HyWays

The European Hydrogen Roadmap

Member States' Report

Vision on the Introduction of Hydrogen
in the European Energy System

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Acknowledgement

HyWays is an integrated project, co-funded by research institutes, industry, national agencies and by the European Commission (EC) under the 6th Framework Programme [contract Nº502596].

Abstract

HyWays aims to develop a validated European roadmap and an action plan for hydrogen in transport and stationary applications. This report comprises the visions on hydrogen energy systems of ten European member states that have participated in the HyWays project. The visions are a direct result of more than 50 member state workshops that were held to provide input to and validate the outcomes of HyWays. By means of an iterative process, the results of the calculations of the various models were discussed during the workshops. The feedback given during the workshops was used to modify input to the models results. Through the stakeholder participation in these workshops, it is ensured that HyWays is not a theoretical model exercise but takes into account country preferences and country specific conditions leading to a validated and well-accepted roadmap.

As a final product of these workshops, each country created a specific hydrogen energy vision document that describes the role of hydrogen in their respective energy system over a time horizon of 2020, 2030 and up to 2050. The vision document includes a general vision of the energy system, but also more detailed descriptions of the expected distribution of hydrogen, used feedstocks for production and infrastructure for different periods. It should be noted that the visions of the stakeholders as described in this document are not necessarily identical to the outcomes of the final model calculations. The visions of the stakeholders are used to modify the input for the model calculations. The outcomes of this exercise can deviate from the expectations of the stakeholders.

This Member State Vision Report is one of the final deliverables of the HyWays project. Other deliverables, such as an Executive Summary Report, the Hydrogen Roadmap and an Action Plan are available for download at the HyWays website (www.HyWays.de).

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Summary

HyWays is an integrated project founded by the European Commission and industry partners with the aim to develop a validated and well-accepted roadmap for the introduction of hydrogen in the European energy system until 2030 and provides an outlook to 2050. The aim of HyWays was to take into account country specific conditions, such as potential for renewable energy and CO_2 storage, and stakeholder preferences. Therefore, more than 50 member state workshops have been held with key stakeholders from each of the 10 participating European member countries. As a result, each member state has produced an individual vision on the future hydrogen energy system.

The member state vision documents represent an integral part of the HyWays project, validating the modelling results and adjusting the energy system according to the countries preferences using an iterative process. In fact, it resembles a bottom-up approach to develop a pathway towards hydrogen energy systems. During the workshops input for the model was collected and discussed, leading to further refinement of the outcomes for each country. The vision document describes the current and future energy system with hydrogen and takes into account three time periods: short-term (2020), medium-term (2030) and long-term (2050). The visions described in this report have been developed using the outcomes of model calculations. However, they do not necessarily resemble the final results of the model calculations, which are based on economic optimisation, one to one.

The visions clearly indicate that no clear choice for a single specific hydrogen pathway can be found. The final choice of hydrogen energy chains is strongly influenced by country specific characteristics. As a result, a much diversified energy production mix is found. In the short term, hydrogen production is based on fossil sources and will be produced by on-site steam methane reforming and on-site electrolysis. Industrial by-product also plays a role. Due to proximity of the production and the emerging demand centres, only short-distance transport is necessary which will be covered by trailer trucks (gaseous or cryogenic). By 2030, the production portfolio broadens up and utilizes renewable feedstock for on-site and centralized electrolysis (wind) and gasification (biomass). Hydrogen production from fossil sources is increasingly equipped with CCS (availability assumed) and shifted to centralised production. The build-up of country-wide pipeline infrastructure starts, with the most of transport still done through truck trailer. On the long term up to 2050, it is a common goal to achieve sustainable production of hydrogen. Major modes of production are electrolysis from renewable feedstock (wind, solar) and from fossil sources (steam-methane, coal gasification) with CCS and gasification of biomass. Marginally, also nuclear energy is utilized along the timeline. Hydrogen supply is expected to be covered by short and long distance pipeline networks with the continuous use of trailer trucks for remote locations.

The Member States have also given their view on a policy framework that can offer the required support of the introduction of hydrogen into the energy system. On the European level, the start of the much anticipated Joint Technology Initiative (JTI) for hydrogen fuel cell technology funded by the 7^{th} Framework Programme of the European Commission is assumed to have a major impact. National governments are nevertheless asked to introduce independent support schemes for (renewable) hydrogen production and demonstration projects, also calling for a decreased tax for hydrogen vehicles. The measures on the local government level include permission to enter restricted city areas, granting free parking access for hydrogen cars and the opening of dedicated bus lanes.

1. Introduction

HyWays is an integrated project founded by the European Commission and industry partners with the aim to develop a validated and well-accepted roadmap for the introduction of hydrogen in the European energy system until 2030 and provides an outlook to 2050. In drawing this roadmap, essential assumptions have been made on the penetration of hydrogen technologies, as well as on the driving elements in the system in which the introduction will take place. Despite the extensive modelling framework used within HyWays, this is not a theoretical model exercise and should reflect real-life conditions, taking into account country specific characteristics of the participating member states. HyWays comprises of two phases, the first group of countries are France, Germany, Greece, Italy, the Netherlands and Norway, which were joined in the second project phase by Finland, Poland, Spain and the United Kingdom.

This report comprises the hydrogen energy vision documents resulting from the validation workshops of the model results, which were held in each of the ten participating European member countries of the HyWays project. The validation workshops with wider stakeholder groups played a crucial role in the HyWays process. It is especially important because the aim of HyWays is the creation of a validated European roadmap for hydrogen, which is not possible without the participation and involvement of the member states. More than 50 MS workshops have been performed to discuss and analyze the countries preferences.

The goal of the national stakeholder workshops was twofold:

- To collect information on stakeholder preferences and other country specific conditions. This information is used to modify the results of the scientific analysis in order to turn the ‘optimal’ pathways, from strict techno-economic optimisation point of view, into realistic pathways that reflect real-life conditions.
- To validate the results of HyWays and to give these stakeholders a say in the process of selecting energy chains and developing realistic and preferable pathways, thus improving the quality as well as the acceptance of the HyWays results.

As a result, each country has created a so-called member state end vision document about the future role of hydrogen in the energy system. The member state visions have been established using an iterative approach. The final vision on member state level has been translated to the input for the final model calculations. It should be noted however that the final results of the model calculations are not one to one identical to the visions as developed by the stakeholders. First, the current energy system is described and how a future energy system would be shaped. For three time periods, short-term (2020), medium-term (2030) and long-term (2050), the member states have described how the hydrogen system evolves over time, including a brief description of production methods and expected infrastructure for the supply of hydrogen. As a final point, a policy framework has been put forward to support the implementation of hydrogen into the energy system. In chapters two through eleven, each of the ten member states has described their vision of the introduction of hydrogen into their energy system. Chapter twelve draws general conclusions followed by an appendix with an overview of all chosen member state hydrogen energy chains.

2. France

2.1 Introduction

The French stakeholders of the national Group HyFrance have thought about an intuitive vision of hydrogen energy in the period 2010-2050, to be taken into account in the 'European Hydrogen Energy Roadmap' of HyWays project. This collective vision, which takes into account the specificities of the French energy system, is consistent with the national energy policy orientations: reduction of energy dependence and guarantee of long term supply; energy supply at competitive costs; sustainable energy development, including the fight against climate change.
As the CO_2 emission reduction target is only 35% by 2050 in HyWays project, the French stakeholders keep in mind that a political consensus on a much more aggressive target is now being reached on a worldwide basis (i.e. 75% for the industrialized countries).

2.2 Development of the French energy system

Today, 90% of the electricity produced in France is CO_2 free (80% for nuclear energy, 10% for renewable energy) and the energy conversion sector has thus a weak contribution to CO_2 emissions. Moreover, the road transport sector is the only major one depending exclusively on oil, without a large substitution movement of fossil fuels by alternative fuels, even if the share of biofuels increases significantly. This sector is also the only one that increases steadily its CO_2 emissions (1 to 1.5% per year, in heavy trend). Conversely, in the stationary sector (residential/tertiary, industry), the trend is to increase the energy efficiency and savings and to substitute fossil fuels by energy forms with CO_2 free (renewable energy) or -reduced (electricity) emissions.

As a result, the power sector in France has no major impact today on climate change, whereas the road transport sector has the highest priority to substitute fossil fuels by clean fuels. In the future, the general trend of a high share of energy sources without CO_2 emission in the power sector will have to be kept, especially under an aggressive energy policy against climate change. In this perspective, France should take advantage of its electricity mix and high potential of renewable energy resources (wind and biomass as a priority) to produce hydrogen by water electrolysis or biomass gasification. Moreover, France hosts one of the biggest natural gas transport and distribution networks in Europe. In the future, the potential of CO_2 storage in sedimentary basins should be mobilized to store the CO_2 produced by steam methane reforming (SMR) which remains today the most competitive process for hydrogen production at large scale.

2.3 The role of hydrogen in the energy system

Assuming that hydrogen will play a role in various energy sectors, including transport and stationary sectors, the specificities of the French energy system described above will lead to favour three basis sustainable options to produce hydrogen:

- Centralized SMR with CO_2 Capture and Storage (CCS)
- Low or high temperature water electrolysis, centralized or decentralized, using the French electricity mix or dedicated wind (preferably off-shore) or nuclear power (EPR at first)
- Dry biomass gasification, using cost-effective regional resources.

This strategy will assume an appropriate use of the renewable electricity generated (above all wind electricity) to produce hydrogen by water electrolysis in decentralized installations. In addition, the future centralized production of CO_2 free hydrogen will require new electrolysis systems, more efficient and economical, using the energy provided by a dedicated innovative nuclear reactor.

2.4 Short-term vision (up to 2020)

According to the stakeholders, in the short-term phase hydrogen will be served to develop the early energy markets, including transport (captive fleets, specialist vehicles), stationary markets (UPS, back-up power), portable micro fuel cells and by-product hydrogen. The French manufacturers Axane (subsidiary of Air Liquide) and Helion (subsidiary of Areva Group) could play a major role in this perspective. The supply of hydrogen would require small quantities produced by SMR or conventional water electrolysis, either on-site or in centralized installations, using the existing hydrogen infrastructures (e.g. Air Liquide capacities for hydrogen production and distribution). In case of centralized production, hydrogen would be delivered by truck (cryogenic, tube trailer) or pipelines. To refuel vehicles in refuelling stations, another option would be to replace empty cylinders of hydrogen with full cylinders of hydrogen under high pressure.

To foster the introduction of hydrogen in the energy markets, an alternative option would be to mix hydrogen with natural gas in existing natural gas pipelines and use the mixture in various applications, including transport (Hythane® vehicles) and stationary uses (boilers, cogeneration). This option would lead to a faster dissemination of stationary uses of hydrogen and a significant decrease of CO_2 emissions, without requiring yet pure hydrogen systems. An intermediate option would be to extract hydrogen from the mixture at the point of use, provided an efficient central separator is used and an appropriate credit is assigned to the gas-off. This option could be tested through large demonstration projects to check its technical feasibility and economic competitiveness with the reference one (pure hydrogen pipelines).

The Early User Centres (EUC) would be localized in the most favourable border areas (South-East, East, North-East), i.e. those already including demonstration projects, with the local availability of experts and political commitment of regions. In addition, there is a very high R&D and industrial potential for the development of hydrogen and fuel cells in ‘Ile-de-France’, even if the awareness of this potential seems poor among policy makers. But the opportunity to make up for lost time is also very high: see the map below (Figure 2.1).

If applicable, the regional competitiveness clusters, which focus on the key factors of industrial competitiveness such as R&D-led innovation, would be a suitable framework for the development of hydrogen technologies. Three clusters are of particular interest here: Tenerrdis (‘Rhône-Alpes’), Capenergies (‘Provence-Alpes-Cote d’Azur’) and ‘Vehicle of the future’ (‘Alsace’, ‘Franche-Comté’)

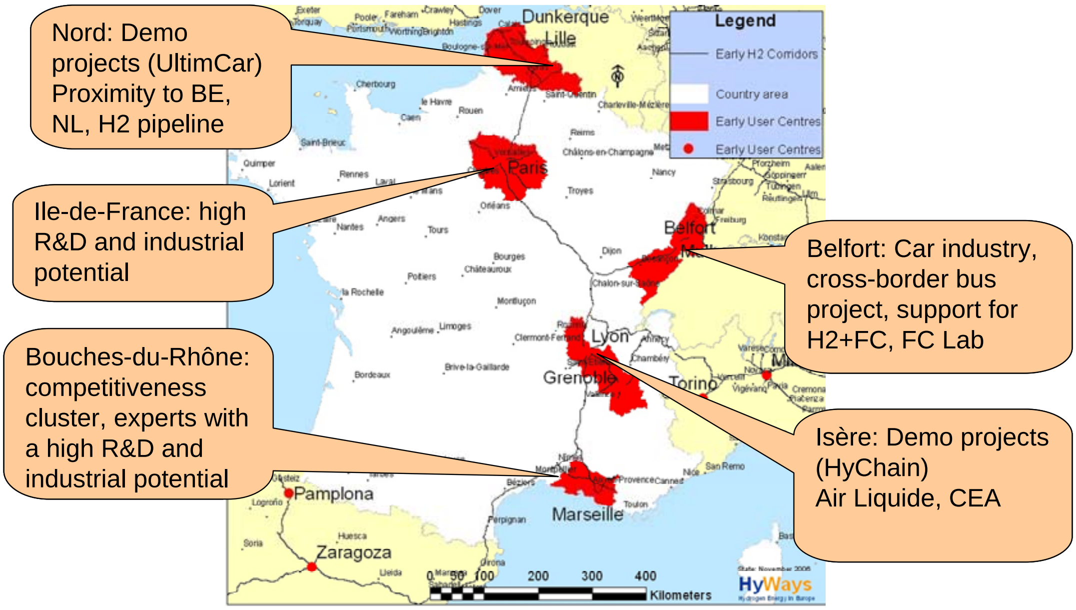


Figure 2.1: *The proposed early user centres and corridors in France*

2.5 Medium-term vision (2020-2030)

In the medium-term or transition phase, the growth of hydrogen demand would enlarge the range of options for decentralized and centralized hydrogen production, taking into account the French specificities. The production of hydrogen using renewable energy would emerge in the most favourable regions, e.g. up to 7 TWh by wind power electrolysis (‘Languedoc-Roussillon’, ‘Bretagne’, ‘Normandie’) and 13 by biomass gasification (‘Lorraine’, ‘Aquitaine’, ‘Rhône-Alpes’) in 2030.

These values result from a first evaluation of French renewable energy resources likely to meet hydrogen demand, although such an evaluation is sensitive as driven by social, economic and political considerations (hydrogen production competes with the other final uses of resources: electricity, heat, other biofuels). Large quantities of by-product hydrogen (up to 0.4 GNm^3/year) would be served to regional markets, according to the economic competitiveness of the operation (good potentials in PACA: Fos-sur-mer, Lavéra), but this contribution would be insignificant after the transition phase.

The capture and storage of CO_2 issuing from centralized SMR installations would be envisaged in this phase at industrial scale, but this option would be privileged afterwards, assuming a dissuasive CO_2 taxation. Although a significant amount of hydrogen would be mixed with natural gas and transported in natural gas pipelines to serve various applications of the mixture (Ch. 2.4 above), the extraction of high quality hydrogen (99.99%) from the mixture at the point of use would be a convincing option at the end of this phase (up to 10% of hydrogen production). This option would take advantage of improvements on the central separator, but its economic interest would disappear afterwards.

SMR would be suitable in areas with large population density (‘Ile-de-France’, ‘Nord-Pas-de-Calais’, South-East), when hydrogen demand is high and CO_2 geological storage feasible at large industrial scale. In areas with a lower population density, hydrogen would be produced preferably by water electrolysis or biomass gasification, whereas SMR would be used depending on the economic competitiveness of the process, including CO_2 transport and storage costs.

However, hydrogen produced from off-peak nuclear generated electricity could play a significant role in the transition phase to a hydrogen-based energy economy.

The transport of hydrogen by dedicated pipeline would be progressively the most attractive option for significant quantities of hydrogen delivered, whereas the transport by truck would be preferred for small quantities. The hydrogen would be delivered to the refuelling stations, for hydrogen vehicles, and to the distribution centres (via local hydrogen mini-grids), for the individual households, buildings and industry. The refuelling stations would be distributed near urban centres and along mains roads and the distribution centres near urban centres and industrial areas.

2.6 Long-term vision (2030-2050)

In the long-term or vision phase, the range of options for hydrogen production will reflect a sustainable vision of hydrogen economy. The centralized SMR with CCS and delivery of hydrogen through dedicated pipelines would be used depending on the competitiveness of the process, penalized by the increasing costs of natural gas. The production of hydrogen using renewable energy could increase to 30 TWh by wind power electrolysis and 35 TWh by biomass gasification in 2050, but these contributions depend on the scenarios adopted for the final use of energy resources.

