table 2.2 shows these project costs split according to the category size of the organisations that are implementing these projects.

Table 2.2 Total project costs per category size

Category size of the organisations	Total project costs (EUR mln.)
1000+	19.0
500-999	15.5
250-499	9.8
100-249	4.5
50-99	4.1
10-49	11.9
0-9	3.3
Final total	*68.2*

This table also shows that there is relatively little R&D conducted by companies with 0-9 and 50-249 employees. However, the categories with 10-49 employees and over 250 staff conduct a relatively large amount of R&D.

Hydrogen technologies

The following technology areas have been analysed: hydrogen production, usage, storage, transport and distribution, plus studies into the hydrogen economy. This last category forms a group that includes projects researching a hydrogen economy as a system, or parts thereof. The emphasis is then generally on non-technological aspects.

Figures 2.2 and 2.3 show the amount of R&D per technology area, which confirm that most R&D focuses on hydrogen production technologies (around EUR 35 million in 2002-2003). With regard to the development of usage technologies (mostly fuel cells), around half of this has been invested. There is far less invested in developing technologies for storage and transport/distribution (approximately EUR 5 million in 2002-2003). NB: Around half of the R&D investments concerning transport and distribution do not (directly) concern the hydrogen economy (compare Figures 2.2. and 2.3).

Figure 2.2 Project costs for hydrogen projects per technology area (mln. EUR)

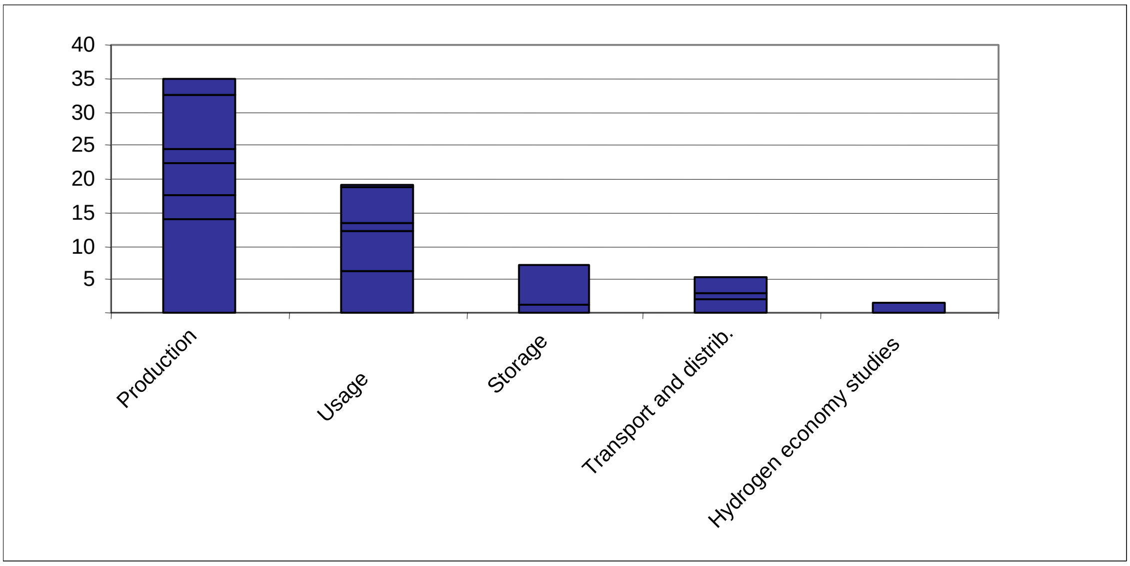
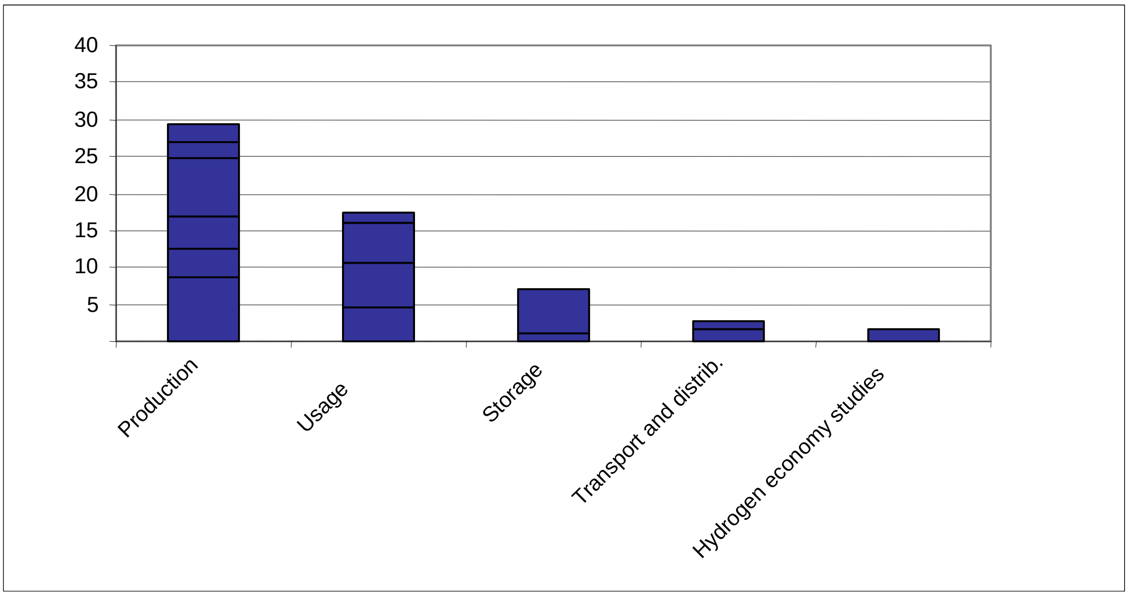


Figure 2.3 Project costs of hydrogen projects per technology area, excl. hydrogen industry projects (mln. EUR)



Figures 2.2 and 2.3 show a difference for R&D investments for production. This is due to the hydrogen production at refineries and petrochemical plants.

Production technologies

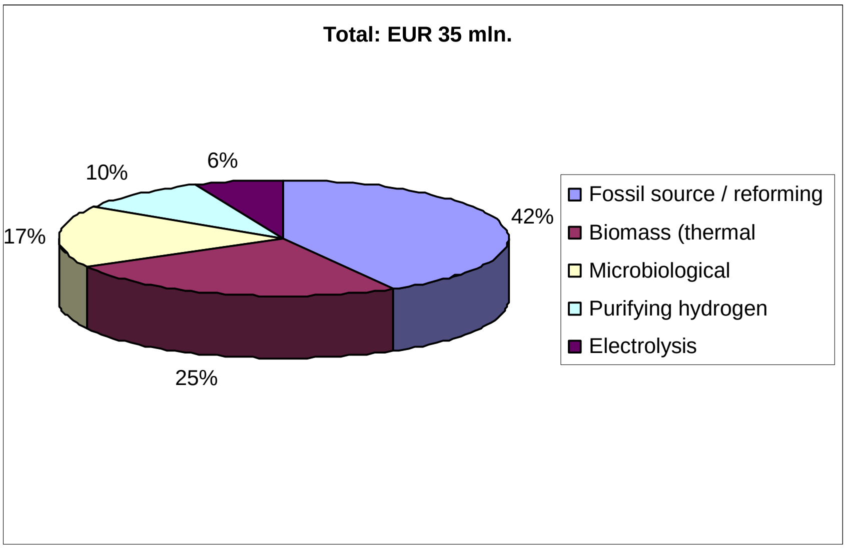
Hydrogen production technologies can be split into five categories:

- Production from fossil sources (reforming, fuel processing).
- Production from biomass (thermal gasification).
- Production from waste and residual products.[1]
- Microbiological production via micro-organisms.
- Purification of gas flows that contain hydrogen.
- Production via electrolysis.

[1] Hydrogen production from waste and residual products was barely found (rounded up to 0%), so that these are not included in the figure.

Figure 2.4 shows the project costs for production split into these five categories. The project costs totalled EUR 35 million for the period 2002-2003.

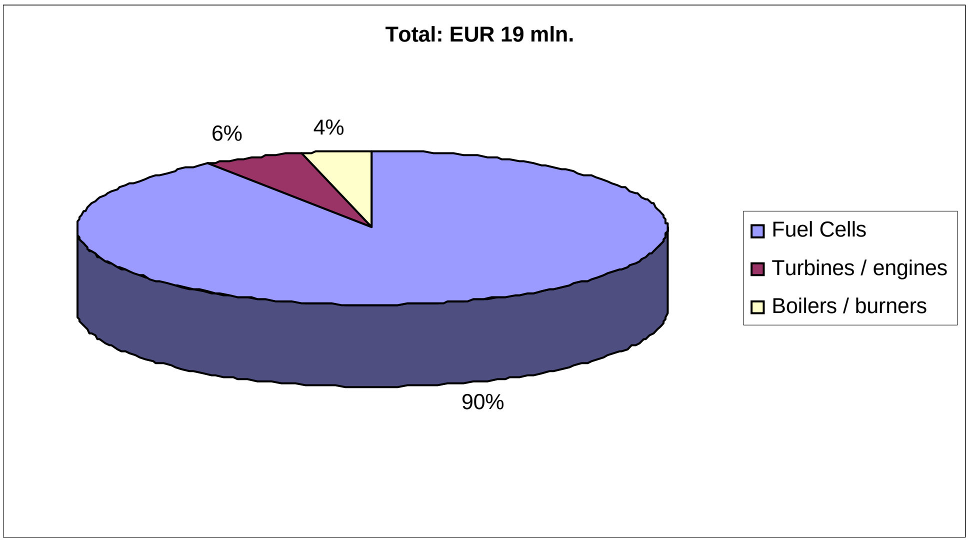
Figure 2.4 Total project costs per production technology (mln. EUR)



Usage technologies

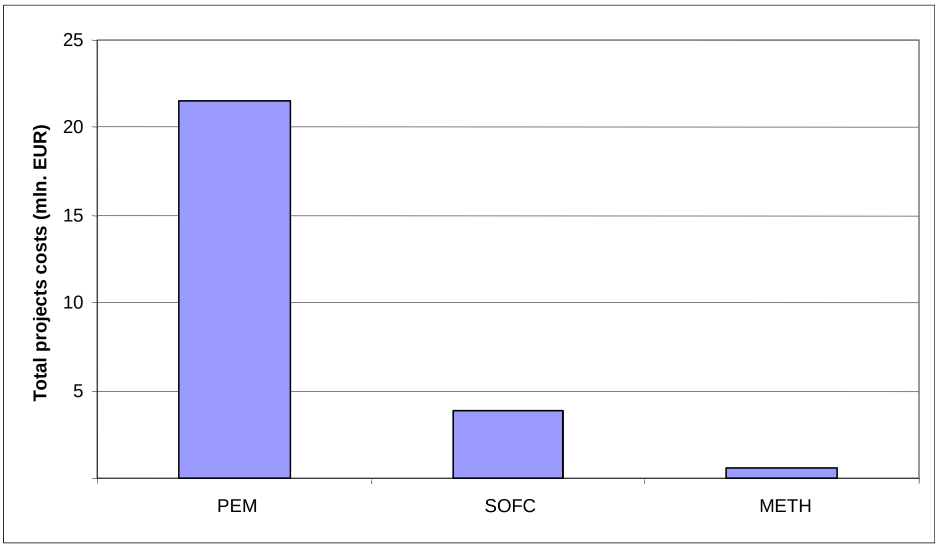
The technologies that use hydrogen can be split into: fuel cells (stacks), turbines/engines and boilers/burners. In total the project costs for the period 2002-2003 amounted to around EUR 19 million for developing hydrogen usage technologies. Figure 2.5 shows the project costs per usage technology.

Figure 2.5 Total project costs per usage technology (mln. EUR)



By far the most R&D into usage technologies concerns the development of fuel cells (90%), although R&D is also conducted into boilers (for hydrogen combustion) and hydrogen burners. The research also indicates which type of fuel cell was studied. Also projects that were not directly focused on developing fuel cells, but which included a reference to a particular type, were included in the analysis. Figure 2.6 shows the amount of project costs concerned per type of fuel cell, for the period 2002-2003.

Figure 2.6 Total project costs per type of fuel cell (mln. EUR)

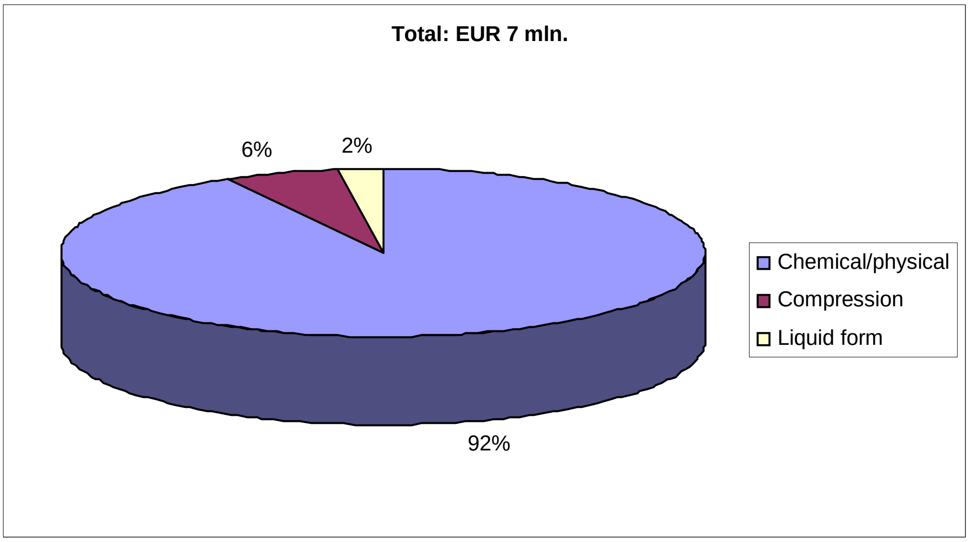


It is clear that most of the R&D concerns the development or use of PEM fuel cells that use hydrogen directly. Far fewer project costs relate to the SOFC type. There is little research conducted into developing methanol fuel cells.

