Hydrogen Master Plan in Aragon

FOUNDATION FOR THE
DEVELOPMENT OF NEW
HYDROGEN TECHNOLOGIES
IN ARAGON

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Foundation for the Development
of New Hydrogen Technologies In Aragon

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Hydrogen Master Plan in Aragon

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Preface

Hydrogen Master Plan in Aragon

Exactly four years ago, one hundred and eighty people met in Zaragoza to learn about and discuss the importance of hydrogen as a new energy vector. This meeting gave rise to the Foundation for the Development of New Hydrogen Technologies in Aragon. Almost three years have gone by since the Foundation was registered in the Foundations Registry Office and two since the start of this Master Plan with the respective taskforces. The reason for this publication is to present society with the results of many hours' work, as well as the reflections and debate that has taken place among the salient actors of our region -research, industry, administration, civil society- to agree upon the most fruitful actions that we must all take in this field.

When we incorporated the Foundation -at that time comprised of twenty-eight entities, but forty-two today- each one of us had a vision and experience. There was already a history of hydrogen in the Autonomous Community: the chemical industries of the Pyrenees, for example, and many cutting-edge research groups in cells and hydrogen production at Zaragoza University and the CSIC. But we did not have an organised way of thinking with efficiency and effectiveness criteria. One of the first agreements reached by the board was to work with a Master Plan.

Preface

The field of hydrogen and fuel cells is too extensive to try to address all of it. The experts must select and agree upon those aspects that are easy to address and that have the greatest impact. The Master Plan is the result of this systema–tisation, which, in our case, has a certain didactic nature, simply because the Foundation works for society in general, and society must be the receiver of the results.

The Master Plan is not a programme of actions. It is not a strict list of projects that must be executed. It is a guide or, perhaps, an inspiration, submitted to criticism and review. In turn, the vocation of the Foundation is to be a meeting point and a project facilitator. It is not a financial instrument or the agent of a development programme. It must be the individual initiative, in the end, which, assuming the efforts and risks, will convert the ideas that teem out of the pages of this book into products, services, wealth and employment.

The hydrogen challenge is enormous. We need to convert our energy system into a more sustainable model. And we must use the opportunities of this change to our benefit, to the benefit of the Community and of society. Europe has done some calculations and it estimates that 6.7 billion euros will be required over the next nine years to prepare technology and enter into a phase prior to marketing. This vast sum of money cannot just come from public subsidies. It must also come from private investment and by establishing a price for the users in exchange for better technology or less contamination. In Aragon, we should invest an average of 2 million euros a year, in proportion to our GNP, just to be in line with this European objective.

The figures shown over the last two years related to the investing effort of the Foundation and of its sponsors are hopeful. But we can and must be ambitious if we want to lead the change. Either that, or wait until the technology is brought to our door and pay for it with delocalisation.

I wish to express my gratitude to all those who have selflessly given over their time, effort, will and ideas, to create this seed, prior to the fruit. Please do not to hesitate to continue to make this seed grow vigorously and to view the Foundation as a good travelling companion in this exciting task.

Zaragoza, 31 March 2007

His. Excell. Arturo Aliaga Lopez
Minister of Industry, Trade and Tourism of the Government of Aragon.
President of the Foundation for the Development of Hydrogen in Aragon.

Hydrogen Master Plan in Aragon

introduction

Introduction

The need to promote new hydrogen technology has never been so clear as today. The increase in oil prices, the lack of stability of that market, the concern for the global warming of the planet, the increasing demand for energy and the future massive markets (China, India), have created a need to think again about the global energy system that includes hydrogen as a flexible and environmentally-friendly vector, and with an extensive and substitutive market, mainly in the transport sector.

The vision of the hydrogen economy is based on the production of hydrogen from autochthonous and environmentally acceptable resources, and also for the end use hydrogen technologies to attain a significant market share, which involves reducing costs in all the links of the chain.

The development of the hydrogen economy can help stabilise the energy prices and be an economic growth factor. This economic growth is based on aspects such as the development of new businesses for industries, the increase of employment or the use of renewable and internal (autochthonous) resources.

If these expectations are achieved, we will evolve towards a system of greater energy safety and of greater environmental quality.

However, to achieve these objectives, many scientific, technical, social and political challenges must be overcome.

Many R&D initiatives and activities are being carried out in the field of hydrogen whose main goals are:

- To reduce hydrogen production costs based on renewable energies.
- To improve hydrogen production techniques based on fossil fuels, mainly introducing systems to capture and confine CO_2.
- To develop the hydrogen supply infrastructure (mainly for the automotive industry).
- To develop and introduce reliable, safe and long-lasting economical as well as environmentally acceptable hydrogen storage and fuel cell systems.

The concept of hydrogen economy has become one of the basic pillars for the sustainable energy policies of the European Union, as well as of the United States, Canada or Japan.

If Europe does not want to miss out on these developments it will have to invest no less than 250 million euros a year, which is the minimum amount to equal the investments of the specific hydrogen plans of the United States and Japan, with investments of 235 and 260 million euros, respectively, in 2005.

Hydrogen is contemplated in the energy programme of the VII Framework Programme (2007-2013) that has a budget of 2.93 billion euros.

Another instrument launched for the VII Framework Programme by the European Commission are the JTIs, Joint Technology Initiatives, whose aim is to create micro-consortiums that foster private investment and integrate innovative companies. The execution of large demonstrative projects is fostered as well as the Lighthouse Projects and industrial development and innovation projects where 50% of the cost would be subsidised with public funds (European Commission, Member States and Regions).

The Commission has proposed 3 JTIs, in three high priority areas: the aero-spatial sector, the pharmaceutical sector and the hydrogen and fuel cells sector.

Introduction

INTERNATIONAL SCENARIO

The hydrogen economy concept appeared in the United States in the seventies, at a seminar to analyse the energy situation foreseen for the year 2000. Precisely until that time, it had still been considered a distant perspective and it remained more or less on a research level within the universities and technological centres.

An important turning point was the Freedom Car initiative and later in 2003 the **Hydrogen Fuel Initiative,** promoted directly by the Bush Administration, with a budget of 1.20 billion dollars to research into hydrogen and fuel cells. The International **Association for Hydrogen Economy -IPHE-** was also created within this framework, in which the US Secretary of Energy invited Canada, Brazil, the European Union, Japan, India and China to participate.

[1] The Freedom Car Initiative was created in 2003, as a consortium between the US Department of Energy - DOE- and the Council for Automotive Research, comprised of Daimler-Chrysler, Ford and General Motors, whose aim was to develop advanced technologies to reduce the dependence on oil. One of the options considered was to place considerable importance on hydrogen as a fuel.

The function of the IPHE is to organise, assess and coordinate multinational R&D&I programmes to help advance towards a hydrogen economy, with the commitment for:

> **"all citizens of the participating countries to have the option to purchase an economically competitive, hydrogen-propelled vehicle and be able to fill up with fuel near their homes and workplaces before 2020".**

The European Union, on its part, created the High Level Group for Hydrogen and Fuel Cells, **HLG,** in 2003.

The HLG prepares a report, "Hydrogen Energy and Fuel Cells. A vision of our future" where they put forward a series of five actions to the European Union:

- Definition of a European political framework.
- Definition of a strategic research agenda.
- Definition of a European roadmap in hydrogen and fuel cells.

- Creation of a European Technological Platform engaged in hydrogen and fuel cells.

The HLG proposals were discussed at the European conference "The Hydrogen economy. A bridge to sustainable energy" (Brussels, 16-17 June 2003), which enjoyed a very high level of political representation, never seen before, to tackle scientific and technological R&D matters.

The following conclusions were drawn at the conference:

- Hydrogen is viewed as a bridge towards sustainable energy development.
- The last objective focuses on an energy system based on renewable energies, with hydrogen and electricity as the main energy bearers.
- All the technological options are kept open (use of fossil and nuclear resources, technology of use based on internal combustion engines or turbines, etc.)
- The Technological Platform must help construct and intensify a coherent approach of the European Union's action in this field.

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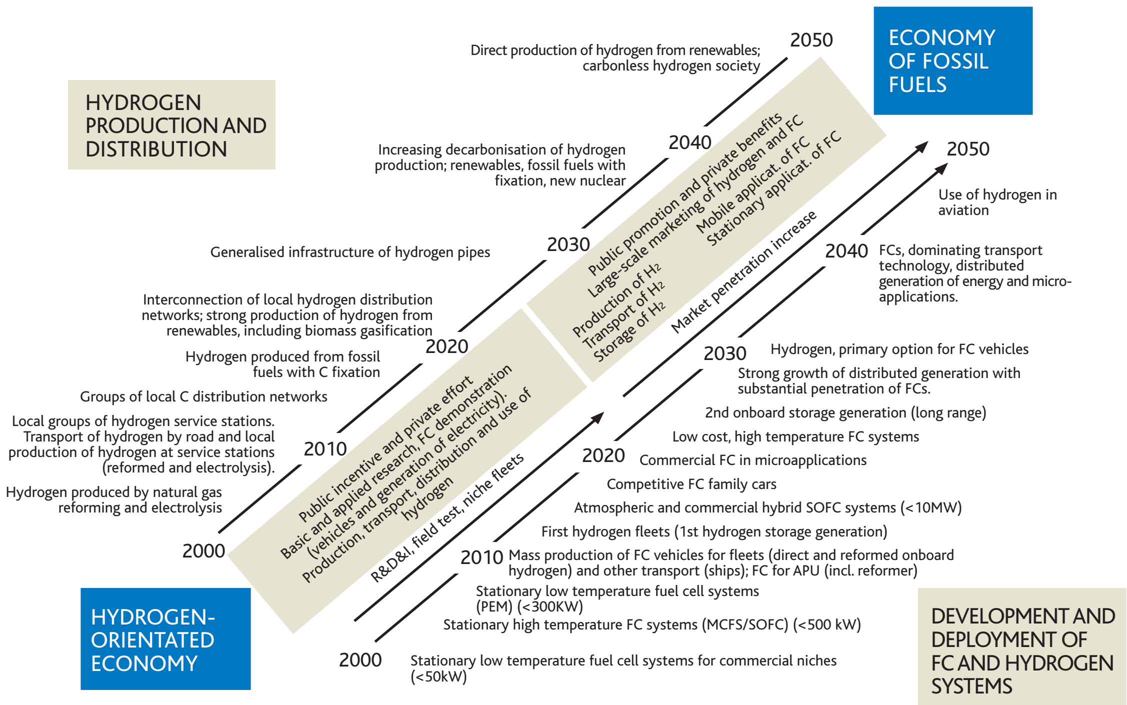
F.01 ROADMAP FOR HYDROGEN AND FUEL CELL



The European Technological **Platform for Hydrogen and Fuel Cells - HFP-** was created in January 2004 in compliance with the HLG guidelines. Its objective was to prepare and manage an effective strategy to place hydrogen and fuel cells on the market to benefit from its entire economic and environmental potential.