The wind electricity would be preferably issued from off-shore wind farms, the wind turbines being integrated with the electricity grid to provide power to the electrolyser in the absence of wind. The economic competitiveness of the process could depend on the feasibility to provide 100% of the electricity from European renewable resources, i.e. either from the wind farm (e.g. 50%) or via the grid (at a bottom price below the market price but including a transport cost).
The production of hydrogen by conventional water electrolysis using dedicated wind electricity or the electricity mix would be promoted for environmental reasons. It would be decentralized or centralized depending on the availability of local off-shore wind resources, regional population density and growth of the demand. However, in case of high demand in densely populated regions, the emergence of innovative nuclear reactors would allow the massive production of CO_2 free hydrogen by high temperature (HT) electrolysis. This process would use the energy (electricity, heat) provided by the nuclear reactor (e.g. EPR), taking advantage of a lower electricity consumption.

The consumption of electricity and heat by the HT electrolyser could justify the construction of dedicated nuclear reactors delivering electricity at the production cost (including recycling of wastes, decommissioning…), below the market price. Conversely, conventional electrolysers would consume the French electricity mix, but at the market price. The contribution of this innovative HT process would be significant in the production mix (10% in 2030, 20% in 2050), thus reflecting the political will to promote hydrogen issued from water electrolysis in the most efficient way.

The economic relevance of such a scenario would depend on various factors, including the economic interest of power utilities not to sell all their electricity on the market at a higher price and the capability of large industrial consumers to negotiate long term contracts with reasonable prices for electricity. Finally, the option of a massive hydrogen underground storage could be studied to control large amounts of hydrogen produced, including wind energy.

Table 2.1 below conveys the global vision of the Group HyFrance of the development of hydrogen energy chains with low CO_2 emissions in France.

	2007	2020	2030	2050
Production	Centralised: SMR Decentralised: SMR, LT Electrolysis (including coupling with RES)	Biomass gasification SMR with CCS LT Electrolysis	HT Electrolysis (nuclear) SMR with CCS RES	
Transport/ distribution	Hydrogen trucks Existing pipelines: hydrogen, mix NG-GH2	Mix NG-GH2, hydrogen pipelines Hydrogen FS	Hydrogen pipelines Hydrogen FS	
Storage	GH2 tanks ★ Solid storage (hydrides) : **Decision-making milestone by 2015**	Solid storage (hydrides)	Advanced storage	
Conversion/ applications	Early markets: by-product, back-up power, portable generators, specialist vehicles, portable micro-FCs…	Transport: buses, specialist vehicles… Stationary: industry, residential…	All applications	

Table 2.1: *Development of hydrogen energy chains with low CO_2 emissions in France*

2.7 Policy framework

The French law of 13 July 2005 has set up the orientation of national energy policy, including a CO_2 emission reduction target of at least 75% by 2050 as well as ambitious targets for energy savings and development of renewable energy by 2010-2030. This strategy will have to fit the new aggressive integrated climate and energy policy for Europe[1] which was affirmed at the last European Council on 8-9 March 2007. In this context, the hydrogen produced with CO_2 free or -reduced emissions could play a major role.

Two State Agencies have been recently created to foster the national scientific research (Agency for National Research: ANR) and to support large-scale, cutting-edge projects driving industrial innovation (Agency for Industrial Innovation: AII). There is a great opportunity for hydrogen technologies to take advantage of these two national instruments. For the present, only the ANR gives funds for innovative projects in the field of hydrogen and fuel cells (20-30 M€/year), through the PAN-H programme (National Action Plan for Hydrogen and fuel cells). The present national vision is consistent with the national R&D strategy, as in 2007 the R&D in PAN-H is focused on hydrogen production (high temperature water electrolysis, low temperature water electrolysis in combination with renewable energy sources), hydrogen storage and fuel cells systems.

The following steps will highly depend on the national R&D and innovation strategy for energy, which will emerge after the change of government next May.

[1] E.g. by 2020, increase of 20% of energy efficiency, contribution of renewable energy to 20% of total energy consumption, reduction of CO_2 emissions of 30% (firm commitment to at least 20%) comparing to 1990 level.

3. Germany

3.1 Introduction

The German HyWays stakeholders have developed a national vision for the deployment of hydrogen as an energy carrier for the next decades. This national vision takes into account: a wide variety of relevant H_2 sources from fossil to renewable feed stocks, as well as the different scales of supply from onsite to centralised production. In this vision CO_2 reduced or CO_2 free sources should play an important role especially in the long-term view. Thus, especially hydrogen production processes using renewable energy sources become very important. Hydrogen needs a rapid market penetration to develop a business case and to contribute to sustainable development. Disruptions and crashes of actual developments and structures are possible but not easy to foresee. They represent risks but they could also help to accelerate new technical developments.

Key drivers for the introduction of hydrogen as an energy carrier are climate protection, energy supply security and international competitiveness. Because of the lack of alternatives in adequate fuel amounts and a predictable competition for biomass use (as other alternative fuels) the transportation sector is under particular pressure to apply hydrogen. Further more the economic importance of the automobile industry in Germany justifies the foreseen focus on the road transport sector.

3.2 Development of the German energy system in general

Because of growing energy efficiency energy consumption in Germany will slowly decrease in the next decades in all sectors (private households, trade & services, industry, transportation). At present the demand of primary energy accounts for approximately 4,000 TWh. It could be 25% less by 2030 and 40 to 50% less by 2050. The most important energy carriers are currently mineral oil (36%, mainly imported), natural gas (23%, five of six parts are imported), coal (13%, two thirds are imported), lignite (11%, own resources) and uranium (13%, only imported). In total 75% of the German primary energy consumption has to be imported. Specifically the trade and services sector will contribute to the reduction in the medium and long-term energy consumption. Also the share of private households and industry can be substantial, while transport will contribute less. Newly EU wide agreed ambition is to reach a share of 20% renewable energies by 2020 (less than 5% at present in Germany).

At present the demand of electricity in Germany is about 540 TWh. It will probably decrease about 10% until 2030 and even further until 2050. In the future the production of electricity will be increasingly based on renewables and natural gas, whilst the importance of coal can remain relatively high, because of new coal and lignite fired power plants. All nuclear power production will phase out until 2025 because of the German phase out decision. Following the newly agreed ambition of 20% renewables by 2020, the electricity sector would have to bear a share of around 30% in Germany (about 12% at present).

3.3 Short-term period (< 2020)

The most promising application area for hydrogen is seen in the transport sector with a focus on cars and regional vehicle fleets using hydrogen in fuel cells - and in the transition phase or for specific vehicle types also in internal combustion engines. Due to the competition with energy savings measures and the increased use of renewable energies stationary hydrogen applications are only envisioned for demonstration projects in this time horizon.

In the first early market years for hydrogen, which are seen after 2010, industrial by-product hydrogen can significantly contribute to a wider use of hydrogen energy. Additionally hydrogen will be produced by distributed SMR plants. Renewable forms of energy such as biomass are integrated early with small shares. Demand centres in densely populated areas will arise and for the transport of hydrogen liquid or compressed hydrogen trucks will play a relevant role. Transport via train or ship could be an alternative.

The concept of early user centres will envision hydrogen applications in population centres where main players are situated and demonstration projects are already in operation (e.g. Berlin, Hamburg, Rhein/Main-Area, Rhein/Ruhr-Area, Stuttgart and Munich). Potential user centres are so close to each other that they could easily be connected to each other and allow commuting (including links to neighbouring countries).

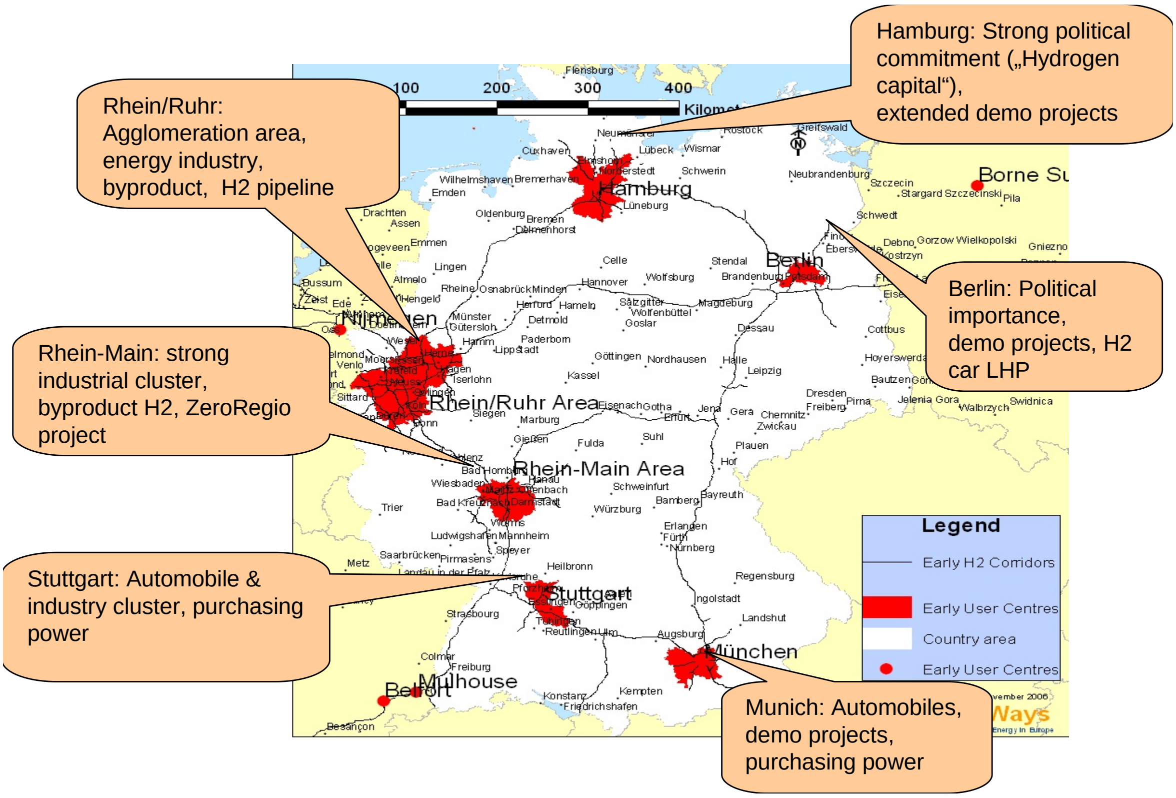


Figure 3.1: *Proposed early user centres and corridors in the transition phase in Germany*

3.4 Medium-term vision (2020 - 2030)

After 2020 the increasing hydrogen demand is expected to broaden the range of options for central and distributed hydrogen production. Annual hydrogen consumption for transport can amount to between 9 TWh (or 270 ktons - low scenario) and 61 TWh (or 1,830 ktons of hydrogen - high scenario) by 2030 (1.5 to 10% of the consumption of the whole transport sector or between 3 and 24% of all passenger and light duty vehicles). The total hydrogen consumption (incl. stationary applications) can grow to between 11 TWh (or 330 ktons - low scenario) and 70 TWh (or 2,100 ktons of hydrogen - high scenario) by 2030 (0.4 to 2.3% of the energy demand across all sectors). These assumptions compare to a total German hydrogen production in the order of 1,600 ktons per year and a merchant hydrogen volume of 175 ktons per year today.

Renewable hydrogen will receive growing support (share of approx. 30%) e.g. distributed biomass gasification and onsite electrolysis (wind electricity). Depending on the hydrogen penetration rate and the technical, economical and social feasibility of CCS, natural gas and coal can contribute to secure higher amounts of GHG emission lean hydrogen. However, due to the increasing resource limitation of natural gas central SMR may serve as a bridging technology, but not as a long-term solution. Integrated gasification combined cycle power plants (IGCC) could become a technology link between electricity and hydrogen markets.

Pipelines for the distribution of hydrogen will be in a build-up phase such that also truck transport (liquid or compressed) and local on-site production will be introduced, especially for the supply in rural areas with warranted demands. The different transport options are proposed to compete with each other - depending on the market, the geographical situation and the transport distances.

3.5 Long-term vision (2030 - 2050 and beyond)

After 2030 hydrogen already plays a major role in the commercial vehicle market, which will further increase to values from 36% (low scenario) to 75% (high scenario) of cars by 2050, excluding trucks) and could also play a remarkable role for stationary applications especially in cities. Therefore the quantity of hydrogen demand by the transport sector can amount to between 90 TWh (low scenario) and 150 TWh (high scenario) by 2050 (18% to 29% of the consumption of the whole transport sector). The total hydrogen demand (incl. stationary applications) can grow to between 100 TWh (low scenario) and 177 TWh (high scenario) by 2050.
Provided that carbon capture and storage (CCS) is already established at industrial scale and at reasonable costs, central hydrogen production schemes based on fossil fuels could play an important role in Germany either from SMR or coal gasification - depending on the long-term price developments of the energy carriers.

Although the end-use competition for the merits of renewable resources - especially for biomass - between different applications (transport, electricity, heat, raw material for industry) will grow, the share of renewable hydrogen will increase and could reach 30 to 60% of total hydrogen production at this stage. Main renewable hydrogen supply chains are wind (on- and offshore) via grid electricity and central or distributed electrolysis as well as distributed biomass gasification. New renewable resources (geothermal, solar energy) might fit the growing hydrogen demand with the help of new storage systems. The import of hydrogen (e.g. from Norway via a European pipeline network or from Iceland via ship) may become another option which may help to overcome a possible resource limitation of renewable energy in Germany and EU. Distribution and partially also transport of hydrogen will be dominated by pipeline. Liquid hydrogen trucks will play a role in regions with lower demand such as in rural areas.

Table 3.1: *Development of Hydrogen Energy Production and Distribution in Germany*

	2007	2020	2030 2050
Production	SMR on-site industrial by-product	SMR centralized CCS Electrolysis on-site Biomass Coal gasification Wind	SMR centralized CCS Electrolysis on-site Electrolysis centralized RES Biomass gasification Coal gasification CCS
Transport/ distribution	Truck CGH_2 Truck LH_2	Truck CGH_2 Truck LH_2 Pipeline short distance	(Truck CGH_2, short distance) Truck LH_2 Pipeline long distance

3.6 Policy support

A major determinant of a German federal policy support scheme in the short term will be the National Innovation Program on Hydrogen and Fuel Cell Technology. The funds provided by the German government, especially by the Federal Ministry of Transport, Building and Urban Affairs and of the participating industry partners (1 billion € over ten years) are foreseen to strengthen and speed up the activities within (basic and applied) research and development on all innovative hydrogen technologies as well as to support the deployment of hydrogen and fuel cell technologies through demonstration projects. Furthermore, support is expected through the seventh EU-framework programme for research, technological development and demonstration activities. Policy support is also needed afterwards during the rollout periods of hydrogen technologies. Concerning this, reliable long-term legal conditions especially tax abatements should be foreseen. Regarding the regulatory framework in Germany (mixture of national laws, federal state laws and municipal orders) coordination is required.

4. Greece

4.1 Introduction

The national hydrogen vision was formulated by the Greek HyWays stakeholders focusing on the possibilities of exploitation of local sources for hydrogen production. Emphasis is given to the use of renewable energy sources, which is expected to have a significant share in the long-term. Furthermore, there were taken into account the local particularities dealing with geographic and social conditions such as the large number of islands and the highly populated cities, as well as, energy system characteristics related to availability of a natural gas grid in specific regions of Greece and the availability of domestic lignite in two mainland regions.

4.2 Development of the Energy System

Oil has also a significant contribution to the primary energy sources, while the primary Greek domestic energy source is lignite, which is mainly used for electricity production and nearly 60% of the currently exploited reserves are located in the western Macedonia. The natural gas is supplied from Russia via pipeline and LNG from Algeria, serving major cities forming a country's north-south pathway. Greece is characterized by the significant potential of Renewable Energy Sources in the fields of solar, wind and biomass, while geothermal potentials are also present.

The Primary Energy Consumption was 31.3 Mtoe in 2005 and was based on liquid fuels (55.7%), solid fuels (29.6%), natural gas (9.7%), RES (4.5%) and electricity (0.5%). In 2010 a small decline of liquid fuels (54.3%), solid fuels (26.8%), RES (4.3%) and electricity (0.0%) is expected while natural gas (14.6%) will increase formulating a PEC of 34.9 Mtoe. Finally at 2020, a similar tendency is foreseen and the PEC of 41.4 Mtoe, will be formed by Liquid Fuels (53.0%), solid fuels (23.0%), RES (4.2%), natural gas (19.6%) and electricity (0.2%).

The final energy demand for 2010 will reach 24.8 Mtoe, with a share per sector of 29.9% industrial, 20.0% domestic, 14.0% tertiary & agriculture and 36.0% transport. In 2020, it is expected to reach 29.7 Mtoe having a increase by sector of +10% in domestic, +13% in industrial, +26% in transport and +32% in tertiary & agriculture. The annual electricity consumption per capita in 2004 was 4.8 kWh while in 2003 it was 4.6 kWh. The tendency of the annual increase from 2001 is in the magnitude of 4% and for the decade 2000-2010 the increase of the electricity demand is expected to be in the range of 3%. The electricity demand will have a continuous increase for the next decade 2010-2020 with a ratio of approximately 2.5%.

