

# TECHNICAL REVIEW

## THE ROLE OF HYDROGEN IN THE ENERGY TRANSITION

March 2018<sup>(1)</sup>

### Key Points

Based on the technological developments and experiments conducted in recent years, we can conclude that hydrogen will contribute to the energy and ecological transition in four major ways:

- As part of a future energy mix that draws substantially on renewable energy sources (solar, wind, hydropower), **hydrogen offers solutions for improved, more flexible power grids**. First, since hydrogen is a gas, it is **storable** and can be used to offset the fluctuations in renewable energies and energy use over time. Moreover, using a power-to-gas system, **hydrogen provides a way to gradually reduce the carbon content of gas grids** and related applications.
- **The storage options made possible by hydrogen technology offer new opportunities for self-consumption within a building, a city block or a small community**. That storage is based on the complementary nature of short-term battery storage and a hydrogen chain, which can store energy for days, weeks or months. A solution of that kind has genuine economic appeal for locations that are not connected to the continental power grid, such as communities in France's overseas territories.
- **Onboard hydrogen offers new solutions for electric transportation**, and heavy vehicles in particular, and can also ensure greater autonomy and availability for light-duty vehicles. As a priority, that includes **commercial vehicles**, whether they operate by land, sea, river or rail. The technology for hydrogen-based transportation is still costly, and as with any emerging technology, the future experimental and testing phases require financial support in order to boost vehicle demand and accelerate commercial scale-up. It appears that, over time, viable financial models for commercial, hydrogen-based electric transportation are attainable.
- The industry is currently using more than 900,000 tonnes of hydrogen per year, produced from fossil fuels; that represents 7.5% of the greenhouse-gas emissions attributable to French industry. **The challenge is to improve existing processes and replace fossil-fuel hydrogen with hydrogen from renewable resources whenever possible**.

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## 1. Introduction: Context and Issues

This technical review discusses the various roles that hydrogen will need to play in the ecological and energy transition in order to combat climate change and reduce the impact of human activity on health and ecosystems.

### 1.1. Managing energy needs and energy efficiency above all else

It is important to note at the outset that the energy transition is based first and foremost on actions to reduce energy consumption and improve energy efficiency in every sector. The use of hydrogen as an energy carrier will offer solutions, flexibility and services for making that transition, but it should not prompt us to cut back on the efforts we need to take, notably with regard to managing both energy needs and energy efficiency.

ADEME's recently updated Energy-Climate Scenario for 2035-2050<sup>1</sup> notes that several steps must be taken in order to meet our objectives for reducing final energy consumption (by 50% between now and 2050) and greenhouse gas emissions (by 75% over the same period), including:

- With regard to building construction and urban planning: greater reliance on low-consumption and positive-energy buildings, with the goal of completing low-consumption renovations in France by 2050; steps to maintain comfort while reining in specific applications for electricity; the use of increasingly energy-efficient equipment; more rational rules for commercial land use, etc.
- With regard to transport: reductions in the number of personal cars and a shift to new transportation methods and practices (carpooling, car sharing, the use of mobility services); broader adoption of electric and gas-powered vehicle engines; slower growth in goods transport through restructured logistics; a shift to rail, rivers and seas for transport instead of roads, etc.
- With regard to manufacturing and industrial processes: improvements in more energy-efficient production technology, more extensive capture of unused energy or energy byproducts such as heat, the use of ecodesign, optimal energy coordination in business environments through improved monitoring, etc.

**In all of these areas, the use of hydrogen as an energy carrier will be more effective if it is accompanied by measures to reduce energy needs and manage energy efficiency.** For example, a vehicle equipped with a hydrogen fuel cell will have less impact on the environment if it has also been designed to be as lightweight as possible and will be carrying several passengers at once or will be shared among several users.

### 1.2. Four major contributions to the energy and ecological transition

Given the support provided to regional innovation and demonstration projects in the past few years, the prospective studies that have been conducted recently and changes in the energy environment in a number of sectors, ADEME has revised its views on hydrogen's role in the energy and ecological transition<sup>2</sup>. The challenges to be addressed over the coming years fall into four major categories:

- Creating more flexibility in energy networks
- Encouraging self-consumption of renewable energy at the local level
- Providing clean, flexible transport solutions
- Reducing the impact of industrial use of fossil-fuel hydrogen

<sup>1</sup> [Actualisation du scénario énergie-climat ADEME 2035-2050 \[ADEME updated energy-climate scenario, 2035-2050\], October 2017](#)

<sup>2</sup> These factors are currently being taken into account in ADEME's new forecasting exercise regarding 2019 and 2020 for the 2035-2050 energy-climate scenarios.

## 2. Creating more flexibility in energy networks

### 2.1. Renewable electrical energy is expanding

There are multiple benefits to developing renewable energy sources<sup>3</sup>: they reduce greenhouse-gas emissions, provide a more secure energy supply, stabilize costs, ensure energy independence, and return jobs and value to the domestic market. ADEME is proposing an ambitious trajectory in which renewable energy's share of the energy mix increases from 15% today to 40% in 2035 and 60-70% in 2050, all sectors of use combined. Within the field of renewable electrical energy, some sectors are already competitive with conventional installations. The full cost of wind power, as determined in 2016, ranges from €57 to €91 per MWh; the full cost of photovoltaic solar power in ground-level plants ranges from €68 to €87 per MWh. But in order to reap the potential from the most significant forms of renewable energy (solar, wind), power grids will need to be strengthened and solutions will need to be devised for energy storage and flexibility.