More than 300 stakeholders take part in the Platform, including:

- The public and private research, technical and socio-economic community.
- Industry (including SMEs) with the entire production and supply chain.
- Public authorities: European, national, regional and local.
- The financial community, banks, venture capital and insurance companies.
- Users and consumers, to guarantee markets and products.
- Civil society, to increase social awareness.

The Advisory Council is formed to guide the activities, with 35 representatives from different origins including the European Commission, industry, public authorities, academics and NGOs from the sector. This advisory council has three Spanish representatives.

Two steering panels were also created called Strategic Research Agenda, SRA and Deployment Strategy, DS, whose objectives are to publish different basic documents for the European technological policy.[2]

Later, in May 2006, the Implementation Panel - IP, was formed, under the management of the Advisory Council of the Platform and whose aim was to define a European action plan (Implementation Plan) in keeping with the Strategic Research Agenda and the Deployment Strategy.

Four innovation and development actions were proposed with a view to 2015:

2 Further information on structure, participants and main documents can be found on the European Hydrogen Platform website, hhttps://www.hfpeurope.org/.

Introduction

- Development of vehicles and infrastructure to start the marketing stage, placing emphasis on cost reduction and the development of car components.
- Production of 10 to 20% hydrogen without CO2 emissions, highlighting low-temperature electrolysis.
- Development of fuel cells to reach the capacity of 1 GW, focusing on three technologies, PEMFC, MCFC and SOFC[3].
- Introduce fuel cells into portable applications and niche markets to facilitate their entry onto the market.

To obtain these objectives a total investment, from both the public and private sectors, of 6.7 billion euros is necessary for the period 2007-2015, which, in agreement with the gross national product of around 17.5 million euros in Aragon, represents 2 million euros per year.

[3] PEMFC. Proton Exchange Membrane Fuel Cells
MCFC: Molten Carbonate Fuel Cells
SOFC: Solid Oxide Fuel Cells

One of the points where most emphasis has been placed in the first draft, is the preparation of the Lighthouse projects (LHP), large joint demonstrative projects, which must be started up as part of the JTIs in the VII Framework Programme.

The European Platform for Hydrogen and Fuel Cells estimates that they are going to need around 250 million euros of public funds per year to attain the research and development objectives (Strategic Research and Deployment Strategy). The contribution of the European Union could be around 80-100 million euros per year. Together with the support of other public funds, this will be combined with the private investments in projects launched by the JTIs.

F.02 TECHNICAL DATA ON HYDROGEN

Density of gas hydrogen	0,0899 kg/Nm³
Density of liquid hydrogen	0,0708 kg/L
Energy density of gas hydrogen	10,8 MJ/Nm³
Energy density of liquid hydrogen	8,495 MJ/L
Boiling point	20,28 K
Melting point	14,02 K
Low Heating Value LHV gas hydrogen	119,972 MJ/kg
High Heating Value HHV gas hydrogen	141,890 MJ/kg
Low Heating Value LHV liquid hydrogen	8,459 MJ/l
High Heating Value HHV liquid hydrogen	10,04 MJ/l
Explosion limits	4 - 75% de H_2 in air
Detonation limits	18,3 – 59,0% de H_2 in air
Spontaneous combustion temperatures	858 K
Specific calorific capacity	Cp= 14,33 J/(kgK)
	Cv=10,12J/(kgK)
Diffusion coefficient	0,61 cm²/s

Pressure (bar)	Compressibility factor
1	1
100	1,065
200	1,132
300	1,201
400	1,272
500	1,344
600	1,416
700	1,489
800	1,560
900	1,632
1000	1,702

Colourless, odourless and insipid.
It is not toxic, or contaminating, or corrosive, or carcinogenic or radioactive.
It is not explosive, it is not self-igniting and it does not decompose.
It is lighter than air and dilutes quickly upwards.
It has an almost invisible flame.

Introduction

Several projects, which include R&D&I in the main areas, are currently ongoing on a European level. Projects such as HyNet, the establishment of the European roadmap, HypoGen, for the coproduction of hydrogen and electricity from fossil fuels to capture and geologically store CO_2, HyWays to define the European hydrogen highway, and the more recent HyLights, to monitor ongoing demonstrative projects and assess the planning of the next phases of these projects, and Roads2HyCom, to assess and monitor the research that is carried out in the stationary and mobile energy application field (European Fuel Cell and Hydrogen Projects, 2002-2006, European Commission, 2006).

NATIONAL SCOPE

Following the creation of the European Platform, national platforms have started to appear in member countries.

The Spanish Technological Platform for Hydrogen and Fuel Cells (PTE-HPC), was created in May 2005 with the task of defining its own reference scenario and the relative series of strategic R&D activities, fitting them into the European scenario, insofar as possible. The main objective of the PTE-HPC is to facilitate and accelerate the development and use of fuel cell and hydrogen-based systems in Spain, related to their different technologies, for application in transport, the stationary and mobile sectors.

On the other hand, in May 2006, the **Industrial Technological Prospective Observatory (OPTI)** published the Prospective Study on Hydrogen and Fuel Cells. The objectives of this study are to identify the critical technologies on the 2030 horizon related to the production and storage of hydrogen, its final use to produce energy and the different types of fuel cells and their applications.

The aim is to provide a vision of the current situation to be able to understand the national position with respect to the development of these technologies and establish the possible paths to achieve their deployment.

Other national references are the Spanish Hydrogen Association -AEH2- and the Fuel Cell Association -APPICE-.

The **Government of Aragon** is aware of the great energy change that is approaching and of the strengths and opportunities of the region, and thus sets the objectives to support the development of new technologies related to hydrogen and renewable energies. It therefore promotes the incorporation of Aragon into economic activities related to the use of hydrogen as an energy vector and fosters the research, technological development, cogeneration and industrial adaptation, contributing to industrial modernisation and to improving competitiveness.

The main reasons that have led it to take this stance are:

- To take advantage of the **renewable energy potential** that the region has to produce hydrogen, also fostering the creation and increase of wind farms.
- To take advantage of the region's **strategic situation** in order to have a good platform here to distribute and transport hydrogen in the entire north-eastern region of the peninsula.
- A **consolidated industrial fabric** with sectors that can apply and develop new products and services. This will help diversify production, create wealth and consolidate jobs, in different sectors such as the automotive, chemical, plastic, metal, energy and innovation sectors.
- Existence **of specialised manpower** and also of a high level of involvement in research groups.

Introduction

The initiative to develop hydrogen technologies in Aragon is subsequently included as a key strategic line both in the **II Autonomous Plan for Research, Development and Transfer of Knowledge of Aragon 2005-2008,** , and in the **Energy Plan of Aragon 2005-2012.**

In both plans, the new hydrogen technologies are a priority line that is deployed in different sub-lines of action, generation, transport, storage and distribution, development of the fuel cell and of the auxiliary industry related to hydrogen technologies.

The fostering and promotion of the Foundation for the Development of New Hydrogen Technologies in Aragon is also established.

The Government of Aragon had already taken the first steps, organising the first seminar on new hydrogen technologies in April 2003 and promoting the creation, in December that same year, together with other regional enterprises and institutions, **of the Foundation for the Development of New Hydrogen Technologies in Aragon,** to direct and assume the challenges that this technological change is going to represent.

The Hydrogen Foundation in Aragon is comprised, to date, of forty-two enterprises and institutions from the automotive, chemical, energy, financial, education, engineering and real estate sectors as well as research and development centres and administration. The composition of the Board covers all the stakeholders of the new hydrogen economy and all the necessary actors to develop products and services, from basic research to financing.

The Hydrogen Foundation in Aragon is already a torchbearer for projects in the field of hydrogen generation based on renewable energies, solar photovoltaic and wind energies (ITHER), to promote these technologies within the Aragonese business fabric, mainly SMEs (EDHA), training (H2-TRAINING), technological surveillance (VITHa) and technology transfer (Hy-TETRA).

It is also present at the most important forums; it forms part of the European Hydrogen Platform and of the Spanish Platform for Hydrogen and Fuel Cells.

F.03 SPONSORS OF THE FOUNDATION FOR THE DEVELOPMENT OF NEW HYDROGEN TECHNOLOGIES IN ARAGON

Introduction

GENERAL OBJECTIVES OF THE PLAN

Have a tool to **identify the opportunities** of the New Hydrogen Technologies detected in Aragon, which will permit taking decisions on an institutional, business and academic level.

Identify the **strategic lines** for the region and establish a time horizon and action plans to deploy these lines.

SPECIFIC OBJECTIVES OF THE PLAN

Review the state of the technology: study the state of art including the identification of key technologies and competence, its current state of development, major research centres and enterprises, extension of the existing market and tendencies of the current market.

Define the possibilities, expectations and best alternatives for Aragon in the future. Identify strategic lines as well as general and specific projects for Aragonese enterprises, mainly Small and Medium Enterprises, which are the foundation for employment in Aragon.

Identity across-the-board aspects or general support aspects: training, sensitisation, financing, policies, which must be managed to guarantee the success of the deployment of strategic lines.

Identify partners and strategic supports for the development in the Autonomous Community.

Carry out a survey with longer time horizons, 2020-2050, defining the continuity of the strategic lines drawn and laying the bases for the steps to take in those horizons.

NEED TO ESTABLISH PLANS OF ACTION

Multiple forms of production and the application of hydrogen as an energy vector mean that different technologies with different levels of technical and economic implementation must be put into place, and therefore, with different investment requirements, R&D&I needs and other factors.

This all makes it difficult, but at the same time very necessary, to **establish priorities** and approaches for the different regional, national and international programmes in this regard, in order to focus efforts on those developments that are really priority in each case. Furthermore, given the effort and duration required by the transition to the hydrogen economy, it is essential to avoid duplicities and **favour synergies.**

These reasons justify the preparation of this Hydrogen Master Plan in Aragon, proposed for the period 2007-2010.

Later and following the relative reviews at the end of this period, it can be used as a guide until 2015.

The work methodology used to prepare the Plan has been based on an external analysis of the state of hydrogen technologies and of the tendencies and policies for its deployment, as well as on an internal analysis of the situation of Aragon with reference to these technologies and tendencies.

Different documents and projects have been reviewed for the **external analysis** to provide a global perspective of the state of the art in hydrogen and fuel cells. The analysis has been completed with personal interviews with experts, as well as by attending forums, congresses and meetings.

The work methodology for the **internal analysis** of Aragon has consisted of detecting what are the main strengths and weaknesses of the region and establishing some strategic lines of action according to the vision of different experts. Thus, a series of taskforces were organised with **experts** in each one of the themes addressed.

Introduction

Furthermore, for the internal analysis, a survey has been **carried out with 100 Aragonese companies,** all of which have potential links with the new hydrogen technologies sector. These companies are from different activity sectors, they have different sizes and geographical locations. **Small and medium enterprises** have been selected as these represent 90% of the Aragonese business fabric, they are clearly attached to the territory and can streamline and consolidate the hydrogen economy.

The objective of these surveys has been to make a qualitative characterisation of the interests and potentialities of the SMEs in the activities within the value chain of the new hydrogen technologies, as well as of their response and success capacity faced with this challenge.

