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HYRREG

THE ROADMAP FOR HYDROGEN AND FUEL CELLS IN SUDOE AREA

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HYRREG:
THE ROADMAP FOR HYDROGEN AND FUEL CELLS IN SUDOE

Esther Chacón, Loreto Pazos, Rei Fernandes, Rui Pimenta, Carole Couhert.

PROLOGUE

Justification for hydrogen economy: energy dependence arguments, emissions, etc.

Energy has always been a key driver in the economy. Nowadays, the security of supply, air pollution, fossil fuels dependence, greenhouse gas emissions, etc… are growing concerns to almost all the countries in the world. An energy economy including hydrogen could resolve most of them.

Hydrogen is an energy vector like electricity. It can be produced from a variety of raw matter and energy resources: fossil fuels, nuclear energy and renewable, like biomass, wind and solar energy with zero carbon content (considering carbon capture and storage (CCS) in hydrogen production from fossil fuels or raw matter). Hydrogen offers a long-term potential for an energy system that produces zero emissions and is based on available domestic resources.

Aim of the roadmap

Despite the promising aspects of hydrogen economy, its realization faces multiple challenges, from economic to technological and institutional barriers. The need for a coordinated Roadmap that defines a strategy to overcome these barriers seems natural.

Several countries have elaborated a National Roadmap for Hydrogen Economy. Even a European one, including ten countries of the EU, was developed under the VI Framework Programme: the HyWays project. HyRREG roadmap aims to define the scientific, technological, economic, political and social capabilities and deficiencies of SUDOE area regarding hydrogen and fuel cells.

EXECUTIVE SUMMARY

SUDOE Region is comprised of 30 regions and autonomous cities of Spain, France, Portugal and Gibraltar representing about 770 120 km2 (18.2% area of EU-27) and 61.3 m inhabitants (12.4% of EU-27).

Renewable energy sources are growing steadily as sustainable policies to reach the EU 20-20-20 targets are being implemented by Member States. Whilst the installed capacity for electricity generation from renewable in EU-27 grew 54% in the decade to 2007, 58% of that capacity was concentrated in just four countries (Germany, Spain, France and Italy). The increase was mainly due to wind capacity and SUDOE accounts for over 35% of that capacity with contributions from Spain (16,740MW), France (3,404MW) and Portugal (2,862MW). The HYRREG consortium therefore believes that there is a good basis for supporting the development and introduction of hydrogen-based technologies in the region especially with respect to the use of hydrogen for storage.

HYRREG analysis is mainly qualitative. Both stakeholders' preferences and country specific conditions such as availability of resources, environmental policies and the characteristics of the current and future energy system are taken into account.

Energy framework and resources are not the same in the three countries comprising SUDOE hence the fact that each of them has selected a different group of H2 chains. On the other hand, some aspects are very similar in the three countries so several H2 chains have been selected in the three of them: natural gas as the current H2 pathway and wind and solar energy for the future.

Not only is necessary a well knowledge of the energetic context in SUDOE for defining a consistent Roadmap for H2 and FC in the area, but also a good understanding of each region´s profile in relation to the future H2 economy. This study was carried out by means of a consultation process to experts in the issue.

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ABBREVIATIONS:

ADEME: Agence de l' Environnement et de la Maîtrise de l' Energie
APU: Auxiliary Power Unit
CCS: Carbon Capture and Sequestration
CGH2: Compressed Gas Hydrogen
CIDAUT: Spanish Foundation for Transport and Energy Research and Development
DGEG: Portuguese Energy and Geological General Direction
EU: European Union
EV: electric vehicle
FC: Fuel Cell
FCEV: Fuel Cell Electric Vehicle
GAC PTEHFC: Capabilities Analysis Group from the Spanish Technological Hydrogen and Fuel Cells Platform
GDP: Gross Domestic Product
H2: Hydrogen
IEA: International Energy Agency
IGCC: Integrated Gasification with Combined Cycle
INE: Statistic National Institute
ITC: Canary Islands Technological Institute.
KCAM: Key Changes and Actor Mapping.
Ktoe: Kilo ton of oil equivalent
OECD: Organization for Economic Cooperation and Development
PHEV: plug-in hybrid electric vehicle
PLOCAN: Canary Islands Oceanic Platform
REE: Spanish Electric Grid
RES: Renewable energies
SME: Small and medium enterprise
SMR: Steam methane reforming
SUDOE: South East European regions
SWOT: Strengths, Weaknesses, Opportunities and Threats
Toe. Ton of oil equivalent

1 INTRODUCTION

1.1 History and context

The SUDOE Region is comprised of 30 regions and autonomous cities of Spain, France, Portugal and Gibraltar representing about 770 120 km2 (18.2% area of EU-27) and 61.3 m inhabitants (12.4% of EU-27).

Portugal and Spain have some of the highest energy dependencies in Europe, surpassed only by Italy, Ireland, Cyprus, Luxembourg and Malta in the European Union (Eurostat 2009). In 2007 the levels of dependency were 82.0% and 79.5% respectively whereas that for France was 50.4%. Eurostat data for the year 2007 indicate that fossil fuels (hard coal, lignite, oil and gas) account for 80% and 84% respectively of the gross inland consumption of energy for Portugal and Spain. In France the equivalent figure is 53% because of the large share of nuclear energy (42%).

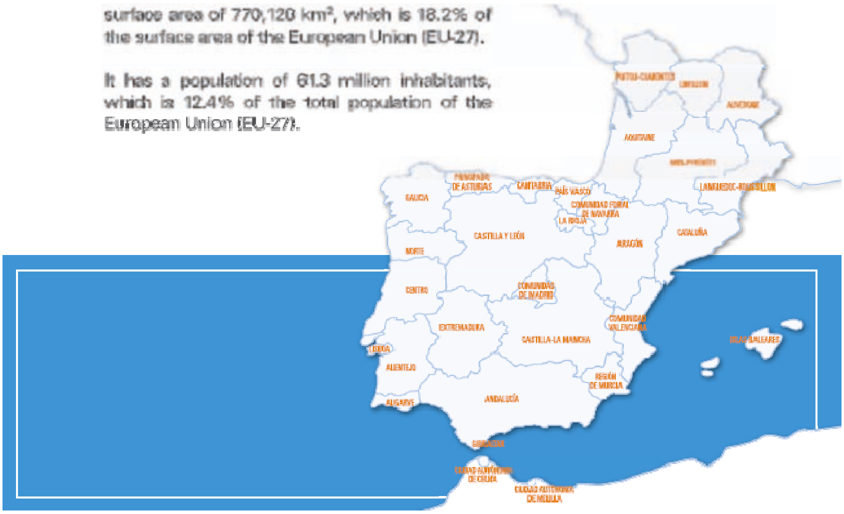
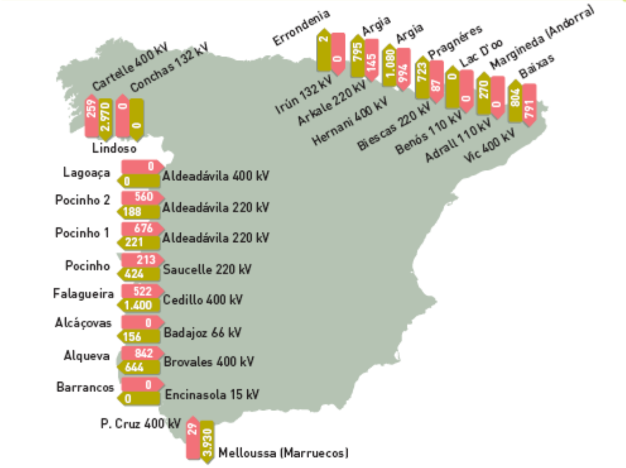


Fig. 1. SUDOE map
Source: SUDOE webpage

Renewable energy sources are growing steadily as sustainable policies to reach the EU 20-20-20 targets are being implemented by Member States. Whilst the installed capacity for electricity generation from renewable in EU-27 grew 54% in the decade to 2007, 58% of that capacity was concentrated in just four countries (Germany, Spain, France and

Italy). The increase was mainly due to wind capacity and SUDOE accounts for over 35% of that capacity with contributions from Spain (16,740MW), France (3,404MW) and Portugal (2,862MW). The HYRREG consortium therefore believes that there is a good basis for supporting the development and introduction of hydrogen-based technologies in the region especially with respect to the use of hydrogen for storage. Renewable energy provides not only security of supply but paves the way for a cleaner environment if is used to produce hydrogen by electrolysis. In France an important alternative under investigation as a means of producing hydrogen is by thermolysis using nuclear energy. For Portugal and Spain the development of renewable energy is particularly important as both countries can be considered as "energy-deficient islands" due to their high energy dependency.

International electric energy exchanges in SUDOE are showed below. As can be seen, SUDOE is an exporting area from the electric point of view.



Saldo de los intercambios internacionales físicos de energía eléctrica (GWh)

	Francia	Portugal	Andorra	Marruecos	Total
2006	4.410	-5.458	-229	-2.002	-3.280
2007	5.487	-7.497	-261	-3.479	-5.750
2008	2.889	-9.439	-278	-4.212	-11.040
2009	1.590	-4.807	-299	-4.588	-8.104
2010	**-1.387**	**-2.931**	**-270**	**-3.902**	**-8.490**

Saldo positivo: importador; saldo negativo: exportador.

Fig. 2. International electric energy exchanges in SUDOE map
Source: REE. 'Spanish electric system report 2010'.

1.2 Background and objectives

National strategies have been defined in different countries to accelerate hydrogen economy deployment. Projects like HyFrance, NorHy, HyNet, HyWays, HiPo have helped towards that definition by developing a roadmapping exercise in different European countries. Canada, Japan and The United States have also published a National Hydrogen Energy Roadmap.

The idea of developing a specific roadmap for SUDOE has its origin in “HyWays,” an integrated project co-funded by research institutes, industry and the European Commission under FP6 that produced a roadmap for introducing hydrogen technologies into the European energy system. Although France and Spain were analysed in the HyWays project some of the generalizations and assumptions used in the HyWays analysis were not best suited for the actual conditions in SUDOE. In addition, there has been demand from stakeholders participating in HyWays to analyse the SUDOE area thoroughly by regions. The HyFrance project has already produced a roadmap for France and Portugal too has made progress towards a national roadmap through the HiPo project. HYRREG will continue to develop a roadmap to define and describe the specific characteristics of the region.

The objective of the HyRREG roadmap is to define the scientific, technological, economic, political and social capabilities and deficiencies of the SUDOE region regarding hydrogen and fuel cells.

The vision of a hydrogen economy in the region is based on the expectation that hydrogen can be produced from different resources, economically and in an environmentally acceptable manner, facilitating the end-use of hydrogen technologies to enable a significant market share in the near future, thus ensuring a greater degree of energy security and an improved environmental quality for the region. It is anticipated that the implementation of hydrogen technologies will contribute towards diversification and technical adaptation involving a large number of industries and SME, affording opportunities to develop new innovative products and services.

1.3 Methodology

The analysis performed in HYRREG is mainly qualitative. Both stakeholders' preferences and country specific conditions such as availability of resources, environmental policies and the characteristics of the current and future energy system are taken into account.

The methodology used in the HYRREG roadmap is mainly based on an iterative enquiry process to a selected stakeholders group involved in the energy context.

As baseline scenario some results and figures from previous work that applies to Europe (or SUDOE) in general are presented in 'Review of previous studies' section and taken into account for realistic predictions.

The results for our analysis are showed in three sections, one for each of the SUDOE regions of Spain, France and Portugal.

1.3.1 SWOT matrix

In order to define the starting scenario for a hydrogen economy a series of questionnaires (Qs) was prepared. Each questionnaire was devoted to one aspect of the hydrogen energy chain: production, storage/distribution, conversion/final use and perception/promotion. These questionnaires were addressed to the relevant regional actors: the stakeholders. Industry, public institutions and decision makers were included in the HYRREG database and asked to collaborate by filling in the questionnaires. A first analysis of SUDOE was made using available documentation and stakeholders´ answers to Qs. As a result, a SWOT (Strength, Weaknesses, Opportunities and Threats) analysis of each region regarding the implementation of a hydrogen economy was carried out.

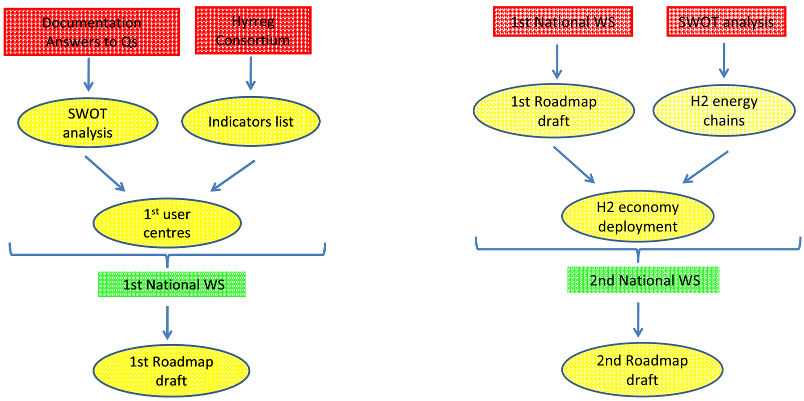


Fig.3: HyRREG roadmap methodology

Source: HyRREG project

Subsequently, the first user centres of hydrogen in SUDOE, i.e., the regions that will act as a seed for a hydrogen economy in the three countries participating in HYRREG, were identified.

1.3.2 Hydrogen production chains

When carrying out a roadmap analysis of a new energy system based on hydrogen, we should analyze how hydrogen is going to be produced and for what purpose. This is the key goal of the hydrogen energy chains' definition: to select the most appropriate pathways to produce, distribute and use hydrogen in each country and to identify the barriers in its implementation.

This process was also carried out with the stakeholders´ collaboration by means of workshops, personal interviews and e-mail communication.

A three-stage time horizon is proposed to define the H2 economy introduction and evolution in society: 2020, 2030 and 2050. H2 energy chains are allocated in the correspondent stage and specific features explained.

1.3.3 Actor analysis

The role of Actor Analysis is to provide an additional layer of largely qualitative information to Region representatives and stakeholders for use and consideration in the construction of their hydrogen energy roadmaps. It is intended to complement the other roadmapping activities of the HYRREG project which do not capture a range of significant information.

The principal methodology of Actor Analysis is called "Key Changes and Actor Mapping" (KCAM), method that seeks to systematically examine each component of each hydrogen chain selected by Regions, and in every case to identify a range of qualitative elements which are not captured in other HYRREG roadmapping components.

Examples of such qualitative elements are:

- Relevant market conditions
- National policy goals and priorities
- Geographical considerations
- Societal considerations
- Historical considerations

- Estimated timeframes for the realization of hydrogen chains
- Estimated difficulties for the realization of hydrogen chains

For the purposes of Actor Analysis a “Key Change” may be defined as: ‘One of a number of distinct changes that are foreseen as necessary to progress from the current energy system to the end-vision as described in each hydrogen chain selected’.

This version of the KCAM methodology focuses on Region Specific Key Changes which are applicable only within the confines of the Regions specific contexts. They apply specifically to the Region in question and avoid describing Key Changes which are more widely applicable such as the technological status of hydrogen technologies. They are related to Region specific energy supply and demand trends, energy transportation infrastructure, political disposition and policies, and national societal knowledge and technology acceptance levels. Region Specific Key Changes are validated by Region representatives and stakeholders following preliminary mapping work.

Actor Analysis culminates in an Actor Analysis Report, which presents the methodology, Key Change Difficulty Summary Charts and Broad Actor Group Heat Charts, as well as cross-cutting analyses. The most relevant results of this report are presented in this document.

KCAM analysis was also carried out by means of an enquiry process to the stakeholders. The results of the interviews were aggregated in different ways, in order to extract as much information as possible. There are 3 main sections in this analysis – components, chains and broad actor groups –, as discussed in subsequent sections.

1.4 Review of previous studies

As a baseline for the H2 and FC roadmap deployment, H2 production prices and the evolution of emissions associated with different H2 process technologies for the mid and long term were taken into account. There are general statements that can be applied to all SUDOE area and are showed in next figure, D standing for distributed and C for centralised.

As can be seen in the figure, extracted from ‘The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles’ report by Mckinsey and Company, SMR and

IGCC are the most economic H2 production pathways in the mid term future. SMR and IGCC costs will rise in the future due to price increase of the fossil fuels and CCS. However the cost of electrolysis costs will reduce because of the efficiency improvement. H2 could be produced in a profitable way at small and large scale –from 0.4 to 1000 tons per day- in centralised or distributed applications.

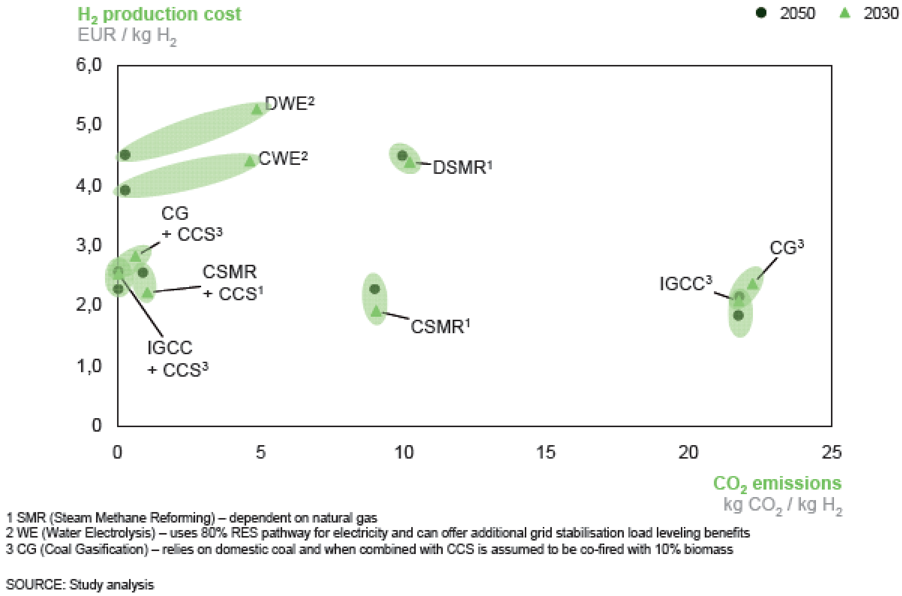


Fig. 4: H2 production prices and emissions evolution associated with different technologies for the mid and long term 2030-2050

Source: 'The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles', from Mckinsey and Company

Some chain components are independent of the source and the conversion process and are common to all H2 chains. They are the distribution, storage and end-use components.

According to the report 'The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles', from Mckinsey and Company, a wide variety of distribution infrastructures can be considered, depending on H2 volume, distance and specifications can be considered. The following graphs and tables can be found in the above mentioned report.

At the initial stage of the introduction of the technology the most relevant infrastructure will be the transportation of compressed gas H2 by truck (CGH2), followed by a transition phase towards transport by pipelines, where liquid H2 by trucks will be used.

DISTRIBUTION SYSTEM	TONS OF HYDROGEN / DAY
Truck -liquid	3.5
Truck -gas	0.4 (250 bar), 0.8 (500 bar)
Pipeline -gas	1, 2.5, 10, 100

Table 1. H2 distribution systems

The use of pipelines will result in a reduction of both the price of hydrogen and in the CO2 emissions. In the figure below, from the same report, the evolution of the distribution systems is represented.

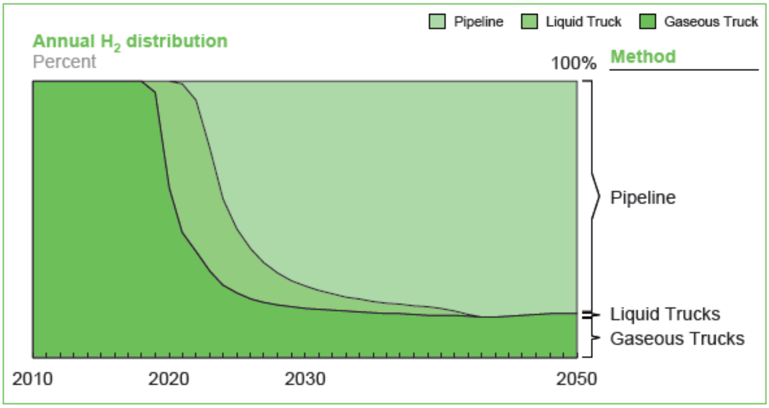


Fig. 5. H2 distribution systems forecast

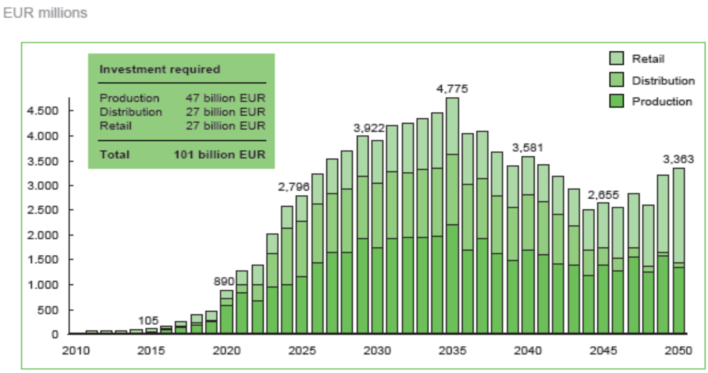
The H2 refuelling stations size will depend on the demand and the area to be covered. In the early stages, when the demand increase is lower than the application area increase, H2 refuelling stations will be small in size, while at subsequent stages when demand increases faster than the area, H2 refuelling stations size will be larger.

Small station (70-100 cars per day)	*2 dispensers, 0.4 tonnes of hydrogen/day*
Medium station (150-250 cars per day)	*4 dispensers, 1 tonne of hydrogen/day*
Large station (450-600 cars per day)	*10 dispensers, 2.5 tonnes of hydrogen/day*

Table 2. Hydrogen refuelling stations sizes

During the first decade, the number of users will be low which will result in an increase in the cost of the stations. It is expected that the large refuelling stations will have a better economic result than the small or medium sized ones.

In 'The Role of Battery Electric Vehicles, Plug In Hybrids and Fuel Cell Electric Vehicles' report, some assumptions and considerations were taken into account in order to obtain illustrative results. Considering a 25% fuel cell vehicles (FCV) penetration rate for Europe in 2050, the total capital investment for a large scale H2 supply deployment was estimated to be 100 billion € over 40 years. In the report it is also estimated that the infrastructure cost for H2 use will be equivalent to 5% of the total price of a FCV (1.000-2.000 € per vehicle). Some figures from the mentioned report are shown next. The first one shows the H2 refuelling station cost distribution forecast from 2020 to 2050.

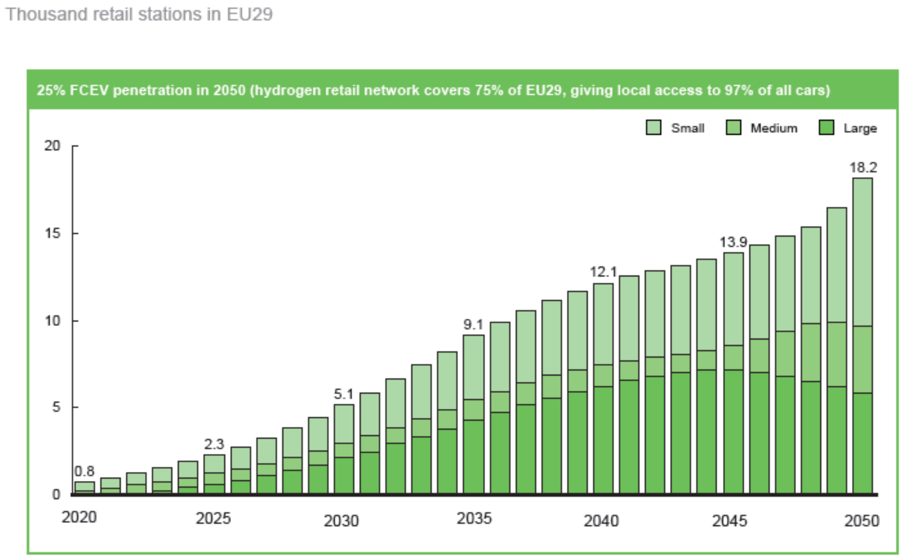


1 Current annual capex requirement for the EU

SOURCE: WIS Global Insight; OVUM; OECD / International Transport Forum; study analysis

Fig. 6: H2 refuelling station cost distribution forecast

During the first decade of a business as usual deployment scenario, H2 supply deployment costs will be high because although the utilization rate is low, a wide enough infrastructure must be available.



Note Small stations have maximum capacity of 400 kg H2/day, medium have 1 tonne H2 /day and large have 2.5 tonnes H2 /day

Fig. 7.- Number of thousand retail H2 refuelling stations from 2020 to 2050

Regarding the use of H2 as a fuel for automotive, several conclusions were obtained from the above mentioned report: Fuel Cell Electric Vehicles (FCEV) have a higher CO2 emissions reduction potential than Internal Combustion Engine Vehicles (IEC) and FCEV emissions rate in 2050 could be close to zero according to “well-to-wheel” life cycle analysis. It is also remarkable that although Battery Electric Vehicles (BEV) have a very low emissions rate, their short autonomy is a limitation that makes them unsuitable for long distance travel which is not the case for the FCEV.

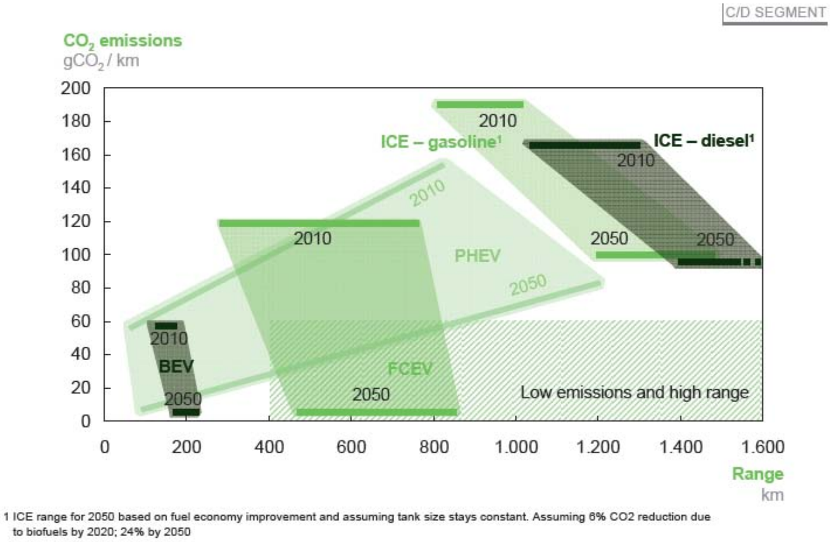


Fig. 8. Emissions and range comparative for different kind of vehicles

1.5 Roadmap evolution

HYRREG´s deployment infrastructure for a hydrogen economy will be established in a three-stage timeframe: short term (2020), mid term (2030) and long term (2050). First user centres are expected to emerge in the short term and, based on natural resources, state of the art and all aspects reflected in the SWOT analysis, first hydrogen energy chains will be selected.

But technological, political, economic and social aspects will lead to a different evolution of this first scenario. Technological advances, mass-production, economy of scale, environmental policy and social acceptance have to be taken into account when defining the future energy system and in consequence, the future scenario for hydrogen.

1.5.1 General statements

To evaluate the possible role of hydrogen in future society, assumptions about how this society will develop in time have to be made. By and large, this means that the energy system has to be parameterised, indicating against which socio-economic background the introduction of hydrogen will take place and hydrogen technologies have to be evaluated for a realistic roadmap.

According to next figure, from the "European Energy and Transport: Trends to 2030" publication (Energy Trends 2030) for general statements about energy, fossil fuels cost evolution will enable new energy vectors as H2 to be considered an alternative.

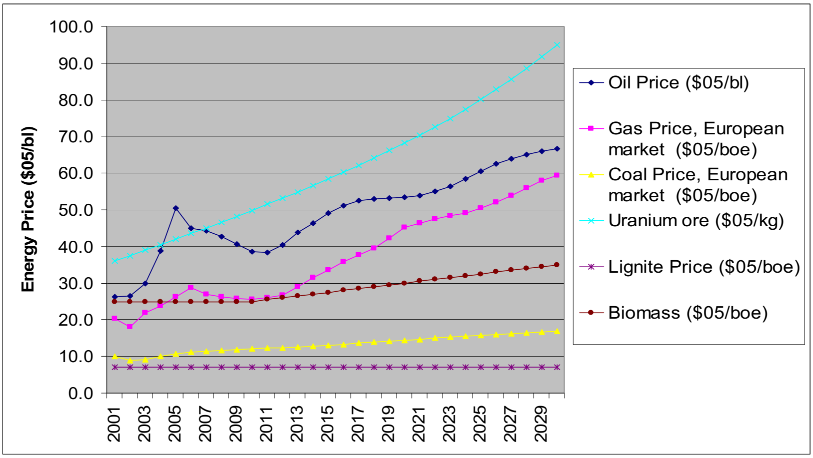


Fig. 9. Natural Resources Evolution Cost

World energy consumption from now until 2030 is estimated to increase by approximately 40% according to the International Energy Agency (IEA) forecasts, largely due to the growing demand from emerging economies, especially China and India, which account for over 50% of the growth in demand. In this scenario, fossil fuels will continue to cover 80% of the world's energy demand, with consumption shifting to Asia and the Middle East, where the bulk of the increase in the demand for natural gas will be located.

The expected rise in energy demand together with the geographical redistribution of consumption will deplete fossil energy reserves and will push up prices in response to an increasing imbalance between supply and demand. Additionally, the environmental impact will foreseeable increase due to growing greenhouse gas emissions associated with increased consumption of fossil fuels.

The European Union, whose energy dependence now stands at 53%, has taken note of its increasing energy consumption and energy imports and is concerned about present trends.

The nuclear disaster that occurred in Japan in 2011 has caused a sudden braking for nuclear energy all around the world. On the other hand, the International Energy Agency (IEA) has warned about the increase of oil prices that have risen above $100 per barrel, a barrier beyond which the recovery of the world economy is in danger. These will help new technologies as H2 and FC technology to be considered as the alternative energy sources of the future.

Some forecasts regarding H2 consumption and costs are presented in the following table.