### 2.2. Power grid balancing between seasons

Hydrogen will play a **gateway role between electric and gas grids, so that large quantities of renewable energy can be stored over long periods of time**. The stored gas is used at a later date to generate electricity to meet demand. This is known as "interseasonal storage" or "power-to-gas-to-power" between surplus periods (generally the summer) and deficit periods (generally the winter). The electrical grid will have an increasing amount of short- or medium-term power storage capacity (in the form of batteries, compressed air or hydropower plants<sup>4</sup>) with charging/discharging cycles lasting several hours or days<sup>5</sup>. The total electricity that can be stored with these methods will be about one terawatt hour per year. When the penetration rate for renewable energy exceeds 80%, interseasonal storage using hydrogen will complement the grid and provide the ability to store several dozen TWh per year in gas grids. Specifically, two forms of storage can be envisioned:

- Direct injection of hydrogen into the gas grids: hydrogen created from electricity and water through electrolysis can be injected into gas pipelines at a rate of 6% by volume at a minimum, or up to 20% under certain conditions.
- The methanization reaction that results when the hydrogen is combined with the carbon dioxide produces synthetic methane. Since that methane is similar in content to natural gas, it can readily be injected in large quantities into the natural gas infrastructure (underground storage<sup>6</sup>, transport and distribution networks).

Thus, interseasonal storage can be used for power grid balancing, by storing renewable electric power available during certain weeks or months in the form of surplus gas that can be used during a subsequent deficit period. Electricity can be produced from the stored gas by a variety of means (centralized gas turbines, fuel cell CHP in the home, etc.).

### 2.3. Using power-to-gas to decarbonize natural gas applications

Aside from interseasonal storage and power-to-gas-to-power solutions, injecting hydrogen or synthetic methane can also serve to reduce the carbon-intensive content of the current natural gas infrastructure. In that way, the traditional applications for natural gas in buildings (heating, hot water, cooking), industry or transport (CNG) could be addressed over time with an energy mix that includes hydrogen and/or synthetic methane. A recent study by ADEME, GrDF and GRTGAZ indicated that a full conversion to a 100% renewable gas-based scenario by 2050<sup>7</sup> was feasible. However, given the relatively high estimated cost of the methane obtained through a power-to-gas solution – typically from €105 to €185 per MWh<sub>PCS</sub> – this could only be a partial solution.

<sup>3</sup> ADEME Advisory Report - *Les énergies renouvelables et de récupération* [Renewable and recovered energy], December 2017

<sup>4</sup> Pumped-storage power stations (PSPS).

<sup>5</sup> An ADEME study entitled *Un mix électrique 100% renouvelable ?* [A 100% renewable electricity mix?], October 2015 defines the storage capacities (short-term, PSPS and interseasonal) that would be needed to balance the system based on specific assumptions (page 77 et seq.).

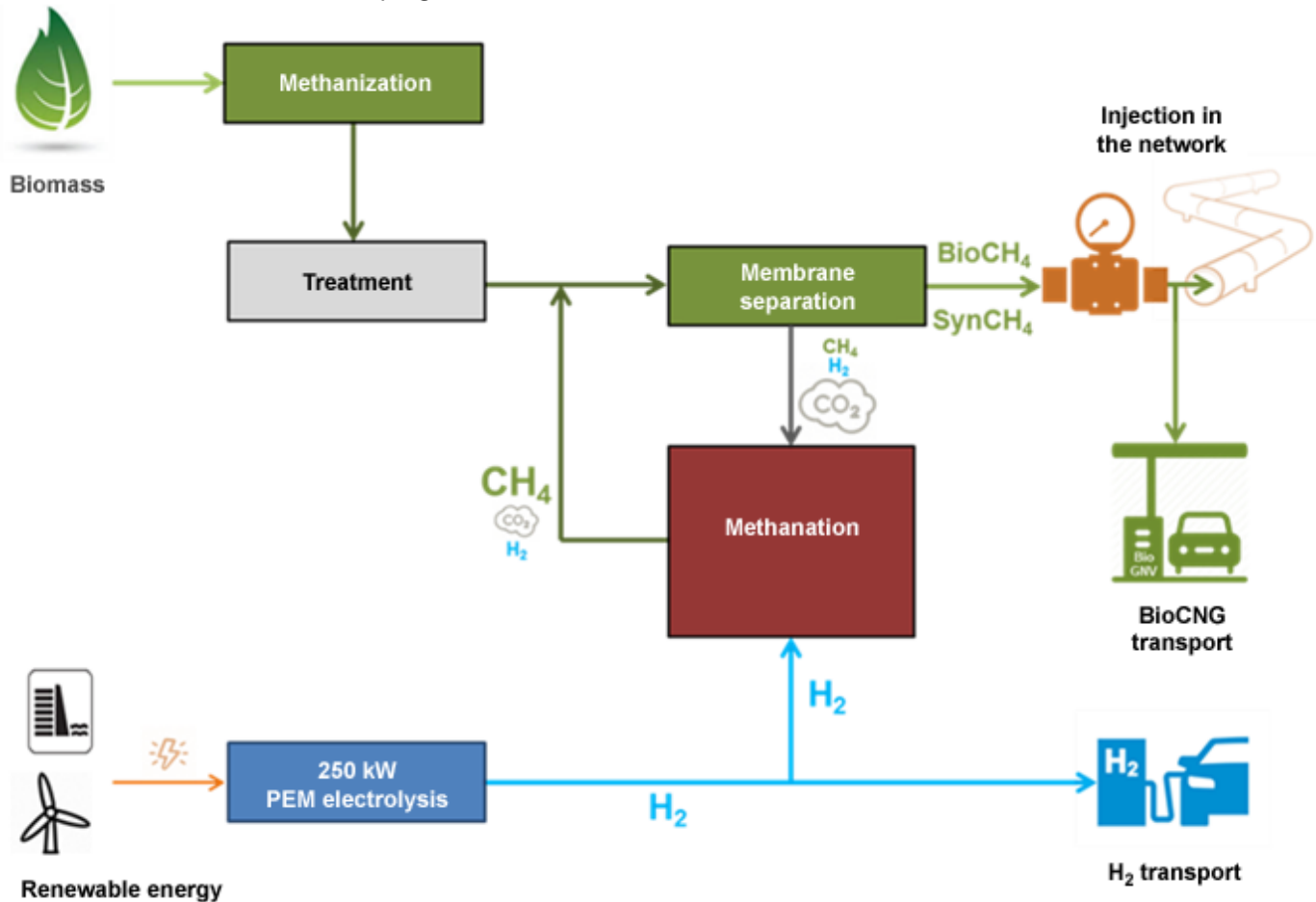
<sup>6</sup> Already, more than 140 TWh of gas can be stored underground.

