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HYCOM pre-feasibility study. Final report

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Publication date:
2005

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Peteves, S. D., Shaw, S., Soria, A., Iacobazzi, A., Mario, F. D., Hasenauer, U., ... Nørgård, P. B. (2005). HYCOM pre-feasibility study. Final report. Petten: European Commission. EUR-21575

HYCOM PRE - FEASIBILITY STUDY

Final Report

Prepared by

ENEA, Italy

Fraunhofer ISI, Germany

Risø National Laboratory, Denmark

A study commissioned and guided by the
European Commission, DG Joint Research Centre
Institute for Energy and Institute for Prospective Technological Studies

Coordinated by S.D. Peteves, S. Shaw and A. Soria

March 2005

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

EUR 21575 EN

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Special emphasis is given to the security of energy supply and to sustainable and safe energy production.

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Luxembourg: Office for Official Publications of the European Communities, 2005

EUR 21575 EN

This report was prepared by the above-mentioned organisations for the Directorate-General Joint Research Centre / Sustainable Energy Technologies Reference and Information System (SETRIS) and represents the views of these organisations. These views have not been adopted or in any way approved by the Commission and should not be relied upon as a statement of the Commission's or the Directorate-General's views.

FOREWORD

The Sustainable Energy Technologies Reference and Information System (SETRIS) of the DG JRC, through the actions at the Institute for Energy (IE) and the Institute for Prospective Technological Studies (IPTS), commissioned this study on the HyCom (HYdrogen COMunities) concept, to its European Science and Technology Observatory (ESTO) Network, upon a request from its partner DG RTD/J (Sustainable Energy Systems). This report presents the work of the ESTO team that took place in the May-to-October 2004 period under the guidance of SETRIS.

This report looks at the establishment of strategically located "hydrogen communities", producing hydrogen from various primary energy sources, and using it for heat and electricity production and as a transportation fuel. It investigates the main technical, economic, social and environmental aspects as well as financial and regulatory barriers associated with the creation and operation of "hydrogen communities". It also proposes a number of concepts for Hydrogen Communities and criteria with which a Hydrogen Community should be evaluated. The study is not in any way intended to be prescriptive.

The study and its findings have been presented in 2004 at two seminars in which a large number of stakeholders and European Commission Services (DGs JRC, RTD and TREN) participated. The study is very thorough and comprehensive and catalysed much thought and discussions amongst the various stakeholders.

It should be noted, in particular with respect to the conceptualization of Hydrogen Communities and the proposals for programme design laid out in the study, that the specific proposals of the study are not to be regarded as final determinants or indicative of a "recipe" for the conceptualization and establishment of a hydrogen community. The study is however considered to provide valuable input towards the definition of a Hydrogen Communities initiative.

It should be noted that while the HYCOM initiative may be portrayed to some extent here as a demonstration initiative, emphasis should also be given to aspects related to technological research and development and the interaction between applied research and demonstration.

The importance of involvement and consultation of industrial stakeholders to the HYCOM initiative, in particular with respect to new technological applications, cannot be stressed enough. Furthermore, it should be recognized that the realization of an industrial critical mass, and thus an "industrial shift", is central to the realization of the HYCOM initiative.

The coordinators of this report feel it necessary to mention that while the approach of the report is to formulate different types of Hydrogen Communities, the *criteria* that would lead to the definition of such communities are considered to be of even greater significance. Moreover, we consider that, while the characteristics of an individual hydrogen community are important, it is the combination of activities across all hydrogen communities in Europe as a whole that is key to the overall success of an integrated European Hydrogen Communities initiative, which will ensure that the development and deployment of technologies continues even after the HYCOM programme has ended. The creation of synergies and complementary activities across communities, while ensuring that community activities are tailored to local characteristics, is therefore be central to the HYCOM programme.

Co-ordinated by

S.D. Peteves, S. Shaw and A. Soria

DG – JRC, IE and IPTS
22 February 2005

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Executive Summary

The Quick-start Programme of the European Initiative for Growth identifies the Hydrogen Economy as one of the key areas for investment in the medium term (2004-2015). Two hydrogen related programmes (or projects) have been outlined:

- **Hydrogen Communities (HyCom).** The creation of a limited number of strategically sited stand-alone "hydrogen communities", producing hydrogen from various primary sources, mostly renewables, and using it for heat and electricity production and as fuel for vehicles, is the main goal of this project (with an indicative budget of ca.1.5 billion EUR).
- **Hydrogen and Power Generation (Hypogen).** A major component will be the first large scale test facility for production of hydrogen and electricity from de-carbonised fossil fuels, with geological storage of CO_2. (with an indicative budget of ca.1.3 billion EUR).

In April 2004, the European Science and Technology Observatory (ESTO) Network of the DG Joint Research Centre of the European Commission made a call to conduct two pre-feasibility studies of HyCom and Hypogen. The studies were awarded to a consortium of ENEA (I), Risø National Laboratory (DK) and Frauenhofer ISI (D). The studies were led by DG-JRC and conducted during the period 1 June 2004 to 1 October 2004, of which Risø National Laboratory was responsible for the HyCom study and ENEA for the Hypogen study. A kick-off meeting was held in Brussels with selected stakeholders on 24 and 25 May 2004 to take into account the views and experiences from key on-going EU projects. Draft summary findings were presented and discussed at seminars in Brussels on 18 October 2004 and 29 October 2004. Comments from these seminars have been considered in the final reports as well as from the project sponsors, the institutes for Energy and for Prospective Technological Studies of DG JRC.

This report presents the results from the pre-feasibility study on HyCom. The results from the Hypogen study are presented in a separate report.

The **objectives of the pre-feasibility study** for the HyCom Initiative were more specifically:

- To provide an overview about technological options and financial, regulatory and other barriers;
- To clarify key issues of the Initiative;
- To identify success factors and risks for hydrogen communities;
- To provide options and recommendations.

The results from the study are expected to stimulate discussions and exchange among all those involved for leading eventually to a more precisely defined concept of Hycom and for providing guidance to the European Commission in its planning of the next steps of the Initiative.

The main conclusions and recommendations from the study address:

- The context in which HyCom will be launched;
- Technology assessment of hydrogen technologies;
- Conceptualisation of Hydrogen Community and its key success criteria;
- Proposals for programme design.

The methodology used is a combination of desk studies and of 19 in-depth case studies of transport, stationary and other demonstration projects in Europe, Japan and Canada supplemented with a number of follow-up interviews with programme officers and other experts.

The Context for HyCom

Regarding the context in which HyCom will be launched, the study points to the need for further clarification on the following topics:

- **Waiting for a European research and deployment strategy.** The HyCom Initiative still waits for the development of a broad and far-reaching hydrogen and fuel cell research and deployment strategy by the European Partnership for Hydrogen and Fuel Cell Technologies. This strategic work is still ongoing (November 2004). It is also demanding to translate the strategies into more detailed research, development and deployment programmes at European level. In particular, it takes time and requires further alignment mechanisms to have some impact on national research priorities and activities relevant to HyCom. *We recommend* that this topic be further evaluated over the next 1-2 years.
- **Finding the right financial balance between research, both basic and applied, and demonstration activities.** The announcement of 1.5 billion EUR over the next 10 years (as suggested by the Commission and endorsed by the Council) to set up a limited number of hydrogen communities has to be put into perspective of the needs for basic and applied research in hydrogen and fuel cell technologies before these can be widely tested and validated. It is crucial that no duplication of activities takes place, but that new knowledge is produced in order to bring the technologies to the market place. *We recommend* that this topic be analysed much more thoroughly and discussed with the Technology Platform representatives as well as with national research managers in Europe and elsewhere.
- **Keeping complexity low in financial engineering.** When combing different funding schemes as, for example, Framework Programme funds, European Investment Bank funds, Structural Funds and national research funds, there is a risk of increasing the complexity of the overall financial engineering of the project. This is especially the case when combining EU schemes, which individually are regarded as highly complex. *We recommend* that experiences in setting up facilitating bodies in Europe and elsewhere be further investigated.
- **Clarifying the goal and management for the HyCom Initiative**. It is necessary to clarify the specific objectives leading to the overall goal of the HyCom Initiative as well as the most appropriate design, management and implementation of the Initiative. *We recommend* analysing this further, for example, by evaluating and assessing different design and management structures of strategic RD&D programmes as well as regional development programmes in Europe and elsewhere. Key assessment topic should be on the effectiveness and efficiency of the programme management to build the European Research Area in the field of hydrogen and fuel cell technologies. Likewise, a regular information service is needed to inform on RD&D activities at national and EU level and elsewhere as well as a technology watch on fuel cell and hydrogen technologies.

Hydrogen Energy Technologies

The main energy-related society problems and needs to be met by the emerging energy technologies are:

- The sustainability of the energy system;
- The environmental impact of energy consumptions; and
- The security of energy supply.

The main energy system problems addressed by the hydrogen economy are:

- The integration of large-scale intermittent renewable energy sources;
- The flexibility in the integrated energy system by the link provided between the electricity and the 'pipeline fuels'; and
- The energy path from renewable energy sources to the transport sector substituting the dependencies of fossil fuels.

The main energy challenges related to the transport services are: sustainability, fuel supply, greenhouse gas emissions and local air pollution.

The overall challenge for the hydrogen technologies is to become *cost-competitive*. None of the hydrogen energy technologies are yet technical and economic competitive to alternative solutions to the problems and needs to be addressed. The hydrogen energy technologies in general still need further development – both the technical and the economic performances must be significantly improved – and the necessary development cannot be expected to take place by boosting the industry only, but needs further generation of basic knowledge, research and innovation, in a combination of technology push and market pull.

The main technical barriers are related to the storage of hydrogen and the lifetime and robustness of the fuel cells. The current state of the hydrogen technology development cannot justify the establishing of widespread hydrogen infrastructure.

A number of hydrogen technologies have been developed for different applications and to different levels, including various hybrid transition technologies – each of the technologies with their specific advantages and disadvantages. The long-term perspective and the success of hydrogen as energy carrier is closely linked to the development of reliable and cost-efficient fuel cell technologies. However, no single hydrogen technology and no single hydrogen rich energy carrier (Hy-fuel) have yet been identified as the most promising. *We recommend* testing different pathways for Hydrogen Communities and hydrogen economies.

The hydrogen technologies must be evaluated in terms of energy, emission and cost in the energy system context and must include the entire energy chain from the primary energy resource to the final energy service (from source to service - S2S).

In a first (10 years) establishment phase, the hydrogen economies are expected to develop their own new business areas in niche applications, suited and optimised for the hydrogen technologies specific characteristics where the price is not the only determining parameter and where the competitions are lowest. In the establishing phase:

- The supply of hydrogen is secured by public support and subsidies, if necessary;
- The use of hydrogen is stimulated and established through the use of hydrogen in fuel mixes or as substitutes to other fuels in mature technologies and applications – like, for example, feeding hydrogen into the natural gas network and running internal combustion engines on partly or pure hydrogen;
- The development of attractive hydrogen storage technologies is accelerated by specific effort and support;
- Specific hydrogen technologies for (new) niche business areas, suitable for the specific characteristics of hydrogen technologies, are developed through the necessary support;
- Standards are developed in parallel as an integrated part of the technology development; and
- The necessary legal framework is established by the authorities;
- A widespread hydrogen infrastructure is not foreseen within the next 10-20 years.

Conceptualisation of Hydrogen Community and Its Key Success Factors

A **Hydrogen Community** is a group of professionals that together with local and other people have shared interests and perform activities in hydrogen and fuel cell technologies for the common learning and good.

The activities are localised in a particular area defined by technical, geographical or socio-economic boundaries (driving range, borders, technical or economic systems, etc.). Knowledge and information linkages are not confined to these boundaries, but go beyond and reach out for exchange of knowledge and knowledge-sharing with external and international stakeholders. The Hydrogen Community goes beyond single demonstration projects and is characterised by over time building a critical mass of different hydrogen and fuel cell research, development and demonstration activities through geographical concentration, specialisation supported by a common vision and strategy, good co-operation with local and other stakeholders as well as good partnership among key stakeholders.

Clarification of all technical, economic, financial, and other aspects is made in feasibility studies, which also assure good safety and compliance with all safety standards and regulations. Quality in test and validation of technologies is at the core of the Hydrogen Community and this is sustained by a good learning environment with links to knowledge institutions, other similar projects, etc. Last, but not least, visibility and outreach is important for a powerful Hydrogen Community.

Key success and risk factors are transformed into what constitutes a good Hydrogen Community. *We recommend* the following criteria.

Good partnership and co-operation of key stakeholders in the project. Such a partnership consists often of the key technology providers and users in order to have the critical knowledge and also hardware represented in the project. But key stakeholders may also include local authorities and regional representatives. It takes time to find and commit highly competent partners with complementary skills and it is an integrated part of preparing and designing the project. Good partnership rests on liberty to choose one’s own partners, decide on responsibility, and activities. This does not contradict research funding eligibility criteria of including different types of actors and locations.

Good co-operation with the local community and local authorities. Establishing good relations with internal and external stakeholders starts already in the preparation phase. Foresight and strategy processes offer a good opportunity to involve local stakeholders and the general public in defining the visions and instruments needed to fulfil these. There are many levels in this. The local community is also among the future users of the technology and establishing a good dialogue from the very beginning is a feasible way to create public acceptance. To take out the permits and get all the safety issues right implies close co-operation with local authorities. Also by pooling resources and risks, and developing complementary functions, communities may achieve economies of scale and scope in the development of demonstrated technologies and related technologies. While geographical proximity matters for informal knowledge exchange, international links are likewise crucial to the further development.

Clarification of all technical, economic, financial, legal and other aspects. Good demonstrations need good preparation, clarification of many aspects and the necessary adaptations to real life conditions. Many of the unexpected challenges are related to the preparation of the project – the time and effort needed to take out all permits and approvals, the financial burden, a good prototype, the adaptation of technology to comply with local safety requirements, and the availability of the required components, technologies, systems, and artefacts. The overall economics of the project and the financial burden should not be underestimated and requires good studies and management.

Good safety and compliance with all safety standards and regulations. This is an important part of the preparation of the project as there are no standard safety rules or procedures yet in Europe for hydrogen fuelling stations, hydrogen vehicles, stationary combined heat and power plants and other applications. Any new technology that will be introduced in large-scale transport and energy infrastructures has at least to be as safe as the established technology and maybe even better. A smooth and effective permit process has often to integrate a variety of regulations and safety codes and standards and may rely on good co-operation with safety and certification bodies. Emergency preparedness is also an integrated part of managing safety issues.

Quality in test and validation of technologies is crucial in bringing the technologies to the market. Some of the topics listed below and the entire project portfolio will:

- Support the development of efficient technologies (in terms of sustainability, energy, CO_2 emission and cost) for production of hydrogen and other Hy-fuels – in particular decentralised production technologies based on renewable sources that is not more efficient used for electricity generation (e.g., surplus wind power, solar energy and thermal energy).
- Support the development of efficient technologies (in terms of sustainability, energy, CO_2 emission and cost) for storage of hydrogen. The lack of satisfactory hydrogen storage technologies (including the necessary conditioning) is a crucial barrier for the break-through of the hydrogen technologies.
- Support the development of the individual components and technologies related to the infrastructure (vessels, tanks, pipelines, compressors, pumping stations, etc.). A widespread development and extension of the hydrogen infrastructure should await a more clear indication of hydrogen as a general energy carrier in the integrated energy system. In addition, a decentralised hydrogen production will eliminate, reduce or change the need for a separate widespread hydrogen infrastructure. One kilometre pipeline demonstrating improved performance should be preferred for 1000 km pipeline building on known technology.
- Support the development of the fuel cell technologies. The success of hydrogen energy is highly dependent on the development of attractive fuel cell technologies (both in terms of technical performance and cost) and the success of the fuel cell applications is dependent on the easy access to appropriate fuels.
- Give priority to projects that include pre-activities, comprehensive laboratory and prototype tests, a step-by-step approach, and a flexibility to include new experiences and knowledge gained during the project.
- Assure that the technology solutions are robust to the changing conditions.
- Favour a variety of technologies, Hy-fuels, solutions and applications. As none of the technologies can be pointed out as the most promising, it is important to be open to all the possibilities.
- Address (for each project, at least one of) the social problems and technical barriers listed and demonstrate a way to overcome the barrier(s). The projects should not just move a problem from one point in the energy chain to another point.
- Demonstrate new technological improvements. All the individual projects should include the demonstration of improvements on a least one of the technical or economic parameters. It is not sufficient, for example, to demonstrate that buses can run on hydrogen – it must be demonstrated that the buses can run longer per fuel unit, that the fuel cell have a longer lifetime, that the fuel cells are less sensitive to contaminations in the fuel or similar measures.
- Contribute to the development of relevant international standards and common regulations for the hydrogen technologies. This might be achieved through the involvement of the relevant bodies.

Good learning environment. Special focus should be on the sequencing of laboratory verification, early field tests, demonstrations and projects and feed back from demonstrations to R&D programmes, especially in the most challenging areas. Close co-operation with research institutes or universities is especially needed in those fields where there still are major research elements included as, for example, fuel cells, system integration, etc. Demonstrations have to test and validate new technologies, and the knowledge gathered during the preparation and implementation of the project has to be used to improve the technologies (and in some cases to substitute the technology by better more promising ones) and test them further in another context and in the ultimate stage bring them into the market. This requires good monitoring and testing of the demonstration, comprising all relevant components, systems, and economics. Exchange of knowledge and exchange of experience with other similar activities in other parts of Europe or elsewhere should be a prioritised activity in communities and individual projects. Part of a good learning environment is public outreach and educational programmes. Public perception of hydrogen vehicles and other applications is key to the market introduction of these technologies. Hydrogen Communities may undergo different developments dependent on the differences in their point of departure and their boundaries. **Different types of Communities** are characterised by:

- Geographical concentration;
- Specialisation supported by a common vision and strategy;
- Step-by-step development of hydrogen and fuel cell activities within the Community, starting from some critical mass in competences, infrastructure, demonstrations, etc., and over time adding new components.

So each Hydrogen Community has its own record and specialisation. The following types of communities should be understood as illustrations for what they may look like, not how they ought to develop. In a real world, different development paths may prevail leading to overlaps and other combinations of activities.

The Town Hydrogen Community

In its most simple form, the Town Hydrogen Community is located in a medium-sized town. This is the hometown of many Europeans. The production of hydrogen may rely on diverse sources, covering both fossil fuels and renewables. Likewise, it may rely on surplus hydrogen from local industry. The distribution of hydrogen depends on whether the production is made onsite or has to be delivered. Both options can be applied. The specialisation is founded on previous or ongoing RD&D activities and focus on stationary CHP for residential use and in a later stage also building complex. Mobile applications play some role, first and foremost founded on existing demonstrations or buses running on hythane (mixture of natural gas and hydrogen) in locations with natural gas network. In later stages when larger numbers of fuel cell vehicles are available, a number of fuel cell buses and light duty fuel cell or hydrogen internal combustion engines vehicles may be included together with more hydrogen fuelling stations within the boundaries of the town or city. Larger projects and fewer technologies are demonstrated in this Community.

The Remote Hydrogen Community

The Remote Hydrogen Community is characterised by the geographical distance and remoteness to the economic centres. It may be a remote area or an island. Its energy and transport system is operated as an autonomous system.

The production is based on renewables (wind, biomass, solar, geothermal). Its specialisation is concentrated on the operation of an autonomous energy system. In the first phases, it will focus on stationary CHP for residential or community use, which step-by-step may be extended to the

Community. Later, a hydrogen fuelling station may be added for speciality vehicles and in the case of islands also for boats and ferries. A single fuel cell bus may be inserted and provide services on demand. Also in the Remote Hydrogen Community, a high number of smaller projects and a diversity of technologies are demonstrated. The Remote Hydrogen Community is larger than the Recreational Community but still relatively small in terms of activities and economic size.

The Marine Hydrogen Community

The Marine Hydrogen Community is located next to a harbour in relatively densely populated areas. Its primary specialisation is on marine applications. The production of hydrogen may come from diverse sources, including surplus hydrogen from local industry. In the very first phases the activities may include FC APU-units powered by hydrogen on board ships or ferries, fork-lifters and other speciality vehicles in restricted and "under-roof" areas of the harbour and a single fuelling station next to the harbour. Later, stationary CHP for visiting centre, ferry terminal and/or community use (10-50 kW) may be added. Light duty FC vehicles operating in the harbour (for example public marine authorities) may be inserted in the later stages. Different types of technologies and applications can be demonstrated. The Marine Hydrogen Community is defined by the size of the harbour and the activities around the harbour, which in some cases also include residential areas, leisure and sports facilities. Visibility is high.

The Recreational Hydrogen Community

The Recreational Hydrogen Community is located in tourist areas with some distance to the large cities and with easy access to nature, sea or major tourist attractions. It relies on natural gas and/or renewables for its hydrogen production or nearby industrial surplus of hydrogen. In the early stage applications are focused on stationary CHP for residential use, for example, hotel, visitor centre, museums, etc. Later, a fuelling station may be added together with speciality vehicles for tourist and recreational purposes within the resort. In the Recreational Hydrogen Communities, a high number of smaller projects and a diversity of technologies are demonstrated. A Recreational Community is relatively small in economic size, but does have a substantial outreach to citizens on holiday and local people.

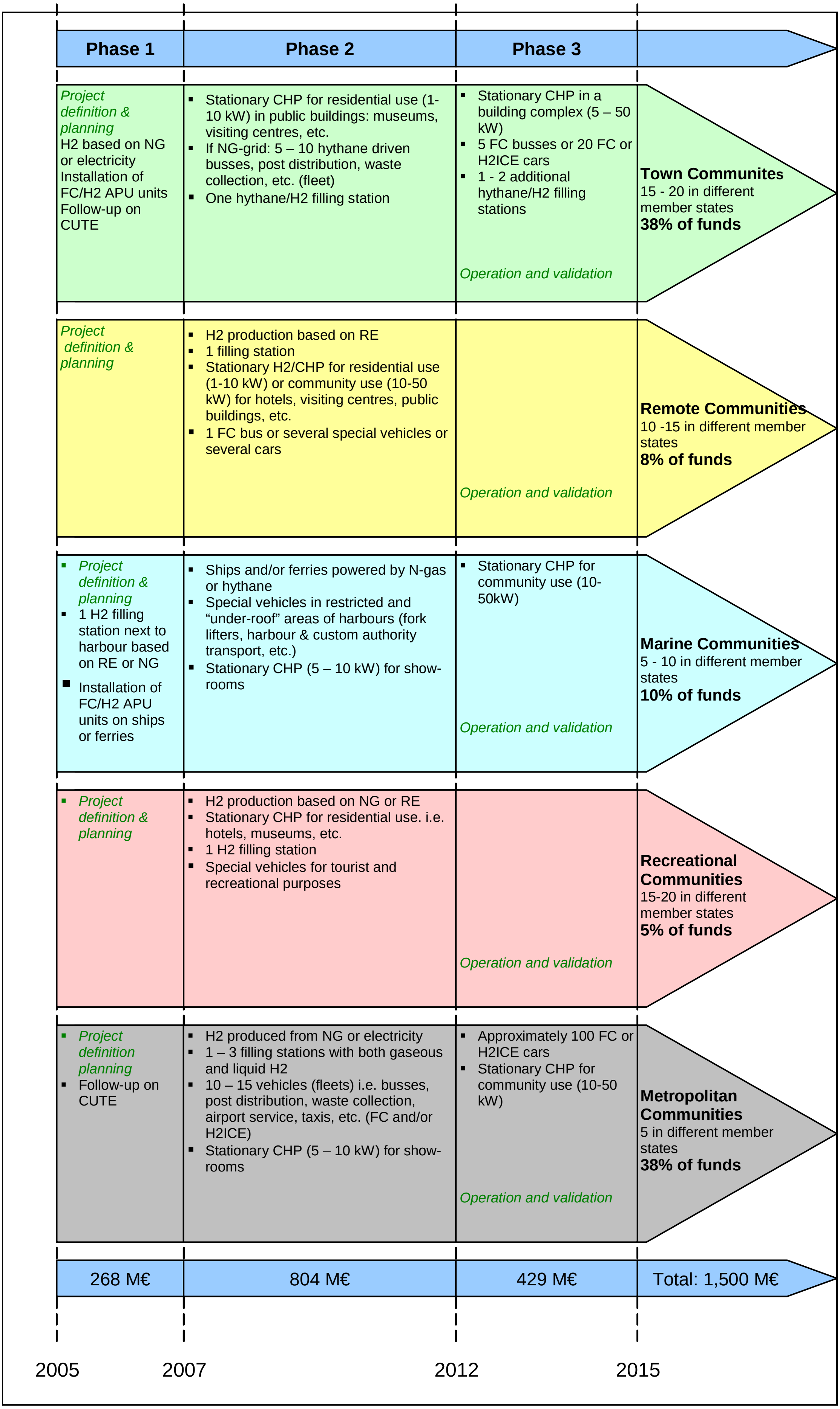
The Metropolitan Hydrogen Community

The Metropolitan Hydrogen Communities are located in large population centres of Europe. The main focus is on transport applications, where single demonstrations with one refuelling station and a few cars are upgraded to a network of refuelling stations and a substantial number of vehicles. Airports will often be included in the network due to the visibility and safety experiences. The network will constitute a first infrastructure and thereby offer the opportunity to understand what it means to build an infrastructure. Networks should be confined to highly populated areas where some infrastructure already exists and where demonstrated results from previous and on-going activities can be used as a starting point. Rather than create corridors between networks, a more dynamic growth of the network may happen. Eventually, a corridor may be created between networks. The hydrogen may be produced from diverse resources on-site or off-site and then trucked in to the filling station in liquid form. The first phase may comprise a few fuelling stations with both gaseous and liquid hydrogen, some FC and H2ICE vehicles (buses or light duty vehicles) to be used in city bus transport, airport bus transfer internally or externally, school buses, post service. Also small stationary CHP units may be demonstrated in showrooms and visitor centres. Later, more vehicles are included, up to 100. For some Communities, an option may be to include stationary heat and power in public buildings. These Communities are large lighthouse projects with high visibility – technically and industrial as well as politically.

We recommend the following portfolio of Hydrogen Communities:

- Between 15 and 20 Town Hydrogen Communities in different Member States covering cold, mild and hot climate zones. Guarantee for vehicles should be required for the third phase. Approximately 20-40 MEUR per Community, in total ~575 MEUR or 38% of total funds.
- 10 - 15 Remote Hydrogen Communities in different Member States. Approximately 8.33 – 12.5 MEUR per community, in total ~125 MEUR or 8% of total funds.
- 5 -10 Marine Hydrogen Communities in different Member States. Approximately 15 – 30 MEUR per community, in total ~150 MEUR or 10% of total funds.
- 15 – 20 Recreational Hydrogen Communities in different Member States covering different climate zones. Approximately 5 – 7.5 MEUR per community, in total ~75 MEUR or 5% of total funds.
- Up to 5 Metropolitan Hydrogen Communities in different Member States. Guarantee for vehicles is required. Approximately 115 MEUR per community, in total ~575 MEUR or 38% of total funds.

Each Hydrogen Community should include technology providers, energy companies and local or regional authorities. Further, Communities should strive for including or establishing collaboration with universities and research institutions actively involved in R&D of fuel cell and hydrogen technologies.
Hydrogen Communities may enter into networks to exchange information and experiences, which should allow for the inclusion of newcomers, for example, through aspirant Communities. At European level, an **Association of Hydrogen Communities** may be established, based on certified membership with obligations and benefits. If organised well, this would contribute to European coherence and international visibility.


Phase 1
Phase 2
Phase 3
Project definition & planning
H2 based on NG or electricity
Installation of FC/H2 APU units
Follow-up on CUTE
Stationary CHP for residential use (1-10 kW) in public buildings: museums, visiting centres, etc.
If NG-grid: 5 – 10 hythane driven busses, post distribution, waste collection, etc. (fleet)
One hythane/H2 filling station
Stationary CHP in a building complex (5 – 50 kW)
5 FC busses or 20 FC or H2ICE cars
1 - 2 additional hythane/H2 filling stations
Operation and validation
Town Communites
15 - 20 in different member states
38% of funds
Project definition & planning
H2 production based on RE
1 filling station
Stationary H2/CHP for residential use (1-10 kW) or community use (10-50 kW) for hotels, visiting centres, public buildings, etc.
1 FC bus or several special vehicles or several cars
Operation and validation
Remote Communities
10 -15 in different member states
8% of funds
Project definition & planning
1 H2 filling station next to harbour based on RE or NG
Installation of FC/H2 APU units on ships or ferries
Ships and/or ferries powered by N-gas or hythane
Special vehicles in restricted and “under-roof” areas of harbours (fork lifters, harbour & custom authority transport, etc.)
Stationary CHP (5 – 10 kW) for show-rooms
Stationary CHP for community use (10-50kW)
Operation and validation
Marine Communities
5 - 10 in different member states
10% of funds
Project definition & planning
H2 production based on NG or RE
Stationary CHP for residential use. i.e. hotels, museums, etc.
1 H2 filling station
Special vehicles for tourist and recreational purposes
Operation and validation
Recreational Communities
15-20 in different member states
5% of funds
Project definition planning
Follow-up on CUTE
H2 produced from NG or electricity
1 – 3 filling stations with both gaseous and liquid H2
10 – 15 vehicles (fleets) i.e. busses, post distribution, waste collection, airport service, taxis, etc. (FC and/or H2ICE)
Stationary CHP (5 – 10 kW) for show-rooms
Approximately 100 FC or H2ICE cars
Stationary CHP for community use (10-50 kW)
Operation and validation
Metropolitan Communities
5 in different member states
38% of funds
268 M€
804 M€
429 M€
Total: 1,500 M€
2005
2007
2012
2015

1 Scope of the Pre-feasibility Study

In November 2003, the European Commission launched the Quick-start Programme for European Initiative for Growth with 56 projects: 31 in transport, 17 in energy, and 8 in communications network, R&D and innovation. The common nominator for these projects was that they were ready to start immediately, and would have a positive impact on growth, employment, and protection of the environment (Speech by President of the European Commission Romano Prodi, 11 November 2003). An annual investment of around 10 billion EUR was expected, to come from public and private sources. Although the contributions from the public and private sector might vary from sector to sector and from project to project, an overall 60/40 split between public and private funding was estimated.

The Quick-start Programme identified the Hydrogen Economy as one of the key areas of investment with two initiatives planned in the area over a 10-year period (2004-2015):

- **Hydrogen Communities (HyCom).** The creation of a limited number of strategically sited stand-alone "hydrogen communities", producing hydrogen from various primary sources, mostly renewables, and using it for heat and electricity production and as fuel for vehicles, is the main goal of this project (1.5 billion EUR).
- **Hydrogen and Power Generation (Hypogen).** A major component will be the first large scale test facility for production of hydrogen and electricity from de-carbonised fossil fuels, with geological storage of CO_2. (1.3 billion EUR).

In March 2004, the Commissioner for Research Philippe Busquin presented these ambitious initiatives to boost a transition from a fossil-based economy to a hydrogen-based one:

> *"Our aim is clear: to develop cost-competitive, sustainable energy systems for future generations. Although hydrogen represents a bridge to a sustainable energy future, it is also a revolutionary technology. It signals major changes in the way we produce, distribute and use energy. Complex transition strategies have to be worked through, involving heavy investments and building consensus between key players."* (Speech at "Fuels for a Future Generation", 18 March 2004, Brussels).

An ESTO[1] call was made in April 2004 to simultaneously conduct **two pre-feasibility studies of HyCom and Hypogen**. The main boundary condition for the studies was the necessity (expressed clearly by the final customer in DG RTD J) of having a final deliverable ready before the drafting of the Quick Start terms of reference for the 6th FP Call for Tenders in fall 2004. This precluded a large ESTO consortium and in this occasion a reduced team would prove easier to coordinate.

Following an evaluation process, the studies were in May 2004 awarded to a consortium of ENEA (I), Risø National Laboratory (DK), and Frauenhofer ISI (G).

The pre-feasibility studies address the key issues concerning the definition and development of the two initiatives, HyCom and Hypogen, in order to make a preliminary evaluation of their feasibility. To this end, technical, economic, social and environmental aspects are considered, with the aim of clarifying the broad content of the initiatives, possible interlinkages of the initiatives and contribution to sustainable economic growth.

The **objectives of the pre-feasibility study** for the HyCom Initiative are more specifically:

- To provide an overview about technological options and financial, regulatory and other barriers;

1 European Science and Technology Observatory (ESTO) is a network of organisations operating under the European Commission's - Joint Research Centre's (JRC's) Institute for Prospective Technological Studies (IPTS) - leadership and funding since 1997.

- To clarify key issues of the Initiative;
- To identify success factors and risks for hydrogen communities;
- To provide options and recommendations.

The results from the study are expected to lead to a more precisely defined concept of Hycom and guide the European Commission in planning next steps of this Initiative.

The studies have been organised with ENEA as Operating Agent for the two studies. ENEA has been responsible for the Hypogen pre-feasibility study and Risø National Laboratory has been responsible for the HyCom pre-feasibility study.

The studies have been conducted in the period 1st June 2004 to 1 October 2004. A kick-off meeting was held in Brussels with selected stakeholders on 24 and 25 May 2004 to take into account the views and experiences from key on-going EU projects. Draft summary findings were presented and discussed at two seminars in Brussels on 18 October 2004 (HyCom) and 29 October 2004 (Hypogen).

This report presents the results from the pre-feasibility study on HyCom. In a separate report, the results from the pre-feasibility study of Hypogen are presented.

The **methodology** used in the study is a combination of desk research and 19 case studies of completed, ongoing or planned demonstration projects in Europe, Japan and Canada supplemented by follow-up interviews with programme officers and other experts. The figure below illustrates the analytic design.