<table>
<tr><th colspan="5">Hydrogen consumption (forecast 2015)</th></tr>
<tr><th colspan="3">HFCV
(Hydrogen Fuel Cell Vehicle)</th><th colspan="2">HICE
(Hydrogen Internal Combustion Engine Vehicle)</th></tr>
<tr><td colspan="3">0.27 kWh/km
(≅ 1 MJ/km ≅ 3 l oil/100 km). It is equivalent to a reduction of 40% in the consumption of a similar advanced internal combustion engine vehicle</td><td colspan="2">0.46 kWh/km</td></tr>
<tr><th colspan="5">COSTS (forecast 2015)</th></tr>
<tr><th colspan="3">HFCV</th><th colspan="2">HICE</th></tr>
<tr><th>EU</th><th colspan="2">US</th><th>EU</th><th>US</th></tr>
<tr><td>100 €/kW
Tax reliefs applied for compensating of externalities reduction make prices´ reduction goals higher than in USA and that at this prices, these technologies are competitive with conventional ones</td><td colspan="2">50 $/kW
FC (30$/kW) +Battery+Engine+AUXILIARIES) for a production of 500000 units/year.
Prices´ reduction goals higher than in USA due to the low petrol taxes. At this prices, these technologies are competitive with conventional ones</td><td>18 €/kW</td><td></td></tr>
<tr><th colspan="5">Storage costs</th></tr>
<tr><th colspan="3">EU</th><th colspan="2">US (forecast 2015)</th></tr>
<tr><th>2020 (Hyways)</th><th colspan="2">2030 (Hyways)</th><th>70 MPa</th><th>Liquid</th></tr>
<tr><td>10 €/kWh</td><td colspan="2">5 €/kWh</td><td>10 $/kWh</td><td>15 $/kWh</td></tr>
<tr><th colspan="5">HFCV ESTIMATED COSTS (2020) with 80Kw FC</th></tr>
<tr><td colspan="5">23-26 K€</td></tr>
<tr><th colspan="5">HYDROGEN SUPPLY AT REFUELLING STATION</th></tr>
<tr><th colspan="2">OBJECTIVE Fuel Cell and Hydrogen Joint Undertaking (2015)</th><th colspan="3">US (2030)
For H2 refuelling stations producing 1.5 tons H_2/day from SMR. Electrolysis will only be competitive for electricity prices ranging between 0.02-0.03 $/kW</th></tr>
<tr><td colspan="2">< 5€/kg (0.15 €/kWh)</td><td colspan="3">2.5-3.0 $/kg</td></tr>
</table>

Table 3. Hydrogen consumption and costs comparative
Source: 2009 Technology Map of the European Strategic Energy Technology Plan (SET-Plan). JRC-SETIS Work Group

Regarding the use of fuel cells in vehicles forecast, a study of KPMG reveals that automotive industry investments for the next five years in alternative technologies will be the following:

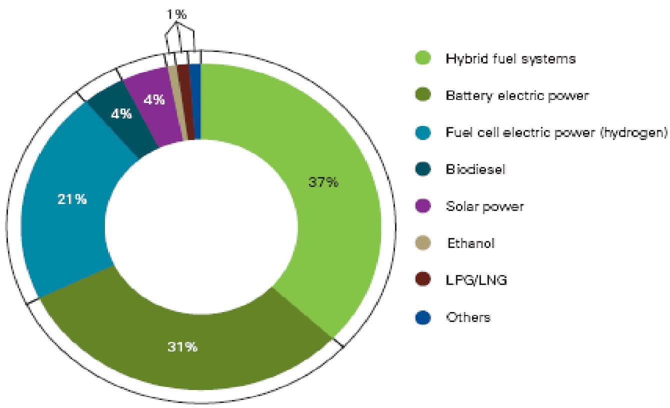


Fig. 10. Investment in alternative technologies for the automotive sector up to 2015
Source: KPMG International "KPMG's Global Automotive Executive Survey 2011"
Creating a future roadmap for the automotive industry

Current investment cost for an on-site hydrogen refuelling station is 1000 €/kW H2, expected to be reduced to 460-550 €/kW H2, in 2030 depending on the size. Total amount in infrastructure investments up to 2030 will be of 60 billion of euros. The under-use of the infrastructures during first stages will lead to an increase in the cost per km for the first users.

1.5.2 General policies

The evolution of a hydrogen economy from 2020 to 2050 will be defined taking into account National, European and Worldwide guidelines. Some of them are defined below.

The '20-20-20' objectives established by the European Commission for all the individual EU states: 20% reduction in emissions, 20% renewable energies and 20% improvement in energy efficiency by 2020 are the main drivers for energy politics in European countries. The implementation of these objectives will lead to important legislative measures in all the European countries. Hydrogen and FC are very good allies to comply with these objectives and so the perspectives in the short term are good.

The recent electric vehicles promotion is defined by Car Manufacturers and Hydrogen Economy developers as a positive fact for the Fuel Cell Hydrogen Vehicle. Both technologies are considered necessary and complementary, never competitors.

Moreover, in relation to “Climate and Energy” actions, the EU commits to supply 10% of the fuels for transport from renewable energies (biofuels, H2 and renewable electricity) by 2020.

The vision of the “Electric and Plug-in Hybrid Electric Vehicles (EV/PHEV) Roadmap” (International Energy Agency) is to achieve a combined EV/PHEV sales share of at least 50% of Light Duty Vehicles sales worldwide by 2050 in order to provide significant reductions in GHG emissions and oil use.

According to “Energy Technology Perspectives 2008”, IEA, deep emission cuts will require substantial application of CO2 capture and storage, nuclear and renewable energy technologies. Emissions can only be cut significantly if all CO2-free options play a role. Achieving the expected outcomes requires accelerated cost reductions and substantial technical improvements in both existing and emerging technologies. These will be dependent on significant increases in, and restructuring of, global RD&D efforts in both the public and private sectors.

In the international area, in 2009, there were major international activities in energy issues related to the environment. Amongst them, the European Commission adopted the legislative package on energy and climate change, which aims to reduce emissions in all the European Union in 2020 by 20% compared to 1990 levels, contemplating the possibility of increasing this reduction to 30% if a satisfactory international agreement on climate change is made.

The EU also aims to reach, by 2020, 20% of its energy from renewable sources and, by improving energy efficiency, reduce energy consumption up to 20% compared with the levels that would be reached if the trend path continues to be followed. The implementation of these objectives will give rise to important legislative measures in all member states of the EU. Spain must attain a reduction in energy intensity of 2% per year up until 2020 to be in line with the 27 EU states.

All these measures are targeted at the achievement of a sustainable energy model in the long term, with new energies and technology developments which contribute to guarantee a future energy security.

2 SPAIN

2.1 General features

This report covers all the territories of Spain including the Canary islands although they don´t belong to SUDOE area, as they are considered key elements for H2 and FC deployment in Spanish territories. To define the introduction and deployment of hydrogen (H2) and fuel cells (FC) in the Spanish energy system, it is necessary to know its history and current situation and to identify the opportunities that exist for this new technology.

2.1.1 Energy framework

Regarding energy, Spain is characterised by a consumption structure dominated by petroleum products which are mostly imported, and this, together with scant contribution from autochthonous resources, has contributed to a high degree of energy dependence and therefore a low level of self-supply. This situation began to change in 2005 within the framework of the current planning policies in connection with renewable energies and energy efficiency, which have allowed for greater penetration of renewable energies to meet domestic demand and hence an increase in the level of self-supply.

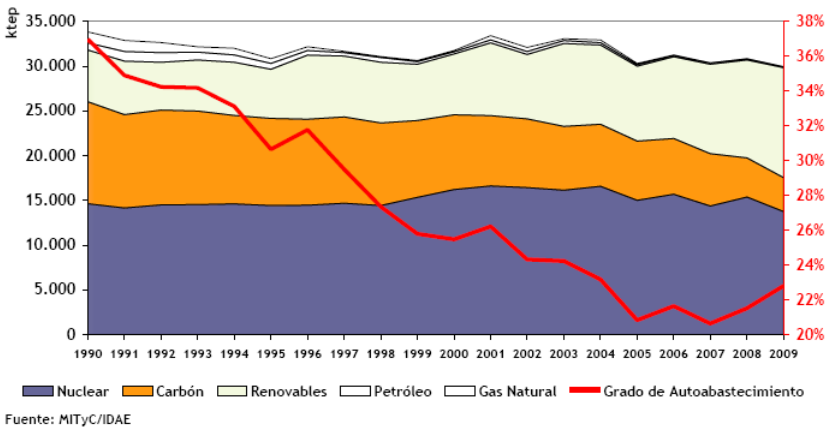


Fig. 11. Development of domestic energy production and level of self-supply

Development to 2009 of primary and final energy consumption

Energy demand, expressed both in terms of primary energy and final energy, has been rising over the last three decades, during which time there have been a number of world energy and economic crises with a negative impact on the economic activity and energy demand of most developed countries. Nevertheless, at the beginning of the 1970's this circumstance served as a catalyst in most Western countries to implement policies aimed at reducing energy dependence and enhancing efficiency in consumption. Spain was almost a decade late in reacting and did not take action until the end of the 1970’s.

The economic expansion enjoyed by Spain since becoming a member of the EU produced a considerable rise in purchasing power and hence an increase in the number of automobiles and domestic appliances and significant development in the building sector. These and other factors have been decisive in the upward trend in energy consumption.

At the beginning of the 1990s a new crisis, this time a financial one, lowered energy demand by a small margin. Subsequent developments kept consumption on the rise until 2004, which marked a new stage in the development of demand both in terms of primary and final energy. It was at this turning point that GDP growth was not followed by a commensurate rise in energy consumption to sustain that economic activity, which would appear to indicate a delinking of economic activity from energy demand reflected in the fall in energy intensity.

2009, is an atypical year as regards the trends observed: on the one hand, the underlying positive change over the last several years in terms of improved efficiency and, on the other, the effects of the crisis, two factors which account for a sharp fall in the demand for energy.

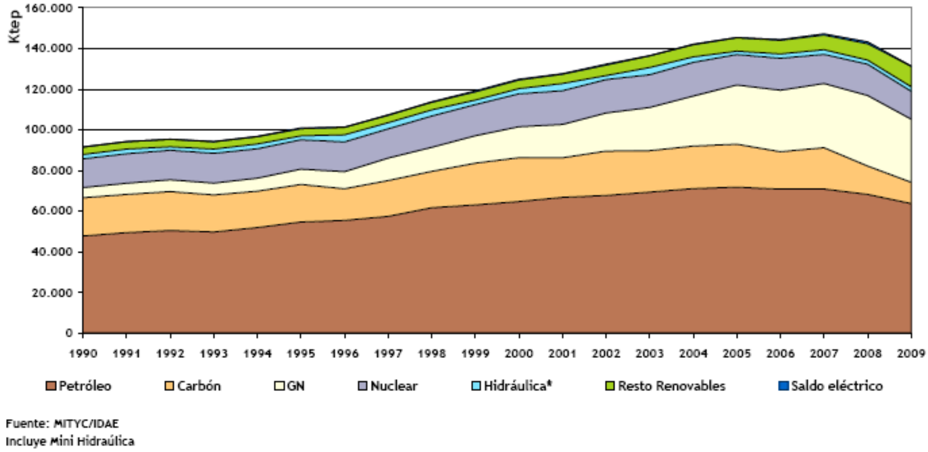


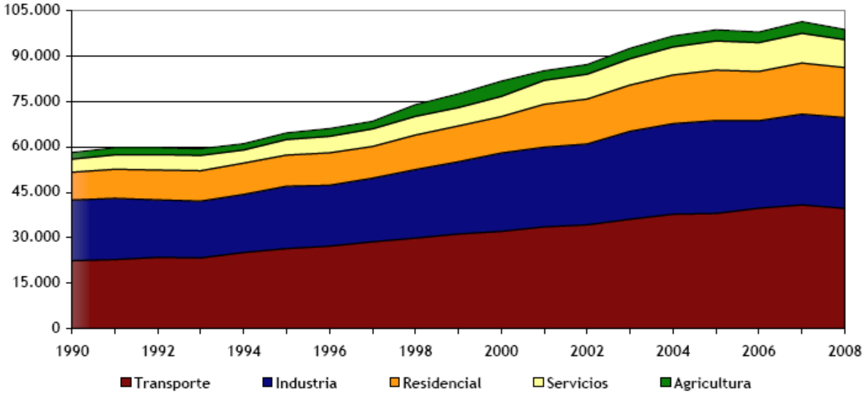
Fig. 12. Development of primary energy consumption

The structure of domestic demand for primary energy has undergone significant change over the last several decades but is especially evident as from the second half of the 1990's when energy sources such as renewable energies and especially natural gas began to play a significant role, resulting in greater energy diversification with positive effect on the efficiency of the transformation system. To a large extent this has been made possible by the actions comprising the different Gas and Electricity Sector Plans, which have entailed a great development of the energy infrastructures needed for the integration of new energy renewable sources.

Final energy consumption has followed a similar pattern to that of primary energy and also demonstrated a trend towards stabilisation and a downturn in demand starting in 2004.

A look at the sectoral breakdown of demand shows that the transport sector is the number one consumer, which accounts for 40% of the gross final consumption, based mostly on petroleum products and is responsible to a large extent for the high level of domestic energy dependence. Second in importance is industry, which accounts for 30% of gross final consumption.

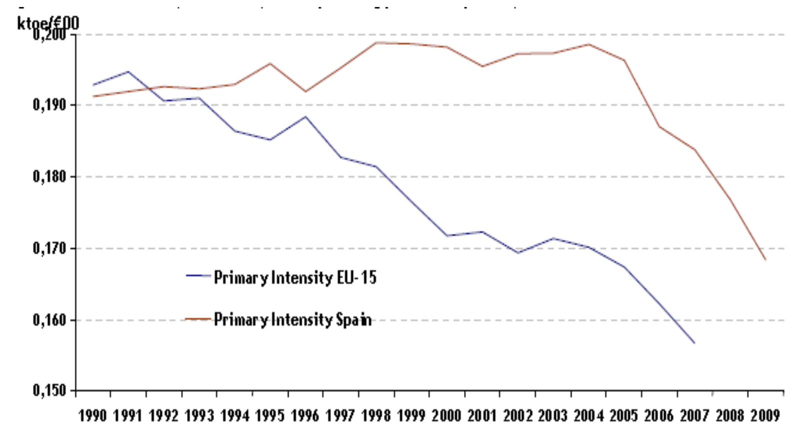
Nevertheless, energy demand from these sectors has decreased slightly in favour of other sectors (the residential and services sectors), in part due to Spain’s expanding tertiary sector.



Fuente: MITyC/IDAE

Fig. 13. Development of final energy consumption by sector.

Energy intensity evolution until 2009



Source: EnR/IDAE (Institute for Energy Diversification and Saving)

Fig. 14. Development of primary energy intensity in Spain and in EU-15

The result of the policies pursued in reaction to the 1979 energy crisis was improved energy intensity which, however, once again worsened as a result of subsequent recovery and economic expansion in the second half of the 1980s. This situation continued during the 1990s and a growing gap opened vis-à-vis the average trend observed in the EU as a whole.

However, since 2005, there was a considerable improvement in energy intensity due to structural effects and effects of a technological nature. While there continues to be a gap between domestic and European primary energy intensity indicators, it is closing.

The situation continued to improve in a context in which the generalised economic expansion that preceded the current economic crisis stands in contrast with declining energy consumption. This has meant a cumulative improvement of approximately 15% in primary energy intensity in the 2004-2009 period. However, in the midst of this crisis situation, sustained decline in demand seems to indicate the influence of factors unrelated to the crisis which are improving energy intensity.

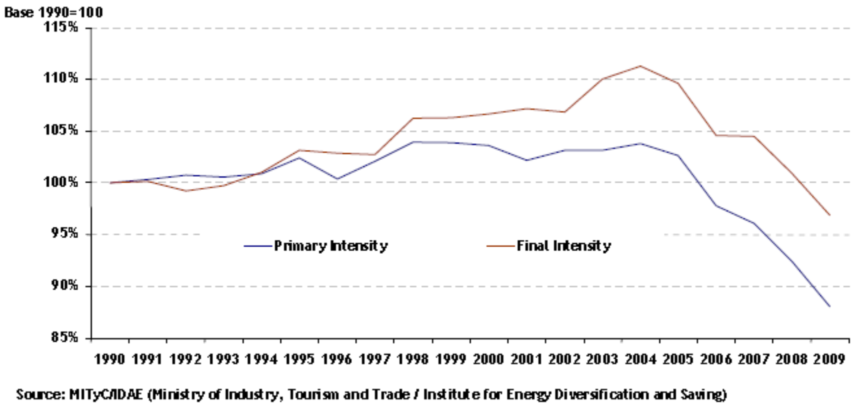


Fig. 15. Development of primary and final energy intensity in Spain

<u>Development of the electricity generation mix up to 2009</u>

Domestic electricity generation in Spain has undergone significant transformation since the end of the 90's, due in part to the progressive penetration of natural gas, mainly in combined cycle plants and in cogeneration, and to renewable energy, which have been growing in importance and today account for over 24% of the Spanish domestic electricity generation.

This situation led to a loss of importance of other sources of energy like coal and fuel oil, and even nuclear energy. From 2006 onwards, the electricity production from renewable sources even exceeded, in a sustainable way, nuclear energy production, also surpassing in recent years coal production.

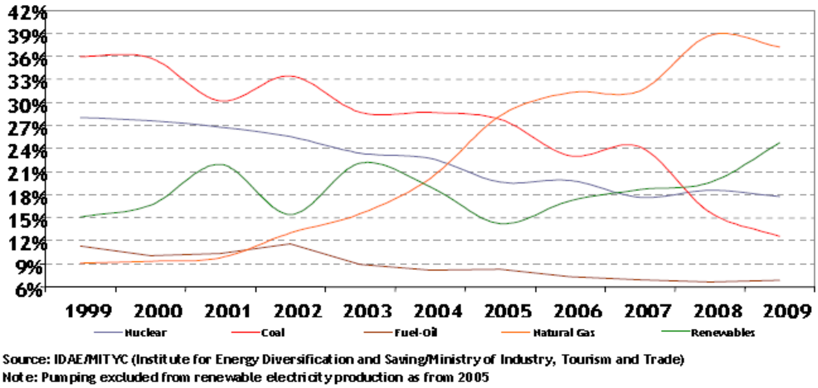


Fig. 16. Contribution of different sources of energy to electricity generation

<u>Development of renewable energies. Situation at the end of 2009</u>

Renewable energies in Spain have evolved to playing an increasingly important role in the energy system, being this evident in the coverage of demand expressed in terms of both primary and final energy. This increased contribution has been especially noteworthy since 2005.

In 2009, the year that marked the beginning of the HyRREG project, renewable energies accounted for 9.4% of the primary energy supply, and exceeded 12% in terms of gross final energy in accordance with the new methodology for calculating the contribution of renewable energies to the gross final consumption of energy.

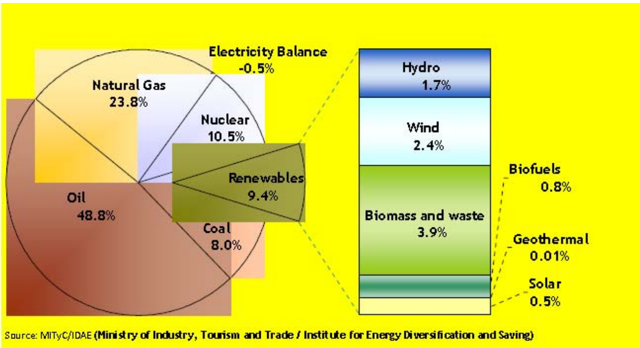
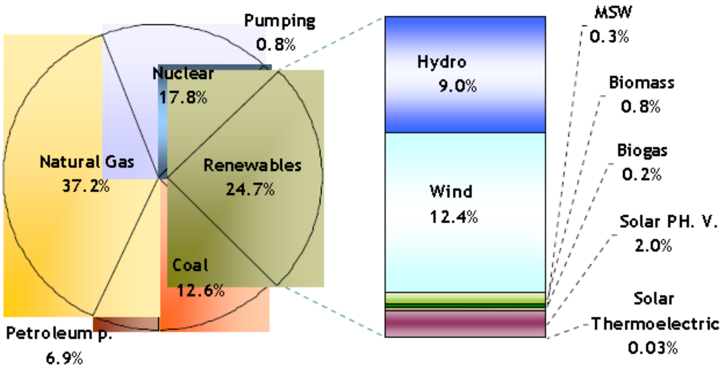


Fig. 17. Primary energy consumption in 2009

Development of electricity generation using Renewable Energies up to 2009

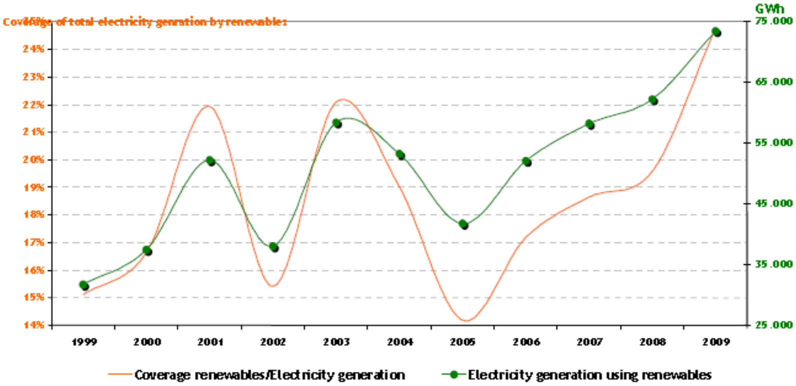
Electricity generation from renewable sources, which is variable due to climate variations affecting rainfall, has been more stable and on the rise since 2005.



Fuente: MITyC / IDAE (Ministry of Industry, Tourism and Trade / Institute for Energy Diversification and Saving)

Fig.18. Electric production of 2009

Over the last ten years, electricity generation from renewable sources has risen by over 40% and by 2009 accounted for 24.7% of the Spain's gross electricity production.



Fuente: MITyC/IDAE (Ministry of Industry, Tourism and Trade / Institute for Energy Diversification and Saving)
Note: Pumping excluded from renewable electricity generation as from 2005

Fig.19. Coverage using renewable energies / total electricity generation

Development of the consumption of biofuels up until 2009

Progress made in Spain, over the last several years, in production capacity of biofuels has been one of the most important advances made in the field of renewable energy. In 2009, Spain's biofuel plants reached an annual production capacity of over 4 million toes. (Tonne of oil equivalent).

However, the growth in production capacity has not gone hand-in-hand with consumption of biofuels. To encourage the use of these fuels, various measures were taken, particularly the approval of Order ITC/2877/2008 of the 9th of October, setting up a mechanism to encourage the use of biofuels and other renewable fuels used for transport. Consolidation of the policy outlined by the diploma of the Ministry, along with the actions taken by the European Commission to protect the European market from unfair trade practices, is expected to have a positive effect on Spanish production plants.

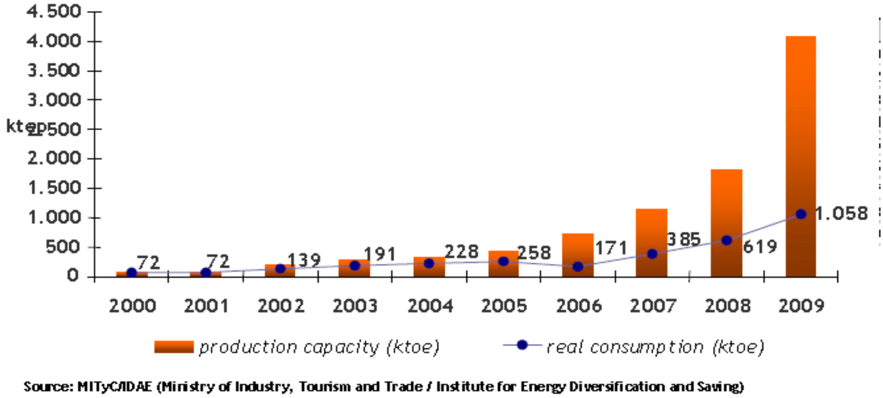


Fig.20. Development of Biofuels (consumption and production capacity)

In Spain, which shares energy characteristics with the EU, the presence of oil and its derivatives in primary energy consumption is considerably higher than the European average. As a consequence of this, and of low domestic energy production, based almost exclusively on renewable energy resources, nuclear generation and a small contribution from domestic coal, Spain's dependence on outside supply is close to 80%.

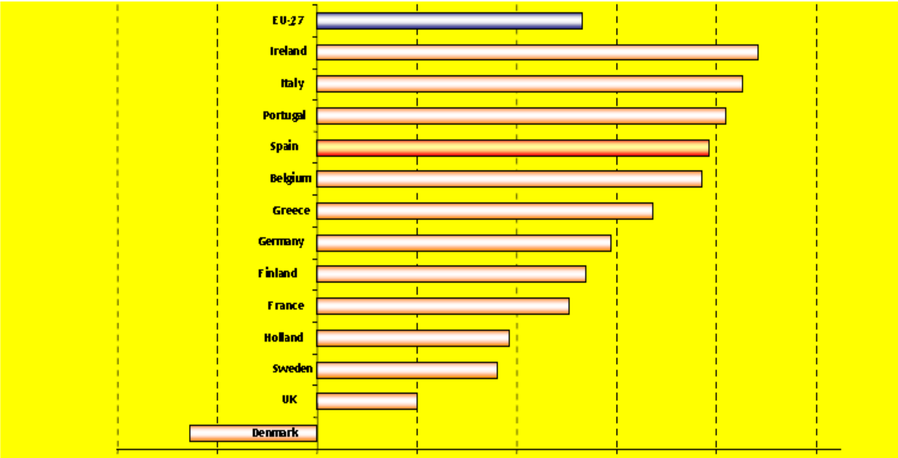


Fig.21. EU-27 energy dependence 2007/2008

Source: Eurostat

Historically, Spain has devised energy efficiency and renewable energy plans. The ones currently in force are the Energy Savings and Efficiency Strategy 2004-2012 (E4) implemented through its 2005-2007 and 2008-2012 Action Plans, and the Renewable Energy Plan 2005-2010.

This energy dependence on fossil fuel imports makes Spain very vulnerable in terms of energy supply security, as well as causing a strong environmental impact.

2.1.2 Conclusion

The growing social commitment towards the environment, the need for an energy dependence reduction of the Spanish economy and the European Union Energy Policies referring to the increase of renewable energies shares up to 20% in 2020 of the final energy consumption, have promoted considerably the renewable energies penetration in Spain.

However, a stable regulatory framework with long-term incentives is needed to continue this trend and to promote some of the energies that, like biomass, have a high potential but are lightly exploited. For example, the current economic incentives associated with solar photovoltaic energy are not foreseen to stay the same in the immediate future due to its considerably high costs. Thus, the recent growth experienced during the last years is expected to vanish.

A stable regulatory framework would be positive for hydrogen and fuel cells too because it will help to establish the investors' confidence in hydrogen solutions.

2.2 Regional analysis: SWOT matrix

It is necessary to understand Spain's national energy situation and also study the profile of each region in relation to the future hydrogen economy for a coherent definition of its Hydrogen Roadmap. This study was conducted through questionnaires sent to key players in each sector (hereinafter the "stakeholders") and through a documental research.

For this purpose a SWOT (strengths, weaknesses, opportunities and threats) matrix was developed for each link in the chain (hydrogen production, storage and distribution, final use and conversion) and for the promotion, dissemination and social awareness of hydrogen, and applications and fuel cells in each region. The details of each region are described below:

2.2.1 Andalusia

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector. *D.2 The penultimate CCAA (Spanish autonomous communities) in terms of GDP.* *D.3 Low number of vehicles per capita and low population density.* *D.4 It consumes more electrical energy than it produces.* *D.5 Hydrogen production using natural gas and coal is not feasible because resources are not available and the strategies of the region are not in the aim of these resources.*	
STRENGTHS	**OPPORTUNITIES**
F.1 Good solar resources. *F.2 The second Spanish autonomous community in electricity production from solar energy also being well positioned in electrical energy production using wind.* *F.3 The existence of high temperature solar energy facilities and projects that aim to produce hydrogen from this source of energy.* *F.4 Enterprises in the region with the capacity to increase the current production of hydrogen.* *F.5 Pilot projects for the production and use of hydrogen as a fuel (Hercules/W2H2/Hydraulic).* *F.6 The presence of enterprises whose purpose is to develop technology in the field of H2 & FC.*	*O.1 Comes second in terms of CO2 emissions.* *O.2 Has growth expectations of wind resources.* *O.3 The potential of H2 as a method for storing surplus of renewable energy.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in metal hydrides.	