4.3 The role of hydrogen in the energy system

Concerning the hydrogen market development, the hydrogen demand of both stationary (CHP) and transport applications will be served by the most of energy chains selected and deals with:

- RES electricity (central and de-central Electrolysis)
- Natural gas with central SMR to extended and local grids
- Lignite gasification to extended and local grids
- Biomass used in centralised and decentralised schemes
- Mixtures of natural gas with H_2 via NG pipelines
- Concentrated solar direct water splitting

Aim of the selection of the above mentioned energy chains were the establishment of an environmentally friendly and economical scheme for hydrogen. A key issue for the selection was also the advanced utilization of local resources focusing mainly on RES, as far as not many other indigenous sources are available. Natural gas will be an economical option for the medium-term and low cost lignite will also play a role which will be increased though the years. The environmental gains from CO_2 free hydrogen utilization is recognized as a critical issue and CCS options are taken into account with respect to their availability. Biomass use will provide an alternative option to the relevant economic sector while solar could be an attractive opportunity for Greece.

4.4 Short-term vision

In the entry phase wind energy and electrolysis should be considered as the first applications for the production of hydrogen in local based supply schemes. Athens and Thessalonica, being the most populated areas of the country, are the centers of the early phase development of the hydrogen infrastructure. Transport applications can be the main driver for the penetration of hydrogen, where stationary applications can be implemented to a lesser extend. Furthermore remote island areas (not connected to the national electricity grid) are foreseen as promising option for first demo cases. In addition, the region of Western Macedonia will be included in hydrogen utilization schemes, due to the availability of lignite.

4.5 Medium-term vision

Hydrogen will be used for transport application followed by stationary applications for households and tertiary sector applications. The share of hydrogen in the transport sector was set to 24% in the high penetration scenario, while hydrogen driven micro CHP in households was 6% and hydrogen driven micro CHP in offices 1.9%. The rates for the low penetration scenario were 8%, 0.5% and 0.2% respectively.

The Greek vision promotes the use of Renewable Energy Sources focusing mainly on wind-electrolysis concepts, expecting to achieve a significant position within the hydrogen production with increasing share in the medium to long-term period. In addition, biomass utilisation is proposed to have a relevant increasing share of the total hydrogen production based on RES at the end of the time period. The hydrogen supply infrastructure through the development of pipeline grids will be established taking into account the high population of urban regions. Supportive actions of linking RES electricity production to hydrogen production by electrolysis are foreseen through the use of the electricity grid.

In the transition phase, natural gas will have a significant role in the evolution of the hydrogen market representing a share of more than one third of the expected hydrogen production demand for both transport and stationary applications. Centralized Steam Methane Reforming schemes are foreseen as the most economically attractive options where Carbon Sequestration and Storage schemes should be considered in terms of their applicability and viability in large-scale options on national level. Lignite gasification for hydrogen production is foreseen to have a limited but continuous contribution to the total hydrogen production, supplying hydrogen to the northern part of Greece.

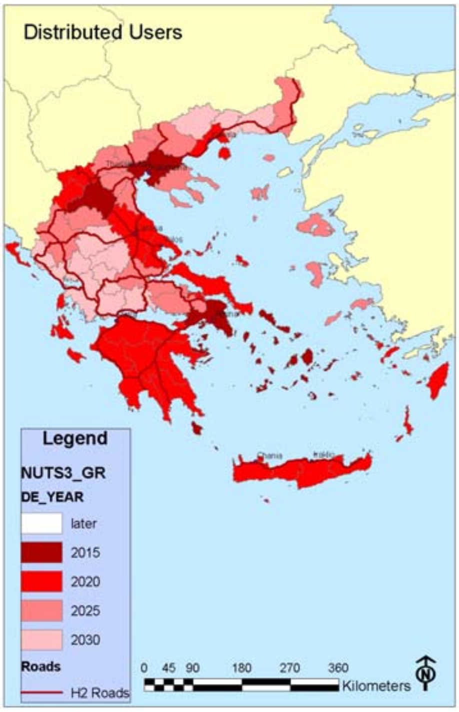


Figure 4.1: *Distributed users in Greece*

4.6 Long-term vision

The vision for 2050 is the promotion of the sustainable and CO_2 free production of the hydrogen, supporting the renewable energy sources potentials, the centralised and decentralised hydrogen schemes according to the regional specifications, the non electricity grid connected areas and the achievement of environmental improvement especially in urban areas. Fossil fuels will contribute by less than 30% to the hydrogen production mix jointly with CCS infrastructure. The share of hydrogen to the transport sector and specifically to hydrogen vehicles was set to 90% in the high penetration scenario, while hydrogen driven micro CHP in households was 15% and hydrogen driven micro CHP in offices 4.9%. The rates for the low penetration scenario were 48%, 5% and 1.7% respectively. The infrastructure to be developed, will supply the whole Greek territory including the islands with hydrogen.

4.7 Policy framework

Central government will have a strong impact through tariffs and funding mechanisms on the penetration of hydrogen, while research and academia will have a significant impact on the technology development and infrastructure requirements. As short-term action, the development of an RTD supporting mechanism is proposed covering the hydrogen technology penetration focusing both to basic research and lighthouse projects development such as hydrogen projects in islands and introduction of hydrogen in public transportation focusing on high populated urban areas. Furthermore, actions dealing with the support to Greek SMEs on hydrogen technologies are proposed as well as the introduction of hydrogen to energy planning and zoning planning and establishment of hydrogen build-up requirements (safety framework, training, etc). Funding opportunities can be based on feed-in tariffs or/and intensives dealing with projects investment cost subsidies.

5. Italy

5.1 Introduction

Italy is a country where the main economy drivers are based on industry (presence both of car manufacturers and oil companies) and tourism (as result of its cultural inheritance and landscape attractiveness). Presently the Italian energy system relies on fuel import (about 85% in 2005). Such external dependency is characterised by high criticality, being mainly based on oil and natural gas (NG). The final energy consumption is almost equally divided by industry, transport and residential and commercial sectors. The NG is the reference fossil fuel for electricity production, while the renewable share accounts for 17%. The blackouts of the last years have created more attention to the energy system, whose future development should meet the following criteria:

1. Achievement of a better energy mix and higher security of the primary energy supply.
2. Increase of the renewable sources share.
3. Promotion of industrial development in high technology innovative sectors, creating conditions for an adequate social and economic growth.
4. Reduction of the greenhouse gas (CO_2) emissions to meet Kyoto and future post-Kyoto commitments.
5. Containment and abatement of atmospheric pollutant emissions in urban and/or in heavily populated areas, where the environmental limits are frequently violated.

The above criteria impose also strong attention to save energy, through the adoption of efficient technologies. In any case, the use of fossil fuels will continue to have large importance even in the far future. This implies that, especially for NG, long-term contracts and security of supply needs to be assured. To reduce the risk of lack of energy, the clean coal will also become an important option, especially for electric energy production. The coal choice will be associated to the Carbon Capture and Sequestration (CCS) process, to meet the above fourth criterion. The use of nuclear energy could also play a role, provided that new concept plants will be designed, with higher safety features and an effective and safe solution for the radioactive waste disposal issue.

5.2 Italian vision on the hydrogen system

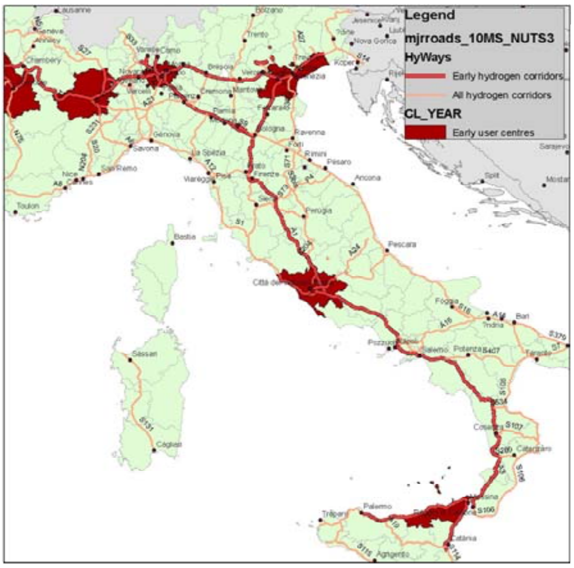
In the Italian energy framework hydrogen will play an important role, being an energy carrier able to meet all the previous criteria. Under the national vision the hydrogen deployment will foster the diversification of fossil feedstocks and the use of renewable sources (biomass, wind and solar in the long term). To this end, H_2 can act as a technical means to manage the energy demand, favouring the market penetration of the renewable sources, as it is able to reduce their negative effects due to their random behaviour. In fact, H_2 can store the excess of energy supply, avoiding troubles to the electric grid, and be converted into electricity whenever the electricity demand increases. Therefore the hydrogen deployment should not only interest the transport sector but also the electric energy generation, for which the hydrogen share can play a very significant role. To this end, the fossil fuel based centralised hydrogen production plants should be able to provide at the same time syngas for use in the electricity generation and pure H_2 for transport and residential applications. This could allow higher plant flexibility (in the first phase of market deployment the hydrogen production plants should be operated at reduced load, due to the low number of H_2 vehicles) and availability, as the hydrogen could be produced whenever the electricity demand is low.

In addition, such higher plant flexibility increase the likelihood for a direct use of the electric energy from renewable plants (mainly wind), even under the low demand conditions, and this can provide higher overall efficiency for the energy system, as the electrolysis process is not very efficient. A special feature of the Italian vision is also the use of urban wastes for hydrogen production and this can help to find and efficient solution for their disposal, which is becoming a very critical issue at national level. It is also clear, in the Italian vision, that hydrogen needs a strong political commitment to foster its deployment, especially at the very beginning. This means that without specific measures and incentives the hydrogen economy will not be able to take off. To this end, HyWays can help and support politicians, giving them valuable indications on the most effective provisions to undertake. Specific focus is also to be given on the opportunity to involve small and medium enterprises (SMEs) in the hydrogen transition, especially looking at the relevant role of the Italian regions in the new economy. In particular SME, due to their flexibility, are able to offer new services and assistance to the local authorities.

5.3 Short-term vision (up to 2020)

In the first period, with hydrogen consumption less than 100 kton/year, the most important production share is associated to steam methane reforming (SMR) in decentralised plants and the hydrogen is transported by trucks, both in liquid and compressed form, and, where possible, mixing the hydrogen in the NG pipelines. In this period the hydrogen will be mainly used in transport applications and produced as close as possible to the sites where it is used. Being the main target the creation of the hydrogen market, quite a large freedom to deviate from the above general energy criteria is allowed and the demonstration of the hydrogen technology performances will prevail in respect to energy efficiency and economic considerations.

The criteria to choose the sites where the first applications of hydrogen can start are manifold and include the following favourable elements:
- ✓ Availability of hydrogen, possible at reduced costs, for instance as by-product.
- ✓ Presence of regional development of plans.
- ✓ Solid industrial presence.



Main criteria

- ✓ Turin: Demo projects, car industry, pollution, airport
- ✓ Milan: Demo projects, pollution, experts, airport
- ✓ Venice: Demo projects, by-product, niche (ships)
- ✓ Rome: Demo projects, pollution, experts, north-south corridor, airport
- ✓ Messina: renewables, experts, by-product

Figure 5.1: *Italian early hydrogen corridors*

On these bases the sites of Turin, Milan, Venice-Padua and Messina area in Sicily have been identified as the most promising. Rome was added to these sites, representing the natural connection between North and South. In particular this choice allows having good territorial filling station coverage, and then the creation of other sites, where the experiences could be replicated afterwards, up to cover the whole country (see Figure 5.1).

An interesting feature, which could help the hydrogen deployment, is related to the availability of a considerable fleet of methane vehicles in the Italian territory. Such vehicles could be easily converted to use CH_4-H_2 mixtures, which could be easily transported through the existing pipelines; this will certainly reduce the investments and contribute to make easier the hydrogen acceptance from the final users.

5.4 Medium-term vision (2020-2030)

In the medium term (up to 2030) the hydrogen production by fossils will be based both on NG and coal, but in centralized plants, with the assumption that the CCS process at that time will be available. In absence of viable CCS technical solutions, the use of fossil sources for H_2 production could become hard, due to the high potential emissions of CO_2 and the lower overall efficiency of the energy chain. This event could significantly modify the vision, imposing a larger share of hydrogen production from renewables on one side and the use of different energy options on the other. Under the assumption that CCS is viable, the centralised plants (size around 500-600 MW) will allow flexible production of electricity and hydrogen and will be located close to the sites where CO_2 can be stored. The hydrogen production from fossils will cover about two thirds of the total; the renewable production is mainly from biomass and urban wastes (often located close nearby main cities), while there is the starting of significant size solar demonstration plants.

The renewable plants have a size of about one tenth of the fossil fuelled ones and are spread on the territory. The hydrogen is mainly delivered through short, medium-range new dedicated pipelines (10-50 km) from the centralized production plants. In fact, the increased hydrogen use makes it quite impossible to rely on the NG pipeline network, as for its safe use the mixing can be allowed only for a small percentage of hydrogen. The hydrogen contribution for the power generation can be of several MW_e, most of which through turbo gas, but with a significant share of FC.

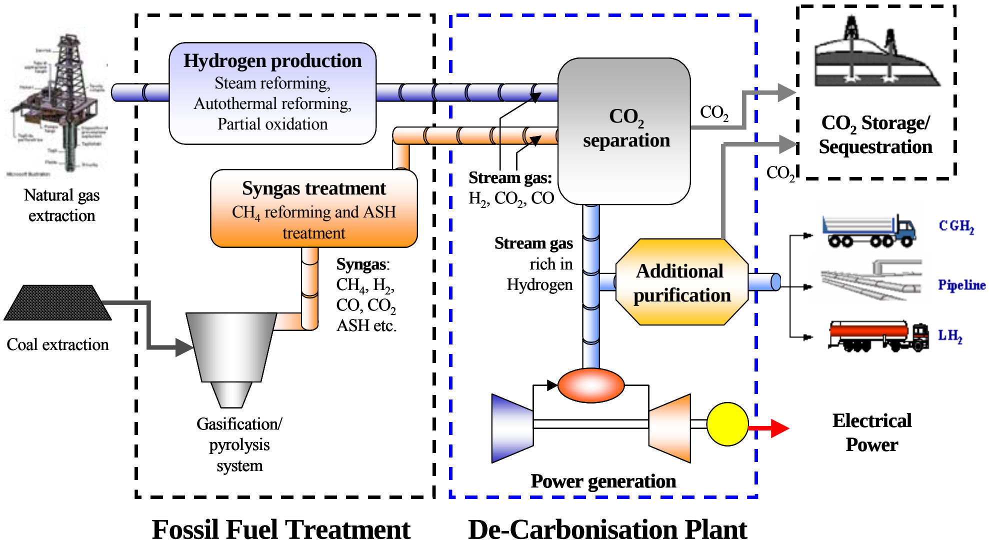


Figure 5.2: *Hydrogen production in centralised plants*

In the transport sector up to one million of vehicles are based on hydrogen and particularly used in cities and places (for instance Po Valley), where the local pollution is a big issue. Most parts of the public transport, captive car fleets and delivery vehicles to be used in urban areas are hydrogen based. At 2030 the deployment of filling stations allows driving without excessive problems in the entire Italian territory. The residential and commercial sectors begin to be involved in the hydrogen transition.

5.5 Long-term vision (up to 2050 and beyond)

In the long-term the hydrogen is made by different sources both fossil and renewable, with the solar having a considerable share. The production from fossils will be almost balanced between NG and coal plants, both with CCS. If the sites to store CO_2 were almost saturated, other primary sources could be considered. Among them the nuclear option could regain some importance, provided that the safety of new concept reactors will be proved and the option economically affordable. The overall hydrogen production can be evaluated as several millions of tons. The renewable share will not go much more above one third of the total, although in quantitative terms the hydrogen production will be much higher. The renewable production will have its main contribution from solar, with the other renewable options not very far. Viable storage systems will be available to accommodate the large time variations of renewable sources and fit the hydrogen demand. There is a considerable improvement of the infrastructures, with the pipelines that are built to transport hydrogen up to some hundreds of kilometres from the production site. The stationary applications will increase, especially considering the residential and commercial sector. In the transport sector, hydrogen will play the main role and the most part of vehicles will be FC based.

5.6 Policy support

In the short-term the main instrument is the Italian platform of which a first draft has been produced, but feedbacks from the Research Ministry are expected to finalise the document. A quite active role is provided by the Italian Regions to foster hydrogen R&D initiatives. Of course a close coordination is required between the national and local Authorities to maximise the positive outcomes.

Subsidies, incentives and public procurement are instead the required conditions to have the start-up of niche level applications. All the provisions are to be kept for a time interval sufficient to reach full competitivity of the hydrogen technologies. The adoption of a suitable legislation, able to foster the use of environmentally more acceptable technologies and/or to penalise the others not meeting such requirements, can be also important to push the hydrogen market.

6. The Netherlands

6.1 Development of the energy system (excluding hydrogen)

In general the present energy flows in the Netherlands show the significance of the Dutch oil refinery industry (mainly for export purposes), the importance of natural gas for household and industrial use, and the importance of transit trade in the Netherlands (oil, gas).

