HYDROGEN MASTER PLAN IN ARAGON

[2011 - 2015]

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PREFACE

PREFACE

The traveller who starts a trip knows that it has stages, that it is necessary to cover each one leading up to the destination, and that every stage supposes a brief look behind, a comforting feeling of having reached another milestone, and a hopeful look towards the following one. We are exactly in this particular situation with this exciting subject matter of the hydrogen energy and the fuel cells. Four years ago, the teamwork analysis and reflection of sixty people resulted in the Hydrogen Master Plan in Aragon, which was supported by the Department of Industry, Trade and Tourism of the Government of Aragon through several measures and investments of approximately two and a half million Euros, clearly making a short term framework until 2010. Many achievements have been obtained but the environment has changed and for this reason it is necessary to re-draw this scenario in which we have to move, to measure our forces again and to check the validity of the initial hypothesis.

The advance carried out and involvement of companies are undeniable facts that, in many aspects, we even did not dare to dream about four years ago. The reading of this Plan is proof of this. Technology continues improving reliability, it provides infrastructures in Aragon, knowledge and experience have been gained. Also, in relationships with the rest of the world, the Council of the Foundation continues growing - nowadays there are 64 members - and we are all recognized as a place where people can work well, where people have clear ideas and where they bet on these technologies. This is going to be a global business from the beginning and we will have to compete with the traditionally most technological countries and with the traditionally most competitive emerging ones because the prize for those who persevere and grow will be a market in the whole world and we are still on time - it is clear that everything is not determined yet

The new stage that marks the revision of the Director Plan tries to cover again a manageable five-year-short-term time frame that allows us to make projections and consider the advance of its progress. In this time, the Fuel Cells and Hydrogen Joint Undertaking, better known as JTI, will have given projects financial support of about €350 million, distributed in the four annual announcements pending. During this period of time, car manufacturers tell us about beginning their mass production, established in 2015 by several of the most relevant. Furthermore, we will see the development of

the basic infrastructure of hydrogen refuelling stations in relevant countries such as Germany or the Scandinavian countries. We must see these signs and persevere in the well-directed work. It is not of minor importance that in 2016 Saragossa will be the world's shop window of technology, with the celebration of the 21st World Congress of Hydrogen Energy. What better occasion are we going to have than this one?

We know that in 2015 we will still have a long way to go, as Europe is looking towards 2020 as the reference date for the evolution of the energetic scene, with its well-known aims of 20% improvement in efficiency, 20% in renewable energies and 20% in emissions reduction. This is not a very long period of time and on which actions are needed from right now, and in which all the technologies fit a priori, among them, of course, the fuel cells and the hydrogen.

We are living in a unique moment - hard, uncertain and raw on the one hand, when now, more than ever, good ideas, effort and cooperative work are the key for the success. We must also acknowledge the opportunity offered to us by the situation, with the global energy challenge and the very challenge of leading our economy - our society - towards a model of higher added value of the knowledge, more technological and, definitely, more industrial.

Finally, I want to repeat my gratitude to all those who have made this first stage possible - members, businessmen, technologists, collaborators in the Foundation - and especially to those who, unselfishly, have contributed with their ideas, their effort and their time to this necessary task of updating our roadmap, the Hydrogen Master Plan in Aragon. I ask all of them to undertake the new stage looking confidently towards the future.

Zaragoza, 1st, March, 2011

His Excell. Arturo Aliaga López
Regional Minister of Industry, Trade and Tourism of Government of Aragón
President of Foundation for the Development of New Hydrogen Technologies in Aragon

00.

INTRODUCTION

00. INTRODUCTION

The main sources of energy used nowadays by society, such as coal, oil and natural gas, are under a deep analysis (being put under the spotlight) mainly due to two specific characteristics: they are fossil fuels and they contain carbon. Being fossil fuels with the current pace of consumption, in which the rate of extraction is several orders of magnitude higher than the one of regeneration, there will come the day when they will not be available. On the other hand, the fact that they contain carbon in their composition means that their combustion generates carbon dioxide, a known greenhouse gas and influential in the climate change. In order to add a major

complexity to the scene, both oil and natural gas are concentrated in few regions of the planet, in addition politically complex and this provokes a high instability in the prices.

For one reason or another, rationality in energy consumption and diversification of the sources of energy are vital for countries with limited fossil resources. In that sense, there are not many alternatives as long-term sources of energy - we have the Sun or radioactive isotopes. Even supposing that sustainable energy is provided, it is not enough to cover electricity demands. It is necessary to have an "energy vector ", that is to say, a way to store energy for its transport. Within this frame, hydrogen arises as a flexible and environmentally respectful vector with a wide and substitute market in many sectors of the economy and a business opportunity for many entities can be glimpsed.

Up to now, the boost and the search for alternative technologies, among them hydrogen technologies, can be the key to reducing the energetic dependence in many countries. However, this is not easy and it is necessary to work and to invest resources to overcome many scientific, technical, social and political challenges.

When we speak about hydrogen technologies, we are referring to technologies in continuous development, with a great number of applications and business sectors involved, which allow new market gaps to be filled. These technologies are an opportunity to increase the innovative capacity of the big companies and SMEs, as an element for the improvement of the productivity, the competitiveness of businesses and the strengthening of the productive fabric, and all of this lined up with the European strategy of innovation and sustainable development, where the need to develop new business and projects for the survival and the success of the national, European and, of course, regional companies is clear.

It turns out to be essential for all the related sectors to get ahead and to be prepared to avoid being left out of the incipient markets that are already arising regarding hydrogen and fuel cells. Considering these statements, we must promote the following activities:

- To take advantage of the opportunities of the new hydrogen technologies to strengthen the technological and industrial activity on a regional basis, helping to minimize the risk of relocation due to the importance of the automotive industrial sector in the region and stimulating other sectors that can find an opportunity to diversify their products and services.
- To put the different entities (big companies, SMEs, research centres, etc) in contact with Europe and with the new hydrogen technologies and its integration into the renewable energies.
- To hold the activity in a strategic sector, as it is indicated in the National Plan for R&D and Innovation 2008 - 2011: ENERGY AND CLIMATE CHANGE, with the additional advantage that Aragon, due to its territory, business network and growth pace, makes it possible to guide the R&D&I in energy to a direct application not only to new products, goods and services, but also to the direct benefit of society (sustainable development and climate change).

00. INTRODUCTION

Innovation and business strengthening can turn the threats into opportunities through the launch of projects and initiatives that open new business lines. In no other sector it is truer than in that of hydrogen and fuel cells.

Photo: Xavier Häpe

EUROPEAN SCOPE

Europe has identified hydrogen technologies and fuel cells as a strategic sector in R&D&I, and it has constituted one of the five Joint Technology Initiatives in this field, the only one in energy. This Joint Technology Initiative for hydrogen and fuel cells – (FCH JTI) also known as Joint Undertaking (FCH JU) proposed by the European Commission from the work of the now extinct European Hydrogen and Fuel Cell Technology Platform and the National Platforms, aims to manage the budget of the above mentioned programme in hydrogen and fuel cells, and it is a public-private consortium with a particular programme of applied research and technology development.

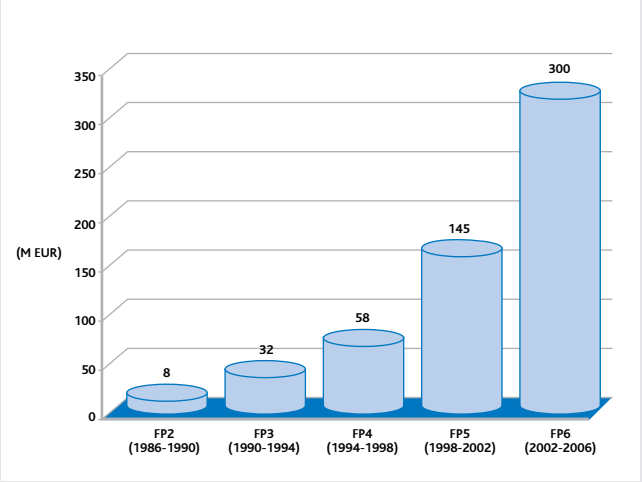
The JTI program tries to line up with the national programmes of the Member States, the European Regions or other international programs in hydrogen and fuel cells. The main objective is to identify the possibilities of global cooperation for mutual benefit.

The JTI is formed by a Research Grouping, constituted by the association N.ERGHY which assembles the leader European R&D centres in these matters, and an Industry Grouping that is the New Energy World association, formed by active companies in the sector and by the European Commission. The Industry Grouping and the Commission have made the commitment to contribute equally to the €940 million budget of the JTI, entirely set aside for hydrogen technologies.

- Up to now, more than 45 European companies are part of the Industry Grouping (New-IG) where there are just four Spanish ones.
- As for the JTI Research Grouping (N.ERGHY), Spanish participation is stronger, where 12 entities are involved, mainly research centres. The Foundation for the Development of New Hydrogen Technologies in Aragon belongs to this group and nowadays it is part of its Board of Directors.

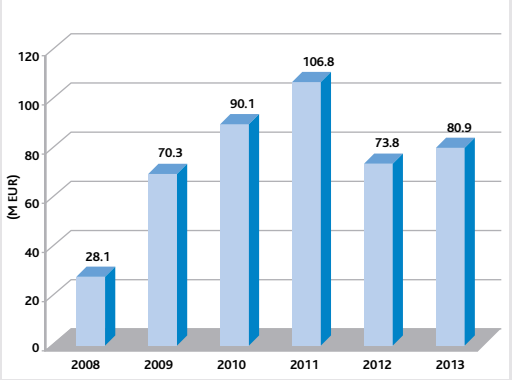
Regarding the specific hydrogen and fuel cells subject matters, there has been an evolution of the assigned budgets in the last number of years, with €300 million having been invested in the last Framework Programme (2002-2006). In the new Framework Programme (2007-2013), the amount invested far exceeds the previous one.

F.01 Evolution of budgets for Hydrogen and Fuel Cells projects of in the Framework Programme.



The global JTI budget nowadays amounts to €940 million, of which 50% will be provided by the European Union (European Commission, Member State and European Regions) and the other 50% will be contributed by the industry.

F.02 Annually distribution of the JTI budget in the 7th Framework Programme.



If we pay attention now to the results published in the FCH JU 2008 summon resolution, we will see that from a total of 16 approved projects, there are only three where Spanish entities appear as partners. That is why it is necessary to create strong consortia, using the potential we already have to create a stronger major presence and returns on a European-wide scale.

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In this respect, it is also necessary to emphasize the European Regions and Municipalities Partnership for Hydrogen and Fuel Cells (HyRaMP), founded in April 2008. Its mission is to provide the European Regions and Municipalities with a representative body that can be coherent, distinguishable and influential towards the FCH JTI and all relevant stakeholders and decision makers at both public and private level. This Partnership allows its Members to play a key role in the implementation of strategies that the JTI aims to carry out. Nowadays, the Government of Aragon is a member of HyRaMP and of its Board of Directors, thus reiterating the regional interest in these technologies.

AIMS AND GOALS IN EUROPE

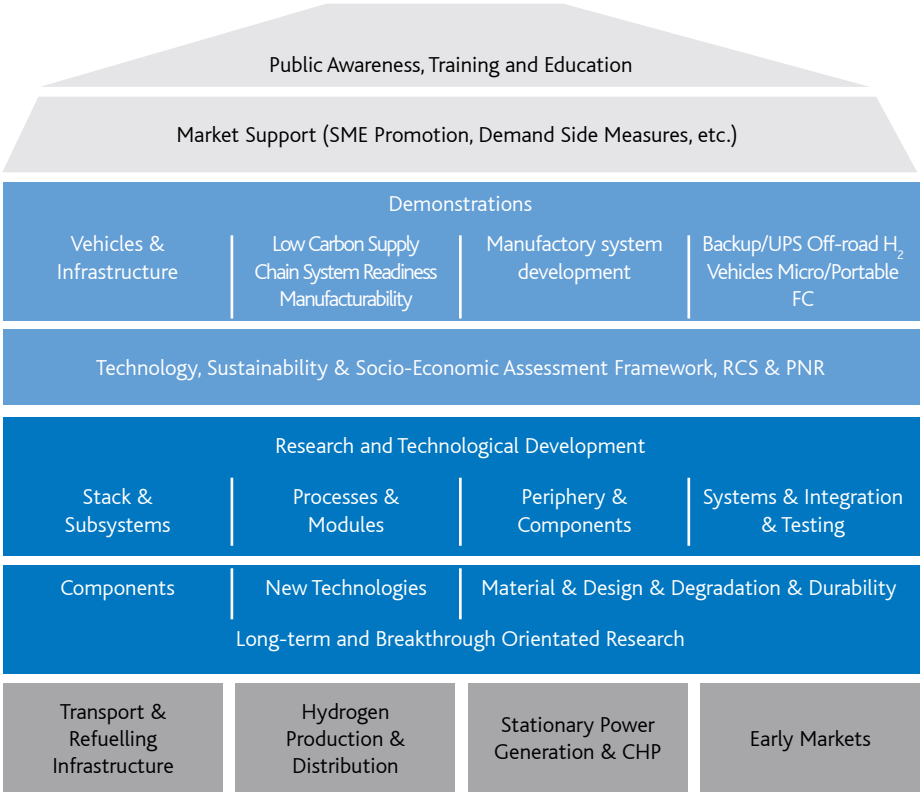
The aim of investigation in energy in the 7th Framework Programme (FP7, 2007-2013) is to adapt the current energetic system so that it can be more sustainable, competitive and safe. In this sense, one of the prioritized activities in the FP7 is hydrogen and fuel cells again, as has been previously seen.

Already in January 2004, and following the recommendations from the High Level Group, the European Commission created the European Hydrogen and Fuel Cell Technology Platform (HFP), an association of more than 300 stakeholders whose task was to prepare and direct an effective strategy to push hydrogen and fuel cells into the market with the purpose of benefiting from its great economic and environmental potential.

The now extinct HFP set some short-term aims to be fulfilled by 2020. According to its predictions, between 400,000 and 1,800,000 hydrogen cars per year, around 250 million of small fuel cell electronic devices (with an average power of 15W) and 100,000 portable electric generators (10kW) will have been sold in Europe by this time. In addition, there will already be between 100,000 and 200,000 home electricity generation systems (of approximately 3KW average power) and industrial ones (350kW) based on these technologies.

Therefore, according to many prospective researches and projects, such as the **HYWAYS** project, the prospective research by the OPTI Foundation "Hydrogen and Fuel cells ", the project **Roads2HyCom,** and the predictions by the extinct European Hydrogen Platform in the "Deployment Strategy" and in the "Implementation Plan - Status 2006 ", it is expected that these technologies will be introduced at different rates. These rates now have been set by 2008-2013 in the MAIP (Multi Annual Implementation Plan) approved by the FCH JU in May 2009 and in which the priority lines are marked on a European-wide scale due to the technological development and research for the 7th Framework Programme when they are going to be financed.

F.03 The Structure of the Multiannual Implementation Plan (FCH JU MAIP).



Ambitious objectives and targets have been identified for the four application areas and cross-cutting activities following a thorough assessment performed mainly by working groups comprised of representatives of the Industry and Research Groupings and in consultation with the European Commission. The most important targets are presented in the following table.

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The targets are qualitative and quantitative in order to assess the progress of the FCH JU. They also represent decision points to consider future budgets, including potential redirection of activities. Therefore, these targets will be reviewed periodically:

F.04 MAIP (Multiannual Implementation Plan) Aims and Goals for the FCH JTI

Application Area	Target 2010	Target 2015	
		Volume	Cost and Technology
Transport & Refuelling Infrastructure.	• 110 additional road vehicles (single site) plus mobile deployment on sites with existing hydrogen refuelling infrastructure capable of refuelling up to 50 vehicles. • 20 buses on 3 sites with an appropriate refuelling capacity.	• 500 Light Duty Vehicles (mainly cars) on 3 additional sites with 3 new stations. • 500 buses on 10 EU sites (of which at least 7 new ones) with refuelling stations with a daily refuelling capacity higher than 400 kg..	• System cost: €100/kW • Durability of cars: 5,000 hours • Roadmap for the establishment of a commercial European hydrogen refuelling infrastructure.
Hydrogen Production & Distribution.	• Appropriate H_2 supply chain (including fuel purification process) to fulfil Transport, Stationary and Early Markets requirements of the transport sector. By 2015 between 10 - 20% of general H_2 demand should be produced through renewable-like processes.		Cost of H_2 delivered at refuelling station < €5/kg (€0.15/kWh). Improved system density storage (9% weight of H_2).
Stationary Power Generation & CHP	• 3 - 7 MW installed in the EU for precommercial demonstration.	• 100 MW installed.	• Cost of € 4,000 - 5,000/kW for micro CHP. • Cost of € 1,500 - 2,500/kW for industrial/commercial units.
Early Markets	500 new units in the EU. • 50 UPS/back-up power. • 20 industrial and off highway vehicles. • 400 fuel cells for portable applications.	14.000 new units in the EU: • 1.000 UPS/back-up power. • 500 industrial and off highway vehicles. • 12.000 - 13.000 fuel cells for portable applications.	

As the principal conclusions derived from this table, it can be indicated that fuel cells have a predictable application in transport and portable applications (mobiles, laptops, etc.) and in heat and electricity generation, not only on a small scale (single-family houses) but also on a large scale (power stations and industries).

The degree of technological development of the fuel cells makes us think that this option is likely to succeed and in fact, the principal car brands have shown prototypes of hydrogen propelled cars during the last few years. Hydrogen and fuel cells technologies mean an opportunity to keep a high added valued industrial and innovative activity, which supports the competitiveness of our companies as opposed to those of third countries.

The design and manufacture of systems based on fuel cells supposes involving a very wide industrial chain, from the components and materials manufacturers to the integrator (that puts a product into the market with a certain function) and even the recycling (PEM cells have high levels of platinum and other precious metals).

As well as fuel cells, the targets related to the development of production, storage and hydrogen logistics technologies that must be stimulated in parallel to finally obtain the necessary infrastructure and technology that facilitate their implementation are already fixed.

Given everything previously explained, it is hardly surprising that in the National R&D&I Plan 2008-2011, in the National Energy Program and in the paragraph related to the promotion of renewable energies and emergent technologies, fuel cells are included.