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in fuel cell demonstration projects for portable and stationary applications and transport.	*O.1 The use of FC in the automobile industry, because of the existing experience in manufacturing conventional vehicles, system integration, fuel cells and electric vehicles (EV).* *O.2 In stationary applications because of the decoupling between the generation and demand of electricity and because of the existence of large remote areas and new homes that need electricity supply.* *O.3 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be the easiest option to create hydrogen demand in the Spanish autonomous communities.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Political support, which the Andalusia Sustainable Energy Plan (SKIP 2007-2013) (that comprises something on hydrogen) is an example of. *F.2 Fiscal and administrative measures for sustainable energy development in Andalusia for the 2009-2014 period.* *F.3 On-going demonstration projects.* *F.4 The Andalusia Energy Agency has prepared a compilation document on H2 and FC in Andalusia.* *F.5 Existing projects like Smart City in Malaga to promote carbon-free vehicles.* *F.6 The hydrogen economy is thought to bring benefits to this Spanish autonomous community, e.g. job opportunities, reduction of emissions, development of renewable energy, uprising of a new field of expertise in the automobile industry, growth of energy efficiency.*	*O.1 The existing environmental policy strategy – Andalusia's Climate Action Plan for the 2007-2012 period.* *O.2 Awareness campaigns on climate change.* *O.3 Tax on greenhouse gas emissions in the atmosphere.* *O.4 Stakeholders believe that people react positively.* *O.5 It is thought to be easier to create demand through transport applications rather than stationary ones.*

2.2.2 Aragon

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Spanish autonomous community with a high level of GDP (5th place nationally). *F.2 Generates more electricity than it consumes (5th position in terms of surplus electricity).* *F.3 High electricity generation under the "special regime", especially Renewable.* *F.4 Surplus of wind energy that could be used to produce hydrogen.* *F.5 Feasibility, in the mid-long term, of Hydrogen production from high temperature solar thermal energy in the region.*	*O.1 The highest percentage of fossil fuel consumption in the region occurs in the transport sector (70%).* *O.2 The highest percentage of electricity consumption in the region occurs in the industrial sector (51%).* *O.3 Considers the production of Hydrogen by electrolysis from Renewable in the short term, and biomass gasification and high temperature solar thermal energy in the mid-long term to be feasible.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in compressed H2 tanks at 200 and 350 bar and in cryogenic tanks. *F.2.Has two hydrogen stations separated by only 85 Km.*	*O.1 Progress in H2 storage techniques will have niche market in Aragon since:* *- There are remote areas with no connection to the national electrical grid that could be supplied through H2 and FC.* *– Energy surplus that cannot be introduced in the electrical grid could be used to produce hydrogen and stored for when needed.* *–The highly polluting existing vehicle fleet could be replaced with hydrogen and fuel cell vehicles.* *O.2 Aragon could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location, its high level of GDP and its' potential for producing hydrogen from RES (Renewable Energy Sources),*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in fuel cell demonstration projects for portable and stationary applications and transport.	*O.1 Using FC in the automobile industry, because of the existing experience in manufacturing conventional vehicles, system integration, fuel cells and electric vehicles.* *O.2 In stationary applications because of the decoupling between the generation and demand of electricity and because of the existence of large remote areas that need electricity supply.* *O.3 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be in the Spanish autonomous communities the easiest option to create hydrogen demand.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Its regional energy policy: Aragon has an Energy Plan for the 2005-2012 period as well as a Hydrogen Plan. *F.2 The existence of Institutions and Foundations.* *F.3 Aragon has a defined environmental policy strategy. The government hands out subsidies for renewable sources, energy savings and efficiency.* *F.4 On-going demonstration projects.* *F.5 Stakeholders believe that people react positively to the hydrogen economy.* *F.6 The hydrogen economy is considered to be feasible and provides independence from fossil fuels.* *F.7 The existence of initiatives to promote electric vehicles.*	*O.1 The hydrogen economy is thought to create employment opportunities, reduce emissions, develop renewable and increase energy efficiency.* *O.2 It will create a new field of expertise in the automobile industry of the Spanish autonomous communities.*

2.2.3 Asturias

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 GDP per capita above national average. *D.2 Its' electricity production structure is mainly based on renewable energies.*	
STRENGTHS	**OPPORTUNITIES**
F.1 The principality of Asturias generates more electricity than it consumes. *F.2 Existing hydrogen generator developed by INCAR.*	*O.1 In the production of Hydrogen using coal gasification due to the abundant presence of this resource.* *O.2 The generation of electricity accounts for the majority of fossil fuel consumption.* *O.3 High level of CO2 emissions.*

No answers were received for storage and final use questionnaires

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 Absence of political support.	
STRENGTHS	**OPPORTUNITIES**
F.1 The Principality of Asturias has defined an Energy Strategy for 2012: maintaining coal as the main energy and improving energy efficiency, developing RES, improving transport and energy infrastructures and balancing the primary energy structure. *F.2 The existence of fiscal measures and investment support to promote the development of RES, emerging technologies and to increase energy efficiency.* *F.3 Existing environmental policy: "Strategy for Sustainable Development of the Principality of Asturias".*	

2.2.4 Balearic Islands

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Low generation of electricity using renewable energy. *D.2 It produces the electricity it consumes.*	
STRENGTHS	**OPPORTUNITIES**
F.1 6th Spanish autonomous community in terms of GDP per capita. *F.2 Its high Number of vehicles / number of inhabitants.*	*O.1 The insularity of this region.* *O.2 The energy sector plan identifies strategies to promote the use of RES.* *O.3 The high population density would facilitate its use.*

No answers were received for storage and final use questionnaires

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 Absence of hydrogen and fuel cell demonstration projects.	
STRENGTHS	**OPPORTUNITIES**

2.2.5 Canary Islands

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 It occupies the 12th national position in terms of GDP per capita. *D.2 It produces the electric power it consumes.* *D.3 Its electrical system is monopolistic which makes it difficult to convince the sector to introduce new technologies, without a competitor that would compel them to do so.*	*A.1 It hasn't either NG or coal to produce H2.*
STRENGTHS	**OPPORTUNITIES**
F.1 Good wind resources. *F.2 Existing experience in the production of hydrogen by wind electrolysis.* *F.3 Currently there is a possibility of increasing the volume of hydrogen production.* *F.4 The Canary Islands' energy plan, El PECAN, includes among its strategies, the generation of hydrogen from renewable sources and its introduction as a new energy vector, especially in the transport sector.* *F.5 On-going demonstration projects such as RES2H2, Hydrobus Christmas Tree.* *F.6 In the short term, the region sees the production of hydrogen through an electrolysis network or by wind energy as more likely, considering high temperature solar energy in the midterm.* *F.7 Renewable electricity is cheaper in the Canary Islands (about half the price) than in the mainland due to the abundance of sun and wind. It has the necessary resources to produce H2 by electrolysis. Electricity and water at hand (water desalination technology is well known for them).*	*O.1 High Number of vehicles / number of inhabitants.* *O.2 The region's insularity. It has a weak electric network, only Lanzarote and Fuerteventura are electrically connected. The rest of the islands are isolated. A new way of generating electricity via FC, especially if done through cogeneration, could be very beneficial to the islands.* *O.3 The potential of wind energy still to develop.* *O.4 The high population density would facilitate its use.* *O.5 The existence of surplus energy.* *O.6 Pilot project on the island of Hierro 'The Hierro 100% Renewable Energy', which promotes the production and use of H2. The island will be the first in the world to be self-sufficient in terms of energy.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in metal hydrides.	*O.1 Having a storage system in an isolated system which offers a much easier management of the electrical network, considerably reducing the number of incidents.*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector. *D.2 Greater economic effort due to the difficulty of applying economies of scale to a fragmented territory.* *D.3 Lack of normative regulation.*	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in FC demonstration projects for stationary and transport appliances. *F.2 Because the distance between the islands does not exceed 40km, the H2 vehicles would not require very high pressures or large deposits.*	*O.1 Using FC in the automobile industry, because of the existing experience in system integration and fuel cells.* *O.2 In stationary applications due to the possibilities of increasing the penetration of renewable energy thanks to the storage of hydrogen and its subsequent re-electrification thereby strengthening the network.* *O.3 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be the easiest option to create hydrogen demand in the Spanish autonomous communities. It is important to note the construction of sustainable buildings that should be role models to be followed in every city.* *O.4 Replace the import of polluting fuels for transport by using local and renewable H2.* *0.5 The electric bikes have been sold in the Canary islands for a long time now but they need to be constantly recharged and have low autonomy capacity: FC vehicles have in the Canary Islands a niche market that will imply a second phase of the electric vehicle.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 Lack of social awareness. The society ignores the potential of hydrogen and how it can help them respect the environment. *D.2 Unclear political support and the lack of well-defined guidelines that allow investors to invest in this technology.*	
STRENGTHS	**OPPORTUNITIES**
F.1 There is experience in the production of hydrogen by electrolysis and wind and experience in studies regarding hydrogen storage combined with RES. *F.2 Stakeholders believe that people react positively to the hydrogen economy.*	*O.1 The public is aware of the CO2 emission problem and that hydrogen can solve the problem of the existing decoupling between the production and demand of energy.* *O.2 The Hydrogen economy is thought to bring benefits to this Spanish autonomous community, e.g. employment opportunities, reduction of emissions, development of renewable energy and growth of energy efficiency.* *O.3 Create small building complexes using hydrogen that will become role models to follow.*

2.2.6 Cantabria

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Produces less electricity than it consumes (-52.75%).	*A.1 Getting out of the initial stage of the hydrogen economy development.*
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 8th national position in terms of GDP per capita. *F.2 Practically all the electricity produced is from Renewable energy.*	*O.1 High percentage of consumption of fossil fuels in the transport sector (34.5%).*

No answers were received for storage and final use questionnaires

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 Absence of hydrogen demonstration projects.	
STRENGTHS	**OPPORTUNITIES**
F.1 A program that supports RES facilities and investment in energy savings and efficiency - PER 2009 GENERCAN. *F.2 Existing environmental policy "Air Quality and Climate Change Control Program in Cantabria."*	*O.1 One of Cantabria's' Energy Plan 2005-2011 objectives is to increase awareness.*

2.2.7 Castile La Mancha

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 It occupies the penultimate national position in terms of GDP per capita	
STRENGTHS	**OPPORTUNITIES**
F.1 Produces more electricity than it consumes (+90.26%). *F.2 The amount of electricity generated by wind power is the highest in Spain* *F.3 Could produce hydrogen from nuclear energy.* *F.4 Currently there is an Elcogas plant that could produce hydrogen from coal gasification.*	

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Lack of normative regulation.	
STRENGTHS	**OPPORTUNITIES**
F.1. FC manufacturer in the region	

No answers were received for storage and distribution questionnaires.

2.2.8 Castile and Leon

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 There isn't a clear answer on behalf of the stakeholders as to the best form of hydrogen production in the region. The answers regarding raw materials and the energy to be used in the short, mid and long term, are very diverse.	*A.1 Some stakeholders are not sure of the utility of hydrogen in the adjustment of the disconnection between the generation and demand of energy.*
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 9th national position in terms of GDP per capita. *F.2 Produces more electricity than it consumes (+109.96%).* *F.3 It has coal as feedstock.* *F.4 The electrical power generated by wind is the second highest in Spain.* *F.5 There is experience in hydrogen production by autothermal reforming and electrolysis from photovoltaic energy.*	*O.1 High percentage of fossil fuel consumption in the transport sector (59%).* *O.2 It's the third Spanish autonomous community in terms of GHG emissions.* *O.3 Large vehicle fleet.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in compressed H2 tanks. *F.2 Experience in metal hydrides.* *F.3 Existing enterprises in the region.* *F.4 The University of Valladolid has experience in research on hydrogen storage in nanotubes and nanoporous materials.*	*O.1 The existence of surplus energy.* *O.2 Castile and Leon could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location, its high level of GDP and its potential for producing hydrogen from RES.*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F. Experience in FC demonstration projects for stationary and transport applications. Ex: HYCHAIN: incorporation of vehicle fleets with low fuel cell power (up to 10 kW), in selected niches of market, PILER: Demonstration of the use of fuel cells in the residential sector or AEROPILA: continuous power generation system combining renewable energy (wind and photovoltaic). *F.2 Experience in integration.* *F3. The existence of application projects.*	*O.1 Using FC in the automobile industry because of the existing highly pollutant vehicle fleet and because of the existing experience in system integration, fuel cells and electric vehicles.* *O.2 In stationary applications due to the existence of remote areas that need electricity supply.* *O.3 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be the easiest option to create hydrogen demand in the Spanish autonomous communities.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 On-going hydrogen demonstration projects: HYCHAIN, PILEREN, COPICO-GAS, REFORDI, AERO PILA, STORHY SAR, HYDROSOLAR 21. *F.2 Support measures such as subsidies for energy saving and efficiency investments in various sectors.* *F.3 Regional legislation on environmental education, the regional environmental award "Fuentes Claris" ("Clean Sources"), dissemination bulletins, etc.* *F.4 The existence of institutions and foundations.* *F.5 It is thought that people will react positively to the hydrogen economy* *F.6 There is support for the promotion of cogeneration plants among others.*	*O.1 Castile and Leon has an energy savings and efficiency plan for the 2008-2012 period. Its strategy is based on a joint action between the national and regional plan.* *O.2 The hydrogen economy is perceived as an opportunity to create employment and a new field of expertise in the Spanish autonomous communities' automobile industry, reduces emissions, develop RES, as well as increase energy efficiency.*

2.2.9 Catalonia

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Produces less electricity than it consumes (-10.66%). *D.2 Low percentage of electricity production from RES (10%). There is an intention to modify the existing plan to improve the penetration of renewable, especially winds power.*	
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 4th position in terms of national GDP per capita. *F.2. Electricity generation is not dependent on oil, but mainly on nuclear energy (47%) and natural gas (40%).* *F.3. There is H2 production for the refinery consumption, and for the chemical industry as a by-product, with capacity to meet H2 demand in the initial stage of the H2 economy.* *F.4 Existing enterprises in the energy sector working with H2, with headquarters in the region.*	*O.1 It is the Spanish autonomous community with the highest level of GHG emissions.* *O.2 The transport sector is the largest consumer of final energy in the region (40%).* *O.3 Large vehicle fleet.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Industrial gas companies working with H2, with headquarters in the region. *F.2 Experience in metal hydrides*	*O.1 Remote areas with no connection to the national electrical grid.* *O.2 Existence of surplus energy.*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1: Catalonia's industrial fabric. *F.2: Economic capacity.* *F.3 Barcelona's municipal transport enterprises' experience in working with H2 buses and their refuelling system (project CUTE)* *F.4: Autonomous community with the largest installed capacity of cogeneration.*	*O.1 New opportunities for Catalan plants in the vehicle, motorcycle and auxiliary sectors.* *O.2 Stationary use of biogas and NG (Natural Gas) in hotels, hospitals, and industries that need heat to develop their activity, such as the metallurgic industry, very important in Catalonia.* *O.3 Experience in FC installation for industrial cogeneration.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1: Lack of R&D infrastructures. *D.2: Weak short-term institutional support.*	
STRENGTHS	**OPPORTUNITIES**
F.1 The 2009 Review of Catalonia's Energy Plan for the 2006-2015 period, is committed to energy saving and efficiency, increasing the share of Renewable in the electricity mix and committed to electric vehicles. *F.2 The constitution of a commission to monitor the IVECAT (Electric Vehicle Implementation in Catalonia).Financial support especially for captive fleets (for infrastructures, 7000 € / vehicle, etc.).* *F.3 The impulse given by IREC (Catalonia Institute for energy research) with great institutional support towards SOFC (solid oxide fuel cells) and offshore wind projects.*	*O.1 Taking the European guidelines in to account, the Catalan government perceives H2 to be the 3rd pathway to energy diversification in transport, after biofuels and NG.* *O.2 Significant presence of technological centres with the ability to work on fuel cells or hydrogen.* *O.3: Opportunity to include the production of H2 in the IREC offshore wind project.*

2.2.10 Valencia Community

HIDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 It occupies the 11th national position in terms of GDP per capita. *D.2 Produces less electricity than it consumes (-20.60%).* *D.3 The percentage of electricity generated from renewable energy is very low.*	
STRENGTHS	**OPPORTUNITIES**
F.1 Gasification. *F.2: Refining plants.* *F.3: Wind capacity.* *F.4 It is the only Spanish autonomous community that has received a positive response from hydrogen production from nuclear energy.*	*O.1 High percentage of fossil fuel consumption in the transport sector (43.6%).* *O.2 It's one of the Spanish autonomous communities with the highest levels of GHG emissions.* *O.3 Large vehicle fleet.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in compressed H2 tanks. *F.2 Experience in metal hydrides* *F.3 On-going project conducted by the Metallurgic Technological Institute that studies the debilitation of materials by hydrogen.*	*D.1 Remote areas with no connection to the national electrical grid.* *D.2 Existence of surplus energy.* *D.3 Highly pollutant vehicle fleet.*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 AIJU'S (Technological institute of toys) experience in fuel cells through the application of this technology to toys.	*O.1 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be the easiest option to create hydrogen demand in the Spanish autonomous communities.*

PROMOTION AND DESSIMINATION

WEAKNESSES	THREATS
D.1 The political strategy planned for these years has not been carried out. *D.2 Lack of visibility.*	*A.1 The Energy Plan for the Valencia Community hasn't been approved yet.* *A.2 Lack of data on the population.* *A.3 The society's suspicion in change.* *A.4: Lack of participation of the electric and enterprise sector.*
STRENGTHS	**OPPORTUNITIES**
F.1 AVEN's support towards RES and energy saving and efficiency. *F.2 The Co2txe Plan to encourage the use of environmentally friendly cars such as hydrogen ones.* *F.3 On-going project to develop an environmental catalyst for hydrogen production.* *F.4 The 2 / 2006 Law on Pollution Prevention and Environmental Quality.*	*O.1 The development of the hydrogen economy is perceived as an opportunity to create employment, reduce emissions, develop RES and new opportunities in the Spanish autonomous communities' automobile industry as well as increase energy efficiency.* *O.2 Articulation of super projects from the research centre network.* *O.3: Experience in manufacturing electric vehicles through the Ford C-MAX program: the Ford plant in Spain, located in Valencia, will manufacture exclusively for the European market, from 2013 onward, all the versions of the new Ford hybrid model derived from the five-seat version of the new Ford C-MAX: a hybrid electric vehicle (HEV) and Plug-in electric hybrid vehicle (PHEV).*

2.2.11 Community of Madrid

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Produces less electricity than it consumes (-95.33%). It's the most energy deficient Spanish autonomous community.	
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 2nd national position in terms of GDP per capita. *F.2 High percentage of RES in electricity production.* *F.3 There are institutions that have experience in hydrogen production (e.g. Project PHISICO2, SOLGEMAC).* *F.4 The community of Madrid has funded H2 production investigation projects.*	*O.1 Correct its deficit position in terms of electricity production.* *O.2 It has high levels of GHG emissions.* *O.3 Large vehicle fleet.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector.	
STRENGTHS	**OPPORTUNITIES**
F.1. Industrial gas enterprises working with H2, with headquarters in the region. *F.2 Experience in compressed H2 tanks.* *F.3 Experience in metal hydrides.*	*O.1 Highly pollutant vehicle fleet.* *O.2 The community of Madrid could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location and its' high level of GDP.*

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
D.1 Absence of enterprises in the region in this sector. *D.2 Lack of normative regulation.*	
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in fuel cell demonstration projects for portable and stationary applications and transport. *F.2 Existing experience in fuel cells, e.g.: FITSA.* *F.3: Madrid's municipal transport enterprises' experience in working with H2 buses and their refuelling system (project CUTE).*	*O.1 Using FC in the automobile industry because of the existing experience in system integration, fuel cells and electric vehicles.* *O.2 In stationary applications because of the decoupling between the generation and demand of electricity and because of the existence of large remote areas that need electricity supply.* *O.3 Captive fleets followed by stationary applications in public buildings, and hydrogen production from wind surplus are considered to be the easiest option to create hydrogen demand in the Spanish autonomous communities.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
	A.1 Several stakeholders consider that people will react negatively to the hydrogen economy because of the lack of information and interest in environmental issues.
STRENGTHS	**OPPORTUNITIES**
F.1 The existence of energy saving and efficiency plans. *F.2 The existence of institutions like IMDEA Energy.*	*O.1 The development of the hydrogen economy is perceived as an opportunity to create employment, reduce emissions, develop RES, and new opportunities in the Spanish autonomous communities' automobile industry as well as increase energy efficiency.*

No answers were received for production questionnaire.

2.2.12 Extremadura

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Occupies the last national position in terms of GDP per capita.	
STRENGTHS	**OPPORTUNITIES**
F.1 Produces more electrical energy than it consumes (+249.94%). It is the Spanish autonomous community with the highest surplus of electricity. *F.2 Could produce hydrogen from nuclear energy.*	

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 No political support	
STRENGTHS	**OPPORTUNITIES**

No answers were received for storage and final use questionnaires.

2.2.13 Galicia

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Occupies the 13th national position in terms of GDP per capita.	
STRENGTHS	**OPPORTUNITIES**
F.1 Produces more electricity than it consumes (+36.99%). *F.2 The electricity generated by wind power is the third highest in Spain.* *F.3 There can be a surplus of wind energy.* *F.4 On-going projects like "Sotavento and Peixe Verde" that aim to produce hydrogen by electrolysis from wind power.* *F.5 The "Sotavento" project as a demonstration of how to control energy disposal through the production of hydrogen.*	*O.1 High percentage of fossil fuels consumption in the transport sector (48.8%).* *O.2 It is an autonomous community with high levels of greenhouse gas emissions.*

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
	O.1 Could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location and potential to produce hydrogen.

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Existing enterprises that work towards the promotion of electric technologies in vehicles. *F.2 Its University has experience acquired within projects on fuel cells (isolated house and project Life-Biosofc).*	

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Existing Plans that foster energy saving and efficiency. *F.2 The Galician Strategy for Sustainable Development and the existence of the Galician Agency for Sustainable Development.* *F.3 Existence of institutions like INEGA (Galicia Energy Institute), ENERXE (Galicia Energy Technological Platform).*	*O.1 The 2007-2012 period Galician Energy Plan stipulates among others the following strategies: -diversification of all types of energy and their origin, -promotion of energy efficiency, taking advantage of resources, encouraging research and development in the energy sector and training and raising awareness of the public.*

2.2.14 La Rioja

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Occupies the 7th national position in terms of GDP per capita. *F.2 Produces more electrical energy than it consumes (+145.19%).* *F.3 High percentage of electrical energy generation from RES.*	

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
	O.1 Could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location, its high level of GDP and its' potential for producing hydrogen from RES.

PROMOTION AND DESSIMINATION

WEAKNESSES	THREATS
D.1 Absence of political support.	
STRENGTHS	**OPPORTUNITIES**

No answers were received for final use questionnaire.

2.2.15 Region of Murcia

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 It occupies the 14th position in terms of national GDP per capita.	
STRENGTHS	**OPPORTUNITIES**
F.1 Produces more electricity than it consumes (+86.07%).	

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
	A.1 It could be left out of the hydrogen corridor that connects Portugal-Spain-France due to its location and low percentage of RES in its energy production.
STRENGTHS	**OPPORTUNITIES**

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
D.1 Absence of political support.	
STRENGTHS	**OPPORTUNITIES**

No answers were received for final use questionnaire

2.2.16 Chartered Community of Navarre

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 3rd national position in terms of GDP per capita. *F.2 Produces more electricity than it consumes (+42.21%).* *F.3 High percentage of electricity production from renewable resources.* *F.4 There is experience in the hydrogen production by wind electrolysis.*	

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
	O.1 Could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location, its high level of GDP and its potential to produce hydrogen from RES.

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 The 360/2000 floral Decree that comprises grants for research, development and innovation projects.	*O.1 The 2010 Horizon Strategic Plan that promotes RES and already includes something on hydrogen.*

No answers were received for final use questionnaire.

2.2.17 Basque country

HYDROGEN PRODUCTION

WEAKNESSES	THREATS
D.1 Produces less electricity than it consumes (-42.39%). *D.2 Low percentage of RES in its electricity production.*	
STRENGTHS	**OPPORTUNITIES**
F.1 It occupies the 1st national position in terms of GDP per capita. *F.2 Experience in hydrogen production from different procedures such as electrolysis, partial oxidation and gasification.* *F.3 On-going projects related to the production of hydrogen for energy purposes such as the Sphere project.*	

STORAGE AND DISTRIBUTION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Experience in compressed H2 tanks. *F.2 Experience in metal hydrides.* *F.3 Existing enterprises in the region.*	

FINAL USE AND CONVERSION

WEAKNESSES	THREATS
STRENGTHS	**OPPORTUNITIES**
F.1 Existing enterprises in the region. *F.2 Experience in fuel cell demonstration projects for portable and stationary applications and transport.*	*O.1 Using FC in the automobile industry due to the existing experience in system integration and FC.* *O.2 The most viable options to create hydrogen demand in the Spanish autonomous communities are believed to be, in first place, captive fleets followed by stationary applications then, finally, surplus wind energy.* *O 3. Remote areas without connection to the electrical grid.* *O.4 Could be part of the hydrogen corridor that connects Portugal-Spain-France due to its location and high level of GDP.*

PROMOTION AND DISSEMINATION

WEAKNESSES	THREATS
	A.1 The benefits of the hydrogen economy can only be felt in the long run.
STRENGTHS	**OPPORTUNITIES**
F.1 The population's' response to the hydrogen economy is thought to be positive.	*O.1 The hydrogen economy is considered to be useful for the autonomous community because it would reduce emissions, avoid dependence on foreign energy, and adjust production to energy demand.*

2.3 Hydrogen production chains

2.3.1 Definition

As mentioned previously, the hydrogen energy chains are the pathways for hydrogen production, transport, distribution and end-use application selected by the stakeholders as the more convenient for each region. Workshops and personal interviews were held with the national stakeholders in order to define them.

There are many ways of grouping possible hydrogen production and utilization chains. A first approach was performed on the basis of the feedstock used . Next, depending on the location of the plant (central, de-central or in situ) for the production process and the end users, a large matrix of possible hydrogen pathways could be created. A three-stage horizon was defined to allocate the chains in time regarding technology development, costs, resources availability, etc.: 2020 as the short term, 2030 as the mid term and 2050 as the long term.

In the Spanish case the set consisted of 7 main feedstocks, based on three renewable sources (wind, high temperature solar energy and biomass), two fossil fuels (natural gas and coal), nuclear energy and electricity from the grid. Different possibilities were then considered for production, transport, distribution and end-users options (Table 4).

In the beginning, the hydrogen demand will be small and it will continue to be produced by the conventional methods currently in use, i.e., by steam methane reforming (SMR) and electrolysis from using grid. Production will be centralized and gaseous hydrogen will be distributed by trucks.

The stakeholders believe that in Spain the first applications will focus on the most industrialized areas, such as Catalonia, Madrid and the Basque Country. It is thought that the first applications will be municipal vehicles that initially will be very expensive and unaffordable to private enterprises. An example of this is the vehicle fleet manufactured for the Expo Zaragoza that is currently not being used, waiting for the municipal enterprise to take care of them, due to the lack of interest from private enterprises.

In the long term as well as an increased commercialization of H2 vehicles, H2 stationary applications from on-site renewable sources will be important.

Chains definition	Estimated timeframe
A.1 Central SMR>pipeline	2030
A.2 Central SMR>CGH2 trucks	2020
A.3 Decentral SMR>CGH2 trucks	2020
B.1 Central coal gasification>CGH2 trucks	2030
B.2 Central coal gasification>pipeline	2030
C.1 On-site wind electrolysis> domestic use	2020
C.2 Central wind electrolysis>grid reinforcement	2030
C.3 Central wind electrolysis>storage and distribution	2030
D.1 Decentral biomass gasification	2030
E.1 Central High T solar electrolysis >CGH2 trucks	2050
E.2 Central High T solar electrolysis>pipeline	2050
E.3 Central High T solar thermochemical cycles>pipeline	2050
E.4 Central High T solar thermochemical cycles>CGH2 trucks	2050
F.1 On-site electrolysis from the grid>Refuelling station	2020
F.2 Central electrolysis from the grid>CGH2 trucks	2020
F.3 Central electrolysis from the grid>pipeline	2030
G.1 Central High T nuclear electrolysis >grid reinforcement	2050
G.2 Central High T nuclear electrolysis >storage and distribution	2050
G.3 Central High T nuclear thermochemical cycles>grid reinforcement	2050
G.4 Central High T nuclear thermochemical cycles>storage and distribution	2050

Table 4. Hydrogen energy chains selected for Spain and estimated timeframe

2.3.2 Chains analysis

Once the Spanish hydrogen energy chains were selected, a technological and social analysis was conducted to define the strengths, the weaknesses and the challenges for that chain to be implemented.

• **Hydrogen production from Coal Gasification**

WEAKNESSES	STRENGTHS	CHALLENGES
• Fiscal, financial and economic policies have not yet been set up for hydrogen. *• The costs related to storage and CO2 emissions. There is an economic cost that can affect the production of hydrogen via conventional energy.* *• Lack of own technology for manufacturing catalysts and membranes.* *• Low demand inhibits the development of productive capacity.*	*• Having an IGCC (Integrated Gasification Combined Cycle) plant in Spain, leader in gasification technology with production capacity of H2 and CO2 capture.* *• Capacity or existing technology for manufacturing sensors and instruments.* *• Synergies in biomass gasification* *• H2 mass-production capacity with lower production costs.*	*• Support coal as a strategic reserve, always linked to obtaining economically viable CCS technologies.* *• Promotion of clean-coal efficient technologies with a tax credit scheme for investment / income, rather than direct subsidy, to prevent deficit (as in the solar energy case) that affect long-term development of technology.* *• Launch CO2 confinement in selected locations.* *• Implementation of facilities of hydrogen production from fossil fuel co-gasification and biomass.* *• Improve technologies related to gasification: separation and purification.* *• Develop pilot plants and demonstration systems based on the separation of CO2 membranes.* *• Information campaigns to achieve social acceptance of technologies for CO2 confinement.*

Table 5: H2 production from coal gasification.

• **Hydrogen production from Steam Methane Reforming**

Similar characteristics to the Portuguese case. See tables 18-20.

- **Hydrogen production from RES-electrolysis**

WEAKNESSES	STRENGTHS	CHALLENGES
• Not having a national manufacturer of electrolysers and their components. *• The lack of progress of H2 through the learning curve method and maturity of the market means that cost reduction is increasingly difficult, and slows down progress in the direct competition with conventional renewable energies.* *• Absence of incentives that promote the production of H2 from RES, of a reduction or elimination of fees relating to the use of H2 as fuel.* *• The production of electricity by renewable H2 continues to be low, which makes it difficult to use the system for energy storage.* *• No competiveness (price wise) between renewable H2 and conventional energy (fossil fuel, nuclear), the first costs 3 to 8 times more.* *• Absence of clear implementation rules relating to H2 facilities.* *• Long and tedious process to obtain construction permits for the facilities.* *• Lack of Spain's' own electrolysis technology, especially on a large power scale.* *• Low demand prevents the development of production capacity.* *• Renewable electricity competition*	*• Great potential of RES in Spain (resource and dissemination capacity of projects due to a legal framework that promotes these energies).* *• Spain is a leader in the development of RES equipment, especially wind.* *• The existence of expert energy business networks in wind power and plant management (power adaptation technologies and control and monitoring).* *• The existing capability to develop technology.* *• Knowledge in management strategies (including technical)and in the integration of RES (wind, solar photovoltaic energy) with H2 production by electrolysis*	*• Streamline the licensing procedures necessary to build these facilities.* *• Include training on this technology in educational programs.* *• Developing RES integration strategies (wind, solar photovoltaic energy) with H2 production by electrolysis, hybrid systems, optimization of the performance of H2 production and reduction of its cost.* *• Development of large electrolysers, used in wind and photovoltaic farms; the existing suppliers (foreign) have not focused their business on this market; Actors in related sectors have potential interest in development.* *• Managing the electrical grid through the ability of hydrogen to store energy, ensuring demand by integrating RES-electrolysis.* *• Work on the integration of distributed networks to: - alleviate the low capacity transmission network in areas where only wind farms are located (often low populated areas) and for on-site consumption in locations without connecting to the electrical grid or with weak grids (energy storage and / or fuel).* *• H2 production from wind energy surplus (that cannot be introduced in the network)* *• Improving weather forecast systems to increase the levels of production for better integration of wind power in the network.* *• Development of new business areas for the renewable H2 produced (niche markets)* *• Making the most out of the large existing potential in industrial development and job creation*

		• *Renovation of the oldest wind farms, which are generally the ones, located in the best wind sites. This would mean an important increase in power and in the efficiency of the facilities.* • *Regarding Spain's Off-shore wind energy: offshore wind resource measures, the development of oceanographic climatology: patterns of waves and wind, specific technologies to adjust turbines to the ocean environment, should lead to climate protection and to a very strong resistance and durability of the ocean environment, submarine cables and electrical marine substations* • *The need to prioritize the production of hydrogen from RES as another milestone in the deployment of hydrogen technologies and fuel cells.*

Table 6: H2 production from electrolysis

In the next figure, comparisons of CO2 emission rates per Nm3 of hydrogen are calculated for different electrolysis process using Life Cycle Analysis (LCA) methodology. The data come from PHISICO2 programme.

