Reducing low-carbon *hydrogen* investment and operating costs

A prerequisite for mass adoption

Capgemini | eit InnoEnergy

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Executive summary

The low-carbon hydrogen[1] sector experienced a period of wide-spread hype and enthusiasm since 2021. However, this enthusiasm has faded with market and regulatory uncertainties with very few projects making it to the investment stage. According to the International Energy Agency (IEA), in 2023, only 4% of projects have entered the Final Investment Decision (FID) phase.

It is this stark disparity between expectations and tangible results that led us to dig deeper and commission this report. Together with EIT InnoEnergy, we aim to uncover the blockages standing in the way of low-carbon hydrogen cost reduction and mass adoption. In our extensive research, we surveyed professionals from nearly 120 companies and organizations in the hydrogen industry between November 2023 and February 2024. These organizations were based in: France (62%), Germany (6%), Rest of Europe (20%), North America (4%), Asia (3%), Africa & Middle East (5%).

1 | Low-carbon hydrogen remains too expensive and uncompetitive compared with hydrogen produced from other sources

Survey participants generally agreed that price will decrease below €7/kg by 2030, while the price of unabated hydrogen is between €1.5/kg and €3/kg. However, respondents disagreed on the final figure. Currently, there is no common vision and a lot of real uncertainty, with estimates far away from previous predictions made just a few years ago, where the consensus was that renewable hydrogen production costs would dip below €3/kg. Now, approximately 21% of those surveyed see the price going between €3 and €4/kg, while 19% predict between €4 and €5/kg.

2 | Major players are encountering strong difficulties in developing low-carbon hydrogen projects at a competitive price

Firstly, 57% of respondents identified electricity prices as a major difficulty. This comes as no surprise because the cost of electricity for electrolysis represents around 45 to 60% of the levelized cost of hydrogen (LCOH). Secondly, lack of demand remained a big issue for 41% of respondents, as well as the price of carbon (36%), which remains too low globally (36%). Additionally, 38% mentioned inadequate public support directed towards offerings as being a pain point. Thirdly, equipment costs were highlighted as a pressing concern by 48% of respondents. These are the second most important cost factor within CAPEX and represent around 35% of LCOH (depending on electricity costs).

In contrast, a lack of employees with the right skill sets was not seen as a large difficulty to overcome, with only 19% of respondents agreeing that this was an issue. This sentiment seems to assuage tensions around previously held assumptions regarding jobs in the sector.

3 | Respondents stressed that regulatory and legislative environments are essential in making hydrogen more competitive in the years ahead

According to 64% of respondents, public support is key in driving demand focused on traditional applications. Offtake contracts were seen as essential for 51% of respondents when it comes to carrying out hydrogen projects at scale in the future. Although, allocations of public aid remain slow – particularly in the European Union with IPCEIs. However, globally, it is starting to be considered more with the launch of several auctions and contracts for difference (CFDs). For example, the European Hydrogen Bank launched its first auction worth €800 million on November 2023, 132 bids were received from 17 European countries. These figures testify to an “enthusiastic market”, said Kurt Vandenberghe, Director General of Climate Action.

61% of experts surveyed feel an increase of CO2 taxes is essential here, while 51% believe market electricity reform to develop more Power Purchase Agreements (PPA)[2] is critical.

4 | In addition to external levers, there are several internal levers that can reduce

low-carbon hydrogen costs

It is no surprise that regarding reducing hydrogen cost structure, lowering electricity costs with an effective long-term electricity purchasing strategy (e.g., PPA contracts, diversification of renewable/low-carbon electricity sources to increase electrolyzer load factor) came in first. About 74% of respondents agreed with this.

The ability to lower equipment costs came in second (68%). While ensuring competitive equipment prices and reliability tied for third place, with 36% of surveyed experts agreeing that these are key factors in carrying out a hydrogen project at scale over the next few years.

Interestingly, lowering financial costs was not seen as a big potential lever – despite the current climate of high interest rates (only 26% of respondents agreed here). But according to the OECD, in 2023[3], the weighted average cost of capital (WACC or cost of capital) has been ranging from 6.4 to 24% for hydrogen projects. As the market becomes more mature, the broad availability of affordable debt will play a pivotal role in executing capital-intensive low-carbon hydrogen projects. Securing substantial debt funding will be viable if lenders can foresee consistent and dependable cash flows over extended periods.

5 | Digital is not yet seen as a key enabler in reducing hydrogen cost and carrying out projects at scale, but it has great potential

74% of respondents see digital as highly useful for hydrogen management systems, while 48% noted its potential in system design and cost estimates. 40% commended digital's ability to improve operational excellence and 49% mentioned its traceability capabilities. However, the presence of digital solutions when carrying out a project and the integration of digital services were seen as being essential in a project by only 1%.

Digital has immense potential from equipment and system design to the operational project phase. During the design phase, digital technologies can improve electrolyzer efficiency, hydrogen production flexibility, and enable more accurate dimensioning. Digital also enables automation, virtual commissioning, and flow simulation to reduce manufacturing and commissioning costs for hydrogen production. Additionally, digital solutions have the potential to reduce OPEX through automated manufacturing, overall plant operation and programming constraint studies, decision-support tools, electrolyzer flexibility and lifetime simulations.

6 | Innovation is an underrated lever that needs to be activated to deliver game-changing impacts

36% of respondents believe innovation will contribute most to lowering hydrogen prices. High-temperature electrolysis is an extremely promising innovation with the ability to use lower-grade industrial heat. According to 53% of respondents, electrolyzers are set to play a critical role across value chain over the next few years. The development of other low-carbon production technologies (including geological hydrogen) is being considered to a lesser extent. However, 32% of surveyed experts indicated that they remain open to possible innovations that could help better deploy hydrogen.

Additionally, according to 49% of respondents, hydrogen certification via digital solutions could also help facilitate heightened market development. Indeed, traceability is key here in effectively identifying the carbon content of each hydrogen molecule, guaranteeing origin, and driving increased adoption around this solution.

1.The European Commission defines low-carbon hydrogen as derived from non-renewable sources with less than 70% of the lifecycle emissions of fossil natural gas. For simplification we include renewable hydrogen within the low-carbon hydrogen definition.

2.PPAs are contracts where a buyer agrees to purchase power from a producer at a predetermined price over a long period.

3. Lee, M. et D. Saygin, 2023, Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies, OECD Environment Working Papers, n° 227, Éditions OCDE

Introduction

Whatever the source, 90 million tons of low-carbon hydrogen[4] by 2030 would be enough to sustain claims that the world is on track to limit warming to 1.5° above pre-industrial levels. But is this really plausible? On the surface, it may seem so. After all, 150 million tons in 2030 would be a 50% increase over the current 95 million tons of annual demand in seven years. This would only requiring a 6% compound annual growth rate.