In 2004, the total primary energy supply (TPES) in the Netherlands was 82.3 Mtoe. The share of renewables was 2.9%. Natural gas accounted for 44.6%, oil for 38.4%, coal for 11.2%, combustible renewables and waste for 2.6%, nuclear 1.2% and non-combustible renewables for 0.2%. Domestic energy production was 67.9 Mtoe in 2004, accounting for 82.5% of the TPES. The most important domestic source is natural gas, accounting for 90.7% of domestic energy production.[2] In present forecasts for 2010 the total primary energy supply is expected to be 86 Mtoe. The share of renewables in TPES will be 3.7% in 2010 (3.2 Mtoe). For 2020 the expectation is that the TPES will be 97.5 Mtoe, with a share of 6.7% for renewables without new policy measures. [3]

The formal Dutch policy objective for the development of sustainable energy is that 5% of total energy will be delivered by sustainable sources in 2010 (uitvoeringsnota Klimaat) and 10% in 2020 (Energy Report 1999). There are various scenarios for the post-2010 period. Vision and policy directions for the long term are being developed in public-private collaborations for 'Energy Transition'. These visions have been incorporated in the HyWays MS workshop discussions.

6.2 Development of the energy system until 2050 and beyond

The present situation is characterised by a strong dependence on fossil fuels; this will gradually develop into a clean fossil system (here referred to as 'sustainable') based on CO_2 capture and sequestration (CCS), possibly in combination with nuclear energy (not renewable, but 'sustainable' from CO_2 and Air Quality perspective). Around 2050 the energy system is expected to be 'sustainable' according to these definitions.

Next to this 'sustainable' development, the share of 'renewable' energy sources will grow continuously, and will become more important than fossil sources (and nuclear) after 2050. This will be due to the expected strong rise in fossil fuel cost on the global market in combination with the rising cost of CO_2.

The nature of the fossil sources will change as well. Domestic produced natural gas will gradually be replaced by import by pipeline from Russia and Norway, and the import of LNG by ship from sources further away. In combination with the expected rise in oil prices this will lead to gas becoming more expensive. Coal, most likely imported by inland and sea shipping, will become more important. Due to logistic reasons power plants will be situated along waterways.

As coal is a more polluting feedstock than gas, a scenario in which coal becomes the dominant energy source without CCS would impede seriously on the success of CO_2 reduction policies.

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2 Eurostat (2006), yearly statistics data 2004

3 WLO GE scenario (2006)

The use of coal will have to be combined with CCS or with the re-use of CO_2 in chemical plants and horticulture glass houses. There are excellent opportunities for CCS in the Netherlands through the nearby presence of large depleted oil and gas fields. On the other hand there are still barriers for actual implementation of CCS, and more research is necessary to solve these. Also there are alternative uses for the depleted gas fields, particularly storage of imported natural gas.

For the same reasons as above it will become increasingly economically attractive to use renewable feedstocks. It is expected that biomass and wind will be the most important ones. There are excellent opportunities for biogas in the Netherlands, due to the existing dense natural gas pipeline grid, and the presence of large amounts of natural waste (sewage, animal manure etc).

More important in transport than biogas will be ethanol. Ethanol will initially be imported from South America (Brazil), but there are risks involved like competition with local food production and ecological concerns. An alternative is domestic (especially sugar beet cultivation) and European production. Besides ethanol there is an (smaller) interest in biodiesel, and much is expected from the development of the future generations of biofuels (such as lignocelluloses ethanol and Fischer-Tropsch diesel).

Formal policies have clear and ambitious targets for wind energy. A number of large fields are planned (some already under construction) in the North Sea. However, other renewable sources may turn out to become more important. Solar energy is often mentioned as having this potential, based on the expected huge drops in the cost of solar cells, and the expected progress in using concentrated solar power.

The nuclear share in the Dutch electricity mix is considerable due to the (partly) liberalised EU energy market (imports from France), but the Dutch formal policy aims at closing down the last nuclear plant in the Netherlands. The share may grow when fossil fuel prices rise further and the French nuclear electricity will become relatively cheaper. The political debate on the use of nuclear power is back under the influence of global warming, air quality and security of supply considerations, but this will not lead to new nuclear plants in the short term.

6.3 Short-term period: by 2010

In the start-up period the urban implementation of hydrogen will contribute strongest to environmental policy objectives. A number of pilot projects will be ongoing both in transport, creating a basic hydrogen infrastructure of fuelling stations that mainly serve regional fleets of buses, vans and urban lorries. They receive hydrogen from existing pipelines: fossil hydrogen with partial carbon capture recycled for greenhouses in the Westland region. Also small-scale on-site SMR will be reasonably affordable. Other fuelling stations will be supplied with liquefied hydrogen from existing liquefaction units.

Hydrogen Internal Combustion Engines will probably play a role in the start-up phase. Shortly after 2010 the hydrogen fuel price will become competitive per EUR/km in the case of FCV’s compared to petrol vehicles. The FCV’s are however still more costly in this period than conventional vehicles. There is very little demand for stationary applications in 2010. A few experiments in Rijnmond use hydrogen from the industrial pipeline (specific project: retirement home Zwijndrecht), and some by-product hydrogen will be used in a few locations (specific project: fuel cell electricity plant).

6.4 Hydrogen in the intermediate period: 2020-2030

This period sees a steep growth of hydrogen demand, mostly as a fuel for road-based passenger transport, i.e. buses, taxis, passenger cars, vans and lorries in urban use. Fuel cell propulsion systems using hydrogen will have become cost-competitive with conventional and hybrid propulsion systems for passenger vehicles running on fossil or biofuels. The growth in hydrogen demand in transport calls for an increasing number of fuelling stations along main roads and in urban centres, starting from the Randstad. The first user centres for hydrogen vehicles will be the Rotterdam area, Amsterdam area and Arnhem/Nijmegen area. Where hydrogen is available for vehicles, combinations will be sought with stationary uses.

The energy mix for hydrogen production will be dominated by natural gas (mostly with CCS), followed by coal (only acceptable with CCS), biomass and a small share of wind energy. In this period distribution of liquefied hydrogen will make way for pipeline distribution and on-site production technology starts being replaced by larger-scale production plants in the user centres. The existing central SMR installations in Rotterdam will be adapted for carbon capture. The plants will feed regional pipeline networks which will evolve from the existing industrial pipeline infrastructures or originate from the new plants. In this build-up period the natural gas grid functions as ‘overflow’ for hydrogen when hydrogen supply exceeds demand. This fits in the policy for ‘greening of gas’ by admixture of biogas and later synthetic natural gas from biomass as well as hydrogen.

In this period the potential for CCS will become clearer. If the promises cannot be fulfilled then policy will push stronger for biomass at the expense of coal, giving impetus to new processes for hydrogen production from biomass like fermentation.

6.5 Long-term contribution of hydrogen: 2050 and beyond

Strong determinants for the introduction path of hydrogen in the Netherlands are the availability of industrial hydrogen in Rijnmond area; the extensive natural gas grid in the country and the important share of natural gas in the energy mix; the strong logistics and transport capabilities (for import of feedstocks like coal and biomass); the promotion of off-shore wind energy; the availability of huge carbon storage locations; and the population and transport densities in the country.

By 2050 (and probably decades sooner) oil production will have peaked, resulting in high prices and insecurity of supply. As described above coal will become a much more important fossil energy source. The geographic spread of the scarce fossil sources will strengthen the need to use renewable sources such as wind and biomass. Important energy carriers will be electricity and hydrogen, which can both be produced from a range of primary sources.

Hydrogen will be the energy carrier of choice for light duty vehicles and buses as no breakthroughs are expected in electric storage technology for pure electric vehicles. Heavy trucks are more likely to run on advanced biofuels. Also inland and short sea vessels can run well on hydrogen, but synthetic fuels will be used as well. For stationary applications the competition with both the natural gas and the electric infrastructure is too stiff for hydrogen. Using electricity directly is more efficient and therefore economically sound than converting electricity to hydrogen and then back to electricity in micro-grids. Exceptions can be edifices in areas without electric grid but near a hydrogen pipeline.

Based on the HyWays hypotheses regarding hydrogen penetration rates, hydrogen will be available by 2050 throughout the country, with the main user centres in the densely populated western part of the country (‘Randstad’: Amsterdam, Rotterdam, The Hague, Utrecht and other towns, comprising some 10 million inhabitants). Smaller centres are the Brabant towns in the mid-south, Arnhem/Nijmegen and Enschede/Hengelo regions in the east, the Limburg towns (Maastricht) in the deep south, and Groningen in the north. These centres are also linked across the borders to the nearby Ruhr area and Flanders.

The hydrogen will be produced from a mix of energy sources, dominated by coal (gasification), followed by natural gas (SMR), biomass (gasification) and a small share of wind energy. Production from fossil sources will be combined with CCS and the re-use of CO_2. Electricity from the wind farms will be put in the grid in most cases but imbalances will be used for hydrogen production through electrolysis. In the longer future also dedicated hydrogen production from wind can be feasible. Natural gas and coal will eventually (by end century) be fully replaced by renewable sources, and the Netherlands may by then be importing hydrogen from e.g. Norway, Iceland or North-Africa.

The widespread use of hydrogen will have justified, and be possible thanks to, the construction of a national pipeline grid for hydrogen. This grid will have grown over the decades by integration of regional pipelines that link up decentralised production plants and fuel stations as well as clusters of stationary users (micro-CHP in newly constructed residential areas and business parks). There will also still be on-site production for small demand or remote users. The technology used to convert hydrogen in 2050 will be fuel cells, which gives zero emissions and has high efficiency. The modular design is a benefit especially for stationary applications as installed power can be increased when energy demand grows. Gas turbines may be preferred for very large installations, possibly combined with high temperature fuel cells.

6.6 Policy support

The policy framework needed should address four main barriers. The first is economics: lack of incentive for hydrogen introduction. There are various solutions to be implemented by government (starting today). At the national level, these are: inclusion of hydrogen in the support frameworks for renewable energy; inclusion of hydrogen in fuel tax framework; reduced vehicle tax for hydrogen vehicles; inclusion of hydrogen in the biofuels obligation; grant/soft loan scheme for fuelling station investments; and eventually a requirement to offer hydrogen at fuelling stations. At the local level, these are: market creation for zero-emission vehicles in urban areas (environmental zones), and granting privileges like free parking. And at EU level, solutions to be implemented are the introduction of generic instruments for pricing CO_2 and other external costs, CO_2 standards, and the inclusion of the transport sector in emission trade system.

The second main barrier is technology: fuel cell and hydrogen technology and carbon capture and storage are not commercially available. Solutions to be implemented by government (until 2025) are funding RD&D programmes for development of fuel cells, hydrogen storage, and Carbon Capture and Storage, both at EU and national levels. In addition government at EU, national and local level should assist in organising demand through public procurement and launching customership.

The third main barrier is infrastructure: the development of pipeline infrastructure and fuelling stations requires large investments and orchestration. Solutions to be implemented by government (until 2025) are public-private investment schemes at EU and national levels, and a national Master Plan for infrastructure development and management.

Finally, the fourth main barrier is institutional, public acceptance, safety and regulations. Solutions to be implemented by government (starting today) are experimentation programmes to provide experience and insight in hydrogen introduction pathways (EU and national), creating learning environments with flexible regulation, licensing etc. (national and local), and education and training (national).

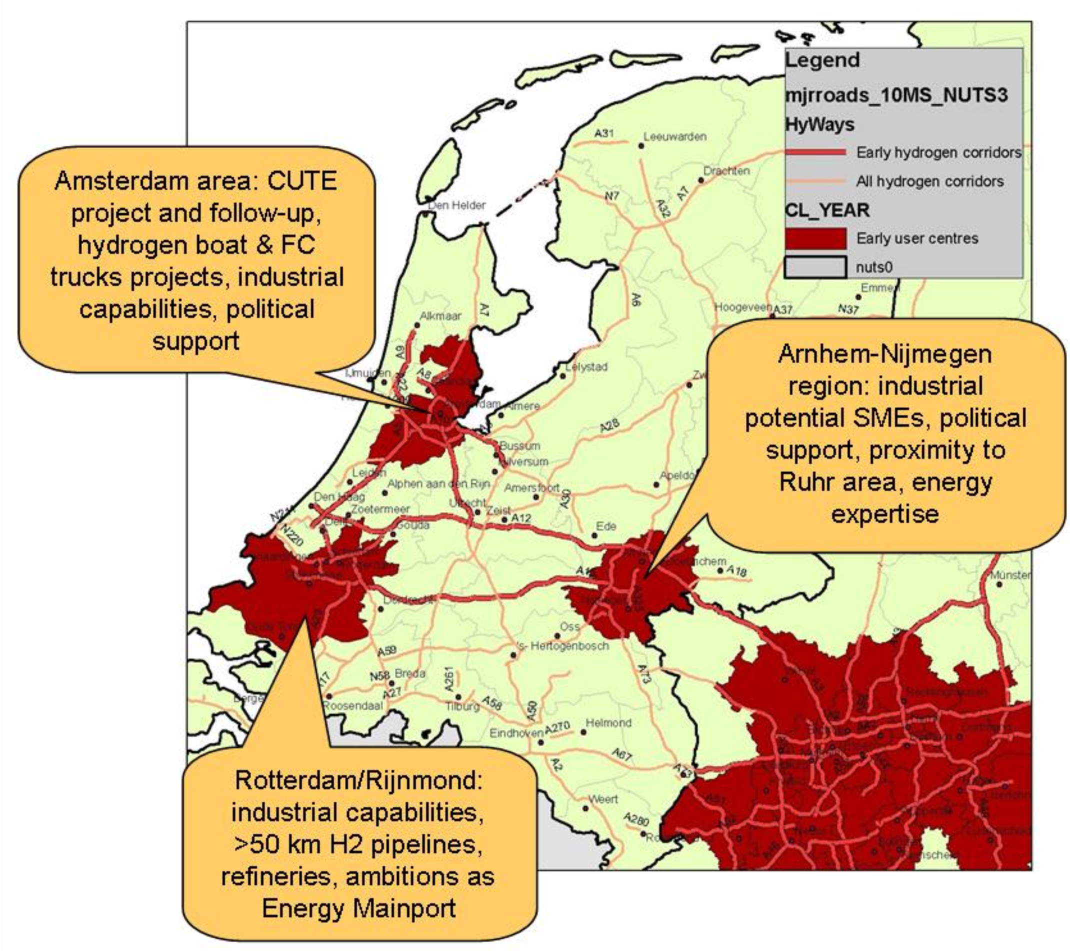

Figure 6.1: *Dutch hydrogen corridors and early user centres*

7. Norway

7.1 Introduction

This document will be used as input to the HyWays European Hydrogen (H_2) Energy Roadmap. It builds upon NOU 2004:11[4] (a Governmental document), input from Norwegian stakeholders, and complimentary work in the national roadmap project NorWays. NOU 2004:11 is a national strategy document where the potential role for H_2 as an energy carrier is outlined, and the importance of national competence and resources such as hydro power and natural gas (NG) is pointed out.

NOU 2004:11 states the there is a threefold rational for focusing on hydrogen in Norway: The potential of environmentally friendly H_2 production from Norwegian NG, given that the CO_2 is captured and stored (CCS), the environmental benefits of increased utilisation of hydrogen and the potential to foster value creation through industrial and commercial development within the area of hydrogen.

The main focus on hydrogen energy in Norway is on hydrogen production and storage. Industrial companies such as Statoil, Hydro and Statkraft are active together with a number of research institutes and other organisations. Lately, the NorWays project was initiated aiming at providing decision support for introduction of hydrogen in the Norwegian energy system. The NorWays project builds upon experience from and is carried out in cooperation with the HyWays project.

7.2 General vision of an energy system

The national hydro power resources have made Norway the world's 6th largest producer of hydro power, which today is utilised in the Nordic electricity network (Nordpool). Currently, the oil and gas industry is about three times larger than any other industry sector in Norway (based on financial contribution). Norway is rated as number seven worldwide regarding oil production, and is the third largest oil exporter. Norway exports large amounts of NG to the EU, and is the forth largest NG exporting country worldwide. Domestic use of NG is low but is expected to increase. Establishment of distribution networks for NG has only recently been incepted by build-up of local grids, mainly for heating purposes. However, such developments will probably be limited to densely populated areas in close proximity to the NG terminals.

It is expected that the development of the national energy system will continue to have a high reliance on electricity from mainly renewable sources. A large number of hydro power sites have been built during the last century. Parallel to this, a nationwide power transmission and distribution system was developed, resulting in a high dependence on electricity as a primary energy carrier. This is used in specific processes in power intensive industry and, to an unusually large extent, heating buildings. In the latter, the electricity use is supplemented by a large share of biomass utilisation, mainly in the form of firewood in wood-burning stoves. This is supplemented with small, but rapidly growing district heating and small heating networks relying on wood chips, and stoves and boilers using wood pellets.

Today the Norwegian electricity mix is more than 95% renewably based, the main source being hydro power. New large hydro power developments are politically difficult, and instead, a de-

[4] NOU 2004:11. "H_2 as the Energy Carrier of the Future". Report from the National Norwegian H_2 Commission.

velopment is foreseen where the increased energy demands will be met by a transition to bio energy and other renewable sources of heating. In addition, one should expect new renewable electricity generation from small hydro power stations, modernised existing hydro power stations, wind (on- and offshore), solar and bio energy. A development of domestic electricity production based on NG with CCS has also started.

