STUDENT SCIENCE CONVENTION ON HYDROGEN

MARCH 2024

CONVENTION
SCIENTIFIQUE
ÉTUDIANTE

UNDER THE PATRONAGE OF

Roland Lescure
Deputy minister for industry and energy

IESF
Société des Ingénieurs et Scientifiques de France

SUMMARY OF THE REPORT

We, the participants of the Student Scientific Convention on Hydrogen, consider that **hydrogen should not be considered as a miracle solution,** but a **relevant technology that needs to be developed for priority uses,** provided that the objectives of sustainable development and sobriety are respected.

Indeed, the deployment of the hydrogen sector should be implemented in compliance with the **Sustainable Development Goals,** in particular in respect of human rights, social justice and the preservation of biodiversity. To this end, we recommend the implementation of a regulatory framework that systematically requires the study of the social, environmental and economic impacts of hydrogen-related projects.

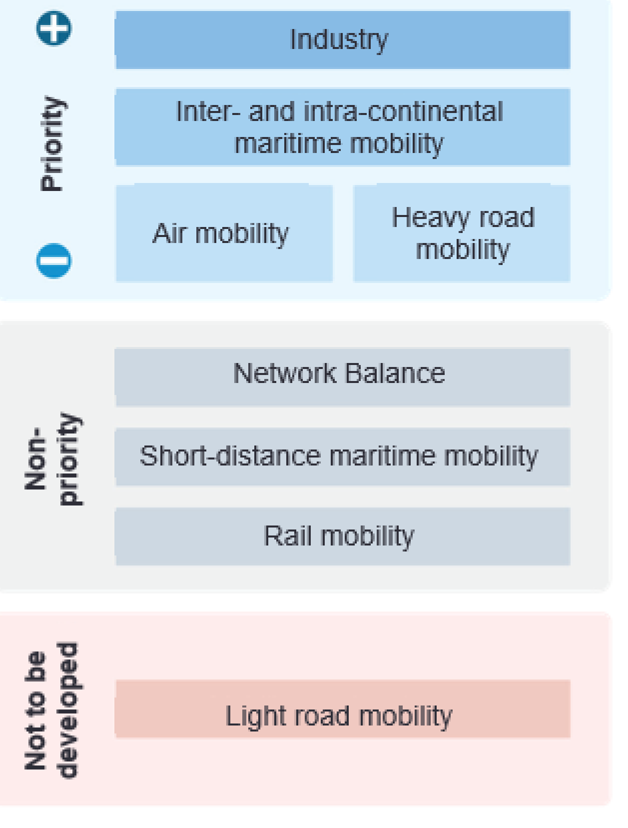
In addition, we conclude that **sobriety is a necessary prerequisite** for the successful implementation of hydrogen on a national scale to decarbonize non-electrifiable uses and sectors. Indeed, as electricity is necessary for the electrification of uses and hydrogen production, this resource will be limited, making sobriety essential to ensure a transition of all sectors.

As hydrogen production is therefore constrained, it is necessary to prioritize its uses. We propose the following hierarchy:

With the aim to prioritize uses, we recommend the use of hydrogen as a priority for **heavy industries,** in particular the steel and chemical industries. It is in these sectors that the decarbonizing power of hydrogen is the strongest, and where the economic opportunities brought by hydrogen are the most interesting.

Secondly, inter- and **intra-continental maritime transport** appears as a priority for accessing hydrogen to produce e-fuels. Indeed, long-distance maritime transport is hardly electrifiable, even though the transport of goods benefits the greatest number of people and is critical for the economy, which justifies its prioritization.

E-fuels are also key to decarbonizing the aviation sector. However, this usage is not a priority compared to the maritime sector, as aviation is economically and socially unequal.



Prioritization of hydrogen uses

Heavy road mobility could also have access to hydrogen for regular and long-distance journeys. However, this concerns a small part of the current truck fleet and not all vehicles, as most of the road freight can be electrified. However, modal shift remains the most effective solution to decarbonize the sector.

Regarding the balancing of the electricity grid, we recommend not using hydrogen for the daily balancing of the grid via P2G2P, which can be provided by alternatives. However, seasonal grid balancing by hydrogen is a topic that needs to be explored further.

The decarbonization of **short sea shipping** (SST) does not require the synthetic fuel solutions envisaged for long-sea shipping. Indeed, alternative solutions are deployable and more relevant. Hydrogen could eventually be integrated into these solutions through fuel cells.

In terms of **rail mobility**, the use of hydrogen is relevant for some specific cases. However, given the relatively low share of rail in the greenhouse gas emissions of the transport sector in France, prioritizing the development of hydrogen trains seems less sensible compared to other applications. In addition, the increase in rail traffic due to the modal shift is, instead encouraging the electrification of many lines.

In addition, since the price of electricity is a determining factor in the development of low-carbon hydrogen uses, we believe it is necessary to reflect on **electricity pricing**.

Indeed, our report only partially addresses the economic issues and costs related to hydrogen. It is important to consider the inevitable increase in costs for public policies, manufacturers and consumers. However, in the context of successful decarbonization, this increase in costs should be offset by the reduction of negative externalities linked to the use of fossil fuels. **In fact, it is only in a context of sobriety and for targeted uses that hydrogen-related technologies appear relevant to achieving our sustainable development objectives.**

REPORT

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MEMBERS OF THE STUDENT SCIENTIFIC CONVENTION ON HYDROGEN

The draw was not purely random. The steering team chose a balanced representativeness according to three key criteria: gender (woman/man), locality (Île-de-France/other regions) and type of training (University Master's degree/engineering degree/PhD).

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The Student Scientific Convention (SSC) is an initiative launched in 2023 by the Young Promotions Committee (Comité Jeunes Promotions) of the Federation of Engineers and Scientists of France (IESF). It aims to bring together scientific students – from master's to doctoral – chosen at random to represent the spectrum of the scientific trainings and programs in France.

On the format of the Citizens' Conventions previously held in France (Climate, End of Life, etc.), supervised by facilitators and guarantors, we participated in four two-day sessions, punctuated by conferences and debates, bringing together experts and speakers from academia, industry, public institutions, NGOs and the political diasphera.

The question that has been asked to the Convention is the following:

> *To what extent and under what conditions are hydrogen-related technologies* relevant to achieving the Sustainable Development Goals, in a world of finite resources? What should be the priority uses of hydrogen?*

The meetings with specialists from various backgrounds have shed light on our understanding of the issues related to hydrogen and enriched the reflections we have carried out collectively. The result of this Convention is a set of recommendations, established after lively debates among us and with our interlocutors on the production and use of hydrogen. This report has been prepared exclusively by our assembly of young scientists.

We are addressing you, public decision-makers, you, the Minister Delegate for Industry and Energy, who have placed this Convention under your high patronage. Our recommendations also aim to raise **awareness among the public and the industrial world of the challenges of hydrogen,** a crucial subject that has its place at the heart of the public debate.

Before presenting our recommendations, we would like to set out here the principles that guided our reflection:

- We are **scientists** who have interacted with people representing cultures and approaches that are complementary to our own.
- We have carried out this reflection with the **knowledge and data to date,** at a time when the scientific, industrial, economic, and political communities say they are in the phase of exploring these technologies.
- Our commitment is in line with the UN's **Sustainable Development Goals (SDGs),** which motivate our thinking.

We have answered the question of prioritizing uses. These debates have also led us to take a position on the **conditions for setting up** the hydrogen sector in France, in particular hydrogen production, governance, or regulation.

** As commonly accepted by the scientific community, we will talk about hydrogen throughout the document, although this is a misuse of language, and we are talking about dihydrogen*

OUR RECOMMENDATIONS

Here, we summarize all 28 recommendations that we developed in the course of our work. They relate to the production and use of hydrogen in different sectors.

Production

Recommendation 1: Do not develop new hydrogen production capacities by steam forming and carbon capture (blue hydrogen).

Recommendation 2: Focus solely on the development of green and pink hydrogen production sectors.

Recommendation 3: Accelerate investment in research and development (R&D) of electrolysers to improve yields and develop disruptive, more resource-efficient technologies (high-temperature electrolysis, reduction of the material footprint, water management, etc.).

Recommendation 4: Deploy vocational training around the hydrogen sector.

Recommendation 5: Prioritize the electrification of uses over the use of hydrogen wherever possible.

Recommendation 6: Promote green and pink hydrogen with the aim of making them competitive, for priority uses, through strong action by the State.

Distribution

Recommendation 7: Develop hydrogen production close to the point of use to minimize transport distances.

Recommendation 8: Support local hydrogen production in France by developing the entire value chain.

Rail mobility

Recommendation 9: Encourage the modal shift from road mobility to electric rail, thus allowing funding allocated to hydrogen to be directed towards other priority uses.

Recommendation 10: Do not give priority to the development of the hydrogen train in France.

Maritime Mobility

Recommendation 11: Transition to synthetic, hydrogen-based fuels (electrofuels, liquid hydrogen, hydrogen gas) for merchant ships.

Recommendation 12: Allocate different forms of synthetic fuels according to the needs of different types of vessels.

Recommendation 13: Rethink global maritime traffic with a view to decarbonizing the sector as much as possible while integrating hydrogen into its energy mix.

Road mobility

Recommendation 14: Plan the use of hydrogen for heavy road mobility at a European level.

Recommendation 15: Do not develop the use of hydrogen for light vehicles.

Recommendation 16: Develop hydrogen for professional vehicles only on long-distance and regular journeys, and for uses incompatible with electrification.

Recommendation 17: The decarbonization of the freight transport sector will necessarily involve a modal shift towards rail, which must be encouraged by public policies.

Air Mobility

Recommendation 18: Favor the normative route, rather than subsidies that could be earmarked for other more socially acceptable sectors, to force investments in the development of Sustainable Aviation Fuels (SAF).