But this target might be difficult to achieve. One of the main reasons is that today, low-carbon hydrogen is not competitive – and even more uncompetitive than previously predicted.

After a period of great enthusiasm for the sector, there has been an air pocket in 2023. In France, for example, only 17MW of electrolyzer capacity has been installed in 2023 – and only 300MW of projects are confirmed financially – which corresponds to 5% of the 6.5GW target for 2030. Few projects are at the investment stage, and according to the IEA, only 4% of projects have entered the FID phase.

Low-carbon hydrogen remains too expensive and uncompetitive compared with carbon-based hydrogen. There are several reasons for this: Difficulties in obtaining supplies of competitive low-carbon electricity, rising interest rates, and difficulties in finding partners – particularly EPC partners.

So, what can be done to bring down the cost of hydrogen and make it a real vector of energy transition?

While several levers have already been used to reduce the cost of investing in and using low-carbon hydrogen, many can still be mobilized by players throughout their value chains (equipment developers and producers in particular). These levers include: Digital, financial engineering, decarbonized electricity purchasing strategies, and partnerships, etc. In order to assess the ability and difficulties of players to mobilize them, we surveyed nearly 120 companies from the hydrogen sector all over the world.

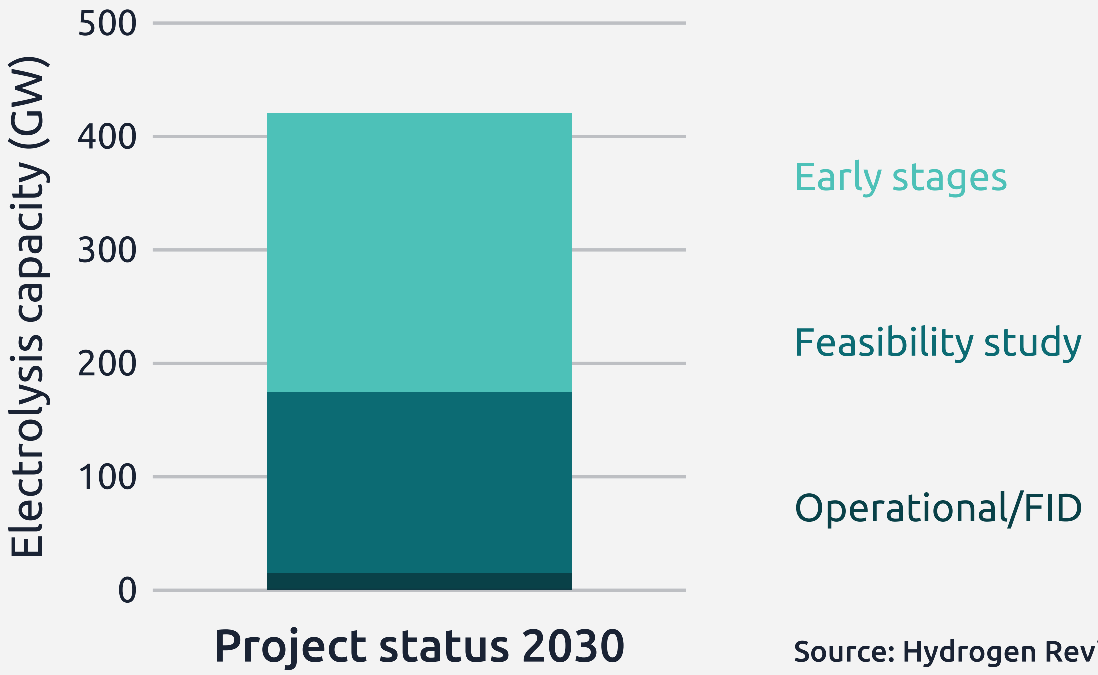
It should be noted that this analysis and survey were conducted across Western markets. We provide a thorough assessment and conduct a deep dive into possible levers that can be applied to reduce low-carbon hydrogen costs.

4.The European Commission defines hydrogen as low-carbon if it produces at least 70% fewer greenhouse gas emissions than fossil natural gas over its entire life cycle.

1 Low-carbon hydrogen remains too expensive and uncompetitive compared to hydrogen produced from other sources

After a period of great enthusiasm for the sector, there has been a bit of stagnation in 2023. According to the IEA, in 2023, only 4% of projects have entered the Final Investment Decision (FID) phase. In addition, low-carbon hydrogen volume forecasts fall.

Figure 1: Electrolysis capacity in 2030 based on announced projects



Source: Hydrogen Review 2023, IEA

The IEA's October 2021 Net Zero by 2050 roadmap contained a figure of 212 million tons of hydrogen by 2030 (of which, 150 million must be low-carbon). The 2023 update of this roadmap saw the IEA reduce the total figure to 150 million tons and drop the low-carbon figure to 70 million.

This situation calls into question the role of hydrogen in the decarbonization of our economies. It also leads to deeper evaluation of hydrogen's relevant applications (where there are few alternatives and where it could be more competitive).

Figure 2: Priority applications of hydrogen

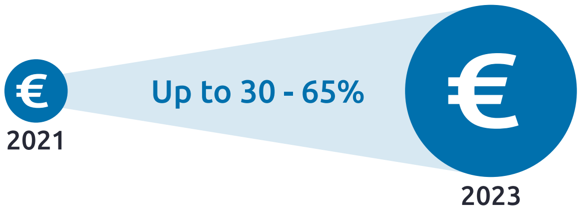
Hydrogen market players generally agree that the price will decrease below €7/kg, but there is no real consensus here, which is leading to a lot of uncertainty overall.

This figure is far from the previous prediction, with production prices expected below €2-3/kg by 2030. In its 2023 Global Hydrogen Review, the IEA still maintains that low-carbon hydrogen could be produced in Europe for €1.60/kg by 2030. While the market has seen hydrogen production costs increase by 30-65% between 2021 and 2023, according to the World Hydrogen Council.

Currently, there is no common vision and a lot of real uncertainty, with estimates far away from previous predictions made just a few years ago, where the consensus was that renewable hydrogen production costs would dip below €3/kg. Now, approximately 21% of those surveyed see the price going between €3 and €4/kg, while 19% predict between €4 and €5/kg.