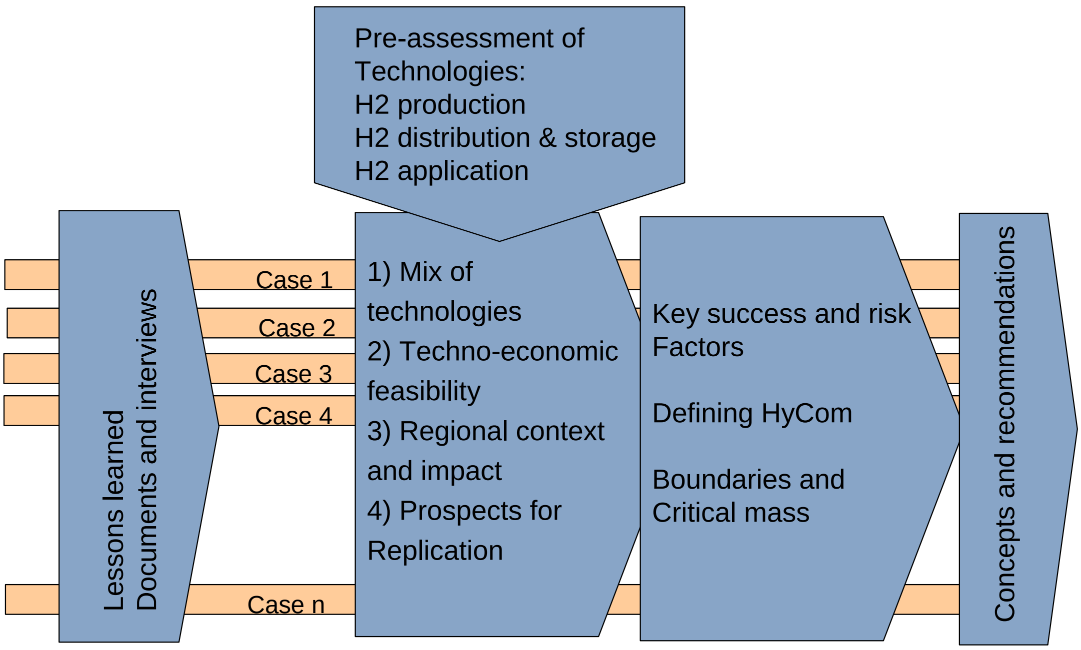


Figure 1: Methodology used in the Pre-feasibility Study

Apart from this initial chapter on the scope of the pre-feasibility studies, this report consists of the following chapters:

Chapter 2 HyCom in Context describes and analyses the context for the HyCom Initiative. In the first part, a short description is made of three international world leaders in the field of hydrogen and fuel cell technologies – USA, Japan and Canada. International collaboration is also touched upon. The second part focuses on the EU activities in the field, ranging from the motivations behind these, the efforts in the framework programmes, the strategic work undertaken first in the framework of the High-level Expert Group and later in the framework of the European Platform for Hydrogen and Fuel Cell Technologies, and to the various expectations to the hydrogen stances of the Growth Initiative. A third part gives account of the financial aspects related to the HyCom Initiative, including legal matters on public-private partnerships.

Chapter 3 Hydrogen Technologies describes the technologies relevant to Hydrogen Communities. In the description of the technologies both current stage and short-term and long-term perspectives are indicated. The short-term perspectives are directly relevant for demonstration projects within the HyCom timeframe (2005 - 2015). The long-term perspectives indicate / identify technologies expected to become relevant in a longer perspective, and is relevant for the priorities of technology developments.

Four main fields of applications are relevant for hydrogen used in Communities: transport, combined heat & power production (CHP), power back-up systems and energy buffers to balance production and consumption. Special attention is given to safety aspects.

Chapter 4 Analysis of Cases comprises an analysis of 19 case studies of hydrogen and fuel cell demonstration projects, mostly in Europe. It groups the demonstrations in three clusters – transport demonstrations, stationary demonstrations and demonstrations with both transport and stationary components. The description is focused on various matters associated with the preparation, implementation and completion of a demonstration project and gives account of the main success and risks factors associated with the project.

Chapter 5 Discussion brings together the various points raised in the previous chapters. Based on the lessons learned from the technology assessment, the case studies and other material, the concept of a Hydrogen Community is discussed and defined: what constitutes its boundaries, what is the critical mass and the key success factors. Different types for future Hydrogen Communities are developed and described in time and costs. Eventually, a roadmap for different types of Hydrogen Communities is presented.

Two appendices are attached:

- Appendix A: Hydrogen Technologies Overview
- Appendix B: Case Study overview. In a separate report, the full case studies are presented.

2 HyCom in Context

In this chapter, the HyCom Initiative will be put into an international perspective. Some countries have been very active within the hydrogen field for a number of years, and a large number of active newcomers now appear on the hydrogen arena.

In the first part of the chapter, the top three world countries in the development of hydrogen and fuel cell activities are described as a benchmark to the EU activities in the field. Likewise, a short account is given on international collaboration in this field.

In the second part of the chapter, the European perspective is described in terms of the main motivations behind the EU involvement in the hydrogen economy, the R&D in fuel cell and hydrogen activities, the strategic activities undertaken by the High Level Expert Group on Hydrogen and later by the European Technology Platform for Hydrogen and Fuel Cell Technologies, and the very recent activities related to the Hydrogen stances of the Growth Initiative.

Financial aspects are discussed in the third part of the chapter. These are closely related to the general set-up of the Growth Initiative, but are also influenced by the agreement between the Commission and the European Investment Bank to provide attractive funding schemes for research and innovation.

Eventually, some conclusions are made related to the preparations for the HyCom Initiative.

2.1 Leading International Hydrogen Activities

The USA, Japan and Canada have for years invested largely in research and development of hydrogen and fuel cell activities and represent some of the most ambitious strategies for bringing the technologies to the market. They are also actively involved in the international activities in the framework of the International Energy Agency and the International Partnership for the Hydrogen Economy.

USA

The USA has recently launched a comprehensive strategy for the development of hydrogen vehicles and hydrogen infrastructure. Over the next five years the Department of Energy (DOE) will spend approximately $1.5 billion on hydrogen R&D. The work will centre on developing fuel cells for automotive and stationary purposes, but will also cover hydrogen production, storage and infrastructure as set out in the recent Hydrogen Posture Plan that envisions long-term goals and technology milestones over the next 12 years. In addition, DOE has laid out a more detailed Multi-year Research, Development and Demonstration Plan with specific technology targets and evaluation points over the next 7 years (Chark and Inoye, 2003: 3).

The programme includes research into three types of fuel cells: PEMFCs, SOFCs and MCFCs. The production of hydrogen from natural gas, clean coal, nuclear, biomass and other renewable will be investigated, as well as hydrogen storage, delivery technologies, sensors and control technologies. Another important task is to develop codes and standards in readiness for the eventual commercialisation of hydrogen technologies. The programme also supports small-scale learning demonstrations, which allow for collecting data on technology operating in real-world conditions, identify areas of improvement, and feed information back into the R&D programme, the so called Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project. In 2004, DOE supported five major learning demonstrations of fuel cell vehicles and hydrogen infrastructure with approximately 190 million US$ over five years. The demonstration projects make up approximately

13% of DOE's hydrogen budget, compared to 85% for basic and applied research (Service, R.F., 2004: 961).

Specific partnerships include:

- *Solid State Energy Conversion Alliance (SECA)*, a partnership between the DOE, research institutions and industry. The main objectives of SECA are to develop high-temperature SOFCs and MCFCs operating on natural gas and syngas, primarily for stationary purposes. Targets for stationary fuel cell systems are a design life of 40,000 operating hours and electric efficiencies of 60–70%, the higher figure to be achieved by combining fuel cells with gas turbines.
- *The FreedomCAR partnership*, an alliance between the DOE and car manufacturers including General Motors, Ford and DaimlerChrysler. The aim is to develop the PEMFCs for transport purposes. The programme sets specific cost targets, such as $45/kW for the fuel cell system and $30/kW for the engine power train.

Japan

Japan has for a number of years been one of the most ambitious countries in developing hydrogen energy technologies. In 2002, the Japanese Ministry of Economy, Trade and Industry (METI) launched a comprehensive programme aiming at full commercialisation of fuel cells and a hydrogen infrastructure by 2020. The total budget is approximately $4 billion, with $250 million set aside annually for the first five years. In 2003, a total of $279 million, of which 23% was used for demonstrations (IEA/CERT/HCG/(2004)x, Sept. 2004 draft).

The programme has three phases. The demonstration phase focuses on developing technology, demonstrating mobile and stationary fuel cells and establishing codes and standards. The introductory phase, which will last from 2002 to 2010, concentrates on research and demonstration. By 2010, 50,000 fuel cell vehicles and 2.1 GW of stationary fuel cells are expected to be in operation. The "diffusion" phase, which will run from 2010 to 2020, will concentrate on the wide uptake of hydrogen technology. By 2020, Japan expects to have 5,000,000 fuel cell vehicles, 4,000 hydrogen filling stations and 10 GW of stationary fuel cell cogeneration plants.

Japan has one of the most highly developed fuel cell and hydrogen demonstration programmes for transportation (and stationary) applications: The JHFC (Japan Hydrogen Fuel Cell) Demonstration Project consists of road test demonstrations of FCVs and the operation of hydrogen refueling stations. These stations will be operated and evaluated along with the FCVs that participate in this project. Moreover, several FCVs and a fuel cell bus from domestic and overseas car manufacturers are participating in this project and various data such as drivability, environmental characteristics, and fuel consumption will be obtained for evaluation. Japan's "Stationary Fuel Cell Demonstration Project" operates 31 stationary fuel cells in various sites, such as residential, heavy traffic, and seaside. It will also evaluate various fuel types (i.e., natural gas, LPG and kerosene). Japan's "Demonstration Project on Distributed Power Generation and Grid Connection" operates solar, wind and fuel cell (typically MCFC) simultaneously by using information technology and establishes technologies for minimizing fluctuations.

These programmes are the latest part of an intensive hydrogen R&D effort that began in the early 1980s. The result is that Japan is a world leader in hydrogen technology, especially in commercialisation as opposed to basic research. The work has largely been co-ordinated by the Government — METI and NEDO (New Energy and Industrial Technology Development Organisation) — but has also been driven by car manufacturers and other industries. This public-private partnership makes the Japanese hydrogen programme extremely efficient, because everybody is pulling in the same direction (see also Morthorst, 2004).

Canada

Canada has for almost two decades been highly active in developing hydrogen energy systems. In the mid-1980's, the Canadian government set up comprehensive national programmes for fuel cells and hydrogen, and this resulted in the establishment of several private companies, including Ballard Power Systems (fuel cells) and Stuart Energy (electrolysis).
Important Canadian initiatives include:

- *The National Hydrogen and Fuel Cell Programme* covers three areas: R&D, hydrogen infrastructure (developed through the Canadian Fuel Cell Alliance) and early market introduction of hydrogen and fuel cell technology. The latter is carried out through the Early Adopters Programme, which is led by Industry Canada.
- *The Fuel Cell Commercialisation Road Map*, whose objective is to accelerate full-scale commercialisation of fuel cells in Canada. Published in 2003, the Road Map sought opinions from all the relevant stakeholders in Canada. The work was led by industry and supported by the Government.
- *Canada's Hydrogen and Fuel Cell Committee* is a partnership of governmental departments and industry and academia that was established in 2003 to help facilitate and coordinate the development and commercialisation of Canadian fuel cell and hydrogen technologies in a time where the Canadian government announced a further 215 million CAN$ to encourage R&D in technologies that can reduce GHGs. This translates into approximately 70 million CAN$ annually over the next 5 years. The Committee oversees and integrates all relevant R&D programmes and activities that span the innovation spectrum, from basic research and development through to the incentives needed for commercialisation of hydrogen and related technologies.

Two major demonstration projects are currently under preparation: The Hydrogen Highway™ in British Columbia, which is a network of demonstrations, both transport and stationary that aims at being in full operation for the Winter Olympics in Whistler in 2010. The Hydrogen Village partnership - a collaboration by industry, government and academia that aims to accelerate the commercialization of hydrogen and fuel cell technology in the greater Toronto area.

International collaboration

The **International Energy Agency** is playing a major coordinating role in international cooperation in the field of energy technologies, especially through the so-called Implementing Agreements (IAs). They focus on research, technology development and diffusion, to which countries can participate on a voluntary basis.
IAs relevant to hydrogen and fuel cell technologies are:

- *IA Hydrogen*. The following countries participate: Canada, Denmark, European Commission, Iceland, Italy, Japan, Lithuania, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. It has just celebrated its 25 anniversary. Its annexes focus on: 14. Photoelectrolytic Production of Hydrogen, 15: Photobiological Production of Hydrogen, 16: Hydrogen from Carbon Containing Materials, 17: Solid and Liquid State Hydrogen Storage Materials, 18: Integrated Systems Evaluation.
- *IA Advanced Fuel Cells*. The following countries participate:
  Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Neth erlands, Norway, Sweden, Switzerland, United Kingdom, United States. The actual work focuses on (Annexes): 16. PEM FC, 17. MCFC for Demonstration, 18. SOFC - Making Ready for Application, 19. Fuel Cells for Stationary Applications. 20. Fuel Cells for Transportation, and 21. Fuel Cells for Portable Application.

- *IA Green House Gas RD Programme*. The following countries participate in this work: Australia, Canada, Denmark, European Commission, Finland, France, Japan, Korea, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, United States, Venezuela.

In addition to these three key IAs, other relevant IAs are IA Advanced Motor Fuels, IA Bioenergy, Clean Coal Centre and Energy Technology System Analysis Programme (Marianne Haug, speech at the IPHE Steering Committee meeting, Beijing 26 – 27 May 2004).
In June 2003, the Hydrogen Coordination Group was established with the following objectives:

- Develop a comparative programme and policy review of relevant national programmes (Agreement sought on scope, timing and working arrangements)
- Review ongoing activities in IEA Implementing Agreements in order to identify needed work on critical-path technologies
- Identify analyses and support that will be needed to help guide the work of the IEA
- Recommend additional collaboration or other activities needed within the context of IEA's technology collaboration programme.

The **International Partnership for the Hydrogen Economy (IPHE)** was established in November 2003 on the initiative of the USA following the establishment of the Carbon Sequestration Leadership Forum (CSLF) in June 2003. The following countries are members: Australia, Brazil, Canada, china, EU Commission, France, Germany, Iceland, India, Italy, Japan, Norway, Republic of Korea, Russian Federation, UK, USA.

IPHE aims at serving as a mechanism to organize and implement effective, efficient, and focused international research, development, demonstration and commercial utilization activities related to hydrogen and fuel cell technologies. It also provides a forum for advancing policies, and common codes and standards that can accelerate the cost-effective transition to a global hydrogen economy to enhance energy security and environmental protection. It has the following functions (www.iphe.net):

- Identifies and promotes potential areas of bilateral and multilateral collaboration on hydrogen and fuel cell technologies;
- Analyzes and recommends priorities for research, development, demonstration, and commercial utilization of hydrogen technologies and equipment;
- Analyzes and develops policy recommendations on technical guidance, including common codes, standards and regulations, to advance hydrogen and fuel cell technology development, demonstration and commercial use;
- Fosters implementation of large-scale, long term public-private cooperation to advance hydrogen and fuel cell technology and infrastructure research, development, demonstration and commercial use, in accordance with Partners' priorities;
- Coordinates and leverage resources to advance bilateral and multilateral cooperation in hydrogen and fuel cell technology research, development, demonstration and commercial utilization; and

- Addresses emerging technical, financial, legal, market, socioeconomic, environmental, and policy issues and opportunities related to hydrogen and fuel cell technology that are not currently being addressed elsewhere.

2.2 EU Activities

The EU activities in the field of hydrogen and fuel cell technologies are closely related to three broad issues:

- Climate change and environmental degradation
- Security of supply
- European competitiveness.

Climate Change and air pollution in cities are some of the major issues behind the vision of a hydrogen economy. Burning fossil fuels is the major contributor to manmade greenhouse gas emissions and local air pollution in cities, and European policies, therefore, address the issues of energy efficiency, fuel substitution, use of renewable energy, emission reductions, etc. The European Union has signed the 1997 Kyoto Protocol to the UN Framework Convention on Climate Change with the goal of reducing EU-15 greenhouse gas emissions by 8% by 2012 as compared to 1990[2]. The Commission's general approach has been to shape a policy framework to reinforce measures being taken at national level. These "common and co-ordinated" policies are, for example, voluntary environmental agreements such as the one with the car manufacturers to reduce the average specific GHG emissions of passenger cars. They also include the promotion of the Flexible Mechanisms of the Kyoto Protocol for emission trading and project-related emission reduction (International emission Trading, Joint Implementation, and Clean Development Mechanism).

Security of supply is key to the European economy, which is steadily demanding more and more energy. The external dependence for energy of the EU is increasing. The EU imports 50% of its energy requirements and if no measures are taken within the next 20 to 30 years, this figure is expected to rise to 70%. This external dependence has economic, social, ecological and physical risks for the EU. Energy imports represent 6% of total imports. 45% of oil imports derive from the Middle East and 40% of natural gas derives from Russia[3].

Measures have been undertaken by the EU to diversify sources and technologies, including the Directive on electricity production from renewables (adopted in 2001), the Directive on Combined Heat and Power (adopted 2004), the Directive on energy saving in buildings (adopted 2002), and the Directive on biofuels (adopted 2003). But more profound and long-term actions are needed to enable Europe to control its energy future. As Commission President Romano Prodi announced in January 2004,

> "*Current trends are clearly unsustainable. Our objective is to realise a step-by-step shift towards a fully integrated hydrogen economy, based on renewable energy sources, occurs by the middle of the century. To turn this vision into reality, however, Europe needs more research, larger demonstration and deployment projects, and regulations and standards appropriate to the future hydrogen economy. These efforts will be successful only if national and European resources, both public and private, are pulled together in a co-ordinated way.*" (Speech at the launch of the European Hydrogen and Fuel Cell Technology Platform, 20 January 2004, Brussels).

Competitiveness is the third and perhaps the most influential motivation behind the European activities within fuel cell and hydrogen technologies. The Growth Initiative is regarded an important

[2] Council decision on the Approval of Kyoto Protocol OJL 130 of 15th May 2002.

[3] Green paper COM(2002) 321 – towards a European Strategy for the Security of energy supply; White paper COM(2001)370 – European transport policy for 2010.

step in the implementation of the Lisbon goal to improve the economic competitiveness and the growth potential through higher investments in physical and human capital.

Today most research and development takes place at national level in the 25 Member States – estimates are that 80% is conducted at this level and the remaining part at EU and international level (Com(2001) 282 final[4]). The efforts in developing and consolidating fuel cell and hydrogen technologies are fragmented, spread across a number of Member States, and often with overlapping activities. To bring together public and private resources across national boundaries, co-ordination and alignment mechanisms are required. One of the main mechanisms is the creation of a European Research Area (ERA), an internal market for research and development in the field of hydrogen and fuel cell technologies in order to assemble a critical mass of resources, to integrate research efforts across institutional, disciplinary and territorial boundaries, and to position European research internationally.

To support the RD&D activities on fuel cell and hydrogen technologies in the framework programmes, the EU Commission established in 2002 the High Level Group on Hydrogen and Fuel Cells to make a strategic outlook on the challenges and prospects of the hydrogen economy. A vision report was then presented and discussed at a conference in June 2003. Following these recommendations, the European Hydrogen and Fuel Cells Technology Platform was established in January 2004 by stakeholders from industry, academia, Member States and the EU Commission. The work plan suggested by the High Level Group concentrates on making a strategic research agenda, a deployment strategy, as well as a comprehensive roadmap for the European hydrogen economy (European commission, 2003a).

The European Technology Platform for Hydrogen and Fuel Cell Technologies is perhaps the key instrument in making an internal market for research for hydrogen and fuel cell technologies (European Commission, 2004a). It is meant to be a mechanism to bring together all interested stakeholders to develop a long-term vision to address a specific challenge, create a coherent, dynamic strategy to achieve that vision and steer the implementation of an action plan to deliver agreed programmes of activities and optimise the benefits for all parties. It is, however, a newly built Platform yet undertaking the various strategic and other tasks to prepare for its activities (see also www.HFPeurope.org).

In the figure below, its organisational structure is highlighted.

[4] Com(2001) 282 final – The Framework Programme and the European Research Area: application of Article 169 and the networking of national programmes.

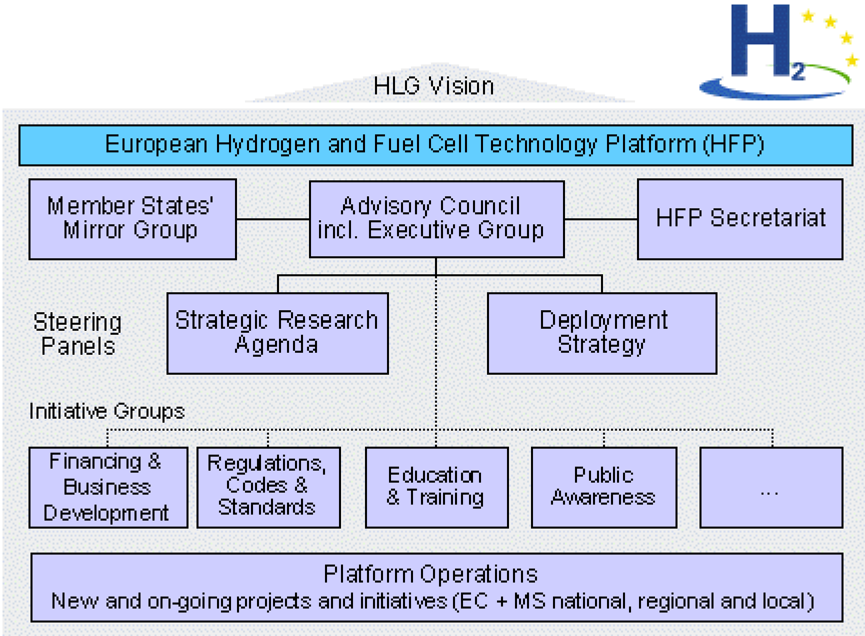


Figure 2: Organisational Structure of the Technology Platform.

Research and Development in Fuel Cells and Hydrogen Technologies

The EU has supported research, technological development and demonstrations in the area of hydrogen and fuel cell technology from the 1970s to the present day. Funding for RTD in this area has grown from 8 million EUR for the Second Framework Programme (1988-1992) to more than 130 million EUR in the fifth Framework Programme (1999-2002).
In FP5, in the field of fuel cell technologies 34 projects and 7 network projects were supported, including basic and applied research as well as the largest fuel cell bus fleet trial worldwide, the Clean Urban Transport for Europe (CUTE) demonstration project. For hydrogen technologies, 17 projects and 4 network projects were supported, likewise comprising basic, applied and demonstration activities. The latter included the Ecological City Transport System (ECTOS), the FC-bus demonstration project in Iceland that has been a model for the CUTE project. Other support actions comprised 4 projects, for example ACCEPTH$_2$ on public acceptance (for more information on FP5 fuel cell and hydrogen projects, see European Commission, 2003b).
In the Sixth Framework Programme (2003 – 2006), the budget for sustainable development and renewable energies has increased to 2.1 billion EUR, of which 250 – 300 million EUR is expected to be earmarked to hydrogen and fuel cell related research and development over a four year period. Some 100 million EUR, and matched by an equivalent amount of private investment, has been awarded to hydrogen and fuel cell projects after the first call for proposals of the Sixth Framework Programme and this will be further reinforced by further calls for proposals. An overview of projects approved or under negotiation is presented in the table below (European Commission, 2004b). The total funding for hydrogen projects is 67.7 MEUR and for FC technologies it is 33.13 MEUR.

Table 1: Overview of FP6 projects in hydrogen and fuel cells, 2004.

Area	**Project Acronym**	**Type of Action**[1]	**Topic**	**EU funding (€m)**	**Co-ordinator**
Productio n	HYTHEC	STREP	Water splitting through High Temperature thermochemical cycles	1.9	CEA (France)
	CHRISGAS	IP	H2 rich gas from biomass	9.5	Växjo University, (Sweden)
	Hi2H2	STREP	High temperature solid oxide water electrolyser	0.9	EDF (France)
	SOLAR-H	STREP	Hydrogen production from renewables		
Pathways	HYWAYS	IP	Elaborating a European Hydrogen Roadmap	4	L-B-Systemtechnik, (Germany)
	NATURALHY	IP	Investigating infrastructure requirements for H2 and natural gas mixes	11	Gasunie, (The Netherlands)
	HYCELL TPS	SSA	Development and Implementation of the European Hydrogen and Fuel Cell Technology Platform Secretariat	1.8	Kellen Europe, Belgium
	INNOHYP-CA	CA	Innovative high temperature production routes for hydrogen production	0.5	CEA, France
	HY-CO	CA	Coordination Action to establish a hydrogen and fuel cell ERA-net	2.7	Research Centre Jülich, Germany
	WETO-H2	CA	World energy Technology Outlook 2050	0.39	Enerdata, France
	CASCADE MINTS	STREP	Case study comparisons and development of energy models for integrated technology systems	0.95	ICSS/NTUA
Storage	STORHY	IP	Next generation storage technologies for on-board applications	10	Magna Steyr Fahrzeugtechnik, (Austria)
	HARMONHY	SSA	Harmonisation of standards and regulations	0.5	Vrije University, Belgium
Safety	HYSAFE	NOE	Networking research in safety issues	7	FZK Forschungszentrum Karlsruhe (Germany)
End use	ZERO REGIO	IP	H2 FC fleet demonstration	7.5	INFRASERV (Germany)
	PREMIA	SSA	Effectiveness of demonstration initiatives	1	VITO (Belgium)
	HYICE	IP	Internal combustion Engines	9	MBMW (Germany)
Subtotal EU funding				**67.7**	
High Temperatu re Fuel Cells	Real-SOFC	IP	Next generations SOFC planar technology	9	Forschungszentrum Jülich (FZJ) (Germany)

Area	Project Acronym	Type of Action[1]	Topic	EU funding (€m)	Co-ordinator
	BIOCELLUS	STREP	Biomass Fuel Cell Utility System	2.5	TU Munich (Germany)
	GREEN-FUEL-CELL	STREP	SOFC fuelled by biomass gasification gas	3	CCIRAD (France)
	SOFCSPRAY	STREP	Porous material for solid oxide fuel cells/high power applications	0.6	Nuevas Technologias para la Distribucion Activa de Energia SL, Spain
Solid Polymer Fuel Cells	HYTRAN	IP	Innovative systems and components for road transport applications	9	Volvo (Sweden)
	FURIM	IP	High temperature polymer electrolyte membrane (PEM)	4	DTU, Technical University of Denmark
	PEMTOOL	STREP	Development of novel, efficient and validated soft-ware-based tools for PEM fuel component and stack designers	1	Bertin Technologies SA, France
	INTELLICON	STREP	Design and prototyping of intelligent DC/DC converter / fuel cell hybrid power trains	0.5	HIL Tech Developments Ltd., UK
	DEMAG	STREP	Integration of a PEM fuel cell with ultra-capacitors and with metal hydrates container for hydrogen storage	0.65	Labor Srl, Italy
Portable applicatio ns	MOREPOWER	STREP	Compact direct (m)ethanol fuel cell	2.2	GKSS Forschungszentrum Geesthacht (Germany)
	FEMAG	STREP	New product = fuel cell + components + expert system/Small vehicles (Non automotive)	0.65	AGT Srl, Italy
General	ENFUGEN	SSA	Enlarging fuel cells and hydrogen research cooperation	0.23	Labor Srl., Italy
Subtotal EU funding				**33.13**	
Total EU funding				**100.43**	

1. IP = Integrated Project; STREP = Specific Targeted Research Project; SSA = Specific Support Action; NoE = Network of Excellence; CA = Coordination Action.

To help the Commission in defining the future research, development and demonstration activities, a call for Expressions of Interests was made in 2004. In the area of hydrogen and fuel cell technologies, a total of 95 Expressions of Interests were forwarded to the Commission by mid March 2004. Some of these proposed Integrated Projects are directly relevant to the HyCom Initiative as for example:

- HyEurope – Advanced Hydrogen and fuel Cell Vehicle Technology for Europe, proposed by DaimlerChrysler (EU-funding: > 15 MEUR). This IP focuses on the development and test of core components for a FC vehicle, with subsystems and components. The results of these efforts shall be the basis for a European light-house project for hydrogen and fuel cell vehicles. This means that more research is needed before a next generation FC vehicle can be introduced in demonstration projects.
- H2 to Sea - Demonstration of hydrogen fuelled ships, proposed by Air Liquide, France (EU-funding: 10-15 MEUR). This project is a marine equivalent to the CUTE project. It focuses on demonstration of hydrogen boats and ships in three different locations – Iceland, the Faeroe Islands and Norway.

- Clean Urban Residential Energy (CURE), proposed by L-B- Systemtechnik, Germany (EU funding: > 15 MEUR). This project is the stationary equivalent to CUTE. It focuses on local hydrogen micro-grids, for vehicle provision and for residential end-use, including small stationary FCs for CHP 10kWel class, FC powered back-up systems, integration of stationary fuel cell and co-generation system using natural gas, decentral "fuelling-station-site" hydrogen generators feeding local hydrogen microgrids, demonstration of different regional-specific primary energies, and the increase of public vehicle hydrogen fuelling station density by adding sites in further European regions.
- NextGenCell – the next generation of stationary fuel cells, proposed by Valliant Gmbh (EU-funding: > 15 MEUR). This project focuses on the development and deployment of highly efficient CHP fuel cells for domestic applications and envisions to extend to about 500 system installations across Europe, in particular Eastern and Southern Europe.

For the remaining part of FP6, a set of joint and coordinated calls for fuel cell and hydrogen technologies are foreseen. For these projects, approximately 150 million EUR and an equivalent 150 million EUR in co-financing are expected.

On 20 September 2004 the Commission organised an information day regarding the next call. A total of 58 project ideas were presented on hydrogen and fuel cell technologies covering both research, development and demonstration projects. At least 14 demonstration projects were presented covering mostly transport applications (both FC vehicles, H2/CNG vehicles, fuelling stations and marine application) but also production of hydrogen from excess wind power. Some of the projects defined themselves as light house projects with a network of localities and applications, for example the Central European Light House Project with Hamburg-Berlin-Leipzig as a nuclear of activities and with possible extensions to other European sites.

For the **short-medium term projects**, the main topics are:

- Demonstration of hydrogen fleets (incl. production storage, distribution and fuelling). Priority will be given to innovative captive fleets that complement technologies currently under demonstration in Europe, for example hybrid fuel cell buses. Appropriate fleets could be buses, post distribution, waste collection, taxis, local delivery, airport fleets, and passenger fleet. Fleet is defined as a coherent group of at least three vehicles normally operated by a single operator (European Commission, 2004: 15). Also synergies with stationary applications and bio-fuel pathways will be explored. (1 IP).
- Coordination action in the form of a European Partnership of the hydrogen transport projects resulting from the call, July 2004.

For the **medium-long term projects**, the main topics are:

- RTD on fuel cell and hybrid vehicle development (1 IP, 2 STREPs) and integration of fuel cell systems and fuel processors for aeronautics, waterborne and other transport applications (2 IPs)
- RTD on electrochemical hydrogen production, small fuel processing units, storage and pre-normative research for regulations and standards (2 STREPs, 1 IP, and 1 STREP)
- Support of the co-ordination, assessment and monitoring of research to contribute to the definition phase for a hydrogen communities initiative. This initiative thus has a very key role in the preparation, implementation, and validation of the HyCom Initiative. The tasks foreseen comprise a permanent technology watch, technology assessment of the various hydrogen pathways, alignment with ongoing research, assessment of renewable hydrogen, socio-economic analysis, possibilities for a joint public procurement programme, and stakeholder involvement (1 IP and links to the coordination action above on transport demonstrations).

According to this call, the HyCom Initiative should be seen as an integrated part of the framework programmes, including making use of the instruments of the same.

Likewise as it is outlined in the guidelines for future European Union policy to support science and technology (COM(2004)353 final[5]), science and technology is seen as the key to Europe's future competitiveness and employment and the fulfilment of the Barcelona targets of increasing the European research effort to 3% of the EU's GNP by 2010. A highly competitive sector, such as hydrogen energy technologies, requires integration of research at European level. This should be made through adding a European value to the activities: to establish a critical mass of resources by aligning EU, national and private resources, to strengthen excellence through competition at European level and trans-national collaboration, and to improve the coordination of activities of Member States in areas of interest to certain countries.
The instruments foreseen in the guidelines include the technology platforms, such as the European Platform for Hydrogen and Fuel Cell Technologies. The research and deployment agendas of such platforms will often be implemented by means of "integrated projects", but in some cases a "joint undertaking" is regarded more appropriate (Article 171 of the Treaty "The Community may set up joint undertakings or any other structure necessary for the efficient execution of Community research, technological development and demonstration programmes"). The two paths for managing the HyCom and Hypogen initiatives are hence laid out and should be clarified in further studies.

2.3 The Financial and Legal Framework

The investment related to establish a limited number of hydrogen communities around Europe might be a financial challenge for most projects. The Growth Initiative foresees that projects including the transport and energy network projects will be financed by public and private funds in the ration 60/40. Mobilising private investments in research and innovation is a central factor in boosting investments, also in the field of hydrogen and fuel cell technologies.
This policy is closely related to the Lisbon goal to become the most competitive and knowledge intensive area in the World by 2010, and the associated Barcelona target of 3% R&D of BNP, of which 1/3 shall come from public sources and 2/3 from private sources.
The indicative budget for HyCom is 1.5 billion EUR over 10 years (2004-2015).

Table 2: Indicative distribution of total HyCom funds

	Million EUR
2005 – 2007	268
2007 – 2012	804
2013 – 2015	429
Total	1,500

The funds are expected to come from a variety of sources:

- Framework Programmes
- Structural funds
- European Investment Bank
- National and regional research programmes
- Private investments

The Framework Programmes

As it has been discussed above, the EU research funds are relatively small compared to national and regional research undertaken at level of the individual Member States. Therefore, the Framework Programmes can only contribute to a relatively small share of the 1.5 billion EUR needed for

[5] COM(2004)353 final – Science and Technology, the key to Europe's future – Guidelines for future European Union policy to support research.

HyCom. Although the Commission has proposed to raise budget for research by 60% before 2013 so that the commitment appropriations from the participating countries are raised from 47.6 billion EUR in 2006 to 76.8 billion EUR in 2013 (News, ELS Gazette, Issue 18, February 2004), this increase will not necessarily benefit the HyCom Initiative, which is expected to rely on a palette of financial funds.

In the next FP6 call, a number of fleet demonstrations are included, but until the Platform has developed both a strategic research agenda and a deployment strategy, it is difficult to assess the need for funds from the framework programmes.

In the guidelines for the future European research policy, the Commission emphasises that the financial and administrative burdens associated with the application, contract negotiation and implementation procedures be reduced and is currently studying the financial mechanisms to bring about certain improvements (COM(2004) 574 final: 3[6]).

Structural Funds

Another plausible source for HyCom is the Structural Funds. In the period 2000-2006, the Structural Funds are foreseen to support infrastructure investments, research, technological development and innovation up to around 60 billion EUR, of which 9.2 billion EUR is earmarked to research, development and innovation.

An overview of the current Objective areas for 2000-2006 is given in the map below.

[6] COM(2004) 574 final - COMMUNICATION FROM THE COMMISSION responding to the observations and recommendations of the high-level Panel of independent experts concerning the new instruments of the 6th Framework Programme.

