Hydrogen energy and fuel cells
# Table of contents

Preamble ................................................................................................................................. 4  
1 Subject area of this roadmap ........................................................................................... 6  
2 Challenges .......................................................................................................................... 11  
3 Key parameters .................................................................................................................. 12  
4 The 2050 visions ............................................................................................................... 14  
5 Obstacles and levers ......................................................................................................... 19  
6 2020 Visions ..................................................................................................................... 21  
7 Research priorities, demonstrator needs .......................................................................... 24  
8 Appendix ............................................................................................................................ 28
Since 2010, the ADEME has been managing four programmes within the scope of “Future Investments”. Groups of experts from research from various industrial fields, research organisms and research programming and financing agencies are responsible, within the scope of collective works, for producing strategic roadmaps.

These are used to launch Calls for Expressions of Interest (CEI).

The purpose of these roadmaps is to:

- highlight the industrial, technological, environmental and societal issues;
- draw up coherent, shared visions of technologies and the sociotechnical system in question;
- identify the technological, organisational and socio-economic locks to be overcome;
- associate time-based objectives with the priority research topics in terms of technological availability and deployment;
- prioritise needs of the industrial research, research demonstrator, preindustrial experimentation and technology test platform, which then act as a basis for:
  - drawing up CEIs;
  - programming research within the ADEME and other institutions such as the French National Research Agency (ANR), the French national strategic committee for energy research (Comité stratégique national sur la recherche énergie) or the French national alliance for the coordination of energy research (ANCRE).

These research and experimentation priorities originate from the junction of the visions and locks, and they also take into account French capacities in the fields of research and industry. Roadmaps can also refer to exemplary experiments conducted abroad and make recommendations in terms of industrial policy.

This roadmap shall be regularly updated.

In order to draw up this roadmap, we consulted with a group of experts from major private contractors, a contaminated wasteland developer, stakeholders involved in pollution control and public research and finally the ADEME.

---

1. Future Investments (Les Investissements d’Avenir) continue along the path set by the Research Demonstrator Funds managed by the ADEME. The four programmes involved are Renewable, low-carbon energy and green chemistry (1.35 billion Euros), Vehicles of the future (1 billion Euros), Smart grids (250 million Euros) and Circular Economy (250 million Euros).
List of members of the group of experts  

<table>
<thead>
<tr>
<th>Nature of the body</th>
<th>Experts</th>
<th>Member body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Privately-owned company</td>
<td>Pascal Moran and Eric Gemot</td>
<td>CETH²</td>
</tr>
<tr>
<td></td>
<td>Franck Masset</td>
<td>PSA Peugeot Citroën</td>
</tr>
<tr>
<td></td>
<td>Hélène Pierre and Stéphane Hody</td>
<td>GDF-Suez</td>
</tr>
<tr>
<td></td>
<td>Marianne Julien</td>
<td>Air Liquide</td>
</tr>
<tr>
<td></td>
<td>Patrick Bouchard</td>
<td>Hélion (Areva Group)</td>
</tr>
<tr>
<td></td>
<td>Alexandre Lima</td>
<td>Veolia Environnement</td>
</tr>
<tr>
<td></td>
<td>Marc Aubrée</td>
<td>France Telecom</td>
</tr>
<tr>
<td></td>
<td>Bernard Declerck</td>
<td>EDF</td>
</tr>
<tr>
<td></td>
<td>Michel Jehan</td>
<td>McPhy Energy</td>
</tr>
<tr>
<td></td>
<td>Philippe Mulard and Daniel Le Breton</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Didier Grouset and Samuel Lucoq</td>
<td>N-Ghy</td>
</tr>
<tr>
<td></td>
<td>Patrick Maio, Jean-Christophe Lanoix, Perrine Tisserand</td>
<td>Hinicio</td>
</tr>
<tr>
<td>Association and local authority</td>
<td>Pierre Beuzit and Michel Junker</td>
<td>Alphéa</td>
</tr>
<tr>
<td></td>
<td>Frédéric Meslin</td>
<td>Mission Hydrogène Pays de Loire</td>
</tr>
<tr>
<td></td>
<td>Claude Derive</td>
<td>AFH²³</td>
</tr>
<tr>
<td></td>
<td>Matthias Altman</td>
<td>Ludwig-Bölkow-Systemtechnik GmbH (LBST, Germany)</td>
</tr>
<tr>
<td></td>
<td>Hugo Vandenborre</td>
<td>V-Energy (Belgium)</td>
</tr>
<tr>
<td></td>
<td>Jean-Marc Pastor</td>
<td>Senator of the Tarn, CEO of the Phyrenees association</td>
</tr>
<tr>
<td></td>
<td>Jérôme Biasotto</td>
<td>Rhone-Alps Regional Council</td>
</tr>
<tr>
<td></td>
<td>Frédéric Solbes</td>
<td>AFNOR</td>
</tr>
<tr>
<td>Research body</td>
<td>Paul Lucchese and Alain Le Duigou</td>
<td>CEA</td>
</tr>
<tr>
<td></td>
<td>Claude Lamy</td>
<td>CNRS/University of Poitiers</td>
</tr>
<tr>
<td></td>
<td>Florent Petit</td>
<td>FC LAB institute</td>
</tr>
<tr>
<td></td>
<td>Alexandre Rojey</td>
<td>IFP Energies nouvelles</td>
</tr>
<tr>
<td></td>
<td>Cécile Barbier</td>
<td>UTT⁴</td>
</tr>
<tr>
<td>Public body</td>
<td>Axel Strang</td>
<td>MINEFI - MEDDLT / DGEC⁵</td>
</tr>
<tr>
<td></td>
<td>Bernard Frois</td>
<td>ANR-NTE⁶</td>
</tr>
<tr>
<td></td>
<td>Daniel Clément, Karine Filmon, Loïc Antoine</td>
<td>ADEME</td>
</tr>
</tbody>
</table>

². This roadmap is based on the works performed by Hinicio, a service provider taking part in holding debates and publishing works. The group of experts also received support from a technical office comprised of Luc Bodineau and Michel Gioria of the ADEME.
³. European company of hydrogen technologies.
⁴. French hydrogen association.
⁵. Technological university of Troyes.
⁷. National research agency – New energy technologies.

Hydrogen energy and fuel cells
I Subject area of this roadmap

Subject area
Hydrogen energy and fuel cells

This roadmap covers two main topics: the use of hydrogen gas as an energy and fuel cell technology.

Dihydrogen gas (H₂), more commonly known as “hydrogen”, can be used in various different applications due to its high energy potential. Because this gas does not exist in a natural state, it must be manufactured from a primary energy source, then transported, stored and distributed to the user. Hydrogen as a carrier or hydrogen energy is often spoken of as an energy carrier carrying energy between a primary source and its end use.

This roadmap covers the energy potentials of hydrogen, even if this gas is mainly used today in industrial applications as a chemical compound (outlined below). This notion of industrial hydrogen does not fall within the scope of this roadmap, however shall be taken into account as an existing industry related hereto.

Hydrogen energy and fuel cell industries are connected to each other. They may be complementary in nature, however also develop independently from each other. For example, the development of hydrogen energy is not mandatory for the development of fuel cells and vice-versa.

Definitions
Hydrogen energy: hydrogen used to cover energy needs. It is converted into electricity, heat or a driving force according to the desired end use.

