HyWays

European Hydrogen Energy Roadmap

BACKGROUND DOCUMENT

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Intended audience	HyWays partners and Member State stakeholders in Spain
Purpose of document	Within HyWays Context The results will be used as an input for HyWays hydrogen pathway / chain selection as well as input to the energy models (e.g. potentials for biomass, wind, CCS etc.). The results will also be used for end vision building by the transition analysis team run by ECN. Task Specific Reports that aim to outline the main issues that are discussed by national stakeholders regarding the present potential, the identified potentials, and the future vision for hydrogen energy at the national level in a structured way that aids ongoing discussion and provides information which could be used for purposes of comparison and selection.

Member State Profiling Report – Spain

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Aims and Objectives

This profiling report has been prepared to provide qualitative socio-economic input to the HyWays hydrogen pathway selection process, and ultimately, to the energy modelling work. The report will be used in the end vision building process conducted by the transition analysis team at ECN, as shown in Figure 1.

Specifically, the report will provide an overview of the current energy system and its expected evolution, and outline the main issues regarding the present potential and future vision for hydrogen in Spain with particular reference to barriers and drivers of hydrogen development, thus providing a foundation for subsequent work.

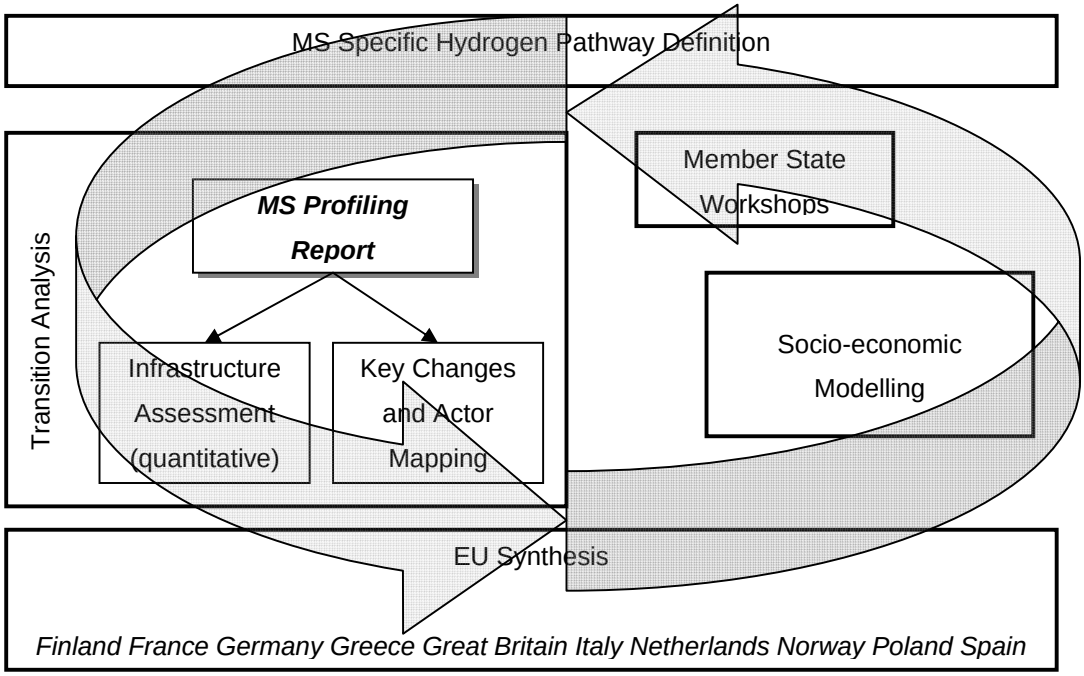
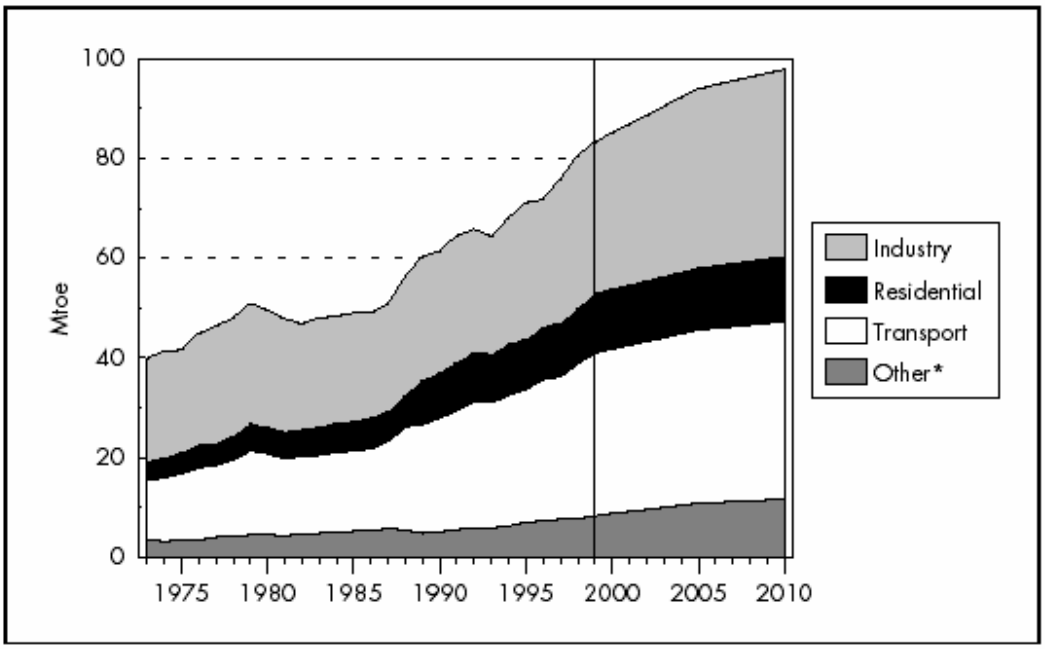