<sup>7</sup> *Un mix de gaz 100% renouvelable en 2050 ?* [A 100% renewable gas mix by 2050?], January 2018

The GRHYD<sup>8</sup> and Jupiter 1000<sup>9</sup> demonstration projects currently underway in Dunkirk and Fos-sur-Mer will help to remove the technological barriers. An emerging synergy with methanization could be an important factor in the years to come. Methanization systems produce a biogas that is up to 40% carbon dioxide of biological origin and must be purified before injecting the biomethane that makes up 60% of the biogas. An electrolyzer could be used with some of those systems to recover the biological carbon dioxide and produce synthetic methane that could be injected into the gas grid. This improves the biomass recovery rate and yields an injection consisting of biomethane (60%) and synthetic methane (up to 40%). The Méthycentre project aims to demonstrate this combination and may subsequently be replicated.

### A Closer Look: The Méthycentre Project

Storengy, an Engie subsidiary, will be testing a power-to-gas demonstrator in Céré-la-Ronde in central France. The idea is to produce a synthetic gas from two sources: carbon dioxide resulting from biogas generation, and renewable hydrogen produced from electrolysis of 250 kW of surplus renewable electric power. The project will also provide an opportunity to refine the technology contributed by the project's partners: the electrolyzer (AREVA H2Gen), the methanation unit (Atmostat) and the purification membrane (Prodeval). This project is receiving support from ADEME as part of its Investments in the Future program.



<sup>8</sup> GRHYD project

<sup>9</sup> Jupiter 1000 project

## 2.4. New avenues for mobilizing renewable energy

The electrical network can also capitalize on direct recovery of hydrogen on behalf of the end applications and thereby reduce the cost of the system as a whole. Recent technical and economic simulations conducted by Artelys for ADEME show that by 2035, a power grid comprised of 64% renewable energy could supply 30 TWh of hydrogen annually for less than €5/kg – a competitive cost for applications in transport and industry. The average cost of the electricity consumed by the electrolyzers in these simulations is €42/MWh.

## 3. Encouraging self-consumption of renewable energy at the local level

While hydrogen offers solutions for managing energy networks on a large scale, it can also be used to capitalize more effectively on locally generated renewable energy, as close as possible to the point of consumption. However, this is not always justified from a technological or financial standpoint. **For individual buildings, islands or isolated communities, the need for energy autonomy can provide a justification for storing some energy in the form of hydrogen.**

### 3.1. Buildings, islands and isolated communities not connected to the grid

Mainland France has an extensive power grid that connects most points of consumption across the country. That is not the case in Corsica, on certain islands and in France's Overseas Territories, which generate their own power and have their own networks or microgrids. In those regions, power generation is dominated by oil-fired thermal power plants that run at a relatively high cost – averaging €225/MWh of generated electricity in 2013<sup>10</sup> – and face a more difficult task in balancing supply and demand than on the mainland. Campaigns to reduce electricity demand, the development of renewable energy sources and energy storage all play a predominant role. Given those conditions – which exist in other regions of the world as well, including South America, Africa and Southeast Asia – hybrid electricity storage that combines a battery and the hydrogen chain can in some cases prove profitable. The battery allows for short-term storage: it is charged during the day when the solar panels produce excess energy, and discharges in the evening and at night to cover electricity needs after sundown. The hydrogen chain provides supplemental storage in the form of reserve energy, allowing a building, island, village or community to maintain its energy independence during those days or weeks when solar power and battery storage are insufficient.

#### A closer look: the La Nouvelle project on Réunion

The village of La Nouvelle, which lies in the heart of the Cirque de Mafate volcanic caldera on the island of Réunion, has been testing a hybrid battery/hydrogen chain storage system since the summer of 2017. The project is being led by EDF SEI and SIDELEC (the association of electricity providers on Réunion), with backing from the Regional Division of ADEME. The installation includes a photovoltaic production facility (7.8 kWp), lithium batteries (15.6 kWh), an electrolyzer and fuel cell (3 kW) and a hydrogen storage system (3 kg). As a result, three buildings – the clinic, the school and the French Forestry Commission building – are 100% energy self-sufficient. If the pilot project yields conclusive results, it will be expanded to include the entire village, which will then have no further need for fuel oil to power its generators.



<sup>10</sup> France's Inspectorate General for Finance, General Council for the Environment and Sustainable Development (CGEDD) and the General Council for the Economy (CGE), *Revue de dépenses, Péréquation tarifaire de l'électricité avec les zones non interconnectées* [Spending review, Electricity tariff equalization among non-interconnected regions], October 2017.