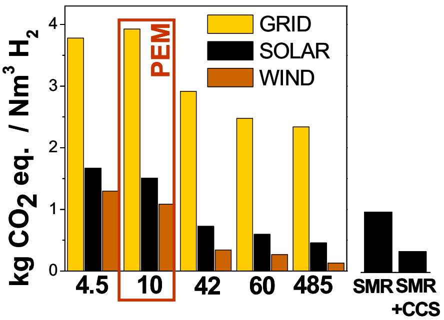


Fig. 22.: CO2 emissions rate per Nm3 H2 produced from electrolysis for electrolysers with different capacities per hour

Source: PHISICO2 project

The case of the PEM electrolyser is outlined in red whilst the rest of them are of the alkaline type. It can be observed that electrolysis from the grid is the most polluting pathway for hydrogen production. However, CO2 emission rate decreases when hydrogen production rises. It is worth mentioning that electrolysis from wind power is the least polluting process, even better than SMR with CCS. Photovoltaic solar energy has poor results due to the very energy consuming life cycle of the photovoltaic panel.

In fig.22 it is remarkable that there is no big difference between the 60 and 485 (decentralised) scale, what means that electrolysis scale affects up to a limit where CO2 emissions remains almost constant.

- **Hydrogen production from Biomass gasification**

Weaknesses	Strengths	Challenges
• Lack of coordination prevents Spain from taking advantage of a huge amount of biomass. *• Seasonal availability of the resources.* *• Heterogeneity of biomass' quality and availability* *• Non total solid conversion (char formation) and production of tars* *• Logistics are expensive* *• Lack of a strategic plan for developing forest and fields for biomass production in Spain* *• Lack of knowledge about better feedstock for hydrogen production from biomass* *• Lack of regulation for biomass implantation in Spain* *• Competition with other uses for biomass like thermal applications or biofuels.*	*• Great potential in Spain* *•European Directive has fixed 20% share of renewable energies for 2020* *• Spain holds a high position in research publications in thermochemical processes* *• Spanish policy supports implementation of renewable energy production in general* *• Large amounts of forest residues detected* *• Expertise in biomass gasification for electrical supply* *• Way of getting rid of municipal wastes*	*• Coordination with other biomass actors (farmers, fire departments, …) to create a competitive energy chain* *• Introduction in an emerging external market* *• Reforestation of large land areas currently energetically unproductive.* *• New catalysts and additives development for increasing H2 ratio (dolomite, Ni-based)* *• Improve gasifier´s design* *• Due to the economic crisis in Spain, previous forestry demand for the construction sector has decreased and forestry is heading towards energy production for stock balance.*

Table 7: H2 production from biomass gasification

- **Hydrogen production from High Temperature Solar Technologies**

Weaknesses	Strengths	Challenges
• The absence of specific and well-known laws and regulations for standardisation of prototypes • Applications of these technologies entail large investments, both in the installation of production plants and in their operation.. • The absence of fiscal policies that promote financial and economic exploitation of these technologies, beyond the R&D grants. There have been only small-scale projects funded for scientific purposes to date. • Hydrogen facilities with low efficiency and short life expectancy which do not demonstrate profitability in many applications. • Thermochemical processes are very corrosive and imply large investments for generation plants. • The uncertainty of the cancellations of funding grants for R&D projects in Spain is threatening the development of production technologies with high temperature solar energy due to the current preliminary stage.	*• Considering current technology and research, Spain has a chance to achieve a leadership role, particularly in hydrogen production using high temperature solar energy •Wide renewable energy potential in terms of weather conditions • Obtained experience in pilot and research projects, provide a favourable starting point to continue developing this type of technology and consolidate the possible Spanish leadership in the future. • The integration of thermochemical processes in high temperature solar systems allowing high-purity hydrogen, being economically competitive regarding low temperature electrolysis. • Thermochemical processes and high temperature electrolysis out of the carbon cycle (CO2 free).*	*• Fostering social awareness about hydrogen and fuel cells in order to improve technology and the knowledge of companies, customers and providers. • Development of strategic plans and support lines for these technologies, promoting the results of global approach and acceptation for all stakeholders levels, in the same way that wind energy was promoted or electric cars are beginning to be promoted. • Improvements in sophisticated materials for achieving higher efficiency • Further progress in developing product-oriented technology to get the integration in a competitive energy market model.*

Table 8: H2 production from high temperature solar technology

- **Hydrogen production from nuclear electrolysis**

Weaknesses	Strengths	Challenges
• Public and governmental opposition to nuclear energy • Lack of research nuclear reactors • Nuclear waste disposal • The lack of specific codes and standards.	*• Existing technology for sensor and instrument manufacture • Good level in catalysers research applicable to this technology*	*• Good opportunity for fostering nuclear energy in the country • Avoiding to be left behind the rest of the countries in relation to nuclear technology*

Table 9: H2 production from nuclear electrolysis

2.3.3 KCAM analysis

KCAM (Key Changes and Actor Mapping) is a way to identify the main barriers or "Key Changes" holding back hydrogen systems development. It enables the targeting of specific actors who could play a part in fostering the hydrogen economy.

- **Analysis per component**

The table A.1 summarizes the results from all 22 stakeholders listed across the first row of the table.. A colour code was used to identify the extreme values for each component, highlighting the wide spectrum of assessments, with most assessments varying more than 2 categories.

Almost all stakeholders agreed that the larger drawback for hydrogen economy deployment is the lack of demand. For demand creation demonstration projects with an assured continuity have to be carried out. Industrial gases stakeholders were confident in the hydrogen technologies, but highlighted that the largest omission in Spanish demonstration hydrogen projects till now had been in the on-site hydrogen production, due to the difficulty that small scale solutions have in terms of operation and efficiency. They bet on CGH2 centralized production for the first demo projects and transporting the hydrogen to the end-use facility. These demo projects will be the seed for future hydrogen markets.

Apart from exceptions, the most optimistic assessment was made by representatives of private companies while the least optimistic evaluations came from energy research centres. The latter are more conservative regarding technological achievements for hydrogen production in the short term. In general stakeholders considered the high solar temperature chain as the most immature for hydrogen production and put it off until 2050.

The success of the hydrogen economy is very dependent on an industry-government alliance. Most of stakeholders laid the blame on the excessive bureaucracy that is required before setting up a hydrogen project due to the fact there are no specific codes and standards for this technology exist and public administration does not authorize them. They asked for speeding up the administrative authorizations to build the facilities. Moreover, in Spain there is no long-term National Energy Plan approved in the Parliament with a wide consensus. It is changed whenever the government changes or even from one year to the next.

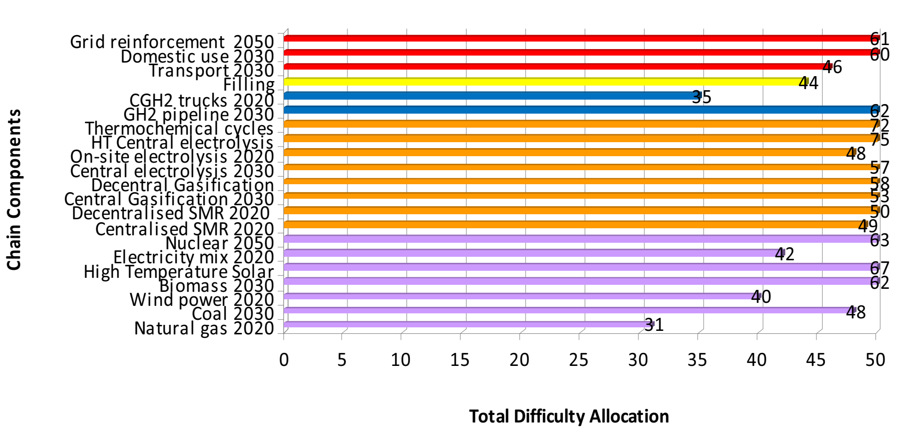


Fig. 23 Total difficulty allocation per chain component for Spain

Colours code: purple- feedstock, orange-process, blue-transport and distribution, yellow-filling system, red- final use.

The stakeholder from the FC manufacturer company pointed out that the bottleneck for this technology development is that it is expensive. Mass market could help them reduce prices but incentives should be applied to the general public for the purchase of fuel cells in order to foster the fuel cells sales.

The Energy Research Centres and Renewable Energies Companies believe that hydrogen can play an important role in peak renewable production, storing the electricity produced from wind during peak hours. The aggregation of the difficulty allocations (Figure 23) shows a high difficulty level in most sections. Current hydrogen chains (NG and electricity mix) are the most favoured options, together wind energy which is very well assessed. Nuclear and the rest of renewable options are less favoured, even after coal. On-site production is preferred to centralized electrolysis. SMR and FC transport comes as the obvious choice for hydrogen use, followed by domestic use and grid reinforcement.

Chain Component	Estimated Timeframe 2020	2030	2050	Energy Innovation Company	Energy Research	Energy and Transport Research	Energy Research	Renewable Energy Company	FC company	Hydrogen and FC Technology Research	Consultancy	Sewage treatment company	Energy Technology Research	Electric vehicles company	Chemistry Research	Consultancy	Renewable Energy Company	Energy Technology Research	Energy Research	Consultancy	Energy Technology Research	Fossil Fuel Industry	Industrial Gases Industry	Vehicles company	Energy Innovation Company	Total
Natural gas	x			2	4	1	2	3	1	2	1	3		2	1	2	1	1	1	1	1	1	1	1	1	33
Coal		x		2	5	4	3	2	1	2	1	4		3	2	2	5	1	1	4	2	2	1	1	3	51
Wind power	x			4	2	2	3	1	1	3	2	3	4	4	2	1	3	2	1	1	2	2	1	1	3	48
Biomass		x		3	4	4	2	5	1	3	3	3	4	4	5	3	3	3	2	3	3	4	1	2	5	70
High Temperature Solar Energy			x	5	3	5	3	4	2	4	4	3		3	2	5	4	5	2	3	4	2	2	1	4	70
Electricity mix	x			4	3	1	2	2	1	4	1	5	3	1	2	2	1	2	1	4	2	1	1	1	2	46
Nuclear			x	1	5	3	2	3	2	4	3	5				2	5	3	5	4	3	4	3	1	5	63
Centralised SMR	x			4	5	2	3	1	5	2	1	4			1	4	2	5	2	3	1	1	1	1	1	49
Decentralised SMR	x			4	5	1	2	4	2	3	2	4			1	3	4	3	3	2	2	2	1	1	1	50
Central Gasification		x		3	5	3	3	2	5	2	2	4			3	4	1	4	3	2	1	2	1	1	2	53
Decentral Gasification		x		3	5	2	2	3	2	4	3	4			1	4	3	4	4	3	2	4	1	2	2	58
Central electrolysis		x		3	3	3	3	2	5	3	4	5	2		2	2	1	4	3	3	3	3	1	1	3	59
On-site electrolysis	x			3	2	2	2	4	1	3	1	5	3		2	2	3	2	4	3	2	2	1	2	2	51
HT Central electrolysis			x	5	3	4	4	5	5	5	4	5	3		4	3	4	5	3	2	2	3	2	2	5	78
Thermochemical cycles			x	5	4	5	4	4	3	5	4	5			4	3	3	5	3	2	2	3	2	2	4	72
GH2 pipeline		x		4	5	3	4	3	3	4	3	3	4		2	3	3	2	3	2	3	2	3	2	5	66
CGH2 trucks	x			1	4	2	2	2	1	2	2	3	2		1	2	1	2	1	2	2	1	2	1	1	37
Filling station/distribution centre		x		2	4	1	3	2	2	3	2	3			1	4	2	1	2	4	2		1	1	4	44
Transport		x		2	3	2	3	1	2	4	1	2	4		2	4	4	2	1	3	2	1	2	1	4	50
Domestic use		x		2	3	3	4	2	2	5	2	2	4		3	2	4	3	4	3	3	3	3	2	5	64
Grid reinforcement			x	4	3	4	4	4	3	4	4	2	3		3	2	4	1	3	1	3	3	3	2	4	64
			Total	66	80	57	60	59	50	71	50	77	36	17	44	59	61	60	52	55	47	46	34	29	66	

Table A.1: Summary of results per chain component for Spain

Difficulty Allocation
1
2
3
4
5

- **Analysis per chain**

The aggregation of the results per chain is shown in Figure 24. The fact that centralized chains have more components leads to higher difficulty levels than decentralized ones. The electricity grid chains (F1, F2, F3) have a clear advantage over other feedstock for similar chains (A1, A3, B1, C1, C 3, E1, E2 and G2).

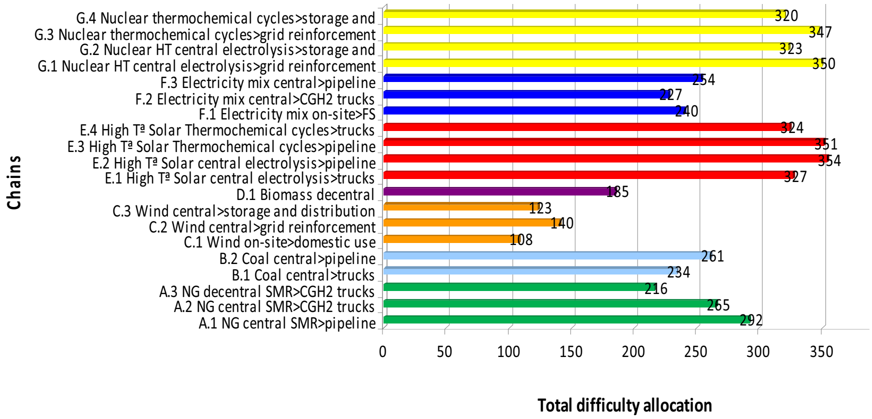


Fig. 24. Total difficulty allocation per chain for Spain

Due to the different number of components in each chain, another graphic was produced, which reflects the average difficulty allocation (Figure 25). Apart from the conclusions mentioned above, it can be extracted from this figure that, transport by truck chains lead the preferences of the stakeholders over transport using pipelines. Looking at the sources, wind power and natural gas reveal lower difficulty levels when compared to other sources, followed by biomass, NG and coal, whilst high temperature solar energy and nuclear the options with most difficulties.

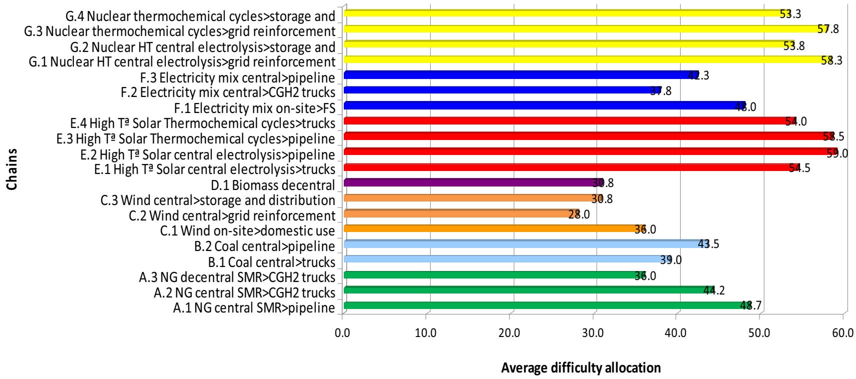


Fig. 25. Average difficulty allocation per chain for Spain

- **Broad actor group**

The summary table with the actors that might play a role in overcoming or positively affecting the realization of the Key Change is provided below (Table A.2). Industrial associations were mentioned as relevant actors too.

Looking at the total values of Table A.2 the attention of the stakeholders is focussed on two actor groups: Energy engineering and Central government followed in turn by: Infrastructure, Regional government and Specialist hydrogen equipment manufacturing. One interpretation of this is that although there is still a lot of research about integration to be carried out in order to reach more efficient technologies, the stakeholders believe that with the proper boost from central and regional government and the availability in the market of the infrastructure and competitive technologies simultaneously, hydrogen can be a reality in Spain after 2020.

Supranational government, Research, academia and consultancy, Transport and logistics sector and the Financial services are the following actor groups most frequently nominated, while there is a small role for the Media, the Agriculture and forestry and Real estate construction and management. It is surprising the automotive sector is not considered by stakeholders as one of the most strategic actor groups whereas they consider the transport sector as being important for the early adoption of H2 and FC in the society. Stakeholders bet on governmental encouragement of the technology bound to a national energy engineering development. Energy–upstream/downstream, civil society and NGOs and Hydrogen associations are not considered as crucial players in this scope.

Section	Chain Component	Energy – upstream / downstream	Energy engineering	Infrastructure	Automotive	Central government	Regional government	Supranational government	Research, academia and consultancy	Civil society and NGOs	Hydrogen associations	Transport and logistics sector	Specialist hydrogen equipment manufacturing	Agriculture / forestry	Media	Real estate construction and management	Financial services
FEEDSTOCK	Natural gas																
	Coal																
	Wind power																
	Biomass																
	High Temperature Solar Energy																
	Electricity mix																
	Nuclear																
PRODUCTION	Centralised SMR																
	Decentralised SMR																
	Central Gasification																
	Decentral Gasification																
	Central electrolysis																
	On-site electrolysis																
	HT Central electrolysis																
	Thermochemical cycles																
TRANSI	GH2 pipeline																
	CGH2 trucks																
DISTRIBUTION	Filling station/distribution centre																
END-USE	Transport																
	Domestic use																
	Grid reinforcement																
	TOTAL	72	161	141	83	192	141	91	104	75	68	104	128	20	48	28	113

Difficulty allocation	
0	<30
1-3	31-60
4-6	61-90
7-9	91-120
10-12	121-150
>13	>150

Table A.2 – Broad actor groups able to overcome or positively affect the realization of the Key Change

2.3.4 Regional study

The hydrogen energy chains for the different regions are described below:

2.3.4.1 Andalusia

In Andalusia, hydrogen production using natural gas reforming or coal gasification is considered to be non-viable because these technologies are not being developed by any actor in the region. Moreover, neither coal nor natural gas is an available resource and the strategic lines of development of the region are not in the pursuit of these resources.

In Andalusia, Hydrogen is foreseen to be produced, in the mid long term (2030-2050), by water electrolysis with electricity from renewable sources (particularly wind energy) and from high-temperature solar energy (thermochemical cycles or high temperature electrolysis).

The 2007–2013 Andalusia Sustainable Energy Plan, or PASENER, defines strategies to prioritize the use of renewable sources (Andalusia is one of the Spanish regions with the highest installed capacity in terms of power generated from renewable energy sources), involving the whole society, and contributing to a balanced spatial planning and economic growth and to the promotion of a competitive business. The plan also makes reference to hydrogen.

2.3.4.2 Aragon

H2 production by decentralized natural gas reforming without CO2 capture is seen as a short-term option (2020) that should change up until 2030 to two versions: centralized with capture and decentralized without capture (on a small scale it is more difficult to capture CO2 and not all places connected to the natural gas network will be able to store CO2).

As for H2 production by coal gasification, the region doesn't consider investing in any these technologies in the long term. Therefore an investment in infrastructure for the use of the existing coal reserves does not make much sense.

Aragon is one of the Spanish regions that exports more electricity and it is also is one of the regions with the largest number of installed capacity of renewable sources, almost all wind power. Therefore, the region considers the production of hydrogen by water electrolysis through surplus wind energy, in the mid-long term. The production of hydrogen from high temperature solar thermal energy is seen as a viable option in the midterm.

It is important to note that Aragon is one of the regions that comprises a section on hydrogen energy in its Energy Plan for the 2005-2012 period and that has also devised a hydrogen plan for the region.

2.3.4.3 Asturias

No answers were received from this autonomous community.

Nevertheless, the document entitled "Energy Strategy of the principality of Asturias with Horizon for 2012" outlines the following strategies: -maintain coal as a major power in the region, improving the energy efficiency of Asturias' economy, foster the development of renewable energy, improve energy and transport infrastructure and primary energy structure.

2.3.4.4 Balearic Islands

No answers were received from this autonomous community.

The Balearic government has drawn up an Energy Sector Master Plan for the Balearic Islands that aims to identify the energy needs of the Islands for the next fifteen years. The strategies outlined are the following: pipeline interconnection with the mainland, a plan to boost renewable energy, an energy efficiency plan, electricity transport networks and the promotion of the use of renewable energy.

2.3.4.5 Valencia Community

As for H2 production from natural gas reforming (SMR), this region regards the lack of CCS (Carbon Capture and Storage) in any form of hydrogen production from natural gas as a factor that prevents them from replacing fossil fuels. Therefore only CCS integration plants will invest in this form of production and this will not occur before the midterm (2030). However until that point, H2 demand will continue to be produced by SMR technology without CCS in the short term.

H2 production from coal gasification is not considered in this region due to the current lack of industrial processes, coal processing, and coal deposits that promote or induce the transition in this region. Logistical costs associated with the import of hydrogen are considered to be than more those associated with coal processing and for the transport of coal to Valencian community.

Centralized H2 production from nuclear energy is foreseen to be viable in the midterm (2030), as well as centralized H2 production from biomass gasification, evolving over time towards decentralised production.

The option of producing H2 from high-temperature solar energy (thermochemical cycles or high temperature electrolysis) is viable in the long term.

Finally, this region is committed to producing hydrogen through water electrolysis using surplus wind electricity in the short, medium and long term.
Valencia's Energy Plan comprises fiscal and investment support for RES development and for energy efficiency increase, but not H2 in particular.

2.3.4.6 Canary Islands

As for H2 production from natural gas reforming or coal gasification the stakeholders argue that these resources are not available in the region nor are they imported so they don't consider the transport of them to the region for hydrogen production to be feasible. Hydrogen will be produced using other cheaper methods.

Renewable electricity is cheaper in the Canary Islands, about half the price of that in the mainland due to the abundance of sun and wind. It has the necessary resources to produce H2 by electrolysis and electricity and water at hand (water desalination technology is well known in the region). Based on this, hydrogen production from high temperature solar thermal energy is seen as viable in the midterm and the surplus wind-electrolyser-FC integration system is considered to be the right combination to reduce the Islands' energy dependence in the mid long term. However, some of the experts consulted do not perceive this system as the best way to store energy due to the poor performance of its overall process. Nevertheless, they consider the use of H2 and fuel cells in domestic applications without much energy demand. In particular, PEM fuel cells for ceramic heaters, domestic hot water system, heating, gradually replacing NG with H2.

In the Canary Islands the temporary use of NG for FC is believed not to have any benefits. This would only be visible in large scale applications, replacing turbines for FC, which still would be generally inappropriate in the Canary Islands since it needs to import NG.

Regarding the use of H2 and FC in transport, the Canary Islands are committed to using H2 in internal combustion engine for vehicles as a transition to electric vehicles. The

Canary Islands' have three years of experience with electric commercial vehicles (EVs), especially motorcycles.

The technology is considered mature enough to compete with conventional technology in the Canary Islands because, although recharge and autonomy time do not meet current user standards on small islands like the Canaries where the average daily miles driven is 30 to 35, electric vehicles have good performance.

Only professionals who drive many miles daily (delivery drivers, people commuting to work, etc ...) will demand fuel cell electric vehicles. The introduction of H2 in the next phase of the electric vehicle will overcome this challenge.

The PECAN (Canary Islands Energy Plan) marks out the following strategies: studies of the economic and technical feasibility of new sources or energy technologies and the use of renewable sources in remote applications as energy storage. It is important to highlight that the aforementioned Plan comprises hydrogen production from renewable energy sources and its introduction as a new energy vector, especially in the transport sector.

It is a remarkable fact that the Canary Islands will have in 2020 an ocean platform, a unique scientific-technological ocean marine environment research infrastructure. Among the studies that are going to be carried out is the H2 production from off-shore wind power and ocean energy. This centre focuses on the study of electricity and hydrogen production by taking advantage of temperature gradients that appear in the slope of the continental platform with the ocean floor. In some areas it goes from 70 to 500 meters with temperature differences between 18 º C and 12 º C.

2.3.4.7 Cantabria

No answers were received from this autonomous community.

Cantabria has an Energy Plan for the 2005-2011 period. Its strategy is to integrate citizens in the development of the provided energy mechanisms and to increase public awareness. The Plan does not mention Hydrogen.

2.3.4.8 Castile-La Mancha

It is one of the Spanish power exporting regions with the highest share of energy from renewable sources. It is also one of the Spanish regions with the highest number of renewable energy installed capacity.

Therefore, the general opinion is that hydrogen production, both in the short, medium and long term, by electrolysis from wind power, is the most adequate option for the Spanish autonomous communities.

Centralized H2 production from high temperature solar thermal energy is foreseen to be viable in the midterm, as well as the production of H2 by biomass gasification, which will evolve over time towards a decentralised production.

The option of centralized production of hydrogen from nuclear energy is viable in the long term.

It has an energy saving and efficiency plan. This plan does not include hydrogen.

2.3.4.9 Castile and Leon

It is one of the Spanish power exporting regions that has the greatest number of installed renewable energy capacity making it one of the autonomous communities with the highest share of renewable sources in its overall electricity production.

This drives the autonomous community to consider hydrogen production by electrolysis from wind power over both the short, medium and long term.

As for H2 production by SMR, the region bets on centralized production with CO2 capture and sequestration for 2030, the year predicted for it to have already reached its environmental sustainability.

The same applies to the H2 production from coal gasification. Although the region possesses this resource, it does not consider the option of producing H2 from coal if there is no capture of CO2 (CCS). Decentralized and centralized H2 production with CCS is considered in the long term if the technology exists.

The option of producing hydrogen from high temperature solar thermal energy is viable in the midterm as well as the production from biomass gasification, which initially will be centralized, evolving over time towards decentralized production. It is not a surprise that Castile and Leon is currently the second region with more installations of biomass for energy purposes.

Castile and Leon has an Energy Saving and Efficiency Plan for the 2008-2012 period. Its strategy is carried out in the seven sectors with the greatest potential for energy savings: industry, transport, building, residential appliances, public services, agriculture and energy transformation. This plan does not include anything specific on H2.

2.3.4.10 Catalonia

In the short term, H2 production from natural gas, biogas and petroleum derivatives SMRs, as well as biofuels and electrolysis from the electric mix will emerge centrally. Catalonia is the region that has the highest number of biomass boiler installations. Catalonia’s commitment to this energy source also includes H2 production from on-site biomass gasification.

In the midterm H2 will continue to be produced by natural gas steam reforming and decentralized production will also be considered. Production by centralized on-site wind electrolysis and solar thermochemical cycles will also begin in this period.

The region bets on H2 production using biomass gasification, wind electrolysis and solar and nuclear thermochemical cycles in the long term.

Catalonia has an energy plan for the 2006-2015 period which focuses especially on the challenge to achieve a low carbon and energy intensity economy with a diversified energy mix to maximize the importance of renewable energy. This plan does not include H2.

2.3.4.11 Extremadura

The only forms of H2 production that are seen as being viable in this autonomous community are coal gasification in the long-term and electrolysis from wind power surplus in the mid-long term.

The first energy plan for this region is currently being drawn up.

2.3.4.12 Galicia

It is one of the Spanish autonomous communities with one of the highest installed capacity in terms of power generated from renewable energy sources and with a high proportion of renewable electricity in the overall of its electricity production.

This region is opting to produce H2 by wind energy electrolysis in the mid-long term due to insufficient resources.

Galicia has an on-going energy plan entitled “Galicia energy plan 2007-2012”. Although the plan out-lines, amongst its strategies, the development of energy such as renewable energy, it leaves out hydrogen and FC.

2.3.4.13 La Rioja

No answers were received from this autonomous community.

It is the Spanish autonomous community with the largest share of renewable energy overall in its electricity production. This region has an action plan for an energy saving and efficiency strategy for the 2008-2012 period, that does not comprise H2 as an energy vector.

2.3.4.14 Community of Madrid

No answers were received from this autonomous community.

The Community of Madrid has an energy plan for the 2004-2012 period entitled "Energy Plan for the Community of Madrid 2004 - 2012" that has among its objectives the goal to meet the energy demand of the Community of Madrid, enabling power generation initiatives with energy resources from renewable sources. This energy plan does not include a specific strategy for the introduction of H2 in the region but the support of regional policy to EV (tax exemption in parking restricted area, road tax reduction, inclusion of 106 electric vehicles in the municipality fleet) is preparing the ground for the introduction of H2 vehicles.

2.3.4.15 Region of Murcia

The production of H2 from natural gas SMR (Steam methane reforming), biogas or biofuels with CO2 capture and sequestration will emerge in the short term.

In the mid-long term H2 production by biomass gasification and high temperature solar thermal energy is considered as an option.

It has a "Regional Energy Plan" that aims to reduce its oil dependence through the promotion of the use of renewable energies in the region such as wind, solar and biomass. The energy plan also mentions hydrogen.

2.3.4.16 Charted Community of Navarre

H2 production from fossil fuel is not considered an interesting technology for this autonomous community due to the lack of this resource.

Since Navarre is one of the Spanish regions with the highest percentage of electricity production from renewable sources, this region is investing in water electrolysis from wind over the short, med and long term.

Navarre has a "Strategic Plan Horizon 2010". The strategies defined in it comprise the promotion of renewable energy, conventional power generation, energy savings and efficiency as well as the promotion of infrastructures. Hydrogen is briefly mentioned in this plan.