The information is going to be presented in agreement with the six differentiated areas that cover the entire hydrogen chain:

01. Generation with renewable energies.
02. Generation with renewable energies.
03. Storage, logistics and distribution.
04. Fuel cells.
05. Application in automotive industry.
06. Social and economic impact: awareness-raising, training, regulation and safety, financing, technology transfer.

Within each of these areas, which form the sub-chapters, the information is organised as follows:

- Introduction.
- SWOT.
- Conclusions.
- Strategic lines of the sector.

The work was carried out within the framework of the EDHa project, Strategy and Development of Hydrogen Opportunities in Aragon, within the Consolidation and Competitiveness Plan of the SME (PCCP/2005/267). It has been improved and published within the framework of the VITHa project, Technical Surveillance in new hydrogen technologies for Aragonese SMEs (PC-CP/2006/42).

01 Hydrogen Master Plan in Aragon

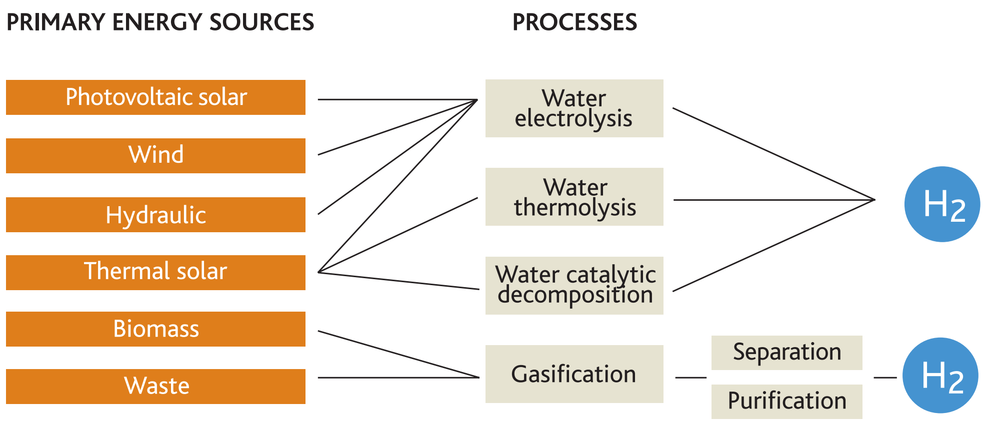
generation
with renewable
energies

01

Generation with renewable energies

As an energy vector, hydrogen can be obtained from a great variety of primary energies. Approximately 95% of the hydrogen is currently produced from fossil energies, more specifically from natural gas reforming, but the possibility of obtaining it from renewable energy sources makes the hydrogen chain more sustainable. It also involves an increase in energy safety.

F.04 SOURCES AND PROCESSES TO OBTAIN HYDROGEN WITH RENEWABLE ENERGIES



One of the main objectives of the hydrogen economy is to obtain it from renewable energies, which are autochthonous and environmentally acceptable resources.

Electrolysis is basically the most developed process to obtain hydrogen from renewables.

Electrolysis is an electrochemical process by means of which hydrogen and oxygen are generated via the dissociation of water and electrical energy in continuous current, transforming the electrical energy into chemical energy.

$$H_2O + \text{electrical energy} \longrightarrow 1/2\ O_2 + H_2$$

The equipment that carries out this process is called an electrolyser. There can be three types:

- Alkaline electrolysers: this is the most developed and extended technology.

Photovoltaic installation. Foundation for the Development of New Hydrogen Technologies in Aragon.

- Proton exchange membrane, PEM, electrolysers: these are the ones that have been developed the most over the last few years.
- Solid oxide electrolyser: this technology is under development.

Distributed generation, critical in isolated and environmentally sensitive areas, is a key factor where accessibility for traditional distribution networks represents a high economic and environmental cost.

Generation with renewable energies

The production of hydrogen in centralised wind farms is detected as a possible application, where the surplus power that cannot be downloaded into the grid is used. Another factor of great importance is to guarantee the power that the generating installations can supply and to improve the stability of the grid.

All of these options enable us to produce renewable hydrogen at different scales, both in large and small production plants depending on what it is used for.

The production of hydrogen from energy crops is especially interesting in Aragon, as an important alternative to traditional agriculture to continue this activity in our Community after the reforms of the Common Agricultural Policy, especially taking into account the large amount of land available in the region.

Currently there are several ongoing renewable energy based hydrogen production projects in the world, some of the most outstanding being:

1. Utsira project (Norway), consisting of an isolated installation, comprised of two 660 kW wind generators, where hydrogen is used as an intermediate energy storage system, to supply 10 homes located on the island.
2. RES2H2 project, located in Attica, Greece and comprising one 500 kW wind generator, whose objective is to produce hydrogen for storage at 200 bar.
3. ITHER project, located in Huesca, Spain, comprising 3 wind generators with a total power of 635 kW and 100 photovoltaic kW, whose aim is to be used as a real-scale test bench to produce hydrogen with renewables.
4. HYDROSOL-II project, located in Greece, consisting of the development and construction of a pilot plant (100 kW) to produce hydrogen from solar energy via the dissociation of water in a thermo-chemical process.
5. CHRISGAS: Located in Sweden, consisting of producing a hydrogen-rich gas from biomass at a pilot plant with 18 thermal MW.

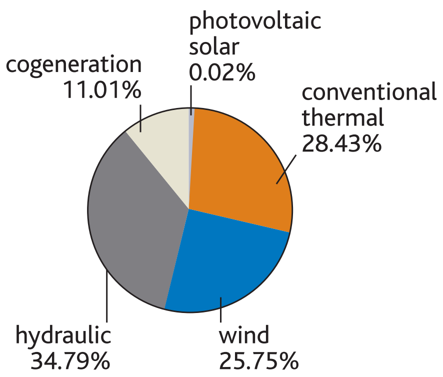
With respect to the time horizon, until 2020, the mass production of hydrogen is foreseen using traditional energy sources, although the gradual use of renewables in production will be significant. The objective is to reach 30% hydrogen produced via energy from renewable sources in the long term (Deployment Strategy, European Platform).

The production of hydrogen from renewable energies, wind and solar, is priority in Aragon, as indicated by the data included in the 2005-2012 Energy Plan of Aragon. They form one of the bases for the launch of the hydrogen economy on a regional level. The chart below shows the electrical power installed in the community and shows that more than 25% corresponds to the existing wind farms.

In 2050 the objective is for 30% hydrogen to be produced via energy from renewable sources.

F.05 INSTALLED ELECTRICAL POWER BY TECHNOLOGIES IN ARAGON

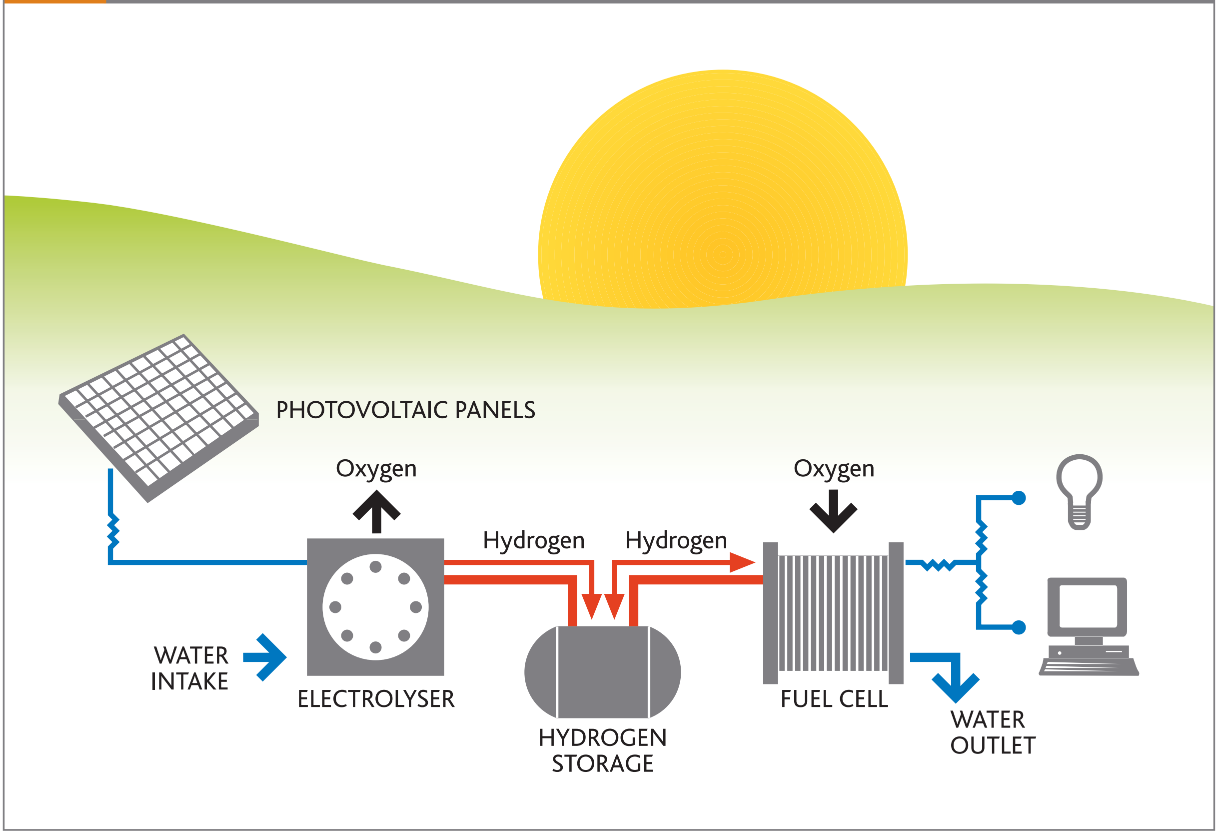
YEAR 2004



Reference: Energy Plan of Aragon 2005-2012. IDAE

Generation with renewable energies

F.06 PROCESS FOR OBTAINING HYDROGEN FROM PHOTOVOLTAIC SOLAR ENERGY



STRENGTHS

- Abundant resources: sun, wind, water and territory.
- Region with surplus electrical production and a pioneer in wind energy.
- Cutting-edge research groups.

OPPORTUNITIES

- Existence of demonstrative projects to obtain hydrogen, on an international scale.
- Change in the Common Agricultural policy (CAP) favouring energy crops.

WEAKNESSES

- Incipient development of solar energy, on both a state and regional level.
- Complexity in processing renewable energy projects.
- Very incipient agricultural diversification towards energy crops.
- Lack of technologists in certain key aspects (electrolysers).

THREATS

- Apparent high competition due to the different ongoing projects on a state level.
- Renewable hydrogen not covered in the Special Regime.
- Absence of legal framework.

Generation with renewable energies

1. Aragon has a great installed power of renewable energies, mainly **wind energy**. **Hydrogen production** is a solution to **appropriately manage it.**

2. Furthermore, Aragon has a **great potential for renewable sources** that are still not being exploited and which can be applied to the production of hydrogen.

3. Although there are currently no companies involved in the development of **electrolysers in Aragon, Aragonese companies have the opportunity to develop system components.** The industrial sectors involved in this are very important in Aragon: machinery, mechanical, electrical, electronic and automation equipment.