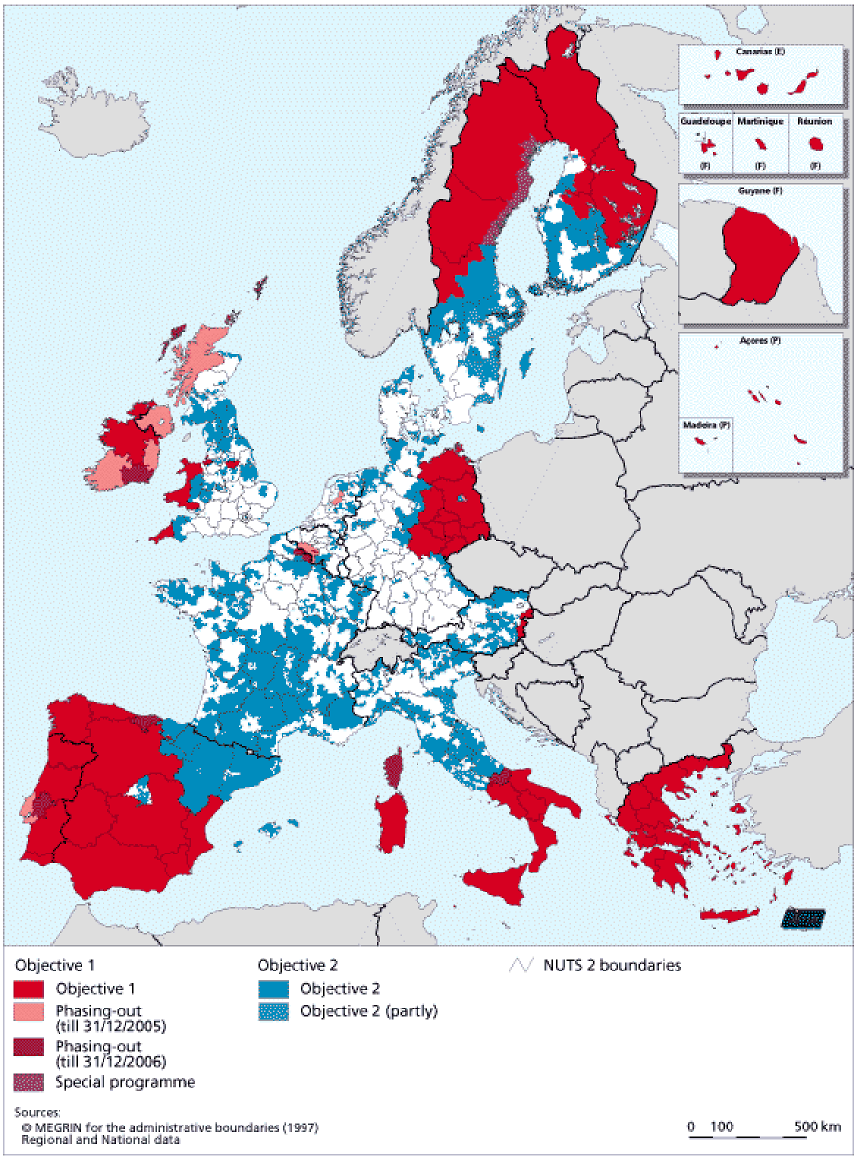


Figure 3: Overview of Objective Areas in 2000-2006 Programming Period.

In the proposal for the programming period of 2007-2013, a new architecture for EU cohesion policy is discussed, in which growth and cohesion are regarded as mutually supportive. Part of the Structural funds will support the development of research capabilities in the three proposed objectives areas (COM(2004)492 final[7]):

- **Convergence regions** concerning the less developed Member States and regions (GDP/inhabitant less than 75% of EU average). These regions will be supported by financial resources from the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the Cohesion Fund.
- **Regional competitiveness and employment** for regions outside the least developed Member States and regions. Here ERDF and ESF will support regional development programmes to anticipate and promote economic change in industrial, urban and rural areas.
- **Territorial cooperation** concerns regions along internal terrestrial borders and certain regions along the external borders as well as certain neighbouring maritime borders.

[7] COM(2004)492 final - Proposal for a COUNCIL REGULATION laying down general provisions on the European Regional Development Fund, the European Social Fund and the Cohesion Fund

In the communication on the guidelines for future European research policy, it is pointed out the complementarity between the research budgets and the Structural Funds should be enhanced and also increase their combined use (Com(2004) 353 final: 8-9[8]). It is too early to judge the implications for the HyCom Initiative, but at least attention should be made to the funding schemes for the Convergence regions as well as for territories with specific needs and characteristics as for example remote areas, islands, mountain areas, sparsely populated areas in the North and certain border regions and urban regeneration areas.

In the proposal for the regulation on the provisions on the ERPD, ESF and the Cohesion Fund, it has been emphasised to simplify the management system by introducing more transparency, differentiation and proportionality while ensuring sound financial management (COM(2004)492 final: 8).

European Investment Bank

A Joint Memorandum between the Commission and European Investment Bank (EIB) was signed in June 2000 to reinforce co-operation and information to prepare for more significant EU finance for research and technology. The aim is to complement EU research grants with EIB loans as well as European Investment Fund venture capital to increase the overall financial scheme for research. The EIB follows its normal assessment procedures when judging the quality of a given project, assessing the whole package of technology, finances, markets, management etc. These conditions are also applicable to large research projects where some of the major challenges are, indeed, management and finances. This new way of thinking is now being introduced so that technology development is combined with market thinking. Financing can for example be applicable for laboratories for production of fuel cells, infrastructure etc.

The European Platform for Hydrogen and Fuel Cell technologies has established a Joint Group of Financing and Business Development and discusses with the Commission and the European Investment Bank, which horizontal financial instruments should be developed for research, technology and demonstrations as well as the magnitude and conditions for funding (Interview with Angel Landabaso, DG Research, 7 September 2004).

A number of EIB schemes relevant for HyCom are:

- **The Innovation 2010 Initiative** (i2i-2010) supports research, development and innovation and will deliver up to 50 billion EUR by 2010 and offer a broad range of need adapted instruments. It is rooted in the Innovation 2000 Initiative (i2i) launched in June 2000. The initiative seeks complementarity between EIB loans and EU grants in the FP6. An indicative lending envelope of 20 billion EUR for the period 2003-2006 has been established. Priorities are given to projects that further or result from synergies between public and private sectors. The i2i-2010 will give absolute priority to projects located in regional development areas in order to ensure the creation of centres of excellence in the less favoured regions of the EU and in the new Member States and the three Accession Countries (Bulgaria, Romania, and Turkey).
- **New funding arrangements** are being developed to foster the development and market introduction of new technologies, including grouped loans for specific research activities, technology platforms, and simplified lending procedures for small and medium sized enterprises. A proposal for a guarantee loan scheme is currently discussed for projects / proposals coming from the Platform. It has not been possible to get a copy of this draft proposal for this pre-feasibility study.

The critical issue is whether a Hydrogen Community relying on various EU funding schemes has to comply individually with each scheme and learn how to manage different requirements and evaluation criteria.

[8] Com(2004) 353 final - – Science and Technology, the key to Europe's future – Guidelines for future European Union policy to support research

National and regional research programmes

Apart from EU and EIB funds, the applicant hydrogen communities should seek funds in national and regional RD&D programmes.

Various mechanisms are foreseen to align EU, national and regional research, development and demonstration activities. The use of Article 169 of the Treaty is taken into consideration as it enables the Community to launch research programmes with a 'subset' of Member States and thereby improve the coordination with national research programmes.

The work undertaken by the Mirror Group of the European Platform for Hydrogen and Fuel Cell Technologies is another mechanism that aims at assuring an appropriate interface of coordination of EU, national, regional and local initiatives. It also explores possible synergies and cooperation across national boundaries and helps to identify and define prestigious light house projects in the Member States (Draft Terms of Reference and Rules of Procedure for the Member State Mirror Group; Common expectations and contributions from the members of the Mirror Group, 8 June 2004). Just like the other activities of the Technology Platform, this work is still in its start up phase, but future Hydrogen Communities should inform themselves on this alignment activity.

In the framework of the IEA Hydrogen Coordination Group, a review of national RD&D activities in the field of hydrogen and fuel cell technologies has been undertaken from October 2003 – September 2004. During this relatively short time span, changes have been made to national priorities and activities. The Danish and Norwegian examples show that the increased interest in the hydrogen economy is reflected in changed policies and priorities:

- Denmark is currently preparing together with the main stakeholders from industry, academia, the energy sector and governmental departments a comprehensive research strategy covering both basic, applied research and development and demonstrations. Funds from the high technology fund yet under development will also be used for funding.
- The Norwegian Government is currently discussing a national plan for the hydrogen economy that emphasizes research, development and demonstration into hydrogen technologies related to transport and stationary applications. The estimated cost of the plan is between 825 and 974 million NOK (99 and 117 million EUR) over a period of ten years.

The rapid development and the constant changes in national and regional priorities and activities make it difficult to provide updated information unless a regular watch of national and regional funding possibilities is established and made accessible to possible future Hydrogen Communities.

Private investments in view of public-private partnerships

In general terms, it is difficult to assess the willingness of the private sector in investing in HyCom or in selected activities of a Hydrogen Community. This will depend on the scope and the financial requirements from a variety of funding schemes. As the coordinator of the CUTE project explained regarding the financial challenges in each of the cities involved, "W*e had to investigate the financial possibilities in each location and each location had to find its own financial way*" (Interview with Manfred Schuckert, 29 September 2004).

Private investment also depends on the legal form for the various activities and the Hydrogen Community as such and how the investment risk is distributed among the partners.

Public-private partnerships (PPP) have been developed in several areas of the public sector, such as transport, public safety, energy, waste etc. The basic idea of a PPP is to achieve value for money for the public sector by transferring appropriate risk and responsibility to the private sector in a way, which creates incentives and optimises the technical solutions and the cost of the system. They are characterised by a relatively long duration of the relationship, involving cooperation between the partners on different aspects of the planned project. Funding may be a complex arrangement between the various players, including both public and private funds. Although the risks generally borne by the public partner are transferred to the private partner, the distribution of risks between the public and private partner is something, which is determined case by case. However, under Community Law, there is no specific system governing Public-Private Partnerships. Some PPPs

will qualify as "public contracts" and must comply with the Directives coordinating procedures for the award of public contracts, others like "work concessions" and "service concessions" are not covered by the Directive (COM(2004) 327 final[9]).
Joint Undertaking is a public-private legal form, which can either be a joint venture or a joint concession company (PWC, 2001; www.galileoju.com). In the case of the Galileo project, the European Community and the European Space Agency (ESA) would hold the majority of the equities and with the private sector as minority in the development phase. Hereafter, the role of the joint venture would transfer to an operating company for the deployment and operation phases. This is illustrated in the figure below.

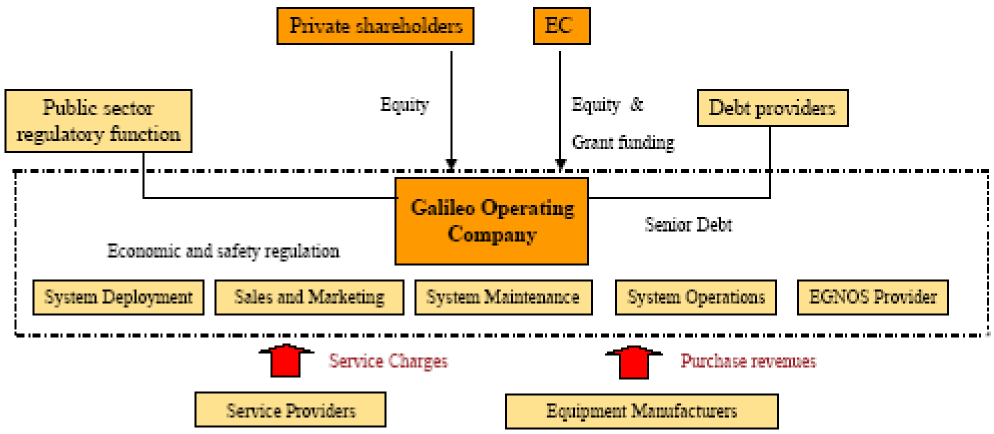


Figure 4: Joint Venture Model Deployment and Operations Phase (PWC, 2001: 12).

In the case studies described later in this report, more detailed information is given on various forms of partnerships, including both public-private partnerships and private-private partnerships.

Summary of Financial Options

Unlike the Galileo inception study prepared by PriceWaterhouseCoopers with detailed analysis of sources for revenue, analysis of system and costs in development and deployment and operations phases, financial projections and cash flow, cost-benefit analysis, it is outside the scope of this ESTO study to do something similar.

But a very rough indicative overview of financial sources is suggested in the table below. The distribution could have been based on the Barcelona target of 1/3 public contribution and 2/3 private contributions to R&D, but we have instead chosen the distribution closer to the 60/40 split foreseen for the Growth Initiative and also in line with warnings from several experts not to rely too much on private funding for demonstrations (Interview with Mr. Nicolas Bardi, CEA, 27 September 2004). Dependent on which programme management is chosen for the HyCom Initiative, being top-down or bottom-up managed, being managed as a joint undertaking for the whole initiative or rather being a network of Hydrogen Communities supported and coordinated by the Technology Platform and the Commission, each of the Hydrogen Communities will differ in technical scope, economic size, and financial engineering.

[9] COM(2004) 327 final – Green paper on Public-private Partnerships and Community Law on Public contracts and Concessions

Table 3: Indicative distribution of financial sources for HyCom. Million EUR..

Period	EU (FP, Structural Funds, etc.)	Member State	EIB	Private sector	Total
	30%	20%	25%	25%	100%
2005-2007	80.4	53.6	67	67	268
2007-2012	241.2	160.8	201	201	804
2013-2015	128.7	85.8	107.25	107.25	429
Total	450.3	300.2	375.25	375.25	1,500

2.4 Conclusion for the HyCom Initiative

There are major differences between the Growth Quick-start Hydrogen Initiative and other leading demonstration activities around the World and clarification is needed how to position HyCom in the European research, development and demonstration policy context.
The challenge remains how to orchestrate the identification and design of setting up a limited number of hydrogen communities over the next 10 years so that this HyCom Initiative is designed and managed in an effective way that brings together different stakeholders in high quality and ambitious Hydrogen Communities across Europe over the next 10 years.

Waiting for a European research and deployment strategy

The HyCom Initiative needs the development of a broad and far-reaching hydrogen and fuel cell research and deployment strategy by the European Partnership for Hydrogen and Fuel Cell Technologies. This strategic work is still undergoing (October 2004). There is still some way to go before consensus will be reached by the Technology Platform. It is also demanding to translate the strategies into more detailed research, development and deployment programmes at European level. In particular, it takes time and requires further alignment mechanisms to have some impact on national research priorities and activities. A study is currently undertaken by DG RTD J/Technopolis on ways of improving complementarity and synergy between national and community research in the field of non-nuclear energy (Draft 1 October 2004). Among others, it recommends to have a stronger coordination through the creation of multi-lateral networks of national and regional programme managers. The question remains whether the Mirror Group of the Technology Platform may fulfil this role or whether other mechanisms are necessary.

Finding the right financial balance between research, both basic and applied, and demonstration activities

The announcement of 1.5 billion EUR over the next 10 years to set up a limited number of hydrogen communities has to be put into perspective of the needs for basic and applied research in hydrogen and fuel cell technologies before these can be widely tested and validated.
Although demonstrations play an important role in the US hydrogen programme, it only accounts for 13% of total funds. The Japanese RD&D programme in 2003 earmarked 23% to demonstrations. It is without doubt that the push for setting up Hydrogen Communities is founded in the rationale to bring economy of scale into the development of fuel cell and hydrogen technologies. In the long list of Expressions of Interest regarding hydrogen and fuel cell technologies the whole knowledge value chain comprising basic and applied research as well as demonstration and pre-competitive activities is included.

For the individual Hydrogen Community, the mix of various demonstration and research and development component will probably vary and also depend on the local innovation system. What is crucial, however, is that no duplication of activities takes place, but that new knowledge is produced in order to bring the technologies to the market place. This problem will be further developed in the following chapter, where the hydrogen and fuel cell technologies are assessed in terms of their development stage and expected future improvements in efficiency, durability and cost reduction.

Keeping complexity low in financial engineering

When combing different funding schemes, there is a risk of increasing the complexity of the overall financial engineering of the project. This is especially the case when combining EU schemes, which individually are regarded as highly complex. From a programme management point of view, the challenge for the Commission is how to bring together the various EU funding schemes to the benefit of HyCom while at the same time not to make the fund seeking too difficult and cumbersome for the individual Hydrogen Community.

In Canada, the Canadian Hydrogen and Fuel Cell Committee H2FCC has a facilitating role towards the various development and demonstration projects across the country. It has for example made a Programme roadmap with more than 32 programmes spanning the innovation spectrum from basic research to demonstrations and policies needed for mass commercialisation. Also industrial associations as for example the Fuel Cell Industry is giving strategic and concrete advice as well as secretariat assistance to the large demonstration projects under way.

For HyCom, a similar facilitating body with national nodes could help assist interested regional stakeholders in designing projects and identifying the right financial instruments to be used in different components. Experiences in setting up such bodies should be further investigated, including the Innovation Regions framework (www.innovating-regions.org).

Clarifying the goal and management for the HyCom Initiative

The overall goal of the Hycom Initiative has to be clarified, in particular the interlinkages between the development of the European research area in the field of hydrogen and fuel cell technologies and the push for the hydrogen economy. These objectives have different pace and time perspectives – the first is linked to the framework programmes and the latter to contribute to the European energy and climate targets. The time schedule for preparing and implementing the hydrogen communities should be agreed upon in an overall roadmap, including which instruments to be used and when.

Once when the overall goal is clarified and agreed upon, the most appropriate implementation of the Initiative has to be clarified and agreed upon. The Canadian hydrogen demonstration activities are facilitated and coordinated by a public-private partnership in a bottom-up process where the industry has a key management and monitoring role in the Highway cluster of demonstrations. A top down approach is used by Japan, where the two large demonstration programmes are mainly driven by the Government, though in close cooperation with industry and research. In between, we have the US learning demonstration programme where five consortia have been selected in a solicitation process according to few territorial selection criteria and strong technical feasibility criteria linked to the milestones of the Multi-year Research, Development and Demonstration Plan.

The design, management and implementation of the HyCom Initiative should build on the existing hydrogen and fuel cell RD&D activities undertaken at EU and national level, align the various efforts across national and institutional boundaries and add to these a powerful, future oriented

direction. The interest demonstrated in both the Expression of Interests, the interests demonstrated during this pre-feasibility study from a variety of stakeholders and interest raised at the information meeting in Brussels on 20 September 2004 leaves no doubt that a lot of regional and local activities are under their way.
The **challenge** for the Commission is therefore how to successfully heading these activities and give them a common direction. This may include:

- Cooperation across the various DGs and clarified policies.
- More in-depth studies on the pros and cons in the design and management of relevant RD&D programmes and regional development programmes in Europe and elsewhere
- A watch and facilitating service to inform on RD&D activities undertaken at national and EU level and elsewhere.
- A technology watch on fuel cell and hydrogen technologies.

3 Hydrogen Technologies

3.1 Introduction

Focus in this chapter is on hydrogen technologies relevant for hydrogen community applications. Technology development is in general problem driven, and the main problems for the energy sector are: the security of supply, the greenhouse gases and the air pollution. Hydrogen is often presented as *the* answer to many of the technical energy problems, and certainly the hydrogen technology addresses the above problems, but hydrogen alone cannot solve them, and the problems might also be addressed by other means.

The annual global emissions of hydrogen are about 80 Tg – mainly from natural processes, but about 20 % due to combustion of fossil fuels (Novelli et al.,1999). The current annual worldwide production of hydrogen – with a significant leakage – is about 50 Tg (or 500 GNm^3) (Di Mario et al., 2003). So, the human activities already have a significant impact on the amount of hydrogen in the atmosphere. The introduction of the 'hydrogen economy' can change this impact in both directions, depending on the way hydrogen is handled. Hydrogen's potential influence on the atmospheric processes (the green house effect, the ozone layer effects etc.) is still not clearly understood and documented.

Hydrogen technologies offer qualities such as flexibility in the energy system, reduction of greenhouse gas emission, reduction of the air polluting exhaust and noiseless operation. However, hydrogen is not the only option providing these advantages, and hydrogen also has several disadvantages and may not turn out to be the only and optimal solution.

One specific advantage that only hydrogen (and ammonia) can demonstrate is the directly CO_2-free end-use. It is, however, technically possible to sequestrate CO_2 from other hydrocarbon fuels on site – even in mobile applications. In other aspects hydrogen cannot demonstrate better technical and economic performance than other hydrogen rich fuels (Hy-fuels). Therefore an open approach to the perspectives provided by other (synthetic) hydrogen rich fuels is recommended.

It should be emphasised that hydrogen is not a primary energy resource and cannot solve any lack of energy resources. However, hydrogen (and other Hy-fuels) has the ability to act as energy carriers in both stationary and mobile applications. In particular they offer the potential for transition from reliance on fossil fuels to increased contributions from renewable energy sources.

According to the fundamental of physics, energy cannot disappear, it can only change form – and at the end it all ends up as heat. Therefore when talking about 'loss of energy' it should be understood as energy that is not utilised – typically in the form of undesirable heat (to be) transferred to the surroundings. All conversions from one form of energy to another involve some amount of energy in other forms that often will be treated as losses.

The evaluations and comparisons of the various technical solutions to obtain a given energy service (e.g. transport or heating) should be based on the analysis of the entire energy chain from the exploitation of the primary energy sources through all the necessary steps to the final energy service provided – a source-to-service (S2S) analysis (Figure 5). For the specific energy service, the primary energy required, the greenhouse gas emission and the cost should be considered.

The feasibility of hydrogen (or other Hy-fuels) is closely related to the development of practical fuel cell technologies. The flexibility in the energy system may be obtained by reversible fuel cell links between the electrical system and the hydrogen (Figure 6). The non-polluting exhaust can be obtained by fuel cells operating on any of the Hy-fuels, and the noiseless operation is a fundamental property of the fuel cells. However, only hydrogen as fuel will not produce CO_2.

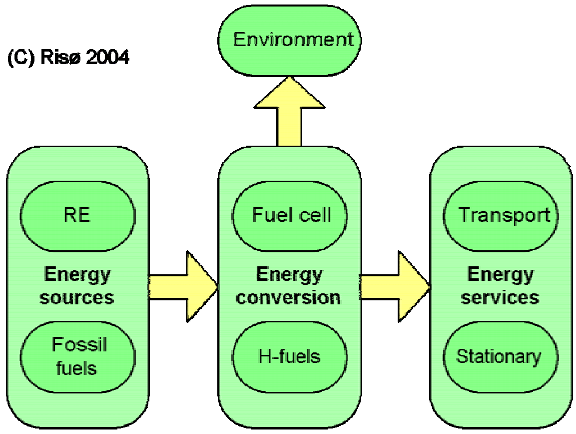


Figure 5: When evaluating the energy technologies (e.g. hydrogen and fuel cells) focus must be on the cost (in terms of money, primary energy sources and environmental load) relative to the energy services provided (e.g. transport).

The overall challenge for the hydrogen technologies is to become cost competitive. Hydrogen's specific quality as a 'clean' fuel seems not to justify a significant higher cost than the alternatives. The fact that hydrogen as an energy carrier has to be produced from other primary energy sources with the related cost of conversion equipment and unavoidable energy losses imply that the hydrogen solutions necessarily will be less energy efficient than more 'straightforward' energy paths, if at all possible. E.g. if the final need is electricity, a temporary conversion from electricity to hydrogen and back again cannot be justified. The only exception is production of hydrogen directly from solar energy – a technology that is not expected to be available in the near future.

3.2 Technical and Economic Assessment of Technologies

A number of valuable studies on the 'hydrogen economy', hydrogen as an energy carrier and hydrogen and fuel cell technologies have been performed and reported on in the past. The present technical study is mainly a desk study based on what has already been reported supplemented with interviews of dedicated experts.

It is important to distinguish between physical and technical constrains and limitations – the physical limitations cannot be changed or removed, while the technical limitations or barriers are a question of scientific knowledge and technical development and might be moved or overcome.

The technical and economic status, expected developments and the perspectives for the various hydrogen technologies are presented below. The hydrogen technologies are indicative compared to alternative and competing technologies in order to indicate the necessary development of the hydrogen technologies to become attractive options (comparative analyses).

It should be emphasised that the socio-economic costs and benefits depend crucially on the assumptions made. Therefore, the actual figures should be interpreted carefully and both the comparative studies and the development trends should be treated as relative indications.

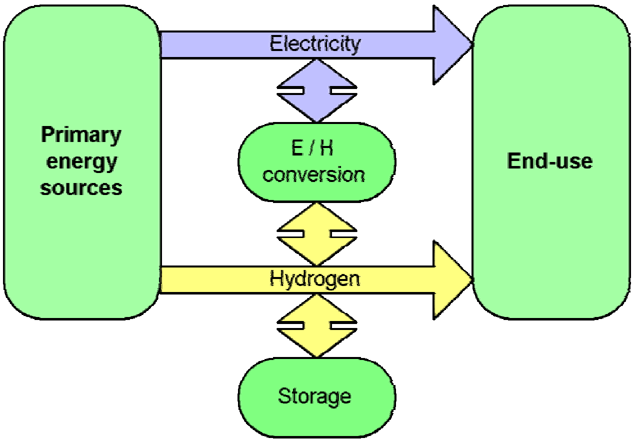


Figure 6: By its link to electricity, hydrogen (or another Hy-fuel) offers an increased flexibility in the energy system.

The various technologies present a number of technical challenges or barriers to be overcome for the technologies to be attractive. The demonstration projects to be selected for support from the HyCom Initiative should address at least one of these challenges and demonstrate new abilities and possible synergies.
The study uses a broad understanding of the terms 'hydrogen' and 'demonstration'. *Hydrogen* is understood to cover also other Hy-fuels. In the present study we distinguish between synthetic hydrogen rich fuels and fossil fuels, although fossil fuels are also hydrogen rich. The term *Hy-fuels* covers synthetically produced fuels like pure hydrogen, methane, methanol, ethanol etc. Biofuels are treated as a Hy-fuel as well. In Table 4, Table 5 and Figure 7 hydrogen is compared to other Hy-fuels by selected characteristics.

Table 4: Some advantages and disadvantages for selected Hy-fuels.

		Specific advantages	**Specific disadvantages**	**Notes**
Hydrogen	H_2	▫ CO_2-free end-use ▫ Simple to produce	▫ low energy density ▫ difficult to handle ▫ difficult to store	
Methane	CH_4	▫ Infrastructure exist (NG consist mainly of methane)		
Methanol	CH_3OH	▫ liquid phase under standard conditions	▫ toxic	Even if methanol is toxic and water-soluble it is still less environmentally problematic than e.g. diesel fuel.
Ethanol		▫ liquid phase under standard conditions		
Ammonium	NH_3	▫	▫ toxic and corrosive	

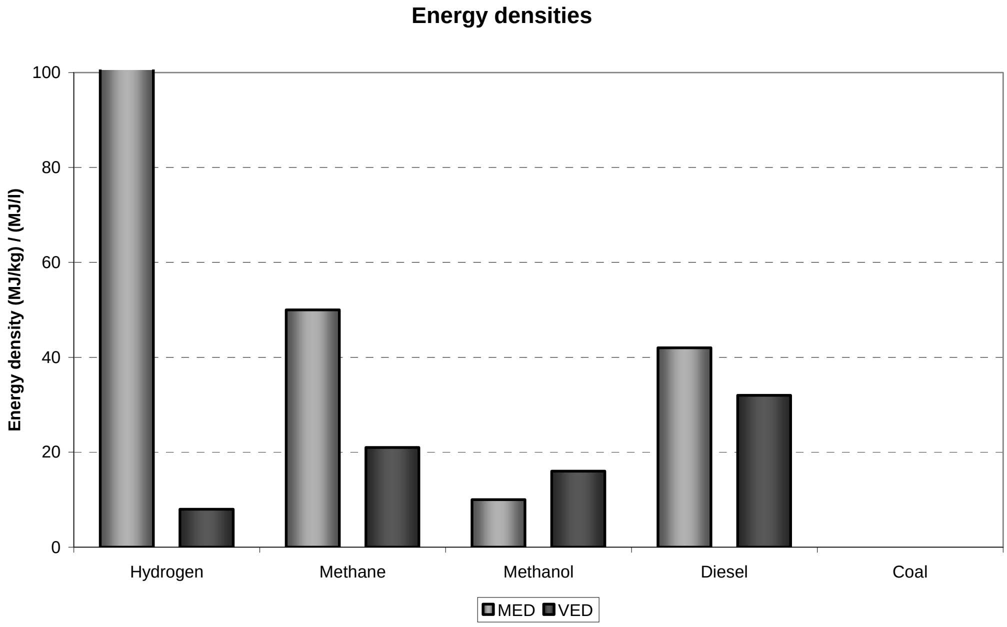


Figure 7: Mass (MED) and volumetric (VED) (@ liquid phases) energy densities for selected fuels. (Source: JRC, Petten, 2003)

Demonstration is defined as a project that shapes the results of industrial research into a plan, arrangement of design for new, altered or improved products, processes or services, whether they are intended to be sold or used, including the creation of an initial prototype which could not be used commercially. A demonstration may include, but is not limited to (Guide to Financial Issues relating to Indirect Actions of Sixth Framework Programmes, version April 2004: 39):

- Prototype design and assembly
- Test bench validation
- Large infrastructure use for testing prototypes
- Pre-certification for testing purposes.

The main driving factors for the introduction of a Hy-fuel based energy carrier include:

- Hy-fuels provide increased flexibility in the energy system – e.g. by their link to electrical power (Figure 6).
- Hy-fuels provide the necessary buffer capability for large-scale integration of intermittent

Table 5: The energy densities and the corresponding volume or weight per energy unit of selected hydrogen based fuels (LHV/HHV).

		Standard		Liquid		Q/V		V/Q		CO_2	
Hydrogen	H_2	89	g/Nm^3			120/142	MJ/kg	90/79	Nm3/GJ	0	kg/GJ
						10.8/12.7	MJ/Nm3				
Liquid hydrogen				71	g/l	8.5/10	MJ/l				
Methane	CH_4	707	g/Nm^3	423	g/l	50/	MJ/kg	/25	Nm3/GJ		kg/GJ
Methanol	CH_3OH					20/	MJ/kg	50/	kg/GJ		kg/GJ
Ammonia	NH_3					/22					
Diesel				700		42/	MJ/kg	24/	kg/GJ		kg/GJ
Coal											kg/GJ

renewable energies;

- Hy-fuels provide an option for reducing pollution from transport applications – particularly relevant in urban areas;
- Hy-fuels provides a link to utilise electricity / renewable energy in the transport sector;
- Hydrogen (as the only fuel) provides CO_2-free end-use;
- Hydrogen provides the option to capture CO_2 when utilising fossil fuel (CO_2 sequestration).

If hydrogen as energy carrier is found attractive in one application and is first introduced, other hydrogen applications are expected to follow. Fuel cell applications where both power and heat can be utilised (CHP) are obvious applications. However, the fuel-cell technology is not linked only to hydrogen, but may also run on other Hy-fuels.

Short-term / long-term perspectives

In the description of the technologies both current stage and short-term and long-term perspectives are indicated. The short-term perspectives are directly relevant for demonstration projects within the HyCom timeframe (2005..2015). The long-term perspectives indicate / identify technologies expected to become relevant in a longer perspective, and is relevant for the priorities of technology developments. The technology developments to be supported (e.g. by HyCom) should (also) contribute to the long-term development perspectives.

In the longer term electricity, Hy-fuels and biofuels are seen as complementary energy carriers that might be produced in a sustainable way. Electricity is seen as a very competitive energy carrier in most applications except for energy storage and mobile applications.

At present the most competitive large scale electricity storages seem to be based on the flow-cell technology with electrolytes. And the need for energy buffers in the energy system may be reduced by the use of two means:

- by energy exchange over large distances (due to the fact that the renewable energy productions become more uncorrelated with increased distances resulting in some smoothing effect of the fluctuations in the aggregated production); and
- by intelligent load management (shifting part of the load in time).

For vehicles in short-term, the hybrid combustion engine-electricity technology seems to be the most competitive.

SI-units have been used throughout the report. Fuel energy densities are indicated by their Lower and/or Higher Heating Values (LHV / HHV, representative for processes producing water in vapour phase or liquid phase respectively). If not specifically indicated, the LHV is used.

The commonly accepted methods for evaluation of energy conversion technologies are based on the use of the lower heating value (LHV) of combustible energy carriers. This means that efficiencies of conversion are calculated based on the energy content of the input energy carrier but excluding the condensation heat of water vapour. The water vapour is generated during combustion from the hydrogen content and the moisture or water content of the input energy carrier. This convention of using the lower heating value stems from the fact that almost no conversion technology can make use of the condensation heat of the water vapour. There are however exceptions from this convention. Natural gas for example is traded on the base of the full energy content referred to as the higher heating value (HHV). With the introduction of hydrogen as an energy carrier, it might become useful to refer to the higher heating value.

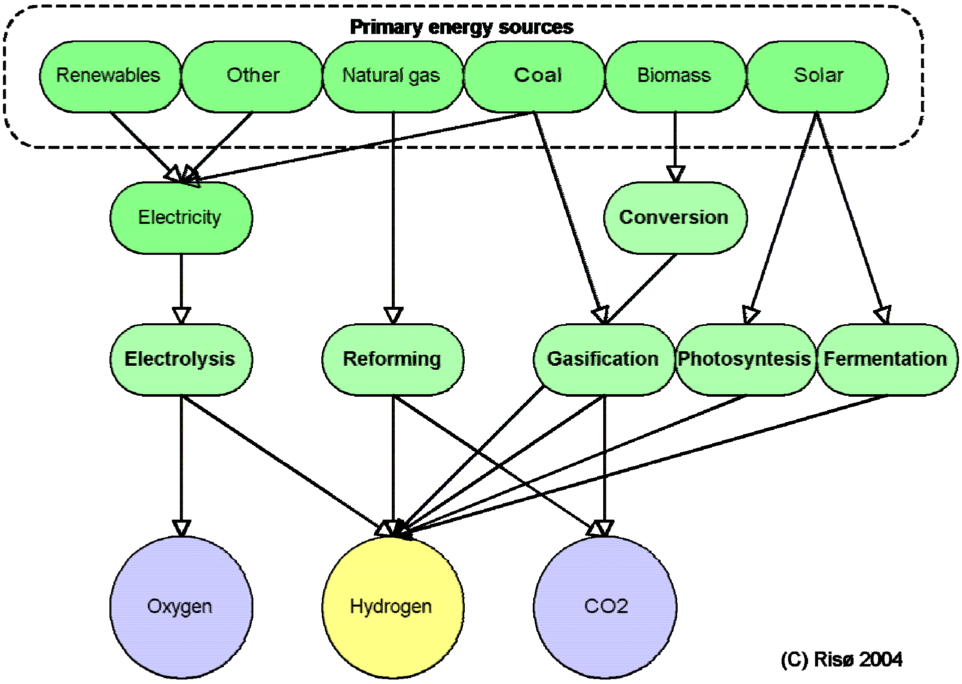


Figure 8: Various paths for hydrogen production.