The development of the energy system is expected to be compatible with preservation of the natural ecosystems (fjords, mountains, forests, waterfalls, glaciers and the long coastline). This unspoiled nature is the foundation for an extensive tourism industry, which combined with high environmental consciousness, challenges further exploitation of both fossil and renewable energy resources. Utilisation of fossil energy resources is closely linked to transport. The Norwegian maritime sector (with 12,000 coastal vessels and a large international fleet) is important in the national economy. The energy use in this sector is expected to remain high, but with a gradual change to less polluting energy carriers.

7.3 A long-term vision of the energy system

Electricity continues to be one of the dominating energy carriers, and is produced from hydro, wind (on- and offshore), solar, bio and wave power. Bio energy plays in addition an increasingly important part for meeting the energy demand, both as biomass for heating and biofuel for transport. Fossil oil and particularly NG are still important.

7.4 The role of hydrogen in this energy system:

As was pointed out in NOU2004:11, H_2 is expected to play the main role as fuel in most cars, vans, buses, lorries and boats. In 2050, over 1.8 million cars, that is 65% of the total number of cars, is expected to run on H_2. Stationary H_2 use (for electricity needs of buildings and industry) is foreseen at small scale in remote locations without access to main electricity grids. In addition, in combination with export of H_2, stationary use could be seen, e.g. for offshore installation and in areas with limited electricity grid capacity.

The dominating production of H_2 is expected to be water electrolysis based on electricity from renewable energy sources, and reforming of NG with CCS. Renewable energy resources are important in local H_2 production in favourable regions, such as coastal regions with wind and wave energy as important sources to power water electrolysis, and in regions with biomass (wood waste) utilisation.

The main H_2 production is envisaged for local and regional use, but transport of H_2 by pipeline is gradually becoming an attractive option for transport of larger quantities of H_2, e.g., to densely populated regions and ports requiring larger amounts (e.g. for maritime use). In addition, pipelines are likely to be seen for export to other European countries (based on offshore wind or reforming NG with CCS). The export of this H_2 (produced without CO_2 emissions) is a longer term option for replacing part of the NG export.

The national electricity net is more extensive and has higher capacity than in many other European countries, and could be made available for distribution of electricity to H_2 production, especially in situations where this would be connected to improved capacity utilisation of the grid.

Even with the energy distribution loss, this could be a cost competitive alternative to the energy demanding H_2 transport by truck.

7.5 Short-term vision: by 2010 with policy support

Highlights:
- *Early demonstration projects*
- *Good competences in H_2 storage, fuel cells, energy systems and infrastructure*
- *Major governmental policy support*

As the national action plan[5] for development and utilisation of H_2 for the period 2007 to 2010 states, the energy system can only absorb small quantities of H_2. Commercial markets have yet to be developed; the H_2 energy utilization is limited to a few demonstration projects (incl. HyNor, Utsira and HyTrec). The small amounts of H_2 needed to meet the demand are provided from industrial by-products, on-site electrolysis, small-scale steam methane reforming and biomass utilisation. The foundation for the increased focus is strong national competences in H_2 storage, fuel cells, energy systems and infrastructure.

7.6 Medium-term vision: 2020 - 2030

Highlights:
- *Maritime H_2 use developing*
- *Export of H_2 emerging*
- *H_2 from NG (w/CCS) becoming cost-effective on industrial scale*

H_2 demand is rapidly increasing, mainly as a fuel for cars, taxis, buses, lorries and vans. It is expected that Norway has almost 300,000 H_2-cars in 2030. Maritime use of H_2 is developing and infrastructure build-up is making H_2 available as a real fuel alternative for ferries in specific ports. Industrial by-product H_2 is important to satisfy local demand in some areas. However, if the H_2 taken out is replaced with NG in the industrial facilities, no overall CO_2 reduction is to be expected. H_2 production with CCS from NG reforming facilities has high focus and is envisaged to be cost-effective on an industrial scale. Another option is combined H_2 and electricity production from large NG plants.

Export to e.g. Germany and the Netherlands, of H_2, as well as NG and green electricity for H_2 production in these countries, is emerging. H_2 export could replace part of the NG export, offering H_2 a specific role and economic opportunity (provide carbon free energy) as a value added replacement for NG. Export of H_2 produced from offshore wind is another option.

7.7 Long-term vision: 2030 - 2050 and beyond

Highlights:
- *Well established export of H_2*
- *Biofuel and H_2 major transport energy carriers*
- *Well established maritime H_2 use*

The long-term vision for H_2 use in Norway is that of a sustainable energy system based on H_2, bioenergy and electricity as main energy carriers based on renewable sources. Even though fossil energy sources are expected to diminish, oil and NG (with CCS) still play important roles. Norway exports H_2 and electricity produced from NG (with CCS).

[5] http://www.forskningsradet.no/servlet/Satellite?pagename=hydrogen%2FPage%2FHovedSide&cid=1135106482633

7.8 Policy framework

For the short-term period major financial support is essential to carry out national demonstration projects and research activities. A large share of this will be provided by governmental ministries, primarily the Ministry of Oil and Energy and the Ministry of Transport and Communications with their funds channelled through the Research Council of Norway, Enova, Gassnova, Innovation Norway. The national action plan for 2007-10 suggests stepwise increases in support from today's 76 mill NOK/year to 200 mill NOK/year for the period 2010-2015. EU support through participation in the 7th RTD Framework Programme is also expected.

National regulation, such as exemption from road toll, vehicle tax, fuel tax, parking fees, etc., is necessary for introducing H_2 vehicles. In 2006 the government declared exemption of tax for H_2 vehicles. The vehicle tax constitutes a large share of the total cost (typically 50%). The national and international support is needed both in the short and intermediate term, until H_2 is cost effective.

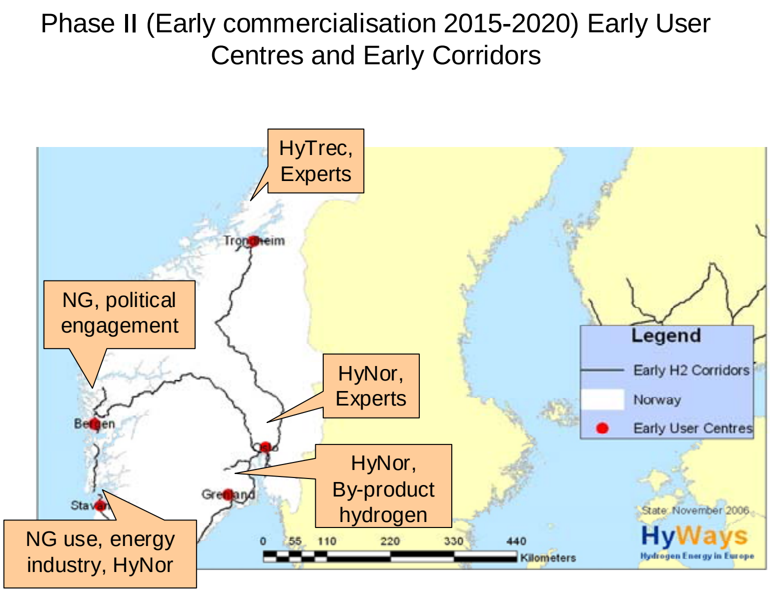

Figure 7.1: *Early user centres and corridors in Norway*

8. Finland

8.1 Development of the Finnish energy system until 2050 and beyond

Energy sector is important for the Finnish society and economy, as energy use per capita is relatively high due to cold climate (space heating), large geographical area (long transport distances) and structure of industry (high share of energy-intensive process industry). Since Finland is largely dependent on imported fuels, the development of self-sufficiency depends mainly on the choice of primary energy source for the new energy generating capacity and transportation fuels. It has been estimated that the demand for new electricity generating capacity would be about 14,000 MW in 2030. Because of the expected growth in transport volumes and mileages (+25% by 2040), total road transport energy demand is expected to grow from the present-day level of 160 PJ to over 200 PJ.

Natural gas is delivered from Western Siberia in Russia, and the existing natural gas grid covers now southern and south-eastern parts of Finland. An extension to the west coast is being planned, and will be carried out probably by 2010, which would increase the coverage and consumption. Furthermore, the share of nuclear energy is expected to remain high or even increase after the new 1,600 MW nuclear reactor will be in operation in 2010.

Because of cold climate the energy demand for space heating is high. District heating is competitive in towns and cities but not in sparsely populated areas, which are common in Finland. Current share of CHP for district heating is about 50%, and not expected to grow significantly, because most of the current district heating potential has already been constructed.

The renewable energy consumption is currently about 20% of the total energy consumption, and some 10% in electricity production. The large share of wood biomass in primary energy consumption is explained by pulp and paper industry, where waste wood (mainly bark and saw dust) and black liquor are used for on-site energy production. However, the potential to increase the utilization of bioenergy in Finland is still great, and the share of almost 30% of primary energy consumption is indicated the target value for biomass use in 2025 in the Finnish energy strategy.

Hydro power has long been a significant source of electricity in Finland, currently around 11-14% of electricity supply depending on the amount of the yearly rainfall. However, there are only limited non-built resources, which are mostly located in the rivers of northern Finland (Lappland), where some potential to increase large-scale hydro power exist. However, because of the fairly flat geography, spatial needs for those reservoirs will be extremely large, and among other things the recent decisions to include territories in Lappland into the European Natura programme rules out the possibility to use these for the benefit of hydropower reservoirs. Therefore, the added capacity would be modernization of old hydro power plants and small-scale hydro power.

Wind turbines now produce 0.1% of electricity in Finland. The onshore wind resource is to date considered limited, as the land and even the shoreline are largely forested. However, as the coastline is quite long, current estimate of potentially feasible on-shore wind energy amounts to about 1.5 TWh/a. The large-scale use of wind energy requires off-shore deployment, which has been considered also. Furthermore, the increase of the height of the wind power mills over the average forest height opens up new possibilities, but this potential is still largely uncharted.

8.2 Finnish vision of hydrogen chains

The Finnish vision of hydrogen chains has been elaborated using a geographical distribution of the national territory in different areas, depending on the population and transport density, wealth (relative GDP) and primary energy supply (PES) potential. The choice and allocation of shares for H_2 pathways is primarily made in reflection to that regional PES potential, so to minimise the necessity to transport feedstocks for hydrogen or the H_2 itself. Also bearing in mind the easiest stepwise building of the hydrogen infrastructure, flexible small-scale production was favoured in sparsely populated areas over centralised production that was mostly considered to regions with high population density and users within short distance.

Five primary feedstocks were considered: natural gas (or coal), electricity-mix (primarily hydro power), nuclear electricity, wind electricity and biomass. The chosen production methods are: Fossil SMR (local or centralised; no CCS), water electrolysis (centralised by nuclear electricity, or decentralised by hydro electricity or wind electricity) and SMR of gasified biomass.

In the early phase, natural gas SMR is considered to be the favoured option. Finland has strong traditions in natural gas reforming process because of the Finnish oil refining industry, and currently, 40% of the production of Finnish oil refineries is exported. At present hydrogen production capacity is about 90,000 Nm^3/h and a new production unit with greater production capacity is being built because the new refinery operations call for more hydrogen. The existing steam reforming unit is equipped with carbon capture process and captured CO_2 is sold to industry. However, as Finland does not have suitable storage sites and the sea is not deep enough for CO_2 storage, we have chosen not to include large-scale CCS in the fossil-fuel based pathways.

This present hydrogen production is also situated in the vicinity of the highest urban population area, the Helsinki metropolitan area. Thus it would be possible to utilise it in the earliest phase, when the launch of the hydrogen-driven vehicles takes place, probably in captive fleets like urban buses or taxicabs. However, when demand for hydrogen rises over time, the primary energy used for production must become more and more carbon free. As CCS was not considered as part of the equation, this means that the share of hydro power, nuclear or wind electricity as well as biomass must rise over the fossil feedstocks.

8.3 Near-term vision (up to 2020)

In the near-term phase, hydrogen use will develop with the early markets, including transport (captive fleets, specialist vehicles), stationary markets (UPS, back-up power…) and portable fuel cells. At this stage the supply of hydrogen would mostly come from the existing, centralized hydrogen infrastructures, such as Neste Oil refinery capacities for hydrogen production and special gas companies (Woikoski, AGA, Messer etc.) for distribution. Hydrogen would be delivered by truck (cryogenic or tube trailer) or by rail. Furthermore, also small quantities will be produced on-site by SMR or water electrolysis.

The Early User Centres (EUC) would be localized in the most favourable areas already fostering some demonstration projects, having local availability of experts and political commitment of regions. If applicable, the regional competitiveness clusters, which focus on the key factors of industrial competitiveness such as R&D-led innovation, would be a suitable framework for further development of hydrogen technologies. Three EUC's based on drivers listed above have been identified. These are Uusimaa region (NUTS3 code FIN-01), for its high population density and relative wealth, as well as high educational level, and Satakunta region (NUTS3 code FIN-04) for its pioneering of a pilot-scale demonstration and development platform in Äetsä, where a 'hydrogen village' has been created to utilise hydrogen produced in a chemical plant as a by-product.

Applications include small-scale CHP system for single household use, as well as small light-weight local transport applications. Satakunta region also has some wind energy and soon almost 70% of the nuclear power production capacity that both could be used in favour of carbon-free hydrogen production already early-on.

The third potential EUC is foreseen in Åland region (NUTS3 code FIN-21) and the large archipelago between this and the mainland. This is the region with high installed capacity of wind power, and has lots of potential left for growth, and many development projects are underway. Furthermore, for geographical reasons the power grid is rather weak and road network quite limited. All of these aspects favour the application of hydrogen as intermittent energy storage for stranded wind electricity, as well as using fuel cell based CHP for households, as they are predominantly small in this region. As driving distances are also short, the limitations in range, expected for early hydrogen-fuelled vehicles, is not a particular barrier.

The expected mix of hydrogen pathways would be predominantly fossil-SMR and over 60% of total H_2 would be consumed in the southern parts and south-west coastal areas (02, 05, 06, 07, 08, 09, 10), as NG grid is present in almost all of those regions already. The exceptions to this rule would be East-Uusimaa (NUTS3 code 20), where nuclear electricity would be dominant, and Satakunta, where nuclear and wind electricity would entail some 50% share. Central parts of the country, where demand is very low at this stage, could use either grid electricity and small-scale decentralised production, or the first central installations based on biomass gasification. The north-west coast and far north would solely rely on wind or grid (hydro power) electricity and small-scale decentralised production, if any refuel support is foreseen at all.

8.4 Medium-term vision (2020-2030)

In the medium-term or transition phase, the growth of hydrogen demand would enlarge the range of options. Transition in the feedstock break-down towards non-fossil options should also be on its way, and expected share of fossil should be well below 40%. Regions adjacent to nuclear power could start to rely more on that source, and centralised production would become feasible in areas of high demand density.

Such high demand areas are Uusimaa (01), where production could be both NG-SMR at Neste refinery or electrolysis run by nuclear electricity near Loviisa power plant. At this stage building of a transport pipeline from Neste refinery to deliver hydrogen to metropolitan area could start to become feasible, as the distance is only about 50 km. Also Varsinais-Suomi region (NUTS3 02), aside EUC of Satakunta could become reliant on a central unit at the other nuclear power station site (Olkiluoto). This way nuclear electricity share could get close to 30%.

Growth of the installed wind power capacities should give possibilities to increase the relative share of that primary energy to about 30% in those designated areas, archipelago and western region (21, 02, 04) as well as north-west coast (14, 15, 16,17) contributing up to 10% of total H_2 demand.

8.5 Long-term vision (2030-2050)

In the long-term or vision phase, a sustainable and carbon-free production of hydrogen should become a necessity, and H_2 derived from biomass gasification should reach 13 to 15%. However, overall quantities of hydrogen delivered would still remain so low that transport by truck (or rail) would be preferred for most of the cases. Only short-range transport pipelines could become feasible, and at this phase construction of a pipeline from Loviisa nuclear plant (primary candidate site for a central electrolysis production), could start to link it with the pipeline already foreseen between Neste refinery in Porvoo and the metropolitan area. Some 70 km new pipeline would then be needed.

The refuelling stations would be still sited predominantly in urban centres and along main roads to enable longer extra-urban trips of hydrogen vehicles.

The centralized/decentralised SMR is favoured in south-east regions (05, 06, 07, 08, 09) and partly also in central Finland (13), as NG grid is either in place or expected to reach those areas by then. The local/on-site production of hydrogen by conventional water electrolysis using the electricity mix would still be in use where regional population density and growth of the demand remain low.

8.6 Policy support

At present the policy support to hydrogen technologies is rather weak, limited mainly to RD&D funding. There is no political commitment to hydrogen as an energy vector. However, development of a strategic policy paper is underway.

Main issues that are foreseen for the policy measures to address in short term on local/regional level are related to the development in planning to allocate and prepare sites for hydrogen filling stations, and taking into account procedures for later upgrade of existing stations. Also fostering of demonstrations of hydrogen technology is important. On national level most important would be a car tax reform to change it towards environmental taxation, and basic education of policy makers of the benefits of hydrogen. Furthermore, it would be important for the long term to start preparations for standards for permitting and construction of hydrogen installations and large public transport stations for hydrogen-fuelled vehicles, as well as continue support for R&D. The latter applies also to EU-level, along with fiscal harmonization for non-fossil fuels and harmonized regulations of fuel tax exemptions for EU27.