Figure 1 Member State Profiling in the HyWays process

Current Status of Energy System

In 2003 the Spanish total primary energy supply (TPES) was 136.10 Mtoe, to which domestic energy production contributed 32.99 Mtoe, while net energy imports amounted to 109.71 Mtoe.[1] Energy consumption has grown strongly in Spain over the last few decades, rising from around 40 Mtoe in 1973 to 146,2 Mtoe in 2005.[2] This trend is expected to continue, driven largely by growth in the industrial and transport sectors, Figure 2.



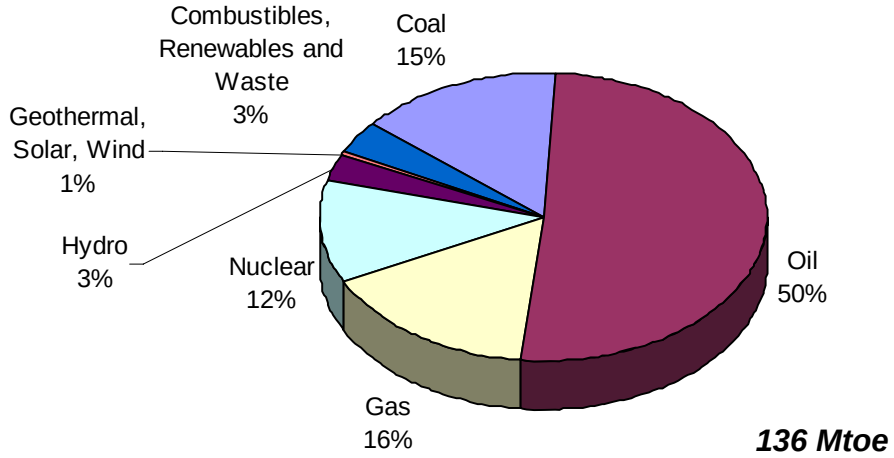
* includes commercial, public service and agricultural sectors.
Sources: *Energy Balances of OECD Countries*, IEA/OECD Paris, 2001, and country submission.

Figure 2 Total Final Energy Consumption by Sector, Spain 1973-2010

The Spanish energy mix is dominated by oil, which makes up 50% of TPES, Figure 3 and Figure 4. However, gas is an increasingly important sector in the Spanish energy system – gas consumption grew by 266% between 1993 and 2003[3] – and Spain boasts the fastest growing natural gas market in the EU.[4] Spain has only very limited domestic reserves of gas and the majority of its supply is imported, mainly from Algeria, Figure 5. Spain benefits from two international gas pipelines, connecting it to Norwegian gas fields via France, and Algerian gas fields via Morocco. Spain is also the second largest LNG gas importer in Europe after France,

and has LNG terminals at Barcelona, Cartagena, Huelva and Bilbao.[3] Two additional LNG terminals are under construction and are due for completion in 2006.