There are energy conversion technologies for hydrogen that can make use of the condensation heat. First of all there are the condensing boilers already in use with natural gas, but on top, there are low-temperature PEM fuel cells under development that should also be able to exploit the condensation heat. When looking now at conversion technologies with dual products electricity and hydrogen like the envisaged Hypogen facility, the referencing to the higher heating value reveals an advantage for hydrogen. The combined cycle unit cannot make use of the condensation heat, whereas the hydrogen still carries the full energy content. Of course the potential advantage of the hydrogen as energy carrier can only be realised if one of the – still very few - technologies is employed that use the condensation heat.
When taking coal as an input energy carrier, the difference between higher heating value and lower heating value is in the order of 5 %. This is already a considerable amount of energy that would lead to a significant increase of efficiency if being utilised. So, the option of making exploitable the condensation heat by converting coal to hydrogen should be kept in mind when appraising future technology paths. With more hydrogen rich energy carriers such as natural gas, the difference between higher heating value and lower heating value becomes even more dominant.

The hydrogen technologies

The hydrogen technologies are divided into

- production technologies,
- conditioning, storage and distribution technologies,
- conversion technologies and
- application technologies.

The storage and the distribution technologies are overlapping and described in a common section.

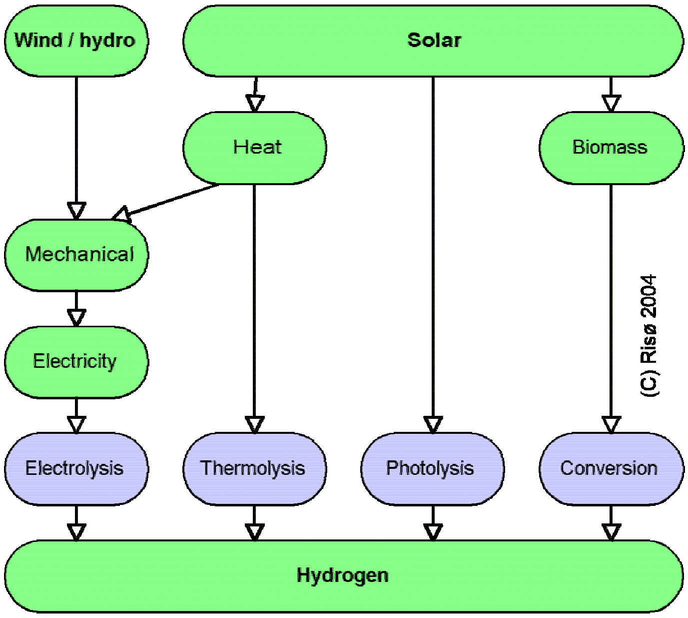


Figure 9: Sustainable paths to hydrogen.

3.3 Hydrogen Production

The hydrogen fuels exist as natural resources only as natural gas, but they may in a variety of ways be synthetically produced with use of other energy resources (Figure 8). Current annual world hydrogen production is about 50 Tg (500 GNm^3) (Di Mario et al., 2003).
A number of options for making hydrogen are available:

- In *electrolysis* electrical current breaks water (H_2O) into its components (H_2 and O_2).
- Heat (e.g. from sunlight or nuclear reactor) breaks water in a *thermo-chemical process*.
- In *steam reforming* steam breaks fossil fuels (e.g. NG) into its components – H_2 and CO / CO_2.
- In *gasification processes* heat breaks H_2 out of coal or organic matters.
- *Biological processes* employ organisms to break water or organic matter.

The energy efficiencies of the various hydrogen production technologies are evaluated based on the energy needed to produce one energy unit of the hydrogen fuel.
In sustainable hydrogen-based energy system the predominant options for the production of hydrogen are expected to be based on (a combination of) the three primary energy sources:

- clean fossil fuels (by CO_2 sequestration),
- safe nuclear power,
- renewable energy sources.

However, none of these options are straightforward. The clean fossil fuels based on coal and natural gas requires the sequestration of the CO_2. The development of safe nuclear power is very uncertain. The renewable energy technologies require a fundamental change in the approach for energy supply, but fit well to a decentralised energy structure like the hydrogen infrastructure.

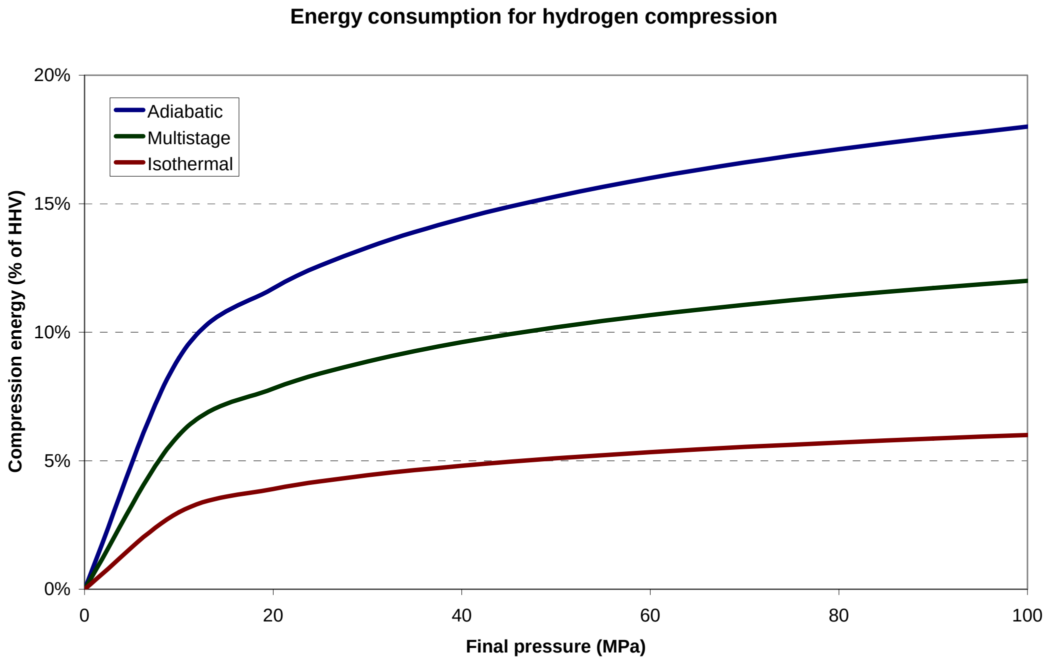


Figure 10: The graph indicates the energy needed for the compression of hydrogen relative to the HHV energy in the hydrogen. (Source: Bossel, 2003).

Biological processes

Hydrogen may be produced biologically by photosynthetic processes, fermentative processes or by gasification of biomass. Gasification of biomass is well developed, demonstrated e.g. by the Blue Tower Project in Germany. Photosynthesis and fermentation will not be available in short-term. The technologies need significant developments to become technically and economically attractive alternatives.

Conclusion – hydrogen production

Even under very optimistic assumptions, electrolytic hydrogen derived from renewable electricity sources would be at least twice as costly as hydrogen derived from coal with geological sequestration of the separated CO_2, using technologies commercial available today.

3.4 Hydrogen Conditioning, Storage and Distribution

Conditioning

Hydrogen conditioning is an important sub-sector in a hydrogen energy system. Compared to conventional fuels, hydrogen has a very poor volumetric density. In order to achieve efficient storage or distribution of hydrogen, compression or liquefaction is necessary.

Compression

Hydrogen compression is a well developed, commercially mature technology (HySociety, 2004). In principle the same standard piston type mechanical compressors as for natural gas can be used. Slight modifications of the seals are sometimes necessary in order to compensate for the higher

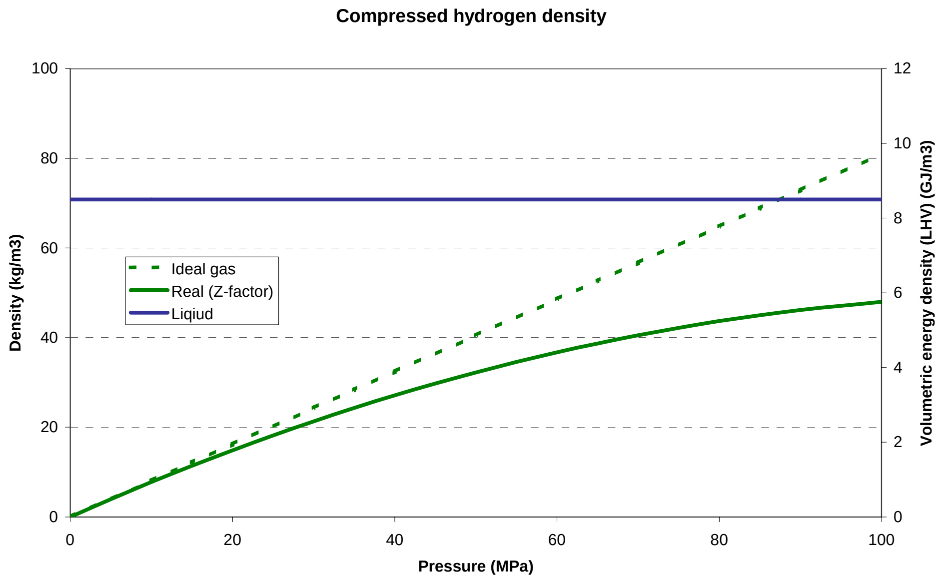


Figure 11: Real volumetric hydrogen density as a function of pressure (@ Z-factor function, 20ºC) compared to the ideal gas and the liquid phase. For a real gas the compression becomes less density efficient with increased pressure. The assumption of ideal gas behaviour will lead to significant errors in estimating the volumetric energy density of hydrogen. The volumetric energy density (Source: Tzimas et al., 2003)

diffusivity of hydrogen (Züttel, 2004). The energy efficiency depends solely on the energy needed for compression – the work on the gas itself (5..15 % relative to the LHV energy of the hydrogen depending on the pressure level (Tzimas et al., 2003) and the energy consumption of the compressor. When hydrogen is compressed e.g. from 30 to 850 bar, the electricity demand is approximately 0.06 kWh/kWhH2 and the cost around 1.022 c/kWh(H2). For a compression from 30 to 500 bar it is roughly 0.055 kWh/kWh(H2) and 0.95 c/kWh (HySociety, 2004). Cost of compressors is expected to be between: 1 and 5 €/W at compressor power range from 1000 to 10 kW (Tzimas et al., 2003).

Liquefaction

Liquefaction technology is also commercially available. R&D requirements especially focus on efficiency improvement, the increase of production capacity and the integration with production either from fossil or renewable sources. The electricity demand for liquefaction is about 0.25 kWh/kWh(H2) and the cost results in 0.0155 c/kWh (HySociety, 2004).

Distribution technologies

As soon as hydrogen is not produced at the place of its usage (on site), the distribution of hydrogen is necessary. In short-term hydrogen communities, gaseous hydrogen is likely to be distributed by short distant high pressure pipelines from the point of production to the end-use applications. Liquid hydrogen will be transported in cryogenic tanks carried by trucks (cryogenic trucks). Both options are mature, safe and commercially available. Gaseous hydrogen transport in pressure vessels, transported by trucks is no viable option, because only a very small amount of hydrogen can be transported per delivery, due to the low energy density of gaseous hydrogen.

Pipelines

Hydrogen delivery through pipelines seems to be the most economical option for delivery at high volumes. Experiences with hydrogen pipelines exist for more than 50 years (Ruhr area, Germany). The total hydrogen pipeline network comprises 1500 km in Europe and 720 km in the USA. Most pipelines operate at a pressure around 20 to 30 bars. For transport applications however, a high refuelling pressure is required. In case of low pressure pipelines, hydrogen is compressed and stored at the filling station. Recently the trend is to increase the pipeline pressure. A pressure of 250 bars for short distances is state of the art. In the context of the 'Zero Regio' project (Italy, Germany), a 100 MPa (1000 bar) pipeline will be developed and built within the next two years. On a distance of several kilometres, no intermediate compressors are necessary. Energy is only needed to increase the initial hydrogen pressure (dependent on outlet pressure of hydrogen production) to the pipeline level. Hydrogen losses are negligible on short-distances. Cost is about 1 M€/km (Infraserv, 2004).

Cryogenic trucks

The transport of liquid hydrogen occurs in cryogenic containers of typically 30-60 m3 capacity carried by a truck. The cryogenic containers are usually super-insulated cylindrical tanks. A disadvantage is the boil-off that may be in the range of 0.3-0.5% per day (for a container of around 50 m3). A cryogenic truck is assumed to cost around 0.5 M€ (HySociety, 2004).

Filling stations for transport applications

The necessary additional investment for the establishment of a hydrogen filling station for transport applications is in the range 1-2 M€ and expects to come down to 0.2-0.5 M€ depending on the capacity, the number of stations built and if the fuel is liquid or gaseous form (HyNet, 2003).

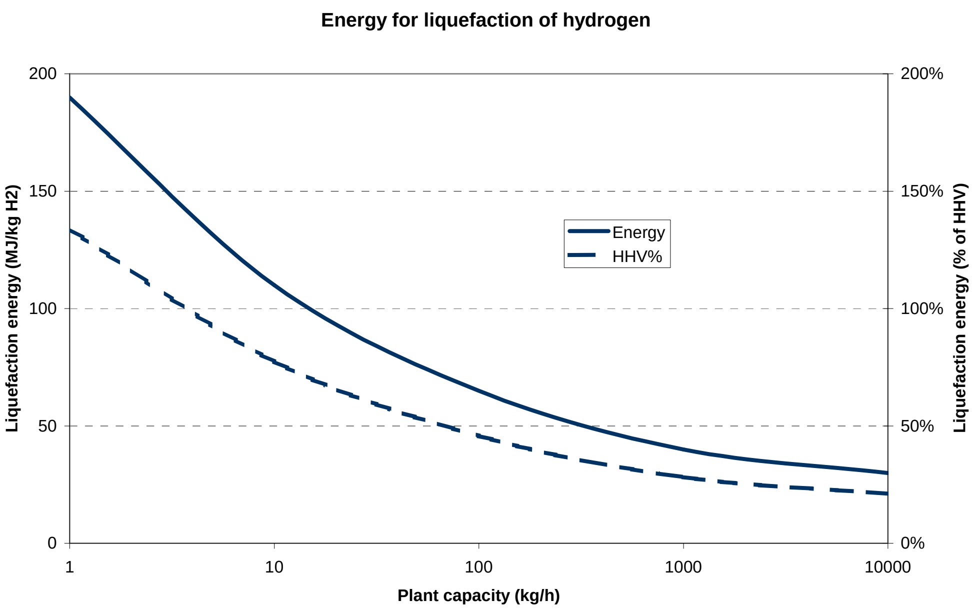


Figure 12: The graph indicates the energy typically used for liquefaction of hydrogen – in actual energy and relative to the energy (HHV) in the final liquid hydrogen respectively – for various production capacities. For small-scale production (< 5 kg/h) the energy used for the liquefaction exceeds the energy in the final liquid hydrogen. (Source: Bossel, 2003)

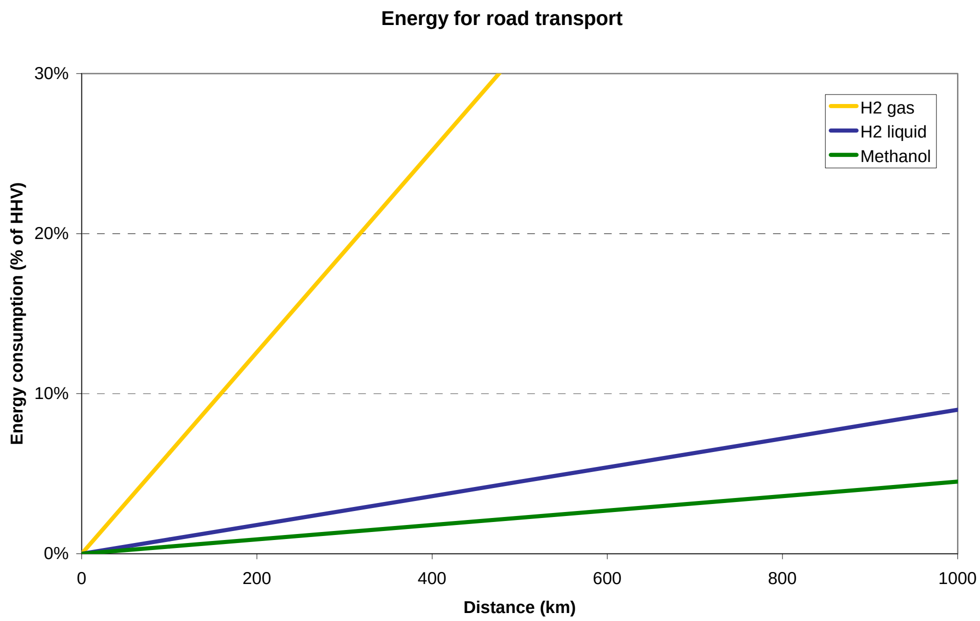


Figure 13: The graph indicates the energy required for road transportation of the fuels relative to the energy (HHV) in the fuel transported. For gaseous hydrogen (@ 35 MPa) all the energy in the fuel will be spent in transportation at about 1000 km. (Source: Bossel, 2003)

Hydrogen storage technologies

Currently several safe and technically mature options for hydrogen storage exist. Among these is high pressure storage at up to 700 bar (systems for 800 bar are currently tested), liquid hydrogen storage and storage in metal hydrides. Challenges are to develop hydrogen storages for vehicle transportation, providing a reasonable driving range at reasonable cost. Besides improving the existing well known technologies, the R&D focus should be on the exploration of new storage material properties and concepts. Complex compounds (e.g. LiBH4 or Al(BH4)3) represent a very interesting and challenging new hydrogen storage option. The main difference of the complex hydrides to the metal hydrides is the transition to an ionic or covalent compound of the metals upon hydrogen absorption. Volumetric and gravimetric storage density promises to exceed that of gaseous, liquid or metal hydride storage systems. However, very little is known about the stability, the sorption kinetics and the reversibility and basic research is needed. The main difference of the complex hydrides to metal hydrides is the transition to an ionic or covalent compound of the metals upon hydrogen absorption (Züttel, 2004). Very promising is also hydrogen storage in carbon nanostructures. This storage technology has shown good results and seems to have a potential for cheap, safe, scalable and energy dense hydrogen storage. Like complex compounds storage systems however, this technology is still at laboratory level and is not expected to be available for hydrogen storage in short-term.

The hydrogen storage technologies are divided by their phases as either gas, liquid or bounded.

Gaseous hydrogen storage

Compressed hydrogen storage is a mature technology, but improvements in weight, volume efficiency, tank design and cost reduction are needed. Systems for 100 MPa (1000 bar) have been tested, but even at this pressure level the energy density is rather low (5.5 GJ/m^3 LHV or 45 kg/m^3). The hydrogen / vessel weight ratio (2005) is < 5 $\%_w$.

The cost level of the vessels is between 0.5.and.2 €/g (4.to 16 €/MJ LHV), depending on the size and the pressure. New tank designs, the reduction and/or substitution of expensive materials, production technologies and compressor developments are expected to reduce the cost.

Liquid hydrogen storage

Liquid hydrogen is stored as a cryogenic liquid at its boiling point (-253 °C). A major concern is to minimize hydrogen losses from liquid boil-off due to heat transfer to the liquid, including the internal hydrogen ortho-to-para conversion. For mobile hydrogen storages, Linde AG has recently developed and patented a system, which makes it possible to significantly extend the time before evaporation losses occur (up to 12 days). When the vehicle is in operation, the surrounding air is drawn in, dried, and then liquefied by the energy released as the hydrogen increases in temperature. The cryogenically liquefied air (-191° C) flows through a cooling jacket surrounding the inner tank and thus acts like a refrigerator. This leads to a delay in the temperature increase of the LH2. Since the cooling system can be accommodated in the existing insulating layer of the tank, it does not affect the size of the tank (HySociety, 2004). Last research approaches aim at using liquid nitrogen as insulation medium and 15 days standing times without boil-off have been achieved. Liquid hydrogen storage has acceptable energy density, but the special handling requirements, the long-term losses, and the cryogenic liquefaction requirements are drawbacks. Cryogenic tanks are commercial available at a price level of 5..100 €/l (corresponding to 0.5..10 €/MJ for liquid hydrogen), very much depending on size and robustness requirements. The overall energy efficiency is mainly determined by the energy needed for the liquefaction process.

Hydrogen storage in metal hydrides

Metal hydrides (e.g. LaNiH6, Mg2NiH4, TiFeH2) are alloys that absorb gaseous hydrogen, much like a sponge absorbs water. Through a chemical reaction, solid metal hydrogen compounds are formed and heat is released. Conversely, hydrogen is released when heat is applied to the materials. Metallic alloys can be charged and discharged many times. The composition of the alloy determines the temperature and pressure level for the desorption and adsorption process. The typical storage density is 1.3-1.5 % of hydrogen with respect to weight, corresponding to 150 l of hydrogen per kg

Table 6: Properties of different hydrogen storage systems (Züttel, 2004)

Storage method	**Gravimetric density [%]**	**Volumetric density [kgH^2/m³]**	**Temperature [°C]**	**Pressure [bar]**
High pressure gas cylinders	13	< 40	Room temperature	800
Cryogenic tanks	size dependent	70,8	-252	close to ambient
Metal hydrides	≈ 2	150	Room temperature	close to ambient
Complex compounds	< 18	150	> 100	close to ambient
Carbon nano-structures	> 25	50-100	-100	close to ambient

of hydride material, or 450 Wh/kg or 1050 Wh/l based on the lower heating value of hydrogen. Predictions from some companies indicate that hydrides with 2 wt % of hydrogen will be available in a short-term perspective. The advantages include:

- A low pressure operation
- Hydrides are considered to be the safest way to store hydrogen, since the temperature decreases during discharge and the hydrogen release is decelerated accordingly.
- The alloys can be charged and discharged several thousand times, depending on the purity of the hydrogen used for charging.
- Metal hydrides store about 60% more hydrogen by volume as compared to liquid storage and hydride tanks are flexible with respect to geometry.
- When hydrogen is stored in metal hydrides, no storage losses occur.
- There is no self discharge of the hydrides in case the device is not in operation for a certain time.
- There is no memory effect.

The disadvantages include

- weight (≈ 2 %w),
- long filling time and
- cost.

No single current state-of-the-art hydrogen storage technology satisfies all criteria required by manufactures and end-users, and a large number of obstacles have to be overcome. The various technology options have their individual advantages and disadvantages with respect to weight, volume, energy efficiency, refuelling time, number of refuellings, lifetime, cost and safety aspects. The cost of storage vessels, hydrogen conditioning (compression, liquefaction), and other auxiliary equipment are key issues.
A fuel cell vehicle needs approximately 5 kg hydrogen for an operating range of 500 km. A density of 100 g/l results in a net volume of 50 l.

	Energy density		**Lifetime**	**Lifetime**	**Energy efficiency**	**Price*)**
	(MJ/l)	(MJ/kg)	(years)	(cycles)		(€/MJ)
Hydrogen						
350 bar tanks	3		-	-	47 %	15
350 bar w/ 10..50% CHP	3		-	-	51..66 %	-
700 bar tanks	5		-	-	45 %	-
Batteries						
Li-ion battery	0.6		10	1000	85 %	80 / 30
Flow batteries	0.1		30	-	80 %	-

*) Present / future prices.

Table 7: Comparison of key performance characteristics for selected technologies to store electrical energy. If battery technology improves dramatically, electric vehicles might become the preferred alternative. (Source: Mazza & Hammerschlag, 2004)

3.5 Hydrogen Conversion Technologies

In the present study the hydrogen conversion technologies are understood as technologies for conversion from hydrogen fuel to heat and electrical or mechanical power.
In the long term, the fuel cell technologies are expected to become the most competitive technologies for most applications, although they still need significant development to become technically and economically attractive alternatives.
In the future, fuel cells are expected to allow for reversible operation (hydrogen fuel ⇔ electrical power).

Internal Combustion Engines

Many traditional internal combustion engine (ICE) technologies can (with minor or no extra cost) be designed to operate on methane, hydrogen or a gas mix (e.g. natural gas) – fully maintaining their performance.
For the hybrid ICE combined with electrical drive with battery buffer, the combustion engine can be operated at optimal operating point and the fluctuating load offered by the battery buffer, giving good tank-to-well energy efficiency performance.
This technology is a very likely 'transition technology' for hydrogen, where ICE's designed for natural gas are adjusted to operate with admixture of hydrogen.

Fuel cell technologies

Fuel cells produce electricity on the basis of a Hy-fuel and oxygen, and in principle – in the reverse mode – produce a Hy-fuel while consuming electrical energy. The electrochemical processes in the fuel cell are, among other things, controlled by the two electrode materials, the membrane material, the catalytic components, and the operating temperature. In addition, the performance characteristics are highly dependent on the design.
Compared to thermal power plants, internal combustion engines and gas turbines, fuel cells promise to be more efficient, cleaner, more convenient, less expensive and able to operate on a variety of fuels. But there is still a long way to go.
The performance parameters / characteristics include: fuel flexibility, energy efficiency, ability to operate in reverse mode (fuel ⇔ electricity), operating temperature, start-up time, and lifetime.

- Fuel flexibility: Some fuel cells operate only on pure hydrogen while others are more flexible and may for example operate on methane.
- Energy efficiency: A high electrical energy efficiency is important for applications where the produced heat is waste to be removed (e.g. in vehicles), while less important for applications where the heat is utilised (e.g. in CHP applications). In general the fuel cells have their maximum efficiency at low relative load, meaning that a higher efficiency can be achieved by increasing the rated capacity (and the investment cost). In principle, there is no upper limit for the overall efficiency – it's only a question of price and volume.
- Reverse operation: In principle the fuel cells can operate in both fuel cell mode and electrolysis mode. In practice however, they are generally designed and optimised for one mode only. In applications requiring both conversion processes (e.g. in electrical storage applications) it would be convenient if one converter component could provide efficient operation in both directions.
- Operating temperature: Some fuel cells operate at low temperature (≈100 °C), others at high temperatures (up to 1000 °C). The low operating temperature is convenient for compact

applications and where quick start-up is required (e.g. vehicles), while a high operating temperature provides heat at high temperature where this is utilised.

- Start-up time: For some applications (e.g. in vehicles) a short start-up time is required. The start-up time depends on many things, but will in general increase with the operating temperature.
- Lifetime: The lifetime of the fuel cell is generally defined by a set of minimum performance requirements. The lifetime is expired when the fuel cell no longer meets the required (or guaranteed) performance – typically when efficiency is reduced by 10 %.

The various fuel cell technologies have their individual strengths and weaknesses. The wish is to develop products having good performance in all or several parameters.
The fuel cell technology is expected to obtain higher energy efficiencies than alternatives for vehicle applications – including the hybrid solutions with the combination of internal combustion engine and electrical drive motors. The electrical drive train is just as energy efficient as the mechanical one and has in addition some advantages in terms of flexibility and controllability. The exhaust from fuel cells is less problematic than the exhaust from internal combustion engines – except for the CO_2. The current best fuel cell option for vehicle applications is PEMFC on hydrogen, which has pure water vapour as exhaust. PEMFC with internal reforming for vehicle applications is at present too expensive and space demanding. An alternative option is hydrogen on ICE.

Table 8: Comparison of technical performance for different fuel cell technologies. The numbers in parenthesis are the expected future values.

Performance parameter	**PEM**	**MCFC**	**SOFC**	**Units**
Fuel flexibility	H_2	Natural gas, Biogas, etc.	Natural gas, Biogas, etc.	
Electrical efficiency (stack)	50 (60)		60 (70)	%
Reverse operation efficiency			90 (95)	%
Operating temperature	100	800	800 (600)	°C
Start-up time			30 (5)	minutes
Lifetime	1000 (5000)	40 000	10 000	hours of operation

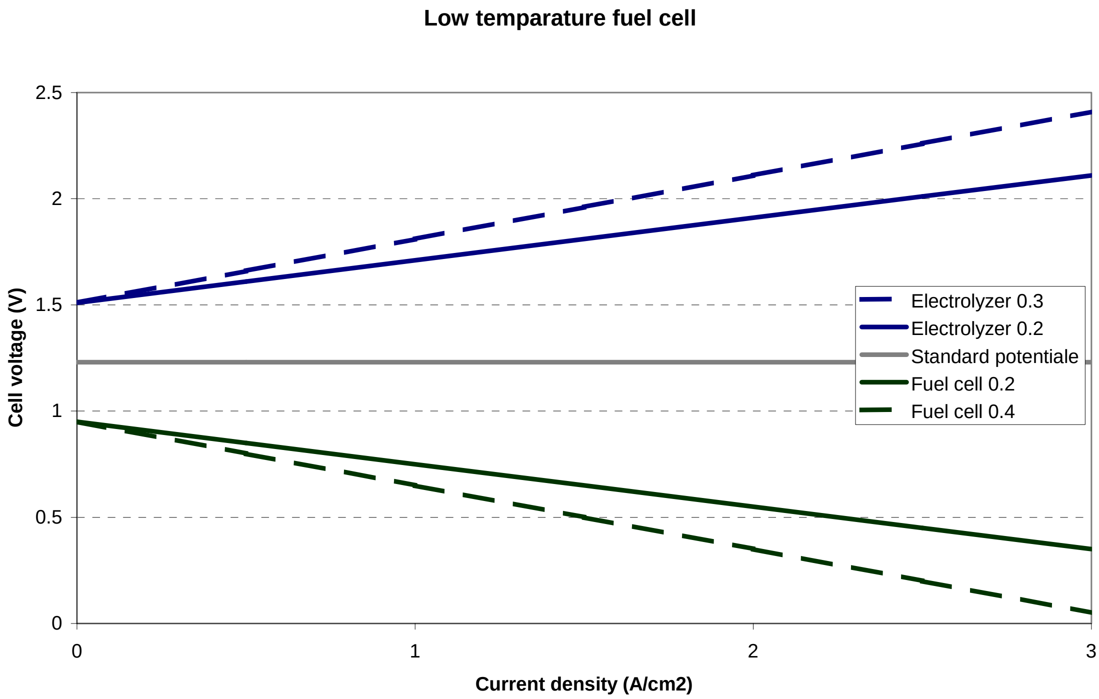


Figure 14: The graph illustrates the electrical characteristics for a low temperature fuel cell in electrolysis and fuel cell modes and for specific resistances of 0.2 and 0.3 Ωcm² @ 1.23 V standard potential, 0.28 V polarization loss. The voltage difference from a given operating point to the standard potential multiplied by the actual current represents the electrical losses in the cell.

Regardless which fuels will materialise for the transport sector in the future, the fuel cell technology is expected in the longer term to be introduced into the vehicles due to its advantages in energy efficiency, less problematic exhaust, the advantages of the electrical drive train (although not linked to the fuel cell technology) and the lack of noise.
As the fuel cell technologies produce both heat and electricity they are in particular well suited for combined heat and power applications.

PEMFC
Both the PEM fuel cell technology and the PEM electrolysis technology are close to being commercially available for specific mobile applications like vehicles and back-up power supply. The PEM cells can only operate on pure hydrogen, and are very sensitive to contaminations. A reformer may be integrated into the system to overcome this limitation. However, theses systems are still quite instable and unreliable and require further R&D. The material used for membrane and electrodes (platinum) is rather expensive. The electrical / overall efficiencies are around 50 % / 80 %, and it is expected this will reach 60 % / 90 % in the future.
The manufacturing cost for a complete fuel cell system for automotive application is 300..500 €/kW and is expected to come down to 50..100 €/kW. The cost for an internal combustion engine drive system is approximately 30 €/kW.

MCFC
The MCFC (Molten Carbonate Fuel Cell) with molten alkaline carbonate electrolyte and operating temperature 600 to 650°C operate on carbon containing gases (e.g. natural gas, synthesis gas).

SOFC
Both the fuel cell technology (SOFC) and the electrolysis technology (SOEC) are at laboratory / prototype stage. The cells are flexible with respect to the fuel and may for example operate on natural gas. The technology is at present not suitable for mobile applications. The optimal operation temperatures are very high (800..1000 °C) and the start-up time is relative long (> 30 minutes). The aim is to obtain efficient operation at temperatures of 600 °C (where standard support materials can be used) and a start-up time of < 5 minutes. The fuel cell's electrical efficiency is 60 %, and is expected to attain 70 % (higher efficiencies can be obtained, but are not expected to be cost attractive). The electrolyser's electrical efficiency is 80 %, and is expected to attain 90 %.
Problems to be addressed / performance to be demonstrated by the HyCom supported projects:

- robustness and longer lifetime
- fuel flexibility
- efficient reverse operation
- cheap materials

3.6 Hydrogen Applications / End-use

The hydrogen applications are divided into stationary applications and transport applications.
We use the same definitions as those used by the European Platform for Fuel Cell and Hydrogen Technologies in "The Strategic Research Agenda, Draft August 2004":

- *Stationary applications* refer to decentralized power generation, including residential 1-10kW and community (5-50 kW), public and commercial buildings and industrial (50kW – 500 kW), and large scale (1 MW and above). It also includes niche and power premium applications as Uninterruptible Power systems (UPS) and other back-up systems.
- *Transport* refers to vehicles and different systems for propulsion applications as well as auxiliary power units for vehicles, defence, marine and aeronautic applications.
- *Portable applications* refer to portable power generators (500W – 5 kW), light traction (wheelchairs, maintenance robots etc.: 100W – 5kW) and device-integrated supply.

Stationary

Current industrial use of hydrogen
Current global hydrogen production is estimated by the International Energy Agency at around 7 exajoules or about 2 % of World total energy consumption (IEA, 2003). 85 % of the hydrogen production is based on natural gas steam reforming while 7 % is derived from oil, 4 % from coal and 4% from electrolysis (NOU, 2004). Half of the hydrogen is used for producing ammonia, 37 % is used in petroleum refining processes, 8 % is used in methanol production, 1 % is used as a fuel in space programmes while the residual 4 % is used for other purposes (NOU, 2004). That is, only one percent of current hydrogen production is used for energy purposes. In principle, hydrogen could be used for energy purposes in industry in the future for example as feed for industrial boilers and process heaters (NA, 2004).

Stationary power and heat for utilities and residential uses
Stationary FC's have performance requirements that are easier to meet and have greater commercial readiness than fuel cell vehicles (APC; 2004: 14; Alternative Fuels Contact Group, 2003: 52). Different types of fuel cell systems are currently being demonstrated and introduced commercially in sizes from a few kilowatts and up to megawatt sizes. The four most developed fuel cell types that can be used for stationary power production are PAFC, PEMFC, MCFC and SOFC (NOU, 2004).