4. The characteristics of the Aragonese territory and the population distribution favour the development of **distributed generation and auto-generation systems** in remote areas, both of which are ideal as hydrogen applications. This is an opportunity to diversify the economy of rural areas.

5. **A business interest** has been detected **in developing demonstrative projects** and hydrogen production from wind energy, photovoltaic solar energy and also via the gasification of agricultural and livestock waste.

6. **Research** into technologies for generating and improving certain processes, such as gasification of biomass, is necessary for its efficient application on an industrial level.

01

Aragon has a great potential of renewable resources that are still not being exploited and which can be applied to hydrogen production.

Generation with renewable energies

INDUSTRIAL ACTIONS	TIME HORIZON
Execution of a pilot hydrogen generation project based on wind and solar energy. Start up by the Foundation for the Development of New Hydrogen Technologies in Aragon at its Walqa facilities.	IN PROGRESS
Involve the private initiative, wind farm exploitation and development companies, and define demonstrative projects as a prior step to its extension on a commercial level.	MEDIUM TERM
RESEARCH ACTIONS	
Improvement of water thermolysis based hydrogen production processes, using solar furnace technologies.	MEDIUM TERM
Improvement of hydrocarbon catalytic decomposition processes using solar furnace technologies.	MEDIUM TERM
Development of own biomass gasification technology to produce hydrogen	MEDIUM TERM
SUPPORT ACTIONS	
In-depth study of the hydrogen production potential, based on present-day wind farms and the forecast for future ones.	SHORT TERM
Actions to propose a special regime for hydrogen production via renewable energies.	MEDIUM TERM
Study of resources available in the region, residual biomass, energy crops and gasifiable waste.	SHORT TERM

02 Hydrogen Master Plan in Aragon

generation with other energies

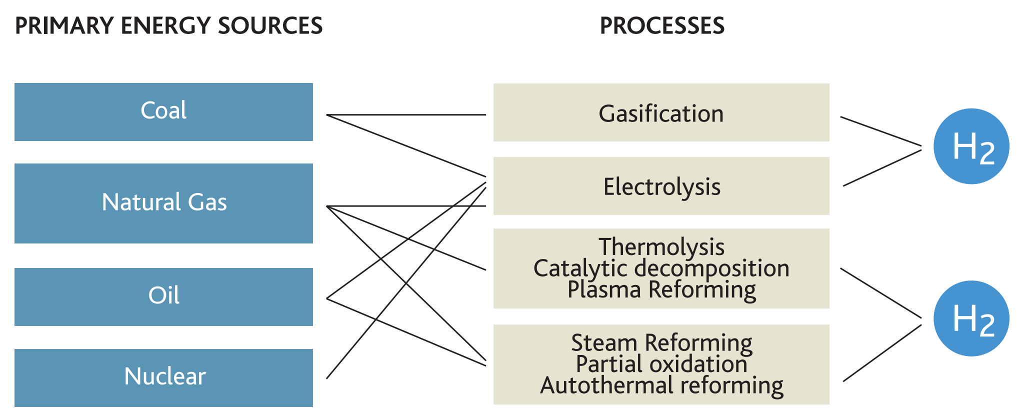
02

Generation with other energies

Currently the hydrogen production is estimated at 0.55 trillion normal cubic metres a year, 95% of this hydrogen being produced from fossil fuels, mainly natural gas, followed by oil and coal, for use at the actual desulphurisation and cracking plant.

A small part of the industrial hydrogen is obtained as electrolysis waste in chemical chorine-soda plants. Here, a solution of soda and potash is electrolysed to mainly obtain chorine, but a large amount of hydrogen is invariably obtained, too. This hydrogen is normally used as a reagent in the

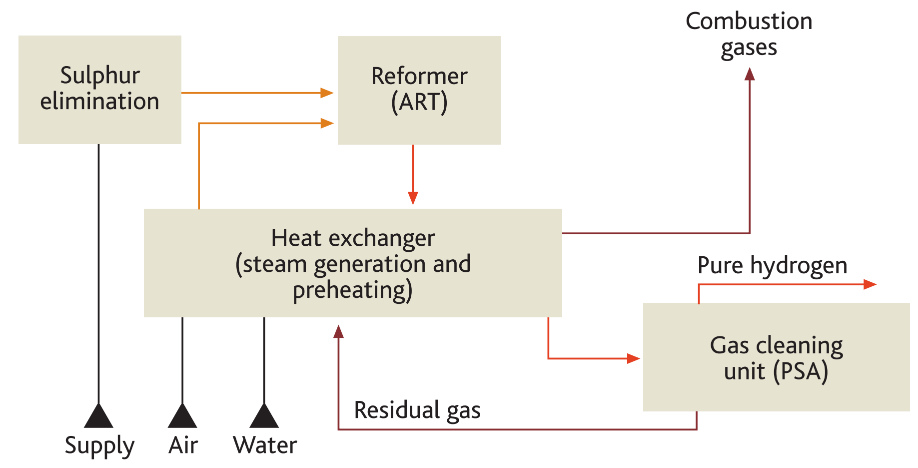
F.07 SOURCES AND PROCESSES TO OBTAIN HYDROGEN WITH TRADITIONAL POWER STATIONS



synthesis of ammonia, hydrochloric acid and other compounds.

The production methods are shown on figure 07. The most generalised processes using natural gas and hydrocarbons as energy sources are steam reforming, partial oxidation and autothermal reforming. In the case of solid fuels such as coal, the most appropriate process is gasification. All of them have the same principle: the hydrocarbon is supplied with steam and air in different proportions depending on the process, working at high temperatures, within the range of 700 to 1000° C. (Fig. 08)

F.08 STEAM REFORMER



Generation with other energies

Currently, the process that is being used, and also the more economical one, is natural gas steam reforming. Work is also being carried out on other processes such as plasma reforming reaching 1,600°C , or catalytic decomposition and thermolysis.

With respect to the method for obtaining hydrogen via electrolysis, this is based on the same principle as explained, the dissociation of water in hydrogen and oxygen via the input of a direct electricity current, but in this case, the energy source comes from fossil fuels, including nuclear power.

The hydrogen economy is based on obtaining an emission-free system and reducing energy dependence. However, there must be an evolution, so in the short-term this system must have the support of fossil fuels to reach the targets set in the long-term.

In the medium and short-term, the mass production of hydrogen will continue to be carried out using fossil fuels, highlighting the natural gas reforming power stations, and from electrolysis with the electricity

In the medium and short term, hydrogen will continue to be mass produced with fossil fuels.

obtained from the fossil fuel thermal power stations. Electrolysis from nuclear power is a possible way of maintaining a continuous reactor load, varying the quantity of electricity downloaded into the grid in agreement with the required demand.

Integrated gasification of coal in combined cycle (IGCC) appears as an efficient way of obtaining hydrogen.

Within this general framework, hydrogen for energy use will be produced in a centralised manner in the traditional industry, and hydrogen produced from renewable energies will gradually reach a greater share. In any case, the support of traditional sources is considered to be necessary as the energy hydrogen demand grows. With respect to the production system, small distributed production plants backed by large centralised plants are used:

- On-site production of hydrogen with different technologies, especially through natural gas reforming processes and electrolysis with renewable energies, optimising the logistics costs.
- Large-scale centralised production, based on natural gas reforming or other traditional fuels. These processes must count on the capture and storage of CO_2.

The development and success of these processes require clean technologies, with capture and storage of CO_2. These are the objectives of projects launched on a European level, such as HYPOGEN, or the FUTUREGEN project in the United States.

Aragon is a region that has an important mining sector. The coal extracted mainly goes to the thermal power stations and in all there are about 1,250 people employed in the coal sector in Aragon. Over the last few years a considerable decrease has been experienced in the number of employees but efficiency has increased, thus maintaining production with few variations. There are 16 exploitations, with an approximate total production of 3.2 million tons in 1999.

According to the latest studies analysed, coal reserves in Aragon exceed 850 million tons. This constitutes a strategic resource reserve within the national territory.

Generation with other energies

STRENGTHS

- Electricity exporting region.
- Strategic coal reserve.
- Saline formations to store CO_2.
- Widespread natural gas network necessary to produce hydrogen from this fuel.
- Cutting-edge research groups in the clean use of coal and production of electricity.

OPPORTUNITIES

- Location of demonstration facilities.
- Development of new technologies to reduce emissions.
- The hydrogen production processes via coal gasification are being developed on an industrial level.

WEAKNESSES

- There are no industrial developments in gasification processes in Aragon.
- Uncertain profitability of facilities engaged in hydrogen production.
- Low coal quality in Aragon.
- Absence of technologists and manufacturers of capital goods for gasification or reforming.
- Complex facilities: cleaning and separation of gases, capture and sequestration of CO_2.

THREATS

- The production of hydrogen may enter into competition with the production of electricity from fossil fuels.
- Penalisation of CO_2emissions.
- The gas obtained in the gasification process can be used directly.

1. **Coal** is considered as a **"strategic reserve" of the resources of Aragon.** On the other hand, the region's coal has a high sulphur content, which makes it difficult to use as a traditional fuel due to the high contamination generated. There is a great opportunity to obtain hydrogen from autochthonous coal, taking advantage of the thermal power stations that exist in the territory.

2. ere are Aragonese **research** groups that are de veloping **methodologies to obtain hydrogen fr om traditional fuels with capture of CO_2**. This ma y be a first step to bring companies closer to de veloping their own clean technologie

Th e generation of hydrogen by natural gas reforming is the most developed and commonly-used tech nology today. Aragon has a **good natural gas supp ly and distribution infrastructure.** This mean s that it can be applied almost immediately in a ctivities and areas where it is economically feasib le.

T

a **sification processes** improvement lines, as wel l as other processes such as reforming or cataly tic decomposition, have great interest on a research level due to the existence in the region of **leadi ng groups in this field.**

Generation with other energies

INDUSTRIAL ACTIONS	TIME HORIZON
Installation of a hydrogen production plant using regional coal. Development of own technologies in gasification, separation and hydrogen purification processes that can be tested at that plant.	LONG TERM
Development of coal and biomass co-gasification technologies.	LONG TERM
RESEARCH ACTIONS	
Development of own technology in coal gasification, hydrogen separation and purification processes (exchange reactors with membranes, interchange reactors with internal capture of CO_2 via carbonisation of CaO).	MEDIUM TERM
SUPPORT ACTIONS	
Study of possibility of storing CO_2 in the Aragonese territory, some saline aquifers of the Ebro basin could be used for this purpose.	SHORT TERM

03 Hydrogen Master Plan in Aragon

storage, logistics and distribution

03

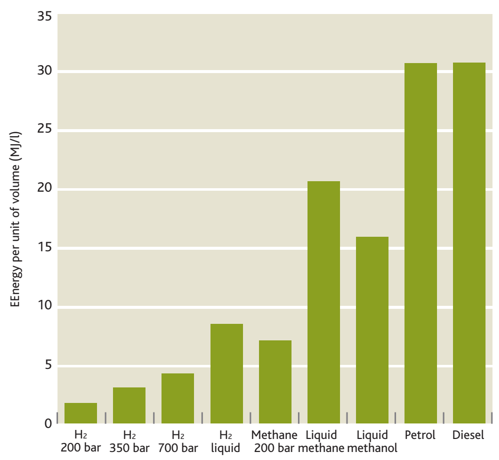
Storage, logistics and distribution

One of the main problems that hydrogen has to face is that, despite having a high heating value per unit of weight, even greater than petrol, its heating value per unit of volume is very low due to its low density.