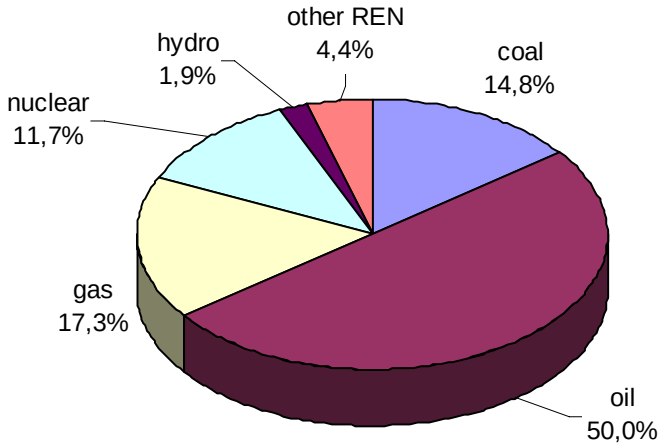
In addition to the limited domestic natural gas reserves, Spain has significant coal reserves, in the form of both hard coal and lignite. However, domestic coal is less competitive than imported coal, and production was reduced between 2000 and 2004. The overall consumption of coal increased by 5.2% in 2004 compared to 2003. In the same period, domestic soft coal and anthracite consumption fell by 0.8% and domestic black lignite by 1.1%, whereas the consumption of imported coal grew by 12.1%[2]. Spain also has a large potential for renewable energy – the country is currently the second largest wind power producer worldwide with 8,200 MW of installed capacity[2], and other renewables such as biomass and solar could also be developed further.[4] Nuclear power is the most important indigenous energy source, representing 15% of total electricity generating capacity in Spain.[5] There are 9 units of nuclear power, with 7,876 MW of installed power capacity. The gross production of energy from nuclear sources in 2004 was 63,606 GWh (22.7% of national energy production) in 2004.



Source: IEA Energy Statistics

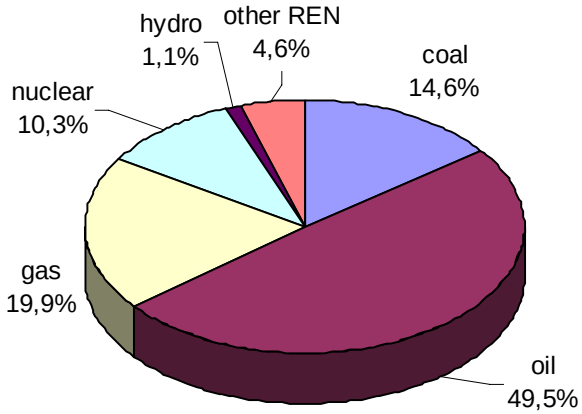
Figure 3 Share of Total Primary Energy Supply in Spain in 2003

Primary energy consumption, 2004



142 Mtoe

Primary energy consumption, 2005

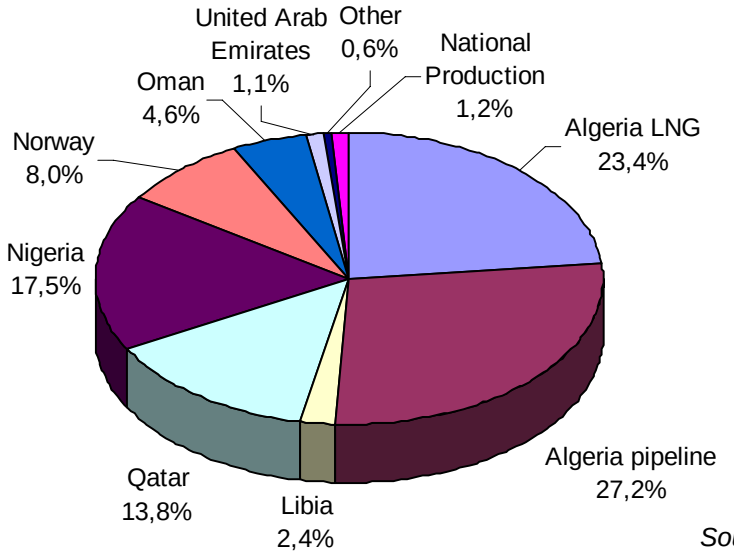


146 Mtoe

PRIMARY ENERGY CONSUMPTION			
	2004	**2005**	**%2005/2004**
coal	21034	21350	1,5
oil	71055	72476	2
gas	24672	29076	17,8
nuclear	16576	15001	-9,5
hydro	2714	1628	-40
other REN	6197	6774	9,3
TOTAL	141987	146188	3

Figure 4 Primary energy consumption in Spain, 2004 and 2005

Source: MITYC energy statistics[6]



Source: MITYC Energy Statistics

Figure 5 Spain natural gas imports by origin

Spain has a formal agreement with Portugal to create a pan-Iberian electricity market (MIBEL), allowing generators in both countries to sell their electricity on both sides of the border. Although the implementation date has been delayed, construction of physical links between the two countries has begun with a new 40 kV power line at Cartelle-Lindosa.[3] Once implemented, MIBEL is expected to create a stronger base for Spanish energy markets.