Storage technologies

Hydrogen storage forms a vital link in hydrogen systems for those occasions when the hydrogen produced is not required immediately. There are various forms of storage being developed: compression in gaseous form, turning hydrogen into liquid form, and chemical and/or physical binding of the hydrogen molecules. Project costs totalled EUR 7 million for the period 2002-2003 (see Figure 2.7).

Figure 2.7 Total project costs per storage technology (mln. EUR)

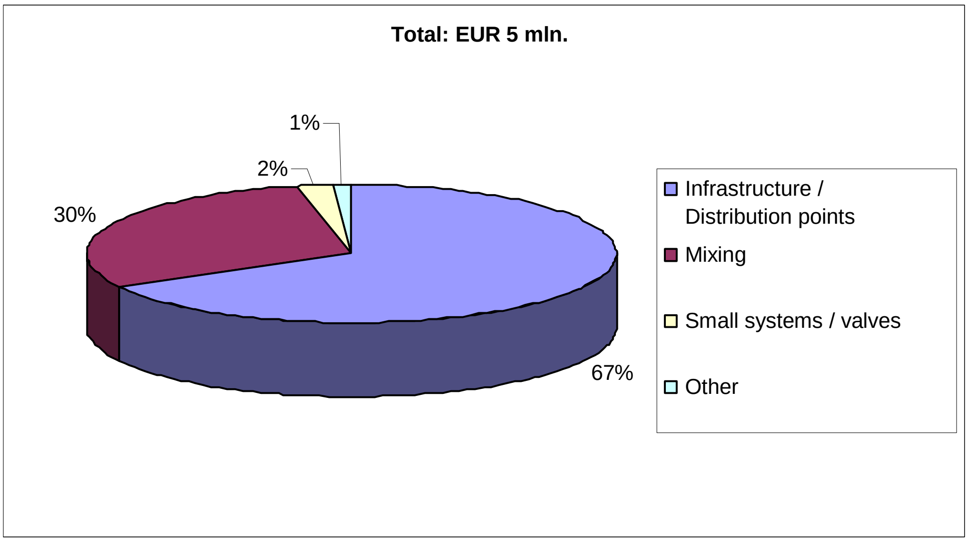


Research generally concentrates on storage in chemical-physical form (92% of the R&D investments). This research is primarily conducted within the ACTS projects from NWO. The most important research teams include those from the TU Eindhoven, Leiden University, Utrecht University, VU Amsterdam and Twente University.

Transport and distribution technologies

The transport and distribution technologies can be split into four categories: infrastructure/distribution points, mixing/additives, small systems/sealing, and others. Figure 2.8 shows the R&D investments (approximately EUR 5 million for 2002-2003) for transport and distribution technologies, split over the aforementioned categories.

Figure 2.8 Total project costs per transport and distribution technology (mln. EUR)



Approximately two-thirds of the R&D investments are spent on infrastructure/distribution points, and one-third on mixing/additives. Considerably less investment is spent on the other categories.

Applying hydrogen technologies

The various hydrogen projects can be categorised according to application area as well as technology area. This refers less to the content of the projects, but looks more at the practical applications on which these projects focus. Figure 2.9 shows the total division of the R&D investments over the various application areas, while Figure 2.10 shows the R&D investments specifically for the hydrogen economy.

Figure 2.9 Total project costs for hydrogen projects per application area (mln. EUR)

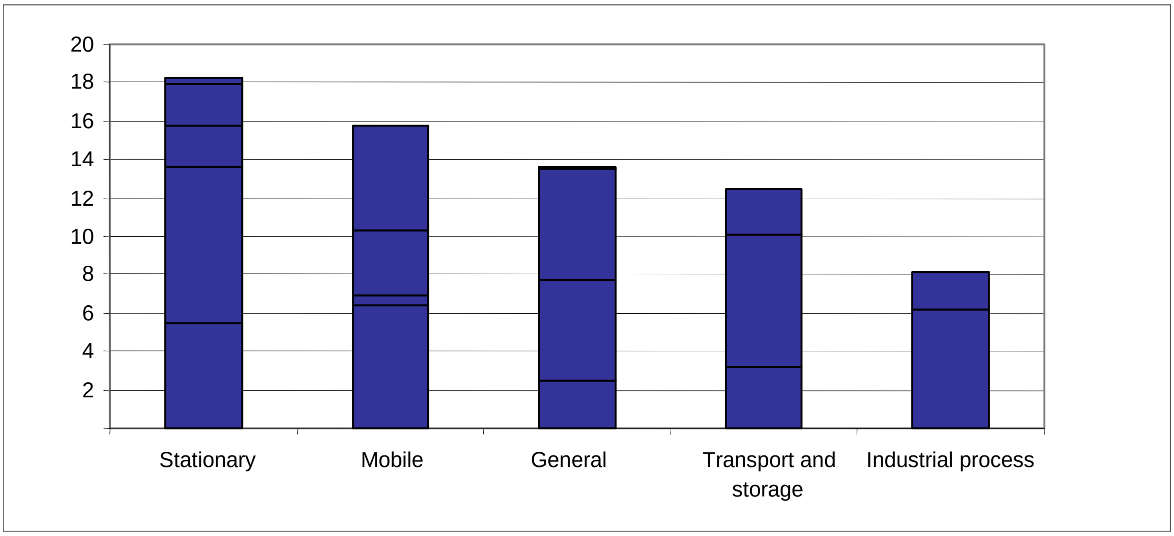
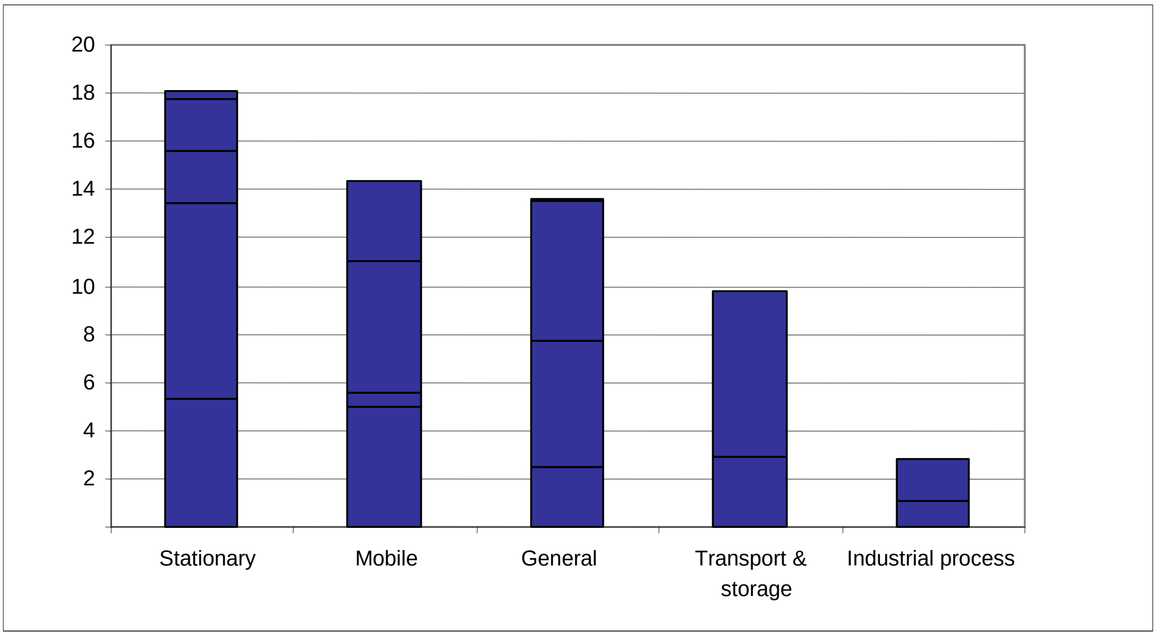


Figure 2.10 Total project costs for hydrogen projects per application area, excl. hydrogen industry projects (mln. EUR)



Perhaps contrary to expectations, most R&D efforts focus on stationary applications. The EDI (energy-saving through innovation) programme has played an important role here. Mobile applications take second place. A considerable amount of the R&D conducted has not led to a specific application, but is possibly important for a variety of applications. Transport and storage also receives little attention, particularly in projects that are supported by the ACTS programme. However, there is a fairly even spread of research over the various categories.

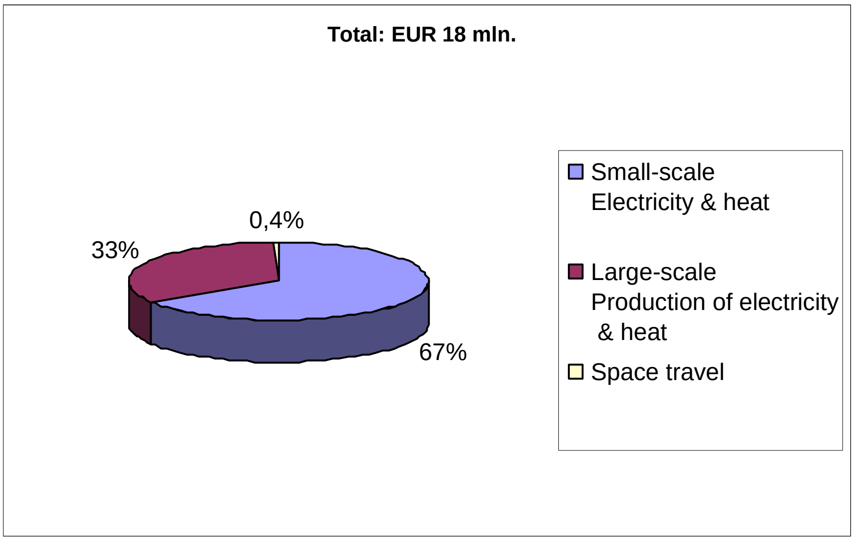
Stationary applications

Various categories of research are differentiated:

- Small-scale production of electricity and heat.
- Large-scale production of electricity and heat.
- Space travel.

Figure 2.11 shows how the R&D investments regarding stationary applications are divided over the aforementioned categories.

Figure 2.11 Total project costs for stationary applications of hydrogen technology



With regard to the stationary applications, two-thirds of the R&D investments are spent on small-scale electricity and heat supply. Shell Global Solutions, ECN, Inoc, Hexion, Plug Power, Nedstack, Gasunie, and Green Vision are the most important parties concerned. The other 33% of the investments are spent on large-scale production of electricity and heat. TNO, MEP, Nedstack, ECN, Exendis, Ecofys and the RU Groningen are the largest implementers of this research. A very small percentage of the R&D is aimed at stationary applications for the space industry (on-board electricity generation).

Mobile applications

Figure 2.12 shows the investments over the various mobile applications.

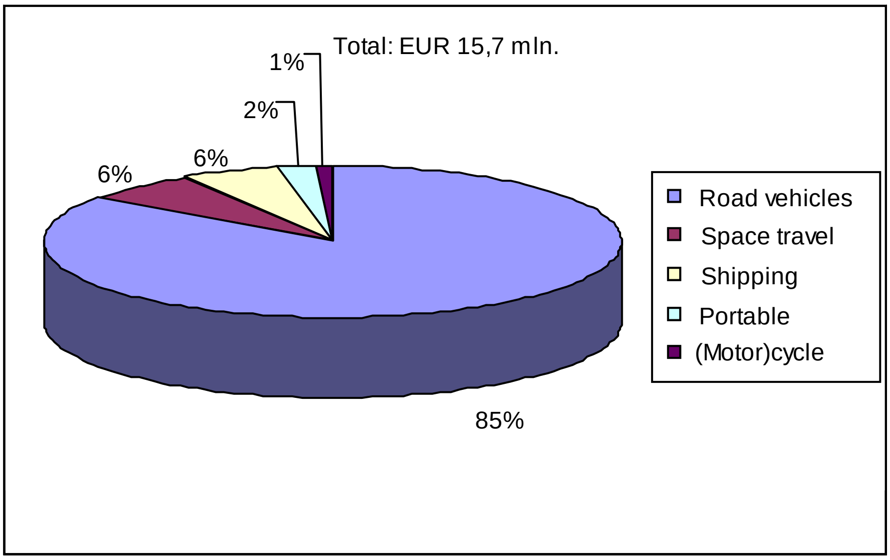


Figure 2.12 Total project costs for mobile applications of hydrogen technology (mln. EUR)

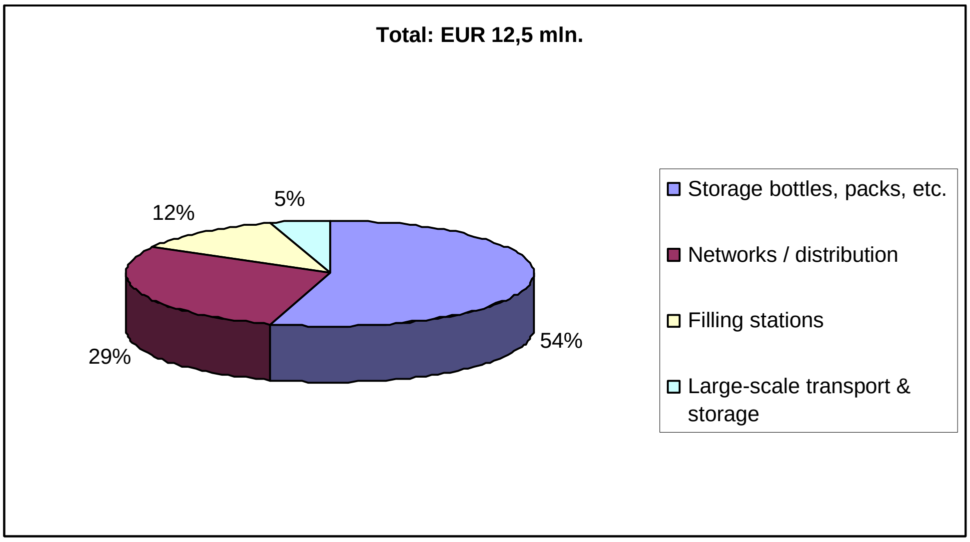
By far the most R&D efforts (for mobile applications) focus on automotive vehicles. The organisations concerned include GVB, Shell Nederland, Shell Global Solutions, Nedstack, CCM, Gastec, Alstom Transport, and Stork Product Engineering. Space travel and shipping each represent 6% of the R&D investment for mobile applications. Organisations conducting research for space travel include Stork Product Engineering, Aerospace Propulsion Products and Bruns Interactive.