Industrial hydrogen: hydrogen used as a chemical compound in industrial methods, mainly in refining and ammonia production. New methods in steelworks and second generation biofuel production could increase these industrial hydrogen uses in the future.

Fuel cells: these electrochemical converters produce electricity and heat by fuel oxidation and oxygen reduction. The fuel used may be liquid or gaseous: hydrogen, natural gas, methanol, ethanol, biogas, liquefied petroleum gas, petrol, diesel. Their size may vary from watts to megawatts, ranging from embedded electronic applications to stationary industrial facilities.

Hydrogen energy and fuel cell applications

Hydrogen energy and fuel cells can be applied in many different fields.

Stationary applications

In the field of residential and tertiary buildings, industry and power grids, this technology may enable energy to be stored and ensure heat and electricity supply: small-scale cogeneration (several kilowatts (kW)), medium-scale cogeneration (several tens to several hundreds of kW), large-scale cogeneration (several megawatts (MW)). These can therefore contribute to developing energy-positive buildings and sectors – that produce more energy than they consume, in addition to smart grids – that use information and communication technology to optimise elasticity generation and distribution and better relate supply and demand between producers and consumers.

Mobile applications

Hydrogen can feed some vehicles equipped with internal combustion engines running on gas, such as buses or household waste collection trucks. The 20% hydrogen/80% natural gas mixture (Hythane®) only requires the minor adaptation of current engines.

Fuel cells can be fitted into any vehicle using electrical energy for traction in all fields of transport: road, sea, river, rail and air transport. With regard to privately-owned vehicles, their application in hybrid mode – mode using multiple energy sources – coupled with batteries could be considered: the integration of a hydrogen tank and a fuel cell on-board an electric vehicle will increase its autonomy and reduce recharging times (2G or second generation electric mobility (the first generation being the electric vehicles under development)). The extent of hybridisation can be adapted to suit the use and type of vehicle.
Early or niche market applications

Aside from these two generic uses, hydrogen and fuel cells were initially demonstrated for more specific niche market uses, referred to as early markets, as they correspond to applications that are the closest to being marketed:

- material handling equipment for logistics centres and airports; special vehicles for city use or use within buildings;
- power supply for isolated sites such as relay antenna and telecommunication bases;
- electrical emergency back-up units for critical or strategic use (computer servers, hospitals, telecommunication relays) or more generally, to support faulty power grids for example in developing countries.
- mobile applications: low-power fuel cells can be used as portable power supply means or to power mobile objects such as telephones, computers, music players and portable lighting devices.

Figure 1 below summarises the state of maturity of these different applications.

Figure 1: Level of maturity of applications for hydrogen as an energy carrier and fuel cells (source: group of experts).
**Hydrogen production**

The dihydrogen molecule is not available naturally, even though the hydrogen atom enters into the chemical composition of different bodies such as methane, water or any organic matter. This must therefore be produced via methods using various different renewable or non-renewable primary sources:

- **Steam reforming** of natural gas is the most common method used today. It generates carbon dioxide, which could in the future be captured and stored or used (CCUS industry: carbon capture, use and storage). Hydrogen can also be produced via this method from biogas.

\[ H_2O + \text{electricity} \rightarrow H_2 + \frac{1}{2} O_2 \]

- **Water electrolysis** is the inverse reaction of that taking place in a hydrogen fuel cell: LT or low-temperature electrolysis (< 200°C) is differentiated from HT or high-temperature electrolysis (> 400°C), which requires a more significant heat supply. Low-temperature electrolysis methods use two types of electrolyte: an alkaline solution or a proton exchange membrane fuel cell (PEMFC). High-temperature electrolysis methods use a solid oxide fuel cell (SOFC).

- **Solid biomass thermochemical gasification and pyrolysis methods.** These methods produce a gas mixture (carbon monoxide and hydrogen), the hydrogen in which can be extracted.

Other methods are also undergoing more upstream research operations: thermochemical decomposition of water; photochemical decomposition of water and biological production from algae and bacteria.

Today, hydrogen is also co-produced in some chemical methods (chlorine production, coking plant, petrochemical industry, etc.). This hydrogen is either used in a method, burnt or discharged.

For the purposes of this document, **low-carbon hydrogen** shall be differentiated from **renewable hydrogen**, with these terms being based on the nature of the primary source and/or method used to produce the hydrogen (outlined below).

---

**Different sources and production methods**

**Low-carbon hydrogen:** hydrogen produced from electricity of nuclear origin, from a renewable energy source (renewable electricity, solid biomass, biogas) or by natural gas steam reforming associated with a CCUS unit. The carbon content of the hydrogen produced or the greenhouse gas emissions generated by this method of manufacture are either reduced or nil.

**Renewable hydrogen:** hydrogen produced from a renewable energy source (renewable electricity, biomass, biogas).
Figure 2: Level of maturity of hydrogen production technology and development perspectives (source: group of experts.

Transport, storage and distribution

Hydrogen supply from its point of production to the end user requires a transport, storage and distribution chain. The low energy density of hydrogen per unit of volume is a major restriction and makes up a key parameter in defining this chain.

Flow in gaseous form – by compressing the gas under different pressure levels, from several tens of bars to 350 or 700 bars – appears to be the most relevant option. Hydrogen liquefaction at -253°C consumes high levels of energy and therefore must remain a niche option. Hydrogen storage in solid matrices, in particular via absorption in metal hydrides, offers alternative solutions that are under development.

Equipment and infrastructures may take on varied forms with the volume of hydrogen to be transported and the distance travelled being the two decisive factors: metal bottles, composite tanks, fuel tankers, dedicated hydrogen pipelines (1,500 km of such pipelines exist in Europe), on-site petrol stations, etc.

The natural gas grid can also contain up to 20% hydrogen by volume without requiring any specific modifications. Some technological obstacles however must still be overcome in order to separate and purify hydrogen downstream of the network.
Geographic perimeter and deadline
From an international to a local perspective

The visions, research priorities, research demonstrator, industrial demonstrator, technology platform and technology experimentation needs identified herein are covered from a national perspective. However where relevant, local, European and international points of view shall be introduced:

• international prior art and foreign initiatives in terms of research priorities and support for technological development, such as the H\textsubscript{2} Mobility and Callux programmes in Germany, the Japanese Large Scale Fuel Cell Demonstration Programme or the US National Hydrogen & Fuel Cell Program, shall be taken into account (details provided in the Appendix).

• for some applications, development and market perspectives require an international approach: automotive industry, emergency back-up for faulty power grids, mobile applications.

• some characteristics of a regional nature also appear to be decisive factors for other applications: the presence of power and/or gas grids, the availability of renewable resources, climate restrictions and topography.

Deadlines

A 2050 analysis, based on the objective of dividing French greenhouse gas emissions by four for the year 2050 compared to 1990 levels (factor 4\textsuperscript{th}), initially highlights differing visions regarding the potential for deploying this industry on a technological, organisational and socio-economic level.

The European “20-20-20” targets\textsuperscript{10} and the directions provided by the French Programming Law relating to the application of the Grenelle de l’Environnement provide a framework for the year 2020 — energy efficiency of buildings, developing renewable energy, reducing pollution, developing power grids - in which strategic areas for developing hydrogen energy and fuel cells can be defined.