PAFC fuel cell systems are the only commercialized fuel cell technology and was introduced in 1991. To date 250 units have been sold at roughly 4 500 €/kW. The PAFC fuel cells have performed well and accumulated 4 million hours of operation, but have failed to become cost competitive with other technologies, so the producer has decided to stop production (NA, 2004). PEMFC, MCFC and SOFC are currently only available as prototypes for demonstration purposes. PEM cells for stationary use are being considered in the 1-1000 kW ranges whereas SOFCs are envisioned in sizes from watts to megawatts and MCFCs are considered mainly for systems larger than 250 kW (NA, 2004). For systems smaller than 250 kW PEMFCs are currently envisioned to be the dominating type of fuel cell whereas for larger systems MCFCs are around 10 years ahead of SOFCs in development (NOU, 2004).

For large generators today's fuel cell systems do not offer higher electrical efficiencies than other technologies that are already on the market such as gas turbines. However, in the future fuel cell systems are expected to bring about higher electrical efficiencies (NOU, 2004). At the utility scale, hybrid systems integrating fuel cell systems and gas turbines could bring systems using natural gas with electric efficiencies greater than 65 % and such systems are envisioned to become cost competitive with competing generating technologies within the next decades (NA, 2004; NOU, 2004). For comparison, current state-of-the-art power plants using combined cycle technology combining gas turbines and steam turbines have electrical efficiencies around 55-60% (Shinnar, 2003) and are currently cheaper (400-500 €/kW) than fuel cell systems (2 500-8000 €/kW).

Technologies available for distributed power generation, with electrical capacities less than 60 MW, include gas turbines, reciprocating engines, micro-turbines, wind turbines, biomass-based generators, solar photovoltaic systems and fuel cells. Some studies foresee that fuel cells might initially emerge as distributed generators in applications where users are willing to pay an extra margin for reliable energy generators. In the United States, there are 10.7 million distributed generators in place of which 99 % are small emergency/standby reciprocating engines that are not interconnected with the grid. The market for distributed generation is typically in the commercial sector in applications where reliable energy is needed or in remote locations where grid power is not available. Such distributed generators should be able to operate 40,000-50,000 hours without major system overhauls and should be available at a price below 400-500 €/kW to become cost competitive. Fuel cells are currently more than four times as expensive as ICE generators and twice as expensive as micro-turbine generators. Therefore fuel cells will be subject to competition from these technologies (NA, 2004).

Another area of interest for fuel cells is small-scale distributed CHP units to be installed in residential buildings. For example, 1.2 kW PEM fuel cells are currently being introduced in Japan in limited volume by Ballard Power Systems (NA, 2004) and the company Vaillant is currently installing a number of PEMFCs in Europe (NOU, 2004). SOFCs can also be made available for small-scale CHP in the future and the Swiss producer Sulzer-Hexis is for example currently testing an SOFC fuel cell system using LPG (NOU, 2004).

Auxiliary power systems

In the future, it might be possible to use hydrogen fuelled PEM fuel cells or gasoline or diesel-powered solid oxide fuel cells (SOFCs) as power sources in auxiliary power units (APUs) in for example trucks and aircraft. Long-haul heavy-duty trucks idling overnight consume fuel and emit pollutants. Truck drivers idle their engines primarily to heat or cool the cabin, to power climate control, refrigerators and televisions and to keep the fuel and engine warm in winter so that the engine is easier to start. Fuel cell auxiliary power units could save much of this fuel, reduce emissions and cut operating costs. Diesel engines are typically only around 10 % efficient in idle mode whereas SOFCs are envisaged to be operating at above 30 % efficiency thereby offering the potential of saving more than 70 % of energy use for idling corresponding around 3-8 % of the total amount of energy used by the heavy-duty truck in its total operational phases. The idea of using

PEMFC or SOFC APUs is currently at the concept stage, but some companies are planning to make SOFC APU prototypes available in limited numbers by 2005. Fuel cells are seen as a potentially promising APU technology that may become available at a competitive cost as compared to the fuel cost savings achieved from reduced idling. Some studies envision that the potential environmental and economic benefits of fuel cell APUs might allow this niche to become the first major commercial application of fuel cells (Brodrick et. al. 2002).

Transport

Passenger vehicles

In recent years, car producers have manufactured a range of prototype internal combustion engine (ICE) and PEM fuel cell passenger cars using hydrogen as the fuel, PEM cars being more energy efficient than ICE models (Weiss & Haywood, 2003). Currently many demonstration projects are being carried out, or are under preparation, in Europe, Japan and the United States. It has not yet been possible to develop a hydrogen storage medium allowing hydrogen fuelled PEM fuel cell cars to have range capabilities comparable to current baseline gasoline and diesel vehicles (NA, 2004). Current state-of-the-art PEM fuel cell prototypes are reported to consume 1.2 MJ (10 g of hydrogen) per kilometre in average driving conditions (Ricardo). Studies comparing hydrogen fuelled PEM fuel cell vehicles to ICE vehicles show that fuel cells are more fuel efficient than ICEs (Weiss & Haywood, 2003). Fuel cell vehicles using pure hydrogen emit only water vapour in operation, but production, compression or liquefaction and distribution of hydrogen requires energy that may be associated with emissions of particulates and gases to the atmosphere. The total energy consumption and emissions per kilometre driven in a hydrogen fuelled fuel cell vehicle thus depends on the type of primary energy used in these processes.

A recent study from Massachusetts Institute of Technology (MIT) makes a comparative assessment of the fuel consumption and greenhouse gas emissions of fuel cell cars on a so called "well-to-wheels" basis taking into consideration the energy consumption and emissions of the whole energy chain, including extraction of primary energy as well as production and distribution of the fuel and the consumption and emissions during vehicle operation. The study compares fuel cell vehicles to conventional gasoline and diesel fuelled ICE vehicles as well as to advanced gasoline and diesel hybrid electric vehicles taking assumptions about possible future efficiency improvements until 2020 into consideration. According to that study there is "*no current basis for preferring either FC or ICE power plants for mid-size automobiles over the next 20 years or so. That conclusion applied even with optimistic assumptions about the pace of future fuel cell development*". The MIT study compares an advanced hybrid fuel cell vehicle using about 0.54 MJ (4.4 g of hydrogen) per kilometre to an advanced gasoline hybrid electric vehicle using 1.07 MJ (equivalent of 31 kilometres per litre of gasoline) per kilometre and an advanced diesel hybrid electric vehicle using 0.92 MJ per kilometre (equivalent of 40 kilometres per litre of diesel). On a well-to-wheels basis the advanced hydrogen fuelled hybrid fuel cell vehicle is anticipated to reduce energy consumption and associated greenhouse gas emissions by more than 60 % over a 2001 baseline gasoline internal combustion vehicle using 2.48 MJ per kilometre (equivalent of 13 kilometres per litre of gasoline) while the advanced diesel hybrid electric vehicle is assumed to reduce energy consumption and greenhouse gas emissions by a few percent less. The assumption used here is that hydrogen will be produced from steam reforming of natural gas at local filling stations compressed to 35 MPa (350 bar) (Weiss & Haywood, 2003). The PEM fuel cell vehicles are envisioned to cause more greenhouse gases than gasoline and diesel hybrid electric cars if using hydrogen based on the current EU electricity mix or coal gasification, unless CO_2 is sequestered (Mazza & Hammerschlag, 2004).

Other studies compare hydrogen fuelled PEM fuel cell vehicles to battery electric vehicles, showing that battery electric vehicles that were on the market in the 1990's use less energy on a tank-to-wheel basis than current fuel cell vehicles (Mazza & Hammerschlag, 2004). However, current battery electric vehicles offer shorter range and take longer time to refuel than baseline gasoline and diesel vehicles and are not cost competitive because batteries are expensive and have a short lifetime. Proponents of battery electric vehicles hold that future advancements in battery technology may allow construction of better and cheaper battery electric vehicles or plug-in hybrid electric vehicles (Mazza & Hammerschlag, 2004).

Consequently, hydrogen fuelled PEM fuel cell vehicles will probably encounter increased competition from advanced diesel and gasoline hybrid electric vehicles as well as battery electric and other alternative vehicle types and fuels. The main advantage of PEMFC vehicles is the absence of emissions in operating mode (also true for battery electrical vehicles), faster refuelling time and better range capability than battery electric vehicles. The main disadvantages of PEM vehicles are the current high cost of PEM fuel cells as compared to internal combustion engines as well as the difficulties in finding an adequate on-board storage medium and the relatively high cost of producing and distributing hydrogen as compared to gasoline. Furthermore, a pre-requisite for widespread introduction of hydrogen fuelled vehicles is the building up of a hydrogen production and distribution system.

Buses

In recent years vehicle producers have manufactured a range of prototype fuel cell buses using pure hydrogen as the fuel.

Another way of using hydrogen in buses is natural gas fuelled ICE buses using a blend of natural gas and hydrogen, so-called hythane, with only minor adjustments to the software in the bus. Use of hythane reduces emissions of greenhouse gases and other pollutants as compared to using natural gas and the vehicles consume less fuel per kilometre.

According to a Norwegian comparative study of energy consumption and emission characteristics of advanced buses in 2020, PEM fuel cell hybrid electric buses are expected to consume around 7 MJ per kilometre and thereby have lower tank-to-wheel fuel consumption than advanced diesel hybrid electric buses expected to be using around 9.5 MJ per kilometre. However, on a well-to-wheels basis the hydrogen fuelled PEM fuel cell bus uses more primary energy than the diesel hybrid and related emissions of greenhouse gases depends on the type of primary energy used. In principle the PEM fuel cell bus offers the potential of eliminating emissions of greenhouse gases and other pollutants if the production of hydrogen is being based on renewable energy, and fuel cells are furthermore favourable because they eliminate emissions of NO_x and particles in the usage phase (NOU, 2004).

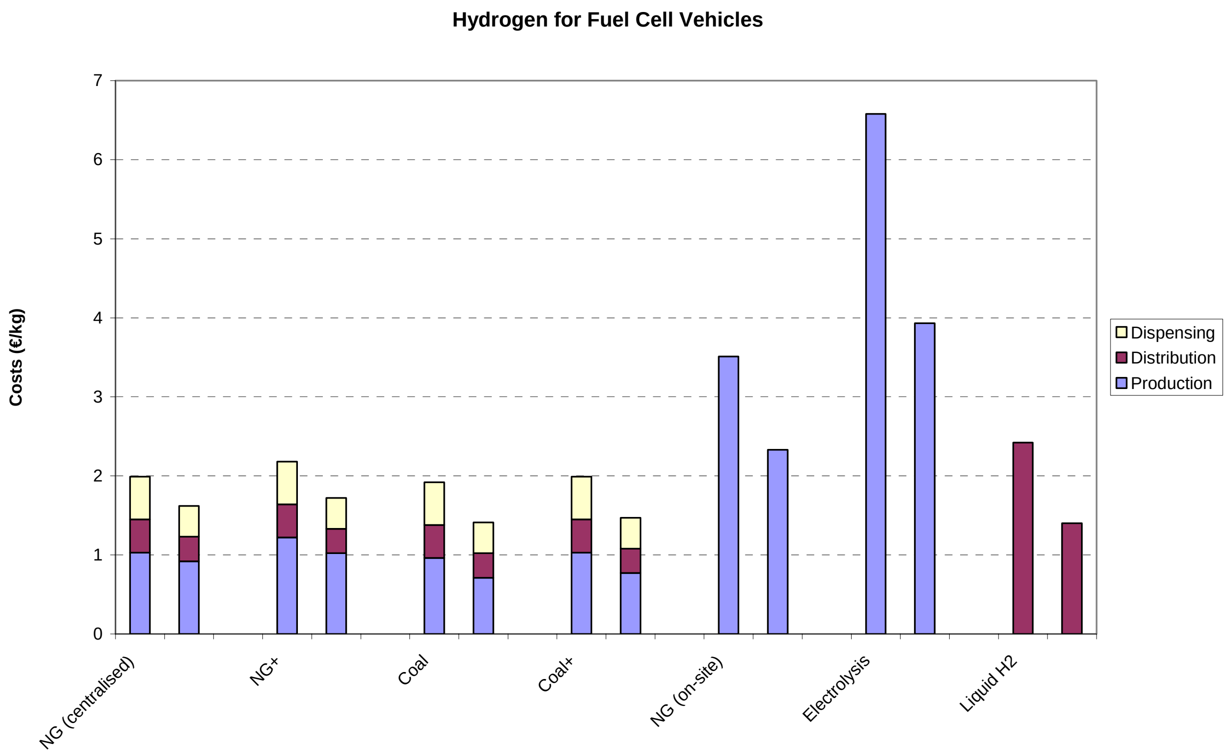


Figure 15: The graph illustrates typical distributions of costs between production, distribution and dispensing of hydrogen to fuel cell vehicles for different energy chains. For on-site hydrogen production there is no distribution costs. (Source: NA, 2004)

Marine

Fuel cells are envisioned for use in marine applications. Small demonstration projects test fuel cells in small passenger boats and submarines. Hydrogen fuelled fuel cells may be used in ships that do not need long ranges and can be filled up frequently whereas ships that need larger range would need to use fuel cells using fuels with higher energy densities, such as liquid natural gas, methanol or ethanol. A major driver for using fuel cells in ships could be that fuel cells offer the possibility to reduce emissions drastically. Marine transport world-wide currently contributes to 14 % of global nitrogen oxides emissions and 7 % of sulphur emissions. The European project FCSHIP – Environmental Impacts and Costs of Hydrogen, Natural Gas and Conventional Fuels for Fuel Cell Ships – indicates possible future concepts, prepares and regulations for design and operation of fuel cell technology in the marine market.

3.7 The Energy Chain

Even if the end-use of hydrogen is friendly to the environment, the use of hydrogen technologies will not necessarily result in overall minimum environmental load or sustainable energy solutions. Their contribution to the overall objectives is highly dependent on every step or component in the entire energy chain – from the exploitation of the primary energy sources through all the necessary steps to the final energy service provided.

As hydrogen is an energy carrier, hydrogen has to be produced by use of another energy source with the resulting energy losses and environmental load. As free hydrogen at normal conditions

(temperature and pressure) has very low energy density, hydrogen has to be conditioned for practical use – with the resulting energy losses and environmental load.
The evaluations and comparisons of the various technical solutions to obtain a given energy service (e.g. transport or heating) should be based on the analysis of the entire energy chain / the full energy cycle from the extraction of the primary energy source, through feedstock preparation, conversion to an energy carrier, conditioning, distribution and conversion to the final service – a source-to-service (S2S) analysis, like the well-to-wheels studies for the transport applications (Figure 5). For the specific energy service, the primary energy required, the greenhouse gas emission and the cost should be considered.
Hydrogen might be produced, stored, distributed and converted to the final energy service in a number of ways. Correspondingly, a number of paths exist from a primary source to the service, each with their specific characteristics. The actual optimal path depends on the actual application, on the local conditions, on the energy market development and on the technology developments. Which path is optimal will therefore change with location and with time, and the technology solutions to be developed should be robust to these uncertainties.
It is therefore important to include all steps involved in the energy chain in the analysis of the feasibility of hydrogen as an energy carrier, and the necessary technological development must take place for all steps involved.

3.8 Safety Aspects for Hydrogen Applications / End Use

In the previous chapters, the Hydrogen technologies are described by addressing the general aspects of security of supply and the potential for environmental impacts of hydrogen on the basis of the energy chain for a hydrogen economy (Markert et al., 2004).
In this chapter, the safety aspects for a future Hydrogen economy are described. In general, all activities belonging to the energy chain also have a safety implication. So any risk assessment to evaluate the safety has to consider all processes, starting from the extraction of the primary energy source, through feedstock preparation, conversion to an energy carrier, conditioning, distribution and conversion to final service. This is illustrated in Figure 16.

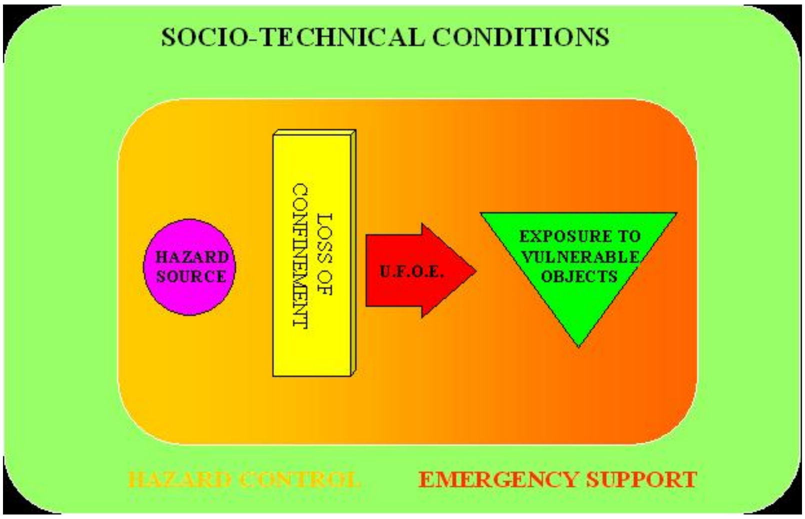


Figure 16 General accident model. In the case of Hydrogen, the Hazard source is any Hydrogen application that can by loss of confinement lead to exposure of persons and properties by an Uncontrolled Flow Of Energy (U.F.O.E. as e.g. fire, explosion)

The assessment can be divided into different phases as shown in Figure 17. There are different methods to approach the safety and they will also be applicable within the hydrogen economy. Methods used in Europe to identify hazard may be categorised into the following:

- Methods based on a top-down analysis, starting from a top event and going down to basic events, e.g., the Master Logic Diagram (form similar to Fault Trees), Function Analysis and Hazard and Consequences Analysis.
- Methods based on a bottom-up analysis, starts with deviations of the process variables/failures of devices investigating the consequences, e.g., HAZOP, Structured What-If Technique (SWIFT), Hazard Screening Analysis (HAZSCAN) and FMEA.
- Methods based on the systematic use of standard checklists, after division of the plant in areas, lessons learnt from past accidents/detailed studies.

The qualitative methods needs to be further tested and approved for the use of hydrogen safety aspects in order to verify the applicability for safety management and policies, for example, to be able to define appropriate safety standards and safety distances for refuelling stations.

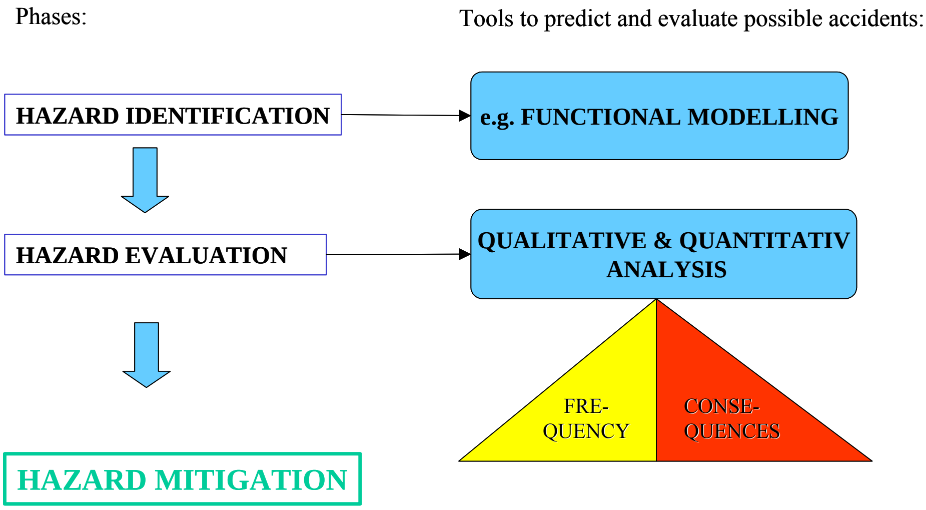


Figure 17 Phases normally used in Risk Assessment

Hydrogen has some properties that make it more dangerous than conventional fuels, such as gasoline, LPG (liquefied petroleum gas) and natural gas. Hydrogen's lower flammability limit in air is higher than that of LPG or gasoline, but its flammable range is very large (4-75% hydrogen in air). In the concentration range of 15-45%, the ignition energy of hydrogen is one-tenth than that of gasoline. The "quenching gap", the smallest hole through which a flame can propagate, is considerably smaller for hydrogen than for the other fuels, which means that the requirements for flame arrestors and similar equipment must be higher. Hydrogen has a number of other properties that might cause hazardous situations if not properly accounted for, such as:

- Hydrogen is a strong reducing agent, and in contact with metal oxides (rust), the resulting reaction can produce heat;
- Hydrogen damages or is otherwise unsuitable for use with many materials conventionally used for vessels, pipelines and fittings;
- In contrast to other compressed gases, lowering the pressure of hydrogen increases its temperature (in engineering terms, hydrogen has a negative Joule-Thomson coefficient at ambient temperature). When hydrogen is released from a high-pressure vessel, the resulting increase in temperature can contribute to ignition;
- Hydrogen forms explosive mixtures with many other gases, including chlorine and other halogens;

- Hydrogen diffuses easily through many conventional materials used for pipelines and vessels, and through gaps that are small enough to seal other gases safely; and
- The safety literature suggests that releases of hydrogen are more likely to cause explosions than releases of methane (Roth & Weller, 1996).

The EIHP working group on safety concludes that hydrogen is overall no more hazardous than conventional fuels. However, says this group, the many ways in which hydrogen differs from conventional fuels make it necessary to perform detailed risk assessment for every stage in the hydrogen supply chain (Alcock et al., 2001).

In contrast to LPG and gasoline vapour, hydrogen is extremely light and rises rapidly in air. In the open, this is generally an advantage, but it can be dangerous in buildings that are not designed for hydrogen. Many countries' building codes, for instance, require garages to have ventilation openings near the ground to remove gasoline vapour, but there is often no high-level ventilation. Hydrogen released in such a building collects at roof level, and the resulting explosion can be extremely destructive.

Hydrogen has been used widely and on a large scale for more than a hundred years in a variety of industrial applications. Of course, there have been incidents with hydrogen, as there have been with other hazardous materials including gasoline, LPG and natural gas. In general, though, experience shows that hydrogen can be handled safely in industrial applications as long as users adhere to the appropriate standards, regulations and best practices (Duijm & Perette, 2004). So the new applications for combined heat and power production (CHP) using hydrogen and fuel cells including power back up systems and distributed power generation with electricity buffers needs to be examined carefully and the necessary standards and legal framework needs to be established (Duijm & Perette, 2004). Other presently unknown aspects relate to special problems related to Hydrogen, as very high pressurized and cryogenic storage systems, not to forget metal hydrides, complex hydrides and carbon nano structure storages under development. The reliability of fuel cells is not only to increase safety, but is also a cost factor to increase competitiveness on the market. There are many other aspects not listed here for the different ways of Hydrogen production and transport in pipelines and by ship and road transport.

Modern, established technologies within energy supply and transportation are at high safety standards. This ensures a secure, safe and user friendly supply of energy in stationary, transport and other system applications. It is the result of a long learning process within these technologies. New Hydrogen and H-fuel applications to be used in the future infrastructure therefore need at least to have the same high safety standards as the established technologies.

The present main use of hydrogen is within the industrial production of ammonia and petroleum refining processes. Also here many years of experience make the large-scale industrial applications very safe in general, but comparing with the application of natural gas the frequency of accidents is 5 to 20 times higher for Hydrogen (Iskov, 2000). The following accident causes have been identified:

- Mechanical failures of vessels, pipes, etc., often caused by Hydrogen embrittlement or freezing;
- Reaction with pollutants (e.g., air);
- Too low purity of Hydrogen;
- Accidents caused by smaller releases due to poor ventilation or flow back of air under ventilation;
- Accidents during purging with in-active gases;
- Non-functioning of safety equipment;
- Wrong operations (by staff);
- Failure in evaporating system (e.g., valve failure) or not intended ignition / fire / explosion.

Zalosh reported in 1978 that in 80% of the Hydrogen accidents ignition occurred and hereof 65% caused an explosion (Zalosh et al., 1978 cited by Iskov, 2000). At that time, 40% of all the Hydrogen leakages have not been detected and, therefore, it was considered to install appropriate detectors in Hydrogen systems.

There also exist long-term experience applying pipelines and underground storages. There are a number of hydrogen pipelines of very different lengths and materials operated in different countries with the largest ones situated in Germany and France with 215 and 290 km, respectively. The German pipeline has been started in 1938 and been operated since, while the French is operating since 1966.

The operating pressure in all the pipelines is also very different ranging from few MPa to more than 100 MPa at Rockwell International S Susana Mountain, Los Angels, USA (Iskov, 2000: 6). There are no accident reports for these pipeline networks and the operators have positive experiences operating the pipelines. The same applies to the underground storage.

There are substantial and positive experiences on handling Hydrogen safely within industries using approved routines by skilled workers. During the last three decades, industries and authorities have increasingly applied risk assessment methodologies to reduce the risk.

However, the introduction of the hydrogen economy will also involve unskilled ordinary persons. One way of coping with this challenge is by gaining experiences fast and establishing a safety monitoring programme for all the test facilities to be built up. The knowledge will help to develop excellent standards, well-designed applications and good and operational procedures for installation and maintenance. The monitoring should be regarding technical parameters and reliability of the components and verification of any measure to improve hydrogen safety including monitoring incidents due to human factors.

The goal is to have future systems that are even safer than the established technologies.

3.9 Hydrogen Technologies – Findings, Conclusions and Recommendations

Below, the specific findings, conclusions and the related recommendations on the hydrogen technologies are summarised.

Findings

None of the single technologies – neither for production, storage, distribution, conversion nor end-use – and none of the single Hy-fuels have demonstrated they have the potential to become the most promising. However, some of the technologies have physical constrains that limit the development potential. Other technologies still need significant fundamental development that needs further basic understanding of the processes and new scientific break-through.

We therefore recommend not to exclude any of the fuel and technology options beforehand and we recommend that the projects to be selected for support also include extensively knowledge gathering exercises.

The projects (to be selected for support from HyCom) should indicate very specifically what they want to demonstrate by the projects and they should demonstrate something new – they should provide new aspects and knowledge. The projects should not simply repeat what has been demonstrated already by other projects. It has already been show technically that hydrogen can be produced in a number of ways, can be handled, stored, distributed, can act as fuel for internal combustion engines and fuel cells in applications as CHP and in various transport means. The new projects should demonstrate new methods, new innovations, improved performance, lower costs or some other new aspect. The hydrogen technologies are still too far from being commercially attractive and competitive to recommend large scale or large quantity demonstration projects. The hydrogen technologies needs more time and several step-by-step developments before it becomes

evident if they can expect to become attractive options for commercial large scale / quantity production.
Most likely, the energy future, as today, will be based on a variety of primary energy sources, energy carriers and technologies present side-by-side and optimised for specific applications and energy services.
Four main fields of applications are foreseen relevant for hydrogen used in communities: transport, combined heat & power production (CHP), power back-up systems and energy buffers to balance production and consumption.

Transport

The societies transport needs can appropriately be divided in various dimensions by their characteristics – in passenger transport versus transport of goods, in individual versus bulk transport, in transport over short versus long distances etc. The specific characteristics for a given combination of these dimensions will define the optimal technology solutions. A number of technological solutions will most likely be developed, optimised and applied for each of these classes of use. Hydrogen as energy carrier will probably only become a competitive solution for limited branches of these very different applications.
Today, typically vehicles for private users are designed for multi-purpose transport needs with specifications including operation range of 500 km, acceleration 0..100 km/h within 10 seconds etc. However, the transport services needed for the future organisation and infrastructure of the societies might change and be provided by other combinations of means than today. The development of technological options and the development of the organisation of the transport infrastructure are closely linked. Future transport means running on hydrogen will not necessarily simply replace existing technologies, but may develop their own new business areas, suited and optimised for the hydrogen technologies specific characteristics.
Inside a community the main transport needs are for shorter distances. Hydrogen as fuel might become an attractive option for technical solutions specifically designed for these specific transport needs, where the transport carriers can be frequently refuelled and serviced by a limited number of filling stations.
Energy challenges related to the transport services – sustainability, fuel supply, greenhouse gas emissions and air pollution – might be addressed in different ways and by different means and technologies. Hydrogen as energy carrier in combination with sustainable primary energy sources is one. Other likely options to meet the challenges are pure electrical vehicles and the use of other hydrogen rich fuels (Hy-fuels) as energy carries in CO_2-low or CO_2-neutral energy cycles with on-board carbon capture as an option. Used as fuel in transport applications, hydrogen can (today) be converted to mechanical power by either internal combustion engines or fuel cells in combination with electrical motor drives.
A main technical barrier for the use of hydrogen for transport application is the lack of appropriate hydrogen storage units fulfilling all requirements necessary to be attractive for mobile applications: high volume and weight energy density, high energy efficiency, low refuelling time and acceptable price level. The critical / acceptable levels for each parameter depend on the actual application (e.g. for buses in fixed-route city service, energy efficiency is important while energy density and refuelling time are less critical parameters as refuelling can be integrated in the schedule). The development stages of the various technologies vary from laboratory stage (e.g. the on-board CO_2 capture) to mature technologies (e.g. the internal combustion engines), and only some of the technologies are relevant for short-term utilisation.

Combined heat & power production (CHP)

At the end-use, where the hydrogen energy is converted to another energy form appropriate for the energy service required, a certain amount of the energy will necessarily be converted to heat – 30..70 % depending on the conversion technology and the form of energy needed. Assuming that a hydrogen economy is established and that hydrogen and fuel cell technology (producing electricity) are linked, we will expect the development of hydrogen applications having both heat and electricity needs.

Other technologies than fuel cells can be used to produce electricity on hydrogen – e.g. gas turbines or Stirling engines – but the fuel cell have potentials for better technical performance. The main barrier for the fuel technology is the price level, and the cost of the fuel cell stacks becomes increasing important with increasing capacity. And other fuels can be used for CHP.

Distribution of heat is generally less energy and cost efficient that distribution of electricity and pipeline distribution of gas. The fuel cell technology is well suited for mass production of small units, and the cost-performance relation for fuel cell CHP-units is only marginal size dependent. Distributed CHP-units designed for the local heat demand and connected to the common / public gas pipeline and the electrical distribution system are therefore likely applications – e.g. for households, building complexes or industrial buildings. The relative quiet operation of fuel cell units is also important feature when applied in living conditions.

In addition, CHP can function as an energy buffer in the form of heat, where produced heat can be stored and utilised later when needed. Intelligent managed CHP can therefore provide a valuable additional flexibility in the power system. This, however, requires the development of a more intelligent control and management of the entire power system – including distributed generation and load management.

The perspectives for hydrogen fuelled fuel cell based CHP are thus dependent on i.e. the development of a hydrogen pipeline distribution system, the development of the fuel cell technologies and the development of the power system. This illustrates the complexity and dependency in the development of the different energy technologies. The perspectives for hydrogen as an energy carrier can thus be extended by general developments of fuel cell technologies and of integrated, distributed small-scale CHP. However, there is no guaranty that further development of both fuel cells and distributed CHP will lead to the use of hydrogen.

Power back-up systems / distributed power generation

Many businesses, critically dependent on electricity (specific industries, computer systems, hospitals, public transport etc.), have their own power back-up facility – typically in the range from few to several hundreds of kW. For these systems, high reliability, low air pollution and minimal maintenance are important parameters while the requirements to long operation time and low cost are less important.

Hydrogen in combination with fuel cells has potentials to fulfil these requirements, assuming a hydrogen storage unit for long-term storage with little losses is available.

In future power system architectures with intelligent distributed generation, the local power generation units may be part of the entire power system under normal operation, and function as local power-backup in failure situations.

The short-term perspective is power-backup systems, which in a longer-term perspective may be operated as integrated part of the entire power systems, properly with the utilisation of the heat generation (CHP).

Electricity buffers

A major problem in energy systems with high renewable energy penetration is to maintain the instantaneous power balance between production and load. A local energy buffer is one way to address this problem. Hydrogen (and other Hy-fuels) can provide this functionality. In periods with excess power, hydrogen can be produced and stored, to be used when needed.

The energy flows may be rather complex. Typically, the excess power is electrical power, while the hydrogen produced could feed the transport sector or used for combined heat & power production.

The challenges

The above examples illustrate the complexities, dependencies and relations in the energy systems. The needs, the organisations and the architectures are dynamic properties that will change with the conditions and the technology options available. Hydrogen economies will materialise only if the businesses are able to create products and markets adapted for the technologies characteristics and will play a significant role only if the hydrogen economies are able to shape the architecture of the entire energy system.

Necessary conditions for hydrogen economies to emerge include that:

- Hydrogen is produced in a sustainable way.
- Hydrogen must be available at the point of end-use, in a comprehensive form and at a competitive price level. This requires cost and energy competitive storage, distribution and deliver technologies and organisations.
- Appropriate hydrogen technologies must be available and reliable with competitive performance and at competitive price levels. As the alternative and competing technologies also develop the competitive performance and price levels will continuously change.
- The hydrogen based solutions (to specific energy service needs) must be able to establish businesses adapted and optimised to the hydrogen technologies specific characteristics – either by developing new business areas or by shaping existing business areas. It is not likely that hydrogen technologies can compete on markets designed, organised and optimised to other energy technologies and solutions.
- The hydrogen solution must have acceptable energy efficiency and CO2 emission performance in the source-to-service account. Solutions that only moves problems from one step in the energy chain to another are not sustainable, and should not be supported from the political levels – neither by taxations, by subsidies nor by development programmes (like HyCom).
- The necessary standards and legal framework must be established in parallel to the technological, business and market developments. Development of standards and legal framework should be integrated parts of the development programmes (like HyCom).
- The politicians can match the established industries. The strong and well-established industries and businesses will naturally argue for their privileges and for their markets, which might be influenced by the political initiatives. The politicians must be well prepared with robust arguments. This requires analyses than justify that the initiatives will really meet the overall objectives. Demonstration activities (like those supported by HyCom) can and should contribute with new knowledge to qualify the argumentations. It is therefore recommended that the projects to be supported by HyCom justify (on a reliable basis) and demonstrate their contribution to the overall objectives.

The above are necessary conditions, but not necessarily sufficient conditions if hydrogen economies should materialise. Even if all conditions are fulfilled the hydrogen economies may still not emerge. It's a classical 'chicken-and-egg' problem: the market will not emerge before competitive technologies are available and competitive technologies will not emerge before the market is present.

Likely development road

The most likely development road for hydrogen economies to be established is through a preliminary phase with physically spread niche applications and through transition technologies. In the establishing phase:

- the supply of hydrogen is secured by public support and subsidies;
- the use of hydrogen is artificially stimulated and established through the use of hydrogen in fuel mixes or as substitutes to other fuels in mature technologies and applications – like e.g. feeding

hydrogen into the natural gas network and running internal combustion engines on partly or pure hydrogen.