Projected Energy System Evolution

The Spanish Renewable Energy Plan 2005-2010 (Plan de Energías Renovables en España 2005-2010)[7] includes a discussion of a number of energy consumption scenarios for Spain until 2010. With respect to energy consumption, two scenarios are included: 'Tendencial' and 'Eficienca', Figure 6. Under the former scenario, energy consumption is predicted to rise to 167.1 Mtoe by 2010. The latter scenario includes the anticipated energy efficiency improvements of the Energy Saving and Efficiency Strategy 2004-2012, giving a smaller increase in energy consumption: 160 Mtoe by 2010. The targets of the Spanish Renewable Energy Plan (PER) have been fixed choosing the "tendencial scenario" as reference.

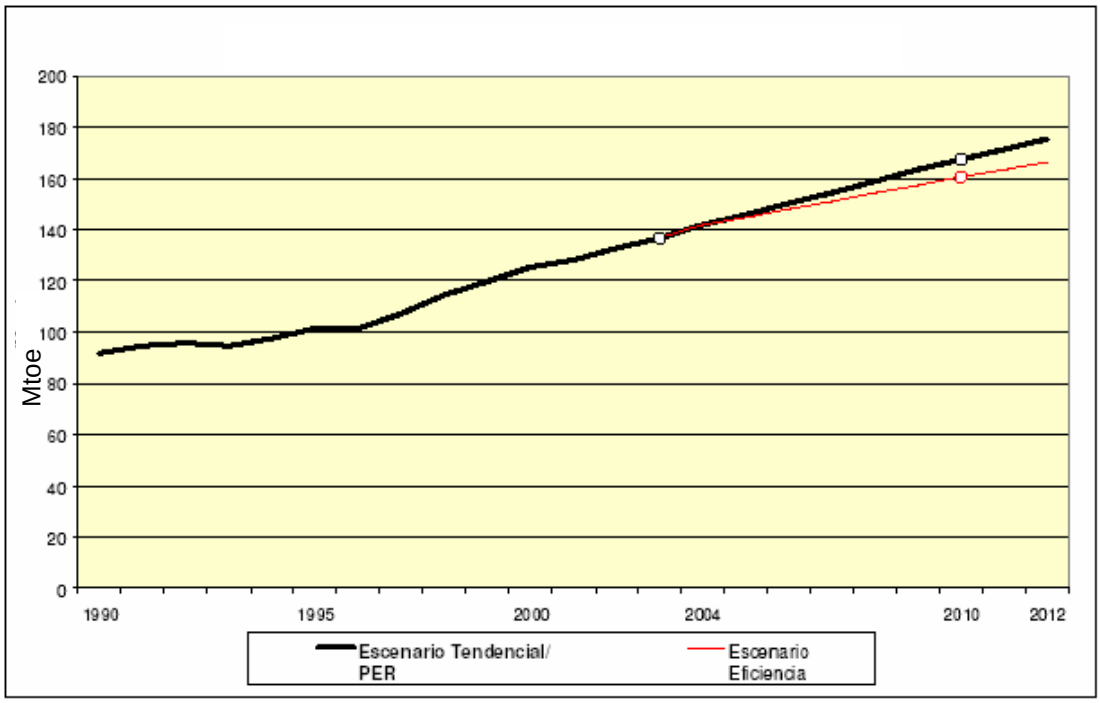


Figure 6 Projected primary energy consumption to 2012

The Spanish government has set ambitious targets for the promotion of renewable energy production in Spain. According to the Renewable Energy Plan 2005-2010,[7] renewables will make up 12.1% of total primary energy consumption by 2010, although oil will remain the most important energy source, This is in contrast to predictions made by the EC Directorate General for Transport, who put the renewable share at just 10.4% by 2030 as shown in the right hand column of Table 1. No projections were available for 2050.

Table 1. This is in contrast to predictions made by the EC Directorate General for Transport, who put the renewable share at just 10.4% by 2030 as shown in the right hand column of Table 1. No projections were available for 2050.