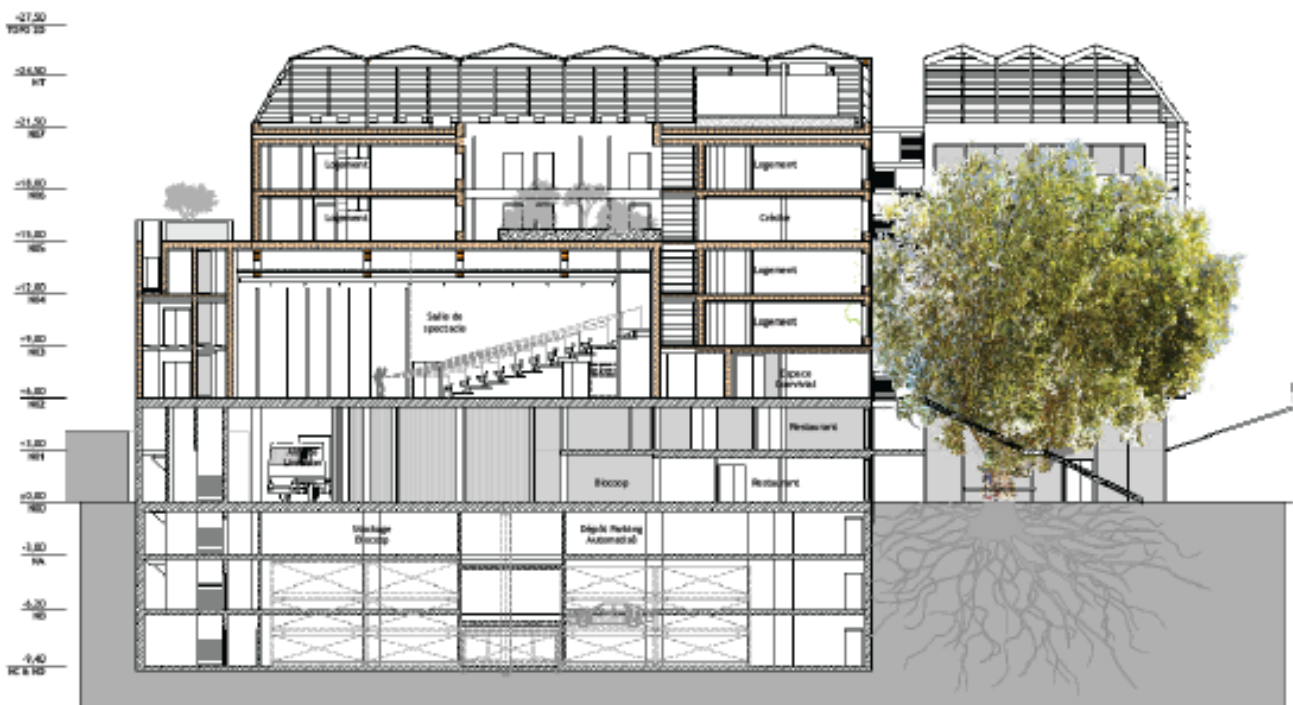
### 3.2. Ecodistricts and ecoblocks

France’s Energy Transition Law for Green Growth sets ambitious targets for buildings, including the renovation of the country’s entire built stock to “low-consumption building” standards by 2050 and the adoption of more stringent regulations for new buildings using the “energy-carbon” label (E+/C-). When connected to local power and gas networks, hydrogen and fuel cells can provide services to specific neighbourhoods or blocks of buildings, including self-supply of renewable energy:

- The principle of hybrid battery/hydrogen chain storage can be implemented for buildings or districts that produce photovoltaic power. They need not be completely energy self-sufficient throughout the year if they are connected to a local grid. On the other hand, storage can expand the service options available, such as backup power for sensitive applications, demand response as needed for the grid, new services such as digital hosting (e.g., the EcobioH2 project) or the supply of energy for electric vehicles. Such services are an essential part of the business model for this type of storage.
- With regard to connection to the gas network, a specific district or building can also produce electricity and heat by means of a gas-powered fuel cell to cover a portion of its needs. That is the principle behind micro combined heat and power (micro CHP), an option that could be even more attractive if the gas networks contain an increasing share of renewable natural gas. The power that is generated can be used onsite, or it can be reinjected into the local power grid for use in the wider area or region as needed – for example, when power demand increases during a cold snap. ADEME and GrDF are jointly planning a demonstration project in 2018 involving fifty residential fuel cells to confirm the technology’s potential. Micro CHP is also being studied in other European countries, including Germany.

#### A closer look: The EcobioH2 project

The Biocoop supermarket in the heart of Avignon will soon be renovated to create a commercial ecoblock that is home to a variety of businesses (retailers, dining establishments, lodging, cultural activities). This high-environmental-performance building, which qualifies for a Gold Mediterranean Sustainable Building label, will include a datacenter equipped with a battery/hydrogen chain hybrid storage system to offer guaranteed 100%-renewable-energy digital hosting for regional businesses and organizations. The integrated system will also include smart energy management for the entire building and its applications.



## 4. Providing clean, flexible transport solutions

### 4.1. Electric vehicles tailored to business use

Hydrogen can be stored in compressed form in an onboard tank to serve as reserve energy for traction or electric-drive vehicles. A fuel cell converts the hydrogen into electricity and heat that power the engine and also provide heating for the passenger compartment. On electric vehicles with a hydrogen fuel cell, the traction chain generally includes a battery and can be hybridized to various degrees, depending on the desired energy and power capacity for the vehicle. **Battery and fuel cell technology can now be viewed as working in tandem for electric-powered transportation.**

Their complementary nature can prove valuable for demanding applications in the area of personal or goods transport, when users are seeking low-emission vehicles that offer a high level of service:

- Improved energy self-sufficiency: commercial vehicles making deliveries, refrigerated vans and vehicles used by home service companies all travel significant distances every day or otherwise consume considerable energy.
- Payloads: battery technology alone is not sufficient to provide the energy and power that heavy vehicles need to ensure acceptable operating conditions. When designed to include both a battery and a fuel cell, heavy goods vehicles, ships, locomotives and electric buses can be used for the applications traditionally made possible by liquid fuels.
- Vehicle availability: the fact that a hydrogen tank can be filled in a matter of minutes eliminates the constraints imposed by having to wait for a vehicle battery to charge. Task vehicles (both on-road and off-road) as well as construction machinery, logistics vehicles and even some taxis are used intensively, and that requires the charging flexibility that hydrogen can provide.
- Conditions for connection to the grid: Fleets that have multiple electric vehicles can impose significant demands on the grid or may need to compete for access to the grid at the site. The use of hydrogen offers flexibility in such a case, since hydrogen production is not necessary in order to fill the hydrogen tanks. Moreover, in the rail sector, the use of hydrogen-powered locomotives offers an alternative to costly track electrification<sup>11</sup>.

The use of battery-powered electric vehicles will make it possible to address multiple transport needs, including the day-to-day travel needs of individuals. **Hydrogen-powered electric vehicles seem appropriate for applications for which conventional electric vehicles are unsuited, and private and public professional fleets in particular.**

#### A closer look: The Cathyopé Project<sup>12</sup>

French firm Green GT will be designing a high-powered (610 HP) electric-hydrogen hybrid powertrain that can be incorporated into a 44-tonne tractor-trailer. The project will include testing under actual use conditions by Transports Chabas, as it makes daily fresh food deliveries to Carrefour stores between Montpellier and Nice. These deliveries are currently being made using diesel-powered vehicles that travel 1,000 km per day. This project is receiving support from ADEME as part of its Investments in the Future programme.