- the development of attractive hydrogen storage technologies are accelerated by specific effort and support;
- specific hydrogen technologies for (new) niche business areas, suitable for the hydrogen technologies specific characteristics, are developed through the necessary support;
- standards are developed in parallel as an integrated part of the technology development; and
- the necessary legal framework is established by the authorities.

The establishment of a widespread and commercial competitive hydrogen infrastructure should await successfully emerging of applications and related technologies demonstrating attractive perspectives. Until then, the risk for establishing an expensive but inappropriate structure is too high.

The hydrogen technologies should in the first phase not aim at competing with well-established and well-developed technologies and businesses areas – like e.g. the multipurpose vehicle for private users.

Attractive technology applications and business areas should be developed, demonstrated and established in this initial establishing phase, within a timeframe of 10 years. HyCom should support this initial phase.

The hydrogen communities (to be supported by the HyCom Initiative) can act as excellent platforms for synergetic experiments, demonstrations, knowledge gathering and capacity building by collaboration between all the players – including enterprises, supporters, researchers and other experts – necessary for the development to take place.

Conclusions

The main conclusions from this chapter on the hydrogen technologies relevant for the present pre-feasibility study are listed below.

- The ‘hydrogen economy’ address mainly the following energy system problems: the integration of large-scale intermittent renewable energy sources, the flexibility in the integrated energy system by providing a link between the electricity and the ‘pipeline fuels’, and the energy path from renewable energy sources to the transport sector substituting the dependencies of fossil fuels.
- Hydrogen is not an energy source, but an energy carrier. Hydrogen as an energy carrier can only be justified if the necessary and sufficient sustainable energy sources to replace the dependency of the fossil fuels are explored and developed.
- The use of hydrogen technologies will not necessarily result in overall minimum environmental load or sustainable energy solutions. The hydrogen technologies contribution to the overall objectives is highly dependent on every component in the entire energy chain, and the necessary technological development must take place for all components involved.
- The hydrogen technologies, hydrogen and the other Hy-fuels should be evaluated in the entire energy system context, including the various primary energy sources and how these are best utilised, the various energy services required and the possibilities for optimising system operation and efficiencies in terms of energy, emission and cost to obtain the required services. The optimal energy path from source to service (S2S) is location dependent and will change with time.
- One specific advantage by hydrogen is the CO_2-free end-use. In other aspects hydrogen cannot demonstrate better technical and economic performance than other hydrogen rich fuels (Hy-

fuels). CO_2 produced by other hydrocarbon fuels may be separated and captured on-site (or on-board for mobile applications) for later sequestration.

- The overall challenge for the hydrogen technologies is to become cost competitive. The necessary development in cost reductions cannot expected to be achieved only by economic scaling of existing technologies, but will need further basic research, further development of existing technologies and development of new technologies.
- The main technical barriers for hydrogen as an energy carrier are related to the storage, the distribution and the handling of the fuel. A significant amount of energy is used for the conditioning of hydrogen (compressing, liquefaction). None of the hydrogen storage technologies are to day able to compete with other liquid fuels. The cost of storage vessels, of hydrogen conditioning (compression, liquefaction), of auxiliary equipment and the overall cost of hydrogen storage are key issues.
- No single state-of-the-art technology satisfies all of the hydrogen storage criteria required by manufactures and end-users, and a large number of obstacles have to be overcome. For most of the storage technologies the performances are limited by physical constrains that cannot be removed. E.g. the metal-hydrides have many technical problems, but are not limited by physical barriers.
- No single hydrogen technology and no single hydrogen rich fuel (Hy-fuel) have yet been identified as (the most) promising. A number of technologies have been developed to different levels and for different applications – each of the technologies with their specific advantages and disadvantages. But none of the single technologies fulfil all requirements.
- Hydrogen as energy carrier will probably only become competitive for limited branches of applications. Some of the problems addressed by the introduction of hydrogen may turn out to be met by more cost competitive alternative solutions. To a certain extend, the electrical power balance between production and consumption in systems with intermittent renewable energy sources may be maintained by intelligent control of the system, including load management. If electrical batteries are dramatically developed they may turn out to be a competitive alternative for part of the transport sector.
- Four main fields of applications are foreseen relevant for hydrogen used in communities in short-term: transport, combined heat & power production (CHP), power back-up systems and energy buffers to balance production and consumption.
- It is essential to take into account the different specific requirements of stationary and transport application. No single technology is expected to be optimal for all applications. A variety of technologies expects to be developed, each optimised for their specific applications. Each of the manufactures expects to concentrate on one technology only, and the synergies from one technology to another may need to go through the independent research institutions.
- The main energy challenges related to the transport services are: sustainability, fuel supply, greenhouse gas emissions and air pollution.
- A main technical barrier for the use of hydrogen for transport application is the lack of appropriate hydrogen storage units fulfilling all requirements necessary to be attractive for mobile applications.
- The interesting technologies to convert hydrogen to mechanical power for transport application are in short-term perspective the internal combustion engines (ICE) and the fuel cell technologies combined with electrical motor drives.
- Future transport means running on hydrogen may develop their own new business areas, suited and optimised for the hydrogen technologies specific characteristics.

- Much more explorative research is needed. Due to the crucial problems still facing each of the technologies, considerable basic research is needed in the short and medium term. The necessary development cannot be expected to take place by innovation and product development alone.
- The current state of the hydrogen technology development cannot justify the establishment of a widespread hydrogen infrastructure. The future use of hydrogen and related technologies is not obvious. It may turn out that other Hy-fuels or other technologies become the optimal and preferred solutions for a number of applications with hydrogen left for specific applications.
- The future prospects of the hydrogen as energy carrier are closely related to the development of the fuel cell technologies. In a short-to medium-term perspective hydrogen may be used with other technologies, but in the long-term the fuel cell technologies with their attractive characteristics expects to offer the best option – in specific for combined heat and power and for transport applications. On the other hand, the fuel cells expect to run on a variety of Hy-fuels and not only hydrogen.
- The lack of international standards and common regulations are crucial barriers for commercialisation of the products. The development of the technology should go hand-in-hand with the development of the standards.
- Natural gas and related technologies are likely to dominate the scene for the next 10 to 20 years. Meanwhile, the hydrogen technologies must develop step-by-step if they should come in a position to be able to take over.
- In the longer term electricity, Hy-fuels and biofuels are seen as complementary energy carriers.

The conclusion may be presented in a SWOT-form (Table 9).

Table 9: The conclusions presented in a SWOT-form.

Strengths	**Weakness**
▫ CO_2-free end-use ▫ Easy to produce ▫ High fuel cell efficiency	▫ Low energy density ▫ 20 % difference between HHV and LHV ▫ Difficult to store, distribute and handle ▫ The hydrogen technologies technical performances are too low ▫ The hydrogen technologies are too expensive
Opportunities	**Threats**
▫ Address the problems with large scale integration of intermittent renewable energy sources ▫ Provide a link between electrical energy and fuels ▫ Provide flexibility in the integrated energy system	▫ Other hydrogen rich fuels have better performance on most characteristics ▫ The CO_2 produced by other fuels may be captured on-site ▫ Natural gas and the related technologies are likely to dominate in the coming decades ▫ Existing competitive technologies present better technical performance (e.g. the hybrid vehicle) ▫ Electrical power balance may to a large extend be maintained by intelligent system control ▫ Competitive batteries for electrical vehicles may de developed

Problems to be addressed by the HyCom Initiative

The HyCom Initiative should both address the overall energy related society problems and the technical barriers for the development, commercialisation and materialisation of the hydrogen technologies.

Society problems
The society problems that the HyCom Initiative should aim to address:

- Environmental problems – including the green house effect and the air pollution.
- Integration of the entire energy system – fossil energy resources, renewable energy resources, electricity, heat, transport etc.
- Alternatives for the transport sector to its dependency of fossil based fuels.
- Large-scale integration of intermittent, electricity generating renewable energy sources into the energy system – including the transport sector.

Technical barriers
Technical barriers / challenges that the HyCom projects should address:

- The energy losses in critical conversion steps involved in the chain from the primary energy sources to the final energy services must be reduced.
- The energy efficiencies for the electrolysis processes must be increased.
- The energy efficiencies for the conversion of fossil fuels (in particular natural gas and coal) to hydrogen must be increased.
- Reverse fuel cells with integrated catalyse processing producing hydrogen rich fuels (other than hydrogen) should be developed for practical use.
- The energy efficiencies for the separation, storage, transportation and sequestration of CO_2 must be increased – and should include mobile applications.
- The energy efficiencies for conditioning of hydrogen (compression, liquefaction) must be increased.
- The energy densities for the hydrogen storage units must be increased – both for volume and weight.
- The energy losses related to the necessary pre-reforming of fuel up-front the fuel cells must be reduced or utilised – e.g. by integrating the reforming process into the fuel cell.
- The fuel cells must be less sensitive to contaminations in the fuel.
- New fuel cell materials should be developed. Fuel cells are typically based on rare and expensive electrode / electrolyte / membrane materials.
- The electrical efficiencies of the fuel cells for transport applications must be increased.
- The lifetime of the fuel cells must be increased.

Recommendations

Based on the findings in the pre-feasibility study performed, we recommend that the individual projects to be selected for support should address at least some of the recommendations listed below and that the entire project portfolio will:

- Support the development of efficient technologies (in terms of sustainability, energy, CO_2 emission and cost) for production of hydrogen and other Hy-fuels – in particular decentralised production technologies based on renewable sources that is not more efficient used for electricity generation (e.g. surplus wind power, solar energy and thermal energy).

- Support the development of efficient technologies (in terms of sustainability, energy, CO_2 emission and cost) for storage of hydrogen. The lack of satisfactory hydrogen storage technologies (including the necessary conditioning) is a crucial barrier for the break-through of the hydrogen technologies.
- Support the development of the individual components and technologies related to the infrastructure (vessels, tanks, pipelines, compressors, pumping stations etc.). A widespread development and extension of the hydrogen infrastructure should await a more clear indication of hydrogen as a general energy carrier in the integrated energy system. In addition, a decentralised hydrogen production will eliminate, reduce or change the need for a separate widespread hydrogen infrastructure. 1 km pipeline demonstrating improved performance should be preferred for 1000 km pipeline building on known technology.
- Support the development of the fuel cell technologies. The success of hydrogen and other Hy-fuels is highly dependent on the development of attractive fuel cell technologies (both in term of technical performance and cost) and vice-versa, the success of the fuel cell applications is dependent on the easy access to appropriate fuels.
- Ensure that scientific knowledge generated in the project is realised, gathered and disseminated. This may be achieved by scientific based monitoring of the operation and performance of the technologies and through participation of scientific based organisations in the projects.
- Ensure a reliable reporting and presentation of results obtained and demonstrated in the project through intensive monitoring of the performance demonstrated by the project.
- Be characterised by quality rather than quantity. Projects that include pre-activities, comprehensive laboratory and prototype tests, a step-by-step approach, and a flexibility to include new experiences and knowledge gained during the project should be preferred.
- Demonstrate a variety of technologies, Hy-fuels, solutions and applications. As none of the technologies can be pointed out as the most promising, it is important to be open to all the possibilities.
- Address (for each project, at least one of) the social problems and technical barriers listed and demonstrate a way to overcome the barrier(s). The projects should not just move a problem from one point in the energy chain to another point.
- Demonstrate new technological improvements. All the individual projects should include the demonstration of improvements on a least one of the technical or economic parameters. It is not sufficient e.g. to demonstrate that buses can run on hydrogen – it must be demonstrated that the buses can run longer per fuel unit, that the fuel cell have longer lifetime, that the fuel cells are less sensitive to contaminations in the fuel or similar measures.
- Contribute to the development of relevant international standards and common regulations for the hydrogen technologies. This might be achieved through the involvement of the relevant bodies.
- The technology solutions should be robust to the changing external conditions and should be flexible for scaling in quantity from small-scale to large-scale.

4 Analysis of Cases

This chapter describes and analyses 19 case studies of demonstration projects in Europe and elsewhere. The aim is to identify and analyse the main issues related to the preparation, implementation and completion of demonstration projects in the field of transport, stationary and other uses. These include technical, economic, financial, legal and other matters. Special focus is put on identifying the key success and risk factors associated with this task.

4.1 Selection and Description of Cases

The HyCom Initiative does not start from scratch, but has the opportunity to take advantage of the efforts performed by EU, national and regional governments and the private sector in setting up demonstrations and field test in mobile, stationary and portable applications in Europe for the last ten years.

The cases selected for more in-depth analysis in this pre-feasibility study have been identified from different sources:

- Results from the Hysociety assessment of challenges, actors and actions in the draft report "Achieving the transition towards a hydrogen-based society", 2004, including the database of 421 demonstrations and R&D projects combined with 51 more detailed studies (Mourek, R. (ed.), April 2004).
- Reports and information on demonstrations around the World made by IEA, www.ieahia.org/case_studies.html.
- Information on ongoing EU and other demonstrations and projects presented at the Kick-off meeting for the pre-feasibility study in Brussels 25 May 2004, including follow up information on these and other projects.
- Information on further ongoing EU and other projects and demonstrations presented at the Hynet Workshop "European Hydrogen Competence Centres" in Brussels 8 June 2004 (www.hynet.info).
- Selection and short descriptions of 10 – 20 key demonstrations and projects made by each of the project partners of this study covering different countries:
  - Risø National Laboratory: Nordic & Baltic countries, UK, Ireland, Spain, and EU
  - ENEA: Italy, Greece, Netherlands, Portugal, Poland and other new MS
  - Frauenhofer ISI: Germany, France, Belgium, and Austria
- Information on Japanese, Canadian and other demonstrations were obtained during the 15th World Hydrogen Energy Conference in Yokohama, June 2004.

The information was transformed into a database, from which 19 cases were selected for further in-depth studies. The selection was made according to a number of criteria:

- Country in which the demonstration was set up.
- Territory in which the demonstration was set (cities (> 0.5 million) towns (< 0.5 million), sparsely populated areas, incl. remote areas or islands.
- Status of the project
- Application area
  - Transport – bus fleet, car fleet, marine, etc
  - Stationary - residential, industrial or other
  - Both transport and stationary use.

Further, as the study had to be completed in June – September 2004 spanning the vacation time for Europe – July for the Northern countries and August for Central and Southern countries - some pragmatism in selection of cases was also needed for making interviews with experts and other representatives from the case demonstrations. In the table below, an overview of the cases is presented.

Table 10: Overview of elected cases

Projects	Country	Territory	Status of Project	Application
Hydrogen project at Munich airport	D	City of Munich	On-going 1997-2004	Transport
CEP – Clean Energy Partnership	D	City of Berlin	On-going 2003-2007	Transport
CUTE – Clean Urban Transport for Europe	UK, S, D, E, L, P, NL	9 cities	On-going 2001 – 2006	Transport
Japan Hydrogen and Fuel Cell Demonstration Project – JHFC	JP	City of Tokyo	On-going 2002-2005	Transport
HyNor	N	6 nodes related to city/towns	Preparation 2005-2008	Transport
Malmoe Hydrogen Energy Staion	S	Town, near City of Cph.	On-going 2003 - 2005	Transport
Zero Regio - Lombardia & Rhine-Main towards Zero Emission	I, D	City of Mantova City of Frankfurt	Preparation 2004-2009	Transport
GlasshusEtt	S	City of Stockholm	On-going 2001-2005	Stationary service
Utsira Hydrogen-wind project	N	Remote island	On-going 2004-2006	Stationary residential
SolTerH	E	Possibly Aznalcollar Village	Feasibility study 2004-2005	Stationary residential
Electric power station in Nürnberg	D	City of Nürnberg	Completed 1998-2003	Stationary residential
REGENERA	E	Valladolid Town	Preparation 2003-2005	Stationary industrial
RES2H2	E GR	Canary Island S-S Lavrion, Attica GR-S	On-going 2002-2007	S-S re-electrification GR-S non-energy related
Baglan Renewable Hydrogen Centre	UK-Wales	Region	Preparation 2004-2007	Combined
HyFuture	S	Region	Preparation 2003-	Combined
Highways	CA	6 nodes related to cities/towns in BC	Preparation 2004-2010	Combined
Bicocca	I	City of Milan	Preparation 2005-2010	Combined
Hydrogen for Arezzo	I	Town	Preparation 2004-2006	Combined
H2ellenic Island	GR	Community	Preparation 2005-2015	Combined

The case studies were made in a consistent way based on a common semi-structured questionnaire complemented by additional project information and studies available. Most interviews were made by telephone and supported by a tape recorder. Based on notes and records, the interviewer prepared a text, which afterwards was revised and approved by the person interviewed. In other cases, the text was made in an iterative way by the interviewer and the interviewee. An overview of the case studies is given in Appendix B. The full case descriptions appear in a separate report.

4.2 Applications

The cases represent three types of applications:

Table 11: Three application forms.

Transport	Stationary	Combinations of Transport and Stationary
Munich Airport	GlasshusEtt	Baglan Renewable Hydrogen Centre
CEP, Berlin	Utsira Hydrogen-wind project	HyFuture
CUTE	SolTerH	Highways, Canada
JHFC	Electric power St Nürnberg	Bicocca
HyNor	REGENERA	Hydrogen for Arezzo
Malmö Fuelling station	RES2H2	H2ellenic Island
Zero Regio		

4.3 Transport Applications

The seven transportation cases cover demonstration projects in 9 European countries and in Japan. They are mostly located in or near cities, but also include networks of nodes passing through smaller towns.

Rationale and Initiator

The rationale of most projects is to test and demonstrate hydrogen and FC technologies and thereby contribute to the development of the technologies and their safe use in real life environments. The ideas to set up the demonstrations are in several cases fostered by governments. This is the case of the Munich Hydrogen Airport project where the initiative came from the state government of Bavaria to build on local industry's competence in aerospace and expand this into new fields of application. The JHFC case illustrates a very ambitious national goal of commercializing fuel cell technologies and brings FC vehicles to the market in a medium term perspective. However, this governmental push for setting up demonstrations is matched by commitment from industry and energy companies in a joint effort to realise the demonstrations.

In some cases the initiative comes from private companies together with city transport companies. Examples are the Malmö Hydrogen Energy Station and the HyNor cases. The CUTE project was initiated by DaimlerChrysler that wanted to get experiences with FC vehicles and stations in open, practical conditions and to improve knowledge on the certification procedures in different countries. Later the concept was further developed together with city transport companies. Likewise, the private push for setting up the demonstration is matched by commitment from local or federal government in terms of financial support, smooth transaction of the necessary permits etc.

The CEP is an outcome of a more theoretical project on transport energy strategy undertaken by private companies together with the federal government and represents a case where it is difficult to separate who originally took initiative to the project. The Zero Regio started out as two separate ideas fostered by the Hessian Initiative for Fuel Cells and Hydrogen and the regional government of Lombardy and later developed into a joint project under the auspices of the EU.

Location

The Munich Hydrogen Airport project was deliberately chosen as demonstration site due to the high public exposure and its generally high safety requirements. In the larger comparative projects, location is also chosen to test FC technologies under different conditions. In the CUTE project, the selection of the nine cities represents different climatic conditions[10] – cold, mild and hot – as well as

[10] This is also the case in other international transport demonstrations. For example the US learning demonstration project required the demonstrations to be located in different regions – hot arid, hot humid, and cold freezing (www.eere.energy.gov/hydrogenandfuelcells/).

different traffic control concepts. They were selected after an open call where apart from the climatic and traffic conditions emphasis was made on performance of the bus company, the financial strength, and the local framework conditions. The 10 fuelling stations of the JHFC project are located in Metropolitan Tokyo in industrial, residential and business areas. One removable hydrogen fuelling station can even be located on demand wherever it is needed. JHFC puts very much emphasis on public education and outreach. A show-room and visitor centre is built in relation to one of the fuelling stations. A visitor centre will also be built at the CEP fuelling site in Berlin.

In those demonstrations where hydrogen is an industrial by-product, the hydrogen can be trucked in as it is the case of JHFC. An interesting and also technically challenging example of another solution is the German part of the Zero Regio where the hydrogen from a near by industrial plant is piped through a 1.5 km and 1,000 bar pipeline due to space problems at the fuelling station.

Location is also determined by existing facilities. The Malmö Hydrogen Energy Station is located together with the natural gas filling station where the city buses obtain their fuel. The rationale behind this is to introduce the bridging fuel of hythane (a mixture of H2 and NG) to be used in conventional natural gas engines and then later offer hydrogen to FC vehicles.

Legal Form and Management

The legal form of the demonstration projects depends on the number of partners involved, whether these are public or private entities, the overall budget, and also requirements from funding bodies. The form primarily reflects the need to limit the economic and technical risks associated with such projects. The large demonstration projects such as CUTE, CEP, and Zero Regio - each with large budgets - are organised as partnerships and with defined responsibilities for each partner. For cases such as Malmö Hydrogen Energy Station with a much smaller budget the activity is integrated in the RD&D activities of the energy company together with the city transport company.

The management of the project is central to the successful completion of the project, exchange of experience and diffusion of results. The information generated in these case studies to some extent makes account of formal management structures, of which most projects have a steering committee with representatives from each partner. More in-depth evaluations are required if management has to be assessed in a thorough way.

For the JHFC, METI is the overall responsible for the project together with two institutes – the Japan Automobile Research Institute and Engineering Advancement Association of Japan. All participating companies are represented in a steering committee. We do not have information how each demonstration is organised.

The CUTE project is organised at two levels – a coordinating level with a steering committee and a daily management group of 8 persons headed by Evobus. In addition, each of the cities has their own steering committee.

The HyNor project is likewise organised at two levels – at the overall level, an Executive Board consists of one representative from each of the six nodes and with an elected chairman. The Board has two working committees – the purchasing committee for hydrogen vehicles and the infrastructure committee for hydrogen electrolyser stations. At local level, each of the nodes is managed by its own board with representatives of local public and private stakeholders.

Budget

The budget and also the time frame vary across the cases. The large demonstration projects such as CUTE, CEP and Zero Regio have five-year budgets between 100 MEUR and 20 MEUR. The Munich Hydrogen Airport project has run for 7 years and with a budget of 35 MEUR. The Malmö Hydrogen Energy Station has an investment budget of 1.15 MEUR, including preparation cost, a fuelling station and a bus.

Table 12: Overview of the investment and financial figures for the CEP project

Project costs	**MEUR**	**Financial sources. Percent**	
Infrastructure	10	German government	10%
Vehicles	41	Industry partners	90%
Total	**51**	Total	100%

Technologies and Vehicles

The cases represent different hydrogen production and distribution routes, spanning from on site production from electrolysis and reforming to trucked-in gaseous or liquid hydrogen from centralised production plants and to piped hydrogen in 1,000 bar pipeline from a nearby chemical plant. An overview is given in the table below.

Table 13: Technologies and application in transport

Project	Production and Distribution	Application	Budget
Munich Hydrogen Airport	Onsite CGH2 from electrolysis and NG reformer Trucked in LH2 to filling station Gaseous and liquid fuelling systems	1 filling station 3 H2ICE buses 1 FC bus Several ICE cars 1 fork lifter	35 MEUR
CEP – Clean Energy Partnership	On-site CGH2 from electrolysis Trucked in LH2 1 filling station, incl.	1 filling station, incl. Garage and visitor center 10 FC cars 2 H2 ICE cars 3 FCEV hybrids 1 FC 2 buses (1 FC and 1 ICE)	51 MEUR, including 10 MEUR for infrastructure and 41 MEUR for vehicles
CUTE – Clean Urban Transport for Europe (+ECTOS)	5 electrolyzers (+ 1) 2 steam reformers 3 trucked in hydrogen (1 liquid, 2 gaseous)	9 filling stations (+1) 27 FC buses (+ 3)	100 MEUR, incl. 22 MEUR from EU. 1.3 MEUR for each bus
Japan Hydrogen and Fuel Cell Demonstration Project JHFC	6 steam reformers 1 electrolyzer 3 trucked in (1 liquid, 2 gaseous)	10 hydrogen filling stations and car and bus fleet and xx vehicles	No budget figures available
HyNor	3 electrolyzers 1 reforming with CO2 storage 1 bio-electrolyzer 1 electrolyse-reforming	6 filling stations and expectations to acquire hydrogen vehicles for different use (taxies, post office vans, passenger cars, bus fleet, garbage trucks and heavy construction vehicles)	25 MEUR for infrastructure No fixed budget for vehicles
Malmoe Hydrogen Energy Station	Green certificate / electrolyzer 395 pressure tanks Hythane (8% H2 + 92%NG)	1 filling station 1 NG bus driving on hythane (8% H2) 1 NG bus driving on hythane (20%)	1.15 MEUR, incl. preparation cost of 0.05 and 0.31 MEUR for adapted NG bus Operation and maintenance data not available
Zero Regio - Lombardia & Rhine-Main towards Zero Emission	1 reformer in Mantova, 350 bar. H2 via 1,000 bar pipeline from industrial by-product (Hoechst) 350 bar, 700 bar and liquid	1 filling station with 3 FC vehicles in Lombardy 1 filling station with 5 FC vehicles in Rhein-Main	20 MEUR

A major difference between JHFC and the CUTE project is that while the majority of JHFC fuelling stations is based on reforming together with purification processes, the majority of the CUTE fuelling stations depend on electrolysis, some even based on green certificates as it is the case in Amsterdam. The quality and properties of the fuel provided at the fuelling stations depend on the type of vehicles involved in the demonstration. In the case of JHFC, 8 different car manufacturers, some even with several prototypes, are involved and hence require both gaseous and liquid hydrogen. In the CUTE project, only one car manufacturer with one FC bus type is involved. CEP disposes of five different types of vehicles, including FC vehicles, H2-ICE vehicles and hybrids. This is also the case with Munich Hydrogen Airport. So similar to JHFC, these fuelling stations offer both gaseous and liquid hydrogen.

Malmö Hydrogen Energy Station offers a short term, cost-effective alternative by providing hythane (mixture of hydrogen and NG) to natural gas fuelled buses, which then only need to undergo smaller adaptations. The project has so far not succeeded in acquiring a FC vehicle to demonstrate a hydrogen driven bus.

CEP reduced the number of vehicles from 100 to 18 (16 passenger cars and 2 buses) to be tested during the project period due to a limited number of vehicles available by the car manufacturers and also because these wanted to allocate this limited number in other projects as well. The actual number of vehicles is about 250 world-wide, which have been produced at high costs as prototypes and recently, for captive fleets in very limited numbers (Alternative Fuels Contact Group, 2003: 39, 43). It seems to be a problem worldwide that the expectations to provide a larger amount of vehicles cannot be fulfilled in a short time. For example, when launching the "Controlled Hydrogen fleet and Infrastructure Demonstration and Validation Project Validation" in 2003, the US Department of Energy required each applicant to limit no more than 50 FC vehicles over two generations and with systems in up to three separate regions of the country[11]. Five learning demonstrations were approved, which then over a five-year period will test 5 x max 50 FC vehicles in up to 15 regions. This will in worst case limit the number of FC vehicles to 16 per region.

Regional Context and Impact

Most demonstrations rely on highly skilled personnel from the technology providers, which often operate on a global market. The local or regional business opportunities are relatively constrained unless technology providers are located in the area. However, the engineering and construction work do often include local companies and personnel. In cities where the demonstration also includes an information centre or other activities, this might have a positive impact on the tourist sector, either in terms of a green image of the city, international exposure, and ultimately more visitors.

Public acceptance is very good in all projects that are in operation and have been so for several years as, for example, the CUTE project, the Munich Hydrogen Airport project, or the precursor of the HyNor project in the city of Oslo, the so-called NEBUS project. JHFC has from the very start of the demonstration project placed emphasis on public education and outreach and parallel to the show and visitor centre in Yokohama, a number of classes and workshops are held for women, school children, students, and citizens. Likewise educational materials are made for different target groups, as booklets, posters, videos, and also on the project homepage.

Future Development

Despite the lack of FC vehicles, the transport demonstration projects seem confident that the demonstrations will continue as test and validation projects, also after the completion of the project. No expression is made regarding an immediate commercialisation of the vehicles. Instead considerations are made to include new project partners, new aspects to test, new sites, and also more vehicles.

The CEP project plans to extend the project by including new partners and new aspects to be tested. This also includes new locations in Berlin and perhaps also in other regions. The CUTE project is currently discussing what to do when the demonstration ends in 2005. There is still a range of issues to further test and investigate and therefore a probable extension of 1 year will probably be negotiated. Hereafter, various options are open. Already today there is a close cooperation with the Icelandic ECTOS project, which in fact was the model demonstration for the CUTE project, and also a close cooperation with the STEP project in Western Australia.

For the Munich Hydrogen Airport project the aim is to apply more vehicles, to increase the refuelling rate at the filling station, and to extend the demonstration to the City of Munich for the

[11] See the solicitation materials for the award of app. $190 million over 5 years with an additional private cost share of approximately $190 million, www.eere.energy.gov/hydrogenandfuelcells/recent_awards.html#vehicle

World Cup in Football in 2006. In terms of infrastructure, Southern Germany seems already today to have a well-developed network of fuelling and hydrogen facilities and also cooperation links to Italy, most notably through the Zero Regio project.
The HyNor project considers consolidating each of the six nodes, and especially in the City of Oslo an ambition plan is to introduce 125 PEMFC buses in 2010-2011. Likewise, the project envisions collaborating with projects in Sweden and Denmark and thereby extending the hydrogen corridor through Sweden and Denmark to the European continent.
The Malmö Hydrogen Energy Stations aims at optimising the mixture of hydrogen and natural gas and will introduce another bus adapted for this. Later, the existing bus fleet may be included as well as FC vehicles. Similar projects could be implemented along the natural gas grid but no firm plans are made yet.

Summary of Key Success and Risk Factors

The main **success factors** highlighted by the projects are:

- Good partnership and cooperation among project partners
- Highly experienced and competent companies involved
- A strategy or vision by the key stakeholders of a project is very beneficial in the preparation phases.
- Clarification of all technical, economic, legal and other topics in the preparation phase
- Good cooperation with external stakeholders such as local authorities, energy companies, etc.
- Good safety and compliance with all safety standards and regulations. This also implies that all necessary permits are obtained.
- Highly visible and safe location of the project and public acceptance.
- Successful test and validation of stations and vehicles
- Preparedness for participating in demanding demonstration projects

Some **unexpected challenges** faced the projects during the preparation process:

- It often takes longer time than foreseen to get all the permissions and approvals to set up filling stations and get the vehicles running.
- As long as there are not international safety codes and standards, products also have to be adapted to local requirements, which in itself is time consuming.
- Adaptation to real world conditions may lead to major technical changes in the project.
- The financial engineering and burden is also mentioned as an unexpected challenge.

These unexpected challenges have all been solved in the preparation phase of the projects so it might be more a question of considering these as an integrated part of a good feasibility study.
The key **risks factors** associated with the projects are:

- In projects where many stakeholders are involved, it is always challenging how to balance the various interests in a proper way and to assure fulfilment of agreed performance by each partner. Good partnership and management may reduce this risk factor.
- If costs and technology requirements are not met. This is in particular a high risk for vehicles. This risk factor may be reduced by making in-depth feasibility studies.
- Financial problems related to cost-demanding projects. This has to be clarified during the feasibility study.
- Lack of FC vehicles. This risk factor may be reduced by making confirmed agreements with the car manufacturers already in the feasibility phase and/or to choose transition technologies as for example adapted NG buses.
- Unfavourable taxation rules on hydrogen. This risk factor may be reduced for the individual project by applying for exemption of the tax. On a more general level, the demonstrations

and early market activities should be accompanied with appropriate policy incentives as for example tax exemption for zero-emission vehicles.
- No common safety standards and regulation. This risk factor may be reduced for demonstrations by collaborating closely with safety bodies, authorities and also building on the experiences from other similar demonstrations. In the longer term, common international codes an standards are to be developed, a task that is currently investigated by the International Partnership for Hydrogen Economy, by the Hydrogen Coordination Group of the International Energy Agency and the various Implementing Agreements as well as ISO.
- If an accident should happen despite very strict safety measures. This risk factor is there. Permits include emergency preparedness.

4.4 Stationary Applications

The six demonstrations are located in five European countries and in very divergent surroundings ranging from large cities, to middle-sized towns, and to remote or sparsely populated areas. They demonstrate or intend to demonstrate hydrogen and fuel cell technologies for power and heat for residential use in houses or service centres, but also for optimising power consumption in industry or simply producing hydrogen for the industrial market by means of renewables. Most cases have a “green” profile as production of hydrogen is or will probably be based on renewables or as waste industrial product.

Rationale and Initiator

The three most advanced projects - Utsira, GlashusEtt, and Nürnberg – aim at producing heat and power for residential houses. Emphasis differs from project to project. On the small remote island of Utsira, the aim is to demonstrate an autonomous energy system and integrate well--known (electrolysis and wind turbines) and new technologies (fuel cells) with renewable energy sources to create a viable renewable energy system for the households. GlashusEtt demonstrates an advanced renewable energy system for heat and power in one building. The Nürnberg PAFC plant yet finished has tested the reliability and feasibility of a PAFC in combination with an absorption-heat pump to supply 763 apartments with electricity and heat.

The idea to set up demonstrations is for the two northern cases fostered by large recognised companies, and often in co-operation with other international technology providers. In the German case, the idea originates from an association for fuel cell application that was founded in 1991 to apply FC’s in a residential area.

The two Spanish cases, still in their preparation stage, are fostered by a private company in close cooperation with a larger industrial and engineering company and its subsidiaries. One case aims at reducing the electricity consumption of a large aluminium plant by 1/3 by utilising a waste gas flow as fuel in a 500kW fuel cell system. The other investigates different pathways for producing hydrogen from renewables and will demonstrate this in a village located in an environmentally damaged mining district undergoing a change to an area relying on renewables. Both projects are highly profiled and have received support, financially and politically, from central and regional authorities. While the first primarily focuses on the environmental and energy aspects of the project, the latter also considers the employment aspects related to such demonstrations.

The dual demonstration project involving two countries, wind power as source for the production of hydrogen, and two different applications – power and industrial production – is an attempt to cluster two individual projects forwarded to the FP5. It seems as if the rationale of each project has drowned in the difficult process to merge two different ideas, designs and management structures into one. What stands is the rationale to produce hydrogen from renewables, though the application is quite different.

Location

The location of the projects reflects what to demonstrate and test, the energy sources available and also who owns the project.

The three hydrogen-wind cases are necessarily located in areas with good wind sources. In addition, the Utsira hydrogen-wind project focuses on autonomous energy subsystems in remote areas such as an island 18 km West of the Norwegian coast. This went well hand-in-hand with the local vision of relying 100% on renewables and being independent from the mainland grid.

The GlashusEtt is located in the City of Stockholm and is in itself an environmental information centre that informs on and demonstrates new environmental friendly energy technologies. This showroom has allowed the public to take a close look at the technologies providing power and heat to the building.