Recommendation 19: To achieve decarbonization objectives and to take into account the scarcity of hydrogen, encourage modal shift when there is an alternative to flying, by aligning aviation prices with those of other types of transport.

Recommendation 20: Do not encourage technologies based on the direct use of hydrogen (fuel cells and direct combustion) for air mobility.

Recommendation 21: Prioritize e-fuels over biofuels in the aviation sector.

Industry

Recommendation 22: Make the use of hydrogen a priority in the industry for decarbonization purposes, excluding the use of public money for the industrial refining branch due to its incompatibility with decarbonization objectives.

Recommendation 23: Replace the grey hydrogen used by industry with low-carbon hydrogen in the first place.

Recommendation 24: Increase the capacity of the grid to allow for the increase in industrial electricity consumption while offering electricity at a competitive price.

Recommendation 25: Require companies to adopt a decarbonization strategy that does not rely on the use of Carbon Capture and Storage (CCS) in the case of fossil fuel-based combustion.

Recommendation 26: Consider hydrogen as a decarbonization vehicle only if the electrification of furnaces is not possible.

Network Balancing

Recommendation 27: Do not use power-to-gas-to-power (P2G2P) but give priority to the development of WWTPs* or Electric batteries for the daily balancing of the power grid.

Recommendation 28 : Don't consider hydrogen import for electrical grid balancing.

**1 Sustainable fuels*
**2 Capture and storage*
**3 A WWTP (Hoping Station. In order to balance electricity by pumping*

INTRODUCTION

In a context of repeated and accepted warnings on the international scene, we feel it is important to recall the urgency **in which we are projecting ourselves.**

The IPCC's sixth report warns that greenhouse gas emissions from human activities have warmed the climate at an unprecedented rate. This group estimates that the global surface temperature has risen by 1.1°C compared to the pre-industrial period. No matter what we do, this warming will reach 1.5°C by the early 2030s. The massive use of fossil fuels is a major contributor to global warming. In France, the energy mix (2,544 TWh in 2022*), although less carbon-intensive compared to other industrialized countries, remains a net emitter of greenhouse gases (GHGs). The share of fossil energy still represents 50% of the energy consumed in 2022 in our country. According to the IPCC experts, limiting global warming will only be possible by accelerating the reduction of GHG emissions now. It is therefore crucial for us, the younger generations, to get involved in this energy transition.

In addition, in the search for future solutions for energy needs, **we consider it essential to integrate the Sustainable Development Goals (SDGs)** into the search for carbon-free energy. The current craze for hydrogen has particularly appealed to us because of its decarbonization potential. Nevertheless, we felt it was necessary to carry out a global assessment of the impacts of the development of this new energy vector, as well as its feasibility. We draw out a systemic vision of the advantages and points of attention of the development of a French hydrogen sector.

Today, 95% of hydrogen is consumed by the industrial sector in France. The three largest industrial markets are petroleum product refining (60%), ammonia synthesis, mainly for fertilizers (25%) and chemicals (10%)*. But this is essentially the result of carbon-based production. In fact, **only 2% of hydrogen comes from renewable energies.**

The molecule is seen as a promise in the global energy transition, with ambitious strategies deployed around the world. The European Commission announced, in July 2020, a target of deploying 40 GW of electrolysers by 2030, enabling the production of 10 million tons of hydrogen.

In France, whose strategy targets energy sovereignty, a clear roadmap is established, with the planned installation of 6.5 GW of low-carbon production capacity by 2030, supported by an investment of 9 billion euros over ten years. Other strategies are being adopted by neighboring countries. Germany, for example, relies heavily on imports to meet its domestic needs in addition to local production (5 GW*). China, as an indication, plans to produce electrolysers for export and invest in hydrogen production, including outside its territory.

*1 Source: *Energy balance of France | Energy Key Figures - 2023 Edition (Sustainable Development. gouv.fr)*
*2 *Source: Hydrogen Deployment Plan (ecologie.gouv.fr)*

3 Source: Revue de l'Energie, Special issue October 2021

To answer the question we were asked, we felt it was essential to consider the sociological**, economic, environmental and political context** of the subject. Because of the plurality of issues, we have defined the framework for our reflection:

Framework - In light of the current state of the hydrogen sector, we have explored the advantages and disadvantages of each of its uses. Among the uses, only the most relevant, studied by the National Strategy for the Development of Decarbonized Hydrogen in France and already the subject of a pronounced interest in decarbonization, were considered. Namely, heavy **industry, road, sea** and **air mobility** as well as **the balancing of the electricity grid.**

Noting that hydrogen **and the resources needed to produce it are only available in limited quantities** and that, on the other hand, the speakers we met testify to the growing interest of all economic sectors in this sector, we believe that we must anticipate this future demand. **The prioritization of the uses of** this energy vector is essential to our reflection.

Geographical framework- We have limited our reflection to the scale of **France and its international interactions**, **particularly within Europe.** Thus, the detailed strategies of other countries are not studied, although geopolitical issues have been taken into account. Due to the nature of the subject matter, it seems necessary to consider the production of neighboring

Thus our recommendations :

- **Do not concern the technical implementation of the hydrogen production chain;**
- **Are intended to be systemic and target the use of the hydrogen produced;**
- **Propose a prioritization of uses.**

Accountability framework - In addition, the

countries on development of a hydrogen sector must take into account some of the **17 Sustainable Development Goals** defined and adopted by the United Nations in 2015. (Appendix ref: doc 17 SDGs)

This report presents our recommendations, which are the result of our collective work and interactions with a wide variety of stakeholders *(See Appendix). The recommendations we make are of three types: - Main recommendations concerning the prioritization between the different uses of hydrogen;- Specific recommendations for each of the uses of hydrogen; - General recommendations on the conditions for the development of the sector.

THE HYDROGEN SECTOR

Among the most abundant elements on the Earth's surface, the hydrogen atom is bonded to other types of atoms in water, hydrocarbons, or biomass. Since the dihydrogen molecule (di for "twice" and "hydrogen" for the atom, which gives the molecule its name) hardly exists in its pure state on Earth, the majority of hydrogen must be produced from primary energy sources. It is used as an energy carrier to transport energy and as a raw material as a chemical molecule.

One of the problems with hydrogen is its **low energy density**: it takes up 4.6 times more space than petrol to store the same amount of energy*. **Another issue is safety**: hydrogen may be very sparse, but explosions are very dangerous.

I. Production

Currently, according to the IEA, 95 Mt of hydrogen* is consumed worldwide, mainly by the chemical and oil industries. France consumes 1 Mt* per year and Europe 8 Mt. 94% of production is made from fossil energy in France*, a very polluting process since the production of 1 kg of hydrogen generates more than 10 kg of CO2e*: for example, hydrogen production in France now represents 3% of national GHG emissions*. In addition to this process, there are other methods that emit more or less GHGs. They are presented in the table below, which shows all the ways in which hydrogen is produced.

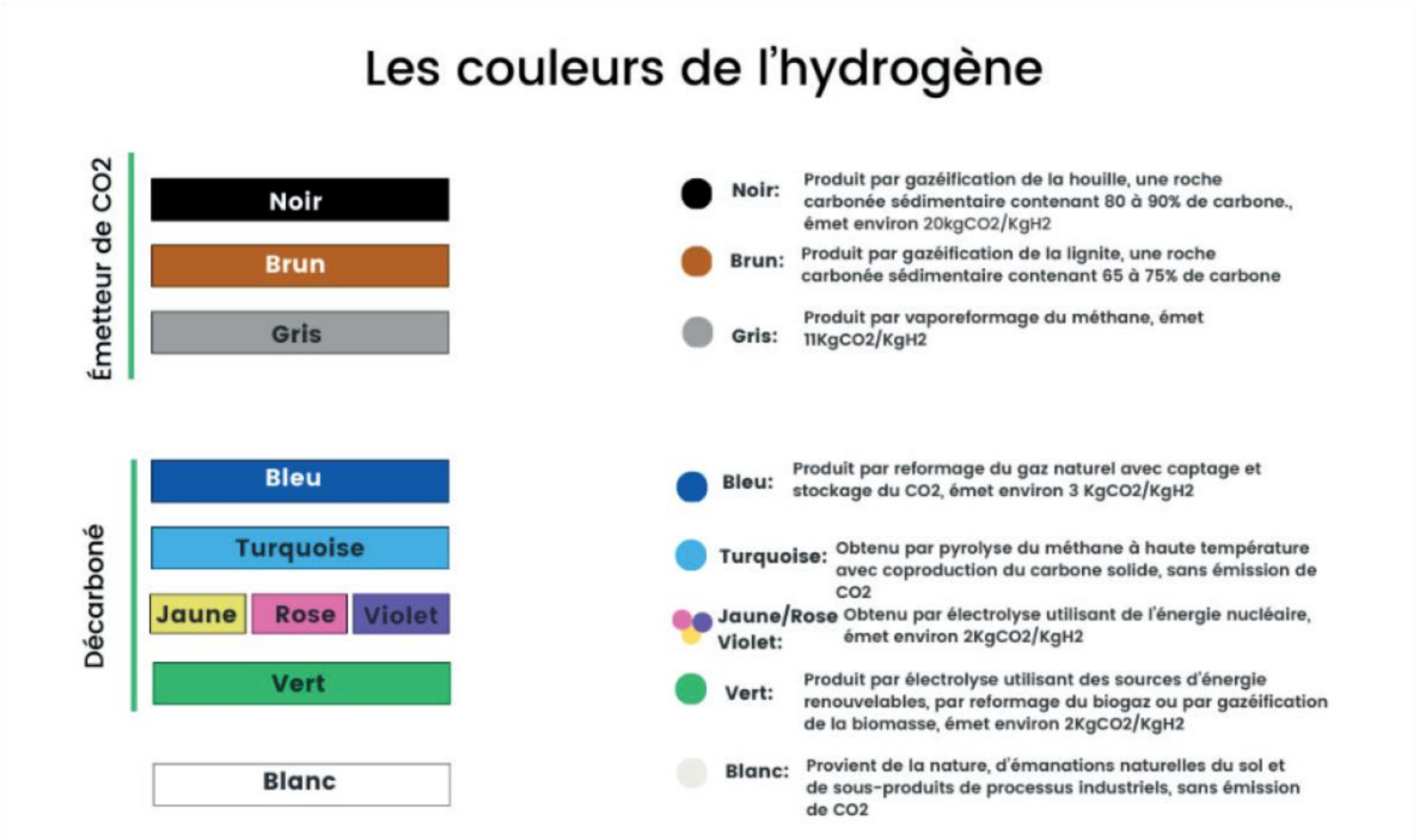
**1 Source: Hydrogen, an energy carrier (cea.fr)*

**2 Around 2% of total global energy consumption.*

**3 Source: Global Hydrogen Review 2023 (International Energy Agency) *4 Source: Hydrogen Deployment Plan (ecologie.gouv.fr)*

**4 The CO² equivalent (CO2e) of a greenhouse gas emission is the amount of carbon dioxide that would cause the same cumulative radiative forcing over a given period of time, i.e. that would have the same capacity to trap solar radiation.*

**5 Source: Hydrogen Deployment Plan (ecologie.gouv.fr)*



Source: Revue de l'Énergie, Special Issue October 2021

White hydrogen, which comes from potential natural sources of hydrogen, is not taken into account in our report due to its very low maturity.