Transport and storage applications

Figure 2.13 shows the division of R&D transport and storage investments over five categories:

- Networks/distribution.
- Filling stations.
- Storage in bottles, packs, and small drums.
- Large-scale transport and storage of hydrogen.
- Large-scale transport of hydrogen.

Figure 2.13 Total project costs for transport and storage applications of hydrogen technology (mln. EUR)



Half of the transport and storage applications concern small-scale storage. Almost one-third of the project funds are spent on network and distribution aspects, 12% focus on filling stations, and 5% of the R&D investments are spent on large-scale hydrogen storage. Only two projects are researching networks and distribution.

General applications

Projects aimed at general applications include:

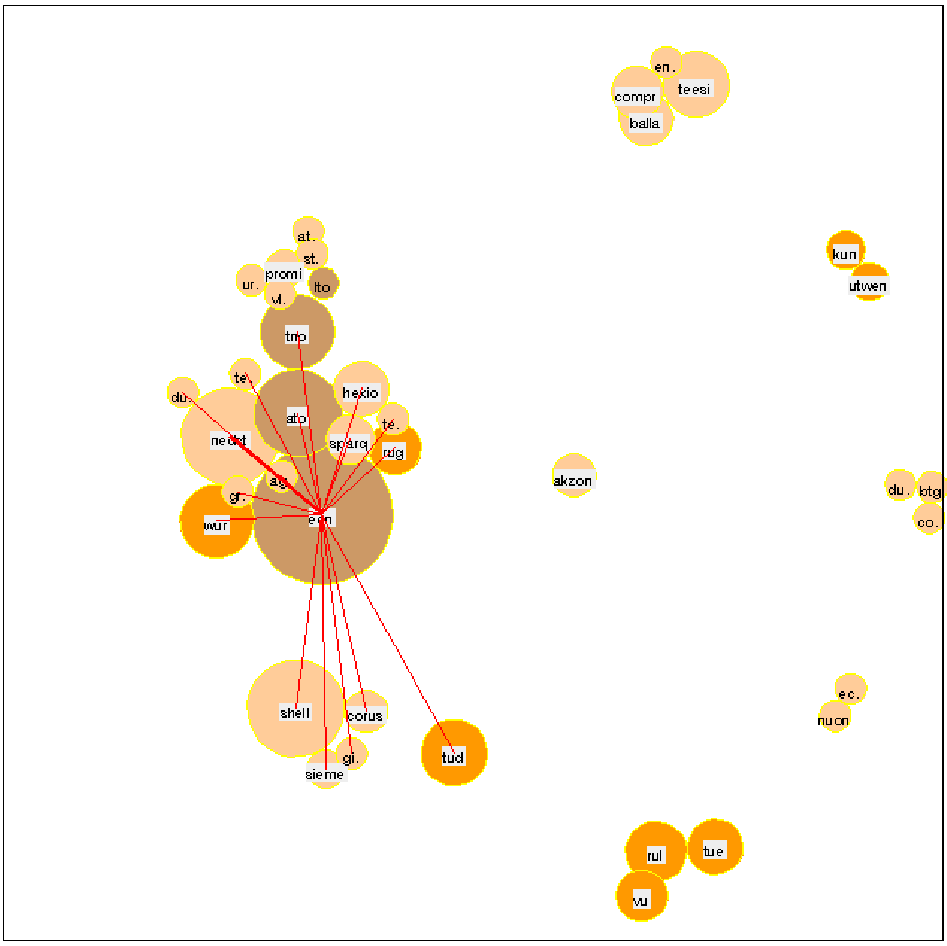
- Research into methods of producing hydrogen from oil derived from biomass.
- Developing fuel processors for hydrogen production.
- Experimental research into producing hydrogen directly from water, using sunlight.
- Experimental research into concepts for hydrogen sensors for large-scale use in a hydrogen economy.
- Gamma research into the best strategies for implementing hydrogen.
- Recovery processes (oxygen and water vapour) for fuel cells.

National collaborations

The following section provide an inventory of the collaboration at national level. The parties are collaborating in production, usage, transport and distribution respectively. Appendix 2 includes a list of the acronyms (organisation names) used in the figure. The knowledge institutes, universities and companies are shown in different colours: companies (salmon colour), knowledge institutes (brown) and universities (orange). The diameters of the circles indicate the total of the project costs for the respective stakeholders. Organisations that often work together are placed closer together. These diagrams were produced by CWTS, an institute under the university of Leiden.

Figure 3.1 shows the organisations that have collaborated in the subsidised projects during 2002 and 2003. Appendix 2 includes a list of acronyms for the organisations shown in the figure. The following list also includes the organisations with which ECN has collaborated in various projects. The knowledge institutes, universities, and companies are shown in different colours: a salmon colour for companies, brown for knowledge institutes, and orange for universities. The diameter of the circles represents the sum of the project costs of the stakeholders involved. The distance between the circles represents the extent of the collaboration (i.e. number of collaborative relationships). The closer the circles, the more collaboration between the organisations.

Figure 3.1 National collaborative organisations



ECN has taken part in the higher number of collaborative projects, followed by Shell, Nedstack, Agrotechnology & Food Sciences, TNO, and Wageningen University. The stakeholders with whom ECN has collaborated include Shell, Siemens, Gipec, Corus, TU Delft, Wageningen University, Nedstack, Agrotechnology & Food Sciences, Hexion, Sparqle, RU Groningen, TechnoInvent, Agromiscanthus, Grontmij, Duynie and Technogrow.

Practical experiments with hydrogen buses in Amsterdam are not included in Figure 3.1 because this is a different type of collaboration, whereby money does not change hands. Evobus and HoekLoos are subcontractors of the GVB Amsterdam and they collaborate with Nuon, Shell Hydrogen, and Amsterdam council's Building Supervisor and Environment department on a 'no money' basis.

National hydrogen platforms

De Nederlandse Waterstof Vereniging (NWV) / Dutch Hydrogen Association
The association aims to promote the use of hydrogen as a clean energy carrier in an increasingly sustainable energy management system. The NWV hopes to achieve this by acting as a central helpdesk for knowledge and expertise regarding hydrogen technology in the Netherlands, at universities, knowledge institutes and companies; encouraging collaboration between scientists, developers and entrepreneurs at knowledge institutes and companies; developing and implementing a strategic vision of the role that hydrogen technology can play in the Dutch energy system. The NWV therefore acts as agent/broker between the various stakeholders, and exchanges knowledge and information between all relevant target groups, including the general public (more information: www.waterstofvereniging.nl).

Supporting project costs

The database includes a total of 325 relevant hydrogen projects for the research period 2002-2003, and does not include those projects for which companies or institutes did not request government support. This also applies to research at universities that was financed through primary funds. It is therefore logical to expect that there is more research in the Netherlands than is mentioned in this report. Projects that were refused funding are also therefore not included in this analysis, because it is not possible to verify whether or not these projects were actually implemented.

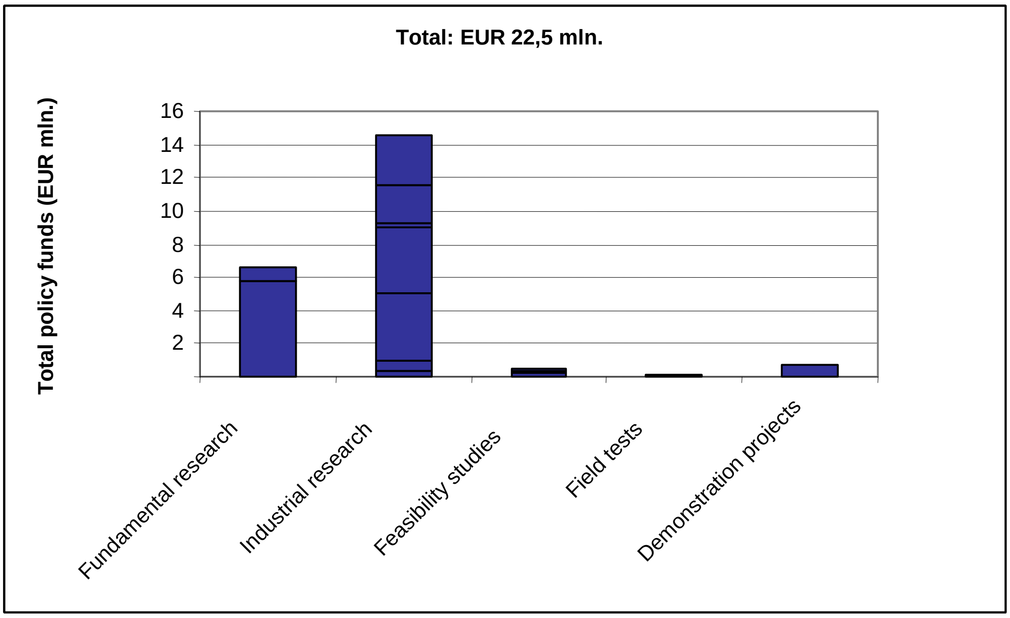
Financing: national schemes and programmes

During the research period (2002-2003) a total of EUR 68.2 million was spent on project costs, through subsidies and fiscal advantages. The last year (2003) shows a clear increase, even when taking into account the projects that were started under the ACTS Sustainable Hydrogen Programme.

National policy funds

Figure 4.3 shows the funds per phase in the innovation path. The majority of the projects can be characterised as 'Industrial research'. More field tests and demonstration projects are expected in the coming years.

Figure 4.3 Total policy funds per phase in the innovation path



Part 2 Analysis of European Hydrogen Projects

European participants in hydrogen projects

Before looking at the content of European hydrogen projects, it is first worthwhile considering the most important stakeholders at the European level. This chapter focuses on the European parties involved, as well as the Dutch companies and knowledge institutes that are well represented. Please notice that in 2003 only a part of FP6 subsidies had been contracted.

Top-25 European stakeholders

Table 1.1 shows the top 25 European project participants. Table 1.2 shows the top 25 and their total project costs in European projects. Appendix 1 explains the meaning of the technology acronyms used here.

Table 1.1 Top-25 European participants (number of project participations)

Number of participations per technology	Technology													Total
Organisation	WO	OC	OG	PA	PB	PE	PF	PO	PZ	TB	TH	VB	VV	
ECN (NL)	3			1	1		5			1		10		21
Centre National de la recherche scientifique (CNRS) (France)	1	3			3		3		1			6		17
Commissariat à l'Energie Atomique (France)	1	1					1			1	1	10		15
Fraunhofer Forschungszentrum (Germany)	3											9	1	13
Johnson Matthey (UK)		1			2		3	1				5		12
Volvo Technology (Sweden)	2	1			1		1				1	5		11
Ansaldo (Italy)	1				4		1					5		11
ENEA - Ente per le Nuove Technologie, l'Energia e l'Ambiente (Italy)	3				4							4		11
Daimler Chrysler (Germany)	3	2			1		1				1	3		11
Norsk Hydro ASA (Norway)	7					1					1	2		11
Instituto Nacional de Tecnica Aerospacial (Spain)	3	1				1					1	4		10
Shell (NL)	3						2			1	1	2	1	10
Consejo Superior de Investigaciones Cientificas (Spain)	1	2		1					1			4		9
Centro Richerche Fiat (Italy)	1		1				1					6		9
Air Liquide (France)	3	1									1	2	1	8
Deutsches Zentrum für Luft- und Raumfahrt (Germany)								1				6	1	8
Forschungszentrum Jülich (Germany)	1				1		1			1		4		8
Kungl Tekniska Hoegskolan (Sweden)		1		1	1							4		7
C.R.F. - Societa Consortile per Azioni (Italy)		1			1		1					4		7
Consiglio Nazionale delle Ricerche (Italy)				1			1					5		7
Imperial College of Science, Technology and Medicine (UK)	3											4		7
Rheinisch - Westfalische Technische Hochschule Aachen (Germany)	1											5	1	7
TNO (NL)	2			1						1		3		7
Electricité de France	1				1							4		6
Gaz de France										1		5		6
Total (mln. EUR)														*249*

Table 1.2 Top-25 European participants (total project costs)

Total project costs per technology (EUR mln.)	Technology													Total
Organisation	WO	OC	OG	PA	PB	PE	PF	PO	PZ	TB	TH	VB	VV	
Rolls Royce (UK)												x		x
ECN (NL)	x			x	x		x			x		x		x
Daimler Chrysler (Germany)	x	x			x		x				x	x		x
Johnson Matthey (UK)		x			x		x	x				x		x
Commissariat à l'Energie Atomique (France)	X	x					x			x	x	x		x
Ansaldo (Italy)	x				x		x					x		x
MTU (Germany)						x						x	x	x
Centre National de la Recherche Scientifique (Fr)	x	x			x		x		x			x		x
Fraunhofer (Germany)	x											x	x	x
Forschungszentrum Jülich (Germany)	x				x		x			x		x		x
Air Liquide (France)	x	x									x	x	x	x
Volvo Technology (Sweden)	x	x			x		x				x	x		x
Nederlandse Gasunie (NL)										x		x		x
BP (UK)	x					x				x	x	x		x
Risoe National Laboratory (Denmark)	x											x		x
Autobus de la Ville de Luxembourg												x		x
GVB Amsterdam (NL)												x		x
Stuttgartner Strassenbahn (Germany)												x		x
Centro Ricerche Fiat (Italy)	X		x				x					x		x
Empresa Municipal de Transportes (Spain)												x		x
London Bus Services (UK)												x		x
Norsk Hydro (Norway)	x					x					x	x		x
Transports de Barcelona (Spain)												x		x
Energie Baden-Wurttemberg (Germany)												x		x
Total (mln. EUR)x														*143.8*

These lists consist of a number of research institutes, (urban) transport companies, car manufacturers and energy suppliers. ECN is one of the largest European stakeholders. The aforementioned tables clearly show that the most important European stakeholders concentrate most of their R&D efforts on developing fuel cells. ECN plays an important role here. There are also many studies conducted into the (integration of) hydrogen economy as an energy system. The attention paid to producing hydrogen is primarily concentrated on hydrogen production from fossil sources and biomass. Both ECN and Johnson Matthey play an important role in studying production from fossil sources, and Daimler Chrysler and Ansaldo are the main frontrunners in production from biomass.