Table 1 Primary Energy Consumption 2004, 2010 and 2030

Primary Energy Consumption *Renewable Energy Plan Tendencial Scenario*	**2004** **ktoe**	**%**	**2010** **ktoe**	**%**		**2030*** **ktoe**	**%**
Coal	21,081	14.9	13,482	8.1		17,320	9.8
Oil	70,490	49.8	76,837	46.0		75,270	42.8
Natural Gas	24,550	17.3	39,632	23.7		44,680	25.4
Nuclear	16,554	11.7	16,602	9.9		20,290	11.5
Renewable Energy	9,152	6.5	20,220	12.1		18,310	10.4
Electricity Import	-261	-0.2	327	0.2		700	0.4
Total	141,567	100	167,100	100		175,940	100

* Data from EC Directorate General for Transport (2003)[8]

Overview of Policies and Measures

There are a number of policies and measures relevant to the introduction of hydrogen technology in Spain. These include targets for the development of various energy technologies, and measures to support the desired development, Table 2. Key policy aims are the development of a sound, safe and efficient power supply system, and the creation of a 12% share of primary energy consumption from renewable sources by 2010.

Table 2 Policies and measures

Policy name	Date	Description
VI National Energy Programme	2003	Creation of knowledge and development of technologies necessary to guarantee a sound, safe and efficient power supply system. The three priorities of the programme are: 1. Optimisation of the conventional uses of energy 2. Boosting renewable energies and emergent technologies (specific technologies include wind, solar, biomass, hydrogen and fuel cells) 3. Thermonuclear fusion
Renewable Energy Plan 2005-2010	2005	Update of the Renewable Energy Promotion Plan. Includes the target that at least 12% of primary energy consumption should come from renewable sources by 2010. The main energies and areas that are considered by the plan are: • Wind – installed capacity to reach 13,000MW by 2011 • Hydropower (<10MW) – installed capacity to reach 2,199MW by 2010 • Hydropower (10-50MW) – installed capacity to reach 3,257MW by 2010 • Solar thermal – installed area to reach 4,900,433m^2 by 2010 • Solar thermoelectric – installed capacity to reach 500MW by 2010 • Solar photovoltaic – installed capacity to reach 400MW by 2010 • Biomass – total installed capacity to reach 2039MW by 2010 • Biogas – production to increase by 188,000 toe by 2010 • Biofuel – total production to reach 2.2 Mtoe by 2010
Special Regime for Electricity Generated from Renewable and CHP Sources	2000	Update of the Real Decreto 2818/1998 promoting electrical generation from renewable energy sources through feed-in tariffs. Tariffs range from €0.03 per kWh (for secondary biomass) to €0.36 per kWh (for PV under 5kW).
Planning and Development of the Electric and Gas Transport Networks 2002-2011	2002	Priority is given to the installation of power lines from renewable energy facilities and combined cycle power plants. Construction of gas pipelines for co-generation and gas combined cycle plants is prioritised.
Modified Aid for Electricity from Renewable and CHP Sources	2004	Royal Decree 436/2004 includes the target that by 2010, 30% of electricity should be generated from renewable energy sources. This Decree defines a system for owners of renewable energy installations, who can opt

Policy name	Date	Description
		to sell electricity either to the distributor or directly on the market. If sold to the distributor, the owner receives a set payment defined as a percentage of the average electrical rate regulated in Royal Decree 1436/2002. If sold on the market, the owner receives the negotiated market price, plus an incentive for participating in the market.

Hydrogen Pathway Components

Feedstock production

- ***Natural gas***

  Although Spain has only limited domestic supplies of natural gas, it has a well-developed natural gas infrastructure. Spain is connected to Algerian and Norwegian gas fields via pipelines through Morocco and France, and to many other gas fields worldwide through imports of LNG. Spain has a large LNG regasification capacity that could be developed to feed hydrogen production.

- ***Coal***

  In 2001, Spain was the fifth largest coal producer out of the European members of the IEA.[5] Total reserves of Spanish hard coal are estimated at 660 million tonnes.[9] However, due to quality problems and cost of production, Spanish coal is less competitive than imported coal and production is declining. Nevertheless, the coal mining industry is an important source of employment in economically depressed areas and the government is unlikely to halt production completely for social reasons.[4] Coal gasification for hydrogen production could potentially provide a value-added product for these regions.

- ***Nuclear power***

  Nuclear power is currently the most important indigenous energy source, and Spanish nuclear reactors generally perform very efficiently. However, since 1984 there has been a moratorium on new nuclear capacity construction, and the current government has publicly expressed its willingness to phase out nuclear power altogether in the medium term.[4] Nevertheless, nuclear power represents a low carbon energy source that could aid in achieving Spain's EU burden-sharing target to limit CO_2 emissions to a 15% rise from 1990 levels.