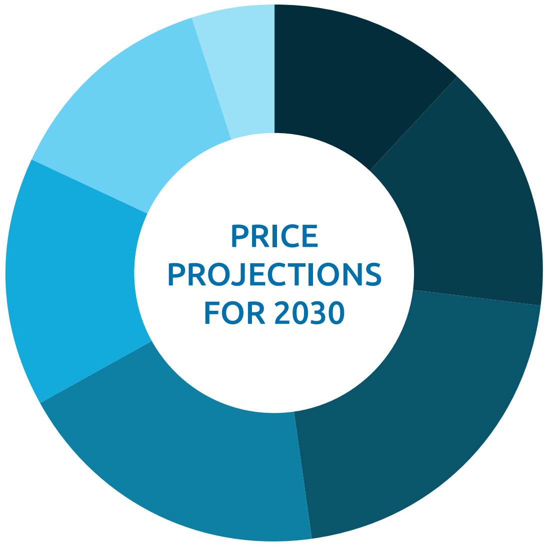
Figure 3: The increased hydrogen production costs and price projections for 2030

INCREASED HYDROGEN PRODUCTION COSTS



Source : World Hydrogen Council, Hydrogeninsights, 2023

PRICE PROJECTIONS FOR 2030 LOW-CARBON HYDROGEN



12%	<2€/kg
15%	Between €2 and €3/kg
21%	Between €3 and €4/kg
19%	Between €4 and €5/kg
15%	Between €5 and €6/kg
13%	Between €6 and €7/kg
5%	>7€/kg

Source : Capgemini survey, 2024

This uncertainty is depriving major market players of a common reference point for building business plans around low-carbon hydrogen-based solutions and developing competitively priced projects.

Indeed, the cost structure of hydrogen is unbalanced and largely dependent on the cost of low-carbon electricity. To a lesser extent, CAPEX still has a strong impact on the cost structure. Other factors influencing LCOH include sizing, load factor and the weighted average cost of capital (WACC).

Figure 4: a. Presentation of modelled hydrogen use cases

		Price	Use case scenario	Selected bricks in the value chain					
1	Hydrogen for road mobility	11.21 €/kg$_{H2}$	Hydrogen supply for 5 road refueling stations (1tH2/d each): 1 800t$_{H2}$/year	✓	✓	✓	✓		✓
2	Hydrogen for industry	8.68 €/kg$_{H2}$	Hydrogen supply for an industrial site : 5 000t$_{H2}$/year	✓	✓	✓			✓
3	E-Methanol for maritime	1582 €/t$_{eMeOH}$	E-Methanol supply for maritime transport demand : 40kt$_{eMeOH}$/year	✓				✓	✓
4	E-Ammonia for chemicals	1487 €/t$_{NH3}$	E-Methanol supply for chemical industry demand : 80kt$_{NH3}$/year	✓				✓	✓

Figure 4: b. Main hypothesis

H_2 production — All the use cases

- Alkaline electrolysis (including H_2 purification)
- CAPEX : 25MW, 75MW, 100MW and 200MW

H_2 compression — Use cases 1 & 2

- Compression from 20 to 300 bar for tube trailers transport

H_2 road transport — Use cases 1 & 2

- Truck transport for gaseous hydrogen

H_2 distribution — Use case 1

- Distribution of 1t$_{H2}$/d for road vehicles

eFuels synthesis — Use cases 3 & 4

- E-Methanol & E-Ammonia synthesis on same hydrogen production site (no H_2 compression & transportation)

Margins & VAT tax — All the use cases

- Inclusion of additional financial costs : VAT tax & Margins based on existing industry values

Main hypothesis

H_2 production

- **Operating hours :** 3942h/y (45%),
- **Electrical consumption :** 55,55kWh/kg$_{H2}$,
- **Other electrical consumption :** 5kWh/kg$_{H2}$,
- **Stack degradation :** 0.12%/1000h (EHO),
- **Reference CAPEX (100MW) :** USD1878/kW,
- **Conversion rate :** €0.9241/USD,
- **Electricity costs :** €80/MWh,
- **Installation lifetime :** 15 years,
- **WACC :** 8%

H_2 compression

- **Operating hours :** 3942h/y,
- **Constant flow rate, CAPEX (associated cost) :** 1120kW (€1.1M) compressor for UC1 and 3055kW (€1.6M) compressor for UC2 (HyJack reciprocating compression),
- **Electricity costs :** €80/MWh

H_2 road transport

- **Transported volume** per trip : 1tH2,
- **Transportation distance :** 300km for UC1, 200km for UC2,
- **Truck transportation cost :** USD1.2/kgH2 for UC1, USD0.8/kgH2 for UC2,
- **Fuel consumption :** 32.5l/100km,
- **CO2 emission :** 2.68kgCO2/l,
- **CO2 market price :** €37.45/tCO2

H_2 distribution

- **Total CAPEX :** k€2133 for 1tH2/d (Lawrence Berkeley National Laboratory),
- **Electricity consumption :** 2.43kWh/kgH2,
- **Electricity costs :** €80/MWh,
- **Installation lifetime :** 15 years,
- **WACC :** 8%

eFuels synthesis

E-Methanol synthesis

- **Hydrogen volume for 1t$_{eMeOH}$:** 190kg$_{H2}$,
- **CO_2 volume for 1t$_{eMeOH}$:** 1.38t$_{CO2}$,
- **MeOH synthesis cost* :** USD50/t$_{eMeOH}$ (IRENA & Methanol institute),
- **CO_2 price :** €89.6/t$_{CO2}$ **

E-Ammonia synthesis

- **Hydrogen volume for 1t$_{NH3}$:** 178kg$_{H2}$,
- **Transformation cost between hydrogen and e-ammonia :** USD1/kg$_{H2}$ (IEA)

Margins & VAT tax

- **VAT tax :** 10%,
- **Margins :**
  - H2 production : 20%,
  - Compression : 10%,
  - Transportation : 5%,
  - Distribution : 10%,
  - EFuels synthesis : 20%