Dutch participation in European projects

Table 1.3 shows the Dutch companies, knowledge institutes and other organisations that participate in one or more of the Fifth or Sixth Framework Programmes (submitted to date).

Table 1.3 Dutch participants in European Framework Projects

Total project costs per partner (EUR)	Framework programme		Total
Organisation	FP5	FP6	
ECN	x	x	x
Gasunie	x	x	x
GVB Amsterdam	x		x
Twente University	x		x
Plug Power Holland	x		x
TNO	x	x	x
TU Delft	x	x	x
Nedstack	x	x	x
BTG	x		x
TU Eindhoven	x		x
ECO Ceramics		x	x
European Commission - DG -Joint Research Centre		x	x
Shell	x	x	x
Hexion		x	x
MESA Research Institute	x		x
Airborne Development	x		x
Continental Engineering	x		x
Sparqle International	x		x
Promikron 3	x		x
DAF Trucks		x	x
Innogas	x		x
Bekaert		x	x
Denso Europe	x		x
Compositeringsbedrijf Zuid-Holland	x		x
Milieudienst Amsterdam (environmental services)	x		x
KEMA	x		x
Netherlands Standardization Institute		x	x
NOVEM	x	x	x
IMTECH Marine & Industry	x		x
European Natural Gas Vehicle Association	x		x
Innovation Support and Partners	x		x
Final total	*26.61*	*11.59*	*38.20*

The Dutch organisations that are conducting the most research under the European Framework Projects include: ECN, Gasunie, GVB Amsterdam, Twente University, Plug Power, TNO, TU Delft, Nedstack, BTG and TU Eindhoven.

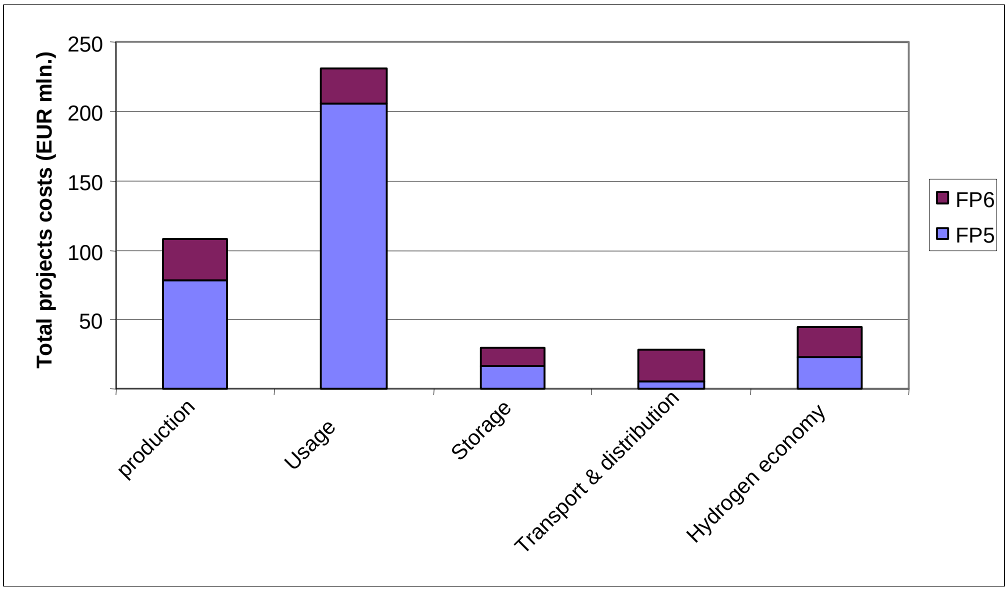
Analysis of European hydrogen projects

This chapter analyses the European framework projects with respect to hydrogen technology. Section 2.1 provides an overview of the total hydrogen research being conducted in Europe, again per technology and application area. Section 2.2 provides a geographic division of the hydrogen research over the various EU Member States, and Section 2.3 gives an overview of the Dutch participation in this European hydrogen research. Section 2.4 lists the most important European stakeholders, and conclusions are provided in Section 2.5

Hydrogen research in Europe

The project costs for the projects approved under FP5 and FP6 for the period 1998-2003 totalled EUR 441 million. This includes all the hydrogen projects submitted under the Fifth Framework Programme, and the projects that, to date, have been submitted under the Sixth Framework Programme. Figure 2.1 shows how the European R&D into hydrogen technology is distributed over the various technology areas. Please not only a part of the FP6 projects had been contracted in 2003.

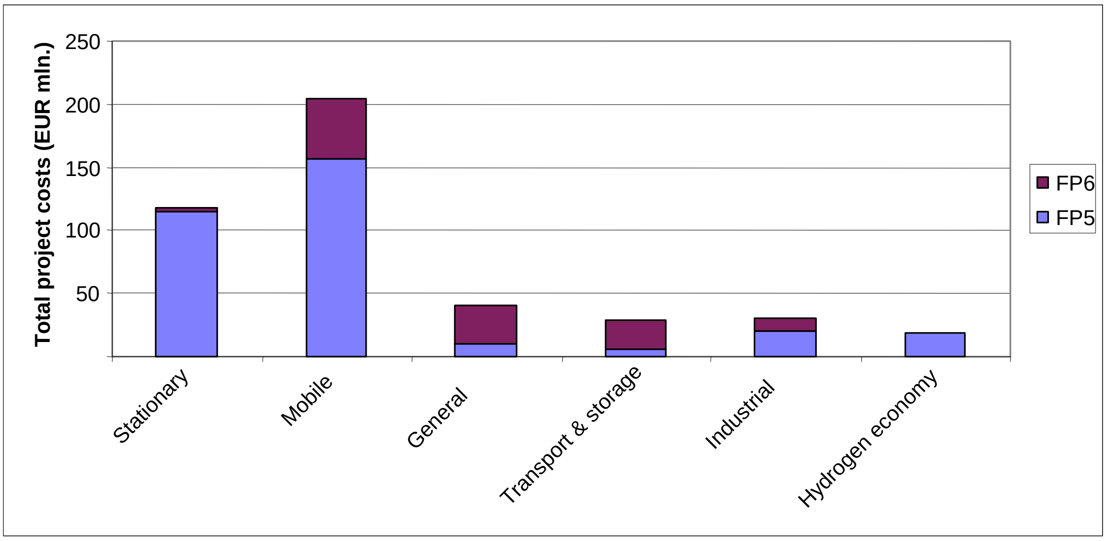
Figure 2.1 Distribution of project costs for European hydrogen projects per technology area (mln. EUR)



Although the Netherlands invests almost twice as much into production as usage, this situation is reversed on a European scale. Most projects focus on the use of hydrogen technology – almost entirely on the development of fuel cells. Storage receives relatively little attention at the European level, and those projects that are implemented concern storage in chemical-physical form.

Figure 2.1 also shows that transport and distribution received relatively little attention under FP5, but that this situation is being redeemed within the FP6 programmes. The project costs for the first FP6 projects are five times higher than for transport and distribution projects under FP5. This is primarily due to the NATURALHY projects, with 61 participants from 15 countries. This includes 10 organisations from the Netherlands. This project concerns a study into using the existing gas infrastructure in the transition towards a hydrogen economy.

Figure 2.2 Distribution of project costs for European hydrogen projects per application area (mln. EUR)



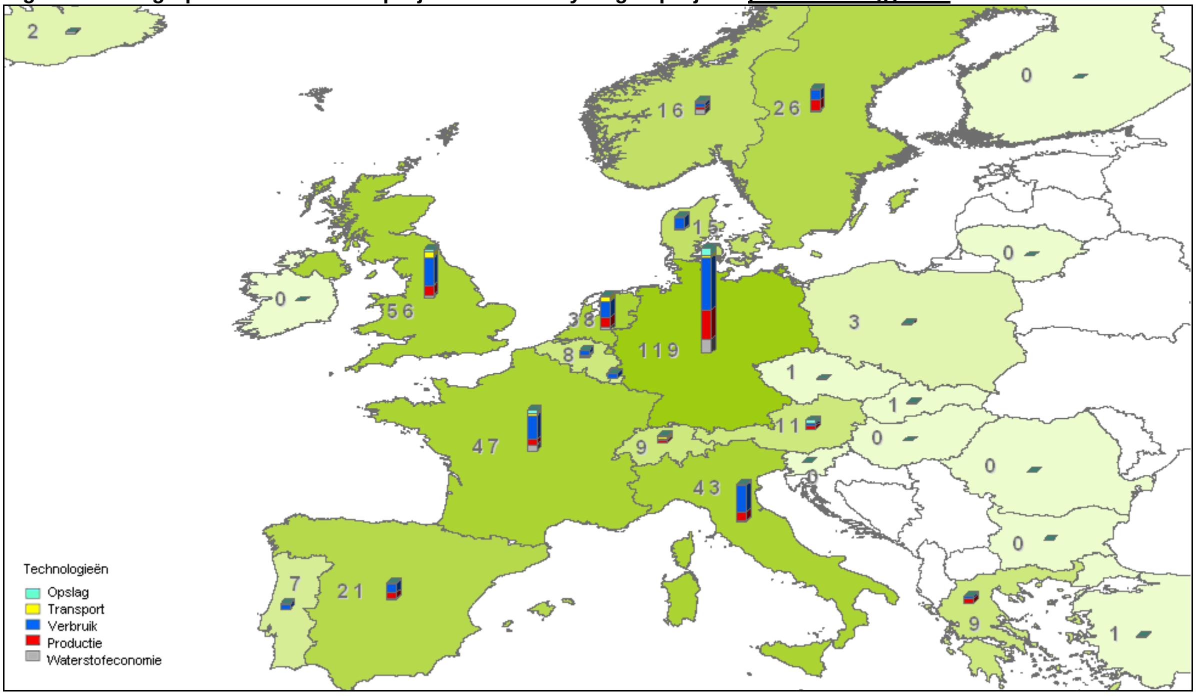
The main emphasis at European level concerns mobile applications of hydrogen technology (primarily in vehicles), while R&D in the Netherlands concentrates on stationary applications. This is understandable, since there is no Dutch car industry.

Geographic division of European hydrogen research

This section shows the geographic division of the European hydrogen research, both per technology and per application area. The absolute R&D investment per country is also related to its GDP, thus giving a better idea of the relative R&D investments.

Figure 2.3 shows the project costs of the European participants, geographically split over the various countries, and the breakdown per technology area. Figure 2.4 shows this same geographic division, but now showing each country's investments per application area.

Figure 2.3 Geographic division of EU project costs for hydrogen projects per technology area



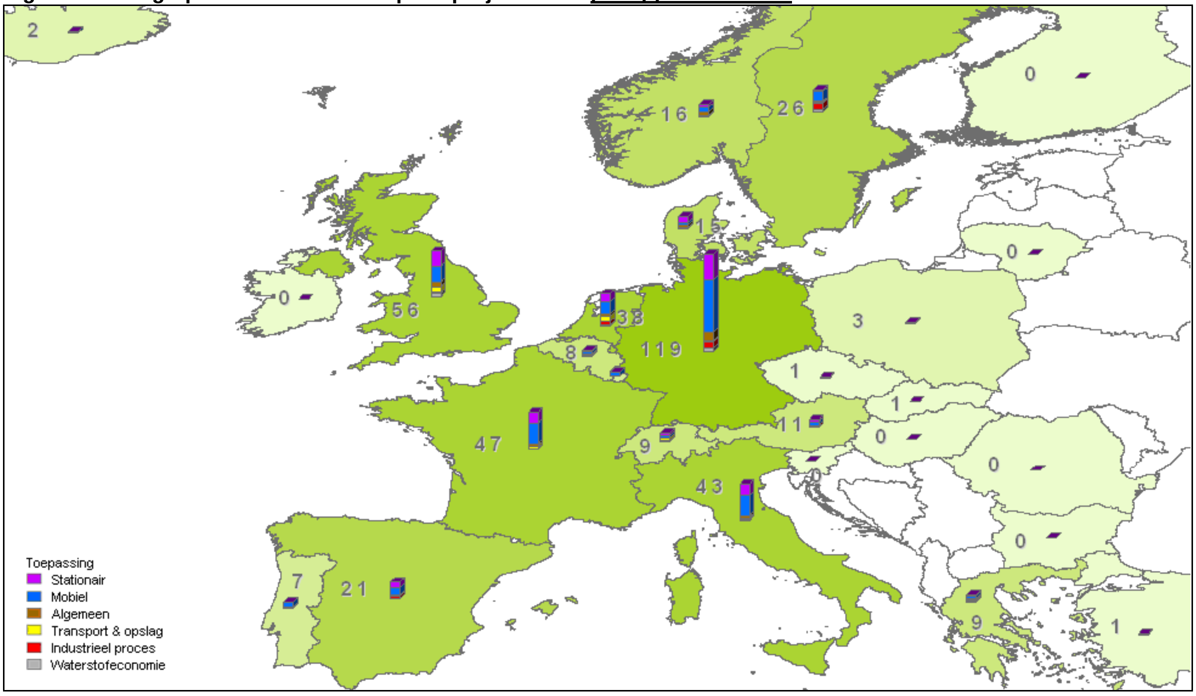
Translation legenda: Technologies
Opslag-Storage, Transport-Transport, Verbruik-Usage, Productie-Production, Waterstofeconomie-Hydrogen economy

Germany is most represented in the European Framework Projects, followed by the UK, France, Italy, the Netherlands, Sweden and Spain. The Netherlands is therefore in fifth place for European R&D investments into hydrogen technology. Germany conducts the most research into storage (26%). Austria and France also conduct relatively large amounts of research into storage. The Netherlands conducts very little research into storage via European projects (though it does participate in the national ACTS programme).

The Netherlands and the UK are really the only countries implementing R&D into the transport and distribution of hydrogen. Studies into the non-technological factors of implementing a hydrogen economy are primarily being conducted by the UK, France, Germany, Norway and the Netherlands.

It is remarkable that Ireland has relatively little participation in EU projects: only around EUR 2.4 million in project costs. This may well present opportunities. Up to now Ireland has implemented its own hydrogen bus project (comparable with CUTE), a study into transporting hydrogen by boat, and a study into using hydrogen for fishing boats. Ireland conducts no research into hydrogen storage.