- ***Onshore wind power***

  Spain is the second largest wind energy producer worldwide, with 8,200 MW of production capacity in operation at the end of 2004, producing 15,270 GWh of electricity[10]. Growth is expected to continue – the current target is for the total installed capacity to reach 12,000 MW by 2010, and this is expected to be upgraded to 20,000 MW by 2012 in the new Energy Plan. Although some opposition to wind power development has emerged recently on grounds of impacts on landscape or bird life, wind power generally enjoys public support. The main constraint to further development is lack

of capacity of the energy transmission grid as wind farms are generally located in low population density areas with weak energy grids. [11] Regional governments are working on the development of distribution grids.

- ***Solar thermoelectric power***

  There is strong government interest in solar thermal electrical production with a target of 500 MW of installed capacity by 2010. The Solar Platform in Almería operates the only solar thermoelectric installations in the country, including a pre-commercial installation of a 5 MW steam generation plant that will be operational soon, and more are at the planning or construction phase. Barriers to further deployment of this technology are technical issues and the absence of government support in the form of grants and feed-in tariffs for further capacity above 200 MW – a total of 325 MW is already at the planning stage. However, the resources in Spain are very favourable for this technology, and there is a wide knowledge base making Spain a market leader in this technology. [7]

- ***Solar photovoltaic power***

  In 2004, a total of 37 MWp of photovoltaic production capacity was installed in Spain. The target for 2010 is 400 MWp of installed capacity. Natural resources are favourable for this technology and there is considerable interest in its further development. The main barriers to further deployment in Spain are lack of financial incentives, and difficulties in connecting installations to the grid.[7] Nevertheless, Spain hosts two of the world's leading companies in solar photovoltaic technology: Isofotón and BP Solar. Both are multinational companies responsible for a number of solar power production projects throughout the world, including some large photovoltaic installations in Spain, such as the Forum Barcelona built in 2004.[12, 13]

- ***Biomass***

  The consumption of biomass in Spain rose to over 4 Mtoe at the end of 2004, with the major consumer being the domestic sector with almost 50% of the total. Despite ambitious government targets for the use of biomass energy, growth has been slow and the original target of 9.629 Mtoe by 2010 has been reduced to 5.040 Mtoe.[7] The main barriers to more widespread use are bottlenecks in supply[4], the absence of transport logistics and a lack of demand[6].

- ***Biogas***

  Consumption of biogas reached 266.7 ktoe at the end of 2004, exceeding the target set in 2003 to be reached by 2010.[7] The main barrier to further development of this resource

is price competition with natural gas. Potentially, conversion to hydrogen could add value. Nevertheless, HyWays project stakeholders ruled out the use of the biomass and biogas to obtain H2 during the First Member State Workshop due to the low production of biomass and the difficulty of obtaining hydrogen with the desired purity.

- ***Other renewables***

  Spain has a relatively well-developed biofuels industry compared to other European countries. Consumption of biofuel reached 228,2 ktoe at the end of 2004. The target for 2010 is 2,2Mtoe[6]. While biofuels are suitable for conversion to hydrogen, they are more likely to be consumed directly as fuels for internal combustion engine vehicles, as they can be used with little or no engine modification.

  Spain has a relatively large hydroelectric capacity, totalling 1,748 MW at the end of 2004 for mini hydroelectric plants (smaller than 10MW) and 2199 MW for hydroelectric plants (power plants between 10-50MW). The total technically feasible potential for hydroelectricity has been estimated at 65,600 GWh per year (although it is unlikely that all this potential could actually be used, mainly because of environmental reasons and competition with other water uses). However, despite ambitious government targets, development of hydroelectric capacity has been slow and dominated by the construction of plants smaller than 10MW.

Feedstock distribution

- ***Pipeline***

  Spain has a fairly well-developed domestic natural gas pipeline network covering almost all regions of the Spanish peninsula, and further investment in the infrastructure is ongoing.[5]

- ***Electricity grid***

  Most of the national high-voltage networks are owned by Red Electrica, the Transmission System Operator.[5] In general the transmission grid is well-developed, with the exception of areas with low population densities where lack of grid capacity can be a barrier to the development of renewable energy sources such as wind power.[11]

- ***Truck***

  The road system in Spain is well developed and should not present any problems for the movement of feedstocks.