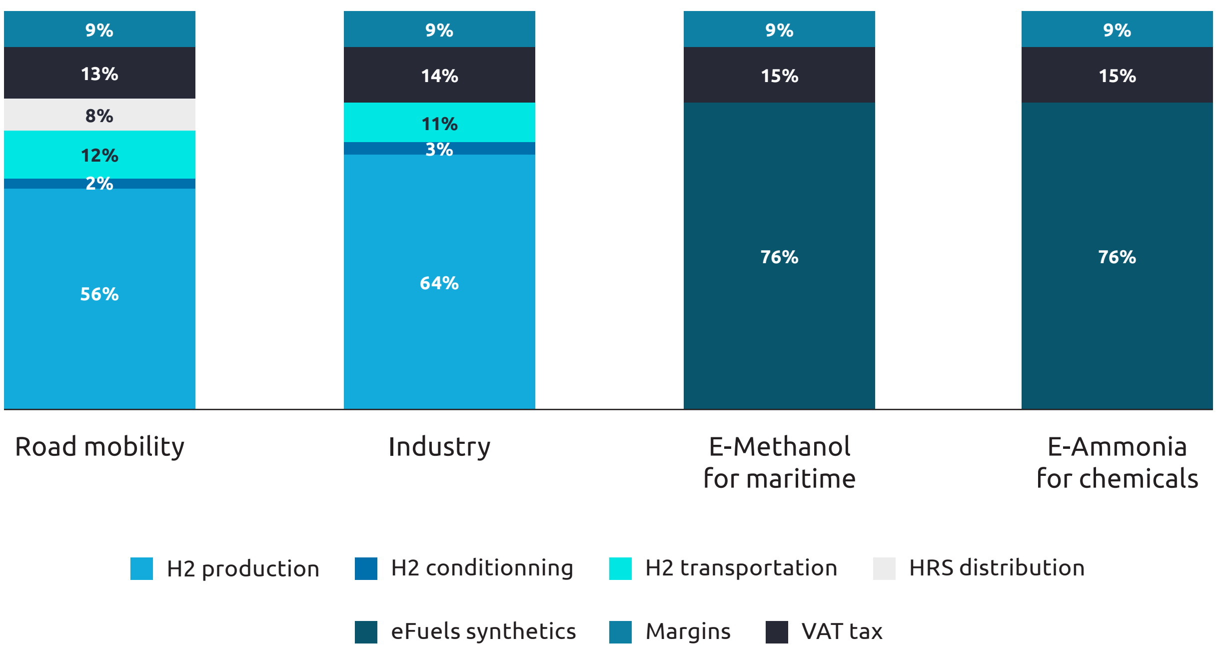
** Without hydrogen and carbon supply*

*** 2024 average EU ETS price*

Figure 4: c. Sensitivity analysis on use case #2 (industrial reference case)

	Reference value	Variations	Impact on LCOH Ref value : 5.57€/kg$_{H2}$	Impact on H_2 price Ref value : 8.68€/kg$_{H2}$
Electrolyzer CAPEX	1980$/kW	-50% / +20%	-1,33 / 0,54	-1,76 / 0,72
Electricity price	80€/MWh	-30 / +30	-1,08 / 1,08	-1,51 / 1,52
Utilization rate	45%	+15 / -10	-0,62 / 0,73	-0,74 / 0,92

Figure 5: The price structure of hydrogen varies greatly according to use cases



2 Major players are encountering strong difficulties in developing low-carbon hydrogen projects at a competitive price

Firstly, electricity prices were identified as a major difficulty identified by 58% of respondents. This is no surprise because the cost of electricity represents around 45 to 60% of the LCOH priced at €80/MWh in our reference model. With an electricity cost of €120/MWh, hydrogen price can even reach €13.35/kg for mobility use cases[5].

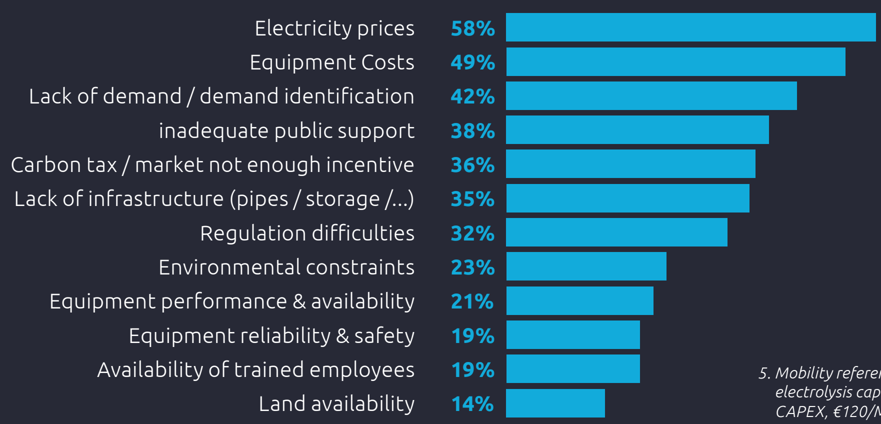
Secondly, lack of demand remains a big issue for 41% of respondents, as well as **carbon tax**, which remains too low globally. Additionally, **poor market incentives (36%)** and **inadequate public support for offers (38%)** were also noted as being problematic:

- **Lack of demand:** According to BNEF, there are identified offtakers for just 7.9 million tons of hydrogen, and of this, just one million tons per year is covered by binding contracts.
- **Public funding:** According to Bloomberg, the amount of global hydrogen subsidies reached $280 billion in 2023. These strategies are mostly directed towards hydrogen supply and equipment production ($215 billion for supply in 2022 – compared with $16.7 billion for supporting global demand).

Equipment costs are also seen as a major difficulty by 49% of respondents. This is the second most important cost factor – with CAPEX representing approximately 35% of the LCOH in our industrial reference scenario[7].

Interestingly, a lack of employees with the right skill sets was not seen as a major difficulty. Only 19% of respondents highlighted this, which seems to assuage previously held negative assumptions around jobs in the industry.

Figure 6: Difficulties encountered in offering competitive prices, according to survey respondents