Figure 2.4 Geographic division of European project costs per application area

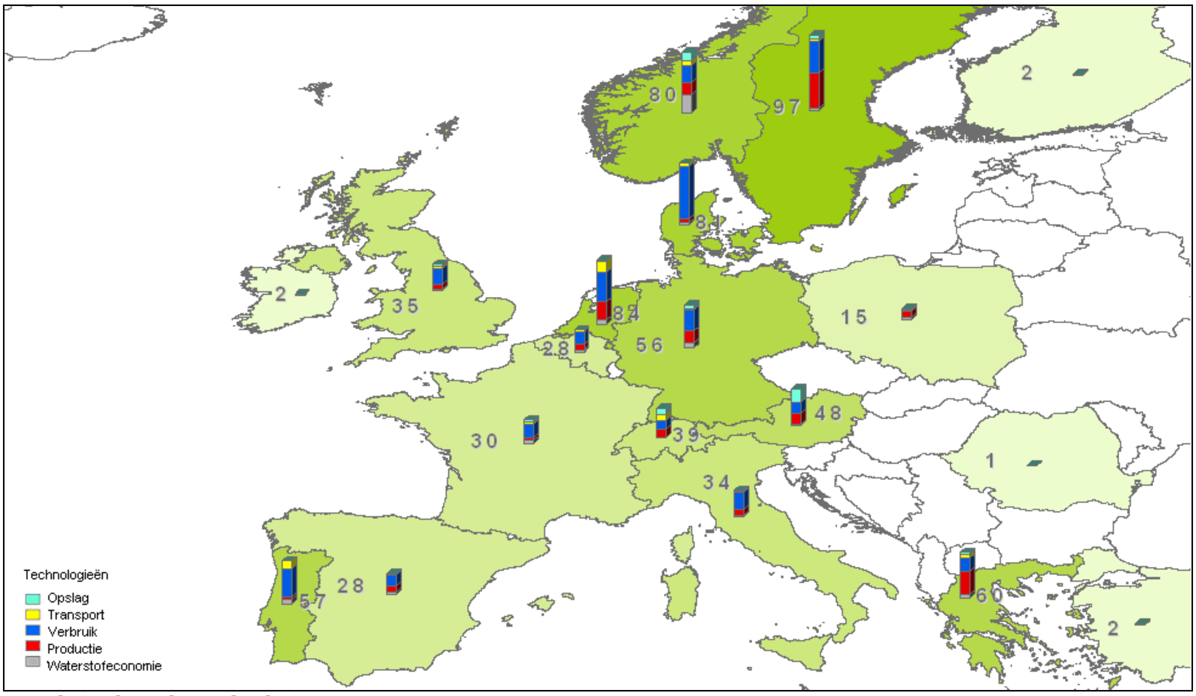


Translation legenda: Applications
Stationair-Stationary, Mobiel-Mobile, Algemeen-General, Transport & opslag-Transport and storage, Industrieel proces-Industrial process, Waterstofeconomie-Hydrogen economy

Only the Netherlands, Germany and Sweden are conducting research into industrial hydrogen applications. With regard to R&D into stationary and mobile applications, it seems that the UK, France, Spain, the Netherlands and Italy invest around the same amount of money in European projects. For these countries, around one-third of the funds are spent on stationary applications, and two-thirds on mobile applications. Various European towns and cities are conducting experiments into hydrogen buses, e.g. Amsterdam, Barcelona, London, Luxemburg, Stockholm, Hamburg, Madrid, Stuttgart and Porto are all participating in the CUTE (Clean Urban Transport for Europe) project. Hydrogen buses are also being used in Reykjavik, via the ECTOS (Ecological City Transport System) project.

In order to give a better idea of the relative R&D investments in the various European countries, the absolute project costs have been divided by the GDP. The values shown in Figure 2.5 indicate this quotient, multiplied by a factor of 1,000,000 in order to achieve practical values.

Figure 2.5 Geographic division of relative project costs in European hydrogen projects, <u>per technology area (related to GDP</u>: absolute investments/GDP*1,000,000)



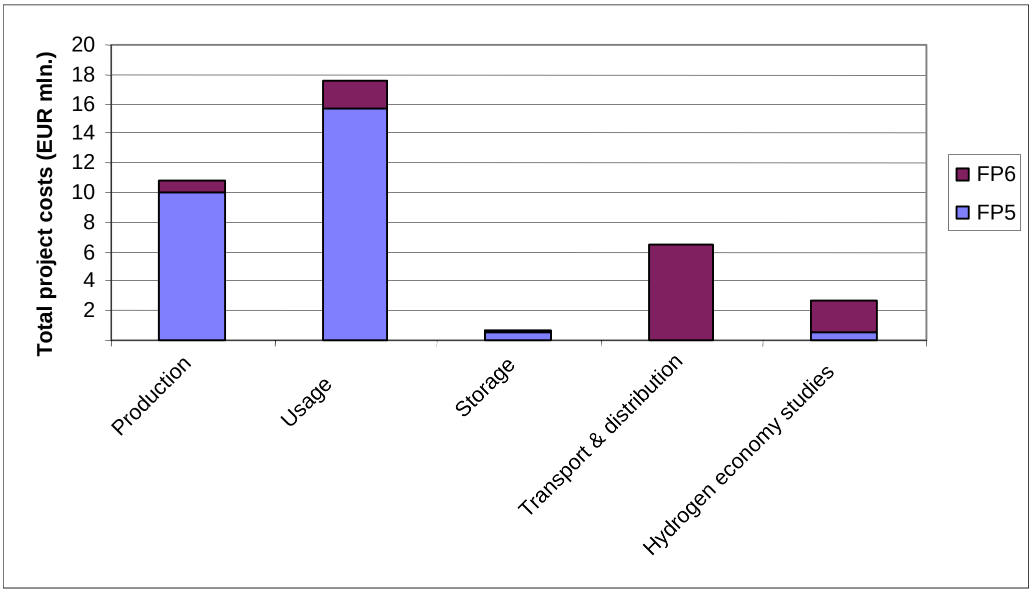
Translation legenda: Technologies
Opslag-Storage, Transport-Transport, Verbruik-Usage, Productie-Production, Waterstofeconomie-Hydrogen economy

Figure 2.5 shows that, with respect to its GDP, the Netherlands conducts considerable R&D into hydrogen technology, comparable to Denmark, Norway and Sweden. Despite the fact that the Netherlands is a small country, it is not being left behind the other countries. In absolute terms, German companies and institutes conduct the most R&D via the EU Framework Programmes (see Figure 2.3). However, when related to its GDP, Germany emerges in the middle of the group, comparable to Portugal, Greece and Austria.

Dutch participation in European research

Of the total budget (EUR 441 million) spent on hydrogen-related R&D in European collaborative projects under FP5 and FP6, EUR 38 million was spent on funding project costs for Dutch stakeholders (around 9%). Dutch organisations were involved in 47 of the 96 projects identified in this report as ‘hydrogen related’ under FP5 and FP6. These 47 projects received a total of EUR 249 million in project costs. Figure 2.6 shows how the R&D funds for Dutch organisations were split over the various technology areas.

Figure 2.6 Distribution of project costs for European hydrogen projects to Dutch organisations per technology area



Over the period 1998-2003 Dutch stakeholders invested almost EUR 18 million in R&D into hydrogen use. Investments into hydrogen production amounted to around EUR 11 million, and FP6 project costs for transport and distribution amounted to around EUR 6 million. Please note that in the period 2002-2003 only a part of the FP6 were contracted.

The Netherlands contributes very little to European storage research (EUR 0.7 million), while all the other EU countries collectively spend EUR 29.5 million on this subject. However, storage projects are conducted at universities on a national level (EUR 7 million in project costs for the period 2002-2003).

European collaboration

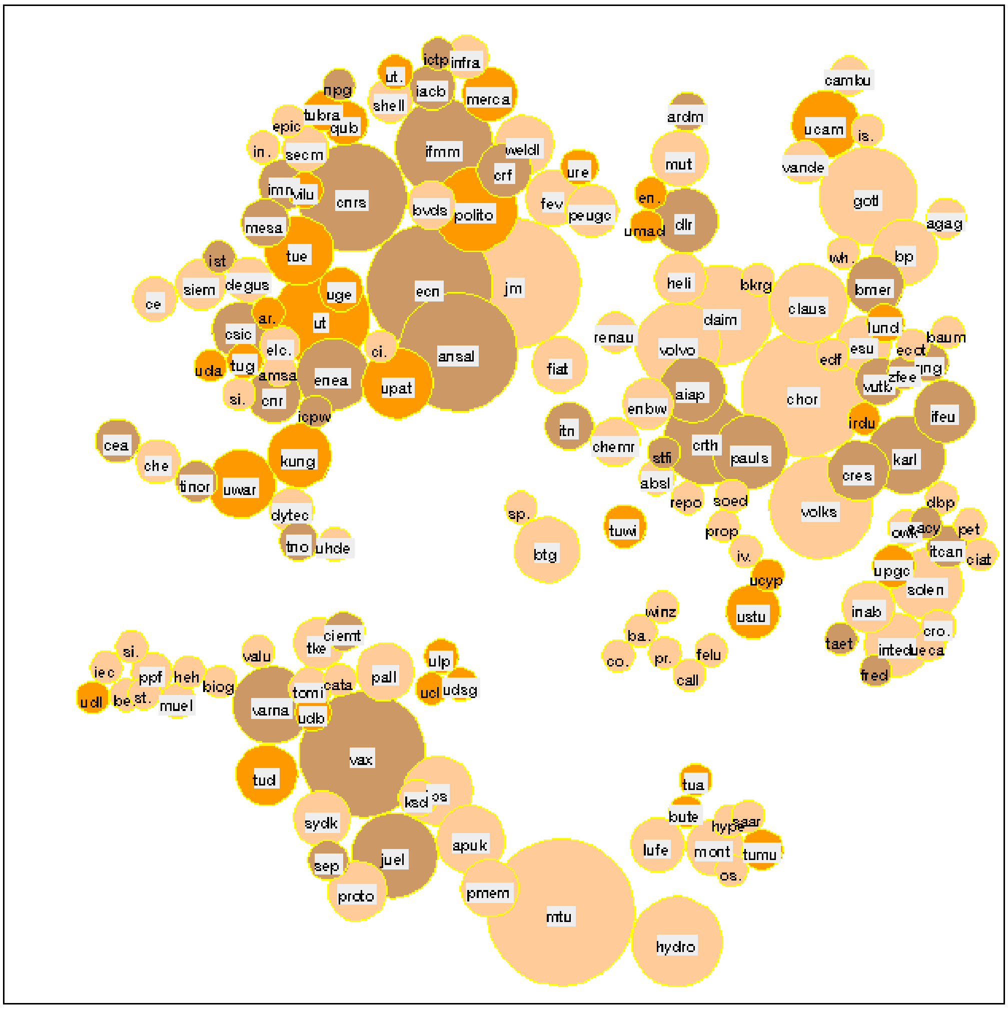
The following sections provide an inventory of the collaboration at European level. Sections 3.1 to 3.4 include the parties that are collaborating in production, usage, transport and distribution respectively. Appendix 2 includes a list of the acronyms (organisation names) used in the figure. The knowledge institutes, universities and companies are shown in different colours: companies (salmon colour), knowledge institutes (brown) and universities (orange). The diameters of the circles indicate the total of the project costs for the respective stakeholders. Organisations that often work together are placed closer together. These diagrams were produced by CWTS, an institute under the RU Leiden. CWTS produces these diagrams from information taken from the EU Framework Programme, as updated by SenterNovem. Several important stakeholders are then highlighted, and the footnotes indicate the FP programme in which they participate. Further information concerning the content of these projects can be obtained from the www.cordis.lu website, where all FP projects are registered.

Section 3.5 contains a geographic overview of the countries where the stakeholders collaborate in certain areas.

Collaboration regarding production

Figure 3.1 shows the collaboration regarding hydrogen production throughout Europe, at organisation level.

Figure 3.1 European stakeholders working on hydrogen production



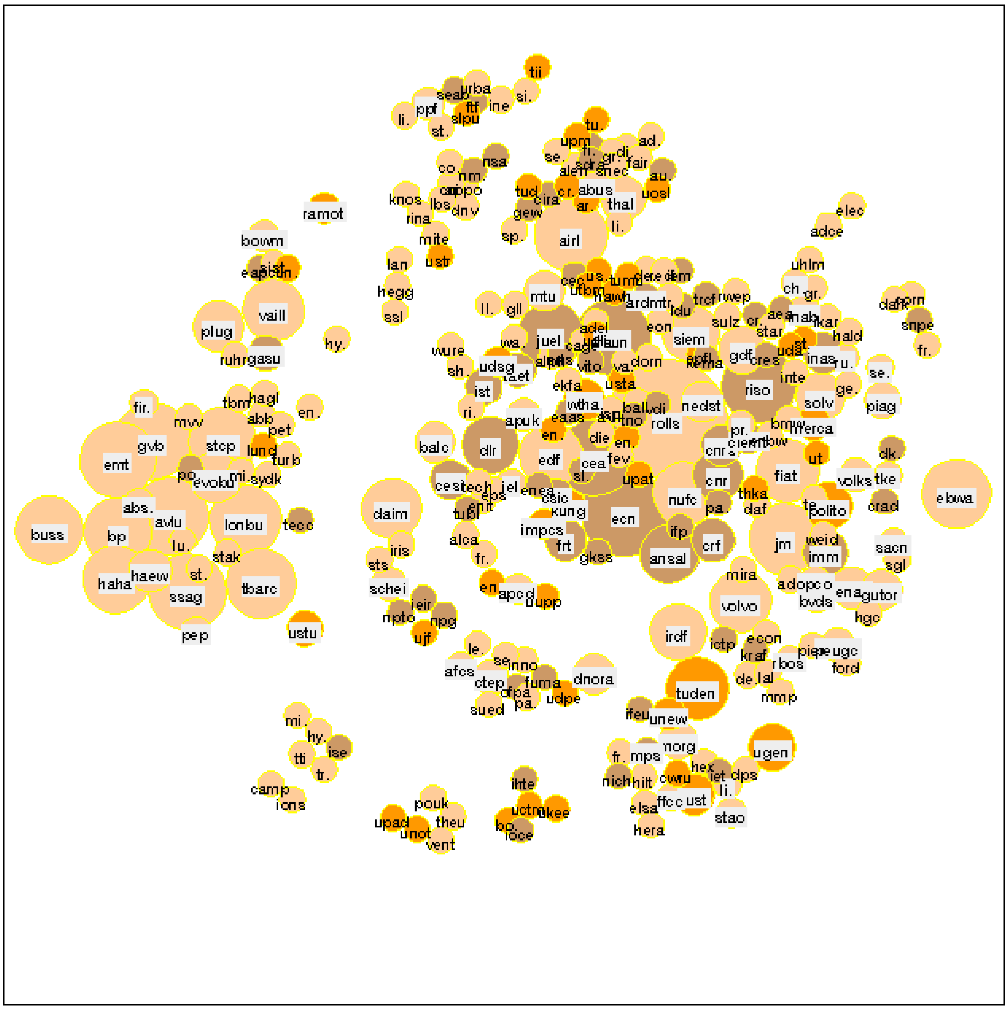
ECN is one of the largest Dutch stakeholders with respect to hydrogen production in the European collaborative projects. Twente University also plays a relatively significant role. Both organisations participate in the cluster shown in the top-left area of Figure 3.1, which primarily concerns projects into sustainable (i.e. biological) hydrogen production and fuel processing (reformers). The bottom cluster also concerns projects on sustainable (i.e. biological) hydrogen production as well as an electrolysis project. The cluster to the right is also working on sustainable hydrogen production projects.