2.3.4.17 Basque country

In the short term, H2 production by natural gas SMR will appear in the same way as it is already occurring in the Spanish autonomous communities. No views on other forms of H2 generation in the Spanish autonomous communities have been received.

There are two on-going energy plans, “The Basque Energy Plan 2005-2010" (a new one is being drawn out) and the "3E2010 Euskadi Energy Strategy. The strategies outlined include the promotion of renewable energy (combined cycle, Renewable, savings) without mentioning H2.

2.4 Hydrogen economy deployment

2.4.1 Introduction

The political framework where hydrogen and fuel cells technology is going to be developed is one of the fundamental factors for a careful analysis of their perspective. Both national and international frameworks have to be taken into account.

National measures pursue the ‘20-20-20’ objectives established by the European Commission for all the individuals EU states: 20% reduction in emissions, 20% renewable energies and 20% improvement in energy efficiency by 2020. This will be a good framework for the development of the H2 and FC economy in Spain as H2 could contribute towards an increase in the penetration rate of renewable energies since its use as a storage system can avoid the intermittencies of renewable energy.

Some data from the Renewable Energies Plan 2011-2020 for Spain (PANER): renewable energies installed power foreseen for 2020 is 69.844 MW. Some perspectives from the Scenario “Energy Revolution” of Greenpeace states that RES will cover 56% of the primary energy demand. Their contribution to electricity generation will reach 80% and 71% of heat supply.

All the RE installed power can be used during off-peak hours to produce hydrogen. This hydrogen will be able to be used in a FC to produce electricity when no RES are available but there is a demand. It will contribute to write off the initial investment in the RES facility sooner than expected.

Over the last few years Spain has been developing measures outlined in the Renewable Energy Plan (PER) for the 2005-2010 period. In 2009, renewable energy accounted for 9.4% of primary energy, and 12.2% of the gross final energy consumption, being the only source of energy to grow that year, especially due to wind and solar generation.

The Action Plan 2008-2012, seeks to achieve primary energy savings of 87,933 ktoes, that is to say, 24,776 ktoes per year. This will avoid the emission of 238 million tons of CO2 over the period of 2008-2012. Since the approval of this plan, oil prices continued to reach levels 50% higher than those reached during the 1970’s oil crisis, hence the urgent need to approve additional measures to enable energy savings and efficiency.

For this purpose an "Energy Savings and Efficiency Activation Plan for the 2008-2011 period, was approved with a budget of 245 M €. This Plan is an ambitious government initiative to develop measures to intensify energy conservation and efficiency, which comprise three strategic areas: sustainable mobility, sustainable building and energy sustainability.
The implementation of the "Activation Plan for Energy Savings and Efficiency 2008-2011” continued in 2009. The measures are organized around four lines: a first cross-cutting line, a second mobility line; third building line, and finally a power savings line. The overall objective is to reduce oil imports by 10% by 2011.

One of the initiatives of the "Action Plan 2008-2012" is to shift the energy saving commitment to private businesses and citizens. In this sense, the programme "Strategic projects for energy saving and efficiency for private enterprises" was launched in 2008. In 2008, twenty-one projects were financed under this program with a total budget of € 60 million.

In 2010, Spain adopted the National Action Plan for Renewable Energy (PANER) that will last until 2020 with the objective of fulfilling the commitments assumed by Spain in the EU renewable energy plan. Renewable energies in 2020 should represent at least 20% of the gross final energy mentioned above.

This Plan also comprises the progressive development of electric interconnections that should account for 10% of the installed capacity, in 2020, in line with the 2002 Barcelona Declaration. This capacity will allow the integration of renewable energy in the system in a technically and economically sustainable manner.

Regarding the international interconnections planned for the coming years, special mention should be made of the increase in interconnections with France and Portugal in the energy sector and in the gas sector through France with the opening of the Medgaz pipeline. Development plans are envisaged in the coming years to enhance, in the electricity sector, the interconnection with France and Portugal and in the gas sector through France with the entry into operation of the Medgaz gas pipeline. However, a good interconnection is indispensable, especially in the electricity case, in order to increase the presence of Renewable in the generation mix in a technically and economically sustainable fashion. Interconnections allow for more efficient management of the balance between production and consumption, thus contributing to the integration of renewable generation during off-peak hours while at the same time reinforcing supply security during peak hours.

The two new electricity connections planned with France – one which is expected to be up and running in 2014 and another requiring a more precise definition of its project and temporary horizon – are insufficient to reach the 2020 target of an interconnection capacity of 10% of installed capacity, which would mean approximately 10,000 MW.

It is important to note the actions dedicated to reducing energy consumption in the transport sector. The "MOVELE" plan has been launched in this direction. This plan is a pilot project to promote electric vehicles and aims to introduce 2000 vehicles in the domestic fleet by the end of 2011. The "MOVELE" budget is 10 M €. Another initiative is the promotion of urban transport by bicycle, with a budget of 2.5M€.

Finally, there is an on-going development of R & D activities in the energy sector, that meet the objectives set out in the National Plan for Scientific Research, Technological Development and Innovation, for the 2008-2011 period. The Strategic Action Plan for Energy and Climate Change is an instrument through which the government articulates a set of national sub-programs in order to promote a sustainable energy model that promotes the use of renewable energy sources, energy efficiency, development of clean burning technologies or emerging technologies (such as hydrogen and fuel cells) and progress in the area of sustainable mobility and modal shift in transport, the promotion of sustainable buildings and areas of mitigation of climate observation and climate change adjustment.

2.4.2 First user centres

The first user centres are defined as the regions that will act as a seed for H2 economy in each country belonging to SUDOE. These regions are meant to be the first ones using hydrogen as a storage energy system for domestic use and as a fuel for vehicles and are the most promising regions regarding the implementation of a hydrogen economy in each of the three countries participating in HYRREG. Hydrogen economy development will be based on them. Infrastructure will spread out over the rest of the country from them.

The selection of the first user centres was based on a list of objective indicators that had to be used to identify these first user centres. In Spain, the Capabilities Analysis Group of the Spanish Technological Hydrogen and Fuel Cells Platform (GAC PTEHPC) had elaborated and evaluated a list of indicators for selecting Spanish first user centres as part of its tasks. As a result, certain regions in Spain were addressed by the Spanish Technological Hydrogen and Fuel Cells Platform as the First User Centres. The list of indicators, as well as the regions selected by the GAC PTEHPC, was discussed by the stakeholders during the first national workshop held in Madrid. They were accepted and validated, so the first centres where the hydrogen economy would start in Spain are: Catalonia, Aragon, Chartered community of Navarre, Canary Islands, Community of Madrid and Basque country.

In the opinion of the stakeholders that participated in the HyRREG project, the regions where the hydrogen economy and fuel cells will first appear and develop do not necessarily have to be the regions where the production is going to be carried out.

Fig. 26: First Spanish H2 user centres map (indicated in blue)

2.4.3 Deployment perspectives

The deployment of the H2 economy and fuel cells from the first user centres to the rest of the country has been defined according to the following criteria:

- Connect the first user centres to each other.
- Cover adjoining areas.
- List of objective indicators examined in all regions.
- Encourage the connection with France and Portugal.

- **In the short term (2020)**

In the first place, a road network in which H2 refuelling is possible will be located in the first user facilities' region, connecting them between each other. Barcelona, Zaragoza and Madrid will be the first cities with a 'hydrogenerator' network (a network of hydrogen production centres filling stations). Roads around the first user centres that have a high population density should be equipped with hydrogen in a first stage because of the importance it will represent to all those people commuting daily to major cities for work purposes.

The demand for hydrogen will be low and cheap production of H2 should be fostered (which is what is currently done: steam reforming of natural gas and network electrolysis) and demonstration projects that demonstrate that the infrastructure is possible.

- **In the mid-long term (2030)**

Taking into account the first user centres selected and following the criteria outlined in the previous section, it is recommended that the second phase of the infrastructure deployment be focused around the first user centres and their interconnections. In the Spanish case the northeast of the peninsula should be the first area covered by hydrogen stations that will allow the use of hydrogen vehicles. In addition, a distribution infrastructure of compressed or liquefied H2 should be implemented in that area to meet the existing hydrogen stations and domestic appliance demand for H2. It is important to note the existence of a small insular infrastructure in the Canary Islands.

The regions that obtained the highest scores after the user centres (applying the list of indicators used for the selection of the first user centres drafted by the PTEHPC4) should, by this stage, have the above mentioned infrastructures. Such is the case of La Rioja, Castile La Mancha, Castile and Leon and Galicia.

The first roads for H2 vehicles between France, Spain and Portugal will be established in this period, with Portugal through Castile and Leon and Galicia and with France through Catalonia and Aragon.

In the midterm (2030), hydrogen pipeline networks will be built in areas where there is a demonstrated economic viability for construction due to regular and high demand.

When demand is high enough, the production has to be carried out using renewable energy. In Spain the most viable pathways to solve the energy self-supply problem in the midterm will be biomass gasification and wind power production by electrolysis that can occur in regions with potential for their production.

Such is the case of Castile La Mancha, where centralized coal gasification with CCS will be, in 2030 an available technology for the production of H2. The biomass potential is particularly important in Castile and Leon, Castile La Mancha and Andalusia.

- **In the long term (2050)**

The last phase of the Spanish H2 economy expansion (2050) will lead to the implementation of an infrastructure that will allow H2 to be used and transported regularly around the country. During this phase there will be as many hydrogen stations as gas stations.

In the long term new technologies are predicted to be sufficiently developed to be used in the production of H2: if nuclear and high-temperature solar energy receive political support, they might become pathways for producing large quantities of hydrogen by high temperature electrolysis or thermochemical cycles.

Solar thermal energy has great potential for development thanks to the existing technological base in Spain and the favourable conditions of these resources. Currently in Spain, and according to the available data, there is an installed capacity, of 182,5Mw, functioning since 2009, and 2300 Mw more are under construction, causing this technology to experience a big growth in the short term.

Noteworthy is the importance that user centres will have in a possible France-Portugal-Spain corridor. In this sense, the current selected user centres meet this requirement on the French border but not on the Portuguese border. The connection with Portugal will have to wait for a second phase of deployment and maturity of the technology that will lead regions such as Castile and Leon, Galicia and Extremadura to work as a corridor to Portugal.

2.4.4 Summary of the study

Analysing the chain components, some conclusions can be extracted:

- Natural gas: depends on Supranational and Central government policies and Transport and Logistic sector. Presently it is the cheapest way to produce H2. In relation to fossil fuels, we will use oil as a fuel until it ends or until the price is too high. Afterwards, we will use NG. The critical point is the CCS. The shift to use NG for H2 production will depend on the Policy actions because the technology is already mature.
- Wind: still requires involvement from the Central and regional governments for a clear and stable economic incentives policy and some improvements in energy engineering.
- Coal: its future for H2 production will depend on policy actions from central government because the technology is already mature. It will only happen if government Supports coal as strategic reservoir. The critical point is the CCS.
- Biomass: too dependent on Forestry and Agriculture sector and regional support policies. It is not yet a mature technology and needs technological breakthroughs.
- High Temperature Solar: depends on the policies from Central government, Energy engineering and Research, academia and consultancy. It is not yet a mature technology and needs technological breakthroughs.
- Electricity grid: future use for the production of hydrogen closely linked to the Energy – upstream / downstream, Energy engineering and Central government special fares. At present, H2 production from electrolysis is expensive and a very energy-consuming process. Technological breakthroughs (high temperature electrolysis, catalysts, etc...) are needed to reduce energy consumption.
- Nuclear: strongly dependent on central government and Civil society and NGOs position. In Spain there is no long-term National Energy Plan but the future of nuclear energy should be discussed in such a Plan.
- SMR: strongly dependent on central government and infrastructure if we talk about centralised production while decentralised production needs special emphasis in Energy engineering for small scale technology and CCS issue.

- Coal gasification: strongly dependent on central government and infrastructure if we talk about centralised production while decentralised production needs special emphasis in Energy engineering.
- Electrolysis: still needs Research and Equipment manufacturing to become a mature technology, namely in terms of efficiency.
- Thermochemical cycles: still needs Energy engineering and Equipment manufacturing to become a mature technology and special financial services
- Pipeline: Infrastructure investments were the unanimous choice for the stakeholders linked to central government plan.
- CGH2: Transport and logistics sector was selected for almost all the stakeholders as the strategic actor group. Regional government and automotive sector were pointed out as very important too.
- Filling stations: Regional government and automotive sector were selected for almost all the stakeholders as the strategic actor groups. Transport and logistics sector and Specialist hydrogen equipment manufacturing were pointed out as very important too.
- FC transport: Automotive industry and Specialist hydrogen equipment manufacturing were the obvious choice for all the stakeholders and a special significance for infrastructure too.
- Domestic use: dependent on Civil society, NGOs and regional government campaigns and their effects on society to promote social acceptance of a new energy vector for domestic use. Specialist hydrogen equipment manufacturing improvements are needed.
- Gas storage for grid reinforcement: viable if the Central government bets on this technology and if the Energy engineering sector provides the proper equipment.

2.5 Conclusions

The majority of the stakeholders believe that hydrogen will play an important role in the energy context of Spain, namely linked to renewable energies. Using H2 as a storage system can be the solution to the intermittent nature of renewable energies. But it is also envisaged that H2 will be used in the transport sector even though several hurdles have to be overcome – the lack of demand, efficiency and the costs of the technology were common references for the experts consulted.

Centralized production won the competition to decentralised solutions due to mass scale economy. Solar PV for H2 production was dismissed by stakeholders regarding costs and efficiency. High Temperature Solar Energy and Nuclear are only considered a good solution in the long term when more technological developments are achieved and costs are reduced.

In Spain, several renewable source chains were selected, even though the cost of hydrogen produced is higher. In the opinion of stakeholders, this happens because these renewable source chains have been of paramount importance to CO2 reduction and Spain’s energy independence.

The aggregation of the components by section showed very similar results, and no obvious bottleneck was evident, although the production pathways and end-uses proved to be a bit more difficult than other components.

Regarding the actors able to overcome or positively affect the realization of the key changes for each of these technologies, mainly Central and Regional Government, Energy engineering, Infrastructure and Specialist hydrogen equipment manufacturing, were selected as the main players. Some technologies still need research to become mature, but others are already near the market and, together with the manufacturers, the proper signs should be given by the national government in order to have the hydrogen technologies available and adopted by the population and companies after 2020.

3 PORTUGAL

3.1 General features

This report covers all the territories of Portugal including the islands of Madeira and the Azores even though the islands are not considered part of SUDOE. For energy purposes, the statistics in Portugal are not divided into regions as is the case with the other countries belonging to SUDOE. These small anomalies and divergences when compared to the other SUDOE countries are unlikely to make a significant difference to the analysis and to any subsequent interpretation and use of the data.

Fig. 27. SUDOE regions in Portugal

3.1.1 Energy framework

The electric energy consumption in Portugal amounted to 50,5954, 5 GWh in 2008 . The electric energy production during this period (41,164 GWh) falls in the category 10%-50% lower than demand. Eurostat data dating back to 1998 indicate that the energy dependency of Portugal has been in excess of 80% and reaching over 88% in 2005.

Year	1998	2000	2005	2006	2007	2008
Energy dependency — all products (%)	83.4	85.0	88.4	83.1	82.0	83.0

Table 10. Energy Dependency in Portugal

Source: Eurostat

The source of electric energy production is dominated by combined cycle (31%) followed by coal (25%), According to fig. 28 hydro power and wind power each account for 14% of the energy mix with fuel/gas amounting to 9%. The installed capacity of non-renewable sources is dominated however, by fuel/gas (40%), indicating a preference in the use of combined cycle despite the facilities for fuel/gas being predominant. Coal still accounts for 25% of the installed capacity. Portugal has no nuclear installations for energy. The percentage of external energy dependency in 2009 was 79.5%.

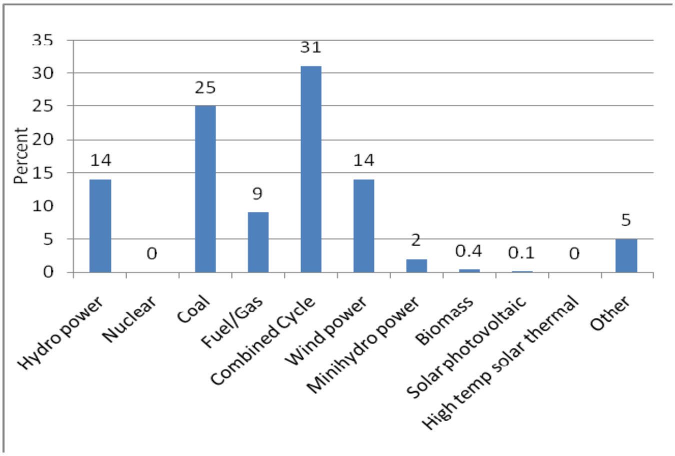


Fig. 28. Electric energy production mix

Hydropower is clearly the main source of renewable energy in Portugal, representing 59% of the installed capacity. The installed wind power capacity has been growing steadily in recent years and presently accounts for over one third of the renewable installed capacity.

Portugal does have tax incentives to foster energy efficiency, renewable energies and emerging technologies and a number of policy instruments, mostly of short term, to promote the use of hydrogen and fuel cells. H2 and FC implementation in Portugal would help to decrease energy dependency on other countries, act as a new energy storage system and reduce pollutant emissions.

3.2 Regional analysis: SWOT matrix

With the answers received from the Portuguese stakeholders a SWOT matrix of H2 and FC technologies in the region has been prepared.

PORTUGAL	THREATS	WEAKNESSES	STRENGTHS	OPPORTUNITIES
H2 production	*- Cost and efficiency of production - Pump hydro as competitive technology for energy storage*	*- Current low production of H2 - Lack of demand - Lack of mature technologies*	*- Capability for an increased production of H2 in the medium term from multiple sources, but mostly from renewable energy sources (RES), where the country is making a strong bet*	*- Production of H2 from RES, namely from off-peak wind (already viable), decentralized in 2030 and from solar in 2050 - Decreasing energy dependency on other countries - Capability for energy storage*
Storage and distribution.	*- Costs due to the low demand - Social acceptance*	*- Some stakeholders question the role of H2 in energy storage - Lack of mature technologies*	*- Research work in several areas - Most stakeholders trust in H2 for energy storage, namely due to its value when linked to RES and for use in remote areas*	*- Extensive natural gas (NG) pipeline grid in the main urban centres - Large percentage of inhabitants located in major cities, making more obvious the location of refuelling stations*
Conversion and applications	*- Alternative technologies with higher efficiency and lower costs (i.e. plug-in electric vehicles)*	*- Low durability and reliability - Restricted use of hydrogen cars to areas where hydrogen refuelling stations are available - Fuel cell (FC) costs - Lack of regulation, codes and standards*	*-National demonstration projects of new car technologies - Efficiency of FC - Lower emissions in industry, domestic and transport sectors - Independence from the electricity grid -Demonstration projects in several areas*	*- Portable applications will be an entry door for H2 in the short term, such as FC for portable electricity generation - FC for transport will be the most important end-use in the medium term, after an initial use of H2 in internal combustion engines, with public and private demonstration projects working as the kick-off of these technologies - Battery and FC hybrid electric vehicles as most probable technologies for cars - In the medium and long term, FC for centralised electricity production, co- and trigeneration will also be relevant end-uses*

				- Existence of several remote areas in the country may lead to a niche market for stationary applications
Perception and promotion	*- Lack of policy and economic support* *- Need for technological breakthroughs*	*- Need for social consciousness campaigns and participation in international forums*	*- Experience with H2 and FC* *- Lower emissions* *- Lower external energy dependence* *- Storage of excess energy from RES allowing for an easier management of these sources* *- Adapting electricity production and consumption* *- National plans for electric vehicles*	*- Open-minded population to the use of new technologies* *- Large penetration of NG in urban centres may ease the entry of H2 when mixed with NG in pipelines* *- Creation of jobs* *- Create H2 demand by producing it from excess wind power and using it for electricity generation and using it for stationary applications in public building (city halls, hospitals, police stations, etc.)*

Table 11: SWOT matrix for Portugal

3.3 Hydrogen production chains

3.3.1 Definition

The hydrogen energy chains selected for Portugal are the following:

Section	Chain Component	Estimated Timeframe	
		2020	2030
FEEDSTOCK	Wind	X	
	Solar PV		X
	Natural gas	X	
	Electricity grid	X	
PRODUCTION	Onsite electrolysis	X	
	Central electrolysis		X
	Onsite SMR	X	
	Central SMR with CCS		X
TRANSPORT	CGH2 truck	X	
	Pipeline (mixed with NG)	X	
	LH2 truck		X
	Conversion to liquid vector (e.g. ammonia)		X
DISTRIBUTION	Filling station	X	
	Distribution centre	X	
END-USE	FC transport		X
	Industrial use	X	
	Domestic use		X
	Gas storage for grid reinforcement	X	

Table 12: Portuguese chains

Current production of hydrogen in Portugal is estimated to be relatively low. The major industrial gas companies (for example Air Liquide, Petrogal, Praxair, Gasin (Air Products) and Linde) supply hydrogen but specific information on their facilities and production capacities is sparse. In 2010 Sinopec International delivered a steam reformer to Sines with a capacity of 90,000m3/h. In 2007 Air Liquide announced an undertaking to deliver around 15,000 Nm3/hour of hydrogen from a new unit dedicated production facility at Esterreja about 50km south of Oporto. Petrogal (Galp) constructed a plant in 2002 for the production of 32000 Nm3/hr at the coastal refinery of Sines about 150km south of Lisbon, one of the largest refineries in Europe with a distilling capacity of 10.8 million tonnes a year, or 220 thousand barrels a day. Hydrogen is produced by steam methane reforming of natural gas and naphtha.

However, there exists capability for an increased production of H2 in the medium term from multiple sources, but mostly from renewable energy sources (RES), where the country is making a strong bet.

It is also important to define the first applications for H2 and FC in Portugal because they will determine the kind of infrastructure to be developed. According to Portuguese stakeholders portable applications will be an entry door for H2 in the short term, such as FC for portable electricity generation. FC for transport will be the most important end-use in the medium term, after an initial use of H2 in internal combustion engines, with public and private demonstration projects working as the kick-off of these technologies. In the medium and long term, FC for centralised electricity production, co- and regeneration will also be relevant end-uses. Existence of several remote areas in the country may lead to a niche market for stationary applications.

3.3.2 Chains analysis

A technological and social analysis was conducted to define the strengths, the weaknesses, the opportunities and the threats of Portuguese´s chains.They are reflected in the table below.

	Strengths	Weaknesses	Opportunities	Threats
STATE OF THE ART	Mature and proven technology for onshore wind energy projects with high reliability and low risk. High levels of R&D already exist in Europe. Consumer perception that the wind generated electricity is better than other competitive sources of energy because wind energy is known as 'green energy' which has a certain kind of attractiveness for the consumers. Environmentally friendly source of energy, reducing CO_2 emissions from energy production. Traditional energy engine manufactures like Siemens or GE, have invested heavily in wind power in the last decade. This allowed significant economies of scale and cost reductions on wind energy projects. After hydroelectricity, wind energy is renewable energy with lowest production cost (around LCOE 0,08 €/kWh]. Warranties for wind energy turbines are reaching the breakeven point. This means that the warranty covers the turbine against defects until the period when cash-flows turn positive. Manufacture of wind energy components is a high-tech activity, with highest quality control and more than 30 years of development activities. These developments allowed putting this industry on par with the other energy industries. Minimal land use: wind energy as a high W/m2 of occupied land ratio. Moreover the land below each turbine can be used for other agriculture or farming activity.	Environmental and visual impacts in some areas with highly density of wind turbines due to noise and impact on birds and bats. Variable power output due to the fluctuation in wind speed, results in low availability factor for installed wind power (20-40% depending on wind resource). Difficulties on precise modelling energy resources. Wind energy resource is variable and hard to predict. Less relative mature technology state on offshore wind energy products and higher risk on life span forecasts increasing the final cost of the energy. High investments of wind projects: onshore around 1-2 M€/MW and offshore around 2-3M€/MW. Only big medium investors can promote this kind of project. The electric power transmission system limited capacity to incorporate the large amount of energy produced and not reaching the remote locations where the energy sources often are found. Wind is not dispatchable and may differ from the demand.	Offshore wind turbine size, the energy resource and potential for exploration are bigger than onshore. Important improvements in the technology have to be made in the field of increasing the turbine availability in order to improve operation and maintenance and develop solutions to decrease wind farm array losses. These technological developments will lead to significant cost reductions, like development of transport energy technologies (High Voltage Direct Current Technology) and energy storage solutions. Effect on long-term price development because of the low marginal costs of generating electricity. Development of accurate predictive models for the long term, to optimize the overall operation of the electrical system. New materials development to reduce rotor dimensions, less heavy nacelles, less steel on towers, generators less heavy and more efficient. New solutions for offshore platforms beyond 40 m deep and new customized turbines for offshore projects. Better techniques and methodologies for environmental risk management and social and environmental impact mitigation will increase the acceptance of projects.	Technological challenges like electrical energy storage still unsolved. Risk of offshore projects is substantially larger than onshore, due to complexity of turbine stabilization and fixation, marine currents, waves and storms. New bigger turbines could raise the environmental impact on birds and bats fauna. Some ecological groups continue the opposition to wind projects. Negative impacts on fauna could be one of the biggest treats for the future. The environmental analysis could be most restrictive. It will need comprehensive site assessment studies and better data on migration routes to reduced bird collisions with wind turbines. Other negative impacts like signal transmission interferences (radio, radar or TV signals), in areas with heavy wind power concentration. Wind penetration increase can reduce the economic value of wind power, due to displacing capacity from increasingly lower cost plants, operational losses due to repeated plant starts, unnecessary wind energy production, which cannot be absorbed by the electrical system.

Table 13: Wind energy chain State of the art

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL IN PORTUGAL	High energy potential in several Portugal continental areas with production higher than 2000 equivalent hours (2010: 2 403 equivalents hours/MW[28]). Important installation capacity (4 GW in 2011[28]) and tremendous growth in 10 years. Around 14% of the electricity comes from wind. Wind energy cluster formation in Portugal, associating wind energy production projects (consulting, Engineering Procurement and Construction (EPC), investment) with wind energy products (R&D, turbines, towers, components), developing high quality jobs, technological development and wealth creation. Relevant R&D activities, with important scientific and technical accumulated knowledge, in national laboratories and sector players (manufacture and EPC companies). Hydroelectric plants have fast on/off and flexible operation characteristics, complementing wind energy. In the new Portuguese Hydroelectricity Plan at least 6 new hydroelectric dams will be reversible. With this technology when there is wind energy surplus the water will be pumped to upper the reservoir dam, which will be run through the turbines later when there is demand increase or lower wind energy production. Thus the reversible hydroelectric plant acts as reservoirs of energy. Demand-Side Management (DMS) is being implemented under the Portuguese energy efficiency plan. It was found that the application of DSM measures will reduce the amount of investment needed to integrate intermittent power and will lead to a large reduction in peak power demand.	Bureaucratic process to install new projects, due to different barriers: environmental, social, political, fishing, defense, etc. This slows down the development of a project and detracts possible investors. New connections licenses are not assured. Low relative potential for offshore energy projects due the narrow continental platform induce higher CAPEX. The necessary infrastructure does not exist for offshore cases. A completely new infrastructure will have to be developed in order to make it compatible with the existing grid. In some electrical network zones the transmission and distribution capacity could be congested near the wind farm. In such situations the curtailment of wind power generation can be used to reduce the overall system integration costs. Actually there is sufficient interconnectivity between Portuguese and Spanish electrical grid. However, the interconnection between Spain and France (Europe) is near the limit capacity. Without good interconnectivity cannot sell the surplus of wind energy, so the interconnection with Spain-France is essential. It is expected that it will double from 1400 to 2800 megawatts in 2015. Lack of uniformity and objective criteria in environmental assessment process and lack of adequate environmental monitoring after projects approval.	Despite the lower relative potential in offshore projects, actually all potential areas are to be exploited (4 GW on 2030)[2]. An important onshore potential still to explore (near to 3 GW)[2]. The plan for hydroelectricity previews reversible dams, with energy storage. This could extend the grid capacity for wind energy power storage [3]. Portuguese Energy plan ENE2020 objective 8.500 MW total wind energy installed capacity will initiate new contests for new grid access[3]. The Government will support (at least indirectly), companies that could reinforce the wind energy cluster, especially the ones that create more qualified jobs. Prices of conventional sources of energy (oil, natural gas) will increase in the future. Expansion of the construction industry and mechanical engineering sectors could create new business opportunities and jobs. The actual financial crisis could reduce the cost of wind turbine; reduce delivery times (no waiting list) and favour only the best projects. Data for Portugal indicate that there is a favourable complementary relationship between solar energy and wind. The solar radiation varies almost inversely, relatively to the wind velocity (correlation of -0.7[7]). Solar energy can therefore be used to smooth seasonal variations of wind power.	Bureaucratic process and complex environmental requirements and approvals continue to be a barrier. Economic and financial crisis could slow down the implementation of the national energy plans and development of new wind projects. Competition with other renewable energy sources for the incentives and funding could reduce project viability. Only the best projects will be funded, probably the ones with highest ROI, however the best wind resource onshore areas are already occupied. NIMBY effect "Not In My BackYard" is common in Portugal. These effects could reduce new installation areas. The electrical transmission grid may not be ready for the challenge. There are already some network zones with difficulties in absorbing and transporting the energy produced (raising the electrical tension beyond admissible values). New investment on networks are planned, but may not be enough or even fail to start in the next years due to the financial crisis. Since the capacity for the grid to accept wind energy is near the limit (with 4 GW installed), new plants will be more costly, because they will need more energy storage (new reversible hydroelectric could be costly and environmentally unacceptable) and will require combine cycle facilities for fast response.