NATIONAL SCOPE

Many initiatives and projects related to hydrogen technologies have been launched nationwide. The potential of these technologies is very well reflected if we pay attention to the following information: nationwide, we find two National Associations (Spanish Hydrogen Association, AeH2, and the Spanish Fuel Cell Association, APPICE) and one Technology Platform (the Hydrogen and Fuel Cell Spanish Technology Platform, PTE HPC) which brings together over 100 companies and research centres that are working on hydrogen technologies. Both the Government of Aragon and the Foundation for the Development of the New Hydrogen Technologies in Aragon are members of the three institutions, and they take part in their Governance structure, collaborating actively in the activities of promotion and dissemination of these technologies. Other entities of the Region, such as the Carbochemistry Institute of the National Research Council CSIC, the CIRCE Foundation, the University of Zaragoza, the LITEC or The Institute of Nanoscience of Aragon, are also part of some of the Associations or Platforms previously indicated.

Within the INGENIO 2010 programme framework and integrated in the Singular Scientific and Technical Infrastructures Map (ICTS), the Ministry of Education and Science signed a cooperation agreement in 2007 with Castilla-La Mancha Regional Government for the creation of a National Hydrogen and Fuel Cell Technologies Experimentation Centre with headquarters in Puertollano (Ciudad Real). The budget for the development of the project is €130 million for the next 15 years and it is expected that its facilities will be built by 2012.

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The Centre is dedicated to the scientific and technology research in all aspects related to hydrogen and fuel cell technologies, being at the service of the whole national scientific and technological community and open to international cooperation. In this way, the interest for the development of these technologies is clear.

In the last few years, many projects related to hydrogen technologies have been approved in Spain, being launched by different companies or research centres. Nevertheless, in this respect, Spain still has steps to make in order to have a solid structured support for these technologies that would allow it to turn into a world reference in the area of hydrogen. These steps should be directed, first and foremost, towards the creation of national specific programmes for hydrogen and fuel cell projects, like the existing ones in countries such as the USA, Canada or Japan, and later, towards the creation of national public-private consortia similar to the current European JTI, which has already started in Germany, which is going to assign €1,400 million for the deployment of these technologies during the period 2007-2016.

Likewise, it is important to develop products and services of a high technological component level nationwide, and also on a regional basis, presenting the Aragon Hydrogen Foundation as an entity to coordinate efforts and to take advantage of the opportunities that could arise in the region.

Opening of the Third National Congress on Fuel cells CONAPPICE held in Zaragoza in September 2008.

Many initiatives and projects related to hydrogen technologies have been launched nationwide.

REGIONAL SCOPE

The Government of Aragon included the research and the technological development on hydrogen in its commitments for the term 2007-2011, which has placed the region as one of the benchmark territories in this matter.

In addition, the initiative of hydrogen technologies development in Aragon was recorded as a key strategic guideline not only in the 2nd Research, Development and Knowledge Transfer Regional Plan of Aragon 2005-2008, but also in the Energety Plan of Aragon 2005-2012 and nowadays in the lines of action of the Aragonese Climate Change and Clean Energies Strategy (EACCEL).

Hydrogen Foundation in Aragon

The principal instrument implemented by the Government of Aragon is the Foundation for the Development of New Hydrogen Technologies in Aragon (FHa), whose main objective is the development of new hydrogen technologies integrated with renewable energies and the promotion of the Aragon's incorporation to economic activities related to the use of the hydrogen as an energy vector. To that end, it will carry out the organization, management and execution of a wide range of actions in order to generate, store and transport hydrogen for its use in fuel cells, in transport applications or for the generation of distributed energy. Thus, it aims to encourage research, technological development, cogeneration and industrial adaptation, contributing to industrial modernization and the improvement of the competitiveness. The implantation of projects based on sustainable energies that provide technological innovation and promote the energetic and environmental sustainability will be favoured. Nowadays there are 64 members which are part of its Council and they belong to different sectors of interest.

Representatives of the Foundation Council after the meeting held in Zaragoza on November 28, 2008. Posthumous Appointment of Mr Emilio Domingo, former AirLiquide representative, as Honorary Council Member.

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INTRODUCTION

Hydrogen Foundation Council in Aragon (2010).

Since its creation, the Hydrogen Foundation in Aragon has helped launch more than 30 regional, national and European initiatives and projects, supported by public research and technological development funds where a great number of big companies and SMEs were involved, working in cooperation with the research centres.

Below, there is a list of the principal projects jointly funded by public funds that have been carried out or launched during the period of validity of the previous Master Plan for Hydrogen in Aragon:

F.05 List of jointly funded by public help projects developed in the period 2007 - 2010

Title of the project/contract	File	Funding Organization	Period of time
Hydrogen Generation from Renewable Sources of Energy (ITHER).	PCT-A22266217-2005	MEC PROFIT Parks.	2005-2007
International Seminar on Renewable Energies.	PCT-A22266217-2006	MEC PROFIT Parks.	2006-2007
VITHA: Technological Hydrogen Watch Service for Aragonese SMEs.	PCCP/2006/42	MITYC. SME Consolidation Plan..	2006-2007
NECATECH, Identification of the technological needs and innovative capacity of Aragonese SMEs to define developments in European calls in hydrogen and fuel cells.	AR/COPA/07/130	MITYC. INNOEMPRESA 2007.	2008
HYTETRA: Hydrogen Technologies Transfer Project	INN7/ 030625	6th European Framework Programme.	2006-2008
The H2-Training Project: Hydrogen curricula design and pilot experience in vocational training	ES/06/B/F/PP-149461	Leonardo Programme.	2006-2008
CONAPPICE 2008. National Fuel cell Congress.	ACC-120000-2007-2	MEC. Complementary Actions.	2007-2008
PERCEPTHY, Dissemination program for hydrogen technologies and their integration with renewable energies.	CCT005-07-00647	FECYT, The Year of Science.	2007-2008

00. INTRODUCTION

(Continued)

SPHERA Project: Solutions to the Production of Hydrogen as a Source of Energy and the Associated Reconversion.	N/A	Proyecto CENIT (CDTI), Programme subcontracting companies as R&D Centre.	2007-2010
HIDROMED Project: Instrumentation for measurement of hydrogen in hydrides.	IAP-560410-2008-30	MICINN. National Programme for Applied Research Projects.	2008-2009
Optimization of the balance of plant of PEM fuel cells.	ENE2008-06697-C04-02 / CON	MICINN. Research and Development Fundamental National Plan	2008-2009
DEBEH2 Project: Development of the BOP (Balance of Plant) of an alkaline electrolyser.	DEX-560620-2008-112	MICINN. Experimental – Industrial development	2008-2009
ALMAHI Project: Technical viability study to define a series of tests for fuel cells of low and medium capacity, equipment in the area of storage, distribution and transport of Hydrogen.	PPT-440000-2008-6	MICINN. Subprogramme for Collaborative Applied Research in Projects done in Scientific and Technological Parks.	2008-2009
Multi-Purpose Vehicle: Remote-controlled multi-purpose Vehicle-tool with four wheel drive and fuel cell-based propulsion system.	CIT-370000-2008-11	MICINN. Transport and Aerospace Area.	2008-2010
GEHRE Project: Project Management of wind farms with the support of hydrogen to increase the percentage of penetration in the Power Grid..	ECC-590000-2008-145	MITYC	2008-2011
EVIDOS Project: Technical Viability Study for the Development of portable Solid Oxide Fuel Cells.	ECC-590000-2008-100	MITYC	2008-2009
Formula Zero.	N/A	Government of Aragon.	2007-2009
HYRREG Project: Platform for Generating Projects and a Roadmap for Hydrogen in the European Southwest.	SOE1/P1/E100	Interreg Programme IVB SUDOE.	2009-2011
SINTER Project: Intelligent Systems to Stabilize Electrical Grids	PEN-120000-2009-14	MICINN. Extraordinary calls for singular energy strategy projects.	2009-2010

(Continued)

Science Cultural Unit Plan 2009.	FCT-09-56. FECYT	Spanish Foundation for Science and Technology.	2009
Integration of photovoltaic plates and hydrogen technologies in isolated mode.	AQ-11	AAquitaine - Aragon Cooperation. DGA Presidency.	2009
Funding for technical support staff	PTA2008-0967-I	MICINN. Human Resources.	2009-2011
ZeroHyTechPark Project: "Zero emissions using renewable energies and hydrogen technologies in building and sustainable mobility in Technology Parks".	LIFE08 ENV/E/000136	EU LIFE+ Programme.	2010-2013
Microtubular solid oxide fuel cells and steam electrolyzers.	MAT2009-14324-C02-02 (MAT Subprogramme)	CENIT Project (CDTI). Subcontracted by IDOM Zaragoza.	2009-2011
Ecotrans Project, Ecological Urban Transport Technologies.	N/A	Proyecto CENIT (CDTI). Subcontratación por IDOM Zaragoza.	2009-2011
EOLO Project: Consequences of the integration of wind turbines in the electrical distribution and transportation grid.	CTPR03/09	Department of Science, Technology and University, Government of Aragon.	2010-2011
AEI Innovative enterprises association for new hydrogen technologies.	AEI2009L1AR003	MITYC. Supporting programme on Innovative enterprises associations.	2009-2010
Integration of a solar thermal installation using the existing heating system.	1501A00103HU10 / 00193	Government of Aragon and IDAE.	2010
Hyprofessionals Project: Development of educational programmes and training initiatives related to hydrogen technologies and fuel cells in Europe. Coordinated by FHa.	N° 256758	HFC JTI 7th Framework Programme	2010-2012
Project SHEL, Sustainable Hydrogen Evaluation in Logistics.	N° 256837	HFC JTI 7th Framework Programme.	2010-2013

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The Hydrogen Foundation in Aragon has also closely worked with other entities carrying out internal projects on technological development, feasibility studies and cross-cutting dissemination and training activities, all of them aligned with the strategic lines marked in the previous Plan. All of this has allowed the Hydrogen Foundation in Aragon to acquire a great knowledge of technology, and for Aragon to position itself in Europe and to be acknowledged by means of several prizes:

- Jaulín Prize for Defence of Nature by the Town Council and the Cultural Association of Jaulín. 2005.
- VENDOR Prize in the category of Development of Alternative Energies by the Marketing Club of Aragón. 2006.
- National Industrial Engineering Prize 2007, in the category of Engineering Project, for the project Infrastructure and Technology of Hydrogen and Renewable Energies (ITHER) by the Board of Senior Members of the General Council of Official Association of Industrial Engineers.
- Technological Innovation Prize by the Aragón Exterior Association, ARAGONEX. 2008.
- Energy Efficiency Prize by the Research Centre of Energy Resources and Consumption, CIRCE. 2009.
- Prize by the International Energy Agency HIA AEI to Projects 2010.

International Energy Agency Award Ceremony to ITHER Project by the President of the Executive Committee of the Hydrogen Implementing Agreement of the International Energy Agency to Mr Javier Navarro Espada, vice-president of the Hydrogen Foundation in Aragon. Essen (Germany), May, 2010.

Reception by Their Royal Highnesses the Prince and Princess of Asturias to His Excell. Arturo Aliaga Lopez in the ceremony of the National Industrial Engineering Prize 2007 for the ITHER Project.

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The Hydrogen Foundation in Aragon is a leader of "Wind Energy and Hydrogen Integration", Task 24 and "Integrated Systems Evaluation", Task 18b of the International Energy Agency, and it collaborates in other Tasks.

Likewise, it also belongs to the Technical Committee of Normalization in Hydrogen Technologies AENOR/CTN 181 where it contributes to the preparation of regulations on hydrogen technologies of international standards. The Aragon Hydrogen Foundation owns AENOR Technology Watch certification, UNE 166006, renewed for 3 more years in April 2010.

Within the current activities, it is necessary to emphasize that the Aragon Hydrogen Foundation already has technological development cooperation agreements with three European entities:

Jeremy Rifkin receives the Honorary Council Member Award of the Hydrogen Foundation in Aragon from its President, His Excell. Arturo Aliaga.

- IHT, Industrie Haute Technology, which develops in Switzerland high pressure alkaline electrolyzers stacks to be integrated with wind power. One of these stacks has been transferred to the Hydrogen Foundation in Aragon, and Aragonese entities are developing components of the balance of plant and learning from technology.
- Labtech is a Bulgarian company that develops solid-state hydrogen storage systems. The Hydrogen Foundation in Aragon has a cooperation agreement for the development and commercialization of metallic hydrides in Spain and there are several entities involved in the study of the thermal management system, hydrides measurement and development of improved storage systems.
- SRE is a Portuguese company which manufactures low power polymeric cells (<1kW). We have a cooperation agreement for their integration in different applications.

All the activities that have been carried out by the Hydrogen Foundation in Aragon are aligned to the strategic guidelines defined in the previous Hydrogen Master Plan in Aragon 2007-2010 and the new activities defined in this new Plan will allow us to continue working for the creation of new innovative products and services on a regional level in a coordinated way and towards a European scope.

The Foundation line of action answers with the aim of favouring the positioning of the regional big companies and SMEs as companies capable of developing hydrogen technologies thanks to its path in the industry, the knowledge obtained during the last number of years and its bet for the new trends in the energy, industry and automobile sector. The Foundation actions contribute to the international projection of the companies, research centres and other entities, and in this context, the participation in the 7th Framework Programme seems an unbeatable opportunity to reach the aforementioned goal.

Cell of the stack of the high pressure alkaline electrolyzers developed by IHT.

GENERAL AIMS OF THE PLAN

- To have a tool for the identification of opportunities of the new hydrogen technologies detected in Aragon which will allow decisions to be taken on an institutional, business and academic level.
- To identify the strategic lines for the region and establish a time scale and actions plans for the deployment of these lines.

SPECIFIC AIMS OF THE PLAN

- To review the state of technology, current development, projects, sector companies, research centre potential, incipient markets and to define opportunities.
- To identify strategic lines and specific projects for Aragonese SMEs, which represent the foundations for employment in Aragon.
- To set across-the-board and general support actions: training, dissemination, awareness, financing and policies needed to guarantee the success of the deployment of these strategic lines.
- To carry out a survey with longer temporary horizons 2020-2050, defining the continuity of the strategic lines drawn and setting the bases to reach these horizons.

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NEED TO ESTABLISH PLANS OF ACTION

For the definition of this new Plan, an initial review of the previous Plan 2007-2010 has been carried out, focusing on the indicators marked in it and also on the experts' valuation of the defined strategic lines.

Regarding the operating indicators stated in the Plan 2007-2010, the main obtained results are outlined below:

- **More than 75 projects** related to hydrogen in Aragon financed from 2007 to date.
- The number of research groups that develop hydrogen projects in Aragon has reached 13.
- The total number of thesis and publications about hydrogen in Aragon carried out between 2007 and 2009 was **70,** being distributed in the following way: 21 in 2007, 27 in 2008 and 22 in 2009.
- 7 was the total number of patents related to hydrogen requested in Aragon during the year 2009.
- Several thousands pupils have taken part in conferences, training courses and dissemination events related to hydrogen in the last four years, **highlighting that in the course of the year 2009, the number of people interested** in these technologies that visited the facilities of the Hydrogen Foundation in Aragon in Walqa went beyond one thousand.
- **Around 185 entities** have cooperated with the Hydrogen Foundation in Aragon in the last four years, by being part of its Council, doing cooperation projects or actively participating in the Committees, Associations or Workgroups in which this Foundation takes part.
- The number of staff at the Hydrogen Foundation in Aragon has increased from 6 people working for the entity at the beginning of 2007 up to **18 professionals in 2010.**

Prior to this, an analysis on external information, the state of the art and the principal sector trends was carried out in order to evaluate the previously identified lines, giving response to the last indicator proposed on the degree of compliance of the previous Master Plan's strategic lines, to which a line-by-line appraisal of the chances and prospects has been added.

This way, we have the operating indicators from the previous Plan, three condition indicators (knowledge, validity and compliance) and a prediction indicator that are assessed by the participating entities in the review of the strategic lines by means of a capacity and interest survey, six thematic work-groups and several interviews with professional experts and research centres.

Firstly, a survey was sent to approximately 120 Aragonese entities from the areas of industry, consultancy, administration, university, training, etc., which were potentially linked to the sector of the hydrogen and fuel cells new technologies in order to evaluate the different lines defined in the Master Plan 2007-2010 and to obtain new proposals. A total of 52 valid answers were received.

In May 2010, 6 work groups were held, one for each thematic area contemplated in these technologies, and 70 experts from more than 45 different entities from the Autonomous Community took part in them.