While many manufacturers consider hydrogen to be a key energy carrier in their decarbonization strategy, it is necessary for this molecule to be produced in a carbon-free way. This is why the production of green, pink or blue hydrogen seems relevant.

Recommendation 1: Do not develop new hydrogen production capacity through steam reforming and carbon capture (blue hydrogen).
P: 80.5%
C: 4.9%
A: 14.6%

However, the production of blue hydrogen will not allow us to get out of our dependence on fossil fuels. Developing this technology would tie up capital that could be allocated to the production of low-carbon hydrogen by electrolysis. Thus, the development of new blue hydrogen plants does not seem relevant. **However, we consider that existing steam reforming (grey hydrogen) facilities can consider producing blue hydrogen through the addition of carbon capture and storage (CCS) means while waiting for their end-of-life.**

Recommendation 2: Focus only on the development of green and pink hydrogen production channels.
P: 82.9%
C: 9.8%
A: 7.3%

The production of green or pink hydrogen is based on the electrolysis process. Unlike steam forming, electrolysis uses electricity and water to produce hydrogen. It is a low-emitting process if it uses carbon-free electricity, which we have in France. Pink hydrogen relies on nuclear power plants and makes it possible to obtain an almost continuous production of hydrogen, which corresponds to the constant volume needs of large industrial companies. Green hydrogen uses electricity from renewable energy; Its production is by nature intermittent and cannot ensure a continuous flow of production, unless more facilities are built and significant storage facilities are considered, increasing costs. Green hydrogen remains relevant for other uses, as we will see later. The two methods are therefore complementary, as the uses are different.

Thus, in the rest of our report, the term "low-carbon hydrogen" refers to green and pink hydrogen, with blue hydrogen being excluded.

However, the deployment and relevance of a low-carbon hydrogen production sector depends on certain conditions.

Recommendation 3: Accelerate investment in electrolyser R&D to improve yields and develop disruptive technologies that are more resource-efficient (high-temperature electrolysis, reduction of the material footprint, water management, etc.).
P: 97.6%
C: 0%
A: 2.4%

Among electrolysers, alkaline and proton exchange membrane (PEM) technologies are the most mature and have an efficiency close to 70%. High-temperature electrolysers, such as SOEC*, are more efficient but are still at a pre-commercial stage.

France, notably through the French Alternative Energies and Atomic Energy Commission (CEA), stands out worldwide for its cutting-edge research on hydrogen-related technologies, particularly electrolysers. In an international context of the race for technologies, where the challenge is to create increasingly powerful electrolysers, it seems crucial to us to continue to maintain this position as a reference scientific pole at the global level. To achieve this, it is necessary to invest in research and development, both at the industrial level and in research centres.

**1 Solid Oxide Electrolysis Cell: Solid oxide electrolyzer.*

In addition, the production of these electrolysers requires rare metals, which is a geopolitical, ethical and environmental issue. Security of supply, and demanding social and environmental standards regarding extraction, are a major issue. Producing future electrolysers without scarce raw materials, or with a reduced quantity, is an important focus for R&D.

In addition, hydrogen production also consumes clear water: obtaining 1 Mt of hydrogen, which corresponds to current French consumption, requires 0.25% of the water withdrawn from France*. Although there is a tension on water availability and it continues to worsen because of climate change, hydrogen production does not put a strong pressure on the resource in France. Nevertheless, it will be a point of vigilance locally, especially in water-stressed areas of the country.

Recommendation 4: Deploy vocational training around the hydrogen sector.
P: 95.1%
C: 0%
A: 4.9%

Training is another important axis concerning the development of a hydrogen production sector in France: training is required to ensure consistency between the jobs created and the skills needed. This includes initial training, but also retraining.

**1 Based on average water consumption in France over the period 2010-2020, Ministry of Ecological Transition and Territorial Cohesion*

Recommendation 5: Prioritize the electrification of uses over the use of hydrogen where possible.

P: 95.1%
C: 0%
A: 4.9%

To produce 1 Mt of hydrogen, approximately 7 to 13 GW* of installed electrolysers are required. This requires around 55 TWh of electricity per year, or 11% of French electricity production in 2023 according to RTE. This is a major issue since the demand for electricity is also set to grow in a context of electrification of uses (electric vehicles, industrial processes, heat pumps, etc.).

However, from a global perspective of reducing emissions, the electrification of uses is more relevant than the production of hydrogen. Indeed, the efficiency of electrolysers, around 70%, leads to an energy loss. **The priority therefore remains the electrification of uses to reduce our emissions.**

Recommendation 6: Promote green and pink hydrogen with the aim of making them competitive, for priority uses, through strong action by the State.

P: 87.8%
C: 4.9%
A: 7.3%

According to the major manufacturers in the sector, the cost of hydrogen by electrolysis is around €4 to €6 per kilogram, compared to €1.5 to €2.5 per kilogram for hydrogen produced by steam reforming* without carbon capture. However, the industrialization of electrolyser production will make it possible to reduce the cost of hydrogen produced by electrolysis by around €2 per kilogram*. Thus, even with a decrease in the costs of electrolysers, **green and pink hydrogen will remain more expensive than grey hydrogen**: the State must promote the emergence of the sector in order to make it competitive for targeted uses.

**1 The annual output of a one-megawatt alkaline electrolyser depends on its utilization rate. With a rate of 50%, assimilated to a supply of renewable and therefore intermittent electricity, production reaches 80 tons per year. With a rate of 90%, for example with nuclear electricity, we reach 140 tons per year.*

**2 Source: Hydrogen Deployment Plan (ecologie.gouv.fr)*

**3 Source: Hydrogen Deployment Plan (ecologie.gouv.fr)*

II. Distribution

Recommendation 7: Develop hydrogen production close to the point of use in order to minimize transport distances.
P: 82.9%
C: 4.9%
A: 12.2%

Transporting hydrogen by pipeline is a challenge. Due to its small size, the molecule can easily leak: the current gas transport network is not suitable for transporting hydrogen, except at the cost of heavy investments. The other long-distance transport solution is to build a new network of gas pipelines, which is even more expensive and raises issues of acceptance and impacts on biodiversity. It is therefore relevant to minimize the distances travelled by hydrogen, by focusing on local networks on a regional scale. Very long-distance transport, by sea, is an option in the case of imports. The challenge is to keep the hydrogen in a liquid state at -253°C, which is very energy-intensive.

The difficulties of hydrogen transport underline the relevance of local production, making it possible to reduce the distances travelled.

**1 The transport of the molecule must be closely monitored since the global warming power of hydrogen is 11 times greater than that of CO2.*
**2 The energy consumption related to the liquefaction and temperature maintenance of hydrogen represents the equivalent of 30% of the energy transported.*

III. National Strategies

Recommendation 8: Support local hydrogen production in France by developing the entire value chain.
P:90.0%
C: 2.5%
A: 7.5%

As part of the France 2030 plan, 9 billion euros are planned for the development of the hydrogen sector within the country. This investment aims to develop a sovereign sector across the entire value chain. The National Hydrogen Strategy provides for 6.5 GW of electrolysers to be installed by 2030, equivalent to the equivalent of 5 to 7 current nuclear reactors, which covers about two-thirds of current hydrogen consumption. The aim is to ensure French energy security by producing hydrogen locally and using a minimum of import.
The French strategy differs greatly from the German strategy, which relies heavily on hydrogen imports*.

The European Union, for its part, wants to promote national strategies by providing a framework through the IPCEI (Important Projects of Common European Interest), with a target of 10 Mt of green hydrogen produced in the EU and 10 Mt imported by 2030, which seems extremely ambitious to us. The French strategy must therefore be integrated into the European strategy, considering that France could, in the long term, export its hydrogen and/or electrolysers to its neighbors. In addition, producing large quantities of hydrogen requires a strengthening of the electricity grid and an increase in carbon-free electricity production capacities.

In light of the consumption of electricity, raw materials and the cost of hydrogen, production will necessarily be limited and will not be able to meet all the needs currently envisioned by economic players to decarbonize their sector. This justifies, on the one hand, the prioritization of uses, and on the other hand, the use of sobriety to reduce our energy consumption. In fact, it is only in a context of sobriety that hydrogen-related technologies appear relevant to achieving our sustainable development goals.

**1 Source: Press release of the Federal Ministry for Economic Affairs and Climate Protection, International Hydrogen Development*

We have identified three potential areas for the development for hydrogen technology:

- Mobility, whether by road, rail, sea or air
- Industry
- Balancing the power grid

We formulate our recommendations by area before discussing the prioritization between the different uses in conclusion.