The identification of certain obstacles helps determine the research priorities and 2015 intermediary points of passage on a technico-economic and organisational level.

---

\textsuperscript{9} This objective was set out in Article 2 of the French Orientation Programme for Energy Policy Law (13 July 2005).

\textsuperscript{10} 2020 objectives: reducing greenhouse gas emissions by 20%, reducing primary energy consumption by 20%, share of renewable energy equal to 20% of the end energy consumption.
2 Challenges

**Contributing to guaranteeing national energy independence and preserving resources by promoting the use of renewable energy sources for energy end uses**

The renewable hydrogen produced from energy sources available in France appears to be a means for storing, transporting or distributing this energy, which is widespread and intermittent in nature, and thus ease its use.

The final transformation of hydrogen via fuel cells produces varying possible levels of heat and electricity, which enables this hydrogen to be used for leading energy applications: mobility, specific electricity uses, building heating needs. Hydrogen therefore increases the potential for substituting conventional energy sources with renewable energy sources.

The energy benefits generated by hydrogen as an energy carrier partly depend on the overall efficiency of the energy chain between production and end use. The optimisation of this chain thus appears as a key factor determining the energy potential of hydrogen.

**Taking part in reducing the greenhouse gas emissions connected to energy end use by using a low-carbon energy carrier**

The hydrogen content of greenhouse gases mostly depends on the primary energy source from which it originates. This is reduced when using renewable or nuclear energy sources. Its use, by replacing fossil fuels in energy end uses, and more specifically in widespread uses, will generate clear reductions in greenhouse gas emissions.

**Supporting the development of energy grids by promoting storage and intermittence management, and by creating interconnections between these grids**

This encourages the development of power grid architectures and control modes. The increasing intelligence of the exchanges taking place between production systems, transport, distribution and consumption sites will lead to a high degree of grid automation in addition to advanced production and electric load management. The deployment of decentralised electricity generation sites will be further supported by a development in the group of stakeholders involved in control operations.

Hydrogen energy and fuel cells offer electricity generation and storage capacities on demand, which can lead to the improved management of renewable energy intermittencies. They therefore contribute to developing power grids to differing extents: buildings, sectors, districts, renewable power generation parks.

Hydrogen as an energy carrier can also interact with the local natural gas transport or distribution network. It therefore offers the possibility of creating connections between power grids, natural gas grids and renewable energy sources, thus contributing to the more advanced control of the generation and distribution of different end energy forms.

**Reducing pollution connected to energy use, in particular in urban environments**

Mobility in an urban and peri-urban environment, based on internal combustion engine technology, faces problems relating to local pollution: the emission of pollutants such as particulate matter, nitrogen oxide and volatile organic compounds and the generation of noise pollution. Fuel cells, associated with an electric vehicle, constitute a technological breakthrough solution.

**Contributing to improving energy efficiency within buildings**

Energy use within tertiary buildings and residences is undergoing significant developments. Electricity is playing an increasing role in energy needs, connected to the development of new services and the improvement in the thermal efficiency of building structures. Moreover, energy generation and storage could be generalised on a building or sector scale.

In this regard, fuel cell technology, associated with hydrogen or natural gas, can contribute to meeting energy needs with high conversion efficiency. Heat production, exceeding electricity generation, meets the observed and expected development in energy use within buildings.

**Flexibility and modularity**

The energy and environmental potential for hydrogen energy is mainly based on the flexibility and modularity of this energy carrier. Capable of being produced from different primary energy sources, transported, stored and used on varying scales, it boasts many possible energy end uses.
3 Key parameters

The purpose of the long-term visions is to describe, in an extreme manner, the terms and conditions for deploying technological, organisational and socio-economic options which, according to the group of experts would enable hydrogen and fuel cells to contribute to achieving the ambitious objectives set such as the Factor 4 objectives.

These visions do not claim to describe the reality in 2050, but to define that which is possible so as to deduce a set of obstacles, research priorities and demonstrator needs. Reality in 2050 will probably be a combination of the visions provided in this roadmap.

Two key parameters have been identified by the group of experts, dividing the possible 2050 realities into four distinctive visions:

First key parameter: Hydrogen production

The multiplicity of the possible methods for producing hydrogen leads to varying degrees of implementation or varying levels of centralisation. In an extreme manner, two infrastructure logic systems can be identified:

Centralised production:

Hydrogen is produced in large quantities on a restricted number of sites. Large-scale facilities implement the following methods:

• steam reforming of natural gas with CCUS,
• high and low-temperature electrolysis on the site of use or attached to large-scale electricity generation sites (offshore wind farms, nuclear power plants),
• biomass gasification and steam reforming,
• new mass production methods: thermochemical decomposition of water, biological methods.

Decentralised production:

Hydrogen is produced by numerous small and medium-sized facilities spread throughout the nation. The production means implemented are as follows:

• biomass gasification and steam reforming,
• electrolysis, connected to the grid or attached to small and medium-sized renewable electric power plants,
• new processes: photochemical decomposition of water, biological methods.
Second key parameter: Uses

The flexibility and modularity of hydrogen as an energy carrier and fuel cell technology leads to applications varying in size, implementing relatively high volumes of hydrogen:

Intensified uses:
Hydrogen can be used in large quantities on a restricted number of sites for industrial and energy purposes:
- industrial uses: fuel refining, biofuel production, synfuels, the chemical industry, steelworks.
- the production of electricity and heat for stationary use: large-scale cogeneration (> 50 MW) implementing fuel cells using hydrogen or other fuels (such as Hythane®, biogas).

Widespread uses:
Small quantities of hydrogen are consumed in a widespread manner throughout the nation. Fuel cells are used for widespread mobile and stationary applications:
- small and medium-scale cogeneration (from 1 kW to 1 MW) in the field of buildings and industry, operating on hydrogen, natural gas, Hythane® type mixtures or biogas.
- land, sea or river vehicles equipped with fuel cells associated with electric traction or using a Hythane® type mixture in an internal combustion engine.
- various widespread applications: mobile objects, special vehicles, emergency power supply back-up units, etc.

By combining these two parameters, four extreme visions have been defined (described in figure 3 below), which represent four possible configurations from a national perspective.

Figure 3: Position of the 2050 visions according to the key parameters

Hydrogen energy and fuel cells
4 The 2050 visions

Each vision, characterised by a method for producing hydrogen and means for using the hydrogen and fuel cells produced, depends on the infrastructures specific thereto.

The following tables explain in detail and for each vision, what these infrastructures could be and state their possible interactions with other energy sectors and the main socio-economic issues faced.