In medium term on local/regional level as well as on national level, preparation for quotas for hydrogen vehicles procured or leased for public sector could help market deployment. Furthermore, long term tax incentives for H_2 cars and recruiting high-level first users of hydrogen vehicles would advocate technology and increasing visibility. Subsidies and incentives for H_2 production may also be needed. On EU level adequate consideration of cold climate should be included in the operational parameters of the new technology, e.g. fuel cell cars. Also a harmonised system how to include external cost in fuel production for transport applications is needed.

In the long-term a phase out of financial benefits and creation of open markets in hydrogen/hydrogen technology are foreseen to be important on both national and EU level. Finnish 'Vision 2050'

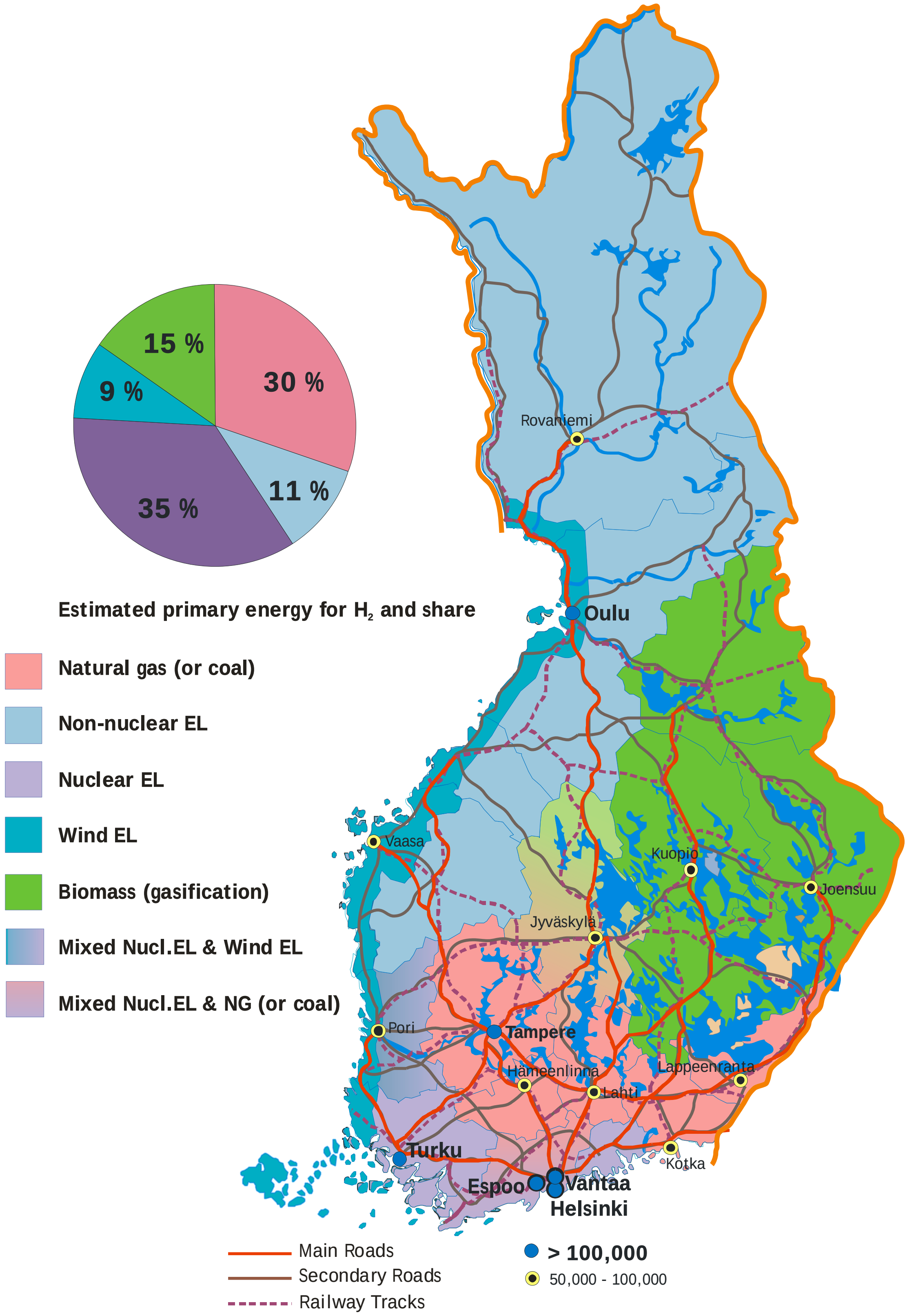

Figure 8.1: *Hydrogen production feedstock divided by primary energy and regions*

9. Poland

9.1 Introduction

According to the Polish stakeholders the transition to hydrogen economy in such a country as Poland will become reality only if major existing synergies and alliances with mature energy concepts and systems are tapped and implemented. The current energy system in Poland is by no means sustainable as it is predominantly based on fossil fuels with a marginal share of renewables. By definition, a sustainable energy system must be achieved at some stage. In case of Poland, the innovation drive of hydrogen economy poses a considerable potential as the aging, low-efficient, coal-based energy system has no chances of surviving the combination of the growing energy demand and the envisaged CO_2 taxes to be imposed.

9.2 The development of the Polish energy system

Developed by the stakeholders, the long-term Polish vision of a sustainable energy system in the period 2050 and beyond anticipates that energy generation will predominantly utilize coal with CCS in saline aquifers, unminable coal seams and depleted oil and natural gas reservoirs, then it will utilize natural gas and synthetic natural gas, nuclear energy and combined RES. A considerable increase in coal-based power generation efficiency is assumed to be achieved within the concept of the so-called Zero Emission Fossil Fuel Power Plant. Within this end vision, the energy system will be characterized by central production in case of coal, nuclear and gas; with decentralized renewables based electricity production according to locally available sources.

9.3 The role of hydrogen in the energy system

The most dominant factor favoring the introduction of hydrogen into Polish energy system is the potential of deriving it from the most abundant locally available energy carrier - hard coal. This in turn would enable making coal-based energy generation sustainable and at the same time would provide hydrogen for mobile and portable applications as well as for chemical syntheses.

9.4 Short-term vision (up to 2020)

With regard to early markets before the year 2020, the stakeholders assume that clean city centers with hydrogen taxis and buses in selected metropolitan areas could constitute some seeding points. Hydrogen communities located in the vicinity of potential hydrogen sources preferably based on renewable energies and by-product hydrogen are also considered as an option. The European Initiative for Growth concept of establishing a limited number of independent hydrogen communities (recreational, remote, marine, town or metropolitan) strategically located around Europe initiated a debate on locating a few of the testing facilities in Poland.[6] The chosen Polish HyCom locations could become H_2 early markets. The proposed locations are described below. Krakow, as one of the most eagerly visited tourist attractions of Central Europe, might be considered as a venue for the so-called town hydrogen community, with local H_2 production, stationary CHP for residential use, for instance in hotels or museums, as well as special vehicles for tourist purposes.

[6] Commission of the European Communities, Communication from the Commission: a European Initiative for Growth - Investing in Networks and Knowledge for Growth and Jobs, Final Report to the European Council, Brussels COM (2003) 690 final

The town of Krakow faces severe problems concerning low emission and the consequent deterioration of its historical and cultural heritage, so introducing FCV's into the town centre instead of conventional municipal transportation and stationary CHP in public buildings could substantially improve the situation.

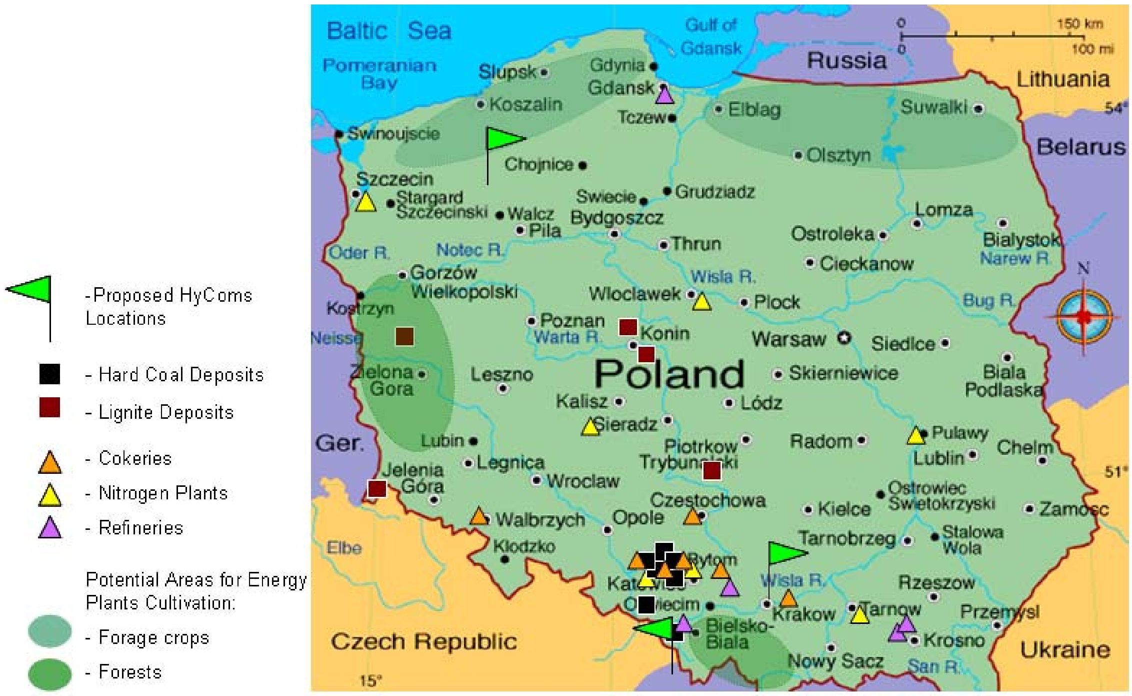

Figure 9.1: *The distribution of resources and proposed HyCom locations*

Localized in Krakow's geographical proximity, the coking plant of Sedzimir Steel Works could provide hydrogen to feed the fleet of FCV's introduced into the Old Town zone and at the same time mitigate considerably the Works environmental impact. A coke oven based H_2 filling station might be located next to the coking plant.

Another possibility encompasses locating the so-called recreational hydrogen community in the Polish/Czech border town of Cieszyn/Tesin. A 'coalition' of Polish and Czech scientists, NGO's representatives and local authorities generated the idea of locating one of HyComs in this town because of its high visibility and availability of local hydrogen sources. At the center of the project lies the idea of creating a public transportation system linking the Czech and Polish parts of the town by means of a dedicated hydrogen fleet. Such a small-scale demonstration project would serve as a mutually beneficial integration tool for the Czech and Polish communities. The third location to be taken into consideration is Borne Sulinowo. The idea of a remote hydrogen community consists in hydrogen production based on renewables, 1 filling station, stationary CHP for residential or community use in hotels, visiting centres or public buildings and 1 FC bus.[7] Situated in the north of Poland, Borne Sulinowo was first the German and next Russian military base until 1993. The town's transformation from a former military base to a civilian municipal entity requires a novel and comprehensive approach; therefore participating in hydrogen and fuel cell activities seems to be quite a promising option. The geographical and socio-economic conditions lay good foundations for generating hydrogen on the basis of various sources.

[7] Commission of the European Communities, Communication from the Commission: a European Initiative for Growth - Investing in Networks and Knowledge for Growth and Jobs, Final Report to the European Council, Brussels COM (2003) 690 final

In each of the above mentioned cases, the effect of synergy is achieved since the proposals combine numerous hydrogen community activities which address societal, economic and political issues. However, it should be emphasized that a strong policy support would be urgently needed in terms of investments, public awareness campaigns and regional development programmes until the seeding points cover bigger areas.

9.5 Medium-term vision (2020-2030)

As far as the intermediate period 2020-2040 is concerned, the energy system is expected to be still heavily dependent on fossil fuels with a slowly increasing share of renewables and as envisaged in the National Energy Policy document the construction of a nuclear power plant (approx. 2030). In the said period, it is assumed that a substantial amount of hydrogen could be produced from coke oven gas as the coking plants located in Poland, predominantly in the South of the country, offer the possibility to utilize the available, raw coke oven gas as a source of hydrogen supply. Only in 2004, Polish coking plants gave 4,385m m^3 of coke oven gas. Having satisfied the needs of the coking plants and the associated steel mills, there was a surplus of 1,363m m^3, of which 1,275m m^3 was sold; the remaining 88m m^3 was burnt. It is estimated that commercial utilization of the coke oven gas generated at the two biggest Polish coking plants, ZK Zdzieszowice and Przyjazn could yield approximately 1,660m m^3 of hydrogen per annum. [8] Furthermore, apart from coal gasification (without CCS) and natural gas reforming, coal bed methane seems to be an additional option of hydrogen supply.

Within the intermediate period, it is envisioned that a major market for decentralized stationary installations might develop provided governmental support is secured as it could generate new industries and stimulate the job market. Thus, local on-site producers may grow in importance. The stakeholders foresee that at that time, a limited number of refueling stations will start to appear in densely populated areas and along the main E roads. The supply of hydrogen will be based on tube trailers and cryogenic trailers. Nevertheless, mobile applications of hydrogen are expected to be still fairly limited due to economic conditions.

9.6 Long-term vision (2050 and beyond)

In the long-term period, hydrogen could be produced in a sustainable way within the concept of the 21st century coal mine understood as an integrated producer of electricity, chemicals for syntheses and hydrogen for different applications. Another path of hydrogen production could be based on an integrated system of a coal power plant with a high temperature nuclear reactor. Figure 9.2 explains the process. Additional energy needed to produce hydrogen locally could be derived from renewables. Moreover, renewable hydrogen is also assumed as a medium of energy storage in peak periods.

The scenario of the continuation of solid fossil fuel use in Poland integrated with distributed sequestration of CO_2 assumes that hard coal and lignite may be gasified to synthetic natural gas whereas the CO_2 emitted at a coal gasification plant could be sequestered in the vicinity of the mining site according to locally available capacities and techniques. Hydrogen, in turn, might be separated at the end of the pipe by means of SMR in places where demand occurs. In this way, hydrogen infrastructure would be in parallel to natural gas pipeline network.

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[8] A. Tramer, M. Sciążko, A. Karcz, *Przem. Chem.* 2005, 84, nr 11, 819

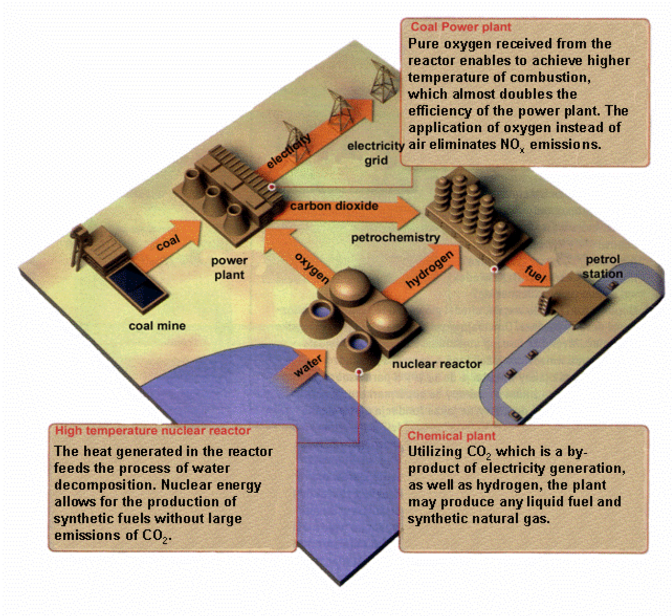

Figure 9.2: *An integrated nuclear and coal 'energyplex'* [9]

The farming soils and mild climate of central and northern Poland could generate suitable environment for biomass cultivation and may be regarded as an area for the development of energy self-sufficiency by means of the so-called energy bio-refinery concept but only provided that market conditions are favorable. Within this approach, the recycle rate of energy from biomass and bio-waste could be maximized and combined with the delivery of hydrogen and a wide range of added value raw materials for local industries. An innovative way of combining the ex-situ coal conversion to synthetic natural gas, hydrogen and electricity combined with enhanced methane recovery and carbon dioxide storage in coal bed is presented in Figure 9.3.[10]

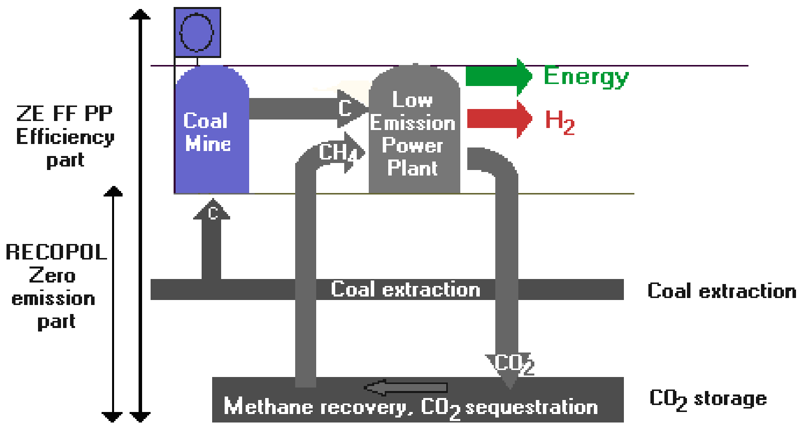

Figure 9.3: *Integration of ex-situ coal conversion with in-situ carbon dioxide storage*[11]

As for the Polish demand of hydrogen, the stakeholders envisage that it would be basically utilized for mobile applications as the market saturation of hydrogen vehicles increases. The stakeholders do not foresee hydrogen for stationary applications in that period. Refueling stations with SMR would be located in the vicinity of the metropolitan areas and along the network of

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[9] The authors and publishers wish to thank NEWSWEEK POLSKA and Mr LECH MAZURCZYK who have kindly given permission for the use of the above infographics.