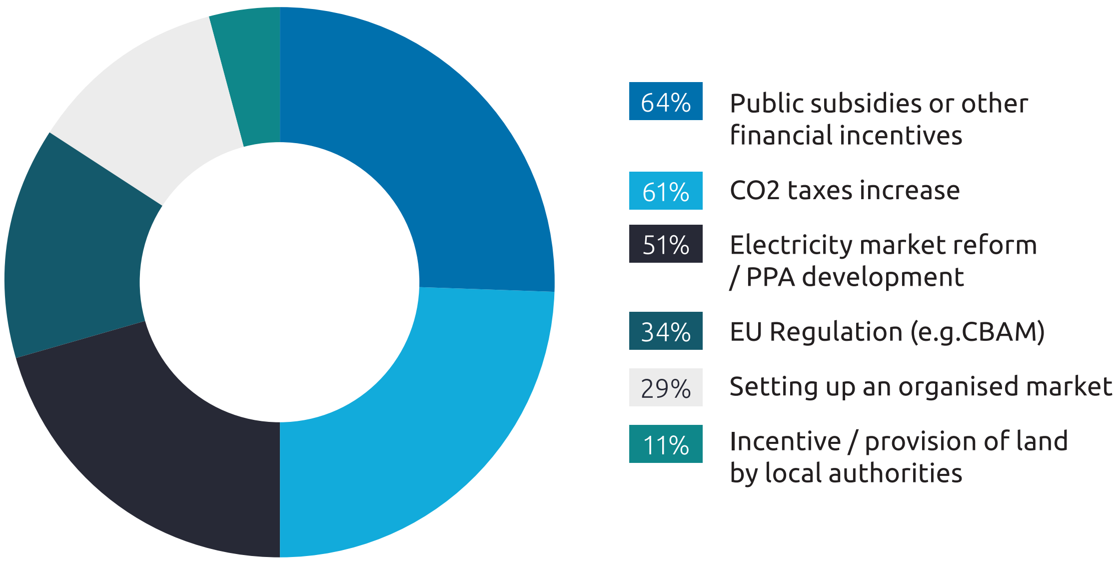


Source : Capgemini survey, 2024

5. *Mobility reference scenario for 25MW alkaline electrolysis capacity (5 HRS supply), $2500/kW of CAPEX, €120/MWh of electricity costs, 8% WACC*
6. *Mobility reference scenario for 25MW alkaline electrolysis capacity (5 HRS supply), $2500/kw of CAPEX, €80/MWh of electricity costs, 8% WACC*
7. *Industrial reference scenario for 75MW alkaline electrolysis capacity, $2000/kW of CAPEX, €70/MWh of electricity costs, 8% WACC (LCOH of €4.3/kg)*

3 To overcome these difficulties, public authorities can play a role in making low-carbon hydrogen more competitive

Figure 7: External levers are essential into making low-carbon hydrogen competitive against other energy vectors

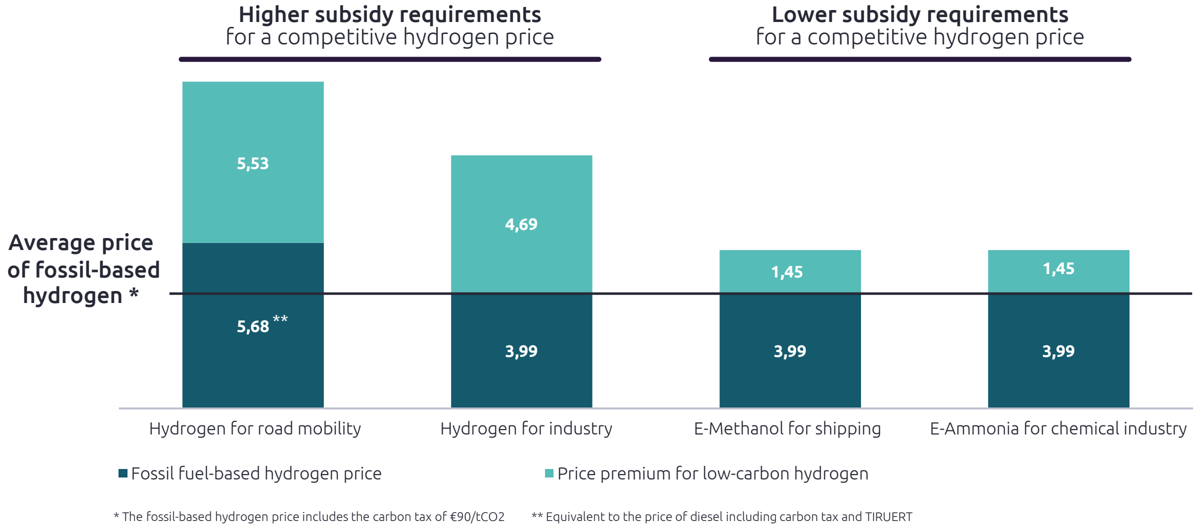


A. According 64% of respondents, adequate public support is critical

Public support is key in heightening demand, which remains focused on traditional applications such as chemical industry. Offtake contracts were highlighted as critical for 51% of respondents in successfully implementing hydrogen projects at scale over the coming years. However, allocations of public aid remain slow – particularly in the European Union with IPCEIs. Although, they are starting to be considered with the launch of several auctions and contracts for difference (CFDs) worldwide. For example, the European Hydrogen Bank launched its first auction for €800 million in 2023.

The need for public support varies depending on the application. Indeed, the graph below clearly shows that low-carbon hydrogen is not sufficiently competitive with fossil fuels or fossil-based hydrogen – particularly for industrial uses or road transportation. Competitiveness is achieved when the price of low-carbon hydrogen reaches the opportunity cost – i.e., the price of fossil-based hydrogen or equivalent energy – including carbon taxes and the TIRUERT within road transportation. According to our model, a subsidy of €4.69/kg H_2 would be necessary to make low-carbon hydrogen competitive for industrial use in France – and a subsidy of up to €5.53/kg H_2 for road transportation would be required to offset the opportunity cost. In comparison, low-carbon hydrogen is more competitive with the production of e-methanol and e-ammonia. Its production cost is 37% lower and it therefore requires a much lower subsidy of €1.45/kg H_2.

Figure 8: Low-carbon hydrogen competitiveness differentials by sector in France



Effectively targeting public support should involve refocusing efforts around specific uses. For example, 34% of respondents think e-fuel production is one of the key aspects of the value chain to be developed in the coming years, while few market players believe in the development of **mobility fuel cells** (7%), **stationary fuel cells** (3%), and **liquid hydrogen tanks** (4%).

B. Carbon taxation & regulation were respectively noted as pertinent issues by 61% and 34% of respondents

The price of carbon remains too low between €56 - 113/t_{CO2e}[8], with trends varying from one country to another. Half of carbon taxation instruments have seen their prices rise, around a third have seen their prices remain stable, and 15% have seen their prices fall.

In the European Union, a significant increase in the EU ETS price above €100/t_{CO2e} will raise the price of steam-reformed hydrogen, making low-carbon hydrogen more competitive. This increase is explained by the reform of the EU ETS with the introduction of a market stability reserve in 2019, which enables surplus quotas to be "stored" instead of reallocated to the market. This price signal became even stronger in 2021 when the EU ETS entered "phase IV." This will also bring tougher targets – with the aim of reducing the cap on emissions by 62% in 2030 relative to 2005. This will phase out the free allocation of allowances, replacing them by 2034 with a Carbon Border Adjustment Mechanism.