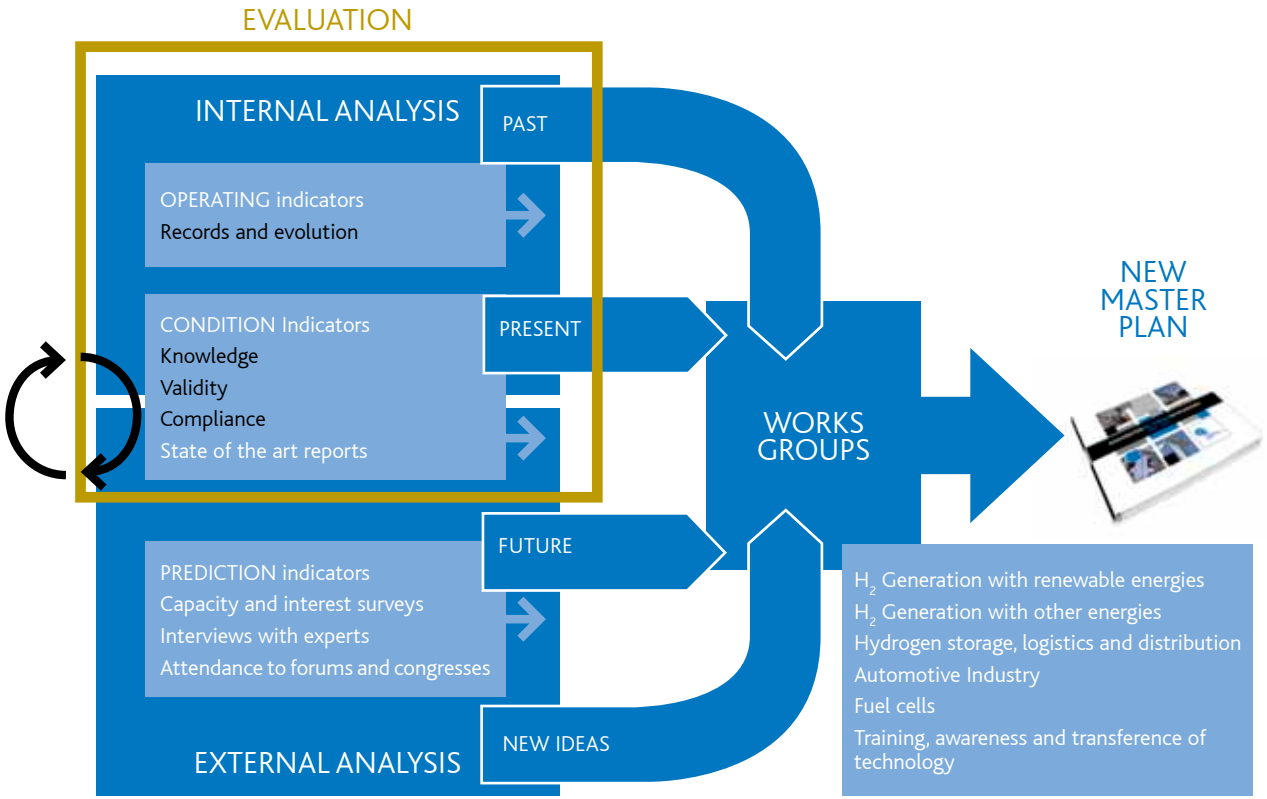
The contemplated theme areas are the following ones:

Theme area	Principal sectors involved
Hydrogen production / generation: renewable route.	Energy, Engineering, Components, Electronics, Chemistry, Research.
Hydrogen production / generation: non renewable route.	Energy, Engineering, Electronics, Chemistry, Research.
Storage, logistics and distribution.	Chemistry, Electronics, Logistics, Transport, Metal, Plastics, Components, Research.
Fuel cells: mobile applications.	Automotive, Transport, Components, Engineering, Research.
Fuel cells: stationary and portable applications.	Energy, Electronics, Components, Plastic, Metal, Real-Estate, Construction, Engineering, Chemistry, Research.
Common activities to all the areas	
Cross-cutting activities.	Training, Funding, Public Administration, Associations, Technological Parks, Research.

00. INTRODUCTION

Summarizing, the work methodology carried out to develop the evaluation of the previous Master Plan and to define the strategy to follow in its next review is shown in the following figure:

F.06 Work methodology.



With regards to the evaluation process obtained, such as the concrete products of the analysis, the following chapters are structured in a similar way to the previous Plan. There is a part related to the technical state of the art (from reports on technology watch, interviews, operating indicators, etc.), a thematic SWOT analysis, a conclusion summary and a few strategic lines derived from all the aforementioned in which the predicted horizon time for its development is detailed concerning the expectations shown in the previous Plan, in case it is not a new line. The lines that have been overcome are eliminated from the set and the timeframe is determined, taking into account the defined indicators, shown in the table on the right.

Meanwhile, a worldwide SWOT analysis has been carried out on the potentiality in these technologies of the Aragonese companies, as well as other 5 additional analyses, one for each one of the defined technical theme areas. This analysis is the one that has mainly served as the base for the strategy definition.

The capacity and potential analysis of the companies in general helps to define the cross-cutting support strategy (training, funding, contacts with other entities, etc.) and also in the search of new markets and actions of internationalization.

The thematic analyses help to specifically define the cooperation projects, which refer to precise developments in each one of the theme areas, valuing the strengths and opportunities and reducing the weaknesses and threats. Therefore, they show the principal cross-cutting activities that must be carried out.

The Plan strategy focuses on taking advantage of the existing strengths and opportunities so that developments and activities on a regional, national and international level can be carried out creating new markets.

On the other hand, this same strategy must reduce the threats and weaknesses, suggesting actions that even manage to turn themselves into opportunities. Thus, the barriers they are finding can be smoothed over and even eliminated.

TIME HORIZON	GRADO DE AVANCE
Without advance or expectations over the obtained.	⏮
Expectations are kept.	⏸
Advances are detected.	▶
Advances over expected.	⏭

To sum up, the most suitable strategy that derives from the analyses for this new Plan 2011-2015 is one that allows:

- To be based on the strong points of the sector and its setting.
- To overcome or to correct the weak points of the sector and its setting.
- To take advantage of detected opportunities.
- To counteract the found threats.

01.

GENERATION WITH RENEWABLE ENERGIES

01.
GENERATION WITH RENEWABLE ENERGIES

In November 2008, the International Energy Agency (IEA) presented the study "World Energy Outlook", where the energetic perspectives until the year 2030 were checked. In that study, it was emphasized that the current trends in energy supply and consumption are unsustainable, not only from an environmental point of view but also from an economic and social point of view, and that a change in the energetic model was necessary to guarantee a low CO_2 emission and reliable energy supply.

Pat the same time, the European Union set a political agenda with regards to energy called the "20-20-20" initiative, through which it promised to reduce greenhouse gases emission by 20%, manage to cover 20% of the energetic consumption with renewable energies, and an improvement in the energy efficiency of 20% by 2020.

Within this new energetic scene, hydrogen appears as a viable alternative to the current fossil fuels.

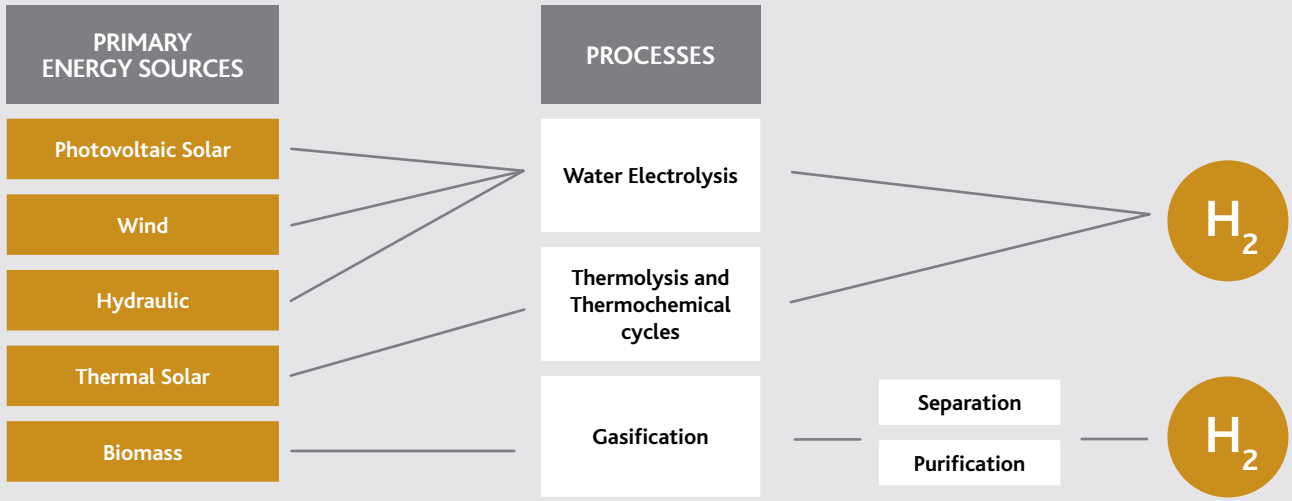
There are lots of hydrogen production methods, although nowadays the majority of it is obtained from fossil fuels (95%), where the production happens mainly from natural gas. Furthermore, there are electrolytic processes associated with the chlorine industry (4%), which have an incipient percentage of hydrogen produced by renewable energies, dedicated for energetic purposes.

An increasing interest exists worldwide in the subject matter of hydrogen production using renewable energy sources, especially by means of wind power in order to obtain a greater manageability, since it is the one that presents a higher level of penetration in the electrical sector and a higher level of maturity. This interest is expressed, among other initiatives, in the International Energy Agency group related to hydrogen and wind matters called Task 24 "Wind Energy and Hydrogen Integration". The Hydrogen Foundation in Aragon coordinates this, which experts from up to 14 different nationalities belong to, and where different aspects (technical, economic, legal and social) of the production and use of the hydrogen from wind origin.

01. GENERATION WITH RENEWABLE ENERGIES

The short-term expectations regarding hydrogen produced using renewable sources are changing, as recorded in the Multi-Annual Implementation Plan (2008-2013), drawn up by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) on a European level, where one of the aims for 2015 is having 20% of the hydrogen with energetic purposes produced from renewable sources.

F.07 Sources and processes to obtain hydrogen with renewable energy sources. Own production.



There are many hydrogen production methods using renewable energy sources, although they can be divided into three major groups:

- Water electrolysis, if only the origin of the electricity used is from renewable origin (wind, hydraulic, photovoltaic, etc).
- Medium and high temperature concentration systems (thermo-chemical cycles 400-2000 °C, and thermolysis, 2.400 °C).
- Biomass processing, mainly by performing a gasification process followed by a purification.

Alkaline electrolyser to pressure 32 bar, 3,5MW. Courtesy of IHT..

Amongst the processes listed above, the most developed now and the one with more future perspectives is the hydrogen production through water electrolysis, which basically uses renewable energy obtained from wind farms and hydraulic power stations.

Nowadays, the costs of photovoltaic electricity generation are much higher than those of energy from wind power, although these are decreasing quickly and they are expected to equal the cost of grid electricity during this decade. On the other hand, the solar concentrator technologies are basically being used for electricity production facilities by means of thermosolar plants (cylindrical-parabolic or power tower), but the practical application for hydrogen production is still being investigated and developed. The same thing is happening with production from biomass, whose content per mass unit in hydrogen is very low, which in the best cases is less than 7% (<7 %), and the purification and separation processes are still expensive and complicated, and that is why it is more appropriate a direct use as synthetic gas.

The nationwide interest in electrolysis is stated in the Priority Actions published by the Spanish Technology Platform for Hydrogen and Fuel cells (PTE HPC), where the line of design of electrolyzers for applications with renewable energies is identified as a priority, since this kind of technology does not currently exist on a national level.

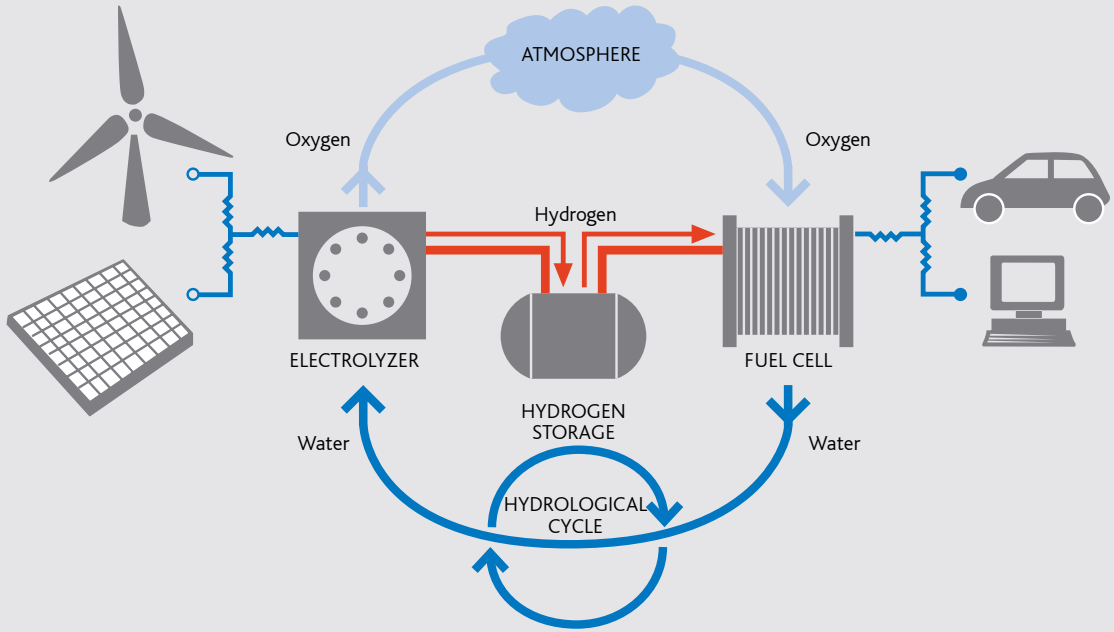
01. GENERATION WITH RENEWABLE ENERGIES

In application to renewable energy sources, and not to the industrial sector as it is the case of the chlor-alkali electrolysis, there are two commercial technologies worldwide which are classified depending on the type of electrolyte they use in the process. These types are:

- Polymer membrane electrolyzers that represent the advantage of high purity hydrogen production (99.9998 %). However, their range of use is reduced to only a few tens of kilowatts (0-60 kW), due to its high cost.

- Polymer membrane electrolyzers that represent the advantage of high purity hydrogen production (99.9998 %). However, their range of use is reduced to only a few tens of kilowatts (0-60 kW), due to its high cost.

F.08 Conceptual process of obtaining an energetic use of hydrogen. Own production.



There are many demonstrative projects about the subject matter of hydrogen production by means of renewable energies worldwide. Here, just three of them are going to be commented on, together with their principal conclusions:

- **Sotavento Project (Galicia, Spain).**
  Installation formed by a system of production (electrolyser of 300kW), storage (200 bar) and re-electrification (combustion engine of 55kW) using hydrogen as a system of energy storage. In this project, the technical viability of the use of hydrogen as an energy storage system has been demonstrated, but due to the low final performance of this system (<15 %), this option is not valid in comparison with other existing systems (pumpings, batteries, etc.)

- **Project promoted by Enertrag (Germany).**
  Installation formed by a wind farm of 6MW, a system of hydrogen production (electrolyser of 500kW), storage (30 bar) and subsequent restructuring with mixtures of biogas. In this project, the technical viability of the use of the hydrogen with biogas mixtures has been demonstrated, in

01. GENERATION WITH RENEWABLE ENERGIES

The ITHER project was awarded the National Industrial Engineering Prize in 2007 and in 2010 it was also named as the best demonstrative project.This last award of recognition was given by the "Hydrogen Implementing Agreement", a body of the International Energy Agency dedicated to the area of hydrogen.

order to take advantage of not only the electricity generated by some combustion engines, but also the heat energy from engines that creates a cogeneration

- **ITHER Project (PCT-A22266217-2005) "Technology Infrastructure for Hydrogen and Renewable Energies" (Huesca, Spain).**
  Project promoted by the Hydrogen Foundation in Aragon that consists of a renewable infrastructure based on a R&D 635kW wind farm and a 110kW photovoltaic installation with different technologies that are complemented by systems of production (70kW electrolyser), compression (350 bar) and hydrogen dispenser. Thanks to this project, the technical viability of the use of the renewable energy sources has been demonstrated, with the aim of using them in fuel production, as in the case of hydrogen which supplies vehicles with fuel cells.

Scheme of the ITHER project. Own production.

Hydrogen production plant from alkaline electrolysis. Hydrogen Foundation in Aragon – ITHER Project.

01. GENERATION WITH RENEWABLE ENERGIES

STRENGTHS

- Abundant renewable resources: sun, wind, water and territory.
- Region with surplus electrical renewable production.
- The Hydrogen Foundation in Aragon, as the driving force in hydrogen technologies in its region, has important energetic companies as part of its Council.
- Existence of pre-commercial demonstrative projects for the obtaining of hydrogen with renewable energy sources.
- Nowadays, the production of hydrogen as a regulator of the electrical system is a technically viable option on megawatt scales, which allows a distributed establishment without any geological requirements nor social or environmental impacts.

OPPORTUNITIES

- Saturation of electricity grid. Need for alternatives to release the renewable electrical energy generated by wind farms.
- Change in the Common Agricultural Policy (PAC) favouring energy crops from 2013.
- Existence of large irrigation areas with potential for energetic crop use.
- Use of the hydrogen generated from renewable sources as an energetic vector for the automotive industry, thus favouring the management of the electricity grid.

WEAKNESSES

- Ways of direct hydrogen production from renewable sources (photoelectrolysis, algae and microorganisms, thermolysis) are on basic research, still a long way off from the demonstrative phases on an industrial scale.
- The conversion of electricity into hydrogen involves higher energetic loss than other ways of energy storage.
- Electrical markets still do not need general energy storage due to the limited production of renewable electricity.
- The Spanish Special Regime is considering fuel cells but not the conversion of renewable electricity into hydrogen.

THREATS

- The possible evolution of the different energy storage technologies still gives a lot of leeway to choose the most appropriate ones for the electricity system.
- The regulation of the electrical sector can have an influence on the storage needs, on its remuneration within the system costs and even on the preference given to some technologies over others.

1. During the period of validity of the previous Plan, particular guidelines, such as the start-up of **demonstrative projects related to hydrogen with renewable energy sources,** the ITHER Project, or a consistent base of knowledge about the renewable resources present in the region, have been fulfilled.

2. In the renewable sector, a **dependence on institutional support** as the main determinant for its use with the new hydrogen technologies has been observed. These have to be understood as a global solution in the **renewable energy management.**

3. The real, consolidated and visible capacities from the business network, the research groups, the infrastructure and the Aragonese environment for the **development of green hydrogen** have been provided.

4. Existence of **clear introduction opportunities together with a business interest in its development,** which must lead to the **start-up of demonstrative projects** on an industrial scale

5. It is necessary to continue developing **new materials** as well as **improving processes,** especially the electrolysis in order to make **distributed generation models** real, and the **exploitation of the already built** facilities through the diversification and increase of production hours.

6. It is necessary **to improve the generation processes from biomass,** as well as making the most of this type of resources in the region in order **to integrate them into the production of hydrogen** in the cases where it would be beneficial.

01.
GENERATION WITH RENEWABLE ENERGIES

INDUSTRIAL ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Specific implication of wind farm promoters and operating companies by means of the definition of demonstrative projects as a previous step for the commercialization.	MEDIUM TERM	▶
Improvement of thermolysis-based hydrogen production processes using solar furnace technologies.	LONG TERM	⏮
Improvement of hydrocarbon catalytic decomposition processes using solar furnace technologies.	LONG TERM	⏮
R&D development and integration of electrolysis processes in the Aragonese industry.	MEDIUM TERM	

RESEARCH ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Research on generation technologies and improvement of biomass exploitation processes.	MEDIUM TERM	⏸
In-depth study of the hydrogen production through current wind farms and the forecast for future ones.	SHORT TERM	▶
Actions to propose a special regime for hydrogen production by means of renewable energy sources.	LONG TERM	⏸
Research on new materials for electrolyser stacks.	MEDIUM TERM	

SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Integration of hydrogen and renewable energies in the rural environment to get the participation of sectors such as agriculture and livestock.	MEDIUM TERM	
Technologists training in hydrogen production from renewable energy sources using the facilities of The Hydrogen Foundation in Aragon.	MEDIUM TERM	

02.