I. Mobilities

Here we express some issues to be taken into consideration before reading the recommendations concerning mobility, they constitute the framework in which we have built our reflection.

• **Sobriety**: to achieve national decarbonization ambitions, the practice of sobriety in uses will be necessary. This is valid for all energy carriers, including hydrogen. For example, if all light vehicles were powered by hydrogen, more than half of France's current electricity production* would go to the propulsion of these vehicles (~260 TWh/year)*. Similarly, if all light vehicles were electric, the associated electricity consumption would represent 20% of French electricity production (~100 TWh/year). In view of the expected increase in electricity consumption in ADEME's various transition scenarios, it seems to us that sobriety will be necessary to succeed in the energy transition.

• **The modal shift** towards low-carbon and/or collective mobility, such as train, bus, bicycle and walking, must be at the heart of any policy concerning heavy and light mobility for people. It is necessary to take into account the support of stakeholders in this transition, in order to integrate **social justice** as a central element.

• It is necessary to initiate national discussions on uses and anticipate the adaptation of territories with regard to the additional costs caused by hydrogen technologies.

• Hydrogen will have to be **available** for sectors that need it: ensuring the safe development **of hydrogen transport and production** is paramount.

• With regard to electric vehicles, R&D efforts must be continued in order to reduce, for example, the material intensity of these vehicles, and to make its development possible and acceptable.

• The transition to less carbon-intensive uses will require more electricity: it is therefore necessary to ensure that **it is available** for all sectors.

**1 French electricity production in 2023: 494.3 TWh, source: RTE*

**2 Calculations made with manufacturer data and figures from the Ministry of Ecological ransition*

(a) Rail mobility

Recommendation 9: Encourage the modal shift from road mobility to electric rail, thus allowing funding allocated to hydrogen to be directed towards other priority uses.
P: 92.7%
C: 2.4%
A: 4.9%

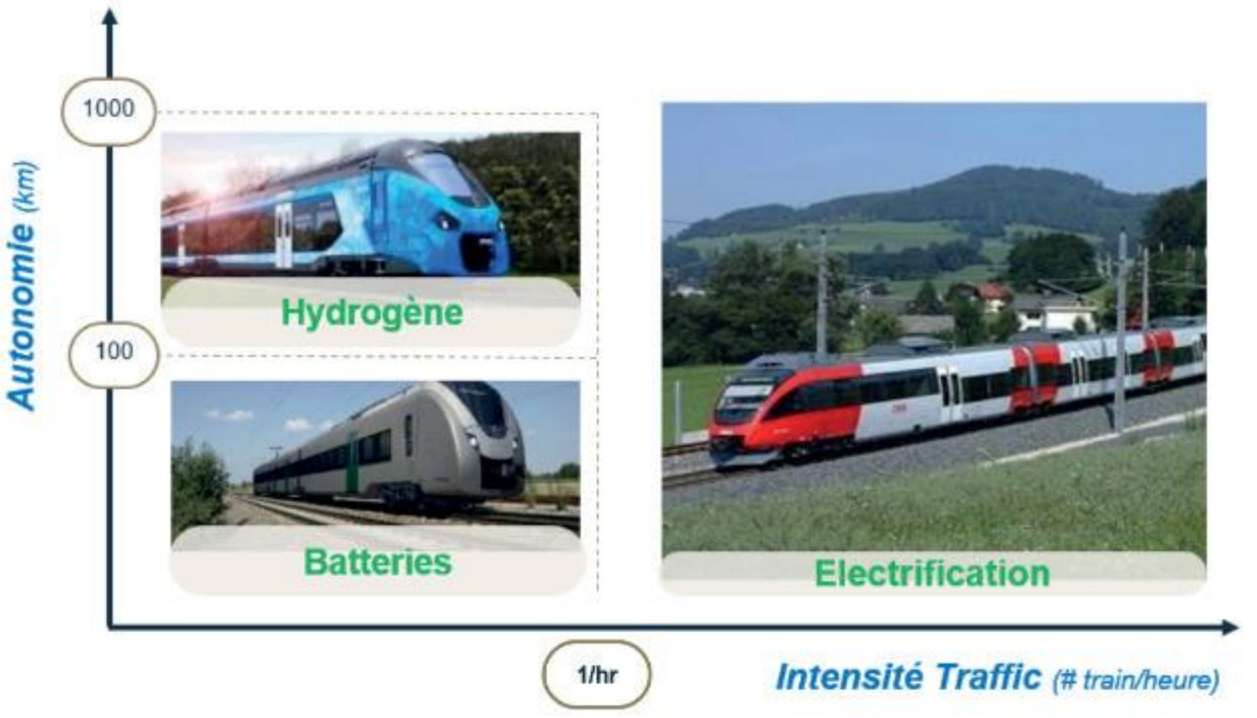
In France, 80% of the journeys made by the SNCF are made by electric trains. Rail accounts for less than 0.5% of total GHG emissions from the transportation sector*, making it the least carbon-intensive type of transportation.
Currently, TER trains are the trains that emit the most GHGs with 401,000 tons of CO2e emitted per year (50% of TER trains are still equipped with thermal traction (diesel)*). To reduce these emissions, there are various solutions: biofuel, hybrid (fuel and electric), battery and hydrogen TERs.

Recommendation 10: Do not prioritize the development of hydrogen trains in France.
P: 63.4%
C: 12.2%
A: 24.4%

For electrically powered trains, the cost of electrification (infrastructure) is between €1 million and €3 million per km*. The cost of hydrogen-related infrastructure is significant, with stations requiring investments in the range of €10 to €15 million, and maintenance centers varying between €500,000 and €3 million*. This will result in higher prices for consumers.

The infographic below shows the potential place of the hydrogen train in rail traffic. The electrification of existing lines is the solution to be put in place as soon as the traffic intensity is sufficient. For lines that are less frequented (less profitable) or for which electrification is not technically possible, the battery should be preferred. Hydrogen has its place in this ecosystem (for journeys for which the battery range will not be sufficient), but it is narrow. **Nevertheless, given the small share of rail in carbon dioxide emissions in the field of transport, the appearance of the hydrogen train in France should not be prioritized.**

**1 Source: Secten 2023 report, Citepa*
**2 Source: SNCF - "What future for hydrogen in the rail sector?", Yann Harcouet*
**3 Source: Alstom – "Hydrogen Trains", Stéphane Kaba*
**4 Source: SNCF - "What future for hydrogen in the rail sector?", Yann Harcouet*



Source: Alstom, "Hydrogen trains", Stéphane Kaba, 01/2024

(b) Maritime mobility

Today, more than 80% of the world's cargo volume transits by sea and the maritime sector is responsible for nearly 3% of GHG emissions, or about 1 Gt CO2e. These numbers have increased by 20% in the last decade*.

Recommendation 11: Transition to synthetic, hydrogen-based fuels (e-fuels, liquid hydrogen, gaseous hydrogen) for merchant ships
P: 95.1%
C: 0%
A: 4.9%

Efforts must be prioritised on the most emitting uses, particularly for large vessels (container ships, bulk carriers, tankers, etc.). They account for the majority of global maritime traffic and are responsible for approximately 75% of the maritime sector's emissions*. **Forecasts for the use of these new synthetic fuels predict a reduction in GHG emissions of between 70% and 100%***, but this will represent a very significant demand in the near future. It will therefore be necessary to develop the e-fuels value chain in the coming years. It should also be noted that the use of hydrogen in these three forms reveals different price scales: e-fuels are more expensive than liquid hydrogen, which itself is more expensive than gaseous hydrogen. These fuels have different storage characteristics that are more or less adapted to their uses.

**1 Source : United Nations Conference on trade and development, Review of maritime transport, 2023*
**2 Aujourd'hui, moins de 1% de la flotte fonctionne avec des carburants alternatifs*
**3 Source : Transport & Environment, 2021, "Decarbonizing European Shipping: Technological, Operational and Legislative Roadmap"*

Recommendation 12: Allocate different forms of synthetic fuels according to the needs of different types of ships.

P: 90.2%

C: 0%

A: 9.8%

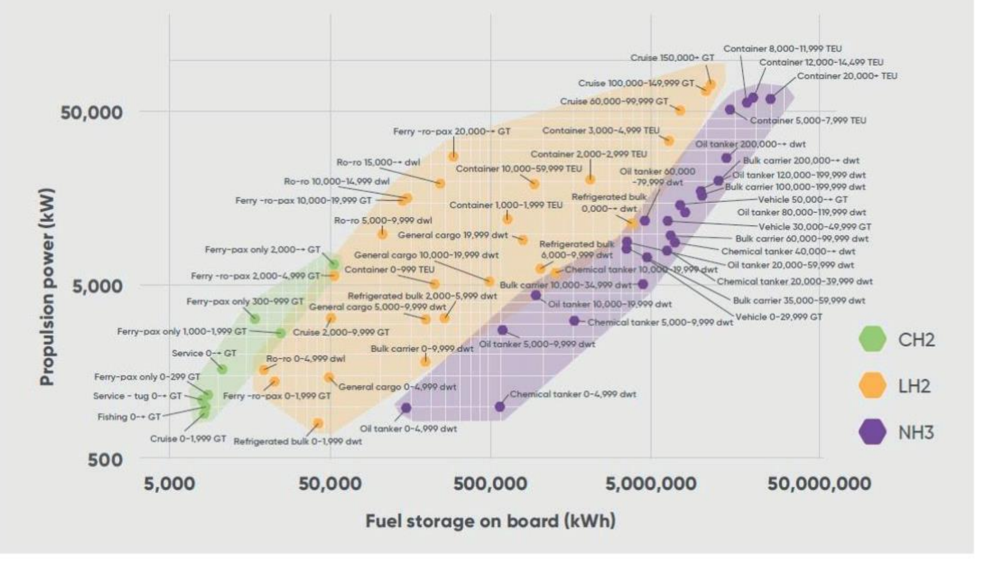
By taking into account the economic and technical dimensions of the different forms of hydrogen and by comparing them with the energy autonomy needs of ships, some forms of hydrogen appear to be more relevant than others for certain routes:

- **E-fuels (e-methanol, e-ammonia) for long (intercontinental) journeys**: Ships engaged in long rotations require a very long range and only e-fuels meet this requirement. The energy density of these fuels makes them suitable for this purpose. It should be noted, however, that the additional cost compared to liquid and gaseous hydrogen will certainly ultimately be passed on to consumers.