Table 14: Wind energy chain Potential

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL FOR H_2 PRODUCTION	Hydrogen is the most abundant element in the universe and has the highest energy per unit weight compared with any fuel. It is a component of water, abundant in chemical substances, and can be obtained by a simply electrochemical process using electrolyser stacks with energy source like wind energy. Technically H2 is one of the options for energy storage – energy carrier - helping wind energy as a regulator of intermittency and the randomness, characteristic of wind energy. The concept of energy buffering for a large wind farms could therefore represent an important market. Wind energy H2 production modularity (could install few kW to hundred of MW), can be used as stand alone, decentralized or centralized energy production for H2 supply. Increased renewable energy integration up to 100% using energy mix and storage strategies with H2. Hydrogen itself is not a pollutant. When hydrogen is produced by for instance excess wind energy, it provides emission free energy and low environmental impact. Several production chains are possible, from onsite domestic production, using electrolysis and fuel-cells to large central plants associated with MW turbines to water electrolysis for energy storage in H2 for electricity production or fuel distribution. Internationally the body of knowledge and lessons learned from designing and operating renewable electrolysis plants is growing.	Converting energy to hydrogen and back is expensive. The conversion equipment is expensive too and the process has a high energy consumption. The round-trip efficiency is considerably lower than that of competing technologies. The H2 volumetric energy density is very low, which means that a lot of space is required to store it. The two methods used to increase volumetric energy density, compression and liquefaction, require a lot of energy. There is no infrastructure with adequate scale for R&D for H2 technologies associated with wind energy. Codes and standards for test procedures, safety issues, technical specifications, etc., are not internationally defined yet. It is crucial to ensure that all the relevant safety issues have been adequately addressed. Financial models see wind energy as traditional investments, driven by IRR and ROI, based mainly in the feed-in-tariff. This scenario could change with tariff parity between wind and conventional energy sources. Technologies used in the production chain, like Polymer Electrolyte Membrane (PEM) electrolyser or fuel cells still immature. High CAPEX cost for the EPC processes associated with wind/H_2 solutions. There are no full-scale wind/storage/H2 projects with total autonomy yet and commercial viable. Technological validation from pilot projects will be important for technological and commercial development.	In the ENE2020 the potential of H2 as a means of energy storage will be evaluated to enable the use of renewable energy on a large scale and to promote innovative solutions in the transport sector[3]. The ENE2020 includes the preparation of a roadmap for H2 technologies in line with initiatives of the SET-Plan and the prospects of international developments. Future more restrictive carbon dioxide emission limits (post Kyoto agreement) can be an incentive to accelerate the development of H2 technology. The growth of wind will depend on storage capacity within the grid. Synergies like the possibility of H2 technologies acts as an energy storage to absorb the excess production during times of lower consumption could be very important for wind energy development. There are theoretical studies [9] on the hypothetical use of wind energy towers for H2 storage (inside: hydrogen tower), with significant cost reductions against conventional storage solution (1/3 cost reduction). Some technological advances have been made with the direct coupling of an electrolyser with a wind turbine, dispensing inverters DC / AC and AC / DC and reducing cost (reduce the cost of wind-to-hydrogen production by 7% [10]). There is an excellent opportunity for R&D in optimizing the electrolyser, in terms of efficiency, cost, and robustness [11]. Wind/electrolysis could be the first economical viable renewable system.	Actual barriers like high costs and very low efficiency prevent the large-scale introduction of H2 technology. Feed-in tariffs can discourage the direct production and use of H2 as a fuel. Some issues exist on product chain safety, principally in fuel storage and the filling process. High R&D efforts are needed to diminish energy loss during operation, improve stability and lowering the cost of infrastructure continues to be a challenge. There are important questions whether the H2 productions chains are the best possible use of renewable energy. Substantial developments and breakthroughs at every part of the production, storage and conversion are needed in order to render hydrogen storage technology competitive to established technology[8]. Hydrogen not known or accepted as an energy storage medium and competing with other energy carriers. Inadequate legislative framework (regulations, permissions, environmental analysis) for hydrogen production and integration with wind energy production. No existing H2 infrastructure. The productive chain is only viable for global scale. A Hydrogen based economy has not yet been implemented successfully.

Table 15: Wind energy chain H2 production

	Strengths	Weaknesses	Opportunities	Threats
STATE OF THE ART	Mature and proven technology for poly and monocrystalline silicon cells as well as thin films. Environmentally friendly source of energy, reducing CO_2 emissions and providing security of supply. Both silicon and thin films have issues with life cycle impacts. Principal raw material: Silicon, widely available geographical with widespread and well know material proprieties. Relevant reduction in energy cost expected in the next 20 years, expected < 1 €/Wp for 2030[2] with mass production, will raise the competitiveness against generation from fossil fuels. Reduce direct environmental impact in production: no noise or emissions in operation. Low OPEX cost (maintenance) for stationary systems. Building integration (BIPV) and urban ambient easy integration. PV is the only renewable resource with easy models for resource prediction that can be installed without any negative impact in urban sites, in almost all types of residential, service and industrial buildings. Short time for Engineering Procurement and Construction: project term around 1-2 years. Lifespan expected for modules around 25 years. The production is highly technological, automatic and in large quantities.	High cost of €/Wp and for the Levelized cost of energy (LCOE) €/kWh. Relative few places yield good quality silicon, not many suppliers. Some of the substances and components used in PV modules such as silver and gold are rare elements. Some of the elements used in thin films are toxic and poisonous. Lifespan for solar inverters, especially with higher DC power than nominal input, is lower than the project expected duration (around 10-15 years against 25 years for the project). Low efficiency of actual commercial modules. Normally commercial Si modules efficiency is less than 17%. The decommissioning and recycling process is still not satisfactory in some technologies and cells are still not recycled. General public still not conscious of the real benefits derived from the use of solar. It is not 100% autonomous and needs a hybrid solution to become viable. PV plants have a high rate of land use due low power density (around 200 W/m2); PV modules fabrication is a highly energy consuming processes and with some environmental impact. New recycling methods and production process will be needed to meet the demand and reduce costs.	Higher efficiency cell (>40%) with new future technologies like triple junction PV cells Cost reduction with "low-cost/ medium efficiency" technologies like thin film technologies and production techniques for raw material reduction. Thin films (other than α-Si), polymer cells and combinations between crystalline silicon cells and thin film technologies open up potential for cheaper and new type of PV module production. Cost reduction on production and implementation projects with dissemination due to economies of scale effects and new production techniques. Building integration of PV giving rise to a decentralized electricity production future. Education of players and actors as the general public in the technological aspects, innovative, vantages and opportunities on PV sector. Replacement of certain raw materials for economic reasons (e.g. silver) and environmental (e.g. lead). New production equipments with low CAPEX and still with low OPEX, low energy consumption and smaller, standardized and automated features. Life span module and inverter increase.	There can be significant energy costs and environmental impacts for some technologies for producing the PV cell. Relatively low lifespan for solar inverters can raise the OPEX and reduce availability ratio. Greater lifespan on this equipment will be needed. Lobby from big energy producers and incumbent energy companies can slow down or skew the processes. Predicted reduction in cost is not easy; the target is to reduce the cost per kWp but the decrease in price is taking longer than expected. Technological challenges like electrical energy storage still unsolved. Resources spent on PV R&D without substantial commercial success may result in redirection of R&D funding. In the future raw material prices and supply and demand effects can slowdown the desired costs reductions. Competition with other renewable energy sources for the incentives and funds could reduce projects viability.

Table 16: Solar photovoltaic chain State of the art

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL IN PORTUGAL	High solar energy potential and easy to predict in all continental Portugal, with average global irradiation 1600-2000 kWh/m^2 and an average production for 1300-1550 h per year. European and National energy and climate policies support market growth turning PV installation economically viable. Feed-in-tariffs for PV production for 2011 are between 250 €/MWh and 380 €/MWh. Portugal has a significant potential in the universities and research laboratories for R&D activities on semiconductors. The high-tech nature of PV is appealing and countries with a PV industry recommend sustained R&D efforts. The Small and Medium Enterprises structure of the PV business in Portugal enables fast reactions and adaptation to the market needs. The Spanish experience – almost 4 GW of installed photovoltaic –, with similar conditions regarding the availability of the resource and geographical distribution, could help the Portuguese projects to build upon this experience. There is a growing interest of financial entities in solar technology projects. Potential development of a production chain leading to a "cluster" of technologies for solar energy.	Limited licenses available and totally in control of the Government. Lack of experience on PV technologies for production and EPC, can raise projects risks and costs. Portuguese PV sector is still small since few companies are international players, but there is potential for some consolidation. The Portuguese strategy for energy sector was not always clear or strong. The objectives in the Portuguese Energy plan ENE2020 for PV power installation are fixed, but there is some doubt as the goals can be achieved. The small size of the country and the national market as well as the peripheral location may not lead to the necessary economies of scale for manufacturing. The electrical network is not yet ready for the challenge. There are already some network areas with PV installation, with difficulties in absorbing the produced energy (raising the electrical tension beyond admissible values). On R&D there is low collaboration and communication levels between academics, Labs, policymakers and companies. This could dilute efforts. Lack of critical mass. Solar energy is inherently extensive technologies, i.e., vast areas are required for solar plants to generate energy. Delay compared with first mover countries.	High potential resources with almost all ideal resources areas being available (9,3 GW in 2030 with slightly more than 200 MW installed in 2011)[2]. Portuguese Energy plan ENE2020 objective is 1500 MW total solar energy installed capacity and so future licenses will be available for new grid access[3]. Micro and minigeneration new laws could permit connections of installations up to 250 kW, in less than six month (from the license request to the grid connection). Possible industrial cluster formation, with opportunities for R&D, productions sites and EPC companies with some national and international investors interested, creating new business opportunities and qualified jobs. The need to comply with international agreements on energy and greenhouse gas emissions (Kyoto protocol targets and pos-Kyoto), European Renewable Directives and European policies on security of supply, will stimulate the PV market. Renewable Energies including PV have by their nature long term potential. New jobs and welfare creation associated with the production chains. Small scale size will certainly provide the right bed for some testing and know-how gathering as the expected commercial concentrated technologies demos.	Bureaucratic process for complex projects. Economic and financial crisis could slow down the implementation of the national energy plans and development of new solar projects. This problem exacerbates the traditional "stop and go" policies and funding programs creating uncertainties in the PV sector and in industry. Part of the cost reduction depends on market evolution, driven by governmental incentives. Possible change in long term government policy and long term return of investments may change the rules of the game "in the middle of the game". Competition with other renewable energy sources for the incentives and funds could reduce the project's viability. Low uptake of opportunities and historically less efficient implementation of projects in Portugal. The PV sector, as it is now, does not respond to the tendencies of the liberalized electricity market. Liberalized markets tend to favour low cost, off-the-shelf technologies. As PV technology is a "new" creation, it is seen as a threat. The National market is not yet aware of this technology although there is a high level of technological knowledge (mostly at R&D level). The Portuguese energy mix already has a high percentage of renewable energy. Without a process for storage it will be hard to incorporate more renewable energies.

Table 17: Solar photovoltaic chain Potential

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL FOR H_2 PRODUCTION	Technically H2 is one of the options for energy storage, helping photovoltaic energy as a regulator of solar resource variability. This combination can ensure a capacity utilization of at least 4200 h/y [13]. This more than doubles the actual production, around 1300-1550 h per annum. PV plus electrolysis technologies have been developed beyond the demonstration phase. Hydrogen itself is not a pollutant. Hydrogen produced from solar PV energy provides emission free electricity and has a low environmental impact. New technologies with high efficiency (>40%), combined with the efficiency of electrolysis (>80%), could reach interesting final efficiencies of up to 30%[13]. The marriage between H2 and solar PV energy brings secure, clean energy—as well as making PV a "24-hour power" option [23].	The cost of H2 production from solar energy is high compared with fossil fuels, or even other renewable energy like hydroelectric, biomass or wind energy. Studies indicate the electricity costs will be a major price contributor to the price of hydrogen produced via electrolysis [20]. Investment cost show little economy of scale. Historically there have been few solar photovoltaic projects in Portugal compared to other equivalent countries. The solar energy developments are relatively small and there are no hydrogen/solar projects in Portugal. Actual H2-PV efficiencies are low, up to 10 % for commercial and up to 20% in the laboratory. The infrastructure for H2 production and distribution is not in place, and the majority of the solar projects are located outside urban areas. Centralized technologies such as Concentrator Photovoltaic (CPV) will require long-distance delivery, which is difficult and potentially the most costly segment of the hydrogen energy system [23]. Centralized PV-hydrogen will not likely be available until the 2040 timeframe and decentralized approaches can be reached by 2035 [23].	Because solar energy is disperse and widespread, H2 can be used to transport energy to the main centres of consumption. Maximum Power Point Tracking (MPPT) and DC/DC electrolyzes can reduce cost and increase efficiency process. Cooperation between Portugal and Spain with similar energy systems and priorities and similar solar resources. New technologies like thermal Concentrator Photovoltaic for H2 production will be competitive with other H2 production methods in the medium term.	Feed-in tariffs can discourage the direct use in H2 production. No legal framework for solar hydrogen projects. Solar energy is one of most expensive renewable energies. High competition against other renewable could be a future problem. The develop of H2 vehicles could be abandoned due to new trends like hybrid, electric plug-in cars or even future solar energy cars an eventual "electrical economy" instead "H2 economy". Electricity may be the chosen carrier making hydrogen less viable. Other fuels can be produce from solar PV, like methanol: conversion of solar energy to electricity via PV, driving a "methalyzer" to produce liquid methanol, and then transporting the liquid fuel (from central sites in the Lewis concept) to the point of use [23].

Table 18: Solar photovoltaic chain H2 production

	Strengths	Weaknesses	Opportunities	Threats
STATE OF THE ART	Widely available resource, including in Europe, America, Africa and the Middle East. NG produces lower emissions of greenhouse gas per unit of energy than coal than other fossil fuels, which gives natural gas a huge environmental advantage (it produces from 1/3 to 2/3 less CO_2 than oil or coal when it is burned). NG is one of the cheaper fossil fuel (by up to 30% per energy unit). Combined cycle thermoelectric power plants can reach efficiencies of around 42%. NG is becoming the fuel of choice because it is more versatile than coal or oil in these power plants. Is a perfect substitute for almost all gaseous fuels and can even be used directly as a fuel in automotive engines. NG has a lower specific density than air, which facilitates its dispersal into the atmosphere in case of leakage and reduces the risk of accidents, unlike liquefied petroleum gas. The combustion is complete without smell, very low level of sulphur oxides and free of nitrogen and soot particles. The combustion characteristic allows extend equipment lifespan. Since most of the distribution process is by pipeline, NG reduces transport and logistics problems. Since NG provide in normally recovered from the same exploration as oil as a by-product, it has a low rate of land use.	Need important safety system due is highly inflammable nature and risks of explosion. Has inferior lower calorific value than other gaseous fuels like butane or propane. Is hard to transport, since it occupies more volume than other combustible gases, even when pressurized. Liquefaction requires temperatures lower than -160ºC, and risk of explosion and instability is higher in this state. Transportation will require (preferable) pipelines, which represent huge CAPEX investments. Methane (principal component of NG) leakage may occur during the phases of exploration and distribution. Methane is one of the most harmfully greenhouse gases. NG is a non renewable and a finite energy resource. When the combustion is poor in O_2, carbon monoxide (CO) can be produced, which is an odourless and highly toxic gas.	NG combined cycle thermoelectric power plants have a fast response time and can act as a standby form of energy to smooth the variability of renewable energy. Paradoxically new NG plants could help renewable energy grow. Conventional and non conventional NG reserves (such as coalbed methane, shale gas or tight sands) can last up to 125 years at the current consumption rate[16]. It represents several years of reserves beyond oil. Growing transport technologies using Liquefied Natural Gas could reach more consumers in the future without construction of expensive pipelines. Some "old" technologies as Hydrogen-enriched natural gas can be useful for gradual introduction of H_2 on energy network. It is possible use up to 20%v/v of H_2 on NG in the actual NG infrastructure reducing relevant implementation costs [26].	NG cost indexation to oil prices (In the past prices of NG and oil moved in unison because they usually come from the same well) and growth in demand can raise the fuel prices. The trend will be a significant increase in prices. Drilling for exploration of NG has always important environmental impacts like potential damage to ground and surface waters. Some NG exploration technologies like hydraulic fracturing are in considerable controversy. Environmental safety and health concerns have emerged and are being debated (Some studies indicated high CO_2 emissions and chemical pollution). Other new fuels like methane hydrate with higher reserves than NG can replace this energy source. Methane hydrate consists of a cage of water molecules trapping a methane molecule within. This can form large crystals of hydrate in cold and heavily pressurized situations (mainly on the continental slope in the oceans)[29]. Since NG is not zero emissions, its produces some harmful emissions that could be penalized economically by the emission of greenhouse gases. In addition researchers may want to replace NG in the future with less polluting fuels. Since non renewable H_2 production techniques always produce CO_2, Carbon capture and storage (CCS) techniques will be critical for these H_2 "sources". CCS still in a very early stage of development, without guaranties of future success.

Table 19: Natural gas chain State of the art

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL IN PORTUGAL	NG in Portugal was regulated in 1989, the network construction start in 1994 and first supply in 1997. Today NG is provided to the principal populated areas of Portugal. Relatively well stabilized sector, with liberalization in progress. The transport and distribution infrastructure is oversized. Limitations of capacity are not expected in the short term. The introduction of NG in Portugal allowed competitive energy and energy resources diversification, reducing dependence on oil and increasing the competitiveness of domestic industry. The introduction of NG improves the competitiveness of national industry, since it is less expensive and has lower greenhouse gas emissions then other fossil fuels.	Natural gas is not endogenous (there are no significant reserves in Portugal). All NG must be imported from countries like Nigeria and Algeria. Despite the liberalization, there is risk of new more complex business combinations, mixing the two sectors (gas and electricity) with few agents, increasing the likelihood of dominating positions and therefore reducing the effectiveness of market competition. Liberalization processes sill incomplete, with few players and significant entrance barriers. Portuguese NG market is not big enough to sustain more than three players in the commercialization sector. In some cases there is excessive regulation where their intervention is not confined to create conditions for equal access and opportunities for new entrants, or in other cases lack of regulation with incumbent abuse from dominant position[17]. More NG will contribute to more external energy dependence in fossil fuels. Poor information about the potential of NG and its contribution to H2 economics.	The new MIBGAS (Iberian gas market), will be very important for consumer and market players. The increased market size and number of participants will increases the level of competition and integration and strengthening linkages contributes to the security of supply. Some studies indicate the possibility of NG reserves in south of Portugal. The growing market for the Liquefied Natural Gas (with around 25% market share in Europe), will transform NG in a global business, since will not depend on pipelines [17]. The market will become an energy market, with old electricity and old gas/oil players acting in the whole market, thereby increasing competition in the energy market. Possible interconnection between Spain and France will substantially diversify the sources of NG. New business opportunities for equipment manufacture like electrolysers, infrastructure equipment, automation, compressors, pipelines, and other services.	All NG consumed in Portugal is imported from countries with high political and instability risk, like Algeria and Nigeria. This can be a future menace for the security of supply due to high political uncertainty. In cases of natural catastrophes like earthquakes, pipelines and conducts can be highly damaged. NG prices can rise with increasing demand and reducing supply. Technologies will compete in the future. For example NG combustion motors against H2/fuel cell motor. Since the NG network (a natural monopoly) has a national importance, for social and systems integrity it is arguable if the national energy transmission system must remain a national entity and therefore be retained by majority State ownership on permanent contract. The recent impositions from the IMF for the privatization of REN (transport energy network state company) could entail significant risks. Eventual supply alternatives such as Russian NG (by European pipelines), does not guarantee security of supply, as could be verified recently with the dispute between Russia and Ukraine.

Table 20: Natural gas chain Potential

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL FOR H_2 PRODUCTION	Methods to produce H2 from NG are well developed and account for almost all hydrogen produced globally. The steam methane reforming (SMR) process is a mature technology, economical, widely used process for hydrogen production, and provides near- and mid-term energy security with high efficiency around 70% [14]. SMR of NG is widely used in industry today. H2 is produced by the SMR process in large centralized industrial plants for use in numerous applications, including chemical manufacturing and petroleum refining. The well-developed natural gas infrastructure that already exists in Portugal is a key factor that makes H2 production from NG attractive. NG represents one of the most viable pathways for introducing H2 as an energy carrier because it is among the least expensive feedstock for producing it.	The SMR process in centralized plants emits more than twice the CO2 than H2 produced. It will require carbon sequestration. Sequestration concepts and technologies are relatively new and there is no long-term test evidence to prove that these technologies will be successful. SMR is operating at or near its theoretical limits and the H2 produced is still expensive compared to the cost targets for producing H2 for future applications. NG is used in many other sectors of economy, including the commercial, residential, and electric generation sectors. If NG is used for H2 production, and the demand of NG in other market sectors continues to grow, the NG reserves would decrease and the supply will be put under greater pressure. This could result in increased natural gas prices. Exploiting sequestration in NG reservoirs requires planning of NG field depletion strategies long before H2 production begins. The Regulatory Framework, necessary to provide incentives and clarify roles and responsibilities, is far from set.	For production technologies like SMR there are opportunities on R&D to improve reforming efficiencies, identify more durable reforming catalysts, and reduce carbon sequestration and overall costs. Direct H2 delivery—either as a high-pressure, medium-pressure gas, or liquid—recognizes that the technical and economic hurdles facing on-board liquid fuel reforming will be the object of new developments. New infrastructure for H2 production parallel to existing ones for NG will be necessary. Economies of scale and synergies could emerge from these new projects. Capture and storage of CO2 from converting NG on H2 via NG natural reservoir repressurization, could reduce meaningfully cost and emissions. But this technological solution is viable only close to NG explorations.	If sequestration (CCS) does not work, clean H2 from NG is not available. Opposition from mature technologies and lack of interest from utilities for H2 production based on NG due to other more profitable uses, like cogeneration. Very limited R&D activities in H2 production based on NG.

Table 21: Natural gas chain H2 production

	Strengths	Weaknesses	Opportunities	Threats
STATE OF THE ART	Generation, transport and distribution of electrical energy are very mature technologies, since it was the first energy network on a significant scale. It is one of the easy ways to transport large amounts of energy from production centres to consumers. Energy transportation operation has very low environmental impact and greenhouse gases emissions. Electrical energy transportation has high efficiency and is a well controlled process when compared with other energy vectors. Using electrical energy as a transport vector allows the introduction into the energy system many different primary energy sources such as coal, diesel, natural gas, biomass, wind energy, solar energy, hydroelectric energy, nuclear energy, etc, giving it great flexibility.	Electricity is not an energy source but merely an energy carrier. It has to be produced from primary energy sources like coal, NG or renewable sources. Even with reversible hydroelectric plants and reservoir dams energy storage is very limited. The grid needs almost instantaneous balancing between demand and supply. There are no queues in the electrical systems. Energy must be available at the minute. High voltage power lines are expensive, have visual and social impacts and potentially can affect the health of populations located too close to the same due to the electromagnetic fields generated. The construction of new high voltage power lines has a significant environmental impact, since deforestation is necessary as well as cleaning the area around the line route, access ways and excavation for tower installation. When electrical energy is, produced from conventional fossil fuel sources, the overall process has a low energy efficiency level (around 30%). The total electric load of any future integration on a large scale of hybrid cars and must be secured by the existing grid.	New development in transmission, especially l over long distances with technologies like VA high-voltage, direct current (HVDC) electric power transmission system can reduce costs and electrical losses. In the future (2020) new technologies like high-temperature superconducting cables, with zero electrical resistance, will be applied in electric power cables reducing meaningfully electrical losses in high tension transmission. Supercapacitors and Superconducting Magnetic Energy Storage (SMES) are two examples of new developments which can provide, in the long run, new possibilities for electrical energy storage. In the Smart grid consumers will become increasingly active agents, responding to economic signals and will be able to provide services using system management mechanisms demand, to assist in resolving critical situations of exploitation.	Grid management can be a limitation. The new electrical grid, the smart grid, will be dependent on complex IT processes, with exposure to new risk like virus, hardware faults, and software bugs, hackers or terrorist attacks. Power lines can be affected also by several issues like vandalism overvoltage due to lightning, bird impacts, pollution, wind and other extreme weather conditions, therefore redundancy is necessary. Actual traditional power utilities only collect data with basic measurement systems consisting of basic readings of power consumption required to issue invoices. Future smart grids will collect many more data, some of which must be protected by strong private controls.

Table 22: Electric grid chain State of the art

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL IN PORTUGAL	The electrical grid is the largest energy network and reaches almost all the country. In some country zones, electrical energy is still the only energy consumed in homes, like in the north of Portugal. Liberalization of electricity market partially concluded with access of private investors to the electrical energy commercialization. Since the electrical grid is a natural monopoly, high tensions transport grid is concentrated in a public company. Smart grids are already a reality, since pilot projects are running since 2010. New connections made over the last decade will result in a significant increase in network security in the country. The national transport network is quite stable. Growing interconnection between Portugal and Spain reduces the risk in the electric network.	Low investment in some grid areas result in low quality electrical energy. In some local areas the electrical network is unstable with low levels of tension and frequently switches off. The interconnection between Spain and France (Europe) is near the limit of capacity. Without good interconnectivity cannot sell the surplus of wind energy, so the interconnection with Spain-France is essential. It is expected that it will double from 1400 to 2800 megawatts in 2015. The interconnection between Portugal and Morocco is very weak.	The Portuguese Energy plan ENE2020 focuses on intelligent electrical networks, since they are a key for the success of electrical cars and energy efficiency, because they will permit the tracking and control as well as management of the production, transport, distribution, storage and consumption more efficiently. Recent market liberalization with the end of regulated rates may represent an increasing number of competitors and cost reductions. Since wind energy penetration is higher than 35%, surplus power storage is necessary to handle the mismatch between load and power production, thus avoiding overloading of the grid due to lack of transmission capacity. New reversible hydroelectric plants could ease this situation, but the problem will remain for new offshore wind power. Here H2 can play an important role due to the possibilities of long-term, low-loss storage and integration of a substantial transport fuel supply need.	Actual tariff deficit are estimated to be EUR 1800 million, representing an enormous load to the accounts of the electrical system. New impositions from financial markets (including the IMF and the EU), will have an important influence on energy markets, and could reduce renewable energy incentives for electrical production and reduce funding for future H2 programs. Since the energy network (a natural monopoly) has a national importance, for social and systems integrity it is arguable that if the national energy transmission system must remain national and therefore be retained by majority State ownership on permanent contract. Recent impositions by the IMF call for the privatisation of REN (transport energy network state company) which could entail significant risks. Future introduction of Electric Vehicles (EV) will require the development of the necessary technologies to enable valley filling and load control as ancillary services. Utilities need to control the scheduling of EV charging. Without these controls EV adoption above 10% of the light-duty vehicle fleet will cause serious problems in meeting demand on the grid [27].

Table 23: Electric grid chain Potential

	Strengths	Weaknesses	Opportunities	Threats
POTENTIAL FOR H_2 PRODUCTION	The potential of H2 as an energy storage means may enable the long-term use of renewable energy on a large scale, promoting innovative solutions in the transport sector. Hydrogen Fuel cell technologies development has a considerable potential to change the current energy paradigm through synergies with decentralized production of energy through renewable energies and energy efficiency. Since the electricity grid is the biggest energy network in the country, hydrogen production will be considered as an integral part of this energy system, given its storage characteristics. Studies indicate that the electricity grid will remain the predominant method of energy transmission and distribution [26]. For long-term storage, H2 offers the advantage of a highly flexible option with the possibility for multiple-use.	The market is dominated by centralized sources and requires higher transmission capacities of intersystem connectors. In the short term H2 will not be an option for overall storage installations due to the low conversion efficiencies and high cost. For future decentralized distributed generation segment will need intelligent control systems to balance supply and demand and to prevent accidental islanding of a part of the grid disconnected for maintenance. This is essential for successful uptake of Fuel-Cell based co-generation technologies. There are no adequate models for the market, regulation and tariff generation that could cope with new challenges of evolving power system at the distribution infrastructure level. Policies and standards are needed to be in place to allow distribution control to be effective. Renewable energies such as wind energy are normally located in remote areas where only the thinnest branches of hierarchical electricity networks reach.	For network balancing storage will require not a single technologies but a variety that can satisfy every requirement; a mix of fast response and long term storage is likely to develop. H2 distribution will be dependent on the existing energy network for start-up. The electrical grid will be an essential part of the H2 economy.	Centralized electricity production by fuel cells is not desirable because of its relatively lower efficiency; higher efficiencies of these particular converters, or lower hydrogen prices, would be required to make them more feasible for realistic inclusion in integrated energy systems [24]. Plug-in electrical vehicles could represent in the medium term a threat for the H2 economy, since this type of vehicles could be used for electrical energy storage and presents several advantages such as, an existing supply network(gas and electrical), more autonomy and security, compare with H2 vehicles or even pure EV.

Table 24: Electric grid chain H2 production

3.3.3 KCAM analysis

The chains for Portugal took as a starting point the work of previous studies HI-PO (2008) and EDEN (2008), which conducted an extensive review of hydrogen energy possibilities for a future hydrogen economy in Portugal. The Portuguese Profiling Report (HYRREG, 2010) provided some updates to this data and together with inputs from relevant stakeholders, led to the final set of chains for evaluation.

The set consisted of 4 main chains, 2 of which were based on renewable sources – wind and solar photovoltaic (PV) –, whilst the remainder were based on natural gas (NG) and the electricity grid. Different possibilities were then considered for production, transport, distribution and end-uses options.

- **Analysis per component**

Production consisted of central and decentralized (onsite) solutions. For the renewable sources and the electricity grid, electrolysis was considered, while steam-methane reforming (SMR) was chosen for natural gas. In this last case, carbon capture and storage (CCS) was included in the central option and not in the onsite one, due to the financial and technical constraints associated with CCS in small plants (IEA, 2007).

For transport, the truck with compressed hydrogen (CGH2) and the mix with NG in a pipeline were the alternatives explored. By suggestion of one of the stakeholders, two additional transport options – liquid hydrogen (LH2) truck and the conversion to a liquid vector (e.g. ammonia) –, were added at the evaluation stage, in order to explore innovative alternatives to other more obvious choices.

In the centralized production chains there was a need for distribution, which mainly relied on filling stations for the fuel cell (FC) vehicles and distribution centres for the industry. Apart from these uses, the domestic consumption of hydrogen in fuel cells for electricity and the storage of electricity for grid reinforcement (via fuel cells) when needed were also included. In all of these possibilities for the use of hydrogen the goal is the same – move away from fossil fuels as primary energy sources, whether they are the main source, as is the case of the transport sector, or by maximizing the use of renewable, with the onsite solutions and the storage for grid reinforcement.
The following table (Table B.1) summarizes the results from all stakeholders. A colour code was used to identify the extreme values for each component, highlighting the wide spectrum of assessments, with most assessments varying more than 2 categories: 1-4, 2-5 and even 1-5.