GENERATION
WITH OTHER ENERGIES

02.
GENERATION WITH OTHER ENERGIES

Despite the fact that hydrogen production with renewable energy sources as an energetic vector in the future and an environmentally sustainable element is currently being studied, the current reality shows that most of the hydrogen which is generated is still obtained from fossil fuels (95%), amongst which the hydrogen production from natural gas stands out against the production generated from oil or coal.

Nowadays, another important source of hydrogen from non-renewable energy sources is the hydrogen which is obtained as a byproduct in chemical plants for the production of chlorine in chlor - alkali plants. This hydrogen is normally used as a reactant in the synthesis of ammonia, hydrochloric acid and other compounds. It is also possible to use it in cogeneration systems for the production of electricity and heat.

Steam reforming, partial oxidation and gasification are the principal hydrogen production methods using natural gas, hydrocarbons and coal respectively. More innovative methods in comparison to the previous ones are currently being studied, for example, reforming using plasma at high temperatures of up to 1,600°C, catalytic decomposition, thermolysis and natural gas decomposition to obtain hydrogen through an electric arc.

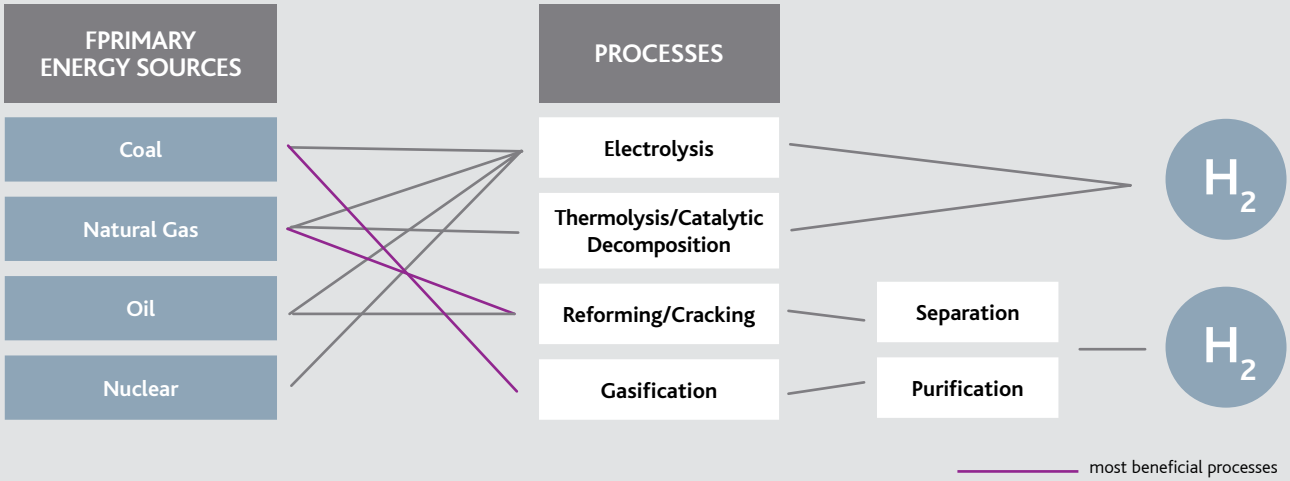
Hydrogen production from non-renewable sources by means of electrolysis would follow the same basic principle as the renewable method, that is, the dissociation of water in hydrogen and oxygen via the contribution of a direct electric current, but in the case of non-renewable sources, the electricity is generated using fossil fuels or nuclear power.

Hydrogen production using non-renewable energy sources will be necessary for its introduction as an energetic vector in the future, favouring the creation of a market in this intermediate stage. Therefore, the advances in hydrogen generation methods through non-renewable sources will be crucial to get a system which is energetically independent and emission-free.

In the medium and short term, hydrogen production will continue using fossil fuels, mainly from natural gas reforming as this is the current method. The peak of natural gas production, in the near future, and the possible advances and cost reduction that the gasification of coal with the capture and storage of CO_2, a much more environmentally-friendly technology, might represent will be the trend for hydrogen production in the medium-term.

02. GENERATION WITH OTHER ENERGIES

F.09 Sources and processes to obtain hydrogen with traditional energies. Own elaboration.



We cannot forget about the electrolysis technology from nuclear power as a medium-term source of production, where the development of high power and robust electrolyzers and their integration in nuclear power stations might favour the manageability of nuclear power, showing the energy consumed in the electrolysis for hydrogen production as an alternative to maintaining a continuous load in the reactors, making it possible to vary the energy running on the grid, depending on the demand.

In the medium term, the hydrogen and electricity grid will begin to be managed in a distributed way, taking advantage of the trend of the electricity sector to move towards the generation based on renewable energy sources. In any case, this variation in the current electrical system from centralized systems to distributed electrical systems will take place gradually, thus maintaining the current fossil fuel generation plants for to medium term. This same transition will be necessary for the hydrogen sector, which will change from being produced in a centralized way by means of natural gas reforming and coal gasification to being produced in a distributed way by means of the electrolysis of renewable energy sources in the long term.

The main current demonstrative projects on hydrogen production with traditional fuels are focused on coal gasification technology using the capture and storage of CO_2, such as the **Peterhead Power Station** project in Scotland, the **FUTUREGEN** project in the United States, Carson Hydrogen Power Project or the **Kwinana** project in Australia, the first one in storing CO_2 in saline formations. In addition, two national projects on hydrogen production from traditional fuels must be highlighted. Firstly, the **CENIT SPHERA** project is a project on hydrogen production through natural gas

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

catalytic decomposition, in whose process, apart from producing hydrogen, high added value coal for different industrial applications is generated. Different companies are participating in this project, such as Gas Natural and various Aragonese research institutes, such as the Carbochemistry Institute from the National Research Council, CSIC, and the Aragón Institute of Engineering Research (I3A) from the University of Zaragoza. On the other hand, it is also necessary to draw attention to the Singular Strategic Project **(PSE) - CO_2,** which is being carried out by ELCOGAS S.A., on the production of hydrogen using coal gasification through the capture of CO_2.

In July 2010, a further step was taken when the energy company Enel became the first company in the world to start a hydrogen combined cycle plant. The facility, which is located in Fusina (Venice, Italy), consumes 1.3 tons of hydrogen per hour which are received from the petrochemical park in Porto Marghera, which is very close by. The plant, that has a power of 16 megawatts, includes a combined cycle of 12MW fed by hydrogen capable of generating energy and heat simultaneously for 22,000 homes per year, reducing by more than 17,000 tons the emissions of CO_2 into the atmosphere.

On the other hand, the projects that are being presented worldwide on electricity generation using the capture and storage of CO_2 on a commercial scale (250-1200 MW) and in the short term (2010-2015) are based on capture during the precombustion process. The majority use coal or coke gasification technology and the rest use natural gas reforming. In all the cases, it is integrated into a combined cycle.

On the national level, Endesa in Compostilla II plant and the previously mentioned ELCOGAS S.A in the Integrated Gasification in Combined Cycle (IGCC) plant – pressurized entrained-flow gasification - in Puertollano (Ciudad Real) work on CO_2 capture technology. The latter, with a production of 335 MW and a pilot plant of 14 MWt (nowadays in test period) of H_2 and electricity production of H_2, is to be integrated in the existing IGCC plant. The high efficiency of this installation (42,2%) significantly reduces hydrogen production costs.

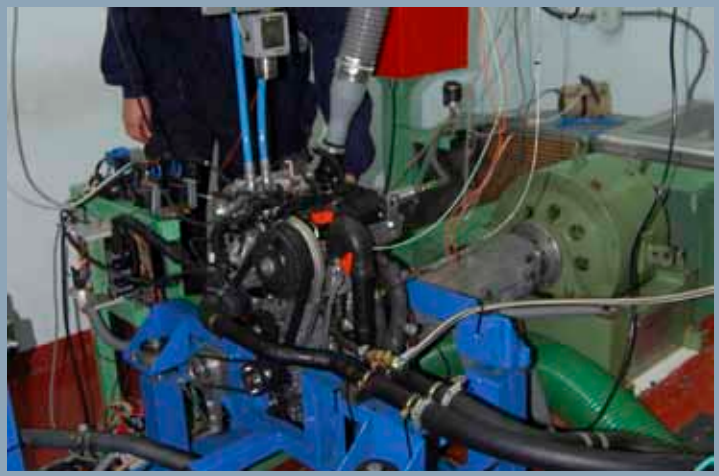
With regards to the Autonomous Community of Aragon, there are not any important facilities or demonstrative projects on energy generation based on hydrogen production with non-renewable sources at the moment. However, there is a significant research activity related to the development of projects on the starting up and optimization of hydrogen production processes from different fossil fuels in the Carbochemistry Institute from CSIC and in the Aragón Institute of Engineering Research (I3A) from the University of Zaragoza..

02. GENERATION WITH OTHER ENERGIES

Some relevant projects carried out in the last few years in the region are detailed below:

NATURAL GAS CATALYTIC DECOMPOSITION: INTEGRATED PROCESS OF PRODUCTION OF MIXTURES FOR ALTERNATIVE INTERNAL COMBUSTION ENGINES AND COAL MATERIALS FOR ENERGETIC APPLICATIONS (ENE2008-06516-CO3-01).

The entities participating in this are the Carbochemistry Institute (ICB-CSIC), the National Coal Institute (INCAR-CSIC) and the University of Zaragoza (Engine Laboratory, Department of Mechanical Engineering). The project studies the catalytic decarbonization of natural gas for the production of high added value carbon nanofibers with a gas fraction formed by hydrogen and unconverted natural gas that can be separated to produce pure hydrogen or be used directly in an internal combustion engine, which is modified for the use of hydrogen and methane mixtures of suitable compositions.

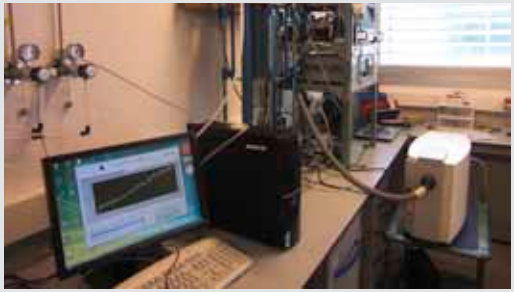


Test bench for hydrogen engines fed with hydrogen and natural gas mixtures. Courtesy of the University of Zaragoza (Engine Laboratory, Department of Mechanical Engineering).

Plant for pilot scale hydrogen production from methane decomposition. Courtesy of the Carbochemistry Institute (ICB - CSIC).

CENIT SPHERA PROJECT "SOLUTIONS TO THE POWER HYDROGEN PRODUCTION AND ASSOCIATE RECONVERSION", 2007 - 2010.

This project aims to develop a sustainable process for hydrogen and commercial valued coal production by means of natural gas thermocatalytic decomposition, TCD, in an air and water free environment in order to reduce carbon monoxide emission. The whole action has been divided into two actions for its execution: Action I involves TCD processes and catalyst regeneration; and Action II deals with methane-hydrogen mixtures separation by means of redox cycles with metal oxides based on iron oxides. The first one had been carried out in the Carbochemistry Institute and the second one in the Aragón Institute of Engineering Research (I3A) from the University of Zaragoza.



Pilot plant for hydrogen production from natural gas catalytic decomposition. Courtesy of the I3A from the University of Zaragoza.

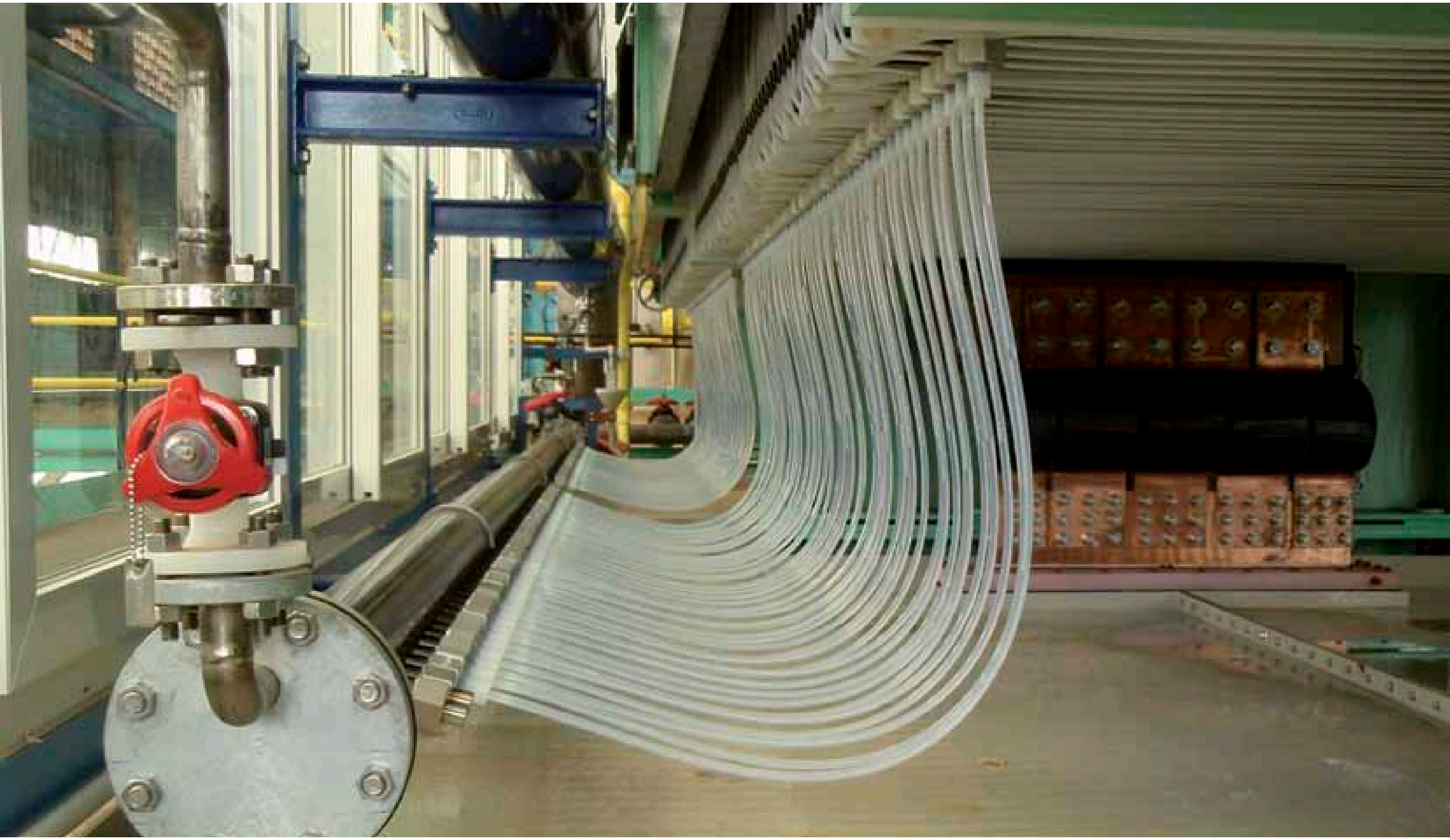
02. GENERATION WITH OTHER ENERGIES

In addition, with regards to the capacities and resources in Aragon for hydrogen production using fossil fuels, it is necessary to highlight the coal resources of the Region. These are lignite-rich, principally in the province of Teruel, where the mining industry sector is important and the introduction of coal gasification plants with hydrogen production and capture and storage of CO_2 would in the future reactivate a mining sector that has suffered a notable decrease in the number of employees in the last number of years. Aragon is also well positioned in the national gas pipeline network, linking the Mediterranean area to the Cantabrian area, and with access to natural gas resources for the obtaining of hydrogen via reforming.

CIRCE Foundation currently coordinates the Spanish CO_2 Platform and International Innovation Unit CO_2, which supposes a relevant strength in this activity for the region.

On the other hand, the chemical plants with chlor-alkali electrolytic technology in the region can provide large quantity of high-quality electrolytic hydrogen, which is a surplus of its productive processes and which might be used for several applications of an energetic nature.

Chlorine production plant with hydrogen generation as by-product. Courtesy of Química del Cinca.


Detail of Ercros plant in Sabiñánigo. Electrolytic hydrogen generation as by-product of the chlor-alkali production process.

02. GENERATION WITH OTHER ENERGIES

STRENGTHS

- Electricity exporting region.
- Existence of strategic coal reserve.
- Existence of saline formations to store CO_2 (and, possibly, hydrogen).
- Existence of saline formations to store CO_2 (and, possibly, hydrogen).
- Cutting-edge research groups in the clean use of coal and in production of electricity, such as CIRCE, that also coordinates the International Innovation Unit CO_2 and the Spanish CO_2 Technology Platform.

OPPORTUNITIES

- Possibility to locate demonstration facilities thanks to the capacities and resources for hydrogen production from fossil fuels in Aragon.
- Possibility to create a line of research that integrates coal and urban solid waste gasification and their use in SOFC.
- Clean use of coal technologies already tested on an industrial scale that might widen the regional coal opportunities.
- Better costs of short-term hydrogen production from non-renewable processes in comparison with RES processes.

WEAKNESSES

- The hydrogen produced nowadays in the reforming and chlor-alkali electrolysis facilities already has a profitable enough non energetic market, that does not motivate an energetic use.
- Low coal quality in Spain.
- Absence of technologists and equipment manufacturers for gasification or reforming.
- CO_2 free hydrogen production from fossil fuels requires to make the facilities more complicated with increased costs for the facilities, such as the cleaning and separation of gases and the capture and storage of CO_2.
- Large investment in studies to locate geological storages.

THREATS

- Social and environmental rejection of hydrogen production from fossil fuel sources.
- Electricity power stations may not see any profitability in hydrogen production until there are technical restrictions on electricity production and an established hydrogen energy market.
- The generalization of gasification power stations might not guarantee the interest of these particular ones to be hydrogen producers and it will depend on the same factors as those for the conventional stations.