<sup>11</sup> Report from the Conseil d'Orientation des Infrastructures, *Mobilité du quotidien : répondre aux urgences et préparer l'avenir* [Day-to-day transport: addressing urgent needs and preparing for the future], chaired by Philippe Duron, January 2018.

<sup>12</sup> [Cathyopé Project](#).



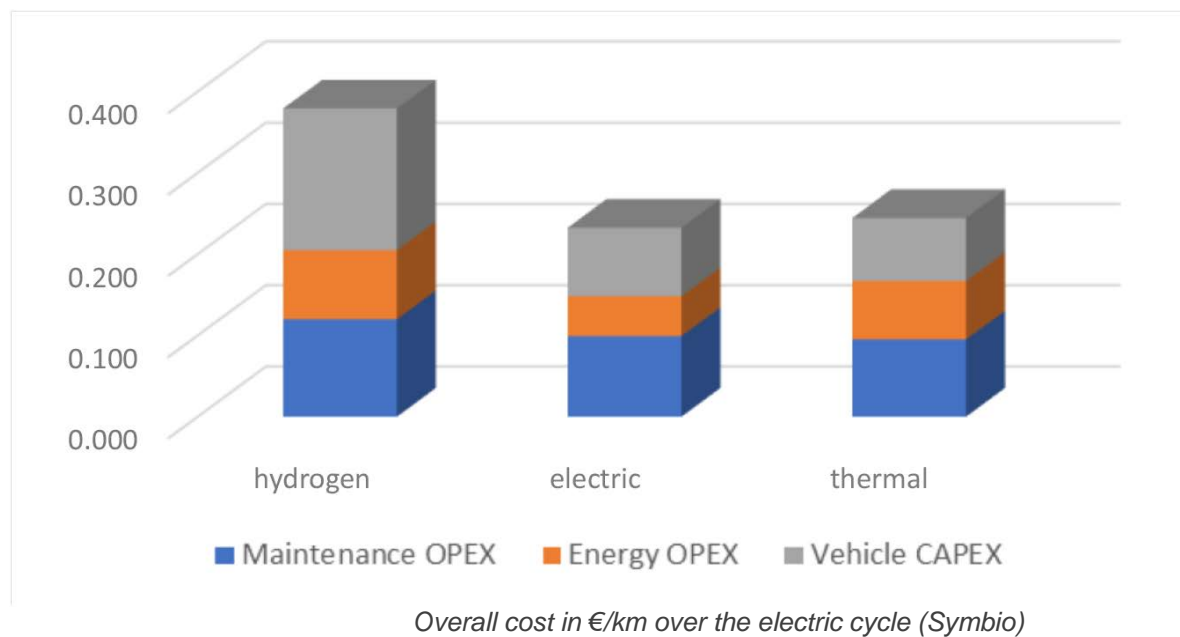
#### 4.2. Business model: local regulations are a key factor

Any move to bring hydrogen-powered electric vehicles to the market must tackle the issue of cost. The technology remains expensive, given the low production volumes, and the number of potential vehicles is limited to a few pilot production runs<sup>13</sup>. Costs can only be lowered by producing fuel cells on a commercial scale and expanding the range of vehicles available.

**Beyond the purchase cost, local regulations in urban areas will be the primary factor in boosting sales of hydrogen-powered electric cars and similar vehicles.** In particular, restrictions on access to city centres, either during certain hours of the day or in specific areas, could potentially prompt changes in the business model for delivery and service companies. For example, if restrictions are imposed on deliveries by vehicles whose particulate or pollutant emissions levels exceed local permits, but zero-emission vehicles enjoy unrestricted access throughout the day, companies could more easily recoup the added cost of purchasing clean vehicles.

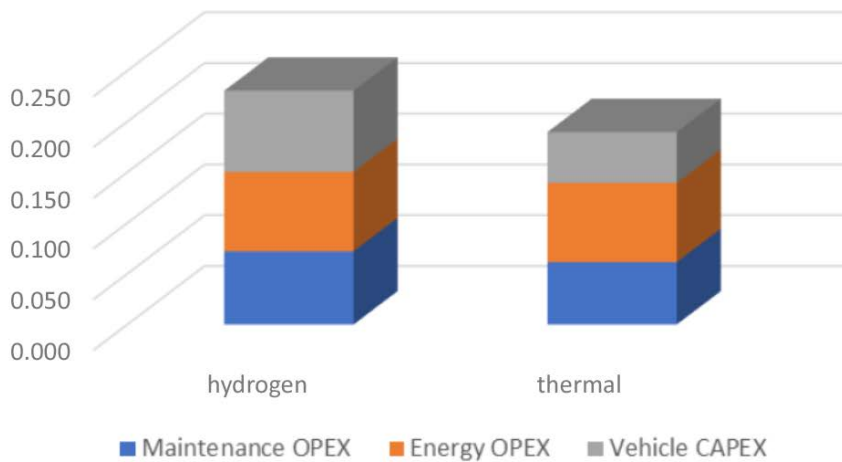
##### A closer look: The HYWAY pilot project<sup>14</sup>

HYWAY marked the first test of Kangoo ZE vehicles equipped with a hydrogen-based range extender for business use in fleets. The test was conducted from 2014 to 2017 in Lyon and Grenoble and included the installation of distribution stations for all thirty of the vehicles in operation. The graphs shown below indicate the total ownership costs for the business that owns the vehicle. The first graph indicates the costs recorded during the project, while the second graph shows projected three-year costs under typical intensive use:



<sup>13</sup> Current light vehicles are sold at a price of around €60,000/unit.

<sup>14</sup> [HYWAY pilot project, complete final report, February 2018.](#)



*Projected three-year overall cost in €/km over an intensive cycle of 37,000 km/year (Symbio)*

Commercial-scale production would reduce the purchase cost for a vehicle of this kind. Nonetheless, it would still exceed the cost of a diesel vehicle by approximately €1,300/year. This cost calculation does not, however, reflect any regulations adopted at the local level that would restrict the use of diesel vehicles and make them more expensive to operate.

### 4.3. Creating regional clustered charging stations

In order to introduce vehicles with a new powertrain, a charging or supply infrastructure for those vehicles will need to be in place. This makes any deployment of hydrogen-powered vehicles for individual users a costly and complex process, one that would require an investment in hundreds of service stations across France in order to spur the market.