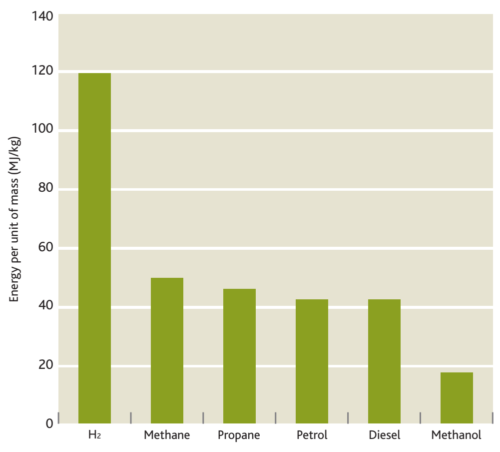
ENERGY EQUIVALENCE OF FUELS:

Hydrogen / 1 kg	Petrol / 2,78 kg
Methane / 2,40 kg	Diesel / 2,80 kg
Propane / 2,59 kg	Methanol / 6,09 kg

F.09 ENERGY PER UNIT OF VOLUME OF DIFFERENT FUELS



F.10 ENERGY PER UNIT OF MASS OF DIFFERENT FUELS



Because of this, solutions must be found to safely and economically increase its energy density so as to be able to offer assumable distribution costs and autonomies for transport that are comparable with current ones.

Hydrogen can be stored as compressed, liquid or solid gas via its adsorption or absorption in different compounds. The equipment used represents the majority of the weight of the storage system, because, as we can see from the table, in the case of compressed

F.11 HYDROGEN STORAGE METHODS

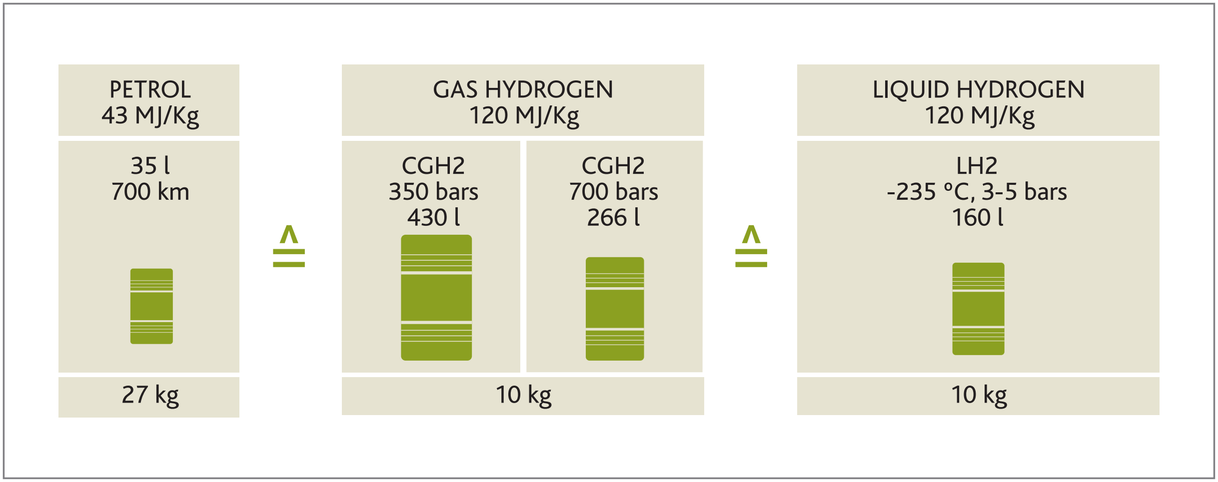
STORAGE	TECHNOLOGY	DEVELOPMENT DEGREES	VOLUME 1 KG OF H_2 (LITRES)
GAS	Compressed at 200 bars	Standard	90
	Compressed at 350 bars	Developed and in use	48
	Compressed at 750 bars	Under development	32
LIQUID	Cryogenic at -253°C	Standard, under improvement	30
SOLID	Metal Hydrides	Research and improvement	18.33
	Nano-structured materials	Research	-

Storage, logistics and distribution

gas hydrogen at 350 bar, the 3.7% in weight of the system corresponds to the hydrogen.

The objectives set by the DOE (Department of Energy of the United States) for 2010 is to have 6% in hydrogen mass in storage systems, to be able to store 4 kilograms of hydrogen (it represents a range of about 400 km in a vehicle) in a volume of 89 litres and 67 kilograms as total weight of the system.

The 2015 target is to obtain 9% in hydrogen mass in the storage system.



In the automotive sector, hydrogen is mainly stored as a gas, although liquid hydrogen is also used due to its greater energy density. Gas hydrogen is used at a pressure of 350 bars, however, the first vehicles moved at 700 bars are starting to appear, achieving high ranges.

The cost reduction associated with storage is a key factor in the introduction of hydrogen onto the market.

It is therefore necessary to develop materials that adapt to the work conditions. It is especially important to develop tanks at 700 bars with compound materials that possess greater resistance and are lighter in weight but at the same time safer. The European project STROHY, which addresses storage in the automotive industry, develops all the systems, gas, liquid and solid hydrogen.

The production, logistics and distribution are currently carried out by the large industrial gas companies. The distribution is performed via compressed gas at 200 bars in steel bottles and the short-term objective is to increase the gas pressure safely to reduce the space and also the weight of the bottles via compound materials.

The distribution by semi-trailers with bottles at 200 bars, with a capacity of around 300 kilograms of hydrogen, is the most appropriate for the low demands that exist at the present time and are going to exist in the short term. When there is an increase in demand, in the medium term, this distribution system will not be sufficient and it will be necessary to carry out the distribution by liquid hydrogen tankers, with a capacity for 3,000 kilograms of hydrogen. In the long term, with a total introduction onto the market, the technically and economically most feasible distribution method will be via pipes, by means of a channelled hydrogen grid.

The creation of a distribution infrastructure is also necessary. The European Hydrogen Platform indicates that in 2020 between 5,000 and 10,000 hydrogen supply stations will be required in European cities.

Storage, logistics and distribution

In agreement with this estimation, between 10 and 20 hydrogen supply stations will be necessary in the first place although the logistics situation of our region may even demand a greater deployment early on.

The **geo-strategic location of Aragon is favourable** as it is half-way between Madrid and Barcelona and at the crossroads between Bilbao, Valencia and France, positioning Aragon at the centre of a network of hydrogen supply stations and as a strategic centre for the production of hydrogen. There is also a natural gas network that spreads out all over the regional territory.

With the aim of improving hydrogen logistics, projects have been launched in Europe such as NATURHY to investigate into the distribution of hydrogen through natural gas pipelines.

Hydrogen supply stations have also been installed within the framework of European projects, such as the CUTE project. This is an especially ambitious demonstration project, which, under real conditions, has commissioned a fleet of 27 clean, silent hydrogen bus prototypes, in the public transport networks of nine European cities (Amsterdam, Barcelona, Hamburg, London, Luxemburg, Madrid, Porto, Stockholm and Stuttgart) together with a hydrogen supply station. In order to give continuity to this project the HyFleet - CUTE has been launched with internal combustion buses.

The HYCHAIN project is a complement to this, whose objective is to test 158 fuel cell supplied vehicles that use hydrogen under real conditions: motorcycles, tricycles, wheelchairs, small utilitarian vehicles and minibuses.

STRENGTHS

- Industrial development in the storage of press urised gas, including hydrogen.
- Favourable geo-strategic location of Aragon for the distribution and logistics of hydrogen.
- Extensive natural gas network.

OPPORTUNITIES

- Developments in auxiliary components and tanks that can be tackled by Aragonese companies.
- Development of distributed hydrogen logistics models.
- Good location to centralise liquid hydrogen logistics on a national level.
- External technology is already reaching the pre-commercial stage in gas, liquid and solid hydrogen (700 bars).

WEAKNESSES

- Regional industry in gas storage does not operate on a global level.
- There is no infrastructure or experience in liquid hydrogen.
- Incipient research into solid storage.

THREATS

- Absence of a regulation and standards framework.
- European projects in storage have no presence of regional actors.
- Complexity and lack of knowledge in handling hydrogen.

Storage, logistics and distribution

1. Aragon has a **very favourable geostrategic position** to enter the initial infrastructure of a distribution network, executing demonstrative projects and developing an **infrastructure with hydrogen supply stations and fleets of hydrogen vehicles.** The opportunities that exist for Aragon in the field of storage, logistics and distribution of hydrogen are considered priority and will immediately be executed.

2. The use of the **natural gas distribution network** to distribute hydrogen in the medium and long term could play a relevant role.

3. There is a positive positioning, with respect to the national situation, **in research into new materials and hydrogen storage nanostructures.**

4. There is a **consolidated and interested business fabric of manufacturers of tanks and auxiliary components.** The companies and groups are also willing to collaborate together.

The opportunities that exist for Aragon in the field of storage, logistics and distribution of hydrogen are considered priority and immediate in their exploitation.

INDUSTRIAL ACTIONS	TIME HORIZON
Create a cluster of companies with a vocation to be leaders in storage, distribution and logistics of hydrogen for energy uses. Development of new products for the distribution of hydrogen and components: hydrogen sensors, pressure regulators, compressors and other component and accessories.	IN PROGRESS
Automation of the processes and development of storage systems at pressures of more than 350 bars with new materials, composites.	MEDIUM TERM
Development of an incipient network of service stations, depending on opportunity, fleet support, or corridor creation opportunities.	3 WITHIN A 10-YEAR TIME INTERVAL
Foster the use of the gas transportation infrastructures that already exist in the region (natural gas pipeline) to transport hydrogen.	LONG TERM