- **Liquid hydrogen for intra-continental voyages**: For medium-range vessels, the use of liquid hydrogen is suitable. It represents the best compromise between cost, energy density and GHG emissions. However, to date, the technology is not mature enough to be developed on a large scale. We encourage research and initiatives on the use of liquid hydrogen as a marine fuel.

- **Complementary propulsion for short journeys (coastal, trans-roadstead, etc.)**: For short sea shipping*, the use of multiple propulsion is the most suitable. Combining the power of wind, electric batteries and hydrogen gas in a fuel cell can best reduce emissions from this sector*.

The graph below shows a breakdown of fuels according to the types of vessels, considering the power required for propulsion and the storage capacities on board.



Optimum zero-emission options for different vessels (Source: Hydrogen Europe, 2020)

**1 River traffic is included in the TMCD*

** 2 Example of the Energy Observer: hydrogen-powered vessel self-sufficient in energy thanks to a mix of renewable energies (solar, wind, tidal), batteries and hydrogen produced on board from seawater*

Recommendation 13: Rethink global maritime traffic to in order to decarbonize the sector as much as possible while integrating hydrogen into its energy mix.
P: 95.1%
C: 0%
A: 4.9%

It is essential to carry out a plurality of actions if we hope to achieve the objectives of the IPCC and the Paris Agreement. While the transition to synthetic fuels is necessary to decarbonize the sector, we are convinced that the following aspects need to be acted in parallel:

- **Decreased ship** speeds (accepting and standardizing slower delivery times would have a major impact on reducing GHG emissions*).
- **Logistics optimization of global traffic** (Right-On-Time method, better management of rotations, reduction of waiting times in ports, etc.).
- **Integrate sail propulsion, regardless of the type of boat** (very positive investment/gain ratio, with significant energy savings possible).
- **Technical optimization of the merchant fleet** (hull shape, materials used, size of ships, etc.).
- **Reduction of global maritime traffic.**

It is important to note that the International Maritime Organization (IMO) as well as the European Union (EU)* are demanding a strong decarbonization of the sector through increasing economic penalties. Our recommendations are therefore in line with those of international bodies. Also, such a transition is necessarily accompanied by major projects in the world's port interfaces to adapt them to the new needs of the sector (new terminals, presence of gas pipelines, new safety standards, etc.). International cooperation is needed on this issue.

(c) Heavy and light road mobility

Mobility accounts for 30% of GHG emissions in France, half of which is attributable to individual mobility*. The number of private vehicles in France is now around 39 million, and this mobility has entered deeply into Western culture. France has thus experienced a dilation of distances, with a lifestyle centered around road mobility, whether in the city, where the majority of food is transported by truck, or in the countryside, where access to the same services requires travel by private car.

**1 Energy consumption, and therefore GHG emissions, increases as the speed increases.*
**2 via the Carbon Intensity Index and carbon taxation.*
**3 Source: Key data | Climate Key Figures 2023 (developpement-durable.gouv.fr)*

The transition to decarbonized and responsible consumption patterns will necessarily involve a change in these forms of mobility and represents a major challenge: accepting a technical, and therefore social, change will be difficult if it is not clearly explained.

In the case of heavy road mobility, we considered only trucks, coaches, and buses, and in the case of light mobility, private and professional vehicles as well as taxis.
In France, 16.8% of new car registrations are 100% electric and 9.2% are plug-in hybrids in 2023*; however, 97% of vehicles on the road on 1 January 2022 were internal combustion vehicles (petrol or diesel)*.

Recommendation 14: Plan the use of hydrogen for heavy road mobility at European level.
P: 78.0%
C: 9.8%
A: 12.2%

The use of hydrogen in heavy and light road mobility must be considered and debated at European and French level, with a coherent plan that will take into account the associated issues (social, economic, environmental, etc.).

Recommendation 15: Do not develop the use of hydrogen for light vehicles.

P: 87.8%
C: 0% A:
12.2%

Electrification enables the decarbonization of light vehicles, in the assumption of a decarbonized electricity system. The two technologies (electrification or hydrogen use) are very different in terms of performance; however, the safety of hydrogen technology is a subject that must be managed by professionals; in addition, the Life Cycle Assessment of hydrogen propulsion is not favorable compared to electric.

Recommendation 16: Develop hydrogen for professional vehicles only on long-distance and regular journeys, and for uses incompatible with electrification.
P: 75.6%
C: 12,2%
A: 12.2%

*1 Source: *The electric car market ended 2023 with its foot on the ground | Les Echos* *2 Source: *38.7 million cars on the road in France on 1 January 2022 | Data and statistical studies (developpement-durable.gouv.fr)*

The majority of professional vehicles (buses, trucks, LCVs, etc.) are electrifyable. The use of hydrogen technologies may be considered in certain very specific cases, such as long-distance non-rail transport. This is because the majority of trucks transport goods over a short distance, making their electrification relevant. The only use that seems compatible with hydrogen is that of trucks that travel long distances on a regular basis. If this development were to happen, the installation of charging stations only on major roads seems relevant to us.
Finally, we believe that, in the long term, rail transport should replace the use of trucks over long distances.

Recommendation 17: The decarbonization of the freight transport sector will necessarily involve a modal shift towards rail, which must be encouraged by public policies.
P: 82.1%
C: 2.5%
A: 15.4%

At the beginning of the twentieth century, rail freight accounted for 80% of domestic freight in France. The rise of the oil truck combined with an increase in trade relegated rail to 10% of flows in France in the early 2000s - against 88% for road and 2% for river transport*.

In Europe, France is lagging behind on this subject. The modal share of rail is on average 2 times higher in our neighbors (18% in Germany).

The 2021 "National Strategy for the Development of Rail Freight" - which aims for a 25% modal share for rail freight by 2050 - remains insufficient. The decline in road traffic, the evolution of our economy and the demand for goods are not taken into account.

To reduce our emissions and not to mobilize capital to develop hydrogen in heavy road transport, the aim is to reduce road traffic and not just to increase rail freight.

Rail freight must be improved and encouraged by strong investments in order to compete with road transport.

(d) Air mobility

Recommendation 18: Favor the normative route, rather than subsidies that could be earmarked for other more socially acceptable sectors, to force investment in the development of SAF (Sustainable aviation fuel).

P: 85.4%
C: 2.4%
A: 12.2%

1 Source: SDES according to Eurostat, DGEC, VNF

Through the RefuelEU Aviation plans, the European Union has established a roadmap requiring Member States to incorporate a minimum rate of SAF in fuels. Without specifying the means to be implemented to achieve this, each European airport must be able to supply from 2% in 2025 to 70% in 2050 of sustainable fuels, including a minimum percentage of 0.7% in 2030 and 35% in 2050 of synthetic fuels (e-fuels).

In the 2024 Finance Bill, in order to align with European objectives, a fuel tax credit with SAF rates was mentioned. We believe that it would be better to set standards and ban fuels that do not meet those standards. In this way, the objectives would be achieved at no cost to the taxpayer and without indirectly financing air travel, which is generally carried out by the wealthiest people. In addition, this measure makes it possible to give a direction to industrialists facilitating the deployment of investments and research in this sector.

Recommendation 19: To achieve decarbonization targets and taking into account the scarcity of hydrogen, incentivize modal shift where there is an alternative to flying, by aligning aviation prices with those of other modes of transport.

P: 73.2%
C: 19.5%
A: 7.3%

A study by ADEME indicates that to meet the objectives of the European plans, the production of SAF in France in 2050 would require between 25 and 108 TWh of electricity depending on the scenarios envisaged*. Thus, we believe it is necessary to add sobriety measures, with the modal shift, in addition to technological solutions. This modal shift could be encouraged by aligning air ticket prices with those of less carbon-intensive alternatives (trains are often more expensive than planes). Several mechanisms could allow this alignment (subsidies, taxes, leaving the market, etc.).

20: Do not encourage technologies based on the direct use of hydrogen (fuel cells and direct combustion) for air mobility.

P: 78.0%
C: 9.8%
A: 12.2%

It is not a question of prohibiting industrialists who have launched research programmes on these subjects from continuing them. However, these technologies are not mature. The fuel cell can only be used for short-haul flights with a low number of passengers, for which we prefer the modal shift. Direct combustion technology, on the other hand, has non-CO_2 effects, such as contrails, which are still poorly evaluated. We therefore believe that they should not be prioritized compared to other technologies with shorter development times (energy efficiency, SAF).

**1 Source: Electrofuels in 2050: what are the electricity and CO2 needs? (ademe.fr)*

Recommendation 21: Prioritize e-fuels over biofuels in the aviation sector.

P: 53.7%
C: 9.8%
A: 36.6%

The technology of e-fuels (fuels based on hydrogen and captured carbon) is currently at a less advanced stage than biofuels (fuels produced from biomass). However, we consider it important to develop research in the e-fuel sector because we will not be able to rely solely on biofuels, given the limited nature of biomass and the tensions linked to the use of land and resources.

II. Industry

Industries are a **priority in terms of decarbonization** in France. They account for a significant share of French greenhouse gas emissions (18%), which are concentrated in key sites: Dunkirk, Fos-sur-mer, Le Havre, the Chemical Valley in Lyon, etc. The three main industrial sectors affected by greenhouse gas emissions are:

- **The steel industry;**
- **The chemical industry, including fertilizers and refining;**
- **Cement works.**

Industry is a **major socio-economic driver.** The underlying issue is the decarbonization of this sector while maintaining its competitiveness.