**Vision 1: low-carbon hydrogen for industrial use**

<table>
<thead>
<tr>
<th>HYPOTHESES</th>
<th>CENTRALISED hydrogen production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural gas reforming with carbon capture and storage</td>
</tr>
<tr>
<td></td>
<td>High and low-temperature electrolysis (on the site of use or attached to large-scale electricity generation sites, in particular offshore wind farms and nuclear power plants)</td>
</tr>
<tr>
<td></td>
<td>Biomass gasification and biogas reforming</td>
</tr>
<tr>
<td></td>
<td>New methods (thermochemical decomposition of water, biological methods)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HYPOTHESES</th>
<th>INTENSIFIED hydrogen uses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Industrial uses: classic fuel refining, biofuel, synfuel, the chemical industry, steelworks, etc.</td>
</tr>
<tr>
<td></td>
<td>Large-scale cogeneration (&gt; 50 MW)</td>
</tr>
<tr>
<td></td>
<td>Small and medium-scale cogeneration units with fuel cells operating on natural gas or biogas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrastructure reduced to a strict minimum, limited to industrial sites with, in some cases, short-distance interconnections between some sites via pipelines (dedicated hydrogen pipelines or pipelines for hydrogen-natural gas mixtures)</td>
</tr>
<tr>
<td></td>
<td>Storage: limited needs due to the in-depth knowledge of supply and demand. Mass buffer storage facilities to be provided for hydrogen originating from renewable or nuclear energy sources</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>Interactions and synergies with other energy sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Synergies with CCUS sectors and biomass, second generation biofuel and other synfuel production sectors, with renewable energy, nuclear power stations, the power grid and the natural gas grid and natural gas uses, in particular within buildings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>Skills and stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The important role played by historic energy and hydrogen producers and distributors in addition to the CCUS industry. Skills specific to fuel cells: small, medium and large-scale cogeneration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>Economic aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The importance of carbon, natural gas and electricity prices</td>
</tr>
<tr>
<td></td>
<td>The possible appearance of an actual hydrogen market</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSEQUENCES</th>
<th>Social aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No change in lifestyles</td>
</tr>
</tbody>
</table>

This vision is the closest to the current situation and will not require any development taking place in the current economic system. It partly relies on the installation of CCUS technology. It also depends on the development of the biofuel industry.

The technological progress required essentially involves the mass production of hydrogen, high and low temperature electrolysis, CCUS. Cogeneration via fuel cells must also have proven its potential: current technology must be improved and be adapted to suit these uses (flexibility, reliability, remote control) with reduced costs (viable economic models for small, medium and large-scale cogeneration).

The main obstacle resides in the desire shown by industrialists to set up mass production methods for low-carbon hydrogen. The carbon market and the development of the European Union Emissions Trading Scheme (EU ETS) will be strong incentives, as will future political choices made in terms of these environmental issues. Carbon constraint must therefore be significantly increased to encourage industrialists to change direction and produce low-carbon hydrogen.
**Vision 2: renewable hydrogen for the industry**

<table>
<thead>
<tr>
<th><strong>Hypotheses</strong></th>
<th><strong>Decentralised hydrogen production</strong></th>
<th><strong>Intensified hydrogen uses</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Biomass gasification and biogas reforming</td>
<td>• Industrial uses: classic fuel refining, biofuel, synfuel, the chemical industry, steelworks, etc.</td>
</tr>
<tr>
<td></td>
<td>• High and low-temperature electrolysis (attached to small and medium-sized renewable energy power plants and/or connected to the grid)</td>
<td>• Large-scale cogeneration (&gt; 50 MW).</td>
</tr>
<tr>
<td></td>
<td>• New methods (photochemical decomposition, biological methods)</td>
<td>• Small and medium-scale cogeneration units with fuel cells operating on natural gas or biogas.</td>
</tr>
</tbody>
</table>

| **Infrastructures** | | |
|---------------------| | • The presence of an infrastructure to collect hydrogen from multiple widespread production sites for transportation to sites for intensified use. |
|                     | | • The use of the existing natural gas grid and construction of a dedicated hydrogen pipeline network. |
|                     | | • The existence of large and small storage facilities located close to production and consumption sites |

| **Interactions and synergies with other energy sectors** | | Synergies with second generation biofuel and other synfuel sectors, the natural gas grid and natural gas uses, in particular within buildings, the biomass sector, renewable energy and the power grid. |

| **Skills and stakeholders** | | • New skills required: decentralised hydrogen production, transport and storage, production of electricity and heat by cogeneration. |
|                            | | • New stakeholders: small renewable energy producers, biomass deposit operators, intermediaries between local hydrogen producers and sites for intensified use. |
|                            | | • Possible appearance of local operators responsible for the adjustment taking place between the different energy carriers (electricity, natural gas and hydrogen). |

| **Economic aspects** | | • A hydrogen price high enough to make the high infrastructure investments profitable |
|                     | | • The development of an open national market |

| **Social aspects** | | No change in lifestyles, however local production means |

In this vision, hydrogen-based solutions are developed if the cost of hydrogen is competitive and if its use leads to profits in terms of greenhouse gas emissions (in particular when mixed with natural gas). As in vision 1, the carbon constraint imposed by the EU ETS on industrial activities is essential. This vision also requires a significant change in the strategy implemented by major industrialists with regard to their hydrogen provision, which is supplied in a widespread manner throughout the nation. Furthermore, the mandatory development of a large-scale storage and distribution infrastructure will have a high impact on costs.

Given the situation today, this vision seems less likely to occur than the previous vision. The injection of hydrogen into the natural gas grid can however be a transitory economic solution, as this would bypass the need to invest in new infrastructures.
This third vision corresponds to a top-down centralised management system for energy supply that is essentially very similar to the current energy grid architecture. Nonetheless, the integration of hydrogen into the future energy mix using this configuration requires significant changes to the energy market. The interconnection between different energy grids requires their simultaneous and integrated management. Grid infrastructures from hydrogen distribution to its widespread uses also represent a large investment.

The large-scale development of hydrogen as a new energy carrier also requires a strong political stance to be taken on the large project model and appropriate support mechanisms, in particular for infrastructure deployment. Carbon cost and other types of incentives play a leading role in the realisation of this vision.
In addition to the technological progress described in the first vision (production of hydrogen by electrolysis, CCUS, new mass production methods, cogeneration), other technological obstacles exist hindering hydrogen use, in particular with regard to transport. Hydrogen storage must also be studied and tested so as to determine the storage modes (mass versus widespread), technology adapted to suit each application and its optimal storage location and dimensioning.

Given the omnipresence of new hydrogen applications in the everyday life of citizens, managing social adhesion is fundamental.

Vision 4: a local renewable hydrogen economy forming a network across the region

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decentralised hydrogen production</strong></td>
<td>Synergies with the biomass sector, with renewable energy, the power grid and the natural gas grid, in particular within buildings, electric vehicles and natural gas for vehicles</td>
</tr>
<tr>
<td><strong>Widespread hydrogen uses</strong></td>
<td><strong>Infrastructure</strong></td>
</tr>
<tr>
<td>Transport: electric ships or land vehicles (fuel cell alone and/or in hybrid mode with batteries), combustion engines vehicles using a Hythane® type mixture</td>
<td>Widespread dispersed production throughout the nation and close to the site of use:</td>
</tr>
<tr>
<td>Small and medium-scale cogeneration (hydrogen, natural gas, biomass, biogas)</td>
<td>• Microgrids on a city or county-wide scale</td>
</tr>
<tr>
<td>Energy supply to mobile objects (micro-computers, telephones, multimedia objects)</td>
<td>• Use of local natural gas circuits</td>
</tr>
<tr>
<td>Emergency back-up power generators (data centres, hospitals, etc.)</td>
<td>• Network of hydrogen and/or Hythane® vehicle refill service stations</td>
</tr>
<tr>
<td>Auxiliary power units (aeronautical applications, the maritime industry, etc.)</td>
<td>• Hydrogen production devices directly installed in private households or service stations</td>
</tr>
<tr>
<td>Hydrogen uses for small industrialists</td>
<td>• Widespread storage facilities</td>
</tr>
</tbody>
</table>

Skills and stakeholders

- New skills: decentralised hydrogen production, transport and storage, production of electricity and heat by cogeneration, microgrid management
- The important role played by small electricity producers and biomass site operators, local stakeholders (SMEs and regional authorities) and major industrialists benefiting from a high local component

Economic aspects

- High storage costs

Social aspects

Generalisation of user contacts with hydrogen and fuel cell applications, proximity of users with production sites and distribution networks
Vision 4 corresponds to a situation involving the decentralisation of decision-making processes in the energy field. The integration of different energy carriers (electricity, gas, hydrogen) results in optimising the management of energy microgrids according to the energy demand and local availabilities (biomass, natural gas, electricity). This requires an in-depth transformation of the energy markets, which can only result from a strong political desire both on a national and local level.