[10] Krystyna Czaplicka, Józef Dubinski, Aleksandra Tokarz, Jan Rogut: Coal Mine of 21st Century: In Situ Producer of Energy, Fuels and Chemicals, International Mining Forum, February 2006

[11] The concept of the demonstration plant for high-efficient, zero emission, electricity and hydrogen production in Polish - Czech Silesia Region

main roads. The distribution centres could be supplied by local gas networks, cryogenic trailers and tube trailers.

9.7 Policy framework

As regards the policy measures necessary to develop hydrogen economy in Poland in the short term; on the local/regional level, technology clusters should be awarded financial means in order to stimulate the launch of hydrogen industries. Furthermore, dedicated hydrogen fleets should be introduced into the transportation systems of selected locations and H_2 fuel stations should be supported. The implementation of local regulations concerning emissions should be considered and there should be some lobbying to create friendly environment for hydrogen activities. On the member state level, hydrogen should be included into the group of renewable fuels. Demonstrations of FCV's and hydrogen communities should be realized. There should be more funds for R&D into hydrogen purification and separation technologies. Hydrogen oriented educational programmes ought to be included into the national curriculum. As far as the EU level is concerned, the introduction of nuclear energy in the new member states would need support. Another important issue would be fostering Poland's participation in JTI in collaboration with neighbouring states such as the Czech Republic, Slovakia and Germany. Both on the MS and EU levels, tax incentives and fuel taxation exemption would have to be considered.

Concerning the policy framework in the intermediate period, the transition activities will require a considerable support probably on the supranational, national and regional levels in order to bridge the gap between the demonstration and mass market introduction. The stakeholders envisage that policy instruments of multifarious nature should be initiated and implemented to foster the transition, for example within the local and regional framework, there is a need for some policy enabling the shift of classic mining technologies to new ones, combined with hydrogen. On the member state level, the infrastructure build-up should be optimized by efficient positioning of hydrogen on the market. On the EU level, the so-called 'environmental tax reform' should be applied to support the development of hydrogen economy.

As far as the long-term policy framework is concerned, both on local/regional and MS levels, there should be measures supporting sustainability through the application of hydrogen technologies. On both, the MS and EU levels, further development and refinement of mobile hydrogen applications ought to be supported.

10. Spain

10.1 Introduction

This document will be used as an input for the development of the 'European Hydrogen Energy Roadmap' carried out by the European HyWays project. For its preparation the opinion of more than 30 Spanish stakeholders belonging to different sectors like industry, research institutes, regional governments, etc., has been taken into account. Strengths and weaknesses of the Spanish energy system will be set out as well as the opportunities for the upcoming hydrogen based economy.

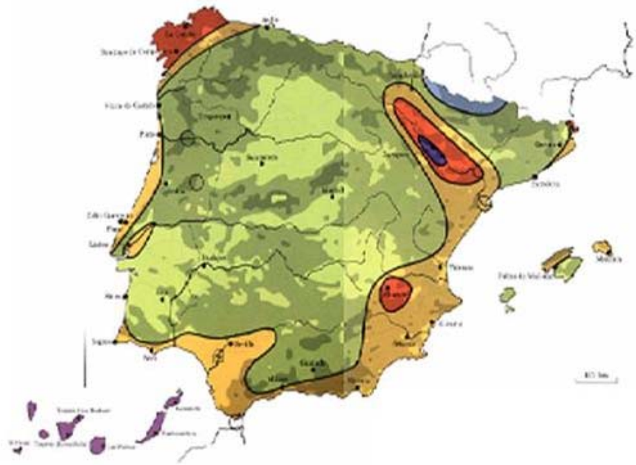
10.2 Development of the energy system

The outstanding difference between energetic demand in the EU and in Spain is that petroleum and petroleum products are the major demanded resources in Spanish structure while natural gas and nuclear energy are more abundant in the European energetic scheme. Therefore, Spain is one of the more energetically dependent countries in the EU. Nowadays, Spain imports almost 82% of its energy. The share of participation on primary energy consumption is the following: Renewable Energy 5.95% (Biomass 2.8%, Hydro 1.2%, Wind 1.2%, Solar 0.045%, Organic Domestic Waste ODW 0.3%, Biogas 0.2%, Biofuel 0.2%, Geothermal 0,01%), Petroleum energy 49.3%, Natural Gas 20.0%, Coal 14.6%, Nuclear 10.3%, Electric balance -0.1% (IDAE, 2005). 26% of this energy is dedicated to household and public service sector, 41% to transport and the remaining 33% to industry. Energetic demand is increasing very fast due to the electricity and transport sector demand. This has involved an increase in the Primary Energy Consumption of 5% in the 90´s.

This situation together with the Kyoto protocol requirement has made the Spanish government act with new initiatives: The Action Plan 2005-2007 to promote the 'Energy Saving and Efficiency Strategy 2004-2012' and the new 'Renewable Energy Plan 2005-2010'. The latter suggest that the 12% of primary energy will be obtained from renewable energies as a goal for 2020. Moreover, there is a strong willingness to include H_2 and FC as an independent thematic area in 'National Energy Plan 2008'. A great potential of wind and solar power energy for combined heat and power use will be developed in order to produce electricity as an energy carrier. CCS should be solved to continue using coal gasification which today in Spain is the most competitive process for H_2 production at large scale.

The national solar and wind power resources besides the well expanded tradition in wind mills and the national technological developments have turned Spain into a world-wide power in renewable energies. Relating to wind power, Spain ranked second in the world in 2005 with 10,000 megawatts of installed capacity. Regarding to photovoltaic potential, Spain is rated as third European country in installed capacity and fourth worldwide producer. Nevertheless Spanish future energetic system will continue being 40% fossil fuels based, mainly central generation with CO_2 free coal gasification, due to the village of Puertollano in Castilla la Mancha counts with one of the two Integrated Gasification Combined Cycles (IGCC) plants existing in Europe. Over the remaining 60%, a 40% of renewable energies emissions free plants with on-site distribution are expected and 20% of advanced nuclear energy will be necessary to cover the increasing energy demand. However the installation of nuclear energy plants will depend on policy framework.

From stakeholders´ point of view nuclear energy should be envisaged in the future but Spanish government is not for it**,** in fact, the current law in relation to nuclear energy is for the closure of all nuclear power plants when their useful lifetime arrives to its end. It makes that the future of nuclear energy in Spain is strongly dependent on policy framework.



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 10.1:*Wind power resource in Spain. (m/s, W/m^2)*

10.3 The role of hydrogen in the energy system

The added value that H_2 can introduce to the Spanish energy system is its combination with renewable energies avoiding their intermittence and reducing Spanish dependence from external energy, especially fossil fuels. Another benefit of H_2 as energy vector is the flexibility it introduces for choosing the primary energies from which to obtain fuels for transport applications. It will make possible to choose the cheapest option and the most convenient (renewable, nuclear or fossils fuels) depending on multiple factors. Furthermore, H_2 will help to provide a healthier environment in city centres where air pollution is so high. Biomass potential for H_2 production will have to compete with biomass for combustion applications. Nowadays most of the Spanish biomass is being exported for its use in co-combustion boilers in other countries where it is better valued.

In the near term, the high price of H_2 technology (fuel cells) and its complexity for individual users remain as the main limitation for a big development of H_2 economy in Spain. Therefore, Spanish stakeholders envisage that H_2 for transport will be used only in captive fleets. A mixed technology of fuels is expected with a relevant role for biofuels because of the easiness to adapt current infrastructure to their infrastructure. Although the use of biofuels for transport will increase during the near and intermediate period, they won't provide the definitive solution for air pollution as they continue emitting NO_x and particles. Therefore, in the near and intermediate period the tendency will be the use of hybrid-electric vehicles (HEV's) which use internal combustion engines and electric batteries to power vehicles. Fuel used for hybrid vehicles will come from a variety of sources: gasoline, diesel, biofuel, compressed natural gas (CNG), H_2, etc. These vehicles will help to increase the energetic efficiency and reduce petroleum product consumptions.

Portable applications like mobile phones, UPS, APS, etc, will be the first market to introduce H_2 to the general public. In relation to stationary uses, household, public services and industry energy demand will be covered mainly by electricity. Electricity infrastructure is already developed whereas H_2 pipeline networks would have to be installed throughout the country which would be too expensive. That is why in the opinion of the stakeholders electricity is selected as the main energy carrier and not H_2. However small H_2 pipeline networks are expected to appear near industries, on-site H_2 facilities production plants and niches like new housing development or isolated areas where the installation of H_2 pipelines can be as expensive as power lines.

10.4 Short-term vision (<2020)

The early markets identified by stakeholders are: portable applications where metal hydrides will be developed as storage system, captive fleets in Madrid and Barcelona (e.g. urban buses or low power airport vehicles) where there is a previous experience with H_2 vehicles due to their participation in European programmes, captive fleets in small cities where H_2 initiative is easily seen and supported by political commitment and stationary prototype installations.

The first user centres identified are: Madrid, Barcelona, Zaragoza, Pamplona and Valencia. Purchasing power, car density and pollution are the main indicators for the choice of Madrid and Barcelona as first user centres whereas in the case of Zaragoza, Pamplona and Valencia, political commitment and the existence or renewable resources are determinant criteria. The construction of new refuelling stations will be needed in all these cities.

First H_2 vehicles prototypes will lead to a new vehicle components industry like fuel cells, compressors, humidifiers and batteries. It will be necessary to coordinate vehicle assembly plants through an 'H_2 ring' that connects those cities where vehicles and their components are manufactured.

10.5 Medium-term vision (2020, 2030)

In the transition period the growth of H_2 demand will enlarge the options for decentralised H_2 production and will justify the appearance of first centralised plants. During this period H_2 will be introduced in Canary and Balearic islands and it will be obtained from decentralised NG and liquid hydrocarbons steam reforming and wind power plants. In the rest of the country the construction of the first centralised plants for hydrogen production is expected, preferably located near natural resources: one or two large-scale central coal gasification and first wind and high temperature solar thermal power facilities are envisaged.

The off-shore facilities at the coast of Galicia (northwest), Andalusía (southwest) and Ebro delta (east) and the carbon capture and storage technology will be envisaged during this phase at industrial scale.

Referring to transport, H_2 and natural gas blends are considered the most probable transition technology to be used as fuel in internal combustion engines and to be transported by pipelines as a first choice to transport H_2. As hydrogen use increases, new infrastructures will be required since the NG network can only stand up to a small percentage of H_2 blend. It is important to note that in Spain exists a good experience in the use of compressed and liquefied natural gas (CNG and LNG) for transport referring to vehicle engineering, development and refuelling infrastructure.

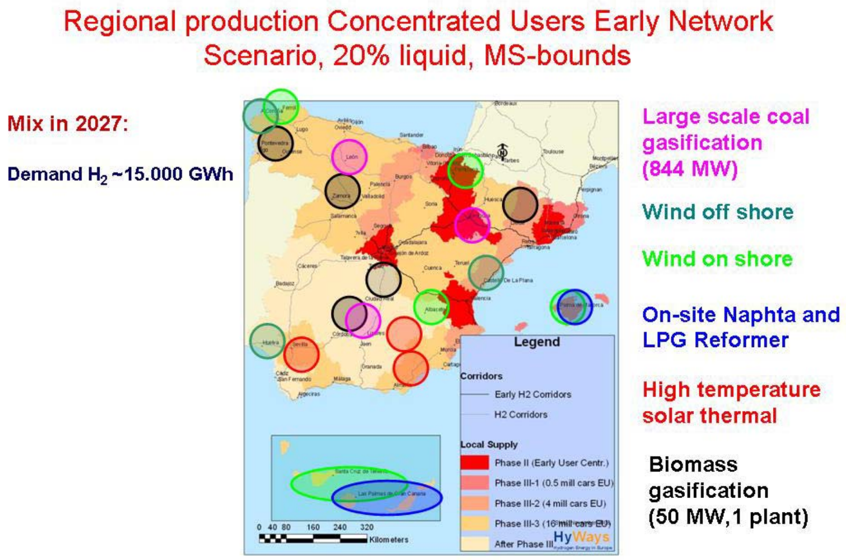


Figure 10.2:*Early user centres in Spain*

10.6 Long-term visions (2050)

Stakeholders envisage that H_2 production will be determined by 2050 by regional features. Renewable energies: wind, solar thermal and biomass will produce 40% of H_2 in 2050. The remaining 60% will be produced in a diversified way, including fossil fuels with CCS, nuclear and electricity mix. Feedstock price will dominate the production costs; especially petroleum and natural gas, and coal gasification with CCS will turn out to be the most economical option for the co-production of electricity and H_2. A multiplicity of on-site (decentral) H_2 production facilities is expected and few central ones. Finally, no H_2 exportation to other countries is foreseen.

Both trucks and pipelines will be considered to transport H_2, liquefied (LH_2) and compressed gas (CGH_2) by truck and only compressed gas (CGH_2) by pipeline. Nowadays, CGH_2 is transported by truck for short distances and small quantities (no more than 400 kg/truck for 400km.) and LH_2 by truck is chosen when bigger distances and quantities are demanded. Although at present there is no liquefaction plant in Spain, once demand reaches relatively high value they will be built. It is expected that Spain counts with one of this liquefaction plant by 2020, so in 2050 a few central ones are expected. There already exists a 25km CGH_2 pipeline network in Spain. It is used for industrial application and is located near production centres. H_2 transport by truck (CGH_2 and LH_2) will increase progressively with the demand and only when consumption turns out to be high, large pipelines for CGH_2 transport will appear. It will become the most attractive option for significant quantities of H_2 delivery, whereas transport by truck will be used for limited quantities. Filling stations will be set every 100 km.

10.7 Policy framework

The scenarios contemplated in this document are strongly dependent on the policy framework, specially regarding to nuclear energy. At national level there is no specific action or development strategy to introduce H_2; it is just considered as an emergent technology as many others in the National Energy Plan.

According to stakeholders´ opinion the first priority is to include H_2 in National Energy Plan as an independent technology and to establish a National Master Plan to develop H_2 structure. As it is happening with some renewable energies there should exist tax relief and subsidies for promoting H_2 systems at national scale as well as a harmonization of codes and standards. Curricular integration of H_2 at different levels should be carried out in next years.

Ecological criteria should be taken into account in tax rates: taxes should be imposed on mechanical traction vehicles based on CO_2 and other pollutants emissions and in low energetic efficiency vehicles. In addition, diffusion and promotion of lighthouse projects and technological advances should be emphasized, public subsidies for generated employment, CO_2 emissions avoided and to buy H_2 vehicles should be created.

Not only national government should be aware of the necessity to support H_2, but also regional and local governments should contribute to the development of initiatives to make H_2 visible and familiarize people with the new technology in small areas where public awareness can be more easily reached. Policy frameworks at regional levels are so different that it makes it impossible to establish a 'H_2 ring' or highway between regions. Therefore, H_2 should be introduced in Regional Energy Plan and regional policies should be harmonised. For example, ecological criteria for taxes, grants for 'green' H_2 production, subsidies for free emissions vehicles as precursors of H_2 ones and exemption for the parking payment for H_2 vehicles are some of the proposed measures. Moreover, the use of H_2 vehicles in public and official fleets and economic support for large-scale demonstration projects should be promoted.

Spain should get involved in big R&D projects and follow European legislation concerning H_2 and fuel cells as well as foster its representation in European forums by Spanish experts involved directly in hydrogen technology and development.

At European level, it could be useful to launch a European public-private partnership between industry and the EC where R&D can be applied to large-scale demonstration projects, perhaps in the form of the so-called Joint Technology Initiative (JTI) for hydrogen and fuel cells. It is also needed to harmonize procedures, specifications, standards, regulations for equipments, safety and quality and fiscal taxes based on pollutant and energetic efficiency criteria.

11. UK

11.1 Introduction

This document summarises the UK stakeholder vision for the use of hydrogen as an energy vector by starting at we are today out to 2050. The UK's stakeholders includes: three active trade associations (UK Hydrogen Association, Fuel Cells UK, Scottish Hydrogen and Fuel Cells Association); 6 active regions, academia, and local and national Government. The UK stakeholders believe that hydrogen is an essential element in achieving sustainable supply options and a low carbon future. This stakeholder vision is aligned with the national energy policy objectives of: a reduction of carbon emissions of 60% from 1990 levels by 2050; security of energy supply (including reliability and diversity); competitive energy industry; every home to be adequately and affordably heated.