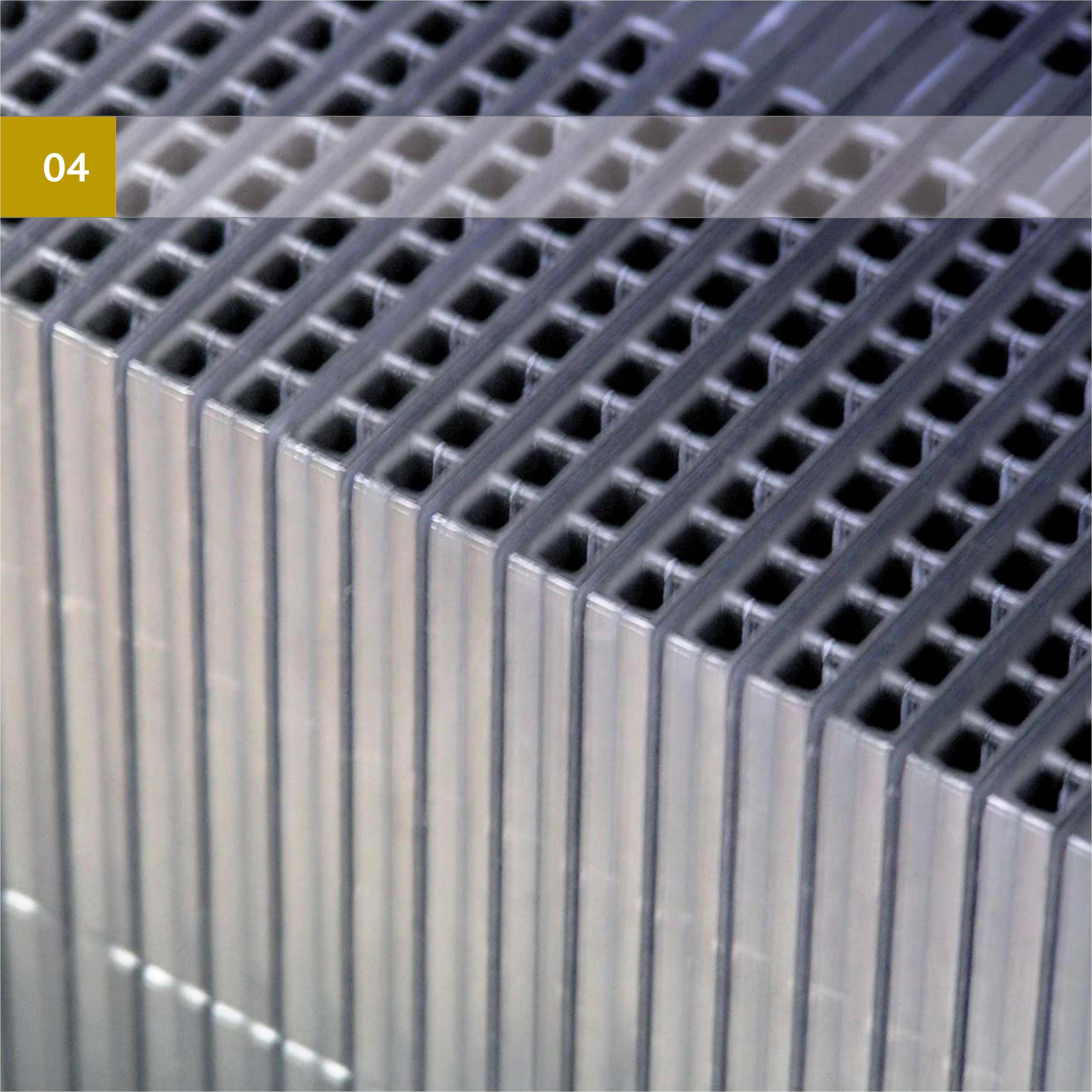
Storage, Logistics and distribution

RESEARCH ACTIONS	TIME HORIZON
New materials for the storage and distribution of gas and liquid hydrogen: fibres, resins, plastics. Cheapening of cost in production systems.	SHORT TERM
Development of new materials for storage and distribution of solid hydrogen: hydrides, carbon compounds, MOFs (metal-organics frameworks), etc.	MEDIUM TERM
Research into the behaviour of hydrogen when mixed with natural gas and also on the materials used for its storage and distribution.	LONG TERM
SUPPORT ACTIONS	
Relations with other national and European initiatives to make Zaragoza the centre of the hydrogen highway corridors on a national level (connecting Barcelona, Madrid, the north of Spain and the Levante coast).	MEDIUM TERM
Support to technology transfer from cutting-edge research groups in new materials and the company	SHORT TERM
Development of hydrogen logistics	LONG TERM

04 Hydrogen Master Plan in Aragon

fuel cells

04



Fuel cells

The use of fuel cells is the great potential for using hydrogen as opposed to traditional fuels. Their main advantage is high efficiency in the electricity generation process compared with current systems (thermal machines).

The efficiency of the thermal machines is limited by the Carnot cycle, as the process involves the transformation of heat into mechanical energy. Fuel cells directly convert chemical energy into electrical energy obtaining between 2 and 3 times more efficiency. Furthermore, they do not produce residual gases or noise.

Fuel cells are electrochemical devices comprised of several interconnected individual cells. Unlike accumulators ("traditional cells") they have the capacity to produce electricity in an indefinite manner whilst fuel and oxidant are supplied to the electrodes. As a result of the reaction, the cell produces electricity, water and heat.

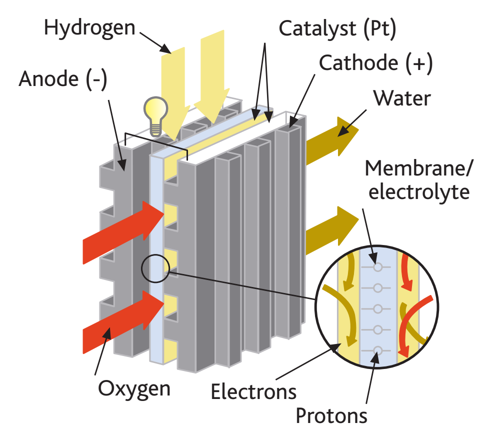
The cell operation is based on the introduction of a flow of hydrogen to the anode, where it is oxidised, producing a current of electrons and hydrogen ions.

$$H_2 \longrightarrow 2H^+ + 2e^-$$

The ions cross the electrolytic membrane and continue to the cathode where they combine with the oxygen molecules, producing water.

$$2H^+ + 1/2O_2 \longrightarrow H_2O$$

F.12 OPERATION OF A FUEL CELL



F.13 TYPES OF FUEL CELLS, CHARACTERISTICS AND APPLICATIONS

CELLS	ELECTROLYTE	OPERATION T. (°C)	ELECTRODE	MAX CO (ppm)	APPLICATIONS
Alkaline (AFC)	KOH	90-100	Nickel	-	Space. Military
Proton exchange membrane (PEMFC)	Solid polymer	60-100	Platinum	10-50	Vehicles. Lap-tops. Stationary generation
Phosphoric acid (PAFC)	Phosphoric acid	175-200	Platinum	500	Stationary generation. Vehicles
Molten Carbonate (MCFC)	Carbonate mixture	600-1000	Nickel	No limit	Stationary generation.
Solid Oxide (SOFC)	Zirconium, Yttrium	600-1000	Pervoskites	No limit	Stationary generation

Fuel cells

ADVANTAGES	DISADVANTAGES
Quicker cathode reaction in alkaline electrolyte. Greater efficiency.	Very sensitive to impurities and CO_2.
Solid electrolyte reduces corrosion and maintenance. Low Temp. Quick start-up.	Costly catalysts. Sensitive to impurities in H_2 or other fuel.
65% efficiency in cogeneration. It accepts impure H_2.	Platinum catalyst. Low current and power. Great weight and volume.
Advantages due to high temperature: greater efficiency, more economical catalysts	Corrosion due to type of electrolyte. Short working life.
Advantages due to high temperature. Advantages due to solid electrolyte.	Corrosion due to high temperatures. Short working life.

There are different types of fuel cells, classified according to the type of electrolyte as observed in table 13. They have a wide range of power due to their modularity that enables them to be adapted for multiple uses. The operation temperature varies from room temperature to 1,000°C.

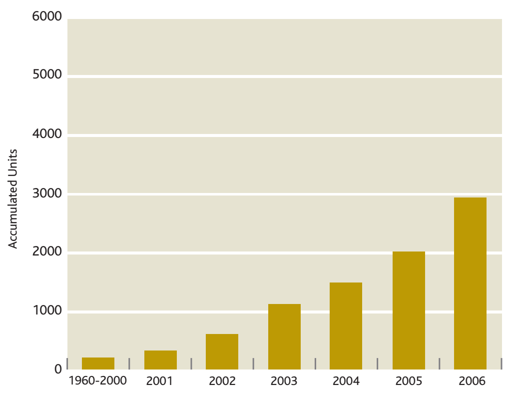
The three main application fields of fuel cells are in portable applications, in the automotive industry and in the stationary generation of electricity, residential and commercial.

For small-scale stationary installations, individual residential uses (up to 10 kW), the PEMFC technology is entering the pre-commercial phase, although the SOFC has potential. For industrial or residential complex applications (10 - 100 MW) the PAFC technology has been sufficiently proven, and in the future, important developments are foreseen in SOFC and MCFC. Market niches will be opened for heat and electricity cogeneration suitable for individual houses and small businesses. It must be underlined that there are approximately 5,000 stationary fuel cell systems in the entire world, used as reserve systems in the case of power-cuts and for residential uses.

With respect to portable applications, the key technologies are polymeric cells (PEMFC) and direct methanol fuel cells (DMFC), with an operation temperature of less than 100°C. It is expected that the introduction of fuel cells into the market will be driven by the applications in small portable electronics, due to the improvement in functionality of these systems, even a greater operation time and elimination of recharging time. Currently, the manufacturing companies have several models, depending on the uses they are designed for, and operation falls within a range of 1 W to 1.5 kW. All the commercial channels are being exploited in products whose features are competitive with the current ones. Currently, there is approximately a total of 11,000 fuel cell systems operating in portable applications.

For 2020, a considerable market penetration is foreseen in the three main applications areas.

F.14 ACCUMULATED UNITS OF SMALL STATIONARY APPLICATIONS



Graphic source:
Fuel cell today. Market survey: small stationary applications.

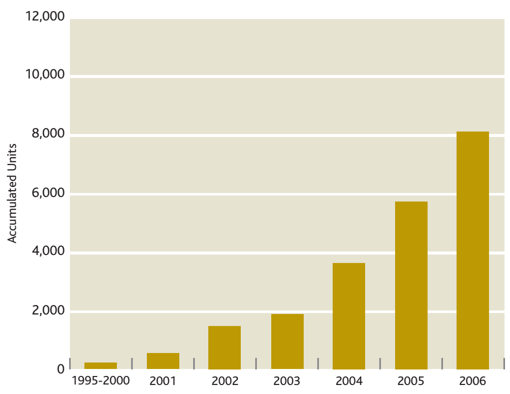
Fuel cells

Related to automotive industry applications, the technology that the different makes of vehicles have adopted are the PEMFC cells. Makes such as General Motors or Toyota already have several prototypes and hope to launch them into the market in the medium term.

For 2020, a considerable market penetration is foreseen in the three main application fields. The strategic products to be developed are Portable Fuel Cells (Micro - Cells, 1-20W), Portable Generators (> 10kWe) and Stationary Generators. For the year 2050, it is expected that the fuel cells systems technology will be mature and have a competitive production (Deployment Strategy, European Hydrogen Platform).

For 2020, a considerable market penetration is foreseen in the three main application areas.reas.

F.15 ACCUMULATED UNITS OF PORTABLE APPLICATIONS



Graphic source:
Fuel cell today. Market survey: portable applications.