It is always good to first test one's own medicine. This we see exemplified in the GlashusEtt, where one of the three owners is also one of the project initiators, and also in REGENERA, where the aluminium plant has common ownership with the project initiator.

The Nürnberg PAFC is located next to the residential area and fuelled with natural gas distributed through the local gas net.

The last case of SolTerH has not yet decided where to locate the demonstration. This depends on which production route is chosen and the energy sources available. Some local employment considerations may also influence the final choice.

Legal Form and Management

The legal form used for the demonstration projects is most often public-private partnerships and is closely related to the various partners involved, being both private companies and public or semi-public research institutes. Demonstrations are organised as projects with defined responsibilities. This also applies to the private joint ventures. It seems as if the final project team and hence the legal form aims at including all key technology and knowledge providers. However, both the Utsira Hydrogen-wind project and REGENERA have sought fuel cell providers and both have had difficulties in getting these on board from the very beginning of the project. In the first case, the fuel cell provider was subcontracted afterwards and a committed partner is still sought after for the latter. Fuel cells are not yet a fully commercial product and are not easily integrated in different systems and fuelled by different sources of hydrogen. The challenge is hence how to involve such providers of prototypes.

We do not have detailed information on the management structures of these projects. For the private cases in operation the partners are few and company managers are in charge. As for the EU project of RES2H2, it is more complicated as this is a merger of two projects located in two different countries and with little common ground except for using the same technology for producing hydrogen. It illustrates that partnership is something that should be encouraged as early as possible and preferably during the application phase so that applicants themselves can identify and negotiate with plausible partners and design the project accordingly. This does not prevent exchange of experiences between related projects as we see in the CUTE, ECTOS and STEP transport demonstration projects.

Budget

The six projects have budget lines ranging from 5.4 MEUR for the dual demonstration of RES2H2 in Greece and Spain, to 4.8 MEUR for the Utsira project, and just 1.2 MEUR for GlashusEtt and the PAFC in Nürnberg, and 0.4 MEUR for SolTerH (Phase I and with an expected phase II of 1.6 MEUR). As the feasibility study is still ongoing for REGENERA, no budget figures are available. In the table below, the total investment and financial figures are given for the Nürnberg PAFC case.

Table 14: Overview of the investment and financial figures for the Nürnberg PAFC

Preparation costs	**EUR**	**Financial sources. Percent**	
Tax handling	4,602	Studiengesellschaft Brennstoffzelle e.V.	46%
Business activity	5,317	Bavarian ministry of economy	26%
Permission costs	14,827	CO_2-Programme Nürnberg	8%
Ground breaking ceremony	17,179	US-Programme	4%
IBN celebration	25,053	Ruhrgas, SFW	9%
Sub-total	66,979		
Investment costs		Sponsors:	7%
Fuel cell	817,300	Alstom Energie GmbH,	
Heat pump	116,370	Austria Ferngas	
Programme for scientific management	66,468	Erdgas Südbayern GmbH	100%
Delivery, installation, pipeline construction/gas control system	33,285		
Structure, fundament, preparation of location	105,070		
Sub-total	1,138,494		
Total	**1,205,473**		

Technologies

The cases represent first and foremost production technologies based on renewable, in particular electrolysis and wind power. These are proven technologies, though not cost competitive to natural gas reforming. In the GlashusEtt case, an advanced system is introduced. Photovoltaic cells produce power either to be used in the power system or be fed into a PEM electrolyser to produce hydrogen to be used in a fuel cell for power and heat. In addition, hydrogen is also reformed from biogas from a nearby sewage plant and is used in the fuel cell.

The major technical challenges lay in the system integration of different components that have to be tested in different modes. It has caused problems in very complex system as the one in GlashusEtt, in particular for the fuel cell operating under different conditions and modes. In the case of Nürnberg, the challenge was to combine a prototype PAFC and an absorption pump and operate these in base load.

The cases illustrate that there is a very delicate balance between laboratory work, early field test, and demonstrations and that feed back from demonstrations help orient the further technological development. They also illustrate that even well prepared and well-designed projects may run into unexpected challenges, mostly related to the availability of larger reliable fuel cell systems. This forced the Utsira Hydrogen-wind project to substitute its original plans for a 60kW fuel cell stack with a 10kW fuel cell stack and a hydrogen internal combustion engine. The challenge for the REGENERA project is to find a solution for its planned 500 kW fuel cell system. The system integration will be quite immense, also because the construction and integration must not interrupt the daily functioning of the aluminium plant. The question in many projects is how to balance the demonstration part and the research component in real life conditions. Careful evaluation and monitoring of the operation of such systems is thus integrated in the GlashusEtt and in the Utsira Hydrogen-wind project and considerations may be made how to balance early field tests and the large-scale demonstration.

Table 15: Technologies and application in stationary use

Projects	Production and Distribution	Application	Budget
GlashusEtt	H2 from reforming biogas and from electrolysis using DC from PVs	Stationary use - heat and power in environmental centre 4kW PEMFC for CHP	1.15 MEUR, incl. 0.3 MEUR to main components and installation
Utsira Hydrogen-wind project	Wind / electrolyzer Prezz. tank 10kW PEMFC 55 kW Hydrogen ICE	Stationary use – autonomous energy system for 10 household - wind power combined with hydrogen produced from excess power to secure uninterrupted supply	4.8 MEUR, incl. feasibility study of 0.1 MEUR and annual operating and test cost of 0.24 MEUR
SolTerH – Hydrogen generation by means of high temperature solar thermal energy	Solar Thermal – different production routes are evaluated, but no choice has been made yet	Stationary use – this has not yet been analysed in detail yet	Phase I: 0.4 MEUR, incl. 0.2 MEUR for feasibility and design, 0.1 MEUR for prototype, and 0.06 MEUR for test Phase II: 1.6 MEUR
CHP in Nürnberg	200 kWel/235 kVA PAFC and absorption heat pump operated in base load	CHP for residential areas of 763 departments	1.2 MEUR, incl. 0.07 in preparation costs
REGENERA	Industrial waste gas from aluminium production, which will be purified to fulfil the requirement in a 500 kW PEMFC	Stationary – supply 1/3 of the industrial electricity demand	Not yet defined – feasibility study still ongoing
RES2H2 - Cluster Project for the Integration of RES into European Energy Sectors Using Hydrogen	Wind electrolyzer Pressure bottles Spain: tanks Greece: metal hydrides	Spain: Autonomous supply of electricity (hydrogen used as a buffer) Greece: Hydrogen supply to the industrial market	Total 5.4 MEUR, incl. 3 MEUR for preparation and design, 1.3 MEUR for system procurement, and 1 MEUR for operation and maintenance

Regional Context and Impact

As in the transport demonstration projects, most technology providers rely on own expertise in the preparation, design and also operation and test of the system. Local and regional business opportunities arise mostly from construction and engineering work. However, as we see in the Utsira case and also in SolTerH, local communities may benefit from the publicity of such demonstrations to profile the location and create new job opportunities, mainly in the tourist sector, and for a centrally located demonstration project as the GlashusEtt the national and international interest and publicity has been high and generated more than 17,000 guests during the last two years, including many politicians and private and public decision-makers.

In general public acceptance is high and local communities have been supportive to the demonstrations yet in operation.

Future Developments

For the projects yet under preparation, it is premature to envision the future development as the task ahead is to realise what is planned. But for those in operation, future developments are closely related to the further developments and test of the technologies and to market development.

When it comes to autonomous systems such as the Utsira project, the hydrogen energy system may be tested in other sites, it may be complemented by additional components, or just optimised in functioning and scope. Although the systems cannot compete yet with conventional technologies, there may be in a few year's time prospects in developing autonomous systems for remote areas in both developed and developing countries, or optimisation of systems integration in distributed power generation.

Once in operation, a demonstration may take advantage of results and experiences from on-going R&D projects and integrate new aspects and components. The case of GlashusEtt offers an interesting example of how R&D from an EU project can be further tested in the demonstration project both to the benefit of the R&D project and also to improvements, technologies and test of the existing system.

The only project completed is the Nürnberg PAFC, and due to other promising fuel cell technologies (SOFC and MCFC) the plant was deconstructed in May 3003. The experiences especially regarding the economics and optimisation can easily be transferred into other stationary fuel cell projects.

Summary of Key Success and Risk Factors

The main **success factors** highlighted by the projects are:

- The project idea itself to demonstrate a future community relying 100% of renewable energy
- Good partnership between highly competent partners with complementary knowledge
- Good collaboration with local community and the authorities already in the preparatory phase of the project
- Well monitored test and operation of the demonstration project to generate knowledge on FC, system integration, optimisation and economics.
- Visible and central location of project to attract visitors

Some **unexpected challenges** faced the projects during the preparation process:

- Acquisition of the FC system is difficult and commission time is long.
- Major adaptation of building to allow for the CHP itself.
- Organisational problems in the cluster due to change of partners and responsibilities
- The availability of FC is closely related to the difficulties technology providers face in keeping costs down and improving efficiencies in a new product. The market is characterised by the risks associated with early market introduction of FC such as acquisitions, closures etc. In a recent study on the Canadian fuel cell industry, it is demonstrated that the industry is operating at a loss. While revenues are increasing, they are insufficient to fund the high R&D costs needed to develop commercially viable fuel cells. It is therefore concluded that sustainable funding remains essential to bring fuel cells to the market (PriceWaterHouseCoopers, 2003).

The key **risks factors** associated with the projects are:

- Technical and operational problems with FC due to unsolved problems for FCs using hydrogen produced from two sources (electrolysis of water and reforming of biogas). This risk factor may be reduced by a more careful sequencing of laboratory work, early field test and the full-scale demonstration unit.
- Risks are associated with the task itself when different components are to be integrated in one system. The challenge is hence to control and stabilize the system. This is not a risk but the conditions under which technologies are to be tested and validated.

- Some of the technologies still need R&D and the development of a prototype. Again this is not a risk but the condition under which the demonstration is to be set up. If some elements still need R&D, it may be a question of whether these should be performed in laboratories or in an early field test.
- Difficulty in finding a FC developer that is willing to join the project partnership. This risk is part of performing a feasibility study.
- Different interests between projects in the same cluster. This risk may be reduced by avoiding forced clustering between partners. Other exchange of experience mechanisms can be used to assure that R&D activities are not duplicated.
- Changes in gas and power prices. This risk illustrates that for high-risk investments, such as hydrogen and fuel cell demonstration projects, it is very crucial to have long term framework conditions that allow these new technologies to compete with conventional technologies. Such framework conditions could be fixed feed in tariffs and subsidies for natural gas used in FC's.
- Large maintenance and operation costs due to frequent break down of pilot plant. This risk factor is associated with the task itself, but could perhaps be minimised by early field tests and better feasibility study.
- Phasing out of one FC (PAFC) for other more promising FC's (SOFC, MCFC). This risk is only a risk if users and producers of one type FC are locked to this technology and blind for other more promising technologies.

4.5 Both Transport and Stationary Applications

The six projects comprising both transport and stationary components are situated in five countries and like stationary demonstrations in diverse surroundings ranging from city, to towns and remote areas.

Rationale and Initiator
The rationale for most projects is to demonstrate the viability of producing hydrogen from a range of renewable energy source, to use this hydrogen in stationary CHP or vehicles, and also to demonstrate the benefits using hydrogen as an energy storage medium for these intermittent renewables (wind, solar).
An interesting example is provided by the Hydrogen for Arezzo project that aims at taking the point of departure in the existing industrial demand for hydrogen (approximately 700 local companies), improving the distribution by an underground pipeline from a production plant based on local resources (possibly biogas from agriculture and waste water treatment) and extending the use of hydrogen to an industrial CHP. The Swedish HyFuture chooses a supply approach. The project takes its departure in surplus hydrogen from a petrochemical production and aims at using this in stationary and applications.
For the large Bicocca project the idea is to build on the facilities and experiences from a 1.3 MW PAFC plant equipped with a natural gas fuel processing system and then utilise this fuelling process to feed both a 500 kW MCFC stack and a hydrogen network. The latter consists of a variety of applications. For example, a 50kW PEFC plant to a railway station, filling station and 5 passenger vehicles and 1 bus as well as a CHP based on 5MW gas turbines using syngas.
Another important motivation behind many projects is regional or business development aspects, in particular those situated in remote areas as the H2ellenic Island, and areas affected by industrial decline (Arezzo) or undergoing major changes in the economic structures (Baglan Renewable Hydrogen Centre).
The Canadian Highway project is initiated by three private companies, which wanted to build on existing hydrogen facilities and projects in British Columbia and extend this to a network of

transport and stationary projects for the upcoming Winter Olympics in Whistler in 2010. So far six nodes have been included in the projects and more will be added following an evaluation of the first projects. The project hence aims at demonstrating a wide variety of transport, stationary, portable and micro power applications that can utilize hydrogen-fuelling infrastructure.
The initiators of the project are often a combination of research institutes or universities, technology providers and regional development agencies.

Location
The Baglan Renewable Hydrogen Centre is located together with the University of Glamorgan and is assisted by its hydrogen research unit. Under the guidance of this unit, a large number of stakeholders have been involved in making a vision for a hydrogen economy in Wales together with a Transition Plan, including the most promising demonstrations. The centre has further linkages to the Hydrogen Valley initiative led by the Welsh Development Agency. It is strategically located along the M4 corridor between Wales and Southern England.
The Canadian case has a wider scope and is situated in the triangle between Vancouver, Victoria and Whistler, an area that comprises 65% of the Canadian industry. The location is defined in the interface of these cities and the location of the Winter Olympics.
As the Milan Bicocca project builds on the previous PAFC plant, the additional components and the hydrogen energy network are located near by. The location of the other Italian case is defined by the industrial market and the idea to provide companies with piped-in hydrogen.
The HyFuture project is developed around the supply of surplus industrial hydrogen and its use in a portfolio of applications in within the regional boundaries of Västre Götaland, including a Test centre, a small CHP for a new Culture Centre near Göteborg, and a filling station for natural gas blended with hydrogen.
The location for H2ellenic is not yet decided, but it will be a small island with no more than 5,000 inhabitants and with an energy demand of approximately 10 MWe to test and validate technologies within defined targets for hydrogen penetration of the whole energy system.

Legal Form and Management
Most of the projects are in their development stage and legal form and management is yet to be defined, but most go to involving key industrial and public stakeholders in public-private partnerships. The Bicocca case is managed by a public-private partnership, involving a utility (owning the PAFC plant), research institute, FC technology providers, and a gas company. The HyFuture cluster case is organised as a joint venture of private industries, associations, public authorities and test and research institutes and coordinated by a private FC company.
The network project in Canada is managed by a Steering Committee with representatives from the fuel cell industry as well as university. Local authorities do not yet play a central role in the network. The daily management is made by Fuel Cells Canada, which is a non-profit industry association representing the whole FC industry. It has a sort of facilitating role between funding bodies and each of the six nodes, and it is also responsible for evaluating the experiences gained and to introduce new nodes in the network.

Budget
As most of the cases are yet under preparation, it may be difficult to give defined budget figures. The preparation cost for both HyFuture and Arezzo is 0.3 MEUR. Estimated budgets are 40 MEUR for H2ellenic, 2.3 MEUR for Arezzo, including 0.3 MEUR for preparation, and 3.4 MEUR for Baglan Renewable Hydrogen Centre. The Bicocca project has a budget of 18.5 MEUR to be used over five years, of which 1.7 MEUR is used for preparation and tendering expenses. These differences in preparation costs across some projects may reflect what is included and excluded in these costs and also what is the total size/budget of the project.

The projects rely on a combination of public research funds (EU and national), private contributions and also regional development funds.
No budget figures are available for the Canadian case though 3 projects and the network management have by now received 1.1 million Can $ from public research funds. International venture funds are also sought.
For the Bicocca project, detailed economic and financial figures are given in the table below.

Table 16: Investment and financial figures for the Bicocca project

Costs	MEUR	Financial sources. Percent.	
Preparation costs	**1.7**	Ministry of Environment	24%
Investment costs	**15**	Regional funds (Lombardy Region)	3%
MCFC	6.4	National funds (FISR)	24%
PEFC	1.7	Private companies	app. 50%
Separation, purification, liquefaction for CO2	1.3		
Purification system for H2	0.55		
Distribution hydrogen pipeline and device for feed cogeneration plant	1.0		
Storage and dispenser for CHG	0.65		
Storage and dispenser for LH2	3.4		
Operation	**1.8**		
Total	**18.5**		

Technologies
As most of these projects are still under development, some technical aspects have not yet been clarified for some of them. The two projects relying on renewables (Baglan and H2ellenic Island) will use electrolysers and distribute the hydrogen in pipelines and pressure bottles to the end-use applications, being both vehicles and CHP. Furthermore, the Greek project will not only use hydrogen, but will also introduce other biofuels in the end-use applications.
The other project under preparation, the Arezzo project, is developed around the demand for hydrogen, and hydrogen production will most probably be based on local resources, more specifically reforming of biogas from agriculture or waste water treatment plants. In the HyFuture case, the hydrogen comes from surplus pure hydrogen available from the petrochemical industry in the area, and it will have a portfolio of projects, including power production on board ships (fuel cell APU), testing and demonstration centre for hydrogen and fuel cells, demonstration of an energy system made up by a PV, electrolyser, storage and a FC in a new Culture Centre near Göteborg.
The more defined project of Bicocca consists of two separate parts, each taking advantage of experiences and fuel processing systems in a previous R&D project. One part is a hydrogen network. Hydrogen will be reformed from natural gas provided by the NG city network. It will be compressed and distributed to the different applications by a 1 km pipeline and if needed stored in cylinders. The CO2 will be captured and sold on the industrial market. A filling station will be built, capable of serving both compressed and liquid hydrogen, the latter being trucked-in in cryogenic tanks. The other part is a 500 kW MCFC at the utility plant, which will use syngas and produce power to the grid. In the short run, the two parts are separated but will in the longer run be integrated and tested as hybrid complex systems. It hereby is an interesting example of the scale-up possibilities including more components, tests, and applications in different near by locations.
The Canadian cluster tries to avoid stranded assets by integrating a supply and market perspective and will to a large extent build on existing facilities and infrastructure. Applications, therefore, also vary across the nodes and comprise airbuses, bus and car fleets, CHP for the Athletic and Whistler villages, etc.

Table 17: Technologies and diverse applications

Projects	Production and Distribution	Application	Budget
Baglan Renewable Hydrogen Centre	Wind and solar PV and electrolysis Local pipelines and distribution	FCs, H2ICE and CHP	3.43 MEUR
HyFuture	Industrial surplus	CHP in culture centre FC APU on board ships FC and H2 test centre	0.3 MEUR in preparation costs
Highways	Diverse	No detailed info on technologies. Sites include airport, athletic and Olympic villages, existing laboratories and a university	No figures available
Milan Bicocca Project	Reforming of NG from city network 1 km pipeline and tanks CH2, Liquid H2	500kW MCFC system using syngas 50 kW PEFC plant for railway station Filling station for vehicles (3 conventional Fiat ICE cars, 1 IRISbus FC bus, 2 BMW ICE) Co-generation plant with 5MW gas turbines (turbogas) at AEM/Technocity	18.5 MEUR
Hydrogen for Arezzo	Reforming of biogas from local resources Underground pipeline from central deposit	Industrial use Stationary CHP in industry Transportation	2.3 MEUR, including preparation costs
H2ellenic Island	RES/electrolysis Pressure bottles, H2 network, FC, biofuels	Target is 10% of power demand, 5% of heat demand and 5% of transport energy (of a total of app. 10 MWe): 1 FC bus, marine use, CHP Oxygen to be used in fish farming or WWT plants	40 MEUR

The availability of sufficient hydrogen vehicles is a major problem. The Bicocca project disposes of 3 ICE cars from Fiat, a fuel cell by IRISBUS similar to the ones in operation in Turin and 2 BMW, but the Arezzo project has not yet a guaranteed vehicle fleet. The other projects of Baglan and H2ellenic have not developed into such detailing yet, but will confront the same problem as other project described (HyNor, Malmö Hydrogen Energy Station, Arezzo, CEP, etc.).

Regional Context and Impact

All projects have a strong regional development focus and aim at stimulating local economic activities, either directly in construction, engineering and technology development or indirectly in service and tourist sectors. Local industries and utilities are actively involved in the preparation and design of the projects underway in Bicocca, Arezzo, HyFuture, and Baglan. At least for HyFuture and Baglan, the projects are sustained in an overall vision and strategy for hydrogen and fuel cell activities in the region. It is still too early to make an assessment of the impact of these projects, which are all yet in preparation.

Future Developments

As mentioned earlier, most projects are yet under preparation so further developments will depend on the results and experiences gained through the operation of these projects. However, some projects are designed in such a way that scale-up of these activities can be done gradually, going from test and validation of few components to more components, from one test mode to various test modes, from one demonstration to a network of demonstrations, from one location to more locations and even with linkages between locations.

In the Canadian cluster, evaluations of the first six nodes will be made before more nodes are allowed to join the cluster. This does not prevent considering further longer-term extensions to Alberta in the East and also to the South with wider networks along the West Coast of USA right through to California.

Summary of Key Success and Risk Factors

The main **success factors** highlighted by the projects are:

- Strong hydrogen network that brings together industries, universities and local government
- Good partnership of key stakeholders
- Good collaboration with local and regional authorities as well as financial support from national programmes
- Combining industrial and energy use of hydrogen and thereby improve the overall economics of a demonstration project.
- Replication in other areas.

Some **unexpected challenges** faced the projects during the preparation process:

- During the preparation phase, it might be a challenge to create consensus about the main goal and activities of a project.
- This challenge is part of bringing together partners and interests in one agreed project.

The key **risks factors** associated with the projects are:

- The localisation of a plant in a city area. This risk may only be reduced by complying fully with all safety regulations and standards.
- Lack of specific regulations and safety rules. This risk can only be compensated by designing a new set of regulations and safety rules derived from the existing ones and combined with the use of hydrogen in new applications. Investigations have to be done on which safety regulations and standards are used in similar projects. Collaboration with safety authorities and bodies is also recommended to decide on how to provide good safety.
- Complexity in management of the whole system of MCFC plant and hydrogen. This risk is associated with the project itself and can only be reduced by a well prepared project bringing in all necessary knowledge.

4.6 Summary

The 19 case studies demonstrate some of the major challenges, which have to be confronted when identifying, designing and implementing hydrogen communities. Although they have different scope and focus, there are some common success and risk factors to take into consideration for future hydrogen communities.

The *key success factors* across all application areas are:

Good partnership and co-operation of key stakeholders in the project. Such partnership consists often of the key technology providers and users in order to have the critical knowledge and also hardware represented in the project. It takes time to find and commit highly competent partners with complementary skills and it is an integrated part of preparing and designing the project. Good partnership rests on liberty to choose one’s own partners, decide on responsibility, and activities. This does not contradict research funding eligibility criteria of including different types of actors and locations.

Good co-operation with the local community and local authorities. Establishing good relations with external stakeholders starts already in the preparation phase. There are many levels in this. The local community is also among the future users of the technology and establishing a good dialogue from the very beginning is also a feasible way to create public acceptance. To take out the permits and get all the safety issues right implies close co-operation with local authorities.

Good safety and compliance with all safety standards and regulations. This is an important part of the preparation of the project as there are no standard safety rules or procedures yet in Europe for hydrogen fuelling stations, hydrogen vehicles, stationary CHPs and other applications. Any new technology that will be introduced in large scale transport and energy infrastructures has at least to be as safe as the established technology and maybe even better. A smooth and effective permit process has to often integrate a variety of regulations and safety codes and standards and may rely on good cooperation with safety and certification bodies. Emergency preparedness is also an integrated part of managing safety issues.

Good demonstrations need good preparation, clarification of many aspects and the necessary adaptations to real life conditions. Many of the unexpected challenges which have occurred in the 19 cases are all related to the preparation of the project – the time and effort needed to take out all permits and approvals, the financial burden, a good prototype, the adaptation of technology to comply with local safety requirements, and the availability of the required components, technologies, systems, and artefacts. The overall economics of the project and the financial burden should not be underestimated and requires good studies and management.

Replicability of the knowledge in other areas. Demonstrations have to test and validate new technologies and the knowledge gathered during the preparation and implementation of the project has to be used to improve the technologies (and in some cases to substitute the technology for better more promising ones) and test them further in another context and in the ultimate stage bring them into the market. This requires good monitoring and testing of the demonstration, comprising all relevant components, systems, and economics. But it also requires the obligation to exchange this knowledge with other stakeholders.

A highly visible location of a demonstration project is one way to reach the general public. This may be an airport, a public institution, or a densely populated area. It can also be an event – the Winter Olympics in 2010 in Whistler is the most profiled described in this report. Public outreach also includes showrooms in relation to the demonstration itself and educational programmes as an integrated part of the demonstration.

The ***key risks*** highlighted in the case studies are the opposite of the key success factors. Many of these can be reduced by making good feasibility studies where all technical, market, economic, safety and other issues are clarified, solved and adapted to the specific conditions, under which the demonstration is to be in operation.

However, although individual demonstrations may conclude specific agreements on tax exemptions, take out permits, and other, it is necessary on a more general level to develop long term framework conditions and incentives that allow these new technologies to compete with conventional technologies. The German feed-in tariff of 5.11 €c/kWh for stationary fuel cells is an example of this.

5 Discussion and Conclusion

This chapter discusses what constitutes a Hydrogen Community. Based on the lessons learned from the technology assessment, the case studies and other material, the concept of a Hydrogen Community is discussed and defined: what constitutes its boundaries, what is the critical mass and the key success factors. Different types for future Hydrogen Communities are developed and described and eventually, a roadmap for different types of Communities is developed.

5.1 Defining Hydrogen Communities

What makes a good initiative for hydrogen communities? This depends on what are the initiative's overall goals, how it is designed and managed, and whether it is implemented efficiently and effectively. Although the overall goal has yet to be clarified by the Commission together with the European Platform for Hydrogen and Fuel Cell Technologies, it is necessary to define a hydrogen community in terms of its boundaries and also discuss what makes it a Hydrogen Community instead of just another demonstration project.

Terminology

The HyCom Initiative uses the term hydrogen communities.
A **Community** is according to The Encyclopædia Britannica Online a unified body of individuals. This can be a state or Commonwealth (one founded on law and united by compact or tacit agreement of the people for the common good). A community is also defined as the people with common interests living in a particular area; as an interacting population of various kinds of individuals in a common location; a group of people with a common characteristic or interest living together within a larger society; a group linked by a common policy; a body of persons of common and especially professional interests scattered through a larger society. From this, one may at least draw three main features:

- Common good, common interest, common professional interest, common policy
- Interaction
- Location

Another term is often raised when discussing large-scale demonstration projects. Lighthouse project is a term that is used by the Contact group for the Alternative Fuels Report.
A **light house** is "a structure (as a tower) with a powerful light that gives a continuous or intermittent signal to navigators". What is crucial in this definition is the interface between the structure with its light and the navigators. Navigators have a decisive role and use the lighthouse to adjust the course, but the light is also visible to other people on board or inland.
In the evaluation of the CUTE project, the term **flagship** is used by the Commission. A flagship is "the ship that carries the commander of a fleet or as the finest, largest, or most important one of a series, network, or chain".
The demonstration projects described in Chapter 4 do not comply with the term light house nor community and only one is characterised as a flagship. Most of them are designed to test and validate specific technologies in real life conditions. Focus is primarily on technologies, though some projects are also supported by broader common environmental and regional development interests. Some of the projects under preparation do have a broader community perspective, which is sustained in a common vision or strategy for the transition to a local hydrogen economy that comprises various and interlinked hydrogen and fuel cell activities in the same location. Therefore,

we will define the boundaries of Hydrogen Communities and clarify the necessary critical mass of such Communities.

Identifying the Boundaries of Hydrogen Communities

Fuel cell and hydrogen technologies still require technical improvements to be competitive with fossil fuels and conventional technologies in transport and heat and power production. Boundaries may be defined by:

- Technical boundaries
- Geographical boundaries
- Information boundaries
- Socio-economic boundaries

<u>Technical boundaries</u>

All the transport projects are good examples of demonstrations that aim at validating and testing vehicles within the **driving boundaries** of hydrogen vehicles. These boundaries may be an airport as the Munich Hydrogen Airport, or the bus district as the Malmö Hydrogen Energy Station and the CEP. Boundaries may be widened by including a network of fuelling stations as the HyNor project, the Japanese JHFC project, or the Canadian Highways. The provision of hydrogen to the fuelling stations is not subject to the same physical boundaries as some stations have on-site production technologies and others have trucked in hydrogen. Stations are normally stationary units, but in the JHFC demonstration programme a mobile fuelling station can be located where needed. Expectations for the first phase of transport communities in Europe are that these are defined by car or bus fleet and hence do not need to leave the district (Interview with A. Postema, Shell, 3 September 2004).

Boundaries may be defined by the **consumers of a CHP system**, which is exemplified by the PAFC CHP case in the City of Nürnberg.

The boundaries may be defined by **existing hydrogen production or industrial surplus production**. Especially in the cases under preparation much effort is put on clustering a number of transport and stationary applications around existing hydrogen production facilities and infrastructure as, for example, the Swedish HyFuture project and the German part of the Zero Region project. This allows for avoiding costly investments in production facilities, and for concentrating on distribution and end-use applications.

The boundaries may also be defined by **existing natural gas network** which allows for cost-effective distribution facilities. This may be used in transport applications as we see in the case of the Malmö Hydrogen Station and also in stationary applications using SOFC.

<u>Geographical boundaries</u>

The two island examples of Utsira and H2ellenic aim at testing and demonstrating an autonomous energy system using local or renewable energy sources. Here the **borders of the island** itself constitute the boundaries. **Remote areas** with no connections to the energy system have the same characteristics as islands and are hence also included.

<u>Information and legal boundaries</u>

Boundaries may not only be physical, but can also be **virtual, transaction boundaries**. The focus is not on testing the technology, but on exchanging knowledge and experiences from testing technologies under different climatic, topographical and traffic conditions. This we see in projects such as the CUTE project and the US learning demonstrations, which are localised in different climatic and geographical sites or regions. If such boundaries are legally defined in terms of a public-private partnership, a joint procurement of key technologies may also be realised.

<u>Socio-economic boundaries</u>

Boundaries may be defined by a **centre of various hydrogen activities, projects and competences**, such as the Baglan case. This center is furthermore embedded in a region where local and regional stakeholders have developed a common vision for a hydrogen economy and identified a number of future hydrogen demonstrations. It thereby represents a **community in a larger community.**

Boundaries may also be defined by **economy**. In the European regional development policy, regions are defined by their degree of economic development: underdeveloped regions (objective 1) and regions in industrial decline (objective 2). The Spanish case of SolTerH aims at demonstrating new technologies to create new jobs and bring development to an underdeveloped region.

Identifying the Critical Mass of a Hydrogen Community

Once having identified the boundaries of Hydrogen Communities, we will focus on what constitutes a critical mass within those boundaries. A Hydrogen Community is more than a demonstration project, and it is not necessarily a light house project, but something in between. First and foremost, it is characterised by having a critical mass of activities in the field.

From the cluster theory, we can identify a range of factors that contribute to gaining a critical mass (see for example Andersson, T. et al., 2004):

- Geographical concentration of the activities
- Specialisation
- Strategic outlook
- The life cycle of the Community

The Hydrogen Community represents a **geographical concentration** of activities related to the research, development and demonstration of fuel cell and hydrogen technologies. Both hard and soft aspects are associated with this concentration. The hard aspects are for example:

- The *availability of specific natural resources* or other unique *local assets*. Excess wind power in some regions as we see in Western Denmark and Northern Germany may be regarded as an asset for the production of hydrogen. It may also be existing natural gas networks, hydrogen pipelines, or existing demonstration activities.
- *Economies of scale and scope* may be optimised most effectively by a limited number of efficient demonstration projects. This may be a number of stations and different hydrogen vehicles. Likewise it can be a variety of stationary use in residential or industrial sites, to which hydrogen is delivered from one production site or from industrial surplus of hydrogen.
- The *interplay with local customers* triggers learning processes and more sophisticated demand. This is closely related to create a good learning environment and bringing the technology closer to the customers and the general public. This market perspective is for example highlighted in the recommendation to analyse different customers' need. This may be the need of local transport companies, the need of local energy companies, but it may also comprise the need of the individual industrial power and heat consumer or the residential power and heat consumer.

The soft aspects of geographical concentration are related to the localisation of *social capital*. Geographic proximity between firms and research institutes tends to facilitate informal exchange and learning. Often fruitful, creative processes of exchange are associated with a special environment, a meeting place. Social capital does not have to be locally tied, but can pass over geographical distances. Adequate "meeting places" should then be provided for. The CUTE project facilitates such meeting places for the participating cities, for the technicians involved in each of the workshops, and for the socio-economic researchers.

Specialisation or common denominator of the Community is closely linked to the core activity associated with developing and demonstrating hydrogen and fuel cell technologies. An efficient Hydrogen Community is likely to entail a strong element of complementary specialisation between its activities, each focusing on core business coupled with linkages and the capturing of synergies in learning processes. The interlinked specialised suppliers and qualified buyers contribute to the overall development of the Community and its competitive profile. The market for fuel cells is a highly international market and a Community may offer a technology provider some good test and validation opportunities in close cooperation with local users and developers.

At best, a **common vision and strategy** will outline the key stakeholders, the design and the sequence of the various components and activities making up the Community. A good example of such visions is the Wales Hydrogen Vision, which brings together the various stakeholders and outlines priorities and actions in a longer-term perspective (see www.h2wales.org). Another example is the regional foresight on the hydrogen economy managed by the Danish County of Ringkoebing. It resulted in a hydrogen energy strategy and action plan, including a regional knowledge centre on hydrogen and fuel cell technologies, demonstration projects etc. (see www.brintamt.dk). Likewise, the Nordic Hydrogen Energy Foresight has brought together experts from different disciplinary, sector and national backgrounds to discuss and agree upon common actions related to strengthen Nordic competences in the field of hydrogen and fuel cell technologies (see www.h2foresight.info). Such foresight processes are in particular important for communication about the longer-term goals, creating consensus and commitment among the key stakeholders, coordinating the various activities and thereby build internal coherence regarding resource demanding technologies such as hydrogen and fuel cell technologies.

The life-cycle of the Community illustrates that a Community may undergo an evolution over time and that the pace of this evolution may differ from Community to Community:

- *Agglomeration*. A few activities in the field of hydrogen and fuel cell technologies, but with no interlinkages
- *Emerging Hydrogen Community*. A number of actors involved in hydrogen and fuel cell activities start to cooperate around a core activity and realise common opportunities through their linkage. This can for example be to make common demonstration and research activities.
- *Developing Hydrogen Community*. New actors in the same or related activities emerge or are attracted to the Community and new linkages develop between all these actors. This may be supported by a common label, connotation, tied to the Community and activity.
- *The mature Hydrogen Community*. Such a Community has reached a certain critical mass of actors and activities. It has developed relations outside the Community, to other Communities, activities, and there is an internal dynamic of new activities through start-ups, joint ventures, spin-offs etc.
- *Transformation* indicates that for the Hydrogen Community to survive, to be sustainable, it has to innovate and adapt to new changes. It may transform into one of several new Hydrogen Communities that focus around other specialisations and activities.