With regard to the issue of infrastructure deployment costs, this vision leads to savings made in terms of numbers as opposed to vision 3, where most savings are made in terms of scale. The risk involved is also lower than in vision 3 as the investments are smaller and can be supported by a larger number of stakeholders.

The technological obstacles described in visions 2 and 3 (hydrogen production by electrolysis, new decentralised production methods, cogeneration, widespread hydrogen storage, hydrogen vehicles) must be overcome for this vision to develop.

As in vision 3, the advantages of hydrogen in terms of flexibility and modularity must be exploited and social feasibility issues must be handled as a priority.

**Summary**

In a caricatural manner, as illustrated in figure 4 below, the four 2050 visions can therefore be differentiated by:

- the way in which hydrogen is used: visions 1 and 2 correspond to industrial hydrogen, whereas visions 3 and 4 correspond to hydrogen for energy purposes.
- the nature of the hydrogen used: visions 1 and 3 use low-carbon hydrogen, whereas visions 2 and 4 use renewable hydrogen.

The characterisation of these potential future visions raises the following two points:

- hydrogen energy applications must be widespread and only involve two of the four visions provided. Industrial uses, although not the topic of this roadmap, act as a reference scenario and may lead to the emergence of low-carbon or renewable hydrogen production.
- the deployment of fuel cells will capitalise on the widespread uses of hydrogen energy (visions 3 and 4), however is also possible outside of these scenarios. The use of other fuels (natural gas, biogas) will lead to the discovery of applications despite the industrial use of hydrogen (visions 1 and 2).
5 Obstacles and levers

Some background elements, external to the hydrogen energy and fuel cells industry, will more particularly influence the deployment of this technology on a national level.

Carbon constraint, in addition to the price of fossil fuels and electricity, firstly affect the competitiveness of these applications. These also affect national energy systems, which evolve under the influence of other technology and other factors: degree of decentralisation, deployment of renewable energy (RnE), penetration of electric vehicles, etc. Finally, the success or failure of initiatives conducted abroad on the same themes will create favourable or unfavourable conditions affecting the development of this technology in France: the development of early markets and mobile applications is closely connected, for example, to the emergence of international markets.

However, obstacles or stumbling blocks specific to the development of the national industry also exist. These obstacles vary in nature.

Technico-economic obstacles

Some technical and economic challenges must firstly be overcome: these are essentially based on optimising current technological building blocks as far as making industrialisable products available at controlled costs. In a general manner, the deployment of this industry does not depend on the emergence of technological breakthroughs.

With regard to fuel cells, the integration of components into systems, extending their life span, improving their reliability and the low-cost industrial implementation of this technology make up the main most common obstacles. For each piece of fuel cell technology, specific obstacles must also be overcome, such as reducing the quantity of precious metals implemented for low-temperature fuel cells, corrosion and resistance to extreme temperatures for high-temperature fuel cells, etc.

In the field of hydrogen energy, the feasibility of CCUS will be decisive in the implementation of a steam reforming industry for natural gas emitting low levels of greenhouse gases. High and low-temperature electrolysis methods and hydrogen storage technology must also be optimised in addition to their industrialised manufacture.

Socio-economic obstacles

The applications implementing hydrogen energy and fuel cells are today confronted with a lack of regulatory framework and adapted standards, with current regulations only recognising the industrial production and storage of hydrogen. A shared, improved understanding of the technological risks associated with all possible applications — hydrogen production, storage and transport or fuel cell applications in uses — must lead to the definition of specific regulations ensuring a high level of security while not overestimating these risks.

Collective representations or images can also act as a stumbling block with decision-makers and the potential users of this technology. In France, “hydrogen fear” is often mentioned, reflecting the high concerns on the technological risks connected to its use. These observations and expectations can be penalising if not taken into account.

Economic and industrial obstacles

The economic maturity of this industry can only be achieved in the medium-term, as applications shall only become competitive in a gradual manner with regard to reference technology. Some of the investments required also appear to be rather consequent in size, for example with regard to hydrogen production or hydrogen distribution and storage infrastructures in widespread environments. Finally, this industry is based on various economic and industrial stakeholders boasting multiple skills, none of which control the entire technological chain.

The economic and industrial risk is therefore high for these stakeholders and may lead to a certain wait-and-see attitude: the production of hydrogen energy therefore depends on the
development of fuel cell applications, which itself depends on the development of hydrogen distribution infrastructures, etc. Risk management in these transition phases of the deployment of this industry is a key element for success.

The table hereinafter specifies the nature of the main obstacles for each 2050 vision and their relative significance:

<table>
<thead>
<tr>
<th>Vision</th>
<th>Technico-economic obstacles</th>
<th>Socio-economic obstacles</th>
<th>Economic and industrial obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision 1</td>
<td>++ feasibility of CCUS</td>
<td>+ regulatory aspects alone</td>
<td>+ lack of carbon constraint</td>
</tr>
<tr>
<td>Vision 2</td>
<td>++ cost of renewable hydrogen</td>
<td>+ local producers, regulations</td>
<td>++ widespread industrial supply throughout the nation</td>
</tr>
<tr>
<td>Vision 3</td>
<td>++ feasibility of CCUS, mass hydrogen storage</td>
<td>++ fuel cell users-consumers, regulations</td>
<td>++ distribution infrastructures, long-term profitability</td>
</tr>
<tr>
<td>Vision 4</td>
<td>++ cost of renewable hydrogen</td>
<td>++ adhesion of local decision-makers and consumers, regulations</td>
<td>++ local circuit-type infrastructures</td>
</tr>
</tbody>
</table>

Three decisive levers have been determined for overcoming these obstacles.

**Political support**

Long-term support from the public authorities is required on several levels. They are firstly and in part responsible for defining an appropriate regulatory framework and standard. The public authorities are also at the very heart of the strategic decisions directing the developments of the national energy system, including power grids: the integration of hydrogen energy and fuel cells in this system requires this technology to be taken into account in these strategic decisions. Finally, politically supporting this industry via investment support mechanisms and via increased awareness of the environmental issues involved with this technology, may contribute to reducing the economic and industrial risks that must be assumed by the stakeholders.