F.16 PERSPECTIVE OF THE APPLICATIONS OF H2 AND FUEL CELLS IN THE 2020 SCENARIO

	FUEL CELLS FOR PORTABLE ELECTRONICS	PORTABLE GENERATORS AND MARKET NICHES	STATIONARY FUEL CELLS (COGENERATION)	ROAD TRANSPORT
Units sold as at the year 2020 in EU	~250 million	~100.000 (~1GWe)	100.000 a 200.000 (2-4 GWe)	0,4 million to 1,8 million
Accumulated sales up to 2020 in EU	n.d.	~600.000 (~6 GWe)	400.000 a 800.000 (8-16 GWe)	1-5 million
Market in EU in 2020	Established	Established	Growing	Start of mass market
Average power of fuel cell systems	15 kW	10 kW	< 100 kW (micro cogeneration) > 100 kW (industrial cogeneration)	-
Cost target of fuel cell systems	1-2€/W	500€/W	2.000€/kW(micro cogeneration) 1.000-1.500€/kW (industrial cogeneration)	< 100 €/kW (for 150.000 units a year)

Ref: European Hydrogen Platform

Fuel cells

The key points in the development of fuel cells are to increase durability and reliability and to reduce costs. This is achieved by way of the following developments:

- New lost-cost material so the current ones can be replaced.
- Components and systems to achieve more efficient operations, greater operation time, smaller size and better features.
- For polygeneration applications, systems integration and plant design to be able to optimise operation costs.
- Efficient current investors to transport the direct current produced in fuel cells into alternating current.
- Control and grid connection technologies.

There are currently many research groups and companies working with cells in Europe, mainly polymeric cells (PEMFC) and solid oxide cells (SOFC).

The Spanish Hydrogen Platform recommends emphasising the high strategic value of the development of Spanish technology fuel cells (PEMFC, DMFC, SOFC) within the field of portable applications and small domestic appliances, as a prelude to future upward scalings, with the consequent diffusion towards other more ambitious applications in size and powers.

There are research groups in Aragon making developments in PEMFC and SOFC cells. However, there are still no regional cell manufacturers, although there are companies with the capacity to do so, backed by an industrial fabric that is able to manufacture their components or integrate them into the final system.

STRENGTHS

- Research groups in Aragon are working on PEM and SOFC fuel cells.
- High energy efficiency of cell as opposed to internal combustion engines.
- Special characteristics of the cells as opposed to traditional systems: wide range of power, low noise level, no emissions, no recharge required.

OPPORTUNITIES

- Aragonese companies have the capacities to manufacture fuel cell components.
- Industrial fabric able to integrate the cells into their final products.

WEAKNESSES

- There are no regional cell manufacturers.
- There are commercial cells in different applications.

THREATS

- Uncertainty in the market evolution.
- Absence of regulation and standards.
- High cost of fuel cells as opposed to other traditional systems (internal combustion engines)

Fuel cells

1. The **industry of auxiliary components** such as valves and control and power electronics represents a very important development niche in Aragon, although in general, innovation will be required in the products insofar as miniaturisation is concerned.

2. Aragonese research **groups are now working on new components for SOFC and PEMFC cells.** On an intermediate horizon, good results can be obtained and be transferred to the Aragonese companies for exploitation.

3. The **cells are integrated into already existing systems** (portable electronics, residential and industrial amenities...), giving them functional advantages and varying their characteristics. The Aragonese industrial fabric has developments in this field, so the evolution of this technology must be observed, carrying out the necessary developments when the market requires them.

4. Although there are no fuel cell manufacturers in Aragon, there are expert **companies in assembly and maintenance,** which have a good opportunity to specifically receive training and increase their activity in this field.

INDUSTRIAL ACTIONS	TIME HORIZON
Development of hydrogen sensors, regulators, control systems, compressors and other components and accessories, adapted in sizes and costs, and operable in the foreseen conditions.	SHORT TERM
Creation of companies engaged in mounting and maintaining fuel cells.	MEDIUM TERM
Creation of companies to automate the manufacturing processes of cells or certain cell components.	LONG TERM

Fuel cells

RESEARCH ACTIONS	HORIZONTE TEMPORAL
Research of the PEM cells components with electrolyser improvement projects and support for projects to manufacture anode/membrane/cathode units, MEAs, with the new gas diffusion electrodes, for PEM cells and projects to manufacture plastic bipolar plates with integrated electrode, or other light and conductor materials.	SHORT TERM
Projects to improve catalyst unit and SOFC cell support.	MEDIUM TERM
Decrease of the operation temperature of the SOFC cells and use of new materials with the components.	MEDIUM TERM
SUPPORT ACTIONS	
Creation of a laboratory where the different components developed by companies or research groups can be tested.	SHORT TERM
Development of a Promotion Plan for the use of cells in the residential and tertiary sector in isolated areas and promotion of the use of higher power cells in municipalities or small companies.	MEDIUM TERM

05 Hydrogen Master Plan in Aragon

applications in the automotive industry

05

Applications in the automotive industry

The automotive and transport sector is the main driver of the economy both in the European Union and in Spain.

This sector faces problems derived from the use of fossil fuels, such as energy dependence, the increase in price of the barrel of oil and the environmental problems they cause, including greenhouse effect problems. Consequently, the use of hydrogen as an energy vector is posed as an alternative that holds special interest for this transport sector and, in particular, for the automotive sector.

The major worldwide manufacturers are currently investing billions of dollars in the research and development of different hydrogen-propelled vehicle prototypes.

These major car manufacturers predict that the full marketing for the public at large will start around 2010, after a demonstration phase in vehicles in captive fleets to continue with a rapid marketing process. The most commonly used cell technology in this type of vehicles is the polymeric membrane fuel cell (PEMFC) with 50-100 kW power. Vehicles moved with fuel cells entail an increase in efficiency. Compared with the 15-20% efficiency of present-day vehicles, these new vehicles can reach 45-50% efficiency, as they directly transform the chemical energy, stored in the H - H bond of the hydrogen molecule, into electricity and steam, which is the only emission produced.

The market surveys carried out indicate that, in the year 2020, 5% of the cars that operate in Europe will be hydrogen cars, which represents about 9 million cars (Hydrogen and Fuel Cells market study, OPTI).

According to the Strategic Research Agenda of the European Platform:

> "the application in transport constitutes the greatest strength of hydrogen".

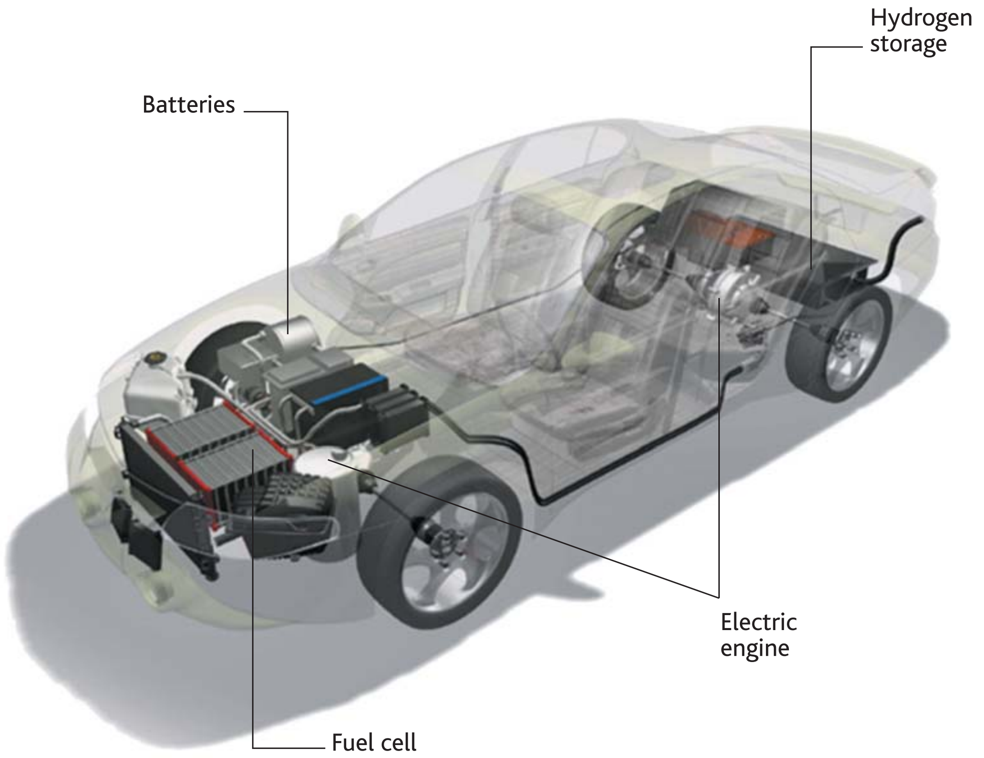
The following actions must be developed:

- Improvement of the fuel cell technologies and storage to reduce the prices of hydrogen cars and make them commercially feasible.
- Creation of the necessary hydrogen supply infrastructure to efficiently supply the fleets.
- Start the deployment of use (implementation) of hydrogen vehicles through captive fleets.

With the introduction of hydrogen, the automotive industry will evolve, increasing the participation of the auxiliary industry. The electrical, plastic, chemical and metal component sectors will also acquire great relevance. This is due to the percentage cost variation of the different vehicle components depending on which propulsion system they use, as on the new scenario, the cost of the electronic components and of the storage tank increases.

It is observed that the automotive sector has started, and will probably continue, to be the innovation and development driver for the different hydrogen technologies. All the areas will be covered in this field, both fuel cells for direct use, as an essential component for vehicles, and for the rest of the processes linked to the value chain of hydrogen in transport: generation of fuel, storage and distribution.

Applications in the automotive industry



STRENGTHS

- Sector with strong roots in the region.
- The automotive industry has a cluster in Aragon, created around the General Motors Plant of Figueruelas.
- There is an Automotive Risk Assessment Centre.
- Aragon as a strategic centre in the hydrogen highway.

OPPORTUNITIES

- Good public acceptance of vehicles driven by alternative fuels.
- Agreements and legislation are in motion to reduce emissions.
- Diversification and defence to delocalisation in the sector on competing for innovation.

WEAKNESSES

- Aragonese companies of the automotive sector carry out few R&D activities.
- The decision centres in the strategy of the automotive multinationals are outside the region.
- The auxiliary car industries have no knowledge of hydrogen technologies.
- There are no vehicle developments in Aragon.

THREATS

- The European financing is focused on countries with greater developments, for example, Germany and France.
- Jobs in the automotive sector could decrease if the necessary industrial developments are not tackled.

Applications in the automotive industry

1. There is a quite significant **volume of automotive suppliers in Aragon.** Specialising in components for hydrogen vehicles is a great opportunity for them.

2. Some of the **most important industrial activity sectors in Aragon,** such as electric-electronic, chemical-plastic, acquire a greater specific weight as suppliers of manufacturers in transition to the hydrogen vehicle.

3. **Looking for other special application niches** such as industrial vehicle, motorbikes, caravans, etc. is considered necessary. The existence of companies with developments in these fields, together with the strategic position and increase of logistics activities in Aragon gives an opportunity to start up captive fleets and also to develop the necessary supply infrastructure.

4. In the long term, the development **of car collection and recycling logistics may be an important niche.**

05

Foster the concern and search for opportunities in the automotive component sector to enter the future market of the electrical car with fuel cell.