Other large European stakeholders in this field include MTU (electrolysis project), Växjö (synthesis gas project, together with surrounding stakeholders), Ansaldo, Johnson Matthey, Centre National de la Recherche Scientifique (SNRS), and the Institut für Mikrotechnik. Choren Industries, Volkswagen and Daimler Chrysler are collectively implementing a project concerning the application of sustainable fuels for advanced vehicle propulsion.

Collaboration regarding usage

Figure 3.2 shows the European collaboration regarding hydrogen usage, at organisation level.

Figure 3.2 European stakeholders working on hydrogen usage



European projects on the use of hydrogen all focus on the development and application of fuel cells. ECN also plays an important role in this field. Other relatively large stakeholders include Rolls Royce, Risoe National Laboratory, Commissariat a l’Energie Atomique, Forschungszentrum Jülich, Nuvera

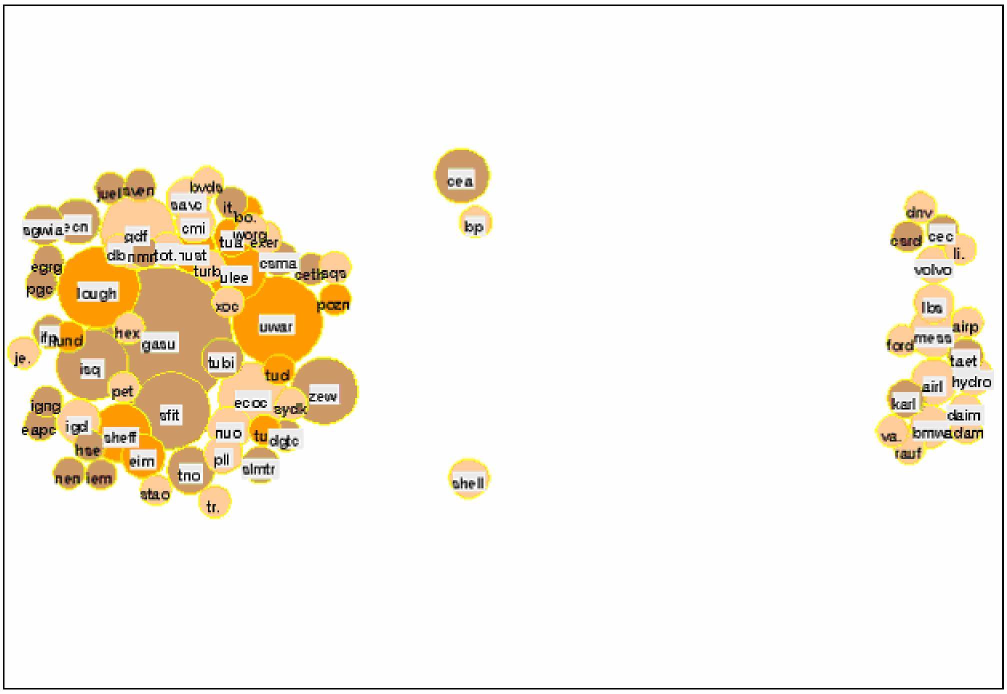
Fuel Cells Europe, Air Liquide, Johnson Matthey, Fraunhofer, Denmark University, Energie Baden-Wurttemberg, Fiat, Daimler Chrysler, Volvo and EdF.

The cluster to the left of the figure represents the CUTE project (hydrogen buses in European cities), in which the GVB Amsterdam participates, along with several other transport companies from European cities. The other stakeholders cannot be assigned to specific clusters, as they collaborate with each other in a multitude of ways, therefore they have been grouped into one cluster (developing SOFC and/or PEM fuel cells).

Collaboration regarding transport and distribution

Figure 3.3 shows the European collaboration with respect to transporting and distributing hydrogen, at organisation level. The cluster to the left concerns the NATURALHY project, which studies the extent to which the existing European natural gas networks could be used as catalyst for the introduction of the hydrogen economy. The Dutch Gasunie coordinates this project, and is the largest participant, with EUR 4.1 million in project costs. The cluster to the right represents the EIHP (European Integrated Hydrogen Project). This generates input for defining new regulations, at both European and global level (to facilitate in harmonising procedures and standards for hydrogen vehicles). The organisations placed between the two clusters are involved in both projects.

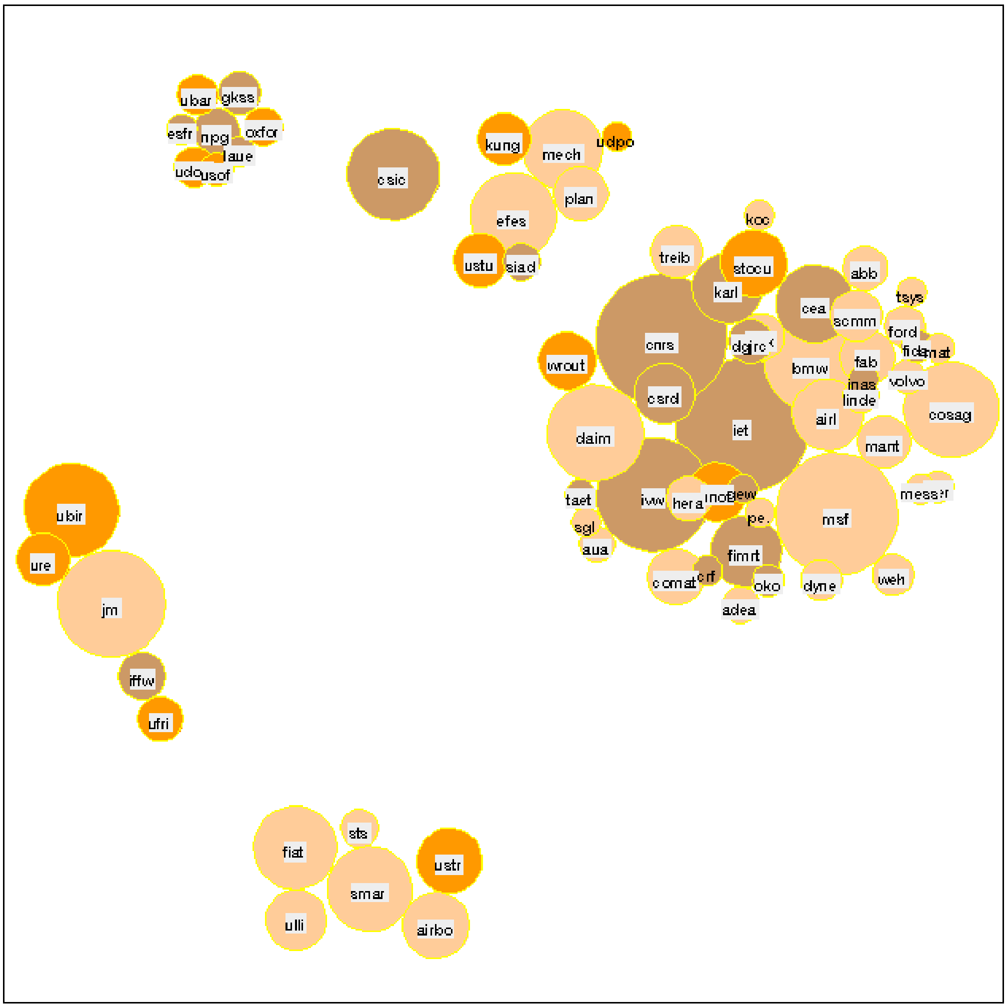
Figure 3.3 European stakeholders working on the transport and distribution of hydrogen



Collaboration regarding storage

Figure 3.4 provides an overview of the European collaboration with respect to hydrogen storage, at organisation level.

Figure 3.4 European stakeholders working on hydrogen storage

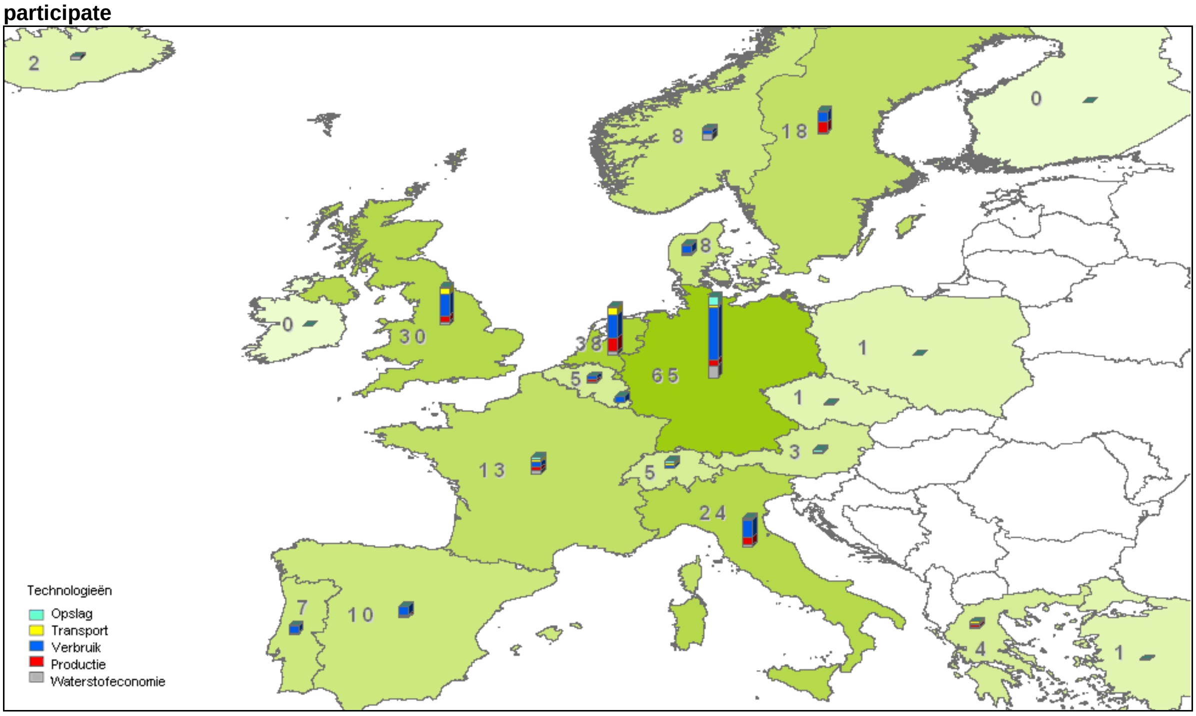


Only one Dutch company participates in storage projects, i.e. Airborne Development BV, in the project entitled ‘Zero hazard gas storage by multi-sensing optical monitoring system’. The largest participants in hydrogen storage projects include Johnson Matthey, Centre National de la Recherche Scientifique, Institute for Energy Technology, Daimler Chrysler, Institut für Verbundwerkstoffe, BMW, Magna Steyr Fahrzeugtechnik, Contraves Space and Consejo Superior de Investigaciones Cientificas. Practically all these projects concern storage in the form of metal hydrides, with only the bottom cluster working on a storage monitoring project.

Geographic collaboration

Figures 3.5 and 3.6 show the geographic division of the project costs for those projects in which Dutch organisations participate: Figure 3.5 shows the technological split per country and Figure 3.6 shows this per application area for each country. The total project costs of the respective European partners (in collaborative projects with Dutch organisations) are also given per country.