Hydrogen production

- ***Steam methane reforming (SMR) of natural gas***

  Reforming of renewable and fossil fuels is an area of considerable research interest in Spain.[14] There is also some industrial experience of hydrogen production through SMR in Spain. For example, Air Products and Technip operate an SMR plant in Tarragona.[15] The Tarragona plant has a production capacity of 400 MNm^3 of hydrogen with a purity of 99.9%. The majority (99%) of the hydrogen produced is distributed by pipeline with the remainder by pressurised bottles.[16]

- ***Coal gasification***

  Spain has considerable experience in coal gasification technology. The 335 MW Puertollano gasification plant operated by Elcogas has been operating on coal since 1998, producing syngas for use in a combined cycled gas turbine. The plant was upgraded in 2003 to include a hydrogen production unit under the HYDROGAS demonstration project.[17] The main barrier to more widespread deployment of this technology is the extra complexity of the process and the higher cost of the resulting hydrogen when compared to SMR.[20]

- ***Biomass gasification***

  Spain has a relatively large experience of biomass gasification technology. A number of domestic companies have developed and commercialised biomass gasification technologies and there are several gasification plants in operation. These include a 500kWe almond shell gasification plant in Mora d'Ebre, which has been operational since 1997. Further plants are planned, including a 7.3 MWe plant at Totana (Murcia), although to date none of them are designed for hydrogen production.[18]

- ***Electrolysis***

  Spain has considerable research experience in hydrogen production through electrolysis, particularly from photovoltaic power. Research in this area began in the 1990s and remains a priority,[14] with a number of demonstration projects in Spain currently using this technology.[19] The main barrier to this technology remains its high cost – unless adequate sources of cheap electricity can be found hydrogen produced by electrolysis will not be cost competitive with hydrogen from SMR.[20] Due to the high development of wind energy in Spain, a lot of companies in this sector are interested in the development of

electrolysers to produce hydrogen as an energy buffer to keep the electricity grid more stable and harmonized.

- ***High-temperature decomposition***

  Although high temperature decomposition for hydrogen production is a relatively immature technology, it has the potential to reduce the cost of hydrogen production significantly through greater efficiency – over 50% efficiency can be expected, although the commercial viability has yet to be shown.[20] This does not appear to be a research priority in Spain at the moment, although it could have synergies with the solar thermoelectric power research currently underway.

- ***Novel hydrogen production technologies***

  There is research interest in emerging hydrogen production technologies in Spain such as photoelectrolysis, photobiology or biomimetic techniques, although these have not yet been commercialised and further research is needed to demonstrate their viability.[14]

- ***Carbon capture and storage (CCS)***

  CCS technology does not appear to be a priority research area in Spain. However, as part of the CASTOR project, the Spanish oil company Repsol is developing the Casablanca oil field for a CO_2 storage demonstration project. Production at this oil field will soon cease, and Repsol aims to use it to store approximately 500,000 tonnes of CO_2 per year, which will be captured at the Tarragona refinery, 43 km from the field.[21] Furthermore, the Spanish energy company ENDESA is an industry partner in the EC GeoCapacity project, which aims to assess the European capacity for geological storage of carbon dioxide.[22] The main barriers to more widespread deployment of this technology are the high cost of post-combustion capture and the lack of accepted verification and validation procedures.[21] Although some studies have been conducted on CCS potential at specific sites in Spain (such as Puertollano) by Elcogas and the National Institute of Geology and Mining (IGME), data on the capacity of these sites was not available. The total CCS potential for Spain is also unknown at present.

Conversion

- ***Compression***

  The main companies with expertise in hydrogen compression in Spain are Air Liquide, whose Spain branch is responsible for compression at the refuelling station in Madrid as part of the CITYCELL project, ABELLÓ- Linde and Carburos Metalicos. The latter two companies have been involved in a number of demonstration projects worldwide including the CUTE hydrogen bus demonstrations.[23] Barriers to more widespread use of compressed gas include technical problems with storage tanks (such as their size) and the low efficiency of the compression process.[20]

- ***Liquefaction***

  As with hydrogen compression, the main companies with expertise in cryogenic hydrogen liquefaction are Air Liquide, ABELLÓ- Linde and Carburos Metalicos.[23] The main barriers associated with this technology are its high cost and relatively low efficiency. There is also a problem with public perception – liquid hydrogen is seen by many as very high tech and unsafe.[20]

- ***Rechargeable metal hydrides***

  The use of rechargeable metal hydrides for hydrogen storage is a research priority in Spain. In the public sector, the aerospace research organisation INTA is conducting research in this area.[24] The Spanish company Hynergreen is also researching metal hydride storage technologies.[25] Barriers to more widespread use of metal hydrides are the weight and cost of the materials.[20]

- ***Carbon-based materials***

  Carbon-based materials such as nanotubes as a possible hydrogen storage technology are also being researched in Spain. The public scientific research organisation CSIC is active in this area.[26] At present it is still unclear whether these materials can be successfully engineered to store high levels of hydrogen at room temperature.[20]

- ***Novel technologies***

  Other hydrogen conversion technologies such as glass microspheres, rechargeable organic liquids and chemical hydrides do not appear to be a research priority in Spain.