Additional worldwide regulations are crucial in bolstering carbon prices that still remain too low. For example, although restrictive, European regulations have the merit of being exhaustive and serve as a model for the rest of the world – particularly regarding the definition of renewable hydrogen. In Europe, the revised Renewable Energy Directive (RED III) introduces RFNBO (Renewable Fuels of Non Biological Origin) into targets for developing the use of low-carbon hydrogen in the sectors most difficult to decarbonize. The objectives vary significantly according to sector. RED III targets 42% low-carbon hydrogen in the industrial sector by 2030 and 60% by 2035. For the transport sector, 5.5% of fuels used in transport shall be biofuels or RFNBO by 2030, with a minimum 1% RFNBO. Member states with ports should also aim to ensure that RFNBO occupies 1.2% of the total amount of energy supplied to the maritime transport sector by 2030. In addition to these targets, this European regulation also details the RFNBOS production methodology.

8.The World Bank's State and Trends in Carbon Pricing report, 2023 with a 2023 average conversion rate of €0.9241/$

Therefore, if a company is seeking to produce renewable hydrogen, it must be via one of the following pathways:

Figure 9: Renewable hydrogen production pathways described by UE regulation

Electricity supply	Renewable hydrogen production criteria
Direct connection with renewable energies	+ The renewable asset cannot come into operation earlier than 36 months before the hydrogen plant
Grid connection	+ If the proportion of renewable power exceeds 90% over the previous calendar year in the bidding zone where the H2 plant is operating
	+ H2 production takes place in a bidding zone where the emissions intensity of the grid is lower than 18gCO2e/MJ and the hydrogen plant must acquire a renewable PPA with temporal and geographical correlation
	+ Power supply can be considered renewable if taken from the grid during an imbalance period. The power is either redispatched, or avoids redispatch
	+ A renewable PPA is signed for the supply of power, and the principles of additionality, temporal and geographical correlation apply

In the United States, the proposed policies for the IRA's Section 45V Clean Hydrogen Production Tax Credits mirror these additionality, and temporal and geographic correlation requirements, calling them the "Three Pillars".

It should be noted that the sectors with the highest objectives are also the least constrained from a regulatory point of view. For example, transportation is more regulated – particularly within carbon intensive sectors like ReFuelEU Aviation and Maritime initiatives – than industrial sectors like ammonia, chemicals, or steel. Aircraft fuel suppliers must incorporate 6% sustainable fuels by 2030, and ships over 5,000 gross tons must also reduce their greenhouse gas intensity by 6% by 2030.

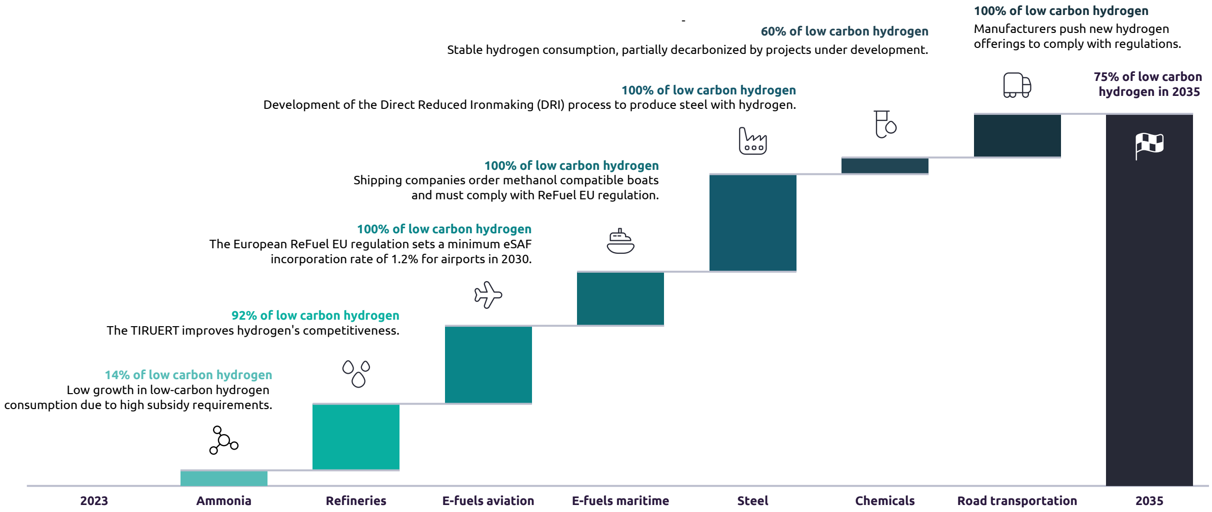
Moreover, to be competitive, low-carbon hydrogen must reach the price of unabated hydrogen in ammonia, chemicals, and steel sectors due to the absence of a fiscal mechanism.

On the contrary, for transportation sectors as well as the refineries, where there is a fiscal mechanism in the European Union (such as TIRUERT[9] in France), low-carbon hydrogen must reach the price of unabated hydrogen, plus the amount of TIRUERT type tax, allowing to be more competitive.

However, the figure 8 shows that the TIRUERT type tax is not sufficient today to make low-carbon hydrogen competitive, as the transportation sector requires the most subsidies to offset the relatively low cost of fossil fuels. For example, in France, the equivalent price of diesel (including TIRUERT and carbon tax) is €5.58/kgH_2, whereas the price of low-carbon hydrogen is around €11/kgH_2.

9.The TIRUERT is a French incentive tax on the use of renewable energy in transportation, whose main objective is not to pay the tax, but to improve the incorporation of renewable energy in transportation. TIRUERT is the transcription, for France, of Directive 2018/2001, a European law that defines a trajectory for the European Union in terms of renewable energy, particularly in road transport.

Figure 10: The most regulated sectors will be the biggest consumers of low-carbon hydrogen in 2035 in France