Figure 3.5 Geographic division of project costs <u>per technological area</u> for projects in which Dutch organisations participate

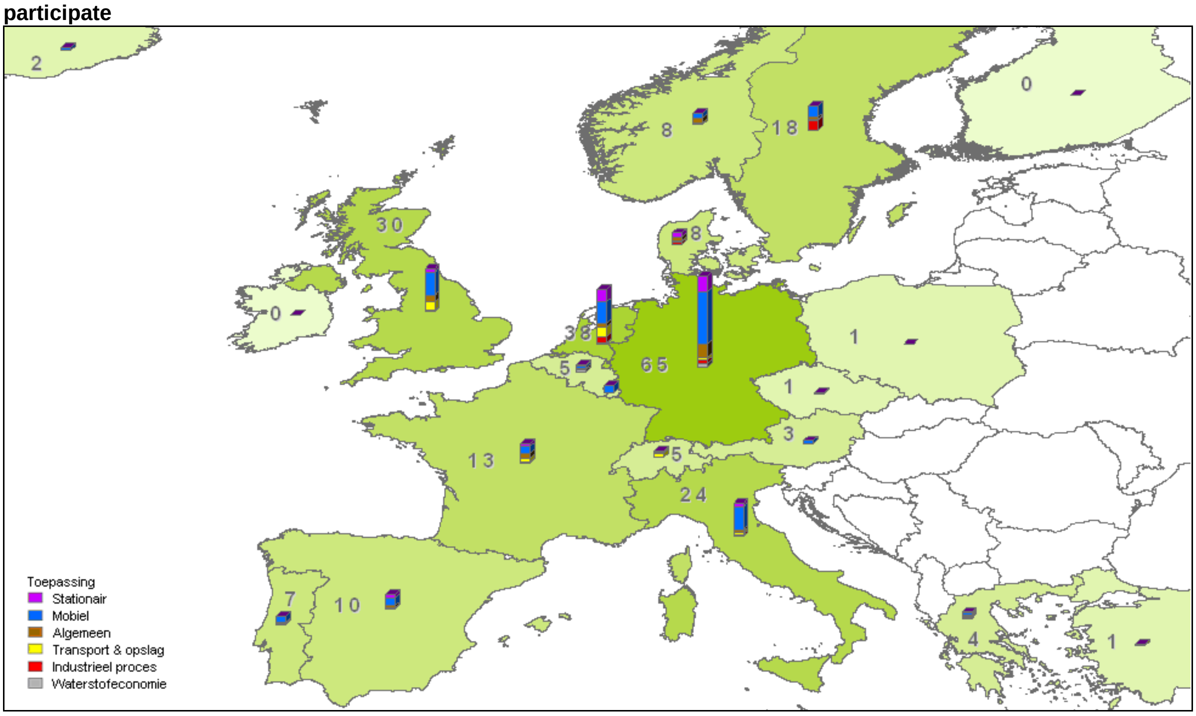


Translation legenda: Technologieën-Technologies, Opslag-Storage, Transport-Transport, Verbruik-Usage, Productie-Production, Waterstofeconomie-Hydrogen economy

The countries with which the Netherlands has the most intensive collaboration in European projects are Germany (EUR 65 mln.), the UK (EUR 30 mln.), Italy (EUR 24 mln.), and Sweden (EUR 18 mln.). Germany is by far the most important partner, particularly for the development of fuel cells, but there is also considerable collaboration with German partners with respect to storage. There is relatively little collaboration between the Netherlands and Germany with respect to hydrogen production.

There is also considerable collaboration with the UK, Italy and Sweden with respect to fuel cells. The Netherlands also works with Italy and Sweden on hydrogen production, particularly biomass-based production. There is generally little collaboration between the Netherlands and France, particularly regarding fuel cells.

Figure 3.6 Geographic division of project costs (<u>per application area</u>) for projects in which Dutch organisations participate



Translation legenda: Toepassing-Applications, Stationair-Stationary, Mobiel-Mobile, Algemeen-General, Transport & opslag-Transport and storage, Industrieel proces-Industrial process, Waterstofeconomie-Hydrogen economy

There is little collaboration between the Netherlands and the UK, Italy, Spain and France with respect to stationary applications. The most important partners in projects focusing on mobile applications include Germany, the UK and Italy. These are the countries with national car manufacturing industries.

European partners

This study found 176 instances where a German partner was involved in projects with one or more Dutch organisations; 69 instances of British partners; 62 Italian; 61 French; 40 Swiss; and 33 Spanish. The largest collaborative partners in Germany, the UK, Italy, Sweden, France and Spain are listed in Table 3.1.

Table 3.1 Most important collaborative partners in countries with which the Netherlands collaborates the most

Germany	UK	Italy	Sweden	France	Spain
Fraunhofer	Johnson Matthey	Ansaldo	Volvo Technology	Centre National de la recherche scientifique	Instituto Nacional de Técnica Aerospacial
Daimler Chrysler AG	Imperial college of science, technology and medicine	ENEA - Ente per le nuove technologie, l'energia e l'ambiente	Kungl Tekniska Hoegskolan	Commissariat a l'energie atomique	Consejo Superior de investigaciones scientificas
Deutsches Zentrum für Luft- und Raumfahrt	BP	Centro Ricerche Fiat	Sydkraft	Air Liquide	Centro de investigaciones energeticas medioambientales y tecnologicas
Forschungszentrum Jülich	Rolls Royce	C.R.F. - Societa Consortile per Azioni	Lunds Universitet	Electricité de France	Foundation inasmet
Rheinisch-Westfälische Technische Hochschule Aachen	Intelligent Energy	Consiglio Nazionale delle Ricerche	Stockholm Universitet	Gaz de France	Instalaciones Inabensa
BMW	University of Newcastle upon Tyne	Politecnico di Torino	Uppsala University	Regienov - Renault recherche et innovation	Chloride Espana
MTU	University of Strathclyde	Universita degli studi	Turbec AB	Peugeot Citroën Automobiles	Elcogas
Forschungszentrum Karlsruhe	University of Warwick	Nuvera Fuel Cells Europe	Värnamo	Institut Francais de Petrole	Ruecker Iberica
L-B-Systemtechnik	Air Products	CESI - Centro Elettrotecnico Sperimentale Italiano Giacinto Motta	Växjö	Association pour la recherche et le developpement des methodes et processus industriels	Universidad Politecnica de Madrid
Technische Universität Hamburg-Harburg	Alstom	De Nora	Alstom	Ecole Nationale Superieure des mines de Paris	Air Liquide

International hydrogen platforms

International

European Technology Platform Hydrogen and Fuel Cells (ETP)

The Netherlands was involved in the creation of ETP. This platform aims to achieve better harmonisation of national and European priorities, and better cohesion of research activities, e.g. by harmonising the agendas for future strategic research e.g., the 7th Framework Program. Platform participants include public, industrial and social organisations. ECN is involved in the Advisory Council, and SenterNovem is involved in the Mirror Group (the connection between national and European programmes). The 'Initiative Groups' include various Dutch hydrogen and fuel cell stakeholders.

Furthermore, various Dutch companies participate in the global normalisation for hydrogen and fuel cell equipment via the NEN (Dutch normalisation institute), i.e. NEC 105 and ISO TC 197.

International Energy Agency (IEA)
The Netherlands also participates in the IEA. This is an autonomous body that was set up by the OECD[2] in 1974 as a result of the energy crisis. The IEA aims to monitor the supply and demand of energy, develop policies to ensure the continuity of the energy supply and regularly publicise their findings.

Within the IEA there are a whole range of international collaborative activities being implemented on the basis of collaborative contracts, the so-called ‘Implementing Agreements’ (IAs); these are managed by Executive Committees (ExCo) that implement selected tasks. Further detailing and implementation take place in the Annexes to these IAs, which report to the ExCo. Countries participating in the IA may also participate in one or more Annexes if they wish to do so. Participation costs are either funded collectively or are paid according to the efforts involved (i.e. cost-sharing or task-sharing).

The Netherlands participates in two IAs: ‘Hydrogen Production and Utilisation’ and ‘Advanced Fuel Cells’. These are task-sharing agreements. SenterNovem and ECN respectively have seats on the ExCos, and various Dutch organisations participate in the Annexes. These international activities aim to increase the efficiency of R&D activities in selected areas and to continually evaluate the most relevant developments, field tests and research subjects.

During the spring of 2003 the IEA initiated the ‘Hydrogen Coordination Group’ (HCG), in which over 25 countries participate, and where several relevant IAs are represented. The HCG aims to implement studies and activities that are of collective and structural importance for hydrogen technology. SenterNovem represents the Netherlands and is co-chair of this group.

[2] Organisation for Economic Co-operation and Development

European policy funds

The EU has supported research projects, technological development and demonstration projects (RTD) for hydrogen technology and fuel cells since the 1970s.

The European Framework Programme (FP5, FP6)

FP2 started by spending EUR 8 million on such projects. This subsidy has since increased to around EUR 130 million for FP5 (1999-2002).

FP5 projects concern: fuel cells (SOFC, MCFC, DMFC, PEMFC), polymer fuel cells (PEMFC), reformers, fuel cell and hydrogen networks, hydrogen (production, sustainable production and acceptance) and related material research.

The hydrogen-related research within FP6 falls under the theme ‘Sustainable Development, Global Change and Ecosystems: Sustainable Energy Systems’. The available budget for this research amounts to EUR 810 million. The calls for tender are published by DG Transport and Energy (short to medium term), and DG Research (long-term projects).

Dutch participation in FP5 and FP6

During the period 1999-2003 European companies, knowledge institutes and universities spent EUR 441 million in implementing projects under the European Framework Programme. The Dutch contribution amounted to EUR 38 million (9%). The Netherlands was involved in 47 of the 96 projects.

Table 4.1 provides an overview of the European policy funds for encouraging hydrogen research in the Netherlands.

Table 4.1 European policy funds from FP5 and FP6

Total policy funds of Dutch participants (EUR mln.)		Framework Programme		
Year		FP5	FP6	Total
	1999	3.3		3.3
	2000	3.9		3.9
	2001	4.2		4.2
	2002	2.3		2.3
	2003	0.03	6.6	6.6
Total		*13.7*	*6.6*	*20.3*

During the period 1998-2002 a total of EUR 13.7 million was spent on funding hydrogen projects under FP5. Within FP6, EUR 6.6 million was allocated as policy funds during 2003 alone, and this programme is due to run up to 2007.

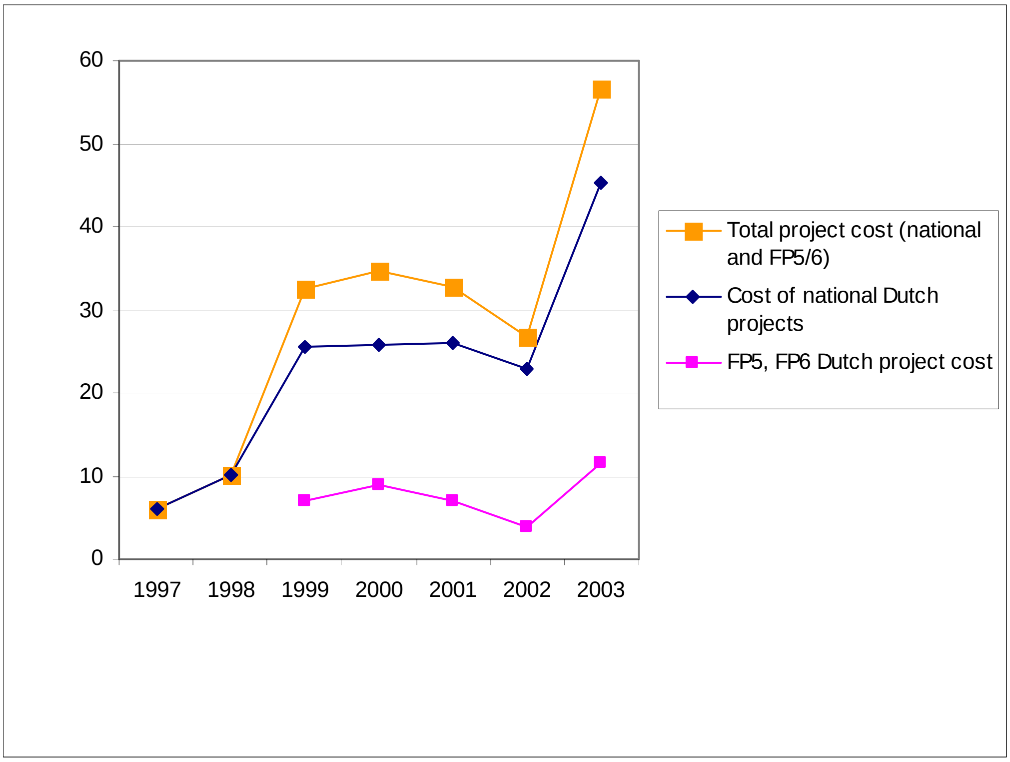
Part 3 Conclusions, Trends and Policy

Conclusions, trends and policy

Stakeholders, policy funds and investments

In total this study found 325 relevant hydrogen and fuel cell projects in 2002 and 2003. Three-quarters of the national projects involve using hydrogen as an energy carrier. The remainder are hydrogen industry projects. The total project costs totalled EUR 83.5 milion for this period (2002-2003). Since 1997 the total annual project costs show a clear upward curve.

Project costs per year (mln. EUR)



Important Dutch stakeholders, both in the national and European research projects include: ECN, Shell, Nedstack, Hexion, Agrotechnology & Food sciences, TNO, TU Delft, TU Eindhoven and Sparqle. These Dutch stakeholders have increasing amounts of policy funds available that the government allocates for hydrogen development. Previous sections of this report noted that the policy funds for hydrogen technology are increasing rapidly. The national policy funds totalled EUR 22.5 million for the period 2002-2003. The EU's Fifth Framework Programme made EUR 13.7 million in subsidies to Dutch participants available for the period 1999-2002. In 2003 these stakeholders received EUR 6.6 million from the Sixth Framework Programme.

Investering in applications

Most of these funds are invested in hydrogen production technologies (EUR 35 million for 2002-2003), followed by usage technologies (EUR 19 million in 2002-2003). Another EUR 7 million was also spent on storage technologies (2002-2003). Production technologies concentrate on production from fossil sources: reforming (42%), purifying hydrogen and electrolysis. Fuel cells are by far the most important subject in usage technologies. Hydrogen storage focuses on storage in chemical-physical form (metal-hydrides, nanotubes, gas hydrates). Infrastructure with distribution points and fuel additives are the most important points within the transport and distribution technologies.

Stationary hydrogen applications are often studied

With respect to application areas, it is remarkable that stationary applications of hydrogen technology (EUR 18 million in 2002-2003) are so often studied. This is in contrast to general European opinion. The most important stationary application is small-scale production of heat and electricity (around two-thirds of the project costs in this area); the remaining one-third is spent on large-scale electricity and heat production. Mobile applications take second place (EUR 14 million in 2002-2003), the most important of these being road vehicles, which takes up 85% of the project costs. The rest concerns mobile applications for the space and shipping industries. There are also many projects that do not specifically concern any single stationary or mobile application, but these are relevant for both types of applications.

Activities per technology area
The total project costs for hydrogen projects in the Netherlands have almost doubled. Over the past two years the upward curve has increased considerably, particularly with respect to hydrogen production projects. This is partially related to the increased demand for industrial hydrogen. Research into microbiological production of hydrogen is still in its infancy.