22: Prioritizing the use of hydrogen in excluding the use of public money to because of its incompatibility with the industry objectives, for the purposes of the industrial branch decarbonization.

P: 87.8%
C: 2.4%
A: 9.8%

*1 Source: Key data | Climate Key Figures 2023 (developpement-durable.gouv.fr)

Coupled with the existence of low-carbon processes using low-carbon hydrogen, the use of this energy carrier seems very optimal. Its implementation in the steel industry has the highest decarbonization intensity*, followed by the chemical industry. As it stands, **we recommend the use of low-carbon hydrogen in the industrial sector for decarbonization purposes.** The rest of the discussion will aim to define its relevance for each of the sector's activities.

Today, the demand for hydrogen for refining amounts to 40 Mt/year. Produced by vaporeform, it is responsible for about 20% of the sector's greenhouse gas emissions*, so the use of low-carbon hydrogen would be relevant. However, we do not recommend encouraging the use of low-carbon hydrogen through mechanisms using public money for this industrial branch because of its incompatibility with decarbonization objectives.

		Potentiel H_2 bas-carbone en 2030 : borne haute (MtH_2)	Intensité décarbonante de l'H_2 bas-carbone (tCO_2e / tH_2)	Potentiel de réduction des émissions en 2030[1] ($MtCO_2e$)
Industrie	Production d'ammoniac	5	12,5	60
	Production de méthanol	10	10	100
	Acier : DRI à l'H_2	3	24	75

Source: Carbone 4 - Hydrogen study

Opportunities for the use of hydrogen for the industrial sector

Some of the industrial activities described above already use hydrogen in their processes, such as chemistry for fertilizer production. Other industries are not yet using hydrogen, but could modify their fossil fuel-dependent processes to use it when it is an optimal alternative. This transition is conditional on the development of a new low-carbon hydrogen production sector (see recommendation 6, above). In addition, the use of hydrogen in industry is not a new safety issue because this sector is already confronted with the use of hazardous substances and has already integrated the safety standards necessary for their handling.

The use of low-carbon hydrogen in industry can be divided into 3 typical cases illustrated by the chemical, steel and cement industries, presented below here.

**1 The decarbonizing intensity corresponds to the number of kg of CO2e avoided per kg of hydrogen used, the concept was introduced by the firm Carbone 4. The decarbonising intensity of hydrogen used in steel is 24, compared to 12.5 for ammonia and 10 for methanol*

**2 Source: Low-carbon hydrogen: what are the relevant uses in the medium term in a low-carbon world? (Carbon 4)*

(a) Industries that already use hydrogen, in the case of the chemical industry

Recommendation 23: Replace grey hydrogen used by industry with low-carbon hydrogen as a matter of priority.
P: 95.1%
C: 0%
A: 4.9%

The chemical industry here illustrates industries that already use (grey) hydrogen in their processes. The chemical industry is divided into 2 sectors: ammonia production and methanol production. They combine hydrogen with nitrogen to produce ammonia (for the manufacture of nitrogen fertilizers) or with carbon monoxide for the manufacture of methanol.

These sectors want to **see the origin of their hydrogen change, to move to the use of low-carbon hydrogen.** By 2050, the companies we met estimate that their ammonia production will double to meet new uses, including shipping. However, to cope with this increase in activity, **they still intend to use blue or grey hydrogen for cost reasons.**

Thus, we believe that it is necessary today to ensure the **competitiveness of low-carbon hydrogen compared to blue and grey hydrogen (see recommendation n°1) and not to favor blue hydrogen because it contradicts our recommendation n°2.**

(b) Industries with an opportunity for transition, in the case of the steel industry

Recommendation 24: Increase the capacity of the electricity grid to allow for the increase in industrial electricity consumption while providing electricity at a competitive price.
P: 92.7%
C: 0%
A: 7.3%

The steel industry is an example of industries that do not use hydrogen today but for which a process change based on it would allow their decarbonization. The steel industry **will change its steelmaking process entirely,** moving from a process using coal to **one using hydrogen and electricity.** This allows the direct reduction of iron ore by the addition of hydrogen (or natural gas) instead of using a coal-fired blast furnace.

According to manufacturers in the sector, the process change **will multiply electricity consumption by 12*** if the gas used is hydrogen (including electrolysis production). For comparison, using natural gas, this multiplication will be 3.5. The use of low-carbon hydrogen would reduce the sector's emissions by 90%.

Today, stakeholders are considering using natural gas in the short term due to uncertainty about the availability of low-carbon hydrogen and electricity at competitive prices.

**1 This is equivalent to one additional EPR per plant. EPR: European Pressurized Reactor (Réacteur Pressurisé Européen)*

Thus, we believe that it is necessary **to increase the capacity of the electricity grid to allow for the increase in industrial electricity consumption while offering electricity at a competitive price.**

(c) Industries with uncertain use of hydrogen, in the case of the cement industry

Two-thirds of the cement industry's greenhouse gas emissions are linked to its industrial process, which inevitably releases CO2 (by clinkerization of limestone). The remaining third is related to the energy consumption of natural gas ovens*.
Although possible, the use of hydrogen to power non-electrifiable furnaces is debated by stakeholders for reasons of cost and availability. The alternative envisaged is the use of biofuels rather than fossil fuels in the kilns and the reduction of the use of products from the emitting process (reduction of the use of clinker).

These players hope to achieve carbon neutrality by relying on CCU technologies.
CCS. The CO2, particularly from the process, would then be stored or used to produce e-methanol.

Recommendation 25: Require companies to adopt a decarbonization strategy that does not rely on the use of Carbon Capture and Storage (CCS) in the case of a process using fossil fuel-based combustion.
P: 69.7%
C: 6.1%
A: 24.2%

It seems very relevant to us to make the use of CCS less attractive than the decarbonization of a process or the use of hydrogen produced from carbon-free electricity. We believe that **CCS technology should not be a substitute for decarbonization, because of the** ambitious technological challenges on which it is based.
As the primary goal is to reduce carbon emissions, we believe that the **regulatory framework for CCS and CCU strategies must** be scalable according to the technological maturity of these solutions.

(d) The case of processed heat, encompassing many industries

Recommendation 26: Consider hydrogen as a driver of decarbonization only if electrification of furnaces is not possible.
P: 83.3%
C: 4.8%
A: 11.9%

*1 Source: Cement Decarbonisation Roadmap (entreprises.gouv.fr)

*2 Carbon Dioxide Capture and Storage

Heat is necessary in many sectors: agri-food, chemicals, stationery, glassware, cement, etc. This heat is typically obtained from fossil fuels, including coal (65%) and methane (20%)*. Electric ovens are not always able to reach sufficient temperatures or are too expensive. Decarbonization alternatives rely on hydrogen (alone or combined with methane) or biofuels. We believe it is important to prioritize electrification where possible, as hydrogen resources are limited.

(e) Prioritization of industrial sectors

The use of low-carbon hydrogen is a priority for the industrial sector. The security requirements of the domain simplify its implementation compared to use by private individuals. Among the various industrial activities, low-carbon hydrogen must be a priority for the chemical industry (ammonia and methanol) and for the steel industry. The chemical industry, which already uses (grey) hydrogen in its process, is particularly conducive to making this transition. As for the steel industry, the use of low-carbon hydrogen has a significant decarbonization intensity, justifying this transition.

III. Network Balancing

The electricity grid includes the generation, transmission, distribution and regulation of electricity. Electricity production must be equal to consumption at all times. Two temporalities must be taken into account: daily and seasonal. Currently, hydrogen is not used to balance the French electricity grid.

On the other hand, hydrogen may have a role to play in balancing the power grid. Indeed, it can be used as a buffer to compensate for the intermittency of renewable energies. During peaks in production due to renewable energies, the amount of electricity produced is greater than the demand. The surplus electricity is thus transformed thanks to Power To Gas (P2G), which transforms the surplus electricity into hydrogen thanks to electrolysers. Its efficiency is around 70%. P2G2P (Power to gas to power) is a P2G process followed by hydrogen storage in a salt cavern, then a reconversion of hydrogen into electricity (reverse process called G2P: Gas to Power) thanks to a fuel cell. The efficiency of P2G2P is low compared to other energy conversion methods, in the range of ~30%*.

We lack data and visibility on the future of the French electricity grid to conclude on the future composition of the electricity mix. As a result, we then introduce avenues for reflection, when we cannot give a confident opinion on recommendations. We have, however, two certainties that we translate into recommendations.

**1 Source : The Shift Project*

**2 The efficiency of P2G is about 70%, that of the fuel cell is about 50%. Storage also leads to some losses. The final yield of P2G2P is therefore in the order of 30%. By comparison, hydroelectric dams have an efficiency of about 80%.*

Recommendation 27: Do not use P2G2P but favor the development of WWTPs* or electric batteries for the daily balancing of the electricity grid.

P: 56.1%
C: 19.5%
A: 24.4%

The efficiency of P2G2P is low and requires new installations and connections to the power grid. Daily storage is provided by alternatives such as existing WWTPs or batteries. In addition, considering an electrical energy mix with less than 75% renewable energy and a relatively large share of nuclear, as predicted by most ADEME* scenarios, the daily P2G2P will not be justified. The small daily surplus of electricity will not be able to produce enough hydrogen to compensate for the intermittency of renewable energies in view of daily consumption peaks. Hydrogen would be better suited to meet seasonal needs, particularly during winter consumption peaks.

Food for thought: P2G2P could be used as a seasonal storage medium to compensate for winter consumption peaks for which batteries and wastewater treatment plants are not always suitable.

Hydrogen is produced with low-cost electricity because it is surplus electricity when production is higher than demand. This hydrogen can be converted into electricity during consumption peaks (P2G2P), when the price of electricity is highest. The low volume of hydrogen, the low filling speed of the tank as well as the irregularity of production would **not allow the stable use of this hydrogen for other uses (industrial, transport, etc.),** which could enhance its value for seasonal balancing of the electricity grid.