Section	Chain Component	Estimated Timeframe 2020	Estimated Timeframe 2030	Electricity Production Industry	Fossil Fuel Industry	Hydrogen Association	Energy Research	Industrial Gases Industry	Energy Innovation Company	Chemistry Research	Energy Technology Research	Energy Policy	Energy and Transport Research
FEEDSTOCK	Wind	X		4	4	1	3	3	2	4	4	3	4
	Solar PV		X	4	4	3	5	4	2	5	5	4	4
	Natural gas	X		2	2	4	4	2	3	1	2	5	2
	Electricity grid	X		3	3	1	2	2	1	2	3	3	3
PRODUCTION	Onsite electrolysis	X		2	1	3	2	3	3	4	2	4	2
	Central electrolysis		X	3	4	3	4	4	2	4	3	3	4
	Onsite SMR	X		3	2	5	3	2	3	2	3	5	2
	Central SMR with CCS		X	4	3	3	5	4	3	2	4	5	5
TRANSPORT	CGH2 truck	X		4	2	5	3	3	4	5	3	2	2
	Pipeline (mixed with NG)	X		3	3	5	3	4	2	3	2	2	5
	LH2 truck		X	-	*4*	*5*	*3*	*4*	-	*5*	*3*	*4*	*3*
	Conversion to liquid carrier (eg amonia)		X	-	-	*2*	*4*	*5*	-	*2*	*2*	*3*	*5*
DISTRIBUTION	Filling station	X		2	1	4	3	3	2	5	2	4	3
	Distribution centre	X		4	2	2	4	3	2	4	2	4	4
END-USE	FC transport		X	3	2	3	3	4	2	3	2	3	3
	Industrial use	X		2	4	5	2	2	2	2	4	3	5
	Domestic use		X	4	4	5	3	4	2	5	3	4	5
	Gas storage for grid reinforcement	X		5	3	5	5	5	2	5	2	2	4
			Total (w/o liquid)	52	44	57	54	52	37	56	46	56	57

Difficulty Allocation
(only extreme values are highlighted in the table)
1
2
3
4
5

Table B.1: Summary of results per chain component for Portugal

The aggregation of the difficulty allocations (Figure 30) shows a wide variety of difficulty levels in most sections, with renewable options being less favoured than status quo (Electricity grid and NG). Also decentralized production is preferred to centralized electrolysis and SMR and FC transport comes as the obvious choice for hydrogen use, followed by industrial use.

It is also evident that components targeted for 2030 appear to be more difficult than those for 2020, except for FC transport.

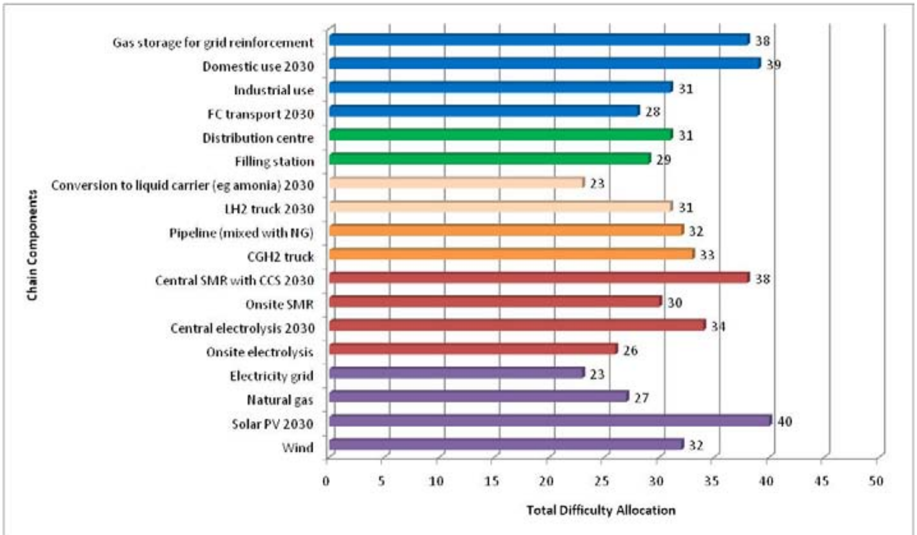


Fig. 29. Chain components total difficulty allocation for Portugal

- **Analysis per chain**

The aggregation of the results per chain is shown in Figure 30. These values were calculated by summing the individual assessments for each component of the chains, as indicated in Table B.4. The fact that centralized chains have more components leads to higher difficulty levels than decentralized ones. The electricity grid chains have a clear advantage over other feedstock for similar chains (A1-3, B1-3, C1-3 and D1-3).

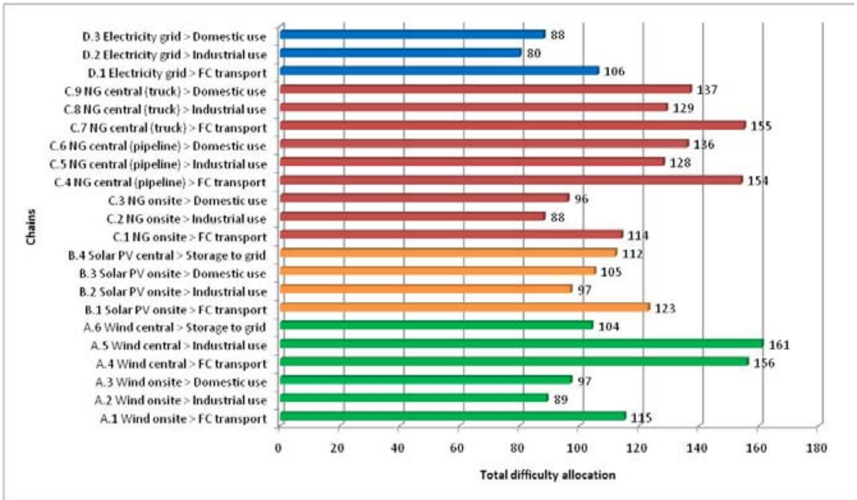


Fig. 30. Total difficulty allocation per chain components aggregation for Portugal

Due to the different number of components in each chain, another graphic was produced, which reflects the average difficulty allocation (Figure 31). Apart from the conclusions mentioned above, it can be extracted from this figure that the FC transport chains lead the preferences of the stakeholders, followed by industrial uses. Looking at the sources, electricity grid reveals lower difficulty levels when compared to other sources, solar PV being the option with most difficulties.

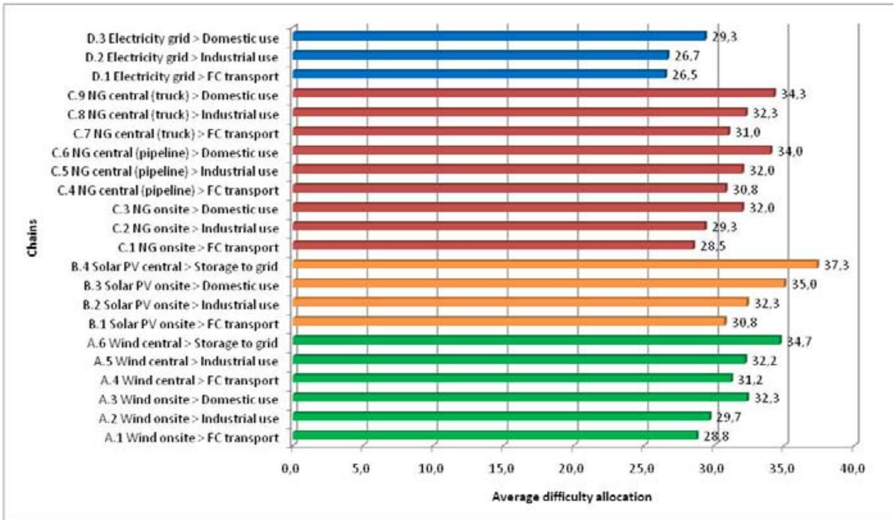


Fig. 31. Average difficulty allocation per chain for Portugal

- **Broad actor group**

The summary table with the actors that might play a role in overcoming or positively affecting the realization of the Key Change is provided below (Table B.2).

Looking at the total values of Table B.2, it is evident that 3 actor groups focus the attentions of the stakeholders – Central government; Research, academia and consultancy; and above all Specialist hydrogen equipment manufacturing. One interpretation of this is that there is still a lot of research to conclude in order to reach more efficient technologies, but the stakeholders believe that with the proper boost from central government and the availability in the market of competitive technologies, hydrogen can be a reality in Portugal after 2020.

Energy and Infrastructure companies, the European Union, the Civil Society and NGO and the financial services are the next most frequently nominated actor groups, while there is a small role for the Media, the Agriculture and forestry and Real Estate sectors and the Regional governments. It is interesting to notice that few people mentioned the Hydrogen associations as crucial players in this scope.

Section	Chain Component	Energy – upstream / downstream	Energy engineering	Infrastructure	Automotive	Central government	Regional government	Supranational government	Research, academia and consultancy	Civil society and NGO	Hydrogen associations	Transport and logistics sector	Specialist hydrogen equipment manufacturing	Agriculture / forestry	Media	Real estate construction and management	Financial services
FEEDSTOCK	Wind																
	Solar PV																
	Natural gas																
	Electricity grid																
PRODUCTION	Onsite electrolysis																
	Central electrolysis																
	Onsite SMR																
	Central SMR with CCS																
TRANSPORT	CGH2 truck																
	Pipeline (mixed with NG)																
	LH2 truck																
	Conversion to liquid carrier																
DISTRIBUTION	Filling station																
	Distribution centre																
END-USE	FC transport																
	Industrial use																
	Domestic use																
	Gas storage for grid reinforc.																
	Total	23	24	30	19	41	2	24	43	27	15	20	59	1	9	3	25

Difficulty Allocation # occurrences	Total
0	
1	<10
2	11-20
3	21-30
4	31-40
5	41-50
6	>51

Table B.2: Relevant actors affecting the realization of the Key Change

3.4 Hydrogen economy deployment

The political framework where hydrogen and fuel cells technologies are going to be developed is one of the fundamental factors for a careful analysis of their perspective. Both national and international frameworks should be taken into account.

3.4.1 Introduction

Portugal has a national energy plan "Portugal Eficiência 2015" that embodies strategies to encourage the use of new technologies, process improvements and organizational changes in behaviour and values that lead to friendly habits of consumptions. It includes twelve programs of action in various areas of energy efficiency. Although hydrogen was not included specifically in this plan a document released in April 2010 named the "National Strategy for Energy 2020" (ENE2020 - Estratégia Nacional para a Energia 2020) does now include a brief section on hydrogen.

At an international level, according to the document "World Energy Outlook 2008"2, IEA 2008, a worldwide agreement to reduce CO2 emissions from the energy sector should be reached after 2012. Moreover, one of the objectives of the OECD countries is a 30% reduction of CO2 emissions by 2020 and even more for subsequent years.

The achievement of these objectives is closely related to the introduction of new technologies like H2 and FC. The Portuguese government has introduced a number of policy instruments, mostly of short term, to promote the use of H2 and FC in the energy and transport sectors (See table below).

Policy Instruments	2020	2030	2050
Tax exemptions in the purchase of hydrogen vehicles to reimburse the additional costs of these vehicles.	Short term		
Free parking in pollutant areas for zero emission vehicles	Short term	Medium term	
CO2 taxation	Short term	Medium term	
Low interest rates for loans for zero emission vehicles	Short term	Medium term	
R&D support for key technologies	Short term		
Limited city centre access to pollutant vehicles	Short term		
Regulations, codes & standards	Short term		
Grants for H2 production	Short term	Medium term	
Curricular integration at all educational level	Short term		
Exemption of the special tax on hydrocarbons in those used for hydrogen production	Short term		
Participation in international forums	Short term		

Table 25. Policy instruments

3.4.2 First user centres

Portugal was not one of the countries that were mapped by the HyWays project even though a research team from IST in Lisbon participated actively in the analysis of the ten European countries studied. National studies focused more on future scenarios and possible hydrogen chains for Portugal. There are therefore currently no studies that have examined specifically the first hydrogen user centres that might emerge in Portugal.

To address this question a short one-page questionnaire was prepared, using the indicators established in the HyWays project and used in HyRREG, for example by the Spanish partners. Stakeholders were invited to assign a value of 0 to 5 to each of 18 indicators for six cities or regions of Portugal to indicate the importance of that particular indicator. The cities chosen for assessment, Lisbon, Porto, Braga and Coimbra, were based essentially on population size and geographic location. In addition two regions were added; the Algarve to represent the cluster of cities along the southern margin of the country and the island communities of Madeira and the Azores. The values assigned for each indicator were totalled for each city or region and were used as an indication of the first user centres.

Fig. 32: First user centres in Portugal

First (●) and Second (●) user centres in Portugal

The respondents to the questionnaire indicated clearly, as expected, that the first user centres to be developed were Lisbon and Porto, ranked almost equally. The next user centres identified were Braga and the Algarve (with a total aggregate value of about 25% lower than that for Lisbon and Porto), followed by Coimbra and the islands which ranked equally.

3.4.3 Deployment perspectives

It is clear that a large proportion of the Portuguese population lives in cities on the coast or within 25 to 30 km of the coast. Should the hydrogen economy start in the two main cities of Lisbon and Porto, it is likely that a corridor will be established between these two main centres to serve the transport sector. Coimbra and Aveiro are the other cities along the route where hydrogen infrastructure and facilities are likely to be developed. The Algarve in the south would also be a likely area of expansion in the medium term. In the initial phases, it is unlikely that the demand for hydrogen will extend to the smaller villages further inland.

On a smaller demonstration scale the use of hydrogen could initiate in the island communities, especially the Azores where there are already advanced plans for introducing hydrogen as an energy vector.

It is also important to define the first applications for H2 and FC in Portugal because they will determine the kind of infrastructure to be developed. According to Portuguese stakeholders portable applications will be an entry point for H2 in the short term, such as FC for portable electricity generation. FC for transport will be the most important end-use in the medium term, after an initial use of H2 in internal combustion engines, with public and private demonstration projects working as the kick-off of these technologies.

In the medium and long term, FC for centralised electricity production, co- and trigeneration will also be relevant end-uses. Existence of several remote areas in the country may lead to a niche market for stationary applications. There may also be niche markets in some of the touristic areas, particularly in the south of the country for applications such as golf carts and APUs for yachts.

3.4.4 Summary of the study

Analysing the chain components, some conclusions can be extracted:

- Wind: still requires involvement from the Energy companies, the Financial services and mainly from the Specialist hydrogen equipment manufacturers

- Solar PV: too dependent on Research, Equipment manufacturers and Funding
- Natural gas: depends on the policies from Central government and Infrastructure investments
- Electricity grid: future use for the production of hydrogen closely linked to the Hydrogen equipment manufacturers and Infrastructure investments
- Electrolysis: still needs Research and Equipment manufacturing to become a mature technology, namely in terms of efficiency
- SMR: similar to Electrolysis, but with less emphasis on Research, except for the CCS issue
- Pipeline: Infrastructure investments was the unanimous choice for the stakeholders who completed this section of the evaluation, similar to what happen with Research for Onsite electrolysis and the Automotive industry for FC transport
- Filling stations: one of the components with more actor groups involved, but the Hydrogen equipment manufacturers is the most important group
- FC transport: Automotive industry was the obvious choice for all the stakeholders who evaluated this section
- Domestic use: dependent on the campaigns and its effects on social acceptance of this technology
- Gas storage for grid reinforcement: viable if the Central government bets on this technology and if the Manufacturers provide the proper equipment

3.5 Conclusions

The majority of the stakeholders believe that hydrogen will play an important role in the energy context of Portugal, namely in the transport sector, where it has proven to be more difficult to replace the fossil fuels. But there are several hurdles to overcome – efficiency was a common reference, together with the costs of the technology.

The link to renewable energies was also mentioned as an asset and a need for the success of hydrogen, conducting these energies to the transport sector (target only for 2030) and maximising its use during off peak periods, storing it through hydrogen. However, the electricity grid chains were evaluated as being less difficult than others, essentially due to its lower investment costs and dominion of the technology. This last factor also contributed to a good performance of some of the NG chains with a very similar evaluation of the corresponding wind chains, more difficult in terms of technology, but with more environmental benefits.

Decentralized production also won the competition to centralised solutions. On the other hand, solar PV, CCS and domestic use were among the technologies with less credibility for the production or use of hydrogen. Poor technological development and lack of competitiveness towards other alternatives were the reasons behind their weak performance.

The aggregation of the components by section showed very similar results, and no obvious bottleneck was evident, although the end-uses appeared to be a bit more difficult than other components.

Regarding the actors able to overcome or positively affect the realization of the key changes for each of these technologies, Central government, Research, academia and consultancy, and mainly Specialist hydrogen equipment manufacturing, were selected as the main players. Some technologies still need research to become mature, but others are already near the market and, together with the manufacturers, the proper signs should be given by the national government in order to have the hydrogen technologies available and adopted by the population and companies after 2020.

Hydrogen has only recently been mentioned in the National plans and as such is a very young and immature technology. There are thus no formal plans for its development in the midterm as the current focus is on electric vehicles in the transport sector. Whilst there are plans to have a network of 1,350 electric car charging points spread in 25 towns in Portugal there are no long term plans for constructing hydrogen pipelines. The deployment of electric vehicles however could provide a platform to launch the fuel cell vehicle as both are electric vehicles requiring a source of electrical energy.

4 FRANCE

4.1 General features

The French regions belonging to SUDOE area are Midi-Pyrenées, Aquitaine and Languedoc-Roussillon. The HyRREG analysis will be focused in these three French regions.

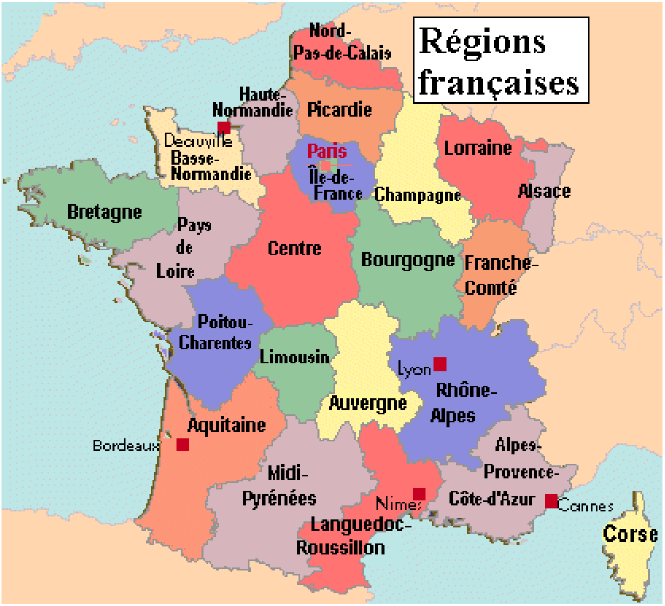


Fig. 33: French regions map

4.1.1 Energy Framework

The French energy situation is a very particular case because of the major use of nuclear resources for the production of electricity. Table 26 shows the energy mix for the French production (137 Mtoe.) and the French consumption (276,6 Mtoe.) from the different feedstocks for the year 2008. According to last data, the independence energy rate for France is 49,5%, so France has to import half of the energy consumed.

	French Production		French primary energies consumption	
	Mtoe	%	Mtoe	%
Coal and coke	-	-	12,8	4,4
Petrol	1	1,0	90,91	32,9
Natural Gas	1	0,6	39,69	14,3
Primary electricity Nuclear Hydraulic	121 115 6	89,3 85,5 3,8	120,56	43,6
Renewable and Waste	14	9,1	13,36	4,8
Total	137	100	276,6	100

Table 26: French primary energies production and consumption (2008)
Source: French Hydrogen Association (2008)

4.1.2 Conclusion

The French intuitive national vision of hydrogen energy in the period 2010-2050 takes into account: the political will to promote water electrolysis using the French electricity mix (90% from non-fossil sources, i.e. without CO2 emission); the potential of renewable energy resources (wind, biomass) which could be mobilised for hydrogen production; the potential of CO2 storage in sedimentary basins; the geographical distribution in six large areas (groups of regions), depending on the population density.

4.2 Regional analysis: SWOT matrix

As the HyRREG project aims to analyse the role of hydrogen in French regions belonging to SUDOE, a specific analysis of these regions was conducted. For this purpose, some questionnaires were delivered to those actors (from now on referred to as stakeholders) involved somehow in the energy sector and a literature review was carried out.

With the answers received from the French stakeholders a SWOT (Strengths, Weaknesses, Opportunities and Threats) matrix of H2 and FC technologies in the region has been prepared.

4.2.1 Aquitaine

AQUITAINE	TTHREATS	WEAKNESSES	STRENGHTS	OPPORTUNITIES
H2 production	*-Price of electricity and fossil fuels* *- No will from the region to develop green hydrogen production*	*-Use fossil fuel to produce hydrogen* *-Few available renewable resources* *-No projects in development in the region*	*-Hydrogen production by electrolysis and hydrogen by-product* *-Potential wind energy in the future* *-Study on hydrogen market in Aquitaine* *-R&D activities (high temperature electrolysis)*	*-Develop hydrogen production by electrolysis with wind energy (and/or solar energy)* *-Possible conversion of a part of an industrial site for hydrogen production*
Storage and distribution.	*-Immaturity of the technology* *- Cost of the technology* *-Few demand*	*-No pipelines grid*	*-Experience with compressed cylinders* *-R&D on hydrogen storage/hydride*	*Decentralised production, on site storage and use for vehicles or for industries* *Storage to produce electricity when the demand is high*
Conversion and applications	*-Hydrogen distribution network is missing* *-Lower features of vehicles and lack of refuelling stations* *-Lack of regulation, safety reasons*	*-Seem not really convinced by fuel cells (in comparison with ICE)* *- Lack of projects of demonstration (stationary and transport)*	*-Big industries using hydrogen* *-Sensitive to pollutant emission decrease* *-Industry specialized in fuel cells*	*-Sell hydrogen because industries need hydrogen in Aquitaine* *-Decentralized cogeneration for isolated sites (stationary application or industries)* *- ICE vehicles or ICE and hydrogen fuel cells hybrid vehicles in medium term*
Perception and promotion	*-No H2 experiences* *-No initiatives at regional level*	*- Not sensitive to the advantages of hydrogen for energy storage*	*-Experiences in renewable energies* *-Incentives for investments and subventions for green electricity production (photovoltaic)* *-Support of the chamber of commerce and industry of Pyrenees Atlantiques*	*- Take the example of renewable energies to promote Hydrogen* *-Inform people of the advantages of hydrogen*

Table 27: SWOT matrix for Aquitaine

4.2.2 Midi-Pyrenees

MIDI PYRINÉES	THREATS	WEAKNESSES	STRENGHTS	OPPORTUNITIES
H2 production	- Big industries with centralized production (outside the region)	-Lack of commercial demand -Lack of confidence	-Technologies in development -Possibility to use biomass, gas, petrol by-products - Lots of projects in development	-Decentralized production with renewable fuels
Storage and distribution.				
Conversion and applications	-Lower features and durability of vehicles -Full cells costs, lack of data, lack of regulation, safety reasons -The regional process on hydrogen seems considered as a threat by influential industrial actors like the sector of the electrical batteries vehicles.	-Lack of projects for stationary applications - The hydrogen community development is restrained by the regulatory framework inadequate.	-Sensitive to Pollutant emission decrease -Experiences in system integration and in electrical vehicles -Projects of demonstration concerning fuel cells vehicles	-Fuel cells for transport in short term -Demonstration projects in short term -ICE and hydrogen FC hybrid vehicles in medium term -Stationary applications because production and demand are very uncoupled
Perception and promotion	-Disinterest of the population - Lack of economic support -The national context remains not favourable to hydrogen	- Not well informed on regional plans to foster electrical vehicles for example -Not well informed on incentives for distributed electricity production and on cogeneration -The regional community suffers from the lack of positioning of the regional council (hydrogen is absent of the regional policy climate/energy) and regional industrial groups	-Experiences in hydrogen -Sensitive to GHG emissions, external energy dependence, adaptation of electricity production and consumption -Policy support -Favourable to hydrogen production from renewable fuels and use of this hydrogen to produce electricity when renewable fuels are	-Develop more projects on green hydrogen production and storage and use hydrogen to produce electricity depending on the demand -Interest the population Research economic support -Organisation of one day for public awareness -Creation of a technological platform H2 in region Midi-Pyrénées

		-The region Midi-Pyrénées is landlocked and distant from the Parisian decision centre	not available -Several political personalities and local authorities support the regional hydrogen community -Association Pyrenees for H2 promotion with support of industries, research centres, public organisms, … -Training experience	

Table 28: SWOT matrix for Midi-Pyrenees

4.2.3 Languedoc-Roussillon

No answers were received from this region.

4.3 Hydrogen production chains

The hydrogen energy chains selected for France are the following:

During the workshop held on June 25th 2010 the stakeholders chose to distinguish among nuclear, hydraulic, solar and wind electricity (and not to consider the electrical grid) because they consider that the use of these different energy sources could lead to different hydrogen applications. Their comments can be found below.

Hydrogen from nuclear source

The first resource for electricity production in France is nuclear power. However it is not the development strategy for the hydrogen energy chain. According to the French Road Map for hydrogen and fuel cells, the renewable energies will be the first resource for hydrogen production.

Hydrogen from hydraulic source

The applications for this source of hydrogen production are the same as that for the nuclear source. In addition, hydrogen could be used for isolated sites (production of electricity and heat with fuel cells) and transports (with engines of fuel cells) too.

In case of isolated sites, electrolysis will be done onsite. In case of transport, electrolysis will be centralized and gaseous hydrogen (under pressure) will be transported to refuelling stations by trucks, trailers or pipelines depending on the distance.

Hydrogen from natural gas

On-site reforming and central reforming were considered.
In the case of onsite reforming, hydrogen could be used for isolated sites or for industries which need it in their processes.

In the case of central reforming, hydrogen can be distributed by pipelines, trailers or trucks to industries or by trucks to hospitals for example (security groups).

Hydrogen from wind and solar energy

French stakeholders considered onsite electrolysis and central electrolysis.

In the case of onsite electrolysis, hydrogen could be used for insulated sites or for electricity production when electricity demand is high in order to equilibrate the electric grid.

In the case of central electrolysis, hydrogen could be distributed by pipelines, trailers or trucks to refuelling stations or by trucks to hospitals for example (security groups).

Hydrogen from biogas

The applications for this source of hydrogen production are the same as that for natural gas. In addition, centralized production and hydrogen distribution (by trucks, trailers or pipelines depending on the distance) to refuelling stations for vehicles are considered.

Chain Component	Estimated Timeframe		
	2020	2030	2050
Nuclear			X
Hydro		X	
Natural gas	X		
Wind		X	
Solar PV		X	
Biogas (from biomass)			X
Central electrolysis		X	
Onsite electrolysis	X		
Central reforming		X	
Onsite reforming	X		
Trucks	X		
Pipeline		X	
Distribution centre		X	
Filling station	X		
Stationary : gas storage and use to produce ele	X		
Stationary : gas storage and use to produce electricity in case		X	
Stationary : electricity or CHP for isolated sites		X	
Stationary : industrial use		X	
Transport	X		
Nuclear			X
Hydro		X	
Natural gas	X		
Wind		X	
Solar PV		X	
Biogas (from biomass)			X
Central electrolysis		X	
Onsite electrolysis	X		
Central reforming		X	
Onsite reforming	X		
Trucks	X		
Pipeline		X	
Distribution centre		X	
Filling station	X		
Stationary : gas storage and use to produce ele	X		
Stationary : gas storage and use to produce electricity in case		X	
Stationary : electricity or CHP for isolated sites		X	
Stationary : industrial use		X	
Transport	X		

Table 29 : Hydrogen chains selected in France

4.4 Chains by region

A French Roadmap was prepared by ADEME (HINICIO, 2010) and based the French Hydrogen Economy on three pillars:

- Green H2 production: from renewable energies by electrolysis (RE storage and grid support) and biomass
- Second generation electric vehicles

-Fuel cells Vehicles (mainly captive fleets)

-Lifting equipment

-Associated infrastructures

- Early markets

-Isolated sites

According to the French Roadmap, the national strategy will address the following objectives:

	2012	2015	2020
Green H2 production: from renewable energies by electrolysis (RE storage and electric energy back-up)	*-No objectives for 2012 but initiation of some projects including hydrogen storage*	*-20MW installed by hydrogen projects with flexible hydrogen uses (electricity production, FC vehicles, industrial use, H2/NG mixes in the NG pipelines, etc.)*	*-5-10% of the hydrogen market for electricity storage.* *-100MW from projects of direct hydrogen use*
Green H2 production: from biomass	*-No objectives at national level for hydrogen production from biomass*	*-No objectives at national level for hydrogen production from biomass*	*-No objectives at national level for hydrogen production from biomass*
Second generation electric vehicles (priority on the vehicle range extender).	*N.A.*	*-FC vehicles: 5 000 in captive fleets.* *-200 lifting equipments installed per year* *-Infrastructure: 2-5 city centres and 20 logistics hubs equipped with hydrogen refuelling stations (and Hythane®).*	*-FC vehicles: 50 000 in captive fleets.* *-400 lifting equipments installed per year* *-Infrastructure: hydrogen stations network covering 10 cities.* *-At national level, a big enough network to cover particular hydrogen initiatives*
Early markets : isolated places powering	*N.A.*	*-Isolated sites: 200kW installed (100 sites.*	*-Isolated sites: 2000kW installed (1000 sites)*

Table 30: French roadmap objectives by ADEME

The objectives for the region follow the strategy for H2 and FC of the road map. An enquiry process was conducted among a stakeholders group belonging to the three French regions which are part of SUDOE. As a result, the hydrogen energy chains were evaluated in each region.

4.4.1 Midi-Pyrénées

In the short term, hydrogen will be produced from natural gas (decentralized production without CO2 capture), from water (electrolysis using renewable electricity and electricity from the grid) and from biomass (decentralized production).

NG steam reforming will evolve to centralised production with CCS in the mid term; centralised biomass gasification will be envisaged in the long term. Also in the long term high temperature solar energy (thermochemical cycles or high temperature electrolysis) and nuclear will be used to produce hydrogen in centralised facilities.

Hydrogen production from coal is not considered as there is no more coal mine exploitation in the region.