H2 transport

- ***Hydrogen pipelines***

  At present there are two hydrogen pipelines operational in Spain, a 20km one in Tarragona and a 5km one in Algeciras. Companies operating in Spain such as Air Products and Carburos Metalicos also have experience of operating hydrogen pipelines elsewhere in the world, and the existing Spanish natural gas pipeline network could potentially be upgraded to transport hydrogen were demand to increase sufficiently to warrant the investment needed.[27]

- ***Road transport***

  Air Liquide, ABELLÓ- Linde and Carburos Metalicos all have industrial experience of transporting hydrogen by compressed gas or cryogenic truck. For example, Air Liquide is responsible for supplying compressed hydrogen by truck to the CUTE project hydrogen refuelling station in Madrid.[28]

Distribution

- ***Refuelling infrastructure***

  Hydrogen refuelling infrastructure already exists in both Barcelona and Madrid. These refuelling stations were constructed as part of the CUTE project and are operated by BP in Barcelona, and Repsol, Gas Natural SDG and Air Liquide in Madrid.[28] There are also plans to install a further four small regional refuelling stations.

- ***Mini grid***

  Hydrogen mini grids exist in all Spanish oil refineries (Repsol:La Coruña, Puertollano, Cartagena, Tarragona; BP: Castellón; CEPSA: Algeciras, Huelva, Tenerife), but these grids don't extend beyond the refineries' installations.

End use

- ***Vehicle usage***

  Demand for private car transport has been rising steadily in Spain, from 232.4 Gpkm in 1990 to 386.8 Gpkm in 2005. It is predicted to continue rising, reaching 470Gpkm by 2030.[8]

- ***Fuel cells***

  Fuel cell technology is the focus of a considerable amount of research in Spain, both public and private. The focus appears to be mainly stationary applications of fuel cells, although there is also some development of fuel cells for transport applications, particularly for buses. Current fuel cell projects include the development of a fuel cell bus for Madrid, fuel cells for defence applications, as well as research into PEM and SOFC fuel cells in general.[14] In the private sector, the Spanish technology company Ajusa has been conducting research into fuel cells over the past few years and has recently launched a commercial PEM fuel cell onto the market.[29] Other companies commercially involved in fuel cell systems include Ansaldo, which installed an MCFC in a power plant in San Augustin de Guadalix in 2004, Ariema and Hynergreen.[23]

- ***ICE***

  Although there are no hydrogen ICE applications currently operational in Spain, systems are under development by Spanish industry. For example, Grupo Guascor is a private industrial group that makes gas engines and cogeneration systems. The “Guascor R&D” division has developed a number of different hydrogen-fuelled engines. Spain has a relatively large cogeneration capacity with 5,520 MWe installed by the end of 2001, most of which is gas-fired.[30] This represents valuable experience for the development of hydrogen-fuelled cogeneration capacity in the future.

Conclusions

Although the current hydrogen infrastructure in Spain is relatively limited with few production facilities and demonstration projects compared to some other European countries, there is a considerable amount of research being conducted in Spain on hydrogen technologies, particularly fuel cells. Spain also enjoys a position as a market leader in renewable energy, particularly wind and solar photovoltaic power, and increasingly also solar thermal power. There is consequently an opportunity to capitalise on these strengths by applying them to the development of a national hydrogen infrastructure.

However, there are significant barriers to such a development. Although Spain is well placed with respect to fossil fuel feedstocks, further capacity for their conversion to hydrogen will need to be developed. At present fossil fuel-based hydrogen is most cost-competitive and is likely to remain so for the short to medium term at least. There is therefore a case to be made for further investigation of technologies for capture and storage of the carbon this process inevitably produces.

The renewable energy sector is growing rapidly at present and is likely to continue to do so, providing an option for low or no carbon emission hydrogen production. Nevertheless, it is unsure whether growth in this area will be enough to replace a possible phase out of nuclear generating capacity. Technologies for the use of this renewable energy for hydrogen production also need further development. There are a number of potentially very interesting technologies at the research phase, but these will need support to reach the market, if indeed they prove viable.

In general, while technology exists for the various components of a hydrogen infrastructure it is often relatively unproven commercially and usually expensive – cost remains the most significant barrier to hydrogen infrastructure deployment.

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