* Estimates excluding own consumption   Source : H2V, Capgemini analysis

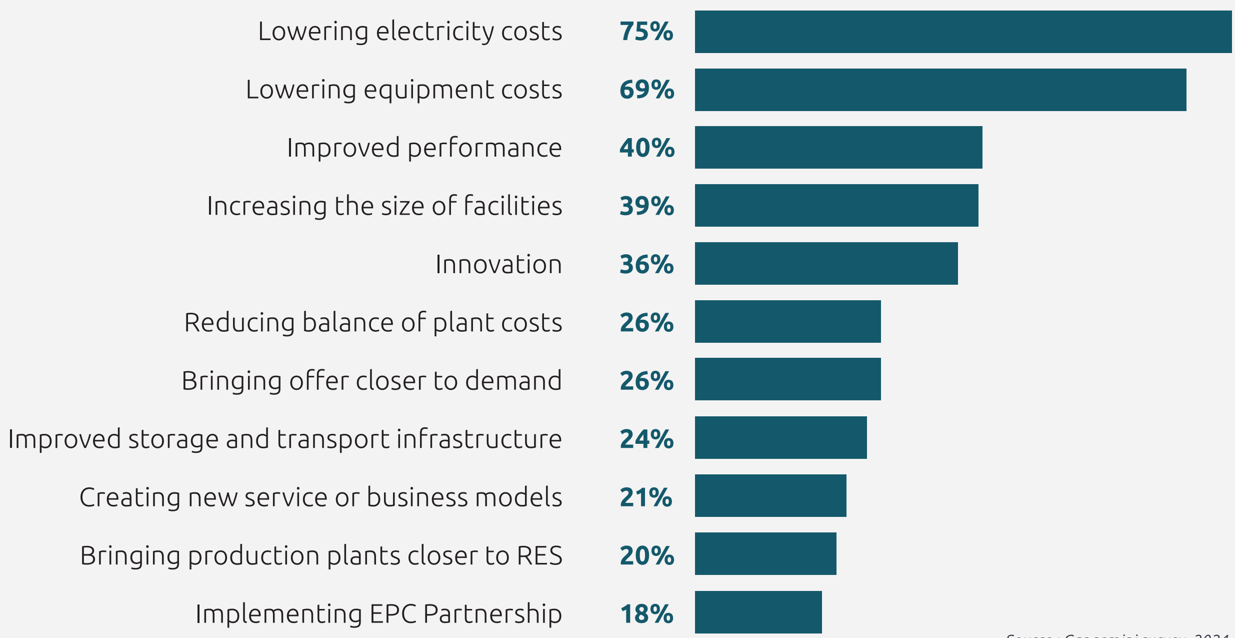
C. Power Purchase Agreements (PPA) were noted as pertinent by 51% of respondents

Public authorities must create market conditions to further accelerate the growth of PPAs. Indeed, developers need to define a relevant renewable energy purchasing strategy to reduce hydrogen production costs. In this context, PPAs are a promising tool for securing energy supplies and therefore maximizing the load factor of electrolyzers. Indeed, low-carbon energy capacity acquired by companies has considerably increased over the last few years (31GW in 2021, 25GW in 2020) but remains too low. According to Lucía Fernández[10], in 2022, a total of 36.7GW of renewable power was contracted through corporate PPAs worldwide, while corporate PPA contract capacity amounted to only 0.3GW in 2012. The signature of PPAs is emerging for hydrogen production, as it is the case between Statkraft and Air Liquide for a 45MW capacity[11].

10. Lucía Fernández, 2023, Renewable PPA contracted capacity globally 2012-2022, Statistica
11. Edouardo Escajadillo, 2023, "Air Liquide signs PPA to produce renewable hydrogen, ICIS

4 Lowering electricity and equipment costs and increasing the performance and reliability of electrolyzers are the key internal levers to reduce hydrogen cost

Figure 11: Levers that contribute the most to lowering prices, according to our survey respondents



Source : Capgemini survey, 2024

A. Lower electricity costs: Electricity costs are the most important cost factor, but there is not much potential for optimization

Lowering electricity cost came first for 75% of respondents. This encompasses electricity purchasing strategy over the long term (e.g., PPA contracts and diversification of renewable/ low-carbon electricity sources to increase electrolyzer load factor) and the value of flexibility. However, in practice, few gains are expected due to technological constraints and economic reasons.

Firstly, improving electrolyzer efficiency is the main lever to reduce electricity costs. While alkaline technology is currently the least expensive, it also consumes the most electricity. The solution is therefore to promote next generation technologies such as PEM electrolysis as a first step and to then accelerate the industrialization of high-temperature or other electrolysis type. Indeed, for the same maturity level regarding large-capacity systems of over 100MW, PEM electrolyzers consume less electricity than alkaline technology. However, its efficiency deteriorates due to the platinum deposits that obstruct the membranes. In this way, high-temperature electrolysis will be the real game-changer with the best yields on the market. For example, SOEC technology offers 26% gains over alkaline technology, with an average system efficiency of 40kWh/kg of hydrogen[12]. According to Genvia, energy consumption could even be reduced by up to 30% compared when mature technologies[13].

Improving the flexibility of electrolyzers is also key in ensuring grid stability and producing low-carbon hydrogen when energy is cheapest. Although, this flexibility can vary widely depending on the technology and usage. Alkaline technology cannot provide the required flexibility (30-40%) due to physical and chemical constraints. Indeed, lessons learned from the first hydrogen gigafactory in China showed that alkaline electrolyzers cannot operate with a load factor of less than 50% raising safety issues as hydrogen permeability increases. However, PEM and high-temperature technologies are more versatile thanks to their modular design enabling the shutdown of individual modules rather than the total system shutdown required for alkaline electrolyzers. Nevertheless, the competitiveness of PEM technology still needs to be improved, and high-temperature electrolysis will not be operational before 2027-2028. Finally, flexibility is not a cost-saving solution for certain usages (such as steelmaking), where the priority is to ensure continuity of the supply of large volumes of hydrogen.

Increasing the load factor technically reduces LCOH, but a diversified renewable energy supply may involve additional costs that are not always economically viable. Using only one RES source doesn't result in an optimized load factor for water electrolysis. Indeed, it can be competitive to produce low-carbon hydrogen only if the electrolyzer works as long as possible every day with a constant electricity supply. However, without considering nuclear power supply, increasing the load factor requires a mixed supply of wind and solar power with a limited potential of PPAs considering the high aggregation costs (up to approximately tens of euros per megawatt hour in France). However, the development of PPAs is happening very fast, with a more liquid market and falling prices over the last 12 months. In recent months, prices have fallen sharply across Europe reaching a 15% decrease according to the EU Power Purchase Agreement Index with wholesale electricity markets returning to pre-2022 levels.

12. Ramboll, 2023, Power-to-X and Hydrogen Technologies

13. H2Mobile, 2021, « Avec ses électrolyseurs haute température, Genvia veut révolutionner l'hydrogène »

B. Lowering equipment costs came in second at 69% – followed by improving performance (39%) and increasing facilities size (36%) – as key elements for carrying out a hydrogen project at scale in the coming years

From a design and innovation perspective, 36% of respondents believe innovation will contribute the most in lowering hydrogen prices. While 53% feel that electrolyzers will be a key element of the value chain to be developed in the coming years. **However, savings from improved design are expected throughout the value chain.**

- **Prior to equipment manufacture and installation, system engineering and design could be implemented to reduce project costs.** System design could be improved to provide greater modularity to facilitate the integration of multiple units that meet specific hydrogen production requirements. For example, one electrolyzer company built a scale-up capacity from 2.5MW to 5MW that will be adapted to the future needs of the customer and avoid early capital investments. Optimized designs that are tailored for specific applications can improve overall system performance and reduce costs. In this way, offtakers' ability to understand and fully integrate their project is a key lever with high earnings potential. For example, some applications do not require 99% pure oxygen, in which case electrolyzer manufacturers will make savings on certain purification equipment.