**Social acceptability**

The 2050 visions based on the widespread use of hydrogen, involve a level of proximity between the users and decision-makers and the hydrogen and fuel cell technology: proximity by their standard integration into buildings and transport; proximity by their connection with renewable energy; by the presence of storage and distribution infrastructures throughout the nation. This technology will be all the more accepted and desired if it meets the following social needs or expectations: contributes to the environmental objectives, increases the service provided in the field of electric mobility, assures the security of electricity supply for sites, etc.

**Committed major French industrialists, associated with an SME fabric**

Given the stationary and mobile applications targeted, the deployment of this technology cannot be considered without the involvement of major energy operators, in addition to industrial manufacturers such as car manufacturers. The industrialisation of technology and deployment of storage and distribution infrastructures also requires significant investments that can only be made by industrial groups. Their commitment however is intertwined with the development of a fabric of specialised SMEs as the industry requires the implementation of complex and varied skills.
The Grenelle de l’environnement sets the objectives to be reached by the year 2020 for all fields of activity on a national scale.

This is the year by which some technological, organisational or socio-economic effects must be observed so as to reach the Factor 4 objective for the year 2050.

In the field of hydrogen energy and fuel cells, the panel of experts has identified four strategic areas for development in the medium-term, outlined below: these approaches, or pillars, correspond to key applications, the feasibility of which must be determined by the year 2020 in view of maintaining the maximum potential of this industry for the year 2050. These are the points of passage or the technological progress required for the aforementioned 2050 visions to be realised. A fifth strategic and transversal pillar complements this 2020 vision and supports the four other pillars.

**Pillar 1: hydrogen convergence and renewable energy**
"Hydrogen by RnE, hydrogen for RnE"

**Pillar 2: new generation electric mobility**
"Extending the electric vehicle markets"

**Pillar 3: fuel cells and hydrogen working towards a sustainable city**
"Fuel cells and hydrogen at the very heart of eco-districts and smart grids"

**Pillar 4: hydrogen and fuel cells, carriers of international growth**
"Exporting the energy technology of tomorrow"

**Pillar 5: transversal support measures for this industry**
Pillar 1: hydrogen convergence/renewable energy

The deployment of hydrogen applications in harmony with renewable energy makes up the first strategic approach. This involves confirming on the one hand the technical and economic feasibility of decentralised hydrogen production and storage from different renewable energy sources, irrelevant of the hydrogen downstream use. On the other hand, this involves confirming the interest in using renewable energy in the form of hydrogen and the benefits provided by this energy carrier in terms of modularity and flexibility; the use of unavoidable renewable electricity\(^\text{11}\) that cannot be injected into the power grid, local energy storage within a building or sector, intermittence management for an isolated power grid, etc.

By the year 2020, a renewable hydrogen production capacity of 100 MW (i.e. 3 tonnes of hydrogen per hour) could be selected as an achievable objective, with downstream energy or industrial use. Hydrogen and fuel cells could also represent 5 to 15% of the market for new energy storage needs including reinjection into electricity and/or natural gas grids.

Pillar 2: new generation electric mobility

Hydrogen and fuel cell applications in the field of mobility, and more particularly the demonstration of their complementarity with privately-owned electric vehicles makes up the second major challenge for the year 2020. Their integration into battery-driven vehicles will extend the autonomy of these vehicles and reduce charging times, thus creating a new generation of electric mobility. Hydrogen applications in this field must be represented by a fuel cell/battery hybridisation, which can be considered at different scales, from vehicles almost exclusively driven by fuel cell to electric vehicles equipped with an auxiliary fuel cell (referred to as a range extender).

The first applications could involve captive fleets, as these can be fed by dedicated infrastructures. Industrialists estimate that, by the year 2020, part of the technico-economic obstacles could have been overcome, thus enabling vehicles equipped with fuel cells to be pre-commercially deployed for private consumers. This deployment is based on the existence of a minimum hydrogen refuelling infrastructure at this time.

\(^{11}\) Quantity of energy inescapably present or trapped in certain processes or products, which may at least in part be recovered and/or used.
Pillar 3: fuel cells and hydrogen working towards a sustainable city

The energy and environmental potential of fuel cells could lead to varied stationary applications promoting the notion of a sustainably city in addition to energy-positive buildings and sectors, and power grids. The use of fuel cells in association with decentralised hydrogen production and storage will optimise energy flows locally: cogeneration, managing local energy supply and demand by storage means, using the renewable energy available, interconnection between gas and electricity smart grids, etc. The use of hydrogen combined with natural gas in the form of a mixture such as Hythane® for local uses also makes up part of this national vision.

The mass market deployment of medium-scale cogeneration systems appears achievable for the year 2020 with small-scale cogeneration at this date reaching a phase of maturity with 5,000 to 10,000 systems installed. According to industrialists, hydrogen and fuel cells would thus represent 10 to 20% of the market for energy-independent buildings and sectors. These deployment operations could revolve around 10 to 20 cities or eco-districts supplied by local hydrogen or natural gas distribution networks.

Pillar 4: hydrogen and fuel cells, carriers of international growth

The markets showing the highest potential for the hydrogen and fuel cell industry are primarily located abroad and more particularly in developing or transition economies, in which power grids may be defective and where the automotive market is growing. Conquering international markets makes up the fourth strategic approach for developing the French industry: French stakeholders are able to position themselves on several high added value links within the value chain, such as high-pressure storage, low-temperature electrolysis, systems integration and more generally on all early applications.

By the year 2020, export could represent 50% of the turnover of French stakeholders in the hydrogen and fuel cell industry, thus positioning the latter as a national growth vector.

Pillar 5: transversal support measures for this industry

The four aforementioned strategic approaches can only be pursued if support measures are set up in parallel for these industries. The purpose of these measures is to overcome some of the aforementioned socio-economic obstacles: defining an appropriate regulatory framework and standard, support policies via economic and/or tax mechanisms, awareness, communication and training programmes.
7 Research priorities, demonstrator needs

The 2020 vision highlights priorities in terms of research works and identifies the preindustrial or research demonstrator needs that appear to be the most important in terms of strategy. These must be used to guide actions undertaken in the short and medium-term.

Pillar 1: hydrogen convergence/renewable energy

<table>
<thead>
<tr>
<th>Research priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 R&amp;D on hydrogen production: no particular path must be prioritised or excluded. Research works must involve all methods (low-temperature electrolysis, high-temperature electrolysis, biomass).</td>
</tr>
<tr>
<td>1.2 Technico-economic system studies: this involves validating the technico-economic interest in producing and using hydrogen derived from renewable energy sources. These works must be based on developing economic models and scenarios and on identifying economic and financial support mechanisms which are essential to this industry.</td>
</tr>
<tr>
<td>1.3 Technico-economic studies for the feasibility of smart energy grids: the potential shown by hydrogen and fuel cells in optimising power grids must be confirmed. These works must specify the challenges and obstacles to be overcome.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demonstration actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 Demonstration projects for renewable energy use via hydrogen as an energy carrier: hydrogen use could be energy-based (captive vehicle fleets, electricity and heat production, etc.) or industrial in nature (refinery, steelworks, second generation biofuels, etc.) and substitute non-renewable energy sources.</td>
</tr>
<tr>
<td>1.5 Demonstration projects for unavoidable hydrogen use: the use of 1,000 tonnes of unavoidable hydrogen on an industrial site for energy-based hydrogen applications.</td>
</tr>
</tbody>
</table>
## Pillar 2: new generation electric mobility