As most of the answers to the enquiry process came from Midi-Pyrénées, this enabled outline of a specific strategy for the hydrogen roadmap in this region to be made. A roadmap has been worked out for the association Pyrenees, the targets until 2020 are listed below:

	2012	2015	2020
Green H2 production: from renewable energies by electrolysis (RE storage and electric energy back-up)	*- 1 or 2 regional projects >1MW size supported by financial support*	*-2 MW available by projects in the regions (or in the adjacent regions with Pyrenees members participation, for example: Smart StorHy) or around 200kg hydrogen produced per day (depending on the needs)*	*-20 MW available by projects in the regions (or in the adjacent regions with Pyrenees members participation, for example: Smart StorHy) or around 2000kg hydrogen produced per day (depending on the needs)*
Green H2 production: from biomass	*-Project VAB'HY'OGAZ production of 10kg of hydrogen/day (depending on the needs)*	*-5 projects in the region producing 1 000kg of hydrogen/day (depending on the needs).* *-Midi-Pyrenees could help to establish similar projects in other regions.*	*-20 projects in the region producing 4000kg of hydrogen/day (depending on the needs)*
Second generation electric vehicles	*-5 FC vehicles of low power depending on the region (like HYREX) + 5 lifting equipments* *-Infrastructure: 1 hydrogen station + 1 logistics hub + 1 platform for green hydrogen supply (projects VULHYB and/or VHYTA).*	*-200 FC vehicles in the region (captive fleets) + 20 lifting equipments* *-Infrastructure: 5 hydrogen stations in the regional cities (outside and inside the city) + 2 logistics hubs supplied by green hydrogen*	*-5000 FC vehicles in the region (captive fleets) + 20 lifting equipments* *- Infrastructure: a big enough regional network to cover particular hydrogen initiatives (50 stations supplied by green hydrogen)*
Early markets : Isolated sites powering	*-Isolated sites: 4kW installed (2 sites) powered by green hydrogen.*	*-Isolated sites: 20kW installed (10 sites) powered by green hydrogen.*	*-Isolated sites: 200kW installed (100 sites) powered by green hydrogen.*

Table 31: French roadmap objectives by Hinicio

4.4.2 Aquitaine

In the short term, hydrogen will be produced from water by means of electrolysis using electricity from the grid.

In the mid term (2030) moderate amount of hydrogen production by means of electrolysis from excess wind power at local nodes of the grid (decentralized) and at the end-use application (on-site) will be feasible. H2 production from biomass gasification is also possible at mid term.

In the long term (2050) high temperature solar energy (thermochemical cycles or high temperature electrolysis) will be used to produce hydrogen in centralised facilities.

4.4.3 Languedoc-Roussillon

No answers were received from the region Languedoc Roussillon. However, this region is very sensitive to renewable energies and the creation of the DERBI competitiveness cluster in Perpignan shows it. Indeed, the region Languedoc Roussillon is interested in hydrogen technologies, even if they are not already developed in the region. Research and development activities related to hydrogen are being developed in research centres. They are involved in membranes development (for hydrogen purification), fuel cells materials, hydrogen generation from liquid hydrocarbons, modelling and simulation of high temperature electrolysers at high pressure and mechanisms in batteries materials.

It counts with a Regional Energy Plan that foster renewable energies and emerging technologies development but nothing specific for hydrogen.

4.5 KCAM analysis

The KCAM analysis of the south of France has been lead by referring to the Road Map of Pyrenees (HINICIO, 2011).

Six main chains have been selected: nuclear power, particular to France, the four renewable energies: hydraulic, wind, solar and biogas, and finally natural gas. The production of hydrogen is done by electrolysis or by reforming, and the transport, if necessary, has to be assured by trucks and distributed by distribution centres or filling stations. Those chains can be used for storage for the grid, emergency groups, isolated sites, transport or industry.

- **Analysis per component**

Among the four stakeholders consulted, hydrogen production by SMR is the most developed, mainly by small and medium enterprises: it has the best evaluation.

Fig. 34 shows the total difficulty allocation for France and figure C.2 shows the average difficulty per chain component.

Chain Component	Estimated Timeframe			Waste treatment and valorisation	Research and teaching	SME hydrogen production by reforming	SME tube and sheet metal assemblies
	2020	2030	2050				
Nuclear			X	3	3	2	4
Hydro		X		2	2	2	4
Natural gas	X			2	2	1	1
Wind		X		2	2	3	5
Solar PV		X		2	2	2	5
Biogas (from biomass)			X	3	3	2	5
Central electrolysis		X		3	2	3	4
Onsite electrolysis	X			2	2	1	3
Central reforming		X		4	4	1	4
Onsite reforming	X			3	3	1	3
Trucks	X			2	2	1	3
Pipeline		X		4	4	2	3
Distribution centre		X		3	2	1	3
Filling station	X			2	2	1	2
Stationary : gas storage and use to produce ele	X			2	2	1	1
Stationary : gas storage and use to produce electricity in case		X		2	2	2	2
Stationary : electricity or CHP for isolated sites		X		3	2	2	4
Stationary : industrial use		X		2	2	2	2
Transport	X			2	2	1	3
			Total	48	45	31	61

Table C.1

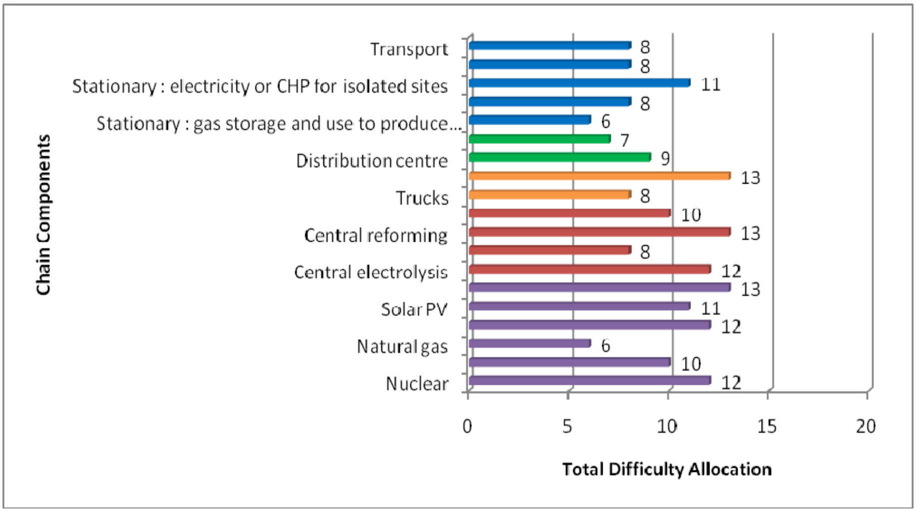


Fig. 34: Total difficulty allocation per component for France

- **Analysis per chain**

According to the KCAM analysis indicators, the chains which should be developed in the hydrogen community in the Midi-Pyrénées region are in the field of biogas (transport, industry), and wind and solar sources (industry and isolated sites).

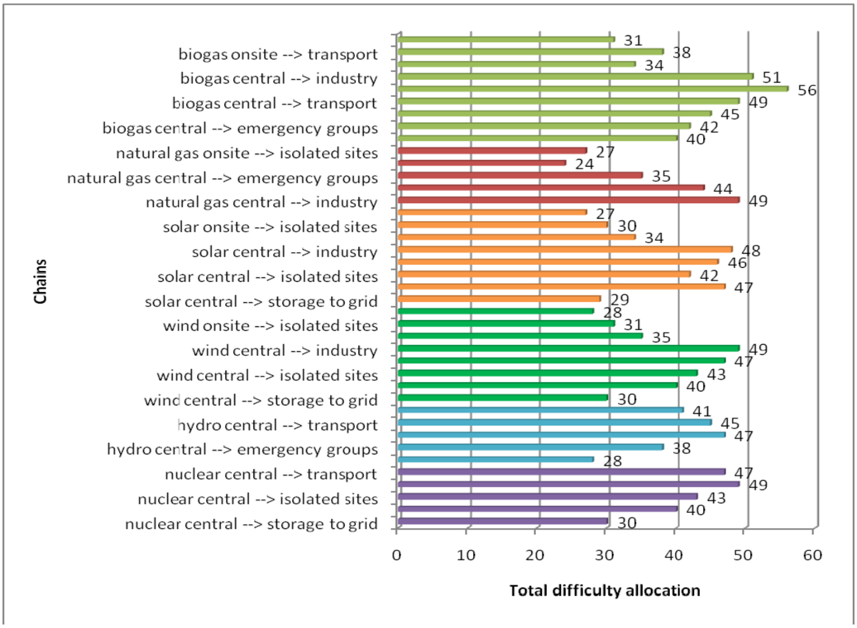


Fig. 35: Total difficulty allocation for France

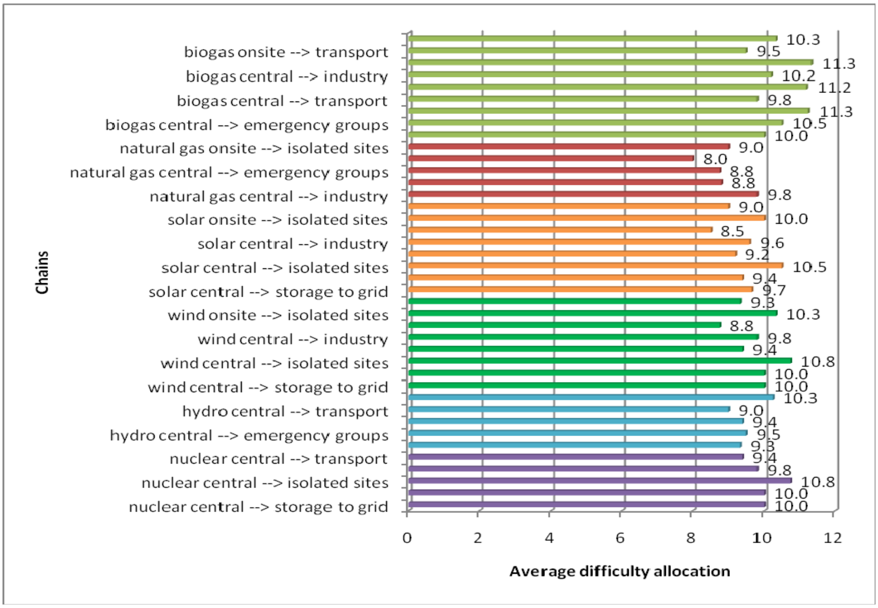


Fig. 36: Average difficulty allocation per chain for France

4.6 Hydrogen economy deployment

4.6.1 Introduction

The political framework where hydrogen and fuel cells technologies are going to be developed is one of the fundamental factors for a careful analysis of their perspective. Both national and international frameworks should be taken into account.

According to “World Energy Outlook 2008”2, IEA 2008, a worldwide agreement to reduce CO_2 emissions from the energy sector should be reached after 2012. Moreover, one of the objectives of the OECD countries is to reduce by 30% the CO_2 emissions by 2020 and even more for subsequent years. These facts suggest that policies that foster carbon-free technologies like H_2 and FC would emerge.

In France, the « Grenelle de l’environnement » or «Programme d’Orientation de la Politique Energétique» of the 13th of July 2005 (POPE law) follows the strategic orientations of reducing CO_2 emission. The national Road Map for hydrogen enters into the framework of this law.

The development of the hydrogen community in the territories of the SUDOE area is part of a direct relationship with the national policy on this subject, but also territorial policies conducted by each region.

4.6.2 First user centres

Because of the poor advance of the hydrogen technology in French society, nowadays in France there are no permanent H_2 user centres. Except for the chemical industry, hydrogen is barely used. However, some research laboratories are very active and develop projects that make possible specific H_2 applications from the production to the use.

In the SUDOE region the following locations have been selected as first user centres:
- The town of Toulouse: Laplace laboratory works actively on fuel cell technology.
- The town of Albi: a car circuit will be devoted to the trials of hydrogen vehicles and the union Trifyl has a project of production and use of hydrogen in a vehicle (vabHyogaz project)

Because of the unclear legislation concerning hydrogen in France, the use of CGH2 is very restricted.

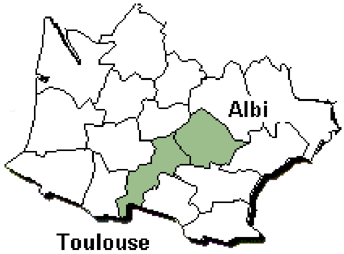


Fig. 37: First user centres for France

4.6.3 Deployment perspectives

It is important to define the first applications for H2 and FC in the French SUDOE regions because they will determine the kind of infrastructures to be developed. It is remarkable that H2 and FC in these regions are mainly associated to smart grid and electromobility (in particular range extender concept). The production of hydrogen should rely on renewable energies; this point constitutes the first priority of the Road Map for the region Midi-Pyrénées.

- **In the short term (2020)**

In the entry phase (by 2010), the early markets would require small quantities of hydrogen produced by SMR or water electrolysis, using the existing infrastructures (pipelines, tube trailer, …). In the transition phase (2010-2030), the growth of hydrogen demand would enlarge the range of options for local and central hydrogen production, taking into account the French specificities. The capture and storage of CO2 issuing from central SMR installations would not be envisaged before 2020 at industrial scale. However, this option would be privileged afterwards, assuming a dissuasive CO2 taxation. The use of existing natural gas pipelines to transport hydrogen would be envisaged in the transition phase, assuming the extraction of hydrogen from the mix at the point of use.

- **In the mid-long term (2030-2050)**

In the vision phase (2030-2050), SMR would be privileged in areas with large population density (Centre-North and South-East of France), when hydrogen demand is high and CO2 geological storage feasible at large industrial scale. In areas with a lower population density (North-West, East, South-West and Centre), hydrogen would be produced preferably by local or central water electrolysis using the French electricity mix, whereas SMR would be used depending on the economic competitiveness of the process, including CO2 transport and storage costs. The renewable energy resources would contribute significantly to local hydrogen production in the most favourable regions. In the long term (by 2050), the emergence of innovative high temperature nuclear reactors could allow a massive production of CO2-free hydrogen.

The transport of hydrogen by pipeline would be progressively the most attractive option for significant quantities of hydrogen delivered, whereas the transport by truck would be preferred for more limited quantities. The hydrogen would then be delivered to the consumers, i.e. the refuelling stations, for hydrogen cars, and the distribution centres, through local hydrogen grids, for the heating needs of 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.

The early markets were also identified as a way of developing the sector in particular the market for remote sites, and logistics. In this case it will be necessary for the Midi-Pyrenees to assess the relevance of the market.

Hydrogen is considered to be produced on the site at the nuclear power plant to be stored and to use it (with a fuel cell) when electricity demand is high and when electricity production from nuclear source is not sufficient. It’s a mean to equilibrate the electrical network.

Another application for hydrogen would be a “security application”. Gaseous Hydrogen could be produced at a dedicated site and distributed in hospitals (for example) by trucks. The purpose is to provide them a mean to store energy and to use it (with a fuel cell) in case of electricity cut.

4.6.4 Summary of the study

Despite H2 and FC technology is not one of the priorities of French National Energy Programme and although at the present time H2 technology is poorly advanced in the French regions belonging to SUDOE, the renewable energy resources’ steadily growth will foster their integration in the area in the mid-term. H2 and FC in these regions are mainly associated with smart grids and electromobility (in particular the range extender concept). The main development should be done on the production and storage as hydrogen is the solution for the intermittent renewable energies like solar and wind.

4.7 Conclusions

Today´s reflections involve local government in a study of the interest in hydrogen as an energy vector for the production of electricity for multiple uses: lighting, heating, transportation, air conditioning, power devices and telecommunication centres. For example, the trade union TRIFYL now has a vehicle that runs on 100% biogas that could be enriched with hydrogen (20% hydrogen, 80% biogas). This technology would introduce hydrogen in the people´s mind. Each step has to be done and it is best to begin with small and careful ones.

Projects are initiated by industry partners in collaboration with Associations to structure the industry. The current main projects are: Vabhyogaz (hydrogen production from landfill biogas), Vhyta (hydrogen vehicles for biogas), Smart StorHy (smart grid). These projects fall within the priorities of the regional road maps.

5 SUDOE

5.1 Common aspects of chain analysis

The energy framework and the resources are not the same in the three countries comprising SUDOE hence the fact that each of them has selected a different group of H2 chains. On the other hand, some aspects are very similar in the three countries so several H2 chains have been selected in the three of them: natural gas as the current H2 pathway and wind and solar energy for the future. Technological and socio-economics hurdles for these chains are common in the three countries and can be found in previous sections.

Likewise, there are some components of hydrogen energy chains that present the same features in the three countries and hence a matrix analysis can be outlined for general aspects. This is the case for hydrogen transport, storage and distribution.

5.2 Hydrogen distribution

WEAKNESSES	*STRENGTHS*	*CHALLENGES*
•Pipeline infrastructures or hydrogen stations without political or economical support. *• Absence of specific legislation and certification standards for materials and hydrogen storage and distribution systems.*	*• Previous experience in gas distribution due to the existing robust and large energy transport and distribution network (natural gas).* *• Experience gained from the hydrogen filling stations within the CUTE project; Experience gained with the Project HYCHAIN (deployment of special vehicles and CGH2 bottle dispensers).* *• Three existing hydrogen filling stations (Zaragoza, Seville, Soria) and the first national fuel cell jeep prototype.* *• Experience in the use of NG in urban transport fleets, which facilitates the transition to hydrogen.* *• The boost that the government is giving to the development of new technologies.*	*• Using the natural gas network for NG and H2 mixtures during a transition phase.* *• Deployment of hydrogen stations* *• Progress in standardization and normalization.*

Table 32: H2 Distribution analysis

Source: Spanish Technological Platform for Hydrogen and Fuel Cells.

5.3 Hydrogen storage and transport

WEAKNESSES	*STRENGTHS*	*CHALLENGES*
• Volume, weight and cost of CGH2 system, inadequate for transport use. *• The energy densities of current solid storage systems are inadequate to achieve market acceptance.* *• Scant business involvement R & D activities in hydrogen storage. Deficient technology transfer.* *• Low commitment to implementation problems facing basic research.* *.• Difficulty of the companies and research groups with the ability to lead European projects. Difficulty in forming partnerships.* *•The main automobile manufacturers have production plants in SUDOE but not engineering centres, hence the lack of effect on the component business (the decision-makers are not in SUDOE).* *• Lack of industrial hydrogen Networks* *• Absence of specific legislation and certification standards for materials and hydrogen storage and distribution systems.*	*• The existence of consolidated R& D groups.* *.• The great potential of renewable energies in SUDOE* *• Current production of H2 in various parts of the country. Well-developed CGH2 logistics with their own technologists.*	*• Obtaining better materials.* *• Progress in standardization and normalization* *• Education and dissemination measures in order to diminish the social perception of H2 as a dangerous energy source.* *• Consolidate the network of researchers and foster the link between R & D and enterprises.* *• Obtaining from institutions financial support to develop the necessary infrastructures.* *• To strengthen SUDOE´s global position in Europe regarding this technology. The fact that the north of France connecting with the rest of Europe did not bet on H2 and FC should not prevent SUDOE from developing infrastructures in this sector.*

Table 33: H2 Storage and transport analysis

Source: Spanish Technological Platform for Hydrogen and Fuel Cells.

5.4 First user centres

The first user centres need to be linked by corridors. A first H2 corridor in SUDOE area should link the following areas.

Fig. 38 : First H2 corridor in SUDOE

It is well observed that the first user centres in SUDOE are not geographycally connected as they are not neighbouring areas. It means that although in the first stage of H2 economy in SUDOE H2 use will be local, in subsequent stages a H2 corridor will be established by promoting H2 deployment in adjacent regions.

Madeira and the Canaries are clearly additional areas of first user centres which cannot be linked by corridors.

5.5 Conclusions

Concerns about global climate change and environmental degradation due to the use of fossil fuels as a primary energy source, along with concerns about security in energy supply, have led many energy analysts to suggest hydrogen as a universal energy vector for the future, creating what has been called the "hydrogen energy economy".

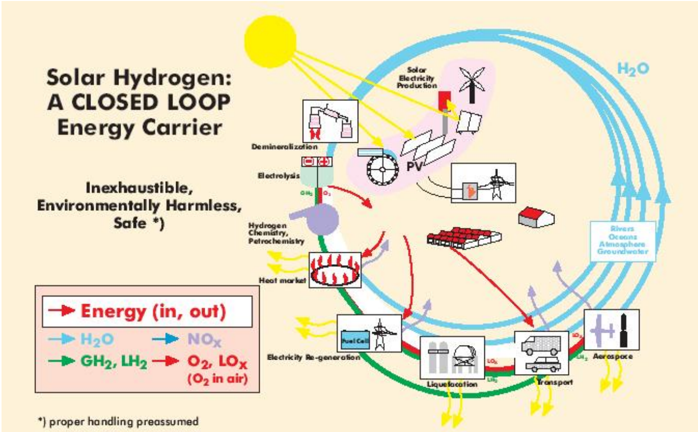
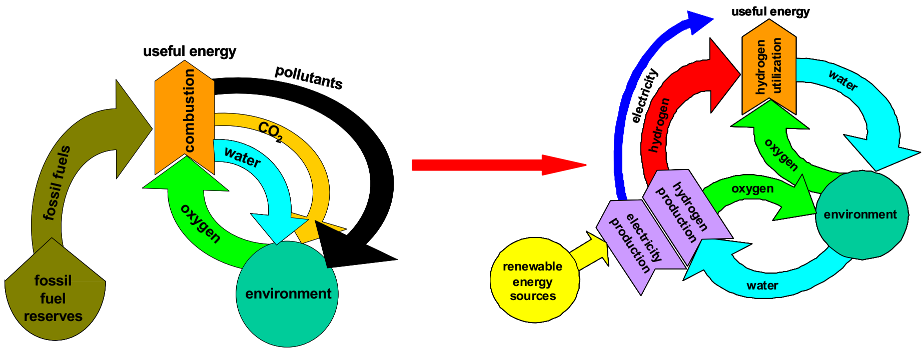


Fig. 39 : Solar hydrogen loop

Source: Hydrogen - Sustainable energy for transport and energy utility market – North Rhine-Westphalia (NRW) Hydrogen Highway

The H2 economy vision is based on the expectation that hydrogen can be produced from economically and environmentally acceptable domestic resources, and that the hydrogen end-use technologies (such as hydrogen fuel cells) will win significant market share. An example of such a sustainable system providing hydrogen from solar resources for the transport and energy markets is illustrated in figure 39.Those who advocate the hydrogen economy believe that if these expectations are met, then it will benefit the world, providing greater energy security due to the diversification of energy sources and improve environmental quality thanks to the significant reduction of local and global emissions (greenhouse gases). Moreover, hydrogen will promote the use of renewable sources of energy and the use of new technologies (fuel cells) may increase efficiency in energy conversion. The SUDOE area, with a high potential in renewable energy has a foreign energy dependence of 82% in the Spanish case and 79.5% in the Portuguese case, as well as an unsustainable energy system based on 85% of nuclear energy. France would be one of the countries that would benefit more from the establishment of a new energy system that favours renewable energy, especially hydrogen and fuel cells. However, achieving this goal requires overcoming many technical, social and political challenges, the last two mentioned being perhaps less important than the first one.



Unsustainable energy system *Sustainable energy system*

Fig. 40 : Energy Systems comparison

Source: Frano Barbir, Associate Director for Science and Technology UNIDO-ICHET, (United Nations Industrial Development Organization). International Centre for Hydrogen Energy Technologies, Istanbul, Turkey.

The integration of hydrogen in the SUDOE energy system has the potential to reduce the dependency on imports and to enable the economy to be flexible and rely on a range of primary energy sources ensuring supply security. In particular, hydrogen can be the perfect ally to increase the penetration rate of renewable sources in the energy sector since it can be used as a storage system.

Furthermore, as hydrogen is carbon free its extended use to produce electricity would provide a reduction or ultimately stabilization of GHG emissions and pollution promoting environmental sustainability as indicated in Fig. 40.

The lack of H2 and FC technology demand and the cost of the latter are the common barriers identified by experts in the field of the three countries of the SUDOE area for the launch of the H2 and FC economy. Without H2 demand, the industry will not invest in the technology, and therefore there will be no development and optimization of the products.

Also, the lack of rules and regulation in this area is an obstacle for the implementation of the technology.

According to the group of experts consulted, demand creation should begin with demonstration projects different from those developed so far, that haven't had, after their completion, much of an impact. Demonstration projects should be continued. Regarding transport applications, the vehicles used should be moved from one city to the other so the experience can be repeated and they can be used to their full extent. They also have to imply some technological innovation because the use of hydrogen as an energy vector is possible and it has been proved that it works on different appliances. Another important factor to promote the success of the launch of this technology is its dissemination: the benefits of hydrogen in vehicles should be promoted to make consumers prefer these over other types of vehicles.

Another common problem encountered is getting the enterprises involved in the development of H2 and FC technology. It is the chicken and the egg problem, which came first? The enterprises do not invest if there isn't a potential market and the possibility of doing business. Subsidies and public support will be needed to encourage both the private and public sector to invest in these technologies. According to the IEA report "World Energy Outlook 2008" a new global climate change policy to reduce CO2 emissions in the energy sector, for beyond 2012, is urgently needed. If we also take into account that one of the OECD's goals on energy is to reduce CO2 emissions by 30% by 2020 and for coming years that reduction is likely to become more drastic, it is expected that policies favouring cleaner technologies such as H2 and FC will emerge. The use of FC and electric vehicles should be encouraged in the Spanish regions with the highest emission of CO2 in the transport sector, such as Madrid, Catalonia, Aragon, Cantabria, Valencian Community and Galicia. The bulk of CO2 emissions In Andalusia, Castille and Leon and Asturias comes from the generation of electricity, therefore a policy strategy that subsidizes high temperature FC domestic facilities for the generation of electricity and heat is recommended.

6 ACTION PLAN

Despite the promising prospects of hydrogen technologies in terms of energy efficiency and sustainability, the introduction of hydrogen into the energy system does not happen autonomously. H2 and FC are very innovative energy technology options that are not compatible with existing systems. New infrastructure and vehicle fleets will have to be built up in parallel requiring very diligent planning and governmental support. Substantial barriers have to be overcome, ranging from economic and technological to institutional. This Action Plan provides a series of actions concerning governments, public administrations, industry, universities, environmental organisations and any H2 and FC related parts that will help to create a strategy to overcome these barriers.

The existence of a common agenda will ease the implementation of these technologies' and at the same time, will foster the investment in the new hydrogen-based energy system.

No single policy tool will ensure that RD&D activities that are needed will occur. A portfolio of policy tools adapted to individual technologies and national systems will be required to make scenarios come true. Therefore favourable measures and policy tools required to foster H2 use as an energy vector in SUDOE are listed below.

6.1 At technological level

- Investment in infrastructures for filling stations to promote the commercialization of EVs.

- Developing H2 and FC demand: according to industry experts the lack of demand for H2 and FC technology is an obstacle in the launch of the H2 and FC economy. Without H2 demand, the industry will not invest in this technology and with no investment there will be no development towards obtaining economically viable CCS technologies.

- Development of strategies for integrating RES (wind, solar photovoltaic) with H2 production by electrolysis. Optimization of the performance of H2 production and cost reduction of the process.

- Development of large electrolysers to be used in wind and solar farms.

- Improvement of weather forecast systems to increase the levels of production for better integration of wind power in the network.
- Coordination with other biomass actors (farmers, fire departments, etc) to create a competitive energy chain.

- Reforestation of large land areas currently energetically unproductive.

- Improve of current H2 storage devices.

- Investment in new materials for H2 storage.

- Improvement in gasifier´s design to increase H2 ratio.

- Increase the efficiency and reduction of CO2 capture and sequestration process.

- Improvements in sophisticated materials and processes for achieving higher efficiency.

- Implementation of demonstration projects with social and technical impact that can be carried on in the near future.

- Coordination of public and private institutions to accelerate the introduction of prototypes into market.

- Development of codes and standards for the design, manufacture and operation of H2 systems

- Challenges mentioned in the matrices of "Technological Analysis of the H2 chains in Spain."

6.2 At policy level

- Dissemination of H2 impact on the environment, public health and energy security in order to give the consumers easier acceptance of H2 and its services.

- Satisfaction and integration of consumers' preferences into H2 economy systems: security, comfort, accessibility and respect to the environment are the principal demand of users.

- Provide a hydrogen specific policy support scheme in the short term to make hydrogen competitive with alternative options to ensure its gradual implementation.
- Establishment of a specific H2 and FC Development Energy Plan as an essential step to developing projects and thereby making the first user centres come true.

- Speed up the procedures to incorporate hydrogen and fuel cells in the list of technological facilities and create legislation and regulations for such facilities.

- Implement more productive mechanisms to facilitate the distribution of subsidies to SMEs (less paperwork, lighter requirements for the formation of partnerships...).

- Streamline procedures for obtaining building permits for such facilities.

- Information campaigns that encourage the social acceptance of CO2 confinement technologies.

- Include in educational programs different levels of training on this technology.

- The need to prioritize the production of hydrogen by RES as a milestone to enable production and therefore its use.

- Align, in the early stage, the interests of all ministries involved in the introduction of hydrogen into the energy system. Ensure mutual cooperation and common convergence.

- Promotion / Incentives for the purchase of fuel cells.

- Promotion / incentives for the purchase of fuel cell vehicles.

- Promotion / incentives for the purchase of household appliances with fuel cells;

- Develop programs for FC installation in areas close to each other to assist the progress of future hydrogen stations and pipeline networks;

- Investment in the dissemination of the H2 and the FC benefits to improve social awareness towards hydrogen and win the public's trust in these technologies.

- Diffusion and promotion of prototypes and lighthouse projects' results

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ANNEXE I

List of HYRREG partners:

- Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón (FHA)
- Universidad Rey Juan Carlos (URJC)
- Instituto Nacional de Técnica Aeroespacial (INTA)
- Fundación Instituto Andaluz de tecnología (IAT)
- Junta de Castilla La Mancha (JCCM)
- Ecole des Mines d´Albi-Carmaux
- Universidade Técnica de Lisboa (IST)
- Association PHyRENEES
- Instituto de Soldadura e Qualidade (ISQ)

FOUNDATION FOR THE DEVELOPMENT OF NEW HYDROGEN TECHNOLOGIES IN ARAGON

www.hidrogenoaragon.org

IAT Innovación y Tecnología

www.iat.es

INTA

www.inta.es

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