Project types
Hydrogen projects can primarily be classed as industrial research. Most R&D concerns industrial research. However, there are also a considerable number of fundamental research projects. Since 2001 several practical experiments and a few demonstration projects have also been conducted. Against expectations, the past few years have seen no experiments started into local hydrogen networks. However, the number of demonstration projects is expected to increase over the next few years. These will be supported by the new Dutch programs: Energy Transition scheme (UKR) and the EOS Demonstration scheme.

Industrial research tops the list of national hydrogen projects

European focus on hydrogen
All previous FP5 (1999-2002) and the ongoing FP6 (2003) projects have been inventoried using the EU's CORDIS database (www.cordis.lu). This allowed an analysis of all European companies, knowledge institues and universities working on hydrogen. The Netherlands is involved in 47 of the 96 European projects.

International position of Dutch knowledge institutes and companies
The Netherlands holds a strong position with respect to gas transport and distribution knowledge. This report has confirmed this advantage through its analysis of the EU's Framework Programmes. ECN has a strong international knowledge position; this is shown by the institutes participation in the European Framework Programmes. The Netherlands spends EUR 11 million on EU projects (1999-2003) and thereby takes second place in the list of EU countries.

The Netherlands holds a strong position with respect to gas transport and distribution

One-third of the research projects confirm that many companies are working together with German companies. Interviews have shown that the German production industry has focused more on hydrogen technology, and even the knowledge institutes take a more practical approach. Analysis of FP5 and FP6 shows that Germany invests more in hydrogen technology than any other country in Europe.

Technology trends: new and ceased developments

Trends in mobile applications and fuel cells:
In recent years the core motives to use hydrogen in traction and stationary applications gained importance. Both the concerns on environmental issues and the availability of suitable fuels ask for

transition to clear CO2 free use of fossil fuels and increased deployment of renewable sources. Hydrogen can be the linking fuel. Various system concepts are now being tested in some realistic dimensions. Some conclusions can prudently be drawn.

Hydrogen storage ‘on-board’ instead of ‘on-board reforming’.
It would appear that the large car manufacturers no longer choose ‘on-board reforming’. Converting (liquid) hydrocarbons into hydrogen is fairly complex and costly for the car owner, and the technology is not yet developed far enough that it can be easily integrated into a car. This conclusion by car manufacturers, leads to have pure hydrogen on-board and increases the need to develop efficient storage systems and gives the relative temperature PEM fuel cells a distinct advantage.

Working towards efficient loads rather than peak loads.
Over the past few years, fuel cell development for mobile applications has primarily focused on achieving a particular (peak) capacity. However, the fuel cell does not function at its most efficient at this peak capacity. System constraints however would appreciate higher temperature than the usual 80 ˚C. The car manufacturers have chosen another strategy. A lower current density by fuel cells than the maximum capacity, e.g. 25% rather than the maximum, increases the efficiency and extends the lifespan of the fuel cell. The greater the efficiency, the less residual heat. This is extremely favourable for mobile applications as consequently less hydrogen needs to be stored on board, and the radiators can be much smaller sized.

Increased demand for additional electrical power in road vehicules.
Cars are requiring increasingly more electricity on board, due to the growing use of computers, DVDs and other (navigational) equipment in the car. This trend helps the introduction of fuel cell systems for mobile applications or additional electrical power (APS).

Suitable for use in portable consumer electronics.
We will probably first widely see applications of fuel cells in small portable electronics, such as cellphones and computers. These applications do not require any large-scale system changes. In Japan, researchers are currently focusing on portable consumer electronics. The first ‘fuel cell battery’ (methanol) has already been launched by Toshiba.

Trends in stationary fuel cell applications:

PEM: high working temperature, resists degradation, longer lifespan.
There are three developments with respect to PEM fuel cells. Firstly, researchers are trying to increase the working temperature of these fuel cells. This would mean that, in stationary applications, the fuel cell could meet the required heat demand (especially the temperature level) without additional hydrogen burners or heat pumps being required. The working temperature is currently around 80˚C. Higher temperatures cause degradation of the polymer. The second development concerns making the PEM fuel cell resistent to toxic components, such as sulphur compounds and carbon monoxide. A certain amount of resistance to these components is required, particularly when a fuel cell is switched directly to a reformer. The third development concerns the lifespan of the PEM fuel cell. There are various mechanisms that degrade a PEM fuel cell. Understanding these mechamisms should lead to improvements in the polymer, improved processing of the fuel cell system, or even result in the development of a new polymer.

Virtual power plants.
It is possible to centrally control and monitor decentralised stationary fuel cell systems (in houses or flats). These decentralised systems together form a so called ‘virtual power plant’. Depending on the scale and possibilities to use the heat produced on the spot, this could be economically viable. In the future these virtual power plants will also be able to run on various energy sources.

Part-load operation provides greater efficiency and opportunities for emergency electrical power.
A fuel cell running at partial capacity is more efficient than one working at full capacity. This is in contrast to conventional techniques such as gas engines and gas turbines. If more capacity is required, the electrical production of the fuel cell can be increased very quickly. Running at part-load is therefore energetically favourable and can also provide a solution to sudden demands for more power.

SOFC: new stack concepts, extending lifespan, improving efficiency.
With respect to the SOFC fuel cell, research in the Netherlands has primarily been carried out by ECN. This research institute has a good knowledge position in Europe on this subject. New stack concepts, lifespan and efficiency are central to this research. More efficiency can be obtained, for example, by reducing the operating temperature of the SOFC.

Due to its high operating temperature (600-1000˚C) and fuelled by various gases, the SOFC is fairly resistant to polluting components. The cell is also suitable for integration into certain chemical and industrial processes at a high temperature.

Trends regarding hydrogen storage:

More demand for hydrogen underlines the importance of hydrogen storage, problem solved?
Various forms of hydrogen states are strongly under research. As previously mentioned, the emphasis on on-board storage of pure hydrogen has increased since the car manufacturers have chosen for this system. However, researchers are still planning to store high-pressure hydrogen in gaseous form. A number of stakeholders have indicated that interest in hydrogen developments are closely monitored by several SMEs who develop parts for energy systems in the built environment. Entrepeneurs are interested to see whether hydrogen can be given a place in their product portfolio, and therefore regularly contact the main stakeholders for information.
Liquid storage has interesting properties as for the storage howerver there is a drawback, the high energy cost when liquifying hydrogen.

Storage in metal hydrides.
Various hydrides, compound of metals and hydrogen, have always been seen as the solution to the storage problem. A car with a metal hydride storage tank will need new suspension due to the incredible weight of the storage tank, but there are also applications where this weight does not constitute a problem. An example is a new German submarine that is fitted with a 30-50 kW Siemens fuel cell. The hydrogen is stored in metal hydride cylinders. Another problem of storing hydrogen in metal hydrides concerns storage and emission speeds.

Storage in hydrogen hydrates.
A new possibility concerns hydrogen storage in hydrogen hydrates. TU Delft has developed a method to form hydrates at a certain temperature and pressure. This research is still in the early stages.

Innovative storage systems important for the breakthrough to a hydrogen economy.
Although storage generally forms a problem, it is not yet decelerating the development of a hydrogen economy. Under the ACTS Sustainable Hydrogen programme, a number of Dutch knowledge institutes have begun researching hydrogen storage.

In Europe a lot of attention is being paid to hydrogen storage. This could be an interesting area for the Netherlands to develop new activities

Trends in industrial processing:

Demand for hydrogen by refineries.

In order to meet the new European norms for diesel, refineries must now remove more sulphur than ever before. This means that the demand for hydrogen by refineries has increased. Consequently, various oil companies and engineering firms have recently extended and optimised large-scale processes for producing hydrogen and researching new possibilities to achieve this.

Industrial hydrogen producers are looking at various new applications.
Industrial gas manufacturers such as Hoek Loos (Linde), Air Products and Air Liquide have recently become interested in hydrogen energy applications. These manufacturers see a clear market and tend to participate in projects.

Typical Dutch trends:

The extensive natural gas and electricity grids make micro-cogeneration plants a good opportunity for the Netherlands

Micro-cogeneration.
This can contribute to energy conservation in all homes. It is extremely suitable for the Netherlands, with its many blocks of flats and rows of rental homes (housing associations). This therefore forms a good opportunity, combined with the extensive infrastructure of natural gas and electricity grids. The Netherlands have considerable knowledge of gas infrastructure, and engineering companies have experience of installing industrial networks. The Rijnmond area seems particularly suitable due to the availability of large amounts of hydrogen. Micro-cogeneration plants are currently being considered in several regional locations.

Integrating with the chemical industry.
Nedstack and Akzo Nobel have initiated a project to develop a 50 MW power plant (PEM fuel cell), in which they plan to couple a fuel cell power plant to a chlorine manufacturing plant. The Netherlands' position on PEM fuel cells is quite strong and we have a key player in Nedstack.

The SOFC can be integrated into high-temperature processes. ECN has a good position in Europe, with respect to SOFC technology. Spin-offs from this research are currently being developed in collaboration with industry.

Producing hydrogen from biomass.
The Netherlands' position concerning the production of hydrogen from biomass is strong – there are several knowledge institutes currently conducting research into this subject. The industriousness of these Dutch activities is quite nearing for pyrolysis, but for supercritical hydrolysis and biological processes are still in its infancy stage.

Inland shipping industry.
The Dutch inland shipping industry has shown an interest in limiting emissions of harmful exhaust gases. There are a number of possibilities here: reforming gas oil into hydrogen, and running the propulsion or on-board electrical systems via a fuel cell. TNO, Stork Special Products, the TU Delft and the VNSI (Netherlands Shipbuilding Industry Association) are all actively working on this subject. The Ministry of Defence is also interested in converting shipping diesel into hydrogen and then electricity.

Appendix 1: Coding for hydrogen technology projects used in this report

The projects discovered during this study have been allocated a code according to the following factors: technology area, application area, application scale, company size, system, development phase, and the sector. A number of questions were used to provide the following qualifications: focus on hydrogen technology, knowledge institute, consultancy, material development, sensors, absorption and membranes.

Technology area (with sub-areas)	Application	Scale	System	J - Yes N - No	Development phase	Sec-tor	Size
P* – Hydrogen production PA – waste / residual product PB – biomass (thermal) PE – electrolysis PF – fossil source (reforming) PM – microbiological PZ – pure hydrogen PO – other	**M* – Mobile** MA – car MD – portable MF – (motor)bike MR – space travel MS – shipping MV – aviation	C – central D – decentral	Combina-tion of : P: produc-tion O: storage T: transport & distrib. V: use NO: no system	Focus on hydrogen economy (spin off) Knowledge institute Consultancy Material development Absorption Sensors Membranes FT - Fisher Tropsch UP – petrochem.	H - feasibility FO – fundamental research project IO –industrial research project P – Practical tests D – demonstration project T – application project	SBI-code	Number of employees in the following categories: A: 1-9 B: 10-49 C: 50-99 D: 100-249 E: 250-499 F: 500-999 G: 1.000-9.999 H: 10.000-24.999 I: >25.000
O* – Hydrogen storage OC – chemical physical form (solid) OG – compressed OV – liquid OO – other	**S* – Stationary** SG – electricity & heat buildings / homes / small scale SR – space travel SE – electricity & heat production (large scale)	Type of fuel cell: PEM SOFC METH MCFC ONB: unknown NO: no fuel cell					
T* – H_2 transport & distribution TA – small systems, valves and pipes TB – additives TH – networks, large infrastructure, distrib. points TO – other	**T* – Transport & storage** TC – storing bottles, packs, barrels (small) TN - networks, distribution TT– refuelling stations TV – transporting hydrogen (large) TG – large-scale transport & storage						
V* – Usage VC – chemical VB – fuel cells (METH, PEM, SOFC) VK – boilers, burners VV – turbines, combustion engines VO – other	**U* – Industrial process** UC – chemical ind. UI – ind. process						
	B - General						
WO – hydrogen economy studies	WO – hydrogen economy studies						

The category 'Other' is given to projects that do not fall within a specific technology area. 'General' refers to projects to do not focus on one specific application, but combine several applications.

Appendix 2: List of abbreviations used in collaboration maps

Dutch collaborative organisations

Organisation	Abbrev.
Agromiscanthus	Agrom
Akzo Nobel	AkzoN
Atlas Copco Compressors Nederland B.V.	Atlas
ATO	ATO
Ballast Nedam	Balla
Compressor Systems Holland	Compr
Corus	Corus
Duynie	Duyni
ECN	ECN
Ecofys	Ecofy
Enertec	Entec
Grontmij Water & Reststoffen	Gront
Hexion	Hexio
LTO Groeiservice	LTO
Nedstack	Nedst
NUON	NUON
Promikron	Promi
RU Groningen	RUG
Shell	Shell
Sparqle	Sparq
Stork	Stork
Techno Invent	TechI
Technogrow	TechG
Teesing	Teesi
TNO	TNO
Urschel Int.	Ursch
Van Vliet Recycling	Vliet
WUR (Wageningen University)	WUR
BTG	BTG
Cogas	Cogas
DuCH4	DuCH4
Gipec	Gipec
KUN	KUN
RUL	RUL
Siemens	Sieme
Technical University Delft	TUD
Technical University Eindhoven	TUE
Twente University	Utwen
VU	VU

Most important European stakeholders

Organisation	Abbrev.
Rolls Royce (UK)	Rolls
ECN (NL)	ecn
Daimler Chrysler (Germany)	daim
Johnson Matthey (UK)	jm
Commissariat à l'Energie Atomique (France)	cea
Ansaldo (Italy)	ansal
MTU (Germany)	mtu
Centre National de la Recherche Scientifique (France)	cnrs
Fraunhofer (Germany)	fraun
Forschungszentrum Jülich (Germany)	juel
Air Liquide (France)	airl
Volvo Technology (Sweden)	volvo
Nederlandse Gasunie (NL)	gasu
BP (UK)	bp
Risoe National Laboratory (Denmark)	riso
Autobus de la Ville de Luxembourg	avlu
GVB Amsterdam (NL)	gvb
Stuttgartner Strassenbahn (Germany)	ssag
Centro Ricerche Fiat (Italy)	fiat
Empresa Municipal de Transportes (Spain)	emt
London Bus Services	lonbu
Norsk Hydro (Norway)	hydro
Transports de Barcelona	tbarq
Energie Baden-Wurttemberg	ebwa