### Research priorities

| 2.1 | **R&D on PEMFCs, embedded storage and systems**: works will aim at optimising performance costs in terms of fuel cell life and according to the materials chosen for hydrogen storage systems. |
| 2.2 | **Technico-economic study for the national deployment of a hydrogen infrastructure for the automotive industry**: this involves exploring the problems within the economic model and identifying the most relevant approach for deploying a large-scale infrastructure on a national level using the available resources and infrastructures. |

### Demonstration actions

| 2.3 | **Demonstration projects for fuel cell-driven vehicles on captive fleets/tests in 2 to 5 cities**: captive fleets form priority targets in view of a 5-year industrial validation operation while looking to minimise supply infrastructure costs. No particular architecture or degree of fuel cell/battery hybridisation must be prioritised. |
| 2.4 | **Demonstration projects for fuel cell-driven vehicles on captive fleets**: this involves deploying vehicles in larger fleets (rental agencies, major groups and service companies), preparing for commercial deployment. |
| 2.5 | **Demonstration projects on the “ship of the future”**: the integration of fuel cell systems in river or sea vessels providing traction or as an auxiliary system could also be demonstrated. |

## Pillar 3: fuel cells and hydrogen working towards a sustainable city

### Research priorities

| 3.1 | **R&D on SOFC small and medium-scale cogeneration**: research actions must lead to reductions in manufacturing costs while ensuring optimal system reliability and sustainability. |

### Demonstration actions

| 3.2 | **Coordinated systems tests for stationary domestic small-scale and medium-scale cogeneration systems**: multisite tests for a dozen fuel cell-type demonstrators will validate the integration of these systems according to the user profiles and installation conditions connected to residential, tertiary or industrial buildings. |
| 3.3 | **Coordinated systems tests for storage and generation in buildings**: similarly, multisite tests shall be based on fuel cell systems associated with decentralised hydrogen production and integrated storage within buildings. |
| 3.4 | **Demonstration project for injecting low-carbon hydrogen into natural gas pipelines**: this involves validating the technico-economic feasibility throughout the chain — compression, buffer storage, transport, distribution — by developing the regulatory framework and standard. |
| 3.5 | **Demonstration projects uniting complete renewable hydrogen chains into local circuits**: 10 to 15 experiments based on the production, distribution and local use of renewable hydrogen for various different purposes (captive fleets, urban transport, small and medium-scale cogeneration) will demonstrate, on different scales, the applicational diversity and flexibility of hydrogen and fuel cell technology. |
| 3.6 | **Demonstration project for a smart energy grid on the scale of a city or eco-district**: upstream of the end energy uses, the potential shown by hydrogen in optimising the management of gas and electricity power grids could be demonstrated within the scope of specific projects. |
| 3.7 | **Deploying Hythane®-type vehicle fleets**: the use of a natural gas/hydrogen mixture in captive fleets such as buses or household waste collection trucks is essential to this industry and its adoption by local decision-makers and users. |
Pillar 4: hydrogen and fuel cells, carriers of international growth

**Demonstration actions**

4.1 **demonstrating special off-road vehicle fleets (auxiliary units, logistics vehicles, handling equipment):** this involves fitting 3 to 4 logistics platforms (airport or seaport sites, etc.) with fuel cell technology demonstrating its specific interest and logistics integration into this type of platform, and developing the regulatory framework and standard in view of deployment.

4.2 **Demonstration projects for emergency back-up applications and power supply for isolated sites:** similarly, these projects will finalise the implementation of fuel cell technology according to these strategic uses in view of subsequent deployment on a national or international scale.

Pillar 5: transversal support measures for this industry

Supporting the development of this industry does not make up a research priority or demonstrator need. However, the panel of experts would nonetheless like to specify what these measures could be, as these also affect the ultimate success of the research and demonstration actions.

**Public support mechanisms**

5.1 **Public equipment orders:** the deployment of some applications could be supported in this manner, including: vehicles equipped with fuel cells for captive fleets, in connection with the national support plan for rechargeable electric and hybrid vehicles; Hythane®-type vehicles with supply infrastructures; emergency back-up units and power supply for isolated sites (hospitals, telecommunication relays).

5.2 **Setting up tools for managing industrial risks:** this type of tool must be drawn up in collaboration with all stakeholders and in particular with those active in the bank and insurance sectors.

5.3 **Financial support and incentive measures:** the classic mechanisms that may be mobilised vary in nature: grants for investments in fuel cells according to the power installed, contributions to investments made for hydrogen storage and distribution infrastructures, purchase price for the electricity generated, tax exemptions, regulatory mechanisms such as the "green certificate" applied to hydrogen distribution, the duty to renew emergency back-up units, etc.

**Specific measures**

5.4 **Coordination and control structure:** such a collective structure would represent the stakeholders to the public authorities and conduct strategic operations for this industry, in particular with regard to standards and regulations.

5.5 **Assessing future training needs:** the deployment of applications connected to hydrogen and fuel cells will require personnel (technicians, engineers) trained in many different fields. These needs must be assessed and the most relevant training approaches identified.

5.6 **Communication and awareness:** the social adhesion to this industry of decision-makers and citizens passes by public communication and awareness campaigns. These campaigns will both raise awareness to the applications and issues connected to hydrogen and fuel cells and lead to a better understanding of public expectations.
Contribution of the strategic approaches to overcoming the challenges faced

Pursuing the research works identified and conducting demonstration actions will enable us to exploit the full potential offered by hydrogen energy and fuel cells. The summary table below specifies the contribution made by each pillar to the energy and environmental challenges previously identified.

<table>
<thead>
<tr>
<th>CHALLENGES</th>
<th>Pillar 1</th>
<th>Pillar 2</th>
<th>Pillar 3</th>
<th>Pillar 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy independence and reservation of resources</strong></td>
<td>Production of renewable hydrogen</td>
<td>Renewable hydrogen applications</td>
<td>Renewable hydrogen applications</td>
<td></td>
</tr>
<tr>
<td><strong>Reducing widespread CO₂ emissions</strong></td>
<td>Production of renewable hydrogen</td>
<td>Low-carbon hydrogen applications</td>
<td>Low-carbon hydrogen applications</td>
<td></td>
</tr>
<tr>
<td><strong>Development of energy grids</strong></td>
<td>Management of intermittences and storage, balancing supply and demand</td>
<td>Interconnections between local energy grids</td>
<td>Emergency back-up systems, strengthening isolated grids</td>
<td></td>
</tr>
<tr>
<td><strong>Reducing pollution in urban areas</strong></td>
<td></td>
<td>Reduced-impact mobility</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Improving energy efficiency within buildings</strong></td>
<td></td>
<td></td>
<td>Efficient production of electricity and heat</td>
<td></td>
</tr>
</tbody>
</table>
Foreign programmes promoting the development of hydrogen and fuel cells

I – Germany

The National Innovation Program (NIP) is a hydrogen and fuel cell development programme associating German industrialists and scientists, initiated in 2007 with support from the government. It is mobilising a budget of 1.4 billion Euros over a ten-year period, half of which is comprised of federal budgets and half of which originates from contributions made by industrialists within this industry. This programme revolves around two development plans in the field of transport and stationary applications. 30% of the funds have been allocated to R&D projects and 70% to demonstration projects and for preparing market development.