1. **Strategic advantages related to territory, research groups and current knowledge networks** have been detected that must be taken advantage of through the development of **gasification, separation and purification technologies.**

2. It is necessary to work on the **transfer of knowledge for the application of these technologies in the industry.**

3. Nowadays, the major acceptance of hydrogen production with renewable energy sources for energetic uses displaces the industrial hydrogen obtained as a by-product. This situation must be interpreted as an opportunity to start up **projects which make the activity of these industrial network sectors more diverse and flexible, possibly resulting in new business and knowledge lines.**

4. **Available natural resources** must be used for the **production and management of new clean production processes,** taking into account the CO_2 capture technologies.

Gasification plant. Courtesy of TAIM WESER.

02.
GENERATION WITH OTHER ENERGIES

INDUSTRIAL ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Development of own technologies in processes of hydrogen gasification, separation and purification from the coal sector, using regional coal for hydrogen production.	LONG TERM	⏸
Implementation of results in the industrial sector of gasification, reforming or natural gas/LPG catalytic decomposition research.	MEDIUM TERM	▶

Pilot plant for catalytic decomposition in continuous operation. Courtesy of the Group of Fuel Conversion, Carbochemistry Institute (CSIC).

RESEARCH ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Development of technology and methods to obtain hydrogen from traditional fuels with capture of CO_2 with limestone.	MEDIUM TERM	II
Development of thermochemical cycles (REDOX) to obtain hydrogen at low temperatures.	LONG TERM	

SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Motivation for the development of CO_2 storage in the territory.	LONG TERM	II

03.

STORAGE, LOGISTICS AND DISTRIBUTION

03.
STORAGE, LOGISTICS AND DISTRIBUTION

The best characteristic of hydrogen is its heating power per unit of weight, which is much greater than other traditional fuels. Nevertheless, due to its low density, its heating power per unit of volume is very low.

This fact implies physical and, above all, economic difficulties in its storage. On the one hand, it is necessary to increase its energetic density per unit of volume in order to be able to offer, for example in the transport sector, the same ranges that traditional fuels offer. On the other hand, it is also necessary to increase this value to reach acceptable final transport and distribution costs of hydrogen.

To increase its energetic density per unit of volume, hydrogen is usually stored as a compressed gas, cryogenic liquid or solid, in metal hydrides or in other new materials that still are being researched.

SYSTEMS OF STORAGE. STATE OF THE ART

Compressed gas hydrogen needs high pressures – at this moment, (year 2010) at 200 bars for the distribution sector and at 350 bars in the automotive sector. However, in the last few years, there has been a great evolution, safely increasing these pressures up to 700 bars in the automotive sector. This way of storing hydrogen has a low energetic cost and it is a very mature technology, but these systems are very heavy due to the high pressure they support, being now around 4% of storage per unit of mass (4kg of hydrogen per 100kg of the whole container).

Hydrogen storage tank developed by the company Lapesa, that is part of the hydrogen service station installed in Walqa Technology Park.

03. STORAGE, LOGISTICS AND DISTRIBUTION

The state of the art related to cryogenic liquid hydrogen (20 K) is based on double-layer storage systems, in some cases even with liquid nitrogen insulation.

This technology of storage represents a higher energetic cost associated with the liquefying process, but it gets 9% of storage per unit of mass. This technology has evolved towards lighter systems with fewer losses due to evaporation. A new concept has been introduced, the cryo-compressed systems, that combine cryogenic temperatures around 170K and pressure obtaining similar densities to the systems of compressed liquid, but more energy efficient

The most conventional method of solid hydrogen storage is via the formation of metal hydrides, specifically the ones made from lanthanum and nickel. Nevertheless, the main bid is for the hydrides made from sodium, aluminium and magnesium because they are very light and their storage per unit of mass is higher than 15%.

In the field of solid hydrogen storage, the Hydrogen Foundation in Aragon has carried out the **HIDROMED** project (IAP-560410-2008-30) between 2008 and 2010, which deals with the development of a test bench that allows the acquisition of information related to the different characteristics needed for the study of metal hydrides hydrogen storage tanks.

The objective set by the DOE (Department of Energy of the United States) for 2010 is to have 6% in hydrogen mass as compressed gas in storage systems in order to be able to store 4kg of hydrogen (which represents a range of approximately 400km in a vehicle) in a volume of 89L and 67kg as the total weight of the system. This aim was revised in 2009 according to the efficiency of the hydrogen-based systems and it was determined that the final target to be reached had to be increased up to 7.5% of density in mass.

Test bench for research on metal hydrides storage systems. Hydrogen Foundation in Aragon.

On an European level, the Multi-Annual Implementation Plan of the FCH JU sets as target to be reached of 9 % of hydrogen mass in the compressed gas hydrogen storage systems by 2015.

In order to meet all these targets, the main research and development lines need the use of new materials, such as carbon fibre compound materials, which allow lighter and safer systems with greater capacity to bear extreme pressures and temperatures to be produced.

Dispenser of the HRS in Walqa TP.

HYDROGEN REFUELING STATIONS AND HYDROGEN HIGHWAY NETWORKS

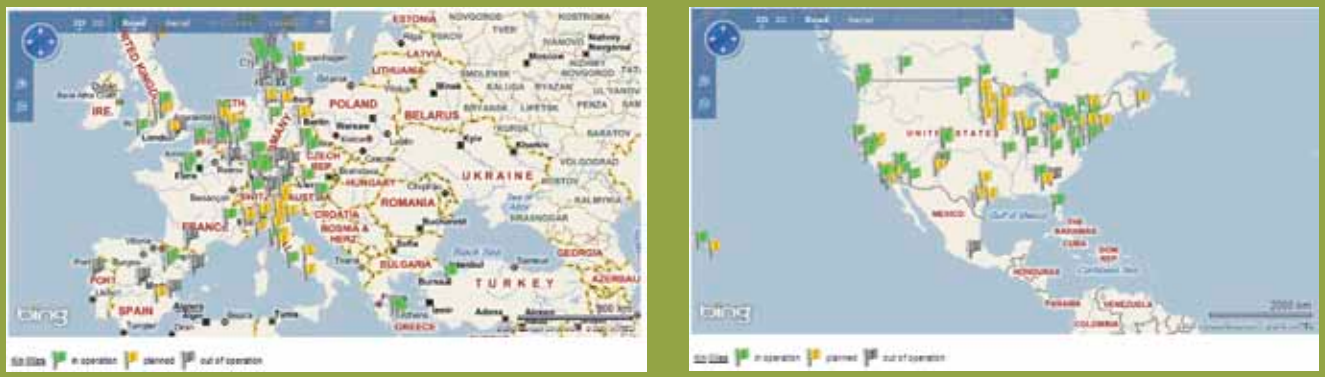
Nowadays, hydrogen production, logistics and distribution are carried out by the large industrial gas companies. The distribution is performed via compressed gas at 200 bar in steel cylinders. The short-term aim is to safely increase the gas pressure in order to reduce the size and also the weight of the bottles by using composite materials.

The distribution by semi-trailers with cylinders to 200 bars, with a capacity of around 300kg of hydrogen is the most appropriate for the low demands that currently exist and are going to continue to exist in the short term. When there is an increase in demand, a channelled gas and hydrogen production plants network will be needed, distributed according to the demands in the points of consumption.

In this respect, some projects have been launched in Europe, such as the **NATURALHY** (finished in November 2009) whose aim was to carry out research on hydrogen distribution through the existing natural gas pipeline grid, having obtained positive results to be able to carry out this type of initiative with concentrations of around 20% hydrogen mass. Therefore, the injection of hydrogen in the natural gas network can be an alternative to manage and to transport this fuel. In Aragon, this alternative can be of particular importance in the future, since within this region, wind power production areas, from which hydrogen generation plants could be established, and the existing natural gas transport network geographically coexist.

03. STORAGE, LOGISTICS AND DISTRIBUTION

On the other hand, a hydrogen supply infrastructure network for the automotive sector is starting to be created, with the European Union, the United States and Japan as the most determined bidders. The short-term aim is that, thanks to demonstrative projects with public support, the basic infrastructure will be developed to introduce this technology onto the market and so that the general public familiarizes themselves with it, getting used to seeing hydrogen powered vehicles, silent and environmentally friendly, all through city streets.



Hydrogen refuelling stations (HRS) network in Europe, the United States and East Asia. Courtesy of H2stations.org of LBST.

With regards to European nations, the initiatives of Germany and Norway are outstanding. In Germany, within its own development of new hydrogen technologies plan and after the agreement among the principal national companies, a hydrogen refuelling stations network is going to be created, which allows its main cities to be linked by the year 2015, thus creating a hydrogen highway grid in the country. This is similar to the aim set by Norway and which will be concluded in the year 2015 following the connection with Denmark..

'Memorandum of Understanding' presentation by the principal German gas companies and car manufacturers for the creation of a national hydrogen refuelling station network. Berlin, September, 2009.

Hydrogen refuelling station network in the south of Scandinavia. HYNOR Project. Courtesy of www.hynor.no

03. STORAGE, LOGISTICS AND DISTRIBUTION

THE FIRST SPANISH HYDROGEN HIGHWAY

Following these strong European initiatives, within the field of the International Exhibition Zaragoza Expo 2008 and its commitment with the environment, the first Spanish public hydrogen refuelling station was started up in Valdespartera eco-neighbourhood in order to feed 4 buses providing a shuttle service to the entrances of the exhibition. In June 2010, the second one was started up in Huesca, in Walqa Technology Park, the headquarters of the Hydrogen Foundation in Aragon. Together, they mean the first Spanish hydrogen highway (89.6 km) whose inaugural tour was carried out by an Opel HydroGen4.

His Excell. Arturo Aliaga López refuelling the model Opel HydroGen4 during the service station inauguration in Walqa Technology Park on June 22nd, 2010. The Hydrogen Foundation in Aragon.

Both facilities are similar. Hydrogen generation is carried out in situ by means of water electrolysis process reaching a capacity of production of approximately 10 Nm3 H_2/h with an electrical consumption of 70kW. The facilities have also a compression unit of up to 350 bar, high pressure storage systems and dispenser at 200 and 350 bar that can be used by cars as well as by buses.

F.10 Scheme of the hydrogen refuelling station in Walqa Technological Park. Own production.

The service station in Zaragoza has maintained appropriate operating conditions, without suffering notable inactivity periods due to problems in the operation of the equipments or their maintenance. In addition, the vehicle refuelling has been done satisfactorily in all the cases and always in line with the necessary safety measures.

Hydrogen refuelling station installed in Valdespartera neighbourhood in Zaragoza. Courtesy of EXPO Empresarial Zaragoza.

As for the hydrogen supply station in Walqa Technology Park, the principal technical advance of this installation is the hydrogen production process by means of energy generated from the wind and photovoltaic farm settled in this business complex, obtaining, in this way, hydrogen fuel from renewable origins.

Finally, there is one outstanding initiative more with a strong activity in the Autonomous Community and which is related to refuelling hydrogen infrastructures and sustainable transport. It is the CENIT ECOTRANS Project: ecological technologies for the urban transport. The aim of this project is to study new efficient exploitation strategies for the urban transport services taking advantage of the whole potential of the hydrogen technologies. The project is led by CAF, Construcciones y Auxiliar de Ferrocarriles S.A., along with the participation of the company IDOM - Zaragoza, the Engineering and Transport Infrastructure Area from the Department of Mechanical Engineering of the University of Zaragoza and the Hydrogen Foundation in Aragon.

During the three months of EXPO Zaragoza 2008, the fleet of vehicles completed a total of 10,000km and transported 60,000 passengers.

03. STORAGE, LOGISTICS AND DISTRIBUTION

STRENGTHS

- Favourable geo-strategic location of Aragon for the hydrogen mass storage, distribution and logistics.
- Starting-up and exploitation of a hydrogen refuelling station in Expo Zaragoza 2008 and of a second one in Walqa Technology Park.
- Industrial development in the storage of pressurised gas, including hydrogen and experience in gas distribution.
- Good positioning in complementary technologies: test benches, logistics, ICTs, etc.

OPPORTUNITIES

- Business opportunities in fields such as development of materials for tanks, different components and high pressure work.
- Synergies with other fields, for example, natural gas mixtures for automotive and other uses. New markets for gas companies in the medium and long term.
- Possibility of hydrogen incorporation to service stations that have already shown their interest and that they are well distributed throughout the territory.

WEAKNESSES

- Absence of global plans for the development of hydrogen storage and distribution infrastructures that cover the national territory and its connection with Europe.
- There is no infrastructure or experience in liquid hydrogen.
- General ignorance in hydrogen manipulation.

THREATS

- The regulatory framework in the hydrogen storage and refuelling facilities, and the qualifications that the staff involved must have, must adapt to these innovative technologies to avoid a delay in the deployment of these infrastructures.
- A limited use of the available infrastructures can reduce the impact that might be achieved by the investments made.
- The development of the necessary infrastructure (hydrogen refuelling stations) is conditional on the manufacturers commitment to have hydrogen vehicles available.

1. Currently, there is a general lack of infrastructure that slows down the starting-up of a global bet for the hydrogen. From Aragon, it is possible **to show the infrastructure and the knowledge developed to provoke steps that make it possible to bring together the development of distribution and demand simultaneously.**

2. It has been verified that the companies of the component sector have carried out interesting developments in the matter and **that nowadays they are in the stage of product industrialization.**

3. **The geostrategic location** of Aragon for the logistics, together with its **vocation as grid centre in the hydrogen implementation roadmaps,** must be consolidated through the cooperation between the clusters and the technology centres.

4. Given the capacities and experience of the industrial network in gas storage and distribution, the importance of the **adaptation of the positioning obtained in complementary technologies** (test and component bench development, research on associate logistics, etc.) **to approach an industrial restructuring towards the new hydrogen technologies must be stressed.**

5. **The research lines related to hydrogen and natural gas mixtures and the development of materials** for storage and distribution must be maintained and even improved.

03. STORAGE, LOGISTICS AND DISTRIBUTION

INDUSTRIAL ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Direct application and interest of the Aragonese sectors of valves, regulators, connectors, etc. in the development of tanks and auxiliary components of H_2.	IN PROGRESS	▶
Implementation of storage systems at pressures of more than 350 bar with new composite materials.	LONG/MEDIUM TERM	⏸
Development of new hydrogen refuelling stations using the communication axes of the region.	MEDIUM TERM	▶▶
Use of the existing natural gas network as hydrogen distribution infrastructure.	LONG TERM	⏸
Development of work lines for the storage of H_2 produced by RES, especially from wind energy, in uses different from the automotive, for example, for domestic uses.	LONG/MEDIUM TERM	

RESEARCH ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Development of new materials for storage and distribution of gas and liquid hydrogen. Cheapening of production costs.	MEDIUM TERM	⏮
Development of new materials for storage and distribution of solid hydrogen.	MEDIUM TERM	⏸
Research on the behaviour of hydrogen when mixed with natural gas and also on the materials used for its storage and distribution.	MEDIUM TERM	▶

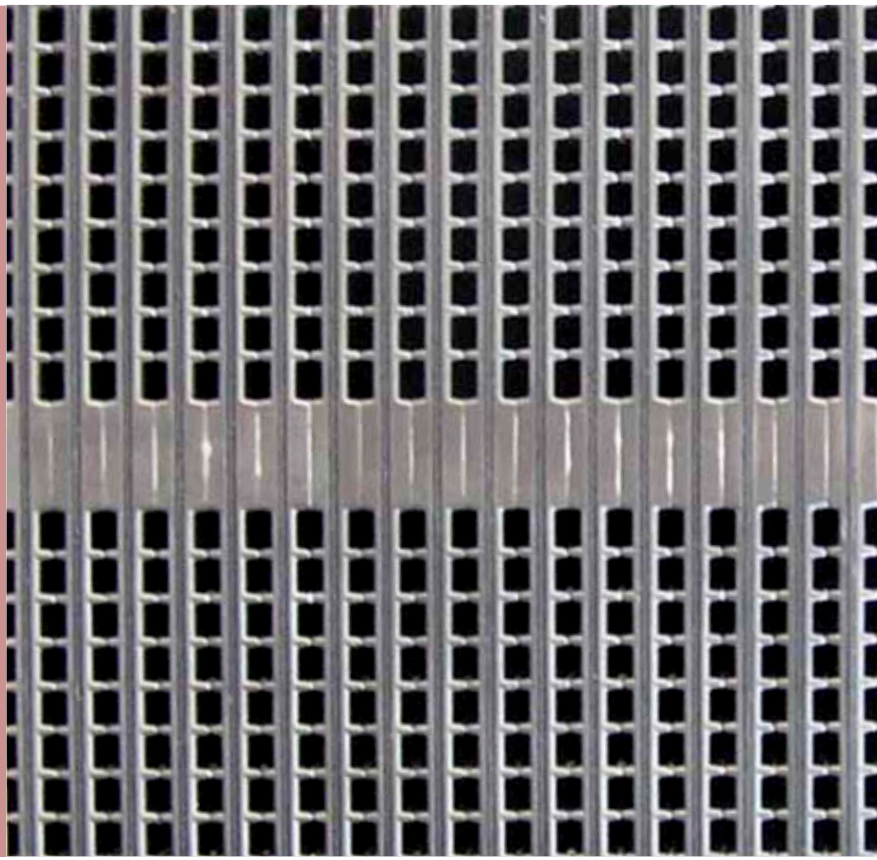
SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Development of national hydrogen logistics plans considering Aragon as a network centre.	SHORT TERM	⏭
Specialized staff training in related technologies (hydrogen manipulation, facilities maintenance, projects, authorizations, etc.)	LONG/MEDIUM TERM	

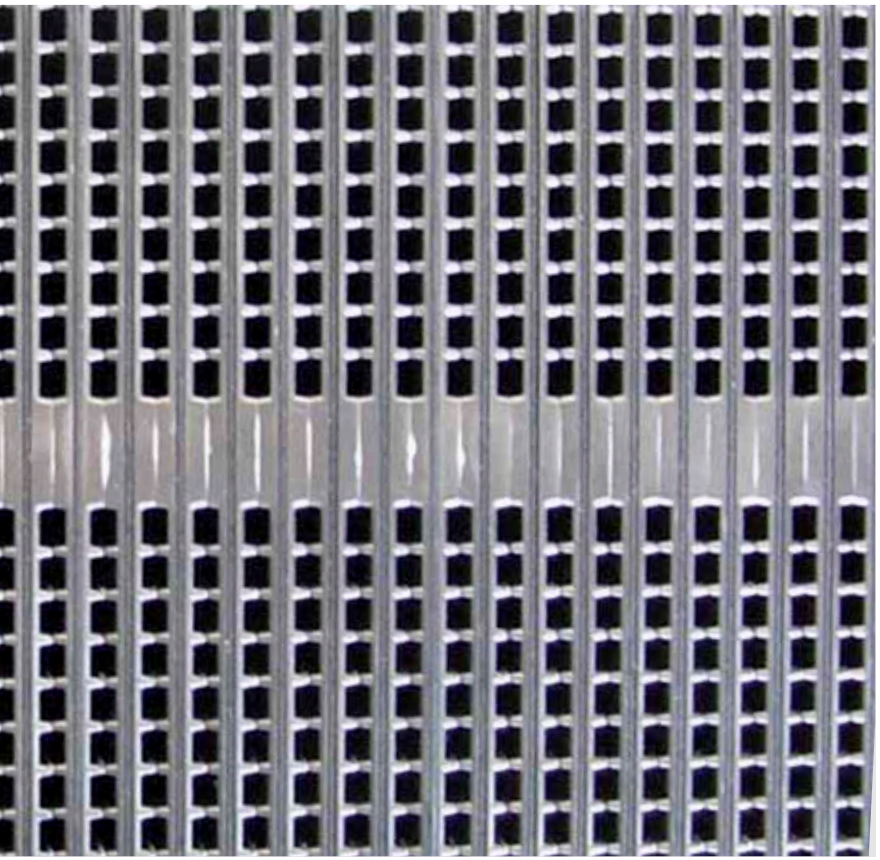
04.

FUEL CELLS

04.
FUEL CELLS

Fuel cells have many characteristics that make them suitable as energy conversion devices, for example, their relatively high efficiency and low environmental impact practically without gas emission or solid particles. In addition, they are able to be adapted to a wide range of uses and powers, from small portable applications to big cogeneration and trigeneration stations, including all kinds of mobile applications.





There is a variety of fuel cells which are in different stages of development. From the numerous types of fuel cells that currently exist, the polymeric fuel cells (PEMFC) are the ones which, due to their simplicity and low operating temperature, around 100°C, the majority of developments are focusing on. As for the high temperature fuel cells, the solid oxide fuel cells (SOFC) are the ones that are reaching a higher technological degree with electrical efficiencies of around 50%, and they could even reach a performance rate of 80% if the residual heat is used for cogeneration.

On the national level, the fuel cell activity is also focused on these two technologies, as it was shown in the last National Congress on Fuel Cells held in Seville in June 2010, CONAPPICE 2010, in which about 80% of the published research articles referred to both types.

Likewise, the development of other types of fuel cell is maintained, for example, alkaline fuel cells (AFC), molten carbonate fuel cells (MCFC), phosphoric acid fuel cells (PAFC) or direct methanol fuel cells (DMFC).

04. FUEL CELLS

POLYMERIC FUEL CELLS

As it has been commented previously, PEM cells offer unique advantages in terms of high efficiency, high energetic density and zero pollution emissions and they continue operating for as long as fuel is provided. Nevertheless, it is necessary to emphasize the fact that the cost and the duration are still two important disadvantages for mass production and its subsequent commercialization.

Certain components make this technology excessively expensive, for example, the catalysts, which are made of platinum particles. The problem is that platinum is a precious metal with very low natural occurrence (only around 150 Tm are extracted annually) and, therefore, it is very expensive. By doing a breakdown of the costs of the stacks (main part of the cell where electrochemical reaction takes place), the precious metals of the PEM catalysts represent approximately 55% of the total cost, which is much higher than the cost of any other component such as the bipolar plate (10%), the gas diffusion layer (10%) or the polymeric membrane (7%). (J.L.G. Fierro - Institute of Catalysis and Petroleum Chemistry CSIC, 2009)

On the other hand, a basic problem of this type of fuel cells is the lack of globally optimized elements in its BOP (Balance sheet of Plant), because, at this moment, this BOP is formed from commercial components designed for other applications that are not necessarily fuel cells. In this sense, it is very relevant because practically half of the cost of a cell is based on the components that form the BOP, with much smaller margin of cost reduction than the stack for industrialization (mass production), but with considerable margin for redesign and optimization.

The first fuel cell (PEM type) mass produced by Ballard Systems which is part of the equipments of the Hydrogen Foundation in Aragon.

Current research projects are focusing on the development of new catalysts with lower level of precious metals, replacing platinum with other compounds in order to reduce costs and, at the same time, increase performance.

They are also focusing on the development of membranes that would allow the temperature of operation to be raised from the current range of 50-80°C to 150-200°C, improving the performance of the electrochemical reactions in the fuel cell, increasing the tolerance to CO presence in the hydrogen flow, simplifying water and heat management and increasing the kinetics of their reactions. The reason why we are currently working at the lower temperatures is because the material with the best properties for its use in membranes in PEM is Nafion, which starts to decompose at 80°C due to the low presence of water at these temperatures.

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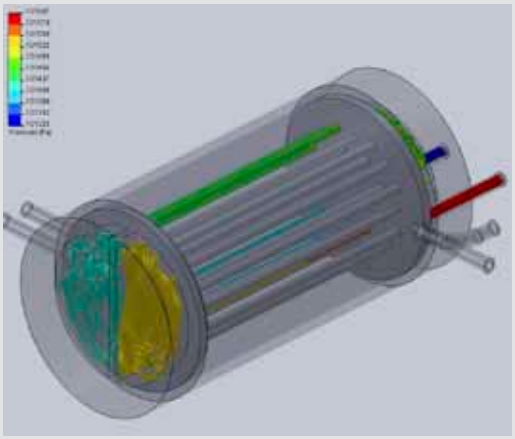
FUEL CELLS

F.11 Fluid dynamic simulation of hydrogen flow inside a SOFC. Own production



SOLID OXIDE FUEL CELLS

In SOFC, since the electrolyte is solid, the cell can have diverse shapes, like tubular or flat. The construction of the cell with solid ceramics eliminates corrosion problems of liquid electrolyte cells (as ones caused by the alkaline, molten carbonate or phosphoric acid), and it has the advantage of preventing the direct gas flow from one electrode to another. The absence of liquid also eliminates the problem of electrolyte movement or a possible flood in the electrodes. Cell kinetics are fast, and CO is a fuel that can be used directly.

At the current temperature of SOFC (900°C), fuel can reform inside the cell, producing electricity and using the heat generated.

Precisely, the University of Zaragoza has one of the few groups in Spain that researches on ceramic and high temperature electrolyser fuel cells for hydrogen production. The group belongs to the Material Science Institute of Aragon, Mixed Institute University of Zaragoza-CSIC, which is directed by Dr. Víctor Orera. The group collaborates with big companies and research centres in the areas of fuel cells and hydrogen production. The manufacture of tubular micro-cells with LSM-YSZ anode, zirconia electrolyte (YSZ) and nickel stabilized zirconia cathode (Ni-YSZ) is the result of these investigations, which have been the subject of the EVIDOS project (ECC-590000-2008-100), by the Hydrogen Foundation in Aragon, on the development of solid oxide fuel cells for portable applications of very low power (<50W).

Tubular cell stack developed for the EVIDOS project. Courtesy of the Material Science Institute of Aragon (ICMA).

The principal problem of these fuel cells is that they need expensive materials (similar to those needed for aircraft turbines) due to its high operating temperature, almost 900°C. This makes it difficult to achieve the generalization of this type of technology. That is why one of the aims in these research projects is, undoubtedly, to reduce this temperature to around 600°C in order to be able to use more economic materials.

04. FUEL CELLS

DEVELOPMENT OF THE TECHNOLOGY. PROJECTS OF REFERENCE

Next, some European, national and regional reference projects described related to the fuel cell technologies (basic research, portable applications and stationary applications) developed in the last few years have been outlined:

ON A EUROPEAN LEVEL:

- **FCANODE Project, "Non-noble catalysts for PEMFC anodes",** stressing the obtaining of new catalysts with controlled particle sizes on the nanoscale (without Spanish participation).
- **ZEOCELL Project, "Nanostructured electrolyte membranes based on polymer/ionic liquids/ zeolite composites for high temperature PEM fuel cells",** coordinated by the Institute of Nanoscience of Aragon, whose principal aim is developing nanostructured membranes based on a new and multifunctional compound material obtained through the synergic combination of ionic liquids, polymers and zeolites.

ON A NATIONAL LEVEL:

- **CENIT DEIMOS Project: "Development and Innovation in Membrane and Solid Oxide Fuel Cells",** with a budget around 30 million Euros, and where 31 entities take part, including companies, technology centres and research institutes, which, amongst other activities, deal with technological research on catalysts and membranes for nanostructured PEMFC. The Materials Science Institute of Aragon, ICMA, is one of the participants in this project.
- **SOFCMETAL Project,** whose aim consists of researching the optimization of the technology that will in the future allow the development of electricity and heat cogenerators based on solid oxide fuel cells (SOFC) with Spanish technology.

Detail of the hydrogen installation corresponding to H2FC – Security Project. Courtesy of GESAN.

ON A REGIONAL LEVEL:

- **SHERA - FEZAR Project,** carried out in collaboration between the FEZAR company and the Hydrogen Foundation in Aragon, on electrical supply by means of fuel cells associated to weak electrical distribution grid.
- **H2FC - SECURITY Project,** developed by the company GESAN and VEA QUALITAS, and with the collaboration of the Hydrogen Foundation of Aragon, for the integration of fuel cells in stationary facilities of vigilance and security.
- **Project called " Optimization of the fluid dynamic and mechanic design of a high temperature PEM fuel cell system"** coordinated by the Laboratory for Research in Combustion Technology (LITEC).

04. FUEL CELLS

FUEL CELLS COMMERCIALIZATION

The number of fuel cells manufacturing plants for different stationary applications (electrical distributed generation, cogeneration, back–up systems, autonomous systems), portable applications (sources of electricity for portable electronics, power generators) and mobile applications is increasing gradually, mainly accumulating in the USA, Europe and Eastern Asia (Japan, China and South Korea).

In Spain, there are currently two PEM fuel cells manufacturers:

10 kW PEM fuel cell in commercialization. Courtesy of AJUSA.

- AJUSA is a national capital company located in Albacete, which has been principally dedicated to the design, manufacture and distribution of components for the automotive sector for thirty-seven years. It also has a Department of Hydrogen Technologies. The synergy achieved between the Department of Hydrogen Technologies and the numerous departments of manufacture has ensured that all the components necessary for PEM fuel cell can be developed and made in an self-sufficient way in AJUSA facilities. In fact, in its most recent catalogue, it offers fuel cells of up to 10kW, power units of up to 5kW with UPS (Uninterrupted Power System) function and the possibility of making metallic bipolar plates under client specification.

- CEGASA, with the support of Cidetec (Centre for Electrochemical Technologies), which is located in San Sebastián Technology Park with extensive knowledge about the running of polymeric membrane fuel cells, their characteristics and the determination of the control algorithms. They also offer stacks and PEM fuel cells between 50W and 10kW of power.

On a regional level, there is a spin-off company from the LITEC (Laboratory for Research in Combustion Technology), a centre ascribed to CSIC and the University of Zaragoza, which is nowadays immersed in the process of PEM fuel cells development in a power range from 500 to 2000W. This company is currently in the optimization phase of the fluid mechanic design of the bipolar and terminal plates that will be used as elements in a 2kW PEM fuel cell, including the reactant gas distribution channels for all the plates of the cell, the flow geometries and the most efficient method for the extraction of the water generated in the cathodes. It is also working on the ideal method of cooling depending on the quantity of heat to extract and on the development of different processes and tools to maximize the cell features, guarantee its correct sealing and facilitate the different assembly processes.

PEM fuel cell stack developed by the Laboratory for Research in Combustion Technology (LITEC).

Test bench for PEM fuel cells developed by the Laboratory for Research in Combustion Technology (LITEC).

04. FUEL CELLS

STRENGTHS

- Research groups in Aragon working on PEM and SOFC fuel cells development.
- Good relationship of Aragonese research centres with other Spanish and European ones and participation in several relevant R&D projects on fuel cells.
- Special characteristics of the cells as opposed to traditional systems: wide range of power, low noise level, no emissions, no recharge required and modular technology which allows to increase the power associating units.
- Experience in fuel cell integration for different applications.
- Availability of laboratory facilities for fuel cell deployment and test benches.

OPPORTUNITIES

- Market still to be established and with the possibility of high real growth in stationary applications as well as in portable ones.
- Aragonese companies have the capacities to manufacture fuel cell components.
- Existence of industrial network able to integrate the cells into their final product.
- Capacities in fuel cell manufacturing process automation.

WEAKNESSES

- Lack of demand that could allow costs to be reduced on industrial production level.
- Lack of globally optimized elements of the fuel cell in the BOP (Balance of plant).
- Reliability of commercial fuel cells has to improve to increase user's confidence in this technology.
- High temperature fuel cells for stationary applications show a significant reduction of their lifetime if they suffer a high number of start-stop cycles.

THREATS

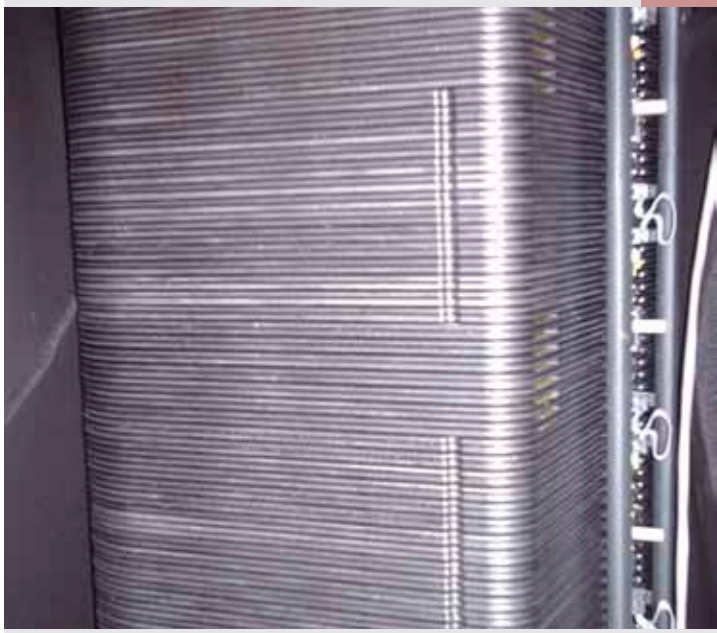
- The degree of development of the advanced cells can determine the number and the scope of the new markets of the fuel cells.
- The Eastern market with very low prices, but with lower quality in the supplied product.
- Since there is not an established fuel cell market, the influence from the big international programmes to promote this technology (JTI-FCH, the USA Department of Energy, etc.) can determine to a great extent the corresponding lines of development.

1. Fuel cell **technology** is, so far, pre-commercial. This means that, although its use is possible with competitive performances, for its final implantation, **several stages of development are still necessary,** basically aimed at **mass production** and the **increase in the demand of applications that require hydrogen,** to promote their commercialization.

2. The research efforts must aim **increasing the durability and reliability and decreasing the cost** of fuel cell systems. To that end, it is basic to optimize components and control systems, to automate the stack manufacturing processes, to develop associate power electronics or to do research into new low cost materials that allow the current ones to be substituted.

3. Aragonese companies have the **ability and experience** not only in the **fuel cell integration into the final product,** but also in the **development of its associate components** (valve, control and power electronics, etc.). In this sense, it is essential to promote the use and development of characterization and test facilities.

4. There are research **groups which are internationally well established** related to the research into PEM and SOFC fuel cells. The activity of these groups should soon have an impact on the improvement of the characteristics, the lifetime, the cost reduction and the start-up of new spin-off by means of the promotion of the technological transfer.



04.
FUEL CELLS

INDUSTRIAL ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Appearance of a development niche in the auxiliary component industry (valves and control and power electronics) in fuel cells, requiring an innovation related to miniaturization in the products.	SHORT TERM	II
Appearance of companies (or existing specific training) concerning fuel cell assembly and maintenance activity.	MEDIUM TERM	II
Appearance of companies to automate fuel cell or their components manufacturing processes.	LONG TERM	II

RESEARCH ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Research into PEM cell components with electrolyser improvement projects.	SHORT TERM	▶
Results and their transfer to new components of SOFC and PEMFC cells (catalyst and support).	MEDIUM TERM	▶
Decrease of the operation temperature of SOFC cells and testing of new materials in components.	LONG TERM	▶
Increase of the operation temperature of PEM cells.	MEDIUM TERM	

SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Creation of PC components testing laboratories developed by companies or research groups.	IN PROGRESS	▶▶
Development of an Action Plan for the use of cells in the residential and tertiary sector in isolated zones, and promotion of the use of higher power cells in municipalities or small companies.	MEDIUM TERM	⏸
Activation of the hydrogen demanding market that generates the necessity to increase fuel cell production.	SHORT TERM	

05.


AUTOMOTIVE

05.
AUTOMOTIVE

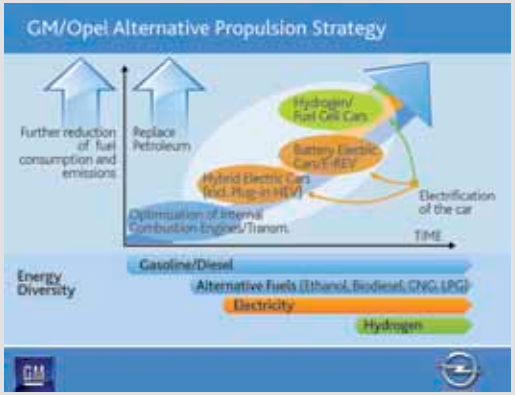
The current development of the mobility is evolving from the improvement of a system established towards the search of complementary and coexistent models.

The transport sector, as a massive oil consumer, has a great importance in the total of greenhouse gas emissions and air pollution - 31% of the total CO2 emissions in Spain, as well as needing almost 15% of the national energy (opposed to the European average which is 10%).

If current models and conditions are maintained, the emission due to transport will exceed by 157% the maximum level taken on by Spain to achieve by 2020 following its signing of the Kyoto Protocol. Nevertheless, the automotive sector has a turnover of 3.5% of the national GDP, employing 8.7% of the active population. In order to fight against this problem and other future ones, such as the energy safety or the different actors implied (social, political, technological, ...) it is understood that it is necessary to favour in-trend measures to reduce the consumption of fossil fuels.

In order to stabilize and reduce CO2 emissions, without acting on the industrial growth, a certain international consensus seems to exist in relation to the fact that the solution comes partly from electric engine vehicles, since their efficiency is four times higher than the one of the internal combustion engine,

F.12 GM/Opel Alternative Propulsion Strategy. Courtesy of General Motors Europe.



and emissions are relevantly reduced going from 300g CO2/km to approximately 75g CO2/km with the use of a pure electric vehicle refuelled by the current mix of the Spanish electrical grid.

The ongoing trend among the development plans of all the vehicle manufacturers is the reduction of emissions through the gradual decarbonization of their technologies until they reach the point when electrical vehicles are running on renewable sources. The technology exists and the limitations would be the range and the recharge times. On the other hand, another derived disadvantage would be the difficulty in the management of an electrical grid with high penetration of renewable energy sources. It is, in these key points, where hydrogen technologies play an important role.

05. AUTOMOTIVE

The majority of the car manufacturers already have several models and prototypes of fuel cell electric vehicle (FCEV), which is positioned to be the final step of the sustainable and efficient automotive. The fuel cells used in automotive are PEM type due to its low operation temperature, which facilitates the start-up period and its fast kinetics, necessary to provide acceleration.

Opel HydroGen4 vehicle.

The manufacturers are keeping focused on the decarbonization of technologies. The electric car is a reality, but the limitations of the first concepts are related to the range and the battery recharge times.

According to the number of developed models, the companies which stand out are Daimler and GM. According to production, the work Honda must also be pointed out because of its FCX Clarity, with a recharge capacity of less than 4 minutes providing a range of 460km and a maximum speed of 160km/h, with it already being on lease as a certified and production line vehicle. Equally the Opel HidroGen4, a crossover with the same maximum speed and a range of 360km, is the transposition to the Chevrolet Equinox fuel cell and the most advanced in its phase of implantation now in Europe. Nowadays, the number of active vehicles is estimated to be at least 1,100 fuel cell cars (108 models) and around 120 buses (18 models). (Source: Fuel Cells 2000 and US Fuel Cell Council, October 2009 and January 2010, respectively).

This background makes hydrogen and fuel cells a solution to the problem of transport for the forthcoming development of an environmental and economically sustainable model.

EUROPE

In the European Union, the **HyFleet: CUTE** project was carried out from 2006 to 2009. This is a continuation to the **CUTE** project from the 7th EU Framework Programme, which dealt with the building, starting-up and behaviour analysis of 33 electric hybrid urban buses fed with hydrogen fuel cell and lithium ion batteries and 14 internal combustion engine buses fed with hydrogen (the latter in use only in the city of Berlin).

The HyFleet: CUTE project was led by Daimler AG and it was developed in eight European cities (Amsterdam, London, Madrid, Barcelona, Berlin, Luxembourg, Hamburg and Reykjavik), as well as the Australian city of Perth and also Beijing. The success of this project is summarized in a few details, such as more than 2.5 million kilometres covered and more than 170,000 running hours by this fleet of buses.

Although in the last few months the news on efficient automotive has revolved around investments and developments in pure plug-in electric vehicle projects, it is necessary to emphasize that the investment in FCEV in Europe has not been stopped. For example, in the years 2009 and 2010, the European Union, through the correspondent hydrogen and fuel cells JTI, invested

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around €120 million to promote the development of demonstrative projects of hydrogen vehicle fleets, highlighting **H2 Moves Scandinavia** project and **CHIC** project regarding fuel cell cars and buses, respectively. It would be necessary to add to this investment the ones made by the different countries which have their own programmes for the development of hydrogen and fuel cell technology, like Germany, with an annual budget of approximately €50 million, of which, an important amount is earmarked for the development of this type of vehicles.

In addition, private investments made by the main car manufacture companies must be considered. They continue, in spite of the current delicate situation, particularly in the automotive sector and in the world economy in general, with the manufacture of their respective prototypes of fuel cell vehicles fed with hydrogen. In fact, a Letter of Understanding (LoU) has been signed between Daimler AG and Ford Motor Company, General Motors Corporation, Honda Motor Co, Hyundai Motor Company, KIA Motors Corporation, Renault SA, Nissan Motor Corporation and Toyota Motor Corporation with the aim of creating a pressure group to urge distribution companies and governments to carry out actions which will lead to the creation of a standardized hydrogen distribution network in the different countries of the European Union.

The expectation of this corporate group is to have enough capacity to accelerate the development process, in such a way that from the year 2015, a significant quantity of electric fuel cell vehicles might be commercialized.

On the other hand, as for vehicle fleets for public transport, it must be emphasized that the Hydrogen Bus Alliance has recently been created, formed by 10 cities and European regions with a strong financial and political commitment to promote the commercialization of the hydrogen bus technology by the year 2015.

SPAIN

On the national level, it is necessary to emphasize the singular and strategic **Hercules** project, with a budget of approximately €10 million and coordinated by the Andalusian company Hynergreen. In this project, solar energy is exploited for the production of hydrogen by means of photovoltaic panels and a Stirling system that generates the electric power used by the electrolyser system. The renewable hydrogen produced is dispensed in a service station to electric vehicles which are capable of being run using this gas.

Another relevant project with Spanish participation is the **HyChain MINITRANS** project, formed by a consortium of 24 European entities whose aim is to display several vehicle fleets driven with fuel cells in four European regions, including the city of Soria, operating with hydrogen as an alternative fuel source. Finally, it is also necessary to talk about the **Don Qhyxote Car 07** project carried out by the company AJUSA, which consisted in developing a six-seater fuel cell vehicle. In addition, this company has applied its PEM cell technology to other vehicles such as scooters and golf carts.

On the other hand, on the national level the public institutions are determinedly opting to promote plug-in electric vehicle development by means of initiatives such as the **MOVELE** project or the **REVE** project that tries to reduce the 75g CO2/km emitted by a pure electric vehicle to 0, using only electricity from renewable energy sources, whilst also trying to increase its manageability From the sector of the hydrogen and fuel cell new technologies, it is believed that the impulse to the plug-in electric car can be a tractor phenomenon for the hydrogen fuel cell vehicle, as that should naturally be the following step.

ARAGON

The Hydrogen Foundation in Aragon has been working on a joint solution of the bounding factors both of the vehicle and of the associated infrastructure (range, recharge and source management) by means of the use of hydrogen technologies.

On the one hand, the ITHER project (Technology Infrastructure for Hydrogen and Renewable Energies, PCT-A22266217-2005) was developed. It is based on the hydrogen production using RES to later use it in an automotive, thus obtaining an ideal management of these energies - injecting the renewable electricity into the grid when there is demand and producing and storing hydrogen when there is not, and this way having 100% of the electricity from renewable resources. As a result of this project, we have the previously mentioned hydrogen refuelling station started in the Walqa Technology Park in June 2010. In line with this, the Hydrogen Foundation in Aragon and different universities, technological centres and companies from the Autonomous Community of Aragon have worked on the design, sizing and construction of a prototype electric kart based on hydrogen fuel cell in order to investigate the behaviour of this technology on a real scale.

The kart competed in 2008 and 2009 against teams from all over the world in the **Formula Zero** international competition, whose aim was to demonstrate that car competition and respect to the environment could go together. This championship has given the opportunity to put fuel cell technology to the test, to improve the involved systems and to show the spectators at the race that it is a powerful, clean and, above all, safe technology.

This vehicle, the first made-in-Spain hydrogen kart, managed to show the general public its characteristics thanks to the keen interest of the media, which served as a testing laboratory as well as a focused way of spreading the message.

All the knowledge acquired in the Formula Zero project is valid for the automotive sector in general. An example of this is the current national project "Multipurpose tool-vehicle teleoperated with full traction and propulsion system based on fuel

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Several photographs of the hydrogen kart. In the photograph below His Excell. Arturo Aliaga López drinks the water generated by the fuel cell which provides the power needed to the vehicle. Presentation of the Formula Zero project in MotorLand Aragón (Ciudad del Motor de Alcañiz), in April 2008.

The Formula Zero championship has given the opportunity to put fuel cell technology to the test, to improve the involved systems and to show the spectators at the race that it is a powerful, clean and, above all, safe technology.

cell" (Spanish Ministry of Science and Innovation CIT-370000-2008-11), which turns this technological knowledge into reality and offers all its advantages to the industrial field. Another example is the **LIFE+ ZeroHyTechPark** project which is going to turn two battery electric vehicles given by Endesa Company into two fuel cell vehicles fed by hydrogen.

Therefore, it can be seen that at present there are already many demonstration projects, which, although far from the commercialization due to manufacture costs, are trying to identify the technical problems in the daily use of this technology. In this sense, international research and development programmes focus on urban collective transport, since its fleet characteristics allow some of the problems to be reduced, especially the one related to hydrogen supply, which facilitates, to a great extent, its introduction in the current society in a nearer period of time.

Battery electric vehicles that will be turned into FCEVs under through LIFE + ZeroHyTechPark project.

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STRENGTHS

- Good public acceptance of vehicles propelled with alternative fuels.
- Automotive sector with strong roots in the region and with its main exponent continuing determinedly betting for the hydrogen vehicle.
- Aragon as a strategic centre in the hydrogen highway. It is the only Spanish region with a hydrogen refuelling station in its two principal cities.
- Strong projection of the image of Aragon regarding hydrogen and automotive sector thanks to the Hydrogen Foundation in Aragon and its Council, the refuelling infrastructure in service and the hydrogen kart project, which has been a great impact initiative on integration of fuel cells in applications of sustainable mobility.

OPPORTUNITIES

- Automotive continues being potentially the great consumer of hydrogen in the medium and long term.
- The impulse to the plug-in electric car can provoke naturally the adoption of the fuel cell in a second step.
- "Range extender" concept: Rechargeable batteries for the city and hydrogen for a higher range on the road.
- Tractor automotive phenomenon in relation with FC technology can imply a global reduction of its price when FCEV reaches a relevant market share.
- Market niches in special applications: industrial vehicles, motorcycles, caravans, APUs (auxiliary power units).
- Fuel cell electric vehicle fed with hydrogen emerges as a regulatory element of electrical grid.

WEAKNESSES

- The decision about investment in development and about commercialization of the fuel cell vehicle belongs to car manufacturers, big global corporations.
- The automotive auxiliary sector is subordinated, in the case of the fuel cell vehicle, to the decision of car manufacturers to proceed to mass production, so it is difficult for them to justify premature efforts in product development in these technologies.
- The electric vehicle in general implies some acquisition costs higher than the traditional vehicles.
- The commercialization of the electric vehicle in general needs a previous investment in an appropriate refuelling network, and training of the technical staff.

THREATS

- The time foreseen for the first commercialization is 2015 at the earliest, with slight growth ramps, a fact that can discourage the prior investment and the infrastructure preparation.
- The big JTI-FCH projects in mobility (until 2015) will benefit the countries, regions and cities that have established clear and long-term strategies on the fuel cell vehicle.
- Due to the existing uncertainty perception on the return of R&D investments for the auxiliary industry, there is a risk for the component companies that have positioned themselves and do not react in the suitable moment that they will be left out of the market.

1. There is still long way to go in order to have fuel cell electric vehicles in our streets, in our industries, in our daily life. For that end, it will be necessary to overcome challenges such as the **cost reduction** up to 100 €/kW levels, **the increase of automotive fuel cells lifetime up** to 8,000 running hours or the creation of a solid **refuelling infrastructure** parallel to the development of the vehicles.

2. There exists an important production volume as for Aragonese automotive sector suppliers whose **concrete diversification towards fuel cell electric vehicle** through R&D and infrastructure supposes an important opportunity.

3. The development of the **electric car implies a tractor phenomenon to the fuel cell model,** with good acceptance thanks to the image projected these last couple of years.

4. The automotive sector is one of the most important industrial activity sectors in the region. With regards to infrastructures, it owns the **first Spanish hydrogen highway** (Zaragoza-Huesca) and **training circuits** (Motorland Technology Park) that provide ideal conditions to place Aragon as a **place of reference in the national and European hydrogen vehicle map.** At the same time, it is necessary to promote the creation of demonstrative **captive urban transport fleets** to achieve a bigger impact and popularization of these technologies.

5. **Real capacity for the creation of market niches** related to the development of **special applications** in terms of industrial vehicles, motorcycles, caravans or APUs.

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INDUSTRIAL ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Manufacture of special vehicles (industrial vehicles, cleaning vehicles, etc.) and start-up of fleets of these vehicles.	SHORT TERM	▶▶
Application of fuel cells as APUs (auxiliary power units) for different applications such as heated tankers, refrigerated lorries, motor home systems, etc.	MEDIUM TERM	▶
Specialization of the automotive suppliers in manufacture and/or development of components for hydrogen vehicles that lower their prices.	LONG TERM	⏸

RESEARCH ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Development of advanced power electronics adapted to hydrogen technologies.	MEDIUM TERM	

SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Actions for the creation of demonstrative urban transport fleets, aiming to achieve a social impact and the promotion of these technologies.	MEDIUM TERM	▶
Training of specialized staff in related technologies.	SHORT TERM	
Promotion of support structures specialized in the testing and maintenance of components and related systems	MEDIUM TERM	

06.


SOCIAL AND
ECONOMIC IMPACT

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SOCIAL AND ECONOMIC IMPACT

In order to boost the new hydrogen technologies, it is necessary to have cross actions as a support for the actions of a predominately industrial and research nature mentioned in the previous chapters.

It is essential to promote the raising of public awareness and to increase the degree of knowledge in these technologies, as well as the definition of regulations, standards and safety requirements for equipments and facilities, and to stimulate policies that help to finance related projects or those activities that favour the transfer and sharing of technology along the set line of company–research centre-university. All of these factors are key for the implantation and deployment of these technologies.

PUBLIC AWARENESS-RAISING AND TRAINING

The socioeconomic success of an innovative process depends not only on its technological innovation, but also on the public acceptance of this innovation, which, if inadequate, can become an obstacle for the development and introduction of a new idea. In particular, the knowledge, confidence and familiarity play an important role in the risk perception, together with the public acceptance of new technologies.

Spreading the use of hydrogen as an energy vector requires an important effort in every sense in raising awareness and training. Current levels of knowledge and awareness-raising in hydrogen and fuel cell technologies are low. Moreover, the usual existing misunderstandings about the proprieties of hydrogen have had a negative effect on global opinion about its safe use.

In Europe, a number of projects have been developed in the last few years whose aim was to improve the degree of public awareness and training of public sectors, which are key in hydrogen and fuel cell technologies:

A clear example is the German **Hytrust** project, which tries to improve the acceptance of hydrogen technologies amongst consumers, and also increase the confidence amongst the principal agents that develop products based on hydrogen technologies.

Since 2007, the Hydrogen Foundation in Aragon belongs to the Scientific Culture Units network (UCC) brought about by the Ministry of Science and Innovation, through FECYT, Spanish Foundation for Science and Technology. The UCC pursues suppor-

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ting the diffusion, communication and spreading of the results of the scientific research and technological development activities generated in the heart of the entity. In this respect, it carries out different activities such as guided tours around its facilities for all kinds of public groups, participation in fairs for the promotion of scientific culture and the organization of events and training activities.

In addition, the Hydrogen Foundation in Aragon leads the Training, Awareness-Raising and Social Perception Group of the Spanish Technology Platform on Hydrogen and Fuel Cells.

Through the **H2-Training** project (ES/06/B/F/PP 149461), where the Hydrogen Foundation in Aragon and the San Valero Foundation took part, a curricular design was carried out between 2006 and 2008 in order to train European technical staff in hydrogen and fuel cells, developing an e-learning pilot action with more than 150 participants from various European companies. As a continuation of this, the **HYPROFESSIONALS** project (N ° 256758) from the FCH JTI, coordinated by the Hydrogen Foundation in Aragon and again with the participation of San Valero Foundation, will develop the actions and the curricular programme, extending the range of levels to ensure the capacity of response of a developing sector.

Work meeting for the H2-Training project. Zaragoza, 2007..

Hydrogen Day in the Water Tribune (Expo Zaragoza 2008), and Dr. Victor Orera receives the award of Honorary Council Member, September 2008.

Staff from the Hydrogen Foundation in Aragon teaching a practical class on photovoltaic energy.

In Aragon, in the area of training, the Hydrogen Foundation in Aragon organizes an annual summer course on hydrogen technologies, which this year already celebrated its sixth year, two of them under the sponsorship of the UNED of Barbastro (2005 and 2007), other two in the Summer University of Teruel (2006 and 2008) and two in the Pyrenees Headquarters of the Menéndez Pelayo International University (2009 and 2010), with almost 200 students in total. Since the academic year 2009-2010, an official Masters on Initiation to Renewable Energy Research is offered in the University of Zaragoza that includes 5 credits (50 teaching hours) on hydrogen and fuel cell technologies.

Booth of the Hydrogen Foundation in Aragon during the "Group Exhibit Hydrogen and Fuel oil Cells" of Hannover Fair in the year 2009.

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Guided tours to the facilities of the Hydrogen Foundation in Aragon in the Walqa Technological Park.t

On the other hand, the University of Zaragoza offers every year the Master on Renewable Energies and the Specialization Diploma in Hydrogen and Fuel Cell Technologies (from 2005 to 2009, later merged with the Master on Renewable Energies), managed by CIRCE Foundation, and with the sponsorship and collaboration of the Hydrogen Foundation in Aragon. A total of 70 students took this Diploma during its four years. In addition, in collaboration with SEAS, the Distance Learning Platform of San Valero Foundation has an online course taken by more than 300 Spanish and Latin American students.

In April 2010, staff from the Hydrogen Foundation in Aragon taught a training course to the Aragonese Public Administration Institute, which probably was the first one on a European scale addressed to civil servants from the Public Administrations who must intervene in the administrative process of facilities associated to hydrogen technologies. Twenty-five people received this training.

With regard to activities of social awareness-raising, over the course of the last 4 years, several thousand people from schools, high schools, universities, research centres, different kinds of associations, companies, political delegations or the general public have visited the facilities of the Hydrogen Foundation in Aragon, having the opportunity to get to know these innovative technologies a bit better. In the year 2009, the number of visitors exceeded one thousand people.

REGULATION AND SECURITY

Developing and publishing regulations and standards is essential in order to establish a receptive environment for the commercialization of safe products and systems.

Regarding hydrogen and fuel cell technologies, in the last four years, two of the most important European projects have been concluded, executed up to now on regulation, standards and security in hydrogen technologies.

With the **HySafe** project, it has been possible to create a network of excellence on the safety of hydrogen as an energy vector. This project has been continued with the creation in 2009 of the HySafe International Association, which is open to entities from all over the world and determines the state of the art of the safety of hydrogen developing constantly strategic research programmes on this matter.

As a result of the **HyApproval** project, a manual has been published that tries to be a base for the regulation of hydrogen service stations in Europe. A key recommendation included in this manual is that a regulative European framework unique for hydrogen service stations should be developed, thus allowing a design of "standard station" that was approved in all the countries of the European Union. In this sense, it is believed that the most efficient method would be through the development and publication of a European Regulation.

In terms of European specific regulation in hydrogen technologies, it has to be mentioned that, at the beginning of the year 2009, Regulation No 79/2009 relative to the homologation of hydrogen powered vehicles was published. The publication of this regulation is considered to be an important first step in order to achieve the aim of establishing a global market of hydrogen vehicles in Europe and to provide a high level public safety and environmental protection.

On a regional scale, there is also important activity in the area of the regulation, codes and standards, and security with hydrogen. In this respect, the Department of Industry, Trade and Tourism of the Government of Aragon, the Hydrogen Foundation in Aragon and CSIC are part of the Plenary the Technical Committee for Standardization 181 of AENOR, whose field of activity is the standardization of the aspects related to systems and devices for the production, storage, transport, measurement and use of hydrogen. This Committee also carries out monitoring and participation activities in the tasks of codes and standards of the International Organization for Standardization ISO/TC 197, elaborates national regulatory documents of interest for the development of the sector and is also means a forum of national meeting for the different interested agents.

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TECHNOLOGY TRANSFER

Carrying out projects that promote the transfer of hydrogen technology is of a great importance to stimulate the competence and the economic benefits of the participating institutions and organizations.

The **HYTETRA** project (INN7/030625), financed by the European Commission through the 6th Framework Programme, was developed between 2006 and 2008 in order to support the European SMEs when facing the hydrogen technologies by means of technology transference activities.

The consortium was composed of relevant entities in the hydrogen knowledge transfer from Sweden, the United Kingdom, Germany, Italy and Spain (the Hydrogen Foundation in Aragon), cooperating at the same time, with a list of 'Technological Suppliers' to monitor the technological offers and demands defined by them and the participating SMEs.

Between 2009 and 2011, the **HYRREG** project (SOE1/P1/E100, Interreg IVB SUDOE Programme), which is coordinated by the Hydrogen Foundation in Aragon, presents the creation of a platform where universities, companies and research centres could find synergies to launch cooperation projects. Another of the actions of this project consists of designing a roadmap for the development of the economy of the hydrogen in the south-western regions of Europe.

Hyrreg project monitoring meeting celebrated in the Hydrogen Foundation in Aragon. June 2010.

Presentation of the Hyrreg project on November 30, 2009 in Zaragoza.

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FINANCING AND ASOCIACIONISM

The financing of the development and deployment of hydrogen and fuel cells is a critical aspect for the settlement of the minimum necessary infrastructure. As such, the Spanish Technology Platform for Hydrogen and Fuel Cells has selected as the action with the highest degree of priority, in short and medium term, in which the greatest efforts should be centred on in order to develop the hydrogen sector in Spain, is that of checking, adapting and continuing with the incentives in investments related to hydrogen and fuel cells, the processes of cell manufacture, and the framework energy, transport and environment policies that prevail the use of hydrogen and fuel cells, with specific budget assignment, as an important engine in the development of infrastructures in Spain.

Europe has identified hydrogen and fuel cell technologies as a strategic sector within R&D, and it has constituted one of the 5 Joint Technology Initiatives on this topic. This Fuel Cell and Hydrogen Joint Technology Initiative (FCH JTI) has the objective of managing the budgets of the 7th Framework Programme aimed at hydrogen and fuel cells and it is formed by public-private consortia with a particular programme on applied research and technology development.

For the time period 2007-2013 which the 7th Framework Programme covers, the JTI global budget is increasing to €940 million, of which 50% is contributed by the European Union (European Commission, Member States and Regions) and the other

Regions and European municipalities that belong to the HyRaMP Association.

50% must be provided by the companies that take part in the projects promoting in this way the private investment and the integration of companies of innovative character.

This JTI is formed by an Industry Grouping and a Research Grouping. The Hydrogen Foundation in Aragon is part of the latter from October 2008 and from 2010, it is part of its Executive Board.

On the other hand, in April 2008, HyRaMP was founded, which is the European Regions and Municipalities Partnership for Hydrogen and Fuel Cells, whose main aim is to provide regions and municipalities with distinguishable legal status and with aptitude to exert influence on the Hydrogen Joint Technology Initiative. At this time (year 2010), the region of Aragon has assumed one of the vice presidencies of the Part-

nership, by means of Mr Javier Navarro Espada, General Director of Industry and SME of the Government of Aragon. The regions that belong to the HyRaMP are at an investing level in these technologies which is at the same level of magnitude as that of the FCH JTI.

Members of the 7PM Aragon Network..

The constitution of the 7PM Aragon Network is another initiative launched in the Community that aims to increase the number of funded European projects and its consequent economic returns for R&D in Aragon.

This Network tries to favour the design and implementation of a common regional strategy that reinforces the participation of the different actors of the Aragonese scientific-technological system in the EU 7th Framework Programme.

The Hydrogen Foundation in Aragon takes part in this Network (coordinated by the University of Zaragoza) with the aim of promoting the financing of Aragonese projects on hydrogen technologies on a European scale.

Finally, it has to be emphasized that in Aragon at this time an Innovative Companies Cluster on Hydrogen New Technologies (AEI NTH in Spanish) is in the process of being created in order to take advantage of the opportunities presented by these technologies to diversify and strengthen the technological and industrial activity on a regional level and to constitute a "network centre" that comes across as a powerful hydrogen technology unit to the outside world, with an assigned group of both companies and researchers that develop R&D joint actions and strategic lines common to the cluster.

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STRENGTHS

- Commitment from the Government of Aragon to support hydrogen as a regional strategy in the medium and long term.
- Maintenance of the strategic line of hydrogen at a European level (JTI).
- Industrial interest in Aragon and existence of the Hydrogen Foundation in Aragon as a support tool for companies and articulator agent to the exterior. Expansion of the Foundation Council up to 64 members.
- Establishment of an extensive contact network, articulated from the Hydrogen Foundation in Aragon, with other companies and entities of the sector on a national and international scale.
- Existence of official training initiatives at a university level.

OPPORTUNITIES

- Emerging market with possibility of high growth.
- Rule development: all the nowadays existing protocols can be turned into rules on the use of hydrogen and its applications.
- Existence of other initiatives on a regional level that can establish synergies and stimulate the development of the new hydrogen technologies (Tecnoebro, university institutes, 7PM Aragon Network Aragon, AEI NTH, etc.).
- Execution in Zaragoza of important events related to hydrogen, such as the World Hydrogen Energy Conference, WHEC 2016, among others.

WEAKNESSES

- Since hydrogen and fuel cell technologies still need a phase of research before their commercialization, the weaknesses of the national science and technology system do not favour us against third countries, such as the science-technology–company relationship, the stability of the R&D staff or the need of higher coordination between the R&D agents.
- The R&D financing instruments favour technologies with shorter pay-back periods.
- Since the markets in these technologies are going to be global, Aragonese SMES should promote more their internationalization.
- The general ignorance creates an exaggerated perception of the dangers of hydrogen, which can stop the acceptance of its use.

THREATS

- The lack of training in these technologies on a technical specialist level can imply a lack of qualified staff in the moment of expansion of the market.
- The adoption of standards and regulation elaboration without the participation of the interested companies can mean that they end up left out of the market.
- Other countries around us have elaborated hydrogen and fuel cell programmes on a national scale that allow the necessary critical mass to be obtained in order to manage competitiveness.

1. **Favourable associativism conditions exist** in an emerging sector capable of formulating business opportunities and reducing the return period of the investments thanks to the support of public programmes.

2. As for the support from the different institutions, a strong and **favourable commitment on a European level, is perceived, as well as on a regional one**. The strengthening of the Hydrogen Foundation in Aragon has to be highlighted, as a joint and promotion mechanism for projects on all these levels, by means of the training of an assigned group of companies and researchers that develop together the actions framed in the Hydrogen Master Plan in Aragon.

3. It is necessary to continue **starting-up and consolidating tools of transfer and result diffusion formats,** for the society in general and for the companies involved. These tools and formats **fill the gaps of knowledge in the perception of the general public** with regards to these technologies, and on the other hand they **technologically support** the industrial sectors involved.

4. Although university specialization in hydrogen technologies already exists as postgraduate and master courses, there is a lack of **training plans for medium level technical staff and qualified professionals in the managing and operating of hydrogen equipment.**

5. In order to strengthen the capacity of lighthouse project development by Aragonese companies, it is necessary to put effort into the **relationship with the university** and the **stabilization of the research staff,** as well as the knowledge and **participation in the main European initiatives** which promote R&D in these technologies.

Opening ceremony for the Hydrogen Foundation in Aragon facilities. Walqa TP, on May 6, 2008.

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SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
General ignorance about the uses, advantages and disadvantages of hydrogen on a wide part of the society. Execution of conferences, dissemination courses and communication actions at several levels that could cover extensive sectors of society.	ON-GOING	▶
Business ignorance of opportunities related to hydrogen. Creation of a state-of-art results dissemination format or technological study addressed to companies.	SHORT TERM	▶
Greater dissemination of the business cooperation tools in hydrogen field. Creation of forums of innovation where the technology transfer takes place.	SHORT TERM	▶
Investment by financial institutions and venture capital companies in hydrogen innovation projects. Appearance of institutions and/or financing mechanisms on a national and European level.	LONG TERM	❚❚
Maintenance of a database on regulations and legislation in all the topics related to hydrogen.	ON-GOING	▶
Lack of regulation on hydrogen, a factor that influences negatively in the development of new products. Promotion of the participation of companies and Aragonese organizations in the standardisation committees.	SHORT TERM	▶
Establishment of research requirements necessary from outside the region and consolidation of relationships with the relevant technological and research centres.	ON-GOING	▶

SUPPORT ACTIONS	TIME HORIZON	DEGREE OF ADVANCE
Although hydrogen specialization already exists at postgraduate and master level, it is necessary to have technical staff and qualified professional training programmes in the managing and operation of hydrogen equipment.	SHORT TERM	
Difficult access that the Aragonese companies have to achieve international visibility. Execution of activities related to the international commercial promotion.	ON-GOING	
Creation of an Innovative Companies Cluster in New Hydrogen Technologies (AEI NTH) in order to use the opportunities of these technologies to diversify and strengthen technological and industrial activity on a regional level with an assigned group both of companies and researchers that develop joint actions and R&D strategic lines common to the cluster.	SHORT TERM	

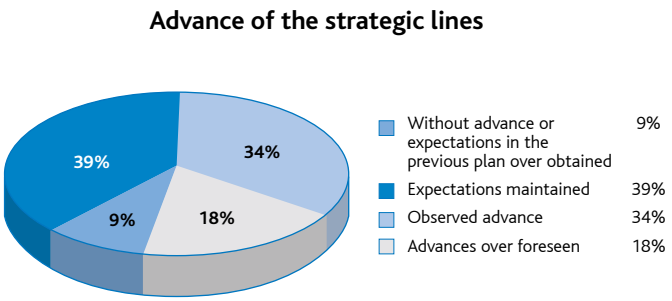
07.

CONCLUSIONS

07. CONCLUSIONS

During the analysis of the previous Master Plan 2007-2010, the evaluation process reveals that all the conclusions obtained that time are still valid, being checked not only through the surveys sent to the entities potentially linked to the new technologies on hydrogen and fuel cell sector, but also through the thematic work groups which have been held, adjusting the formulated perspectives to current reality. Likewise, and in agreement with the exposed methodology, the planned lines with no advance or with formulated foreseen which finally did not reach the aim hoped in 2007 stayed below 9%. On the other hand, **more than 50% of the planned lines have obtained advances,** which have been outstanding, fulfilling the line or surpassing expectations.

F.13 Degree of advance of the strategic lines defined in the previous Master Plan.



In general, the participation of **70 experts from more than 45 different companies and organizations** in the thematic work groups demonstrates the consolidation of a permanent actor core with real interest in the development of these technologies in the Autonomous Community of Aragon. The basic ideas have also been maintained, a sign of their validity under the expectation of their eventual orientation to market and industrial application, and new work lines have been introduced, which indicates the constant evolution of the sector.

On the other hand, during the period of validity of the previous Master Plan (2007-2010) around **€20 million** have been invested in Aragon to promote the deployment of the hydrogen and fuel cell technologies by means of the launch and execution of **more than 75 projects**. In addition, **several thousand** people have been trained in this field through conferences, seminars, information days, university training courses or modules, showing increasing interest in this sector in the region.

One can also see the establishment of knowledge consolidation strategies acquired years ago, the associativism (and lobby) and the R&D work, according to the current economic conjuncture that does not favour carrying out highly technical and financially risky projects, so there is an orientated manoeuvre towards the positioning to wait for the moment when these technologies will erupt. Therefore, the role of hydrogen competed alternatives must be clear in order to see the applications in which this one is going to play a relevant role and to reject the others.

In this line, it is perceived as an opportunity and they represent a confidence indicator for the business initiative, the supports and institutional awards received for the projects on hydrogen development in the region, waiting for their transposition as actions and support to this emergent sector from the national scope.

It is considered necessary to create a real demand for hydrogen in society that activates its development and market, immediately after which, and based on the actor positioning strategies, Aragon will prove to be able to constitute a network to sustain the development of the hydrogen as an energy vector and which re-feeds the opportunities at the same time.

Thus, it is hoped that by 2015 we will see the beginning of the market break and the beginning of these technologies as something everyday by means of, for example, the first models of fuel cell electric vehicles driving around the streets. In the period of validity of this Plan, Aragon can and must deploy its potential to host in Zaragoza, in 2016, the **21st World Hydrogen Energy Conference** as a forefront host of these technologies.

07. CONCLUSIONS

MONITORING

As in the first Aragon Hydrogen Master Plan, an important phase of this second Plan is to monitor its evolution.

This monitoring is based on knowing the evolution of the Plan strategic lines and on defining and compiling a series of indicators that measure the efficiency and the degree of fulfilment of the actions determined in this Master Plan.

The indicators proposed for the Aragon Hydrogen Master Plan 2011-2015 are the following ones:

Work groups for the elaboration of the present Aragon Hydrogen Master Plan 2011-2015. Zaragoza, May 2010.

INDICATOR	PERIODICITY	MAIN SOURCE	USE
No. of financed projects related to hydrogen in Aragon.	ANNUAL	Government of Aragon / National Ministries / European Commission	DISSEMINATION
Global investment carried out in Aragon in hydrogen technologies	ANNUAL	Government of Aragon / National Ministries / European Commission	DISSEMINATION
No. of PhD. theses in the field of hydrogen in Aragon.	ANNUAL	University of Zaragoza	DISSEMINATION
No. of people trained in hydrogen technologies.	ANNUAL	Hydrogen Foundation in Aragon	DISSEMINATION
No. of companies involved in hydrogen technologies in Aragon.	ANNUAL	Hydrogen Foundation in Aragon	DISSEMINATION
No. of professionals dedicated to hydrogen technologies in Aragon.	ANNUAL	Hydrogen Foundation in Aragon	DISSEMINATION
Global return obtained in public calls (regional, national and European) in hydrogen and fuel cell specific projects in Aragon.	ANNUAL	Government of Aragon / National Ministries / European Commission / Hydrogen Foundation in Aragon / 7PM Aragon Network	DISSEMINATION
Return obtained by companies in public calls (regional, national and European) in hydrogen and fuel cell specific projects in Aragon.	ANNUAL	Government of Aragon / National Ministries / European Commission / Hydrogen Foundation in Aragon / 7PM Aragon Network	DISSEMINATION
Degree of advance or fulfilment with strategic lines of the Master Plan.	ANNUAL	Hydrogen Foundation in Aragon	DISSEMINATION

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7PM or FP7 7th	European Framework Programme
AEI NTH	Innovative Enterprise Cluster of New Hydrogen Technologies
AFC	Alkaline Fuel Cell
APU	Auxiliary Power Unit
BOP	Balance of Plant
CHP	Combined Heat and Power
DMFC	Direct Methanol Fuel Cell
EACCEL	The Aragonese Climate Change and Clean Energies Strategy
FCEV	Fuel Cell Electric Vehicle
FCH JTI or FCH JU	Joint Technology Initiative for Fuel Cells and Hydrogen. See "JTI" FCH JU, Fuel Cells Hydrogen Joint Undertaking. Public private partnership created for the FCH JTI implementation. It is formed by EU countries represented by the European Commission, the JTI European Group for hydrogen and fuel cell industry, and the research group which became a member of the official establishment of the FCH JU.
FC	Fuel Cell
HFP	European Hydrogen and Fuel Cell Technology Platform
HyRaMP	European Regions and Municipalities Partnership for Hydrogen and Fuel Cells
ICTs	Information and Communication Technology
IGCC	Integrated gasification combined cycle
JTI	Joint Technology Initiative. It was created within the European Commission Seventh Framework for the promotion of research in specific and priority areas for the industrial competitiveness and highly relevant matters.

LPG	Liquefied petroleum gas
MAIP	Multi Annual Implementation Plan, approved by the JTI
MCFC	Molten Carbonate Fuel Cell
NG	Natural Gas
R&D (&I)	Research and Development (and innovation)
PAFC	Phosphoric Acid Fuel Cell
PEMFC or PEM cell	Proton Exchange Membrane Fuel Cell
Walqa TP	Walqa Technology Park
RCS	Regulations, Codes and Standards
RES	Renewable Energies
SME	Small and Medium Enterprise
SOFC	Solid Oxide Fuel Cell
SWOT	Strengths, Weaknesses, Opportunities and Threats Analysis
TCD	Thermo Catalytic Decomposition Process
UCC	Scientific Culture Unit belonging to FECYT, Spanish Foundation for Science and Technology, Ministry of Science and Innovation
UPS	Uninterruptible Power Supply System
USW	Urban Solid Waste

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