- **Moreover, improving the design of electrolyzers** systems could reduce LCOH by 26%. According to our industrial reference scenario[14], this would correspond to savings of approximatively €1.92/kg on the final price of hydrogen. Improving electrolyzer performance with engineering design is seen as important for 39% of respondents. Almost 80% of costs are frozen quite early in the development process. While disruption, requirement revisions, and new architecture bring a cost reduction of 30-40% – and sometimes can deliver up to 50% in reductions according to our experience. In this way, gains could be found with drawing inspiration from other sectors – with design-to-cost approaches based on a large panel of past realizations in the automotive, aeronautical, medical, and nuclear sectors. Besides, 42% of the electrolyzer process improvement identified by Capgemini concerns the design phase and only 6% concerns materials. For instance, the development of anion exchange membranes to benefit from alkaline operating conditions enables the use of less expensive catalysts and materials.

- **Improved balance of plant design is also a big factor in cost reduction.** Technological improvements are expected for compressors, in order to adapt them to hydrogen's specific requirements. Compressors are not sufficiently designed for hydrogen applications (e.g., embrittlement, hydrogen permeation in steel), with the need to develop a hydrogen range using the most appropriate alloys to increase their durability. In addition, the compressor's degraded efficiency compared with other gases could be improved by design. In the field of regulators and pressure control, a French high-pressure industrial gas expert has developed a cube-shaped design that saves 25% of the costs associated with regulators.
- **Finally, reactor design is an important optimization factor in the production of e-fuels.** The new design of the hydrogenation reactor developed by CEA to produce e-methane improves compactness – enabling savings on raw materials and property. Production capacity is increased with tube extension.
- **Additionally, project sizing is seen as an important lever by only 36% of respondents, as it offers limited optimization gains.** Increasing the capacity of the facilities enables CAPEX gains in a single operation. According to IRENA, costs could be reduced by more than a third by increasing plant size from 1MW to 20MW. However, as the threshold effect is around 50-100MW, there are no savings to be expected from a scale-up beyond 100-200MW.

Manufacturing excellence can also significantly reduce costs – by up to 15%[15]. In Europe, electrolyzer production is currently being industrialized to meet demand, while China has already industrialized its production process.

- Significant savings are expected with this scale-up, but there are still considerable margins for progress. Capgemini has identified 35 improvements in the manufacturing process. In our reference scenario[16], lean production management reduces production costs by 10-15%; i.e., expected gains between €0.74 and €1.10/kg on the price of hydrogen.
- Given the similarities with battery gigafactories, learning from the battery sector would enable faster process improvements. For example, reproducibility is difficult to achieve in cell manufacturing, for both electrolyzers and batteries. Scrap losses will also be significant in the early stages, whereas scrap has been reduced from 50% to 20-30% in today's battery gigafactories.
- When it comes to components, gains on the purifier will be mainly based on process optimization, with the need for scaling up. Purifier technology is already well developed, but there is a lack of research into the manufacturing process to optimize costs. More generally, a certain number of equipment manufacturers are still in the prototyping phase when it comes to creating their hydrogen range and are expecting to reduce costs with the development of mass production.

Financial engineering: Lowering financial costs is not seen as a big potential lever – with only 26% of respondents agreeing with this – despite the current climate of high interest rates.

- **The rise of the weighted average cost of capital (WACC) in recent years has mechanically resulted in LCOH inflation.** According to the OECD[17], it ranged from 6.4 to 24% in 2023 across hydrogen projects. Since renewable hydrogen projects typically require significant upfront investments in infrastructure such as electrolyzers, renewables assets, etc., any increase in financing costs can directly impact overall project economics. Higher financing costs can make it more expensive for companies to borrow money or raise capital leading to increased project expenses.
- **In addition, hydrogen project developers need to mobilize substantial capital to finance the engineering and construction costs and the advance purchase of electricity and equipment.** Following the reform of the electricity market in France, electro-intensive industries will be able to benefit from preferential tariffs thanks to nuclear production allocation contracts (CAPN). However, they will have to pay an advance of around €1 billion to contribute to the investments

14. Industrial reference scenario for 75MW alkaline electrolysis capacity, $2000/kW of CAPEX, €80/MWh of electricity costs, 8% WACC (LCOH of €5.57/kg)
15. Capgemini consolidated data from other innovative industries (e.g. batteries)
16. Industrial reference scenario for 75MW alkaline electrolysis capacity, $2000/kW of CAPEX, €80/MWh of electricity costs, 8% WACC (LCOH of €5.57/kg)
17.Lee, M. et D. Saygin, "Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies", 2023, OECD Environment Working Papers, n° 227, Éditions OCDE

in the nuclear sector. Project developers must also order equipment in advance and assume colossal pre-CAPEX costs paying 20% of the project a year and a half in advance as is the case for offshore wind projects.

- **The cost of investment differs significantly between decarbonization projects in the large industrial companies and those in the transportation sector.** Projects in the transportation sector will be penalized by a higher investment cost than major manufacturers. This is because transportation project owners have a much higher risk profile, whereas large industrial companies benefit from classic risk profiles and solid counterparts.
- **Financial engineering levers can be activated, but they will not be able to offset the rise in electricity prices and CAPEX:**
  - **Firstly, public investment can be directed towards projects based on their territorial dimension and the positive externalities they generate for the economy particularly in terms of job creation.** The political stakes are high for large-scale projects of over 100MW – the biggest future consumers – with a real impact on employment. Public support also makes sense for certain mobility projects, such as public transportation. However, these investments will not be able to offset CAPEX and the cost of electricity necessary to ensure the bankability of the projects.
  - **Private equity also plays an important role – both in supporting the launch of less mature technologies – and in reinforcing the financial robustness of project owners and equipment manufacturers.**
    1 | Project owners need to improve their financial robustness. The industrial stakes are very high, so project developers must have the capacity to operate industrial sites, implying the raising of substantial private equity funds, which could lead to market consolidation. Rationalization of projects should come naturally, as these players are complementary, with distinct strengths and weaknesses