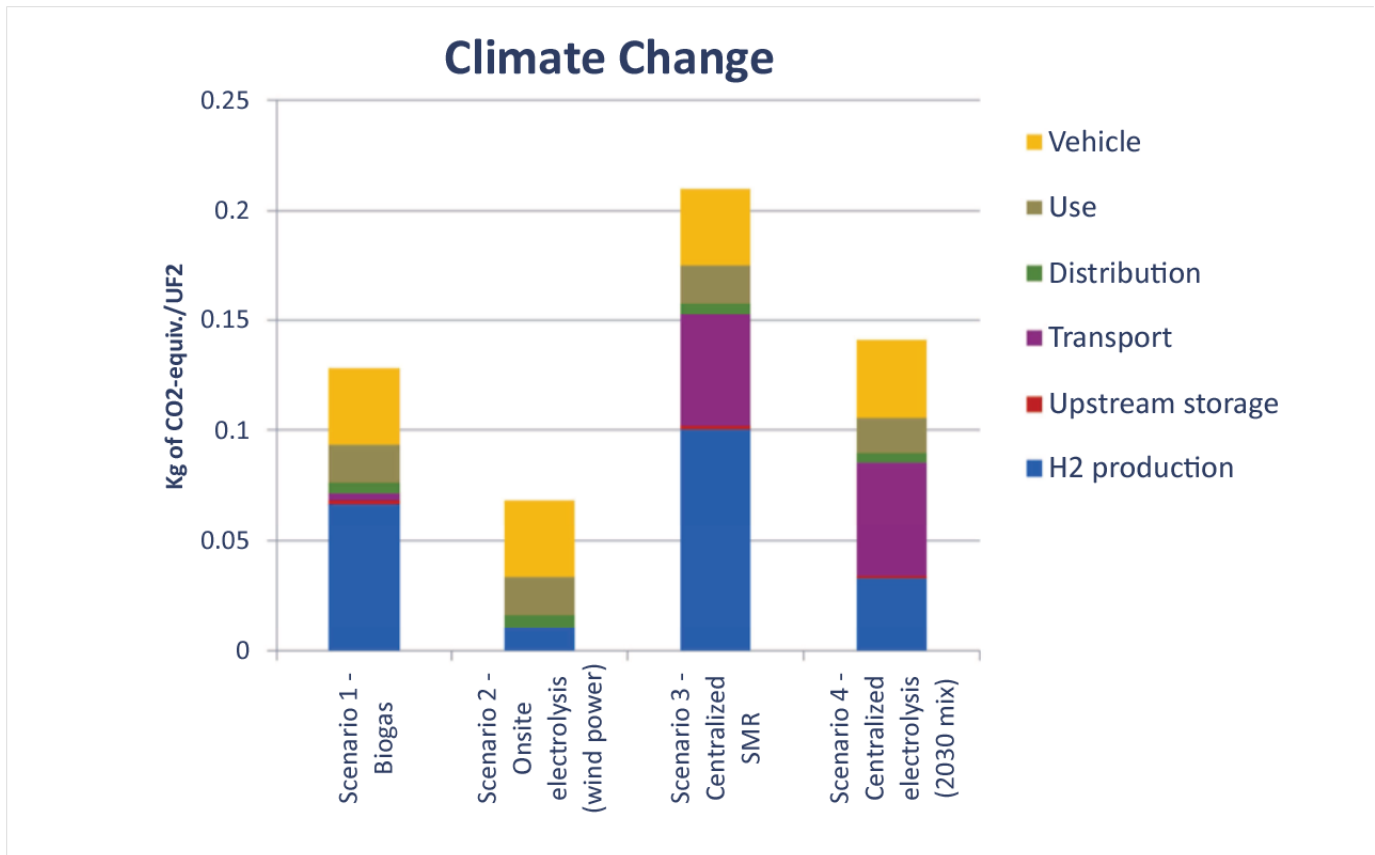
That is not true of the market for business fleets: local service stations for those fleets can quickly turn a profit so long as they are regularly supplying the vehicles that operate in the region. Those stations may be private, attached to a bus depot or airport, or they may be semi-public, i.e., open to various users with regulated access. **In other words, the infrastructure would be deployed in local “clusters”, aggregating users in such a way that a distribution infrastructure becomes a viable investment.** Typically, the business model for a station serving a fleet requires daily consumption of more than 80 kg of H<sub>2</sub> per day, with the hydrogen sold at a price below €10/kg.

### 4.4. Environmental benefits under certain conditions

Hydrogen’s environmental significance for transportation is a complex issue that cannot be analysed in terms of a single indicator or purely in light of its end use. For any truly zero-emission electric vehicle that addresses the problem of air quality, for example, we need to adopt a comprehensive view of the chain. Hydrogen is merely a vector. Therefore, its environmental impact will depend on the primary source from which it is derived, the manufacturing process and the supply logistics as well as the impact from producing the vehicle itself and its equipment.

ADEME commissioned a life cycle analysis in 2013<sup>15</sup> that provided an initial look at the various impacts from driving a hydrogen-powered vehicle for one kilometre. The table below illustrates the contribution to climate change depending on various scenarios. The overall well-to-wheel impact varies from 68 to 210 g of CO<sub>2</sub>-equivalent/km. The table provides a good illustration of how environmental impact – and thus the benefits that can be expected from the use of hydrogen in transport – can vary depending on the scenario.

<sup>15</sup> Environmental evaluation of hydrogen as an energy carrier for transport, July 2013; study conducted by Quantis and Enea Consulting for ADEME (add link to ADEME media library).