Recommendation 26: Consider hydrogen as a driver of decarbonization only if electrification of furnaces is not possible.

P: 83.3%
C: 4.8%
A: 11.9%

The French electricity mix, which is low-carbon thanks to nuclear power, already allows the production of low-carbon hydrogen. In addition, France is moving towards sovereignty vis-à-vis the production of hydrogen. The interest of import is therefore limited for the balancing of the electricity grid.

**1 A pumped storage power plant (STEP) is a pumped-storage hydroelectric power plant. In order to balance the electricity grid, these specific dams have the ability to absorb surplus electricity by pumping water from the reservoir downstream.*
**2 ADEME's "Transition(s) 2050" report.*

CONCLUSION

We, the young scientific students of the Student Scientific Convention on Hydrogen, consider that **hydrogen is not a miracle solution,** but a relevant technology that needs to be developed for priority uses, provided that the objectives of sustainable development and sobriety are respected.

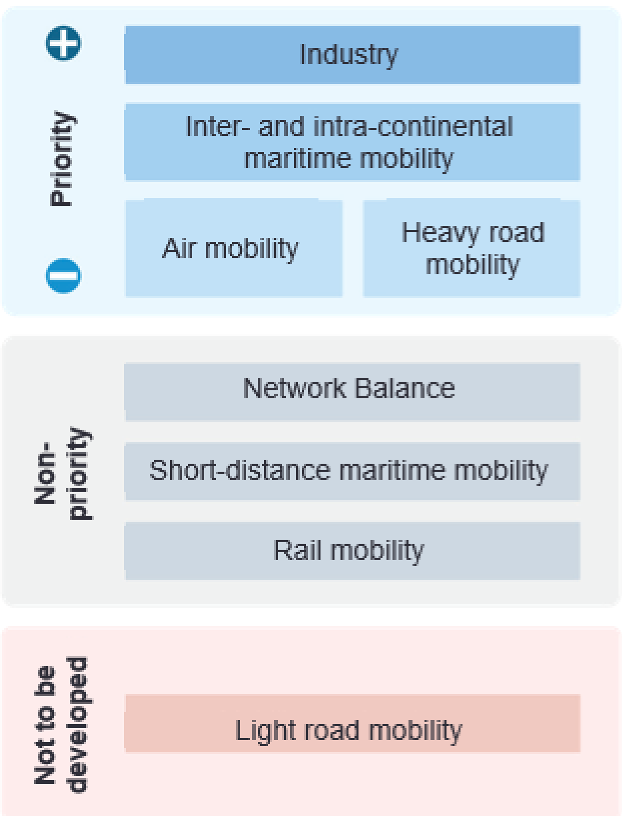
Indeed, the deployment of the hydrogen sector must comply with the **Sustainable Development Goals**, in particular: human rights, social justice and the preservation of biodiversity. To this end, we recommend the implementation of a regulatory framework that systematically requires the study of the social, environmental and economic impacts of hydrogen-related projects.

In addition, we conclude that **sobriety is a necessary prerequisite** for the successful implementation of hydrogen on a national scale to decarbonize non-electrifiable uses. Indeed, as electricity is necessary both for the electrification of uses and for the production of hydrogen, this resource will be limiting, making sobriety essential to ensure a transition of all sectors.

As hydrogen production is constrained, it is necessary to prioritize its uses. We propose the following hierarchy:

We lack data and visibility on the future of the French electricity grid to conclude on the future composition of the electricity mix. As a result, we then introduce avenues for reflection, when we cannot give a confident opinion on recommendations. We have, however, two certainties that we translate into recommendations.

Prioritization of uses



With the aim of prioritizing uses, we recommend the use of hydrogen primarily for **heavy industries,** in particular the steel and chemical industries. It is in these sectors that the decarbonizing power of hydrogen is strongest, and the economic opportunities brought by hydrogen the most interesting.

Secondly, **inter- and intra-continental maritime transport** appears to us to be mobility in which access to hydrogen is a priority in order to produce e-fuels. Indeed, long-distance maritime transport is not electrifiable, even though the transport of goods benefits the greatest number of people and is vital for the economy, which leads us to prioritize it.

E-fuels are also key to decarbonizing the aviation sector. However, this use is not a priority compared to the maritime sector, as **aviation** is economically and socially unequal.

Heavy **road mobility** could also have access to hydrogen for regular and long-distance journeys. However, this concerns a small part of the current truck fleet and not all vehicles, as the majority of road freight can be electrified. However, modal shift remains the most effective solution to decarbonize the sector.

Regarding **the balancing of the electricity grid,** we recommend not using hydrogen for the daily balancing of the grid via power-to-gas-to-power (P2G2P), which can be provided by alternatives. However, seasonal grid balancing by hydrogen is a topic that needs to be explored further.

The decarbonization of **short sea shipping** (SST) does not need the synthetic fuel solutions envisaged for long-sea shipping. Indeed, alternative solutions are deployable and more relevant. Hydrogen could eventually be integrated into these solutions through fuel cells.

In terms of **rail mobility,** the use of hydrogen is relevant for certain specific cases. However, given the relatively small share of rail in the greenhouse gas emissions of the transport sector in France, prioritizing the development of hydrogen trains seems less sensible compared to other applications. In addition, the increase in rail traffic due to the modal shift is encouraging the electrification of many lines.

Finally, we recommend that the development of hydrogen for **light road mobility should not be encouraged.** Indeed, battery-powered vehicles are more suitable in terms of energy efficiency and environmental impact over the entire life cycle of the vehicle, while offering a satisfactory range.

We warn against unconditional support for low-carbon hydrogen, despite its potential to meet climate goals. Its uncontrolled expansion can exacerbate the environmental crisis, particularly through the overexploitation of critical resources such as water and rare metals, and through the socio-environmental impacts of mining, which are necessary for both this technology and battery electrification.

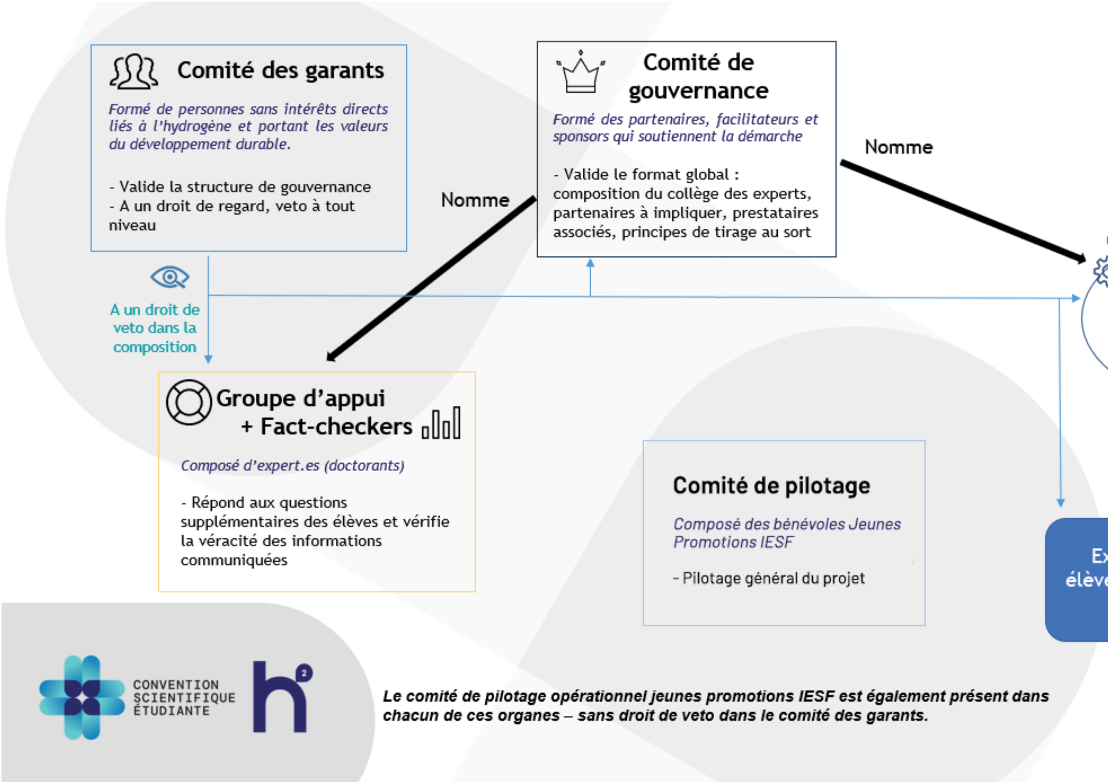
In addition, the development of hydrogen is closely dependent on the progress of infrastructure and the electricity grid. Whether it is to meet the new electricity and hydrogen needs of heavy industry or to meet the growing demand for electric mobility, an unprecedented pressure will weigh on electricity demand. Thus, anticipating **the sizing of the electricity network and connections** to different uses in the long term is a major challenge in the implementation of hydrogen.

In addition, since the price of electricity is a determining factor in the development of low-carbon hydrogen uses, we believe it is necessary to reflect on **electricity pricing.** Indeed, our report only partially addresses the economic issues and costs related to hydrogen. It is important to take into account the inevitable increase in costs for public policies, manufacturers and consumers. However, in the context of successful decarbonization, this increase in costs should be offset by the reduction of negative externalities linked to the use of fossil fuels.

It is only in a context of sobriety and for targeted uses that hydrogen-related technologies appear relevant to achieve our sustainable development goals.

EXHIBITS

Organization of the Student Scientific Convention



Governance Committee

Met 3 times

Made up of our valued partners, facilitators and sponsors, this committee actively supports our approach. It validates the overall format of the project, including the composition of the panel of experts, the partners to be involved, the associated service providers and the principles of the draw.