Applications in the automotive industry

INDUSTRIAL ACTIONS	TIME HORIZON
Manufacture of vehicles that are not traditional passenger vehicles, as for example, micro-cars, mobile industrial and farming machinery, special fleets, captive fleets (rubbish collection lorries, town-cleaning vehicles, gardening vehicles, etc.)	MEDIUM TERM
Application of fuel cells that work as auxiliary power units (APUs). Examples of applications: motor homes, refrigerated lorries, heated tankers, etc.	MEDIUM TERM
Foster the concern and search for opportunities in the automotive component sector to enter the future market of the electrical car with fuel cell. Make use of the capacities and knowledge of existing automotive suppliers in the region.	MEDIUM TERM
RESEARCH ACTIONS	
Development of components and systems by companies of the auxiliary automotive sector.	MEDIUM TERM
SUPPORT ACTIONS	
Actions to create special fleets, urban transport, for example, that have a social impact and can be used to foster these technologies on an individual level.	MEDIUM TERM

06 Hydrogen Master Plan in Aragon

social and economic impact

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Social and economic impact

To develop the hydrogen economy it is not sufficient to just carry out the actions described above, related to each one of the technologies. Across-the-board actions that affect all of them must also be carried out.

Social and economic actions, awareness-raising of the population, training, definition of standards, regulations and safety, financing of projects and technology transfer, are key for the efficient implementation of this new economy.

In this regard, the European Hydrogen Platform makes some recommendations that are listed below:

- The main objective of **public awareness-raising** is to reach a level of understanding about hydrogen and fuel cells that permit the acceptance and marketing of these technologies.
- Develop a clear plan of action for **training** at all levels, above all in the short term, for researchers, engineers and technicians.
- In connection with the **Regulations, Codes and Standards**, a preliminary analysis and an action plan have been established to set standards and create a regulation framework for the safe use of hydrogen and fuel cells.
- For a **business development,** market niches must be identified that can obtain prices with premium due to the functional advantages of hydrogen and the fuel cell systems.

In particular, with respect to the fields of **Public Sensitisation and Awareness-raising and Training:**

a) The appropriate and necessary knowledge in matters related to hydrogen are not perceived in society. Likewise, a lack of training is detected in these fields, which is being corrected with more and more seminars and specific courses.

b) In Aragon, the Hydrogen Foundation in Aragon is carrying out training, sensitisation and technology transfer activities, as well as fostering the business initiative.

Within the business sensitisation field, the start-up of a specific qualification programme is considered with the participation of the SMEs in the developments of new hydrogen technologies, and the efforts in human capital because it is expected that approximately 40,000 people will have to be trained in Europe in the coming 10 years.

Insofar as **Regulation and Safety** are concerned, the European projects that develop this field are the HySAFE project, for the creation of a network of excellence on the safety of hydrogen as an energy vector, the HARMONHy project, whose aim is to harmonise all the standards, regulations and rules development by different world groups for hydrogen, and the HyAppoval project, to prepare a regulation in the field of hydrogen supply stations.

There is a concern for the peculiarities of the Spanish territory (basically the high temperatures reached in summer) to be taken into consideration when defining plans and standards, above all in the automotive field.

The **financing** of the development and deployment of hydrogen and fuel cells is a critical aspect. Clear and coherent policies are required, with incentives proportional to the social and environmental benefits that will help convince both industry and the financial community that they have to invest. We must not wait simply for the market forces to enter into play, as in that way the transition would take much longer than expected.

To cope with these developments, according to the European Union Implementation Plan, a budget of 6.7 billion euros is required in Europe, with both public and private investment, between 2007 and 2015.

Within the field of the VII Framework Programme of the EU (2007-2013), a new instrument is suggested, namely, the Joint Technology Initiative - JTI, proposed by the Commission based on the work of the Platforms, in order to foster R&D in all its areas.

Social and economic impact

More specifically in hydrogen it is expected that the investment of 250 million euros per annum will be reached, that is double the investments to date, to equal the investments of the USA and Japan.

The JTIs must combine public investment with private activities, including provisions to stimulate innovative SMEs and train researchers. The importance of the Lighthouse projects is highlighted, which are large demonstrative projects included in the JTIs.

1. Incorporation of hydrogen into the Renewable Energies Plan.
2. Establish a clear economic policy on technologies related to the clean production and use of hydrogen.
3. Need to deal with hydrogen in agreement with its production method. The electricity produced from renewable energies and downloaded into the electric grid has a premium system. The hydrogen produced from renewable energies, must also receive premiums, as if not, this would represent an economic stumbling block to the introduction of hydrogen as an energy vector.

STRENGTHS

- Support to the use of hydrogen for energy purposes in the Energy Plan of Aragon.
- Official training initiatives on a university level.
- The launch of the Hydrogen Foundation in Aragon as a support tool for companies and researchers in the region.

OPPORTUNITIES

- Establishment of a strategic line within the main national and European programmes for the production, storage, distribution and use of hydrogen and fuel cells.
- Social perception of hydrogen as a non-contaminant and an alternative to the instability of the fossil fuel market.
- Creation of market niches with the support of venture capital entities.

WEAKNESSES

- Lack of company-researcher relationship, there being a lack of knowledge of the possibility of joint developments.
- Lack of business knowledge of its potentiality and future markets.
- Lack of knowledge of public financing channels for R&D&I projects.

THREATS

- Perception that hydrogen is dangerous and difficult to handle.
- Absence of international regulations and standards.
- Limited participation of Aragonese experts in standardisation groups.
- Long investment return periods for companies that get involved in developments related to new hydrogen technologies.

Socio and economic impact

1. The public and society in general ignore the uses, advantages and disadvantages of the new hydrogen technologies. However, it is perceived as a **solution to the present-day environmental problems.**

2. Training initiatives have been **launched at university level**, perceiving a need to be on-going to train technicians for equipment and installations.

3. Although a **regulation and standards** are being prepared **in hydrogen safety and applications,** these are not going to be available in the short run, making it difficult for organisations to start their projects and define new products.

4. A high percentage of the business sector does not perceive the **opportunities of a new market,** as well as the initiatives and developments launched on a European level.

5. The **transfer of enterprise-university technology** is progressing in Aragon, although in the field of new hydrogen technologies there is no mutual knowledge by the companies interested in these developments and the research groups that can support them.

6. The financial **institutions and venture capital companies** are viewing hydrogen as an emerging sector with great potential and therefore they are willing to invest in solid innovation projects in this field.

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The aim is for the Hydrogen Foundation to be present abroad as a powerful hydrogen technology unit.

Social and economic impact

INDUSTRIAL ACTIONS	TIME HORIZON
Hold dissemination courses and conferences at several levels that can cover extensive sectors of society.	ON-GOING
Creation of an attractive results dissemination format of the state of art or technological study aimed at companies.	SHORT TERM
Specialisation of science-technology university students, giving continuity to the post-graduate programme already in progress, of the University of Zaragoza, and creation of free-choice subjects.	MEDIUM TERM
Hold innovation forums where the research groups can mix with the companies interested in hydrogen technology.	SHORT TERM
Get the Hydrogen Foundation in Aragon to become a "network centre", to be present abroad as a powerful hydrogen technology unit, with an associated group of both companies and researchers that jointly develop actions framed within its Master Plan and along strategic R&D&I lines common to the cluster.	SHORT TERM
Search for financing channels, both at home and in Europe, for projects that might arise in Aragon.	ON-GOING
Prepare a database for public use on regulations and legislation in all the topics related to hydrogen.	MEDIUM TERM
Foster the participation of companies and other Aragonese organisations in standardisation committees.	SHORT TERM
Determine which aspects, insofar as research is concerned, are required from outside the Community and establish relationships with the relevant research and technological centres.	ON-GOING

Hydrogen Master Plan in Aragon

conclusions

Conclusions

After the analysis conducted, opportunities are detected in the entire hydrogen chain. The studies analysed present future scenarios with **incipient markets** in the coming years.

In **hydrogen production,** Aragon has practically all the primary energy sources: great potential of renewables, the Teruel coal as a national strategic reserve, the chlorine-soda chemical plants, and the extensive natural gas distribution network. It also has perhaps the greatest concentration of research groups in Spain in hydrogen production.

Even though renewable-based production is increasing very weakly until it acquires a significant market share, the Walqa project is vitally important as a reference to lead the wind-hydrogen technology.

With respect to **storage, logistics and distribution,** the region has great potential due to its geo-strategic position in Spain. It also has an industrial sector with experience in this field.

As at today, Aragon does not have an "industrial champion" in **fuel cells.** However, there are strong research centres in this field, that are used to working with companies as well as an industrial sector with the capacity to supply components on this emerging market and integrate them into systems, providing them with an added value.

The **automotive sector** is a key sector in the Aragonese industrial fabric as a generator of wealth and employment. The threat of delocalisation forces the entire sector to reconsider the future, and the fuel cell vehicle will, precisely, enable the car supplier to increase its added value, as well as its technological capacity, too. Despite the fact that the automotive sector is the most globalised sector, it still has time to join the development of the hydrogen car. The creation of a specific "cluster" of automotive suppliers is suggested.

Consequently, it can be concluded that **there is an emerging market** where there are opportunities for Aragonese companies, but they must keep their eyes and ears open to discover and study the progresses that are made in this field and enter the market at the right time.

MONITORING

A very important phase in the implementation of any strategic plan or master plan is to monitor its evolution. The objective is to verify the state of progress and carry out updates.

The monitoring of this master plan is based on the continuation of the taskforces that started out to continue with the work begun and on indicators.

A series of indicators are defined that will permit measuring the evolution of the different strategic lines of the plan, on the one hand, and the evolution and efficiency of the actions specified in this master plan, on the other. Bearing in mind the definition criteria mentioned, the following indicators are suggested:

F.17	MONITORING INDICATORS		
DEFINITION	**PERIODICITY**	**SOURCES**	**USE**
No. of financed projects related to hydrogen in Aragon	YEARLY	Government of Aragon	DISSEMINATION
No. of new research groups in projects with hydrogen in Aragon	YEARLY	Ministry of Education	DISSEMINATION
No. of new research groups in projects with hydrogen in Aragon	YEARLY	Government of Aragon	DISSEMINATION
No. of theses and publications in the field of hydrogen in Aragon	YEARLY	University of Zaragoza	DISSEMINATION
No. of patents related to hydrogen requested in Aragon	YEARLY	OEMP[4]	DISSEMINATION
No. of students who have taken part in educational talks and courses related to hydrogen	YEARLY	Hydrogen Foundation	DISSEMINATION
No. of companies that collaborate with the Hydrogen Foundation	YEARLY	Hydrogen Foundation	DISSEMINATION
No. of personnel of the Hydrogen Foundation	YEARLY	Hydrogen Foundation	DISSEMINATION
Degree of advancement or compliance with strategic lines of the master plan	YEARLY	Hydrogen Foundation	DISSEMINATION

[4] OEMP: Spanish Office of Patents and Trademarks.

Hydrogen Master Plan in Aragon

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