The principal lessons that ADEME draws from these studies are as follows:

- The environmental impact largely depends on the primary resource used to produce the hydrogen: the network's electricity mix, natural gas (using SMR technology<sup>16</sup>). **In terms of its impact on climate change and the depletion of natural resources, hydrogen-powered transport is attractive only if the hydrogen is produced from renewable energy sources.**
- The logistics for transporting hydrogen from the production site to the service station represents a major factor in the overall impact. **The study strongly recommends that delivery distances be kept to a minimum (less than 100 km) and that local hydrogen production receive priority for local use.**

This preliminary study is currently being updated to reflect technological advances in particular; the results will be available in early 2019. This analysis is being supplemented by other studies on which ADEME is focusing attention:

- Precious metals: the electrolyzers and PEM (proton-exchange membrane) fuel cells require precious metals such as platinum or iridium to use as catalysts. A hydrogen fuel cell, for example, contains anywhere from 1 to 20 g of platinum. The challenge will be to continue efforts to, first, redesign the equipment to reduce the quantity of those metals that is needed, and second, provide for end-of-life recycling.
- Systematic evaluation: the environmental impact of hydrogen-powered transport should be considered from an overall standpoint that takes the circumstances of the vehicle's use into account. This could include trends in use over time; within a fleet, for example, the increased availability of vehicles could mean that a smaller number of vehicles is needed. The gains in terms of space and grey energy should be quantified as well. In addition, the potential impact and benefits for the power grid should be evaluated. The fact that hydrogen production via electrolysis is delinked from vehicle charging can enhance network flexibility significantly and provide help in managing peak capacity periods.

<sup>16</sup> SMR: Steam Methane Reforming.

## 5. Reducing the impact of industrial use of fossil-fuel hydrogen

Currently, more than 900,000 tonnes of hydrogen is produced and consumed in France's manufacturing sector each year<sup>17</sup>. Hydrogen is being used not as an energy carrier but rather as a chemical input or material. Its principal applications are for removing sulphur from petroleum-based fuels and synthesizing ammonia for fertilizer. Hydrogen is also used in glass and steel manufacturing, in the food processing industry and in electronics.

Today, industrial hydrogen is very widely produced from fossil fuels, natural gas and petroleum products, using steam reforming and partial oxidation<sup>18</sup>. Using industrial hydrogen would result in the emission of 10 million tonnes of CO<sub>2</sub>-equivalent, representing 7.5% of the greenhouse-gas emissions from France's entire manufacturing sector.<sup>19,20</sup> To meet the climate objectives set forth in the energy transition law, those emissions must be reduced. Improving process efficiency is a first step towards that goal. A gradual move to electrolysis and biomass conversion processes (biogas steam reforming, pyrogasification of solid biomass) should also be encouraged.

**General industrial consumers, i.e., those that typically consume less than 10,000 t of H<sub>2</sub>/year and are located far from major hydrogen production centres, should be targeted as a priority:**

- For cost reasons: although industrial hydrogen is produced at a low cost at industrial sites (from €1.50 to €2 per kg), packaging and transport to the points of consumption results in high prices (between €10 and €20 per kg). Hydrogen produced via electrolysis or from biomass resources can be competitive in that segment.
- For environmental reasons: as indicated previously, transport of hydrogen by heavy vehicle has a major environmental impact. It is therefore preferable to produce hydrogen near consumption sites to reduce that travel distance as much as possible<sup>21</sup>.

### A closer look: the VaBHyoGaz3 project

Albhyon (a subsidiary of the HERA Group) has developed an innovative process for biogas steam reforming that offers the potential for decentralized hydrogen production (from 100 to 800 kg of H<sub>2</sub>/day). Following a demonstration phase at the Trifyl site in southwestern France, the company is developing the process on a commercial scale, with support from ADEME through its Investments in the Future program.



<sup>17</sup> The most recent statistics come from the HyFrance3 project, *Développement des marchés de l'hydrogène* [Developing markets for hydrogen], January 2011, led by France's Alternative Energies and Atomic Energy Commission's Technical and Economic Institute for Energy Systems (CEA-I-Tésé), in partnership with EDF, IFP, Alphéa, GDF Suez, CNRS, Air Liquide, Total, ADEME and the French Hydrogen Association (AFH2).

<sup>18</sup> *Production d'hydrogène à partir de combustibles fossiles* [Hydrogen production from fossil fuels], September 2014, French Association for Hydrogen and Fuel Cells (AFHYPAC).

<sup>19</sup> Emission factor for industrial hydrogen production: 91 g of CO<sub>2</sub>-equiv./MJ, i.e., 10.9 kg CO<sub>2</sub>-equiv./kgH<sub>2</sub>, Certify Project, October 2015, Deliverable #D2.4.

<sup>20</sup> In 2014, the manufacturing sector and the energy industry accounted for 29% of all emissions in France, totalling 459 Mt CO<sub>2</sub>-equiv. Source: Interprofessional Technical Centre for Studies on Air Pollution (CITEPA), UNFCCC inventory, December 2015.

<sup>21</sup> Hydrogen transport by heavy vehicle emits approximately 1 kg CO<sub>2</sub>-equiv./100 km. Source: ADEME, Environmental evaluation of hydrogen as an energy carrier for transport, July 2013.

## 6. Efficiency and safety: points for discussion about hydrogen

The energy efficiency of the hydrogen chain and the risk of accidents associated with its use are issues that prompt discussion on a regular basis. They are valid points of debate, highlighting the drawbacks connected with hydrogen technology that need to be taken into account for concrete applications.

### 6.1. Energy efficiency

Since hydrogen is merely an energy carrier, it necessarily involves a series of conversions from the primary energy source to the final energy used. Electrolysis – in which an electrical current breaks down a water molecule into oxygen and hydrogen – currently has an efficiency rate of about 70%. Compressing the gas also consumes energy, and recreating the water molecule in the fuel cell, so that it can once more provide electricity, has about a 45% efficiency rate. Consequently, the overall efficiency rate for the chain, from the primary electricity to the recovered usable electricity, ranges from 20% to 30% depending on the application, the storage pressure, the logistics arrangements and so on.

For that reason, and with the aim of overall energy system efficiency, electrochemical storage using a battery should be favoured whenever possible. That form of storage offers greater efficiency (higher than 80%). In the field of transport, for example, electric vehicles powered solely by a battery are preferable for typical use applications, depending on the desired energy self-sufficiency, the required vehicle availability, etc. The use of hydrogen should be considered when a battery-only solution is no longer practical, as explained previously (heavy vehicles, availability for a vehicle fleet).