- **Jane Lecomte,** *Ecological Transition Advisor to the Minister of Higher Education and Research*
- **Sylvianne Villaudière,** *Vice-President of the Société d'Encouragement pour l'Industrie Nationale (SEIN)*
- **Stéphane Gorce,** *partner at Eurogroup Consulting*
- **Cédric Prunier,** *Deputy Director of Strategy, Director of Development, Partnerships, Entrepreneurship and Valuation at Mines Paris*
- **Jean Paul Reich,** *consultant and consultant EnerHy*

College of Experts

Met 5 times

Composed of eminent experts, this college validated the list of experts/planning to ensure a holistic, balanced and impartial vision. He decided on the experts who interacted with the students and he set the schedule for the sessions.

- **Luc Bodineau,** *Deputy Executive Director of Hydrogen Expertise and Programs at ADEME, Vice-President in charge of sustainable development at the University of Paris Saclay and author of the IPCC Group 1 Chapter 6 report*

- **Valérie Bouillon-Delporte,** *co-president France Hydrogène*
- **Abdelilah Slaoui,** *Deputy Scientific Director, Head of the CNRS Energy Unit and Co-Director of the PEPR Hydrogen*
- **Nadège Troussier,** *Deputy Director General in charge of training at ENSAM*
- **Joao Peirera Da Fonseca,** *Project Manager at CDC Biodiversity*

Guarantors' Committee

Composed of people with no vested interest in hydrogen, this committee upheld the values of sustainable development. He had the power to validate the governance structure and exercised oversight and veto at all levels.

- **Matthieu Sanchez,** *former participant of the Citizens' Convention for the Climate, member of the governance committee of the Citizens' Convention on the End of Life and guarantor of the Citizens' Assembly of Est ensemble*
- **Caroline Véran,** *founder and director of the CSR agency Croissance Bleue*
- **Philippe Quirion,** *CNRS Research Director at CIRED*

Animation team

Throughout the duration of the work, the members were accompanied by professionals in engineering and citizen dialogue: Res publica and Eurogroup Consulting. There are 4 professionals who led all the work in person or remotely. The facilitation was conducted in accordance with protocols developed in advance by the facilitators and the Governance Committee of the Convention.

- **Sophie Guillain and Gilles Laurent Reyssac** *(Res publica)*
- **Margaux Boulanger and Thomas Cazin** *(Eurogroup Consulting)*

Support Group and Fact-Checkers

Bringing together experts, in this case doctoral students, this group answered the students' additional questions and ensured the veracity of the information communicated.

- **Myriam Badri, Sebastian Vallejo Jimenez, Thomas Lapi, René Bankati**
- **Michel Colombier,** *co-founder and scientific director of the Institute for Sustainable Development and International Relations*

Operational Steering Committee

Composed of volunteers from the IESF Young Promotions, this committee was responsible for the overall management of the project. He was also present in each of the bodies, without the right of veto in the guarantors' committee.

Mélodie Marin-Lamellet, Amaury Fievez, Cassandre Pradon, Arthur Stainmesse, Meryem Ben Dhiaf, Komla Adjabli, Mélanie Schiffer, Jean Vieville, Pauline Lefebvre, Benjamin Saudreau, Matteo Giordano, Aurélien Guez

OUR PARTNERS

The student scientific convention is placed under the patronage of Roland Lescure, Delegate Minister for Industry and Energy.

ADEME participates in the construction of national and local ecological transition policies. To do this, we rely on our teams, present throughout France, and on a budget dedicated to our means of intervention. Our missions, organization and operation are set out in the Environmental Code. We have been committed to the fight against climate change and resource degradation for 30 years and are determined to make a difference.

Founded in 1923, the Conseil Français de l'Énergie is the national committee representing France at the World Energy Council, a body approved by the United Nations, which brings together more than 3,000 public and private organizations and represents nearly a hundred countries. A non-profit association recognized as being of public utility, the French Energy Council aims to promote the sustainable supply and use of energy for the greater good of all.

The United Nations Educational, Scientific and Cultural Organization is an international specialized agency of the United Nations, established on 16 November 1945 in the aftermath of the devastation and massacres of World War II. World Engineering Day for Sustainable Development is one of UNESCO's international days and is celebrated every 4 March. It was proclaimed by UNESCO's General Conference on 25 November 2019, based on a proposal by the World Federation of Engineering Organizations.

The Société d'Encouragement pour l'Industrie Nationale is a society founded in 1801, to revive the economy of France. In the nineteenth century, it made a direct contribution to the economic development of France. It was recognized as a public utility in 1824 and continues its mission of supporting major industrial, economic, and social changes. It aims to stimulate the French industrial renaissance, to promote technological innovation and to promote entrepreneurship.

Elogen is the French leader in PEM (proton exchange membrane) electrolysis, specializing in the design and assembly of electrolysers for the production of green hydrogen. Driven by a taste for innovation and cutting-edge technological know-how, the company serves, in France and internationally, the industrial and energy markets.

As a major operator in the transmission of high-pressure gas, GRTgaz has a public service mission aimed at guaranteeing the continuity of gas delivery and is resolutely committed to carbon neutrality, the development of renewable gases and the energy transition in the regions.

A global leader in low-carbon energy and services. Together with our 96,000 employees, customers, partners and stakeholders, we are committed every day to accelerating the transition to a carbon-neutral world, through more energy-efficient and environmentally friendly solutions. Guided by our purpose, we reconcile economic performance with a positive impact on people and the planet by relying on our core businesses (gas, renewable energies, services) to offer competitive solutions to our customers.

Hy2gen France SAS was created in 2019 in Aix en Provence. Its corporate purpose is to develop and produce renewable hydrogen, biomethanol and renewable fuels for regional and European markets.

Ernst & Young (EY) is a global provider of professional services, offering a wide range of solutions worldwide. EY provides advisory, insurance, tax and transaction services that help solve our clients' toughest challenges and build a better world of work for all.

Fives is a world leader in industrial engineering, offering innovative and sustainable solutions in the steel, aluminum, aerospace, automotive, logistics, energy and much more sectors

ENERCAT is a French SME active in the field of industrial gaseous waste treatment. Specialising in the reduction of nitrogen emissions, it is a reference for the chemical, incineration and fertilizer manufacturers. Since 2022, ENERCAT has launched an ambitious research program on the vectorization of green hydrogen from ammonia and has developed a unique patented solution that it intends to introduce to the market in 2026.

Eurogroup Consulting is a French consulting firm, specialized in organization, strategy and management, for the private and public sectors. Their mission: transformation and mobilization towards sustainable results, for a more responsible economy and society.

Consulting firm in consultation and collaborative dialogue, Res publica Helps institutions, organizations and businesses to organize useful and effective dialogues. Res publica promotes the society of dialogue, in which people and actors exchange and think together about a desirable future.

The purpose of the Arts et Métiers Foundation is to facilitate access to scientific and technological culture, to promote research and teaching in these fields, to promote the action of engineers in economic activities and to contribute to the work of remembrance of techniques and industries.

Founded in 1846, the Society of Arts et Métiers engineers represents 62,000 "Gadzarts" engineers, including 35,000 members who are graduates of the École Nationale Supérieure d'Arts et Métiers (ENSAM). Its vision is to become an essential force of influence for the environmental, societal, industrial and digital transformation in France while contributing to professional and personal development throughout life. It also shares a common identity with the School and the Union des élèves Arts et Métiers, which makes it unique.

The mission of the Mines Paris Foundation, recognized as a public utility, is to share and support the ambitions of the Ecole des Mines de Paris. Four values guide our actions in support of the School: excellence, commitment, equal opportunities and transparency.

Since its creation in 1783, Mines Paris – PSL has been training high-level engineers capable of solving complex problems in a wide variety of fields. The leading school in France in terms of its volume of contract research, Mines Paris – PSL has a significant research activity oriented in particular towards industry, but its work extends from energy to materials, including applied mathematics, geosciences and economic and social sciences.

CentraleSupélec Alumni brings together the community of students and graduates of CentraleSupélec, Supélec and Centrale Paris. It offers its members support courses on their professional project, conferences and activities throughout their lives. AgroParisTech Alumni is an active and influential community.

25,000 AgroParisTech graduates. We support each Alumni throughout their lives according to their needs, in their view of the world, and in their daily action, because we believe more than ever that Agros skills are valuable in today's and tomorrow's world.

The mission of the AX or the Association of Former Students and Graduates of the École Polytechnique is to create links between students and alumni of the École Polytechnique, to help its members in difficulty and to build a strong community through regular events.

The Energy4Climate Interdisciplinary Center (E4C) launched in June 2019 by the Institut Polytechnique de Paris and the École des Ponts ParisTech is involved in the energy transition through research, training, and innovation. The centre's activities are developed by its researchers in conjunction with industrial players. They combine social and economic sciences, materials science and engineering, applied mathematics, computer science and geophysics.

Based on intensive, high-level research, Centrale Lyon trains engineering assistants, engineers and scientists through a continuum of training from post-baccalaureate to doctorate and supports them throughout their professional careers. The pedagogy combines basic sciences, engineering sciences and economic, human and social sciences and is based on theory, experimental activities and professional situations.

The BNEI, Bureau National des Élèves Ingénieurs, an association under the law of 1901, is the only organization representing engineering students. It is administered and run by engineering students, volunteers. The BNEI represents all 185,000 engineering students by bringing together the Student Offices of the schools and elected officials.

Bpifrance finances and supports companies – at each stage of their development – with credit, guarantees, innovation support and equity. In doing so, Bpifrance acts in support of public policies led by the State and the Regions.

The French Fab, launched on October 2, 2017, embodies companies, economic players, institutions and industrial sites located in France who recognize themselves in the desire to develop French industry.

Ulule supports those who have broad ideas and want to make things happen. Since 2010, we have been facilitating the adoption and development of creative and sustainable projects.