The UK stakeholder note the HyWays assumption is a CO_2 reduction by 30% by 2050, but are agreed that the UK must achieve a reduction of 60% by 2050 and the UK is proud to be firmly on target to meet its Kyoto Protocol obligations. The UK stakeholders are greatly encouraged and welcome the recent adoption at European level of a 20% reduction of CO_2 by 2020.

11.2 Development of the energy system

The final conclusions of the recent UK national energy policy debate on how to meet the objectives above is expected to be published in May and is expected to include specific recommendations with regard to: commercialising innovative technologies (including fuel cells), transport (including hydrogen), fuels, energy efficiency, carbon capture and storage - particularly for fossil fuel chains, and the role of nuclear fission power. The current UK energy mix is shown in Figure 11.1.

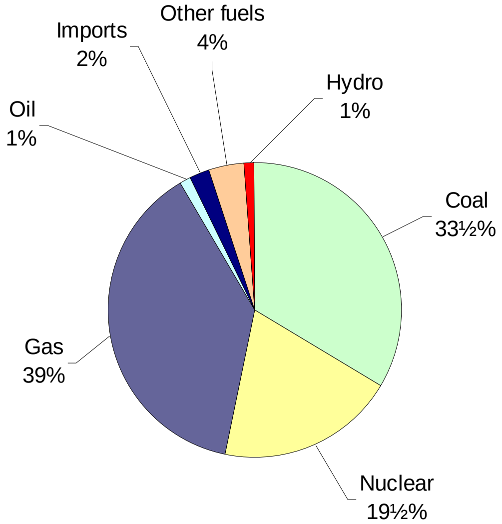


Figure 11.1:*Fuel used in electricity generation, on supplied fuel basis, year 2000*

A portfolio approach is likely to remain but incentives will be developed to allow the deployment of low carbon and renewable energy chains. As well as encouraging the range of technologies it is expected that micro-generation technologies will supply 40% of UK's electricity needs by 2050.

11.3 The role of hydrogen in the energy system

UK stakeholders sees that hydrogen could play a significant role in a developing a low carbon economy. A national level analysis prepared for the UK's Department of Trade and Industry[12] indicates hydrogen for use as a transport fuel in fuel cell vehicles could deliver cost-competitive CO_2 reductions by 2030 and assist in providing diversity of energy supply. This conclusion is accepted by all UK stakeholders.

Stakeholders also see benefit the use of hydrogen in providing stationary power applications to produce electricity for communities not connected to the national electricity grid. For example, in situations where there are substantial renewable energy resources but the export of electricity to the grid is constrained, the production of hydrogen may enhance the viability of renewable energy projects. This may apply to some communities in the Western Isles, the Northern Isles and parts of the Highlands in Scotland.

The use of hydrogen for mainland on-grid power generation is not anticipated to be economic by 2030 (whereas electrolysis, as an important energy sink, will be). Beyond 2030, technological breakthroughs in some of the more novel research areas and the anticipated increase in costs of conventional fuel sources may allow for hydrogen to be used in this way.

In the workshops UK Stakeholders defined relevant characteristics that will influence the deployment of hydrogen and fuel cell technologies in the UK:

1. The UK's energy market is deregulated and strongly protects intellectual property rights which may assist in bringing novel products to market.
2. The UK has the largest new vehicle market in Europe; half of new vehicles sold in the UK can be characterised as fleet vehicles.
3. Excellent opportunities for Carbon Capture and Storage in the North Sea
4. High Government priority for carbon reduction, including support for distributed/micro-generation technologies.
5. High Potential capacity for renewable generation (e.g. wind and marine)
6. Some strong emergent companies in Fuel Cell design and manufacture (mostly PEM and SOFC for system developers, and across the board for component developers), allied to relevant supply chain capabilities
7. High population density, driving the need for advanced systems in public transport and community heat and power.
8. The requirement for investment in new generating capacity.
9. 6 active regional clusters identified as early user centres which are driven by local carbon reduction, economic regeneration, and local environment (air/noise pollution) concerns.

11.4 Short-term vision (from today - 2020)

The UK could be characterised as being in the early demonstration phase of hydrogen and fuel cell technologies (and a number of other emerging energy technologies). The UK is an excellent position to capitalise on its strong and innovative R&D base to assist in the commercialisation of these technologies. The six early user centres identified by the UK Stakeholders are:
- Aberdeenshire, London, Midlands, South Wales, Teesside, and Unst (a Scottish Island).

[12] UK Hydrogen Strategic Framework -Analysis by E4Tech/Element Energy/Eoin Lees (2004) http://www.dti.gov.uk/energy/sources/sustainable/hydrogen/strategic-framework/page26734.html

These locations have been selected by the stakeholders because activity and projects are already operating in these regions. These regions have actionable plans and provide end-user opportunities. Public funding is available to these projects through regional development agencies. Whilst these centres are largely autonomous entities, the UK is seeking to exploit the special characteristics of each to maximise the effectiveness of the whole. It is envisaged that the anticipated hydrogen demand for demonstration projects during the early phase of this period will be supplied almost entirely from fossil fuel sources without any elements of carbon capture. Given the expected small early demand this use is not expected to substantially add to the carbon footprint of the UK. The date 2012 is significant as London is hosting the Olympics in that year and the UK as a whole is keen to use the Olympics to showcase environmentally friendly technologies. The UK is keen to ensure that the ‘Olympic legacy’ is not just about when the games are shown but that the investment going forward now delivers something that is of lasting benefit to the UK.

Post 2012 will be a crucial phase for the development of a potential hydrogen economy for the UK. Lessons from the earlier demonstration projects should now being begun to feed in and assist in the development of early commercial projects. Given regional policy objectives it is expected that early uptake is expected in public transport fleet vehicles, in particular buses and taxis; probably building on earlier demonstrators. Local political leadership, and concerns on local air and noise pollution are likely to be significant factors in encouraging public fleet vehicles to switch to alternative low carbon fuels. Further uptake may be driven by private operators of urban delivery vehicles, for example, supermarkets. Such decisions by retailers are likely to be driven by reputation considerations to be seen as ‘green’ and/or socially responsible.

In terms of stationary power, it is anticipated that this will still apply mainly to niche applications such as remote communities. Increased uptake will largely be driven by increases in fossil fuel prices and technological breakthroughs. It is possible that two or three Island (i.e. off-grid) hydrogen communities could develop over this phase. The following hydrogen energy chains expected to have been demonstrated and commercial development begun during this period: Renewable electricity, natural gas with carbon capture and storage (CCS), coal with CCS.

11.5 Medium-term vision (2020 - 2030)

At this point it is assumed that most of the proof of concept technology challenges relating to hydrogen and fuel cell vehicle technologies will have been met and that early infrastructure will have grown out from the regional clusters. At this point in time - individual consumers are expected to be able to purchase hydrogen-fuelled cars. The challenge for the industry is will consumers want them? - hydrogen cars will be expected to perform well and need to be a desirable product.

Hydrogen for stationary power is still envisaged to apply to niche applications. However, technology breakthroughs in hydrogen production capability could begin to challenge this - and a case for ‘ubiquitous’ hydrogen may able to be sustained. Assuming government targets for the introduction of renewable energy production are met, hydrogen production via electrolysis will, by this stage, be starting to play an important role as a grid balancing mechanism as it can be considered a deferrable load. At this point in time, electrolyser technology is expected to have fallen significantly in cost and will be better suited to the dynamic operation that this role demands. All of the following chains are expected to be significant renewable electricity, nuclear electricity, natural gas with carbon capture and storage (CCS), coal with CCS, biomass with optional CCS and novel hydrogen production technologies (such as energy from waste and non-woody biomass).

11.6 Long-term vision (2030-2050)

Here at this point fossil energy chains are expected to be less important and whilst renewable and woody biomass probably dominate. Novel production such as non-woody biomass and nuclear hydrogen are expected to have been demonstrated and commercially developed by this point in time. At this point hydrogen fuelled vehicles are seen as the mainstay of vehicle applications and are the norm. Further technology development would have lead to improved performance across a range of automotive applications.

Electrolysis for hydrogen fuel production is one of the major demand-side management tools for coping with the dynamic and intermittent output from large amounts of renewable energy supplies (or in the inflexibility of nuclear) on the grid. This duel role of hydrogen is central to the hydrogen economy concept and significantly enhances the cost effectiveness of hydrogen technologies as enables duel revenue streams for electrolyser operators.

11.7 Policy framework

The policy framework needs to contain elements of technology push (grants and incentives for fundamental research, applied research, technology demonstrators) and market pull (demand side stimulation measures). Whilst recognising the challenges to the use of hydrogen as an energy vector; the UK believes the technical challenges can be overcome and that careful attention must also be given to the socio-economic barriers.

There should be an increasing focus on demand side actions: incentives, penalties, regulations and procurement policies can all be used to increase demand and/or to reduce market risk. The pursuit of hydrogen as an energy vector is in the UK's public interest potentially delivering significant cost-competitive CO_2 savings and enhanced security of energy supply by 2030. There is also a significant opportunity for economic development and industry growth, particularly for SOFC and PEM fuel cell companies, system developers, and for the fuel cell component supply industries for all technologies over this time period, but the commercial opportunities for hydrogen are less well-defined currently. UK stakeholders support the efforts of the European Commission, partner European Member States and the Hydrogen and Fuel Cell Technology Platform. The UK wishes to be part of the 'coalition of the willing' in taking the deployment of hydrogen forward.

UK Stakeholders will seek to participate in Framework 7 work programmes and strongly supports the potential Fuel Cell and Hydrogen Joint Technology Initiative and wish to see it established by 1 January 2008. Also, the UK continues to be a member of the International Partnership for the Hydrogen Economy (IPHE) and participates in the IEA Implementing Agreements for Hydrogen and Fuel Cells. There should be support for those sectors closest to market viability and support should include removing the remaining barriers to adoption.

Support for hydrogen energy in the UK includes supporting the development of renewable hydrogen energy chains. Support is likely to continue to be required for projects that cannot or are not yet ready to participate in Framework 7 and/or the JTI mechanisms. Funding for demonstration projects should in particular be available to projects where they can be scaled upwards or developed in other geographic locations and focused on the demand side. UK stakeholders have defined where they have an interest with regard to the work by the HFC Platform and the UK's interest is shown with respect to snapshot 2020 on diagram.

12. European Synthesis

By means of developing a country specific vision for the introduction of hydrogen into their energy system, country specific conditions and member state preferences should be taken into account in the development of a hydrogen roadmap for Europe. The country specific visions were used to refine the input to the various models used in HyWays. As a result, each country utilises its preferences, which is also mirrored in the choice of hydrogen energy chains. Not nominating an unambiguous champion a rather diversified production mix for hydrogen is found.

In the early phase (up to 2020), hydrogen production will be mainly based on existing by-product, steam-methane reforming and electrolysis (both on-site) to satisfy demand. As the energy system evolves until 2050, the production portfolio broadens up, with centralized electrolysis and thermo-chemistry from renewable (solar, wind, biomass) and from fossil sources with CCS and nuclear. This outcome is in line with the model results.

In the time period until 2020, hydrogen demand is gradually evolving around the capital or larger cities. It is expected that demand remains small. Together with geographical restrictions of demand, most countries have selected on-site reformation based on natural gas, electrolysis from grid or industrial by-product as energy chains. Transport options are limited at that point in time and production is located close to demand. Gaseous or liquid truck trailers cover remote locations and small pipelines are utilized for H_2/NG blend.

In the medium term until 2030, the hydrogen production portfolio broadens up and moves towards a more sustainable way of production. Centralized fossil carbon-capture and storage is expected to be available and more renewable sources replace fossil sources. The infrastructure build-up for long-distance pipelines has started. Hydrogen transport gradually moves from the use of existing short pipelines to the build up of long-distance networks, were in a number of countries also the natural gas grid is utilized. Liquid and gasified hydrogen transport by trucks is performed mainly for remote locations.

The member states do play a key role in providing a technology specific hydrogen support scheme. Deployment support schemes, such as tax exemptions for vehicles and hydrogen as a fuel, have to be implemented at the MS and/or local level. On a local level, various instruments are available to create early markets, such as limited city centre access, use of bus lanes for zero emission vehicles and improved parking conditions. In the early phase, member states favour a public-private partnership such as the proposed Joint Technology Initiative (JTI) for hydrogen and fuel cells that is expected to be a key instrument to facilitate the step towards indispensable large-scale demonstration projects.

The influence of European law does not extend so far that national legislation may be ignored. This is the case because the directives do not actually take effect in the member states but must be implemented in national law, and there is a certain amount of scope provided for this purpose. And the influence of European law ends, of course, where the Community has no jurisdiction or does not use its powers to implement legislation. Nevertheless, the European Union has the power to issue a great deal of legislation and is also the first organisation to approach in matters of where legislation should facilitate the market launch and market penetration of hydrogen technologies.

Appendix A Overview of hydrogen energy chains

Chain (central fossil pathways mostly with CCS; stationary and CGH_2 truck pathways not shown)	DE	ES[1]	FR	FI[1]	GR	IT	NO[1]	NL	PL	UK[1]
NG - pipeline - central SMR - H_2-pipeline - CGH_2 FS[2]	X	X[4]	X	X[5]	X	X	X[6]	X[4]	X	X[4]
NG - pipeline - central SMR - liquefaction - LH_2 truck - $LCGH_2$ FS[3]	X	X[4]	X	X[5]		X		X		X
NG - pipeline - on-site SMR - CGH_2 FS[2]	X	X		X		X		X	X	X
NG - pipeline - central SMR - CCGT (Power station)						X				
NG - pipeline - central SMR - NG/H_2-pipeline - CGH_2 FS[2]			X		X	X				
NG - liquefaction - LNG-ship - regional SMR - H_2-pipeline - CGH_2 FS[2]		X[4]					X			X
NG - liquefaction - LNG-ship - onsite SMR - CGH_2 FS[2]		X								
El-mix - central electrolysis - H_2-pipeline - CGH_2 FS[2]	X		X							X
El-mix - on-site electrolysis - CGH_2 FS[2]	X	X	X	X		X	X[7]			X
Nuclear electricity - central electrolysis - pipeline - CGH_2 FS[2]				X						X
Nuclear electricity - onsite electrolysis - CGH_2 FS[2]									X	
Nuclear power - HT electrolysis - H_2-pipeline - CGH_2 FS[2]		X	X							
Nuclear power - HT nuclear thermocycles - H_2-pipeline - CGH_2 FS[2]		X		X					X	X
Offshore-wind-El - central electrolysis - pipeline - CGH_2 FS[2]	X	X						X		X
Offshore-wind-El - on-site electrolysis - CGH_2 FS[2]	X		X	X		X	X		X	
Onshore-wind - central electrolysis - pipeline - CGH_2 FS[2]		X			X					X
Onshore-wind - on-site-electrolysis - CGH_2 FS[2]	X	X			X	X	X		X	X
Biomass (farmed/residual/waste wood) - gasification - H_2-pipeline - CGH_2 FS[2]		X	X		X			X	X	X
Biomass (farmed/residual/waste wood) - truck transport - decentral gasification - CGH_2 FS[2]	X			X		X	X			
Biomass (farmed/residual/waste wood) - train transport - decentral gasification - CGH_2 truck - CGH_2 FS[2]				X						
Biogas - onsite SMR - CGH_2 FS[2]									X	
Municipal waste - onsite gasification - CGH_2 FS[2]						X				
Solar -thermal HT conversion - H_2 pipeline - CGH_2 FS[2]		X				X				
H_2-by-product - pipeline - CGH_2 FS[2] (Poland: large-scale coke-oven gas)	X	X	X				X		X	
H_2-by-product - liquefaction - LH_2 truck - $LCGH_2$ FS[2]						X				
Hard-coal - gasification - liquefaction - LH_2 truck - $LCGH_2$ FS[3]	X			X[5]					X	
Hard-coal - gasification - H_2 pipeline - CGH_2 FS[2]	X	X[4]		X[5]		X		X	X	X
Hard-coal - in-situ gasification - H_2 pipeline - CGH_2 FS[2]									X	
Lignite - gasification - pipeline/liquefaction - (L)CGH_2 FS[2]					X				X	

blue - natural gas based; light yellow - non-renewable electricity based; yellow - wind energy based; green - biomass based; red - solar thermal (HT) based; brown - from by-product; black - coal based; chains added in Phase II marked in red

[1] ES, FI, NO and UK also use CGH_2 truck delivery pathways which are not shown here for simplicity.

[2] CGH_2 filling station: can refill ICE or FC cars and buses with CGH_2, can also be replaced by or combined with local micro-grid to supply stationary users such as fuel cells.

[3] $LCGH_2$ filling station: can refill ICE or FC cars and buses with LH_2 or CGH_2, also supply stationary users after gasification

[4] with and without CO_2 capture and storage [5] no CO_2 capture and storage (CCS)

[6] export energy chain by pipeline [7] electricity mix Nord Pool

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Hydrogen Energy in Europe

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Acknowledgement
This integrated project is co-funded by the European Commission under the Framework Programme 6, priority 1.6 "Sustainable Development, Global Change and Ecosystems"