When assessing the critical mass of a Hydrogen Community it is therefore important to analyse the degree of development and the ambition to interlink, speed up and develop activities.

What Characterizes a Good Hydrogen Community?

Once having defined the boundaries and the critical mass, we will now focus on what makes a well-functioning Hydrogen Community. The discussion is based on the lessons learned from the case studies, the technology assessment and complemented by other studies.

Good partnership and co-operation of key stakeholders in the project. Often key technology providers and users will be partners in order to have the critical knowledge and also hardware represented in the project. Local authorities and regional representatives may also be partners. It takes time to find and commit highly competent partners with complementary skills and it is an integrated part of preparing and designing the project. Good partnership rests on liberty to choose one's own partners, decide on responsibility, and activities.

Good co-operation with the local community, local authorities and other stakeholders starts already in the preparation stage. Foresight and strategy processes offer a good opportunity to involve local stakeholders and the general public in defining the visions and instruments needed to fulfil these. The local community is also among the future users of the technology and one feasible way to create public acceptance is to establish a good dialogue from the very beginning. To take out the permits and get all the safety issues right implies close cooperation with local authorities. Also by pooling resources and risks, and developing complementary functions, Communities may achieve economies of scale and scope in the development of demonstrated technologies and related technologies. While geographical proximity matters for informal knowledge exchange, international links are likewise crucial to the further development.

Clarification of all technical, economic, financial, legal and other aspects. Good demonstrations need good preparation, clarification of many aspects and the necessary adaptations to real life conditions. Many of the unexpected challenges are related to the preparation of the project – the time and effort needed to take out all permits and approvals, the financial burden, a good prototype, the adaptation of technology to comply with local safety requirements, and the availability of the required components, technologies, systems, and artefacts. The overall economics of the project and the financial burden should not be underestimated and requires good studies and management.

Good safety and compliance with all safety standards and regulations. This is an important part of the preparation of the project as there are no standard safety rules or procedures yet in Europe for hydrogen fuelling stations, hydrogen vehicles, stationary CHP's and other applications. Any new technology that will be introduced in large scale transport and energy infrastructures has at least to be as safe as the established technology and maybe even better. A smooth and effective permit process has often to integrate a variety of regulations and safety codes and standards and may rely on good cooperation with safety and certification bodies. Emergency preparedness is also an integrated part of managing safety issues.

Quality in test and validation of technologies is crucial to bringing the technologies to the market. Some of the topics listed below and the entire project portfolio will:

- Support the development of efficient technologies for production of hydrogen and other Hy-fuels – in particular decentralised production technologies based on renewable sources that is not more efficient used for electricity generation.
- Support the development of efficient technologies for storage of hydrogen. The lack of satisfactory hydrogen storage technologies is a crucial barrier for the break-through of the hydrogen technologies.
- Support the development of the individual components and technologies related to the infrastructure. A widespread development and extension of the hydrogen infrastructure should await a more clear indication of hydrogen as a general energy carrier in the integrated energy system. In addition, a decentralised hydrogen production will eliminate, reduce or change the need for a separate widespread hydrogen infrastructure.

- Support the development of the fuel cell technologies as the success of hydrogen and other Hy-fuels is highly dependent on the development of attractive fuel cell technologies (both in term of technical performance and cost) and vice-versa, the success of the fuel cell applications is dependent on the easy access to appropriate fuels.
- Give priority to projects that include pre-activities, comprehensive laboratory and prototype tests, a step-by-step approach, and a flexibility to include new experiences and knowledge gained during the project.
- Assure that the technology solutions are robust to the changing conditions.
- Demonstrate a variety of technologies, Hy-fuels, solutions and applications. As none of the technologies can be pointed out as the most promising, it is important to be open to all the possibilities.
- Address the social problems and technical barriers listed and demonstrate a way to overcome the barrier(s). The projects should not just move a problem from one point in the energy chain to another point.
- Demonstrate new technological improvements. This means that all projects should demonstrate improvements on a least one of the technical or economic parameters. It is not sufficient e.g. to demonstrate that buses can run on hydrogen – it must be demonstrated that the buses can run longer per fuel unit, that the fuel cell have longer lifetime, that the fuel cells are less sensitive to contaminations in the fuel or similar measures.
- Contribute to the development of relevant international standards and common regulations for the hydrogen technologies. This might be achieved through the involvement of the relevant bodies.

Good learning environment. Special focus should be on the sequencing of laboratory verification, early field tests, demonstrations and projects and feed back from demonstrations to R&D programmes, especially in the most challenging areas. Close co-operation with research institutes or universities is especially needed in those fields where there still are major research elements included as, for example, fuel cells, system integration, etc.

Demonstrations have to test and validate new technologies, and the knowledge gathered during the preparation and implementation of the project has to be used to improve the technologies (and in some cases to substitute the technology for better more promising ones) and test them further in another context and in the ultimate stage bring them into the market. Therefore good monitoring and test of the demonstration is required, including all relevant components, systems, and economics.

Another prioritised activity is exchange of knowledge and exchange of experience with other similar activities in other parts of Europe or elsewhere in communities and individual projects. Public outreach and educational programmes are also part of a good learning environment. Public perception of hydrogen vehicles and other applications is key to the market introduction of these technologies. Preliminary results of ex-ante surveys in transport demonstrations in London, Berlin, Luxembourg, and Perth suggest that the support for hydrogen and fuel cell is generally high, but people need more information (Altman et al., 2004).

Good location and visibility. A highly visible location of a demonstration project is one way to reach the general public. This may be an airport, a public institution, or a densely populated area. It can also be an event – the Winter Olympics in 2010 in Whistler is the most profiled described in this report. Visibility also includes showrooms in relation to the demonstration itself and public outreach and educational programmes as an integrated part of the demonstration.

Proposed Definition of a Hydrogen Community

We recommend that a Hydrogen Community be defined as a group of professionals that together with local and other people have shared interests and perform activities in hydrogen and fuel cell technologies for the common learning and good.
The activities are localised in a particular area defined by technical, geographical or socio-economic boundaries (driving range, borders, technical or economic systems, etc.). Knowledge and information linkages are not confined to these boundaries, but go beyond and reach out for exchange of knowledge and knowledge sharing with external and international stakeholders. The Hydrogen Community goes beyond single demonstration projects and is characterised by over time building a critical mass of different hydrogen and fuel cell activities through geographical concentration of the activities, specialisation supported by a common vision and strategy, good cooperation with local and other stakeholders as well as good partnership among key stakeholders Clarification of all technical, economic, financial, and other aspects is made in feasibility studies, which also assure good safety and compliance with all safety standards and regulations. Quality in test and validation of technologies is at the core of the Hydrogen Community and this is sustained by a good learning environment with links to knowledge institutions, other similar projects, etc. Last, but not least, visibility and outreach is important for a powerful Hydrogen Community.

5.2 Types of Hydrogen Communities

Hydrogen Communities may undergo different developments dependent on the differences in their point of departure and their boundaries. We do not define the types around the conventional distinction between mobile, stationary and portable applications because one may then easily overlook the fact that their trademark is the Hydrogen Community.

Rather, we focus on:

- The need for some *geographical concentration*
- The need for *specialisation* of each Hydrogen Community supported by a common vision and strategy
- The *step-by-step development* of hydrogen and fuel cell activities within the Community, starting from some critical mass in competences, infrastructure, demonstrations etc. and over time adding new components.

So each Hydrogen Community has its own record and specialisation.

Five types are therefore proposed. The list below does not indicate any rank of the communities, but the indicative resource allocation does indicate two major priotisations, namely the Town Community and the Metropolitan Community. Due to the limited availability of fuel cell and other hydrogen fuelled vehicles in the short to medium term, some concentration is needed in a few but relatively large network demonstrations. But relatively large demonstrations including existing transport and stationary RD&D activities may be a sound foundation for up-scaling to a Town Community but with more focus on stationary CHP systems and transitory technologies as for example hythane fuelled buses.

- The Town Hydrogen Community
- The Remote Hydrogen Community
- The Marine Hydrogen Community
- The Recreational Hydrogen Community
- The Metropolitan Hydrogen Community

The time phases may differ from case to case, but in broad terms we operate with the phases suggested in HyCom[12]:

Phase 1: 2005-2007

Phase 2: 2007 – 2012

Phase 3: 2013 – 2015

The Town Hydrogen Community

In its most simple form, the Town Hydrogen Community is located in a medium sized town. This is hometown of many Europeans. The production of hydrogen may rely on diverse sources, covering both fossil fuels and renewables. Likewise, it may rely on surplus hydrogen from local industry. The distribution of hydrogen depends on whether the production is made onsite or has to be delivered. Both options can be applied. The specialisation is based on stationary CHP for residential use (1-10 kW). This can be public buildings – museums, visiting centres, etc. In cases with natural gas network, 5-10 NG-buses running on hythane may be inserted as well as one fuelling station. In the next phase, the stationary CHP may be extended to building complex (5-50 kW). This can be offices, apartments, group of houses etc. and 5 FC-buses or 20 light duty FC or H2ICE vehicles may be inserted together with 1-2 hydrogen fuelling stations within the boundaries of the town or city. Larger projects and fewer technologies are demonstrated here.

The Remote Hydrogen Community

The Remote Hydrogen Community is characterised by the geographical distance and remoteness to the economic centres. It may be a remote area or an island. Its energy and transport system is operated as an autonomous system.

The production is based on renewables (wind, biomass, solar, geothermal). Its specialisation is concentrated on the operation of an autonomous energy system. In the first phases, it will focus on stationary CHP for residential or community use, which step-by-step may be extended to the Community. Later, a hydrogen fuelling station may be added for speciality vehicles and in case of islands also for boats and ferries. A single FC bus may be inserted and provide services on demand. Also in the Remote Hydrogen Community a high number of smaller projects and a diversity of technologies are demonstrated. The Remote Hydrogen Community is larger than the Recreational Community but still relatively small in terms of activities and economic size.

The Marine Hydrogen Community

The Marine Hydrogen Community is located next to a harbour in relatively densely populated areas. Its primary specialisation is on marine applications. The production of hydrogen may come from diverse sources, including surplus hydrogen from local industry. In the very first phases the activities may include FC APU-units powered by hydrogen on board ships or ferries, fork-lifters and other speciality vehicles in restricted and "under-roof" areas of the harbour and a single fuelling station next to the harbour. Later, stationary CHP for visiting centre, ferry terminal and/or community use (10-50 kW) may be added. Light duty FC vehicles operating in the harbour (for example public marine authorities) may be inserted in the later stages. The projects are in this type of Community a bit larger than for the former two types of Communities. Furthermore, different types of technologies and applications can be demonstrated. The Marine Hydrogen Community is

[12] This phasing is slightly different from the one suggested by S. D. Peteves when presenting the HyCom Initiative at a Hynet meeting 20 June 2004 in Brussels.

defined by the size of the harbour and the activities around the harbour, which in some cases also include residential areas, leisure and sports facilities. Visibility is high.

The Recreational Hydrogen Community

The Recreational Hydrogen Community is located in tourist areas with some distance to the large cities and with easy access to the nature, sea or major tourist attractions. It relies on natural gas and/or renewables for its hydrogen production or nearby industrial surplus of hydrogen. In the early stage applications are focused on stationary CHP for residential use, for example hotel, visitor centre, museums etc. Later, a fuelling station may be added together with speciality vehicles for tourist and recreational purposes within the resort. In the Recreational Hydrogen Communities a high number of smaller projects and a diversity of technologies are demonstrated. A Recreational Community is relatively small in economic size, but do have a substantial outreach to citizens on vacation and local people.

The Metropolitan Hydrogen Community

The Metropolitan Hydrogen Communities are located in large population centres of Europe. The main focus is on transport applications, where single demonstrations with one refuelling station and a few cars are upgraded to a network of refuelling stations and a substantial number of vehicles. This network will constitute a first infrastructure and thereby offer the opportunity to understand what it means to build an infrastructure. Networks should be confined to highly populated areas where some infrastructure already exists and where demonstrated results from previous and on-going activities can be used as a starting point. Rather than create corridors between networks, a more dynamic growth of the network may happen so that in the long run a corridor may be created between networks. The hydrogen may be produced from diverse resources on-site or off-site and then trucked in to the filling station in liquid form. The first phase may comprise 1-3 fuelling stations with both gaseous and liquid hydrogen, 10-15 FC and H2ICE vehicles (buses or light duty vehicles) to be used in city bus transport, airport bus transfer internally or externally, school buses, post service. Also small stationary CHP units may be demonstrated in showrooms and visitor centres. Later, more vehicles are included, up to 100. For some Communities, an option may be to include stationary heat and power in public buildings. These Communities are large lighthouse projects with high visibility – technically and industrial as well as politically.

5.3 Roadmap for Hydrogen Communities

In the figure below, a first attempt is made to outline a roadmap for different types of Hydrogen Communities.

The inception of Hydrogen Communities may be organised in different ways. We propose to use a combination of competition and cooperation:

- Between 15 and 20 Town Hydrogen Communities in different Member States covering cold, mild and hot climate zones. Guarantee for vehicles should be required for the third phase. ~28-38 MEUR per Community. Total budget of 575 MEUR or 38% of funds.
- 10 - 15 Remote Hydrogen Communities in different Member States. ~8 – 12.5 MEUR per Community. Total budget of 125 MEUR or 8% of funds.
- 5 -10 Marine Hydrogen Communities in different Member States. ~15 – 30 MEUR per Community. Total budget of 150 MEUR or 10% of funds.

- 15 – 20 Recreational Hydrogen Communities in different Member States. ~3.75 – 5 MEUR per Community. Total budget of 75 MEUR or 5% of funds.
- Up to 5 Metropolitan Hydrogen Communities in at least three Member States. Guarantee for vehicles is required. ~115 MEUR per Community. Total budget of 575 MEUR or 38% of funds.

Each Hydrogen Community should include technology providers (fuel cell providers, car manufacturer etc.), energy companies, and local or regional authorities. The inclusion of universities and research institutes involved in hydrogen and fuel cell technologies is also highly welcome to assure that the learning from the Community are directly fed back into the research. Hydrogen Communities may enter into networks to exchange information and experiences. Each network should allow for the inclusion of further Communities over time. This inclusion may be facilitated be including aspirant communities as observant communities. Over time, each Community may develop into a network of new communities and some even making up direct links/corridor between the nodes.

Hydrogen Communities may constitute a group or association of communities, which is based on certified membership and with obligations and benefits. Obligations may include completion of specific quality and quantity requirements in RD&D activities, common monitoring procedures and evaluations etc., whereas the benefits may imply common branding, knowledge sharing, exchange of experiences and best practises, outreach to the general public in Europe and also internationally.

Closer collaboration may be necessary to make comparative testing and validation of technologies. Such collaborations are decided on level of the demonstrations and do not necessarily include all Communities of the same type.

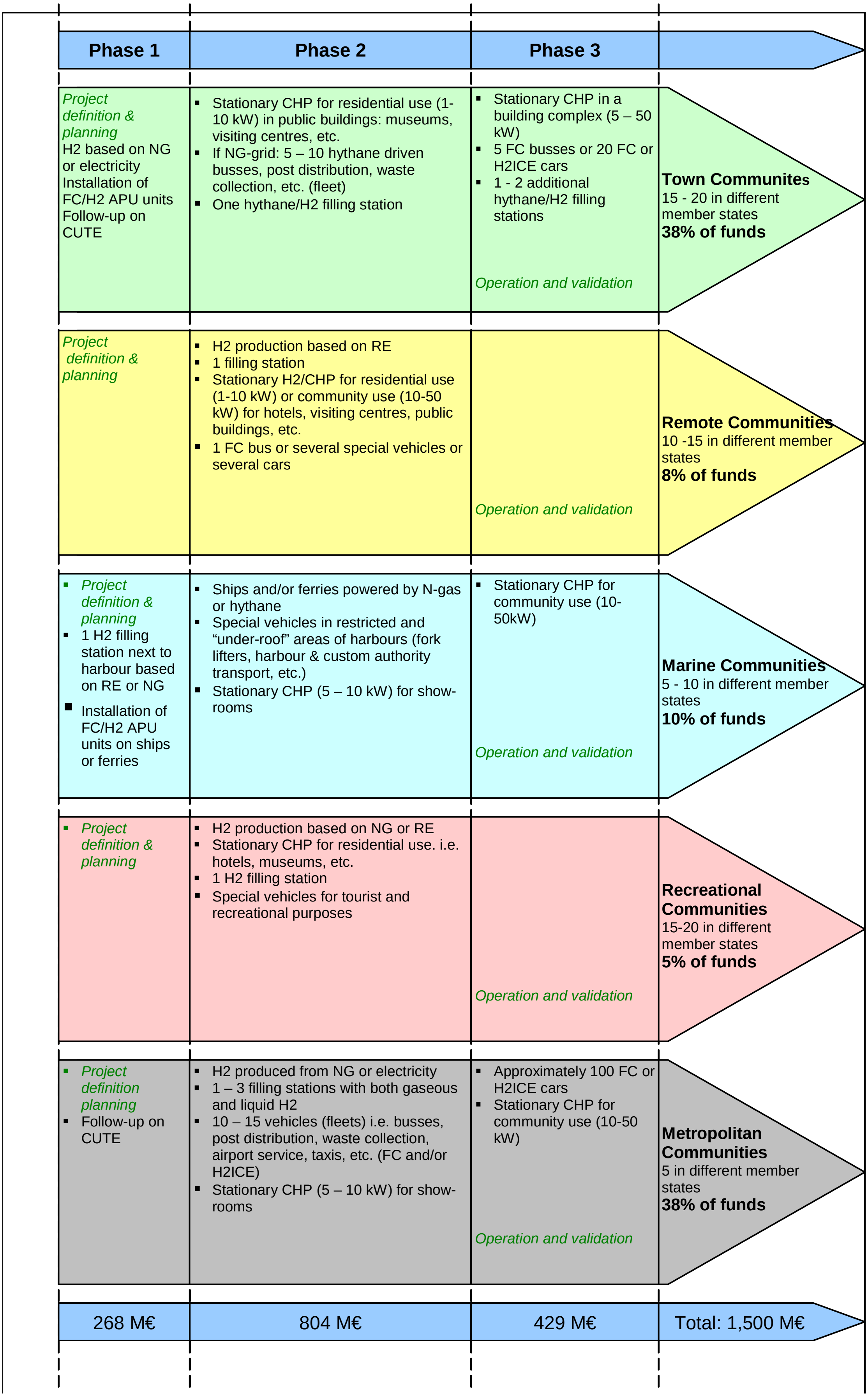


Figure 18: Roadmap for Hydrogen Communities

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- Mr. Adri Postema, Shell, member of the Deployment Group of the Technology Platform, 2 September 2004
- Mr. Angel Landabaso, DG Research, 7 September 2004

Interviews performed by Frauenhofer ISI:

- Mr. Holger Braess, BMW AG Transport and Environment, 24. September 2004
- Mr. Jean-Marc Agator, Commissariat à l'Energie Atomique (CEA) France, Programme "H2-PAC", 23 September 2004
- Mr. Nicolas Bardi, Commissariat à l'Energie Atomique (CEA) France, Programme Hychain, 27 September 2004
- Mr. Stefan Berger, Opel, 7 October 2004

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- Utsira – Ms. Elisabet Fjermestad Hagen, Norsk Hydro, 18 June 2004
- Malmö Hydrogen Energy Station – Mr. Staffan Ivarsson, Head of Development, Sydkraft Gas AB, Sweden, 17 august 2004
- GlashusEtt – Mr. Markku Rissanen, ABB AB, Corporate Research, 19 august 2004
- HyNor – Mr. Jan Arvid Jørgensen, Senior Advisor, Stor-Oslo Lokaltrafikk a.s, 17 August 2004
- Canadian Highways – Mr. Ron Britton, Fuel Cells Canada, conversation during WHEC June 2004.
- Baglan Renewable Hydrogen Centre – Mr. Jon Maddy, Hydrogen Research Unit, University of Glamorgan, 1 September 2004
- REGENERA – Ms. Africa Castro, Hynergreen Technologies, S.A., Projects Division, 28 August 2004
- SolTerH – Ms. Africa Castro, Hynergreen Technologies, S.A., Projects Division, 28 August 2004
- HyFuture – Mr. Robert Aronsson, ETC Battery and FuelCells Sweden AB, 31 August 2004.
- CUTE – Mr. Manfred Schuckert, Evobus, 29 September 2004

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- Munich Airport - Mr. F. Grafwallner, ET-Energietechnologie GmbH, 6 August 2004
- Zero Regio - Mr. A. Boening, Infraserv, 6 August 2004
- CEP - Mrs. Nilgün Parker, State Ministry of Transport, Building and Housing (BMVBW), 20 August, 2004

- PAFC Nürnberg - Mr. G. Meier, Studiengesellschaft BZ e.V., 31 August 2004

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- RES2H2 – Ms. Africa Castro, Hynergreen Technologies, S.A., Projects Division, 28 August 2004
- Milan Bicocca Project – Mr. Francesco Baldanzi, Zindar, 25 August 2004
- Hydrogen for Arezzo – Mr. Emiliano Cecchini, Project coordinator, La Fabbrica del Sole, 23 July 2004
- H2ellenic Islands – Dr. N. Lymberopoulos, August 2004.

Appendices

Appendix A: Hydrogen technologies development overview

In the table below, current (2005), short-term expected (2010) and long-term expected (2030) technical and economic performance parameters are indicated for the various technologies.

		[13]	*2005*[14]	*2010*[15]	*2030*[16]	*Source*
Hydrogen production						
Electrolysis	El: 7 €/GJ (24 €/MWh)	Tech: Eco:	Energy efficiency: 45..55 % (4..5 kWh/Nm3 or 50..60 kWh/kg) Small scale: 12 €/GJ			Norsk Hydro NOU 2004
SOEC		Tech: Eco:				
Reforming	NG 0.05..0.1 €/Nm3	Tech: Eco:	Energy efficiency: 50 % (3.7 (NG) + 0.8 (el) = 4.5 kWh/Nm3) Investment: 100 M€ @ 3 MNm^3/day (300 t/day) capacity Large/small scale: 3..12 €/GJ Inclusive CO_2 sequestration: +20 % (large scale)			Norsk Hydro ESTO 2003 NOU 2004
	Coal	Tech: Eco:	Investment: 300 M€ @ 3 MNm^3/day (300 t/day) capacity			ESTO 2003
Biomass	Gasification	Tech: Eco:	42 €/GJ (5 €/kg) inclusive CO_2 sequestration		20 €/GJ	NA 2004
Sequestration	?	Tech: Eco:		30 €/tCO_2	30 €/tCO_2	ESTO 2003
Hydrogen storage and distribution						
Gas phase storage		Tech: Eco:				
Liquefaction		Tech:	35..55 MJ/kg$_{LH2}$		25 MJ/kg$_{LH2}$	Bossel 2003

[13] Please indicate technical performance figures and economic figures separately as indicated.
[14] Present technology.
[15] Expected development within the HyCom Initiative period.
[16] Expected long-term perspective.

		[13]	*2005*[14]	*2010*[15]	*2030*[16]	*Source*
		Eco:				
Solid phase storage	Metal hydrides	Tech:				
		Eco:				
Other storage		Tech: Eco:				
Pipelines	 0.5 GW capacity	Tech: Eco:	Energy efficiency: 70 % @ 3000 km 0.5..2 M€/km 1..3 €/GJ @ 100..500 km			Bossel 2003 ESTO 2003
Transport in pressure tanks		Tech: Eco:	 4..40 €/GJ @ 20.800 km		Energy efficiency: 32 % @ 500 km	Bossel 2003 ESTO 2003
Transport in cryogenics tanks		Tech: Eco:	 1..3 €/GJ @ 20..800 km		Energy efficiency: 4.5 % @ 500 km	Bossel 2003 ESTO 2003
Fuelling stations Liquid On-site reforming of NG Inclusive on-site electrolysis		Tech: Eco:	 0.3 M€ 3 M€		 0.1 M€ 1 M€ 2 M€	 ESTO 2003 ESTO 2003 ESTO 2003
Conversion						
Fuel cells	PEMFC SOFC	Tech: Eco:	35 $\%_{el}$ / 70 $\%_{e+h}$ 45 $\%_{el}$ / 70 $\%_{e+h}$ 3..8 €/W		40 $\%_{el}$ / 75 $\%_{e+h}$ 50 $\%_{el}$ / 75 $\%_{e+h}$ 0.1 €/W	NA 2004 NA 2004 ESTO 2003
Other		Tech: Eco:				
Applications						
Transport	Buses	Tech: Eco:			PEM: 7 MJ/km TtW	NOU 2004
	Vehicles	Tech: Eco:	PEM: 1..2 MJ/km TtW PEM: € 1.2 000 000		PEM: 0.5 MJ/km TtW Hybrid PEM: € 30 000	Weiss 2003 Ricardo 2003
		Tech:				

		[13]	*2005*[14]	*2010*[15]	*2030*[16]	*Source*
		Eco:				
		Tech: Eco:				
Stationary	Industrial	Tech: Eco:				
	Residential PEMFC CHP	Tech: Eco:	Efficiency: 30 $\%_{el}$ / 70 $\%_{e+h}$ 5 €/W		35 $\%_{el}$ / 70 $\%_{e+h}$ 2 €/W	NA 2004 NA 2004
	Electricity buffer	Tech: Eco:				
Other	?	Tech: Eco:				

Appendix B: Case overview

Demonstration	Country	Territory	Partners	Status of project	Budget	Technology	Application
Hydrogen project at Munich airport	Germany	City of Munich International Airport	Consortium of 13 private companies	Operation Phase I: 1997-2000 Phase II: 1.2001-6.2001 Phase III: 7. 2001 – 12.2004 Phase IV: in preparation	35 MEUR	Onsite CGH2 from electrolysis and NG reformer Trucked in LH2 to filling station Gaseous and liquid refueling systems	Transport – 1 filling station 3 H2ICE buses 1 FC bus several ICE cars 1 fork lifter
CEP – Clean Energy Partnership	Germany	Berlin	Public-private consortium of 9 partners	Operation 2003-2007	51 MEUR, including 10 MEUR for infrastructure and 41 MEUR for vehicles	On-site CGH2 from electrolysis Trucked in LH2 1 filling station, incl.	Transport – 1 filling station, incl. Garage and visitor center 10 FC cars 2 H2 ICE cars 3 FCEV hydrids 1 FC 2 buses (1 FC and 1 ICE)
CUTE – Clean Urban Transport for Europe	7 EU countries (UK, Sweden, Germany, Spain, Luxembourg, Portugal, the Netherlands)	9 Cities with different climatic, topographical and traffic conditions: London, Stockholm, Hamburg, Stuttgart, Barcelona, Madrid, Luxembourg, Porto, Amsterdam	Public-private partnership with 9 cities and 18 private companies	Operation 2001 – 2006: Phase I: H2 generation and filling stations 2001 - 2003 Phase II: Buses 2003-2005	100 MEUR, of which 22 MEUR comes from EU (incl. ECTOS)	5 electrolyzers 2 steam reformers 3 trucked in hydrogen (1 liquid, 2 gaseous)	Transport – 9 fuelling stations 27 FC Citaro buses

Demonstration	Country	Territory	Partners	Status of project	Budget	Technology	Application
JHFC Japan Hydrogen and Fuel Cell Demonstration Project	Japan	Metropolitian Tokyo	Project under the auspices of METI and managed by Japan Automobile Research Institute (FC demo) and Engineering Advancement Association of Japan (Fuelling stations) together with 8 car manufacturers and 13 other private companies	Operation 2002-2005	No budget figures available	6 steam reformers 1 electrolyzer 3 trucked in (1 liquid, 2 gaseous)	Transport - 10 hydrogen refuelling stations and car and bus fleet and xx vehicles
HyNor	Norway	Six nodes along a 540 km long route	Public-private partnership with six separate legal intities	Phase I: preparation 2003-2004 Phase II: Construction and operation 2005-2008	25 MEUR for infrastructure No fixed budget for vehicles	3 electrolyzers 1 reforming with CO2 storage 1 bio-electrolyzer 1 electrolyse-reforming	Transport 6 fuelling stations and expectations to acquire hydrogen vehicles for different use (Taxies, Post office vans, Passenger cars, Bus fleet, Garbage trucks and heavy construction)
Malmoe Hydrogen Energy Station	Sweden	Town of Malmö, near the City of Copenhagen	Energy company Bus company	Operation 2003 - 2005	1.15 MEUR, incl. preparation cost of 0.05 and 0.31 MEUR for adapted NG bus Operation and maintenance data not available	Green certificate / electrolyzer 395 pressure tanks Hythane (8% H2 + 92%NG)	Transport 1 fuelling station 1 NG bus driving on Hythane

Demonstration	Country	Territory	Partners	Status of project	Budget	Technology	Application
Zero Regio - Lombardia & Rhine-Main towards Zero Emission	Italy Germany	City of Mantova City of Frankfurt	Joint venture of 7 industrial partners, 4 universities/research institutes, 3 public authorities and 2 consultants. Designed as a demonstration with defined responsibilities.	Preparation 10.2004-2009: Phase I: 2004-2005 Phase II: 2006-2009	20 MEUR	1 reformer in Mantova, 350 bar. H2 via 1,000 bar pipeline from industrial by-product (Hoechst) 350 bar, 700 bar and liquid	Transport 1 fuelling station with 3 FC vehicles in Lombardy 1 fuelling station with 5 FC vehicles in Rhein-Main
GlasshusEtt	Sweden	City of Stockholm	Private project with two partners	Preparation 2000-2001 Operation 2001-2005	1.15 MEUR, incl. 0.3 MEUR to main components and installation	H2 from reforming biogas and from electrolysis using DC from PVs	Stationary use - heat and power in environmental centre 4kW PEMFC for CHP
Utsira Hydrogen-wind project	Norway	Remote island	Joint venture with two partners each with defined responsibilities	Operation 2002-2006 Phase I: preparation and construction 1.2002 – 6.2004 Phase II: operation 7.2004 – 6.2006	4.8 MEUR, incl. feasibility study of 0.1 MEUR and annual operating and test cost of 0.24 MEUR	Wind / electrolyzer Prezz. tank 10kW PEMFC 55 kW Hydrogen ICE	Stationary use - power to 10 households
SolTerH – Hydrogen generation by means of high temperature solar thermal energy	Spain	Aznalcollar Village	Public-private partnership between two companies and a public research facility	Phase 1: Preparation, feasibility, prototype and test 2004-2005 Phase II: Operation	Phase I: 0.4 MEUR, incl. 0.2 MEUR for feasibility and design, 0.1 MEUR for prototype, and 0.06 MEUR for test phase II: 1.6 MEUR	Solar Thermal – different production routes are evaluated, but no choice has been made yet	Stationary use – this has not yet been analysed in detail yet
Electric power station in Nurnberg	Germany	Nürnberg		Operation 1998-	1.2 MEUR, incl. 0.07 MEUR for preparation	200 kWel PAFC station	Stationary use - Heat and power for 763 residential houses

Demonstration	Country	Territory	Partners	Status of project	Budget	Technology	Application
REGENERA	Spain	Valladolid Town	Public-private partnership	Preparation 2003-	Not yet defined – feasibility study still ongoing	Industrial waste gas from aluminium production, which will be purified to fulfill the requirement in a 500 kWPEMFC	Stationary – Supply 1/3 of the industrial electricity demand
RES2H2 – Cluster Project for the Integration of RES into European Energy Sectors Using Hydrogen	Spain Greece	Canary Island S-S Lavrion, Attica GR-S	Public-private partnership	Operation 2002-2007 Installation in preparation	Total 5.4 MEUR, including preparation and design of 3 MEUR, system procurement of 1.3 MEUR, and operation and maintenance of 1 MEUR.	Wind electrolyzer Pressure bottles Spain: tanks Greece: metal hydrides	Spain: autonomous supply of electricity (hydrogen used as a buffer) Greece: Hydrogen supply to the industrial market
Baglan Renewable Hydrogen Centre	UK-Wales	Region	Public-private partnership	Preparation 2004-2007	3.43 MEUR	Wind and solar PV and electrolysis Local pipelines and distribution FCs, H2ICE	Vehicles and CHP
HyFuture	Sweden	Region around city	Public-private joint venture	Preparation 2003-2005	0.3 MEUR in preparation costs	Industrial surplus	CHP in culture centre FC APU on board ships FC and H2 test centre
Highways	Canada	6 nodes related to cities/towns in British Columbia		Preparation Integration of existing facilities Full operation for the Olympic games in 2010		Diverse	Combined

Demonstration	Country	Territory	Partners	Status of project	Budget	Technology	Application
Milan Bicocca Project	Italy	City of Milan Lombardy Region	Public-private partnership between utility, research institute, FC manufacturers and gas company	Preparation and operation 2005-2010	18.5 MEUR	Reforming of NG From city network 1 km Pipeline Tanks CH2, Liquid H2	Network: 50 kW PEFC plant for railway station Filling station for vehicles (3 conventional Fiat ICE cars, 1 IRISbus FC bus, 2 BMW ICE)) Co-generation plant with 5MW gas turbines (turbogas) at AEM/Technocity Outside network: 500kW MCFC system using syngas (perhaps also H2 incl. CO2 capture)
Hydrogen for Arezzo	Italy	Town	Public-private partnership	Preparation Phase I: preparation 2002-2004 Phase II: Construction 2004-2005 Phase III: Test 2005-2006 Phase IV: Up-scaling 2006-2004-2006	2.3 MEUR, including preparation costs	Reforming of biogas from local resources Underground pipeline from central deposit	Industrial use Stationary CHP in industry Transportation

Demonstration	**Country**	**Territory**	**Partners**	**Status of project**	**Budget**	**Technology**	**Application**
H2ellenic Island	Greece	Island with 5,000 inh.	To be determined from case to case	Idea plan 2005-2015	40 MEUR	RES/electrolysis Pressure bottles, H2 network, FC, biofuels	Target is 10% of power demand, 5% of heat demand and 5% of transport energy (of a total of app. 10 Mwe): 1 FC bus, marine use, CHP Oxigen to be used in fish farming or WWT plants

European Commission

EUR 21575 EN – HYCOM PRE - FEASIBILITY STUDY

Coordinated by S.D. Peteves, S. Shaw and A. Soria

Luxembourg: Office for official Publications of the European Communities

2005– 124 pp. – 21 x 29.7 cm

Scientific and Technical Research series

P 2005/043

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