It's for that reason as well that the applications being developed in the field of hydrogen are generally based on hybrid storage technology that includes both a battery and the hydrogen chain. Hybrid storage, for both onboard and stationary applications, offers a way to capitalize on both technologies. The hydrogen chain is generally necessary in order to provide back-up service or to get around constraints connected with either the vehicle's use or the energy infrastructure that batteries cannot address.

In other words, aside from the energy efficiency rate, the key issue in deciding whether to use a hydrogen chain involves the service it will perform. In some cases, as explained earlier, a hydrogen chain provides flexibility and solutions between the energy source and the application:

- For managing electric and gas grids with a very high renewable energy penetration rate, a hydrogen chain offers the only option for storing large quantities of energy (more than a TWh) from one season to the next. It ensures balanced use of energy systems when energy availability is variable and energy use fluctuates by the season.
- With regard to transport, onboard hydrogen eliminates some of the drawbacks posed by battery technology in terms of battery size and network charging. A hydrogen chain can enhance the performance of electric transportation, making it competitive with internal-combustion-engine vehicles for the same applications. It also provides power grid managers with solutions for regulating charging needs for those new applications.
- For stationary applications, supplying energy to certain regions (such as areas not connected to the grid) requires distributed storage solutions. When used in conjunction with locally available renewable energy, hydrogen makes it possible to dispense with a costly fuel distribution network for diesel generators.

**Thus, there is both a technological and financial justification for storing a portion of available energy in hydrogen form, primarily because of the service it provides and the environmental benefits.** The business models that are currently emerging are built around this service rendered, which complements other available technology.



## 6.2. Accident risk

As with other burning gases or energy sources, there are risks involved in handling hydrogen, particularly the risk it will ignite or explode. Hydrogen has certain physical and chemical characteristics that, in several respects, can make it easier or more complicated to manage the risks it poses compared to other gases and liquids<sup>22, 23</sup>:

- A higher propensity to leak: hydrogen molecules are small in size and low in viscosity, which makes leaks more likely;
- A higher likelihood of ignition as a result of its low minimum ignition energy – a flame or spark is sufficient;
- A lower likelihood of open-air explosion given its high diffusivity, which reduces the risk that an explosive cloud will form in an unconfined environment;
- More rapid combustion, which promotes deflagration;
- A poorly visible, low-radiation flame.

These characteristics are known and managed in a number of industrial environments, such as refineries and ammonia plants, where hydrogen has been used in large quantities for many years. Historically, the regulatory framework governing those hazards has been tailored to those traditional industrial uses of hydrogen. Those years of use have also yielded industrial and technical experience and know-how in handling hydrogen.

The new applications for hydrogen as an energy carrier, used in multiple environments (buildings, vehicles, ports and airports, warehouses, etc.) and in varying quantities, change the nature of its risks and the regulations that govern those risks. Therefore, the regulatory framework has evolved over the past few years as these new applications have emerged, so as to ensure a high level of safety for users and nearby communities. Those regulations call for safety testing, equipment and installation checkpoints, compliance with technical specifications, the installation of safety barriers, anomaly detection procedures and so on<sup>24</sup>. Examples include:

- Regulation (EC) No 79/2009 and its implementing regulation 406/2010, which specifically address hydrogen-powered vehicles and the various onboard equipment;
- Section 4715 of the French law on classified installations for the protection of the environment, which regulates the storage of compressed hydrogen based on the quantities involved;
- French norm NF M58-003, "Installation of hydrogen-related systems", which sets out recommendations for stationary facilities;
- EU Directive 2014/94/EU on the deployment of alternative fuels infrastructure, which draws on the ISO/TS 20100 standard on service stations and the ISO 17268 standard on vehicle refuelling connection devices.

**Accident risk management in connection with hydrogen as an energy carrier requires continued efforts to define an appropriate regulatory framework, one that is based on a joint effort by the French government, the relevant centres of technology and all stakeholders (equipment manufacturers, operators, users, etc.).**

Risk management also depends on the proper dissemination of know-how, through training in the use of these new energy applications. French firefighters, for example, are looking ahead to the introduction of hydrogen-powered vehicles. They have developed both theoretical and practical knowledge<sup>25</sup>, based on the concrete experience gained by various fire and rescue brigades throughout France<sup>26</sup> as well as EU projects such as HyResponse, a hydrogen emergency response training program for first responders<sup>27</sup>. Drawing on their knowledge and experience of the various vehicle engine types, they have defined an appropriate response for each type of fuel in the event of an incident (leak, fire).

<sup>22</sup> ADEME, *Guide d'information sur les risques et les mesures de sécurité liés à la production décentralisée d'hydrogène* [Information guide on risks and safety measures related to decentralized hydrogen production], June 2015

<sup>23</sup> ADEME, *Guide d'information sur la sécurité des véhicules et des stations-service de distribution d'hydrogène* [Information guide on safety for hydrogen distribution vehicles and service stations], June 2015

<sup>24</sup> INERIS [French National Institute for Industrial Environment and Risks], Study report DRA-14-141532-06227C, *Benchmark stations-service hydrogène* [Hydrogen service station benchmarking], September 2014.

<sup>25</sup> French Interior Ministry, Directorate General for Civil Protection and Crisis Management (DGSCGC), *Note d'information opérationnelle relative à l'intervention sur les installations d'hydrogène et les risques liés* [Operational briefing note on responding to hydrogen installations and the related risks].

<sup>26</sup> Video featuring the fire and rescue brigade for a French department, discussing the risks posed by a Kangoo ZE hydrogen vehicle.

<sup>27</sup> French Academy for Fire, Rescue and Civil Protection Officers (ENSOSP), training curriculum.

## ADEME IN BRIEF

The French Environment and Energy Management Agency (ADEME) is responsible for implementing public policies relating to the environment, energy and sustainable development. The Agency makes its expertise and advice available to businesses, local and public authorities and the general public to help them progress in their environmental approach. It also provides assistance in project financing, from research to implementation, in the following areas: waste management, soil preservation, energy efficiency and renewable energy, raw material savings, air quality, the fight against noise pollution, the transition to a circular economy and the fight against food waste.

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