The programme is managed by an independent and dedicated structure: the NOW, National Organisation Wasserstoff-und Brennstoffzellen-technologie. A specific governance system brings together the political, industrial and scientific objectives, thus easing the creation of an industrial policy on hydrogen in the long-term. Four German federal government ministries are involved: The Ministry of Transport, the Ministry of the Economy and Technology, the Ministry of Education, and the Ministry of the Environment.

Transport: the H2Mobility Plan

In the field of transport, Germany is developing the concept of electric mobility, which associates both the development of battery-powered vehicles and that of fuel cell-powered vehicles. More specifically, an agreement protocol, H2 Mobility, was signed in September 2009 by the Linde, Air Liquide, Air Product, Daimler, EnBW, NOW, OMV, Shell, Total and Vattenfall companies, the purpose of which is to deploy a hydrogen infrastructure for the mass production of hydrogen-based vehicles in 2015.

This agreement provides for the drawing up and validation of an economic model by the year 2015 during an initial non-binding phase for stakeholders. If the results are conclusive, car manufacturers (including Daimler, Ford, GM, Honda, Hyundai, Nissan and Toyota) will commit to producing several hundreds of thousands of hydrogen vehicles for the year 2015, whereas energy and gas companies will set up the infrastructure required to supply vehicles with hydrogen. The year 2015 will therefore probably represent a point of reinforcement or change in German strategy in terms of electric mobility.

Stationary applications: The Callux programme

The German programme Callux aims at easing the deployment of small-scale domestic cogeneration systems. As an integral part of the NIP, the first phase of this programme aims at installing several hundred small-scale domestic cogeneration systems which will remain in operation for eight years. The purpose of this first phase, which ends in 2012, is to demonstrate the techno-economic viability of this solution in view of mass deployment by the year 2015. This project costs a total of 84 million Euros, 40 million Euros of which is financed by the Ministry of Transport and Buildings. This budget supports 50% of the investment made to acquire the equipment required. One of the main advantages of this programme is its ability to mobilise all stakeholders involved in this market around precise objectives: heating system developers and fuel cell integrators (Vaillant, Viessmann, Baxi Innotech, Hexis), leading energy suppliers (EnBW, E.ON, EWE, MVV, VNG) and the scientific community (Center for Solar Energy and Hydrogen Research in Stuttgart).
2 – The United States

After having exerted its political leadership at the beginning of the 2000s during the Bush administration, the American federal government now appears much more cautious with regard to industrial avenues involving hydrogen in the transport sector. The priority here appears to be given to electric vehicles fitted with rechargeable batteries and second and third generation biofuels. Some leading groups such as General Motors however continue to develop R&D in the transport sector.

Higher commitments are shown in the development of short and medium-term mobile and stationary applications, which is supported by the Department of Energy (DoE) via its US National Hydrogen & Fuel Cell Program. Some specialists such as Fuel Cell Energy, Plug Power, UTC or gas companies such as Air Products appear to be consolidating their positions on early markets such as small and medium-scale cogeneration, emergency back-up power (benefiting from certain structural weaknesses in the power grid, the occasionally very high carbon content of electricity in some American states and allowances available) and material handling equipment. Moreover, the Department of Defense (DoD) remains a prime contractor and regular purchaser of equipment, thus directly or indirectly financing a certain number of development costs for equipment manufacturers within this industry.

In parallel to the support provided on a federal level, industrialists can count on a certain number of large initiatives which stimulate or support local demand, for example:

- The California Self Generation Initiative, which grants allowances for facilities of up to 5 MW, using different types of renewable fuels or natural gas.

Finally, it should be noted that approximately one hundred hydrogen service stations exist throughout the country, sixty of which are in operation (and thirty of which are located in California alone, twenty of these being on the Hydrogen Highway).

3 – Japan

The Japanese strategy revolves around identifying transversal synergies with other political priorities (concerning transport, energy and the environment), in addition to vertical synergies in national conglomerates (for example, Kyocera, Panasonic, Nippon Oil, Toshiba or Toyota).

According to the Industry Review 2010 published by FuelCellToday, Asia – and mostly Japan – boasted more than 50% of the fuel cell systems installed throughout the world over the last three years, mainly concerning mobile and stationary applications. The residential stationary segment was supported by the Japanese Large Scale Fuel Cell Demonstration Program. Launched in 2009, the Ene Farm programme, which groups together Tokyo Gas, Osaka Gas, Nippon Oil, Toho Gas, Saito Gas Co and Mitsubishi Corporation, targeted marketing 5,000 residential small-scale cogeneration systems in its first year alone. This objective was achieved, in particular thanks to government aids totalling a sum of 1.4 million Yens (i.e. €12,500), covering 50% of the investment costs. The system set up by the government in 2005 provides for progressively reducing public grants according to the sales volumes and therefore aims at easing market introduction.

In the automotive sector, the Toyota group remains the undisputed international leader in terms of developing fuel cell vehicles.
Hydrogen and fuel cells benefit from support from the European Commission via its seventh European Framework Programme for Research and Technological Development (FPRTD 7) and the Strategic Energy Technologies Plan (SET PLAN). This support is more particularly shown by a public-private partnership, established in 2008 and known as the Fuel Cells and Hydrogen Joint Undertaking (FCHJU), between the European Commission, world industry and research organisations.

The purpose of this partnership is to implement a programme for research, technological development and demonstration activities (RTD&D) so as to accelerate the development and marketing of hydrogen and fuel cell technology. To this end, the FCHJU boasts a budget of 470 million Euros originating from the seventh FPRTD for 2007-2013, to which can be added an equivalent investment made by the industry. A multi-year plan setting out the strategic priorities in terms of RTD&D has been jointly drawn up by the European Commission and the Directorate-General for industry and research. This plan, which clearly influences European political and industrial priorities, is broken down each year into work programmes. Therefore in 2010, a total budget of 89.1 million Euros was dedicated to RTD&D activities by the European Commission, complemented by a contribution from the General-Directorate for Industry.

The FCHJU also benefits from support from the Member States and Countries associated with the 7th FPRTD, united within a consultation group: the Fuel Cell and Hydrogen States Representatives Group. This group acts as an interface between the FCHJU and Member States.

The European Regions and Municipalities Partnership for Hydrogen and Fuel Cells (HyRaMP) was founded in 2008 and groups together more than thirty European regions showing interest in or active with regard to hydrogen and fuel cells. The role of the HyRaMP is to represent the regions’ interests to the FCHJU and other European stakeholders within this industry. The partnership therefore set itself the objective of promoting the standardisation of regional activities and financing operations throughout Europe, and the development of joint projects, in particular to promote the deployment of a hydrogen infrastructure. Some French regions are stakeholders in this partnership: Midi-Pyrénées, Pays de la Loire, Rhône-Alpes.
ABOUT ADEME

The French Environment and Energy Management Agency (ADEME) is active in the implementation of public policy in the areas of the environment, energy and sustainable development. To enable them to establish and consolidate their environmental action, ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large. As part of this work the agency helps finance projects, from research to implementation, in the areas of waste management, soil conservation, energy efficiency and renewable energy, air quality and noise abatement.

ADEME is a public agency under the joint authority of the Ministry of Ecology, Sustainable Development and Energy, and the Ministry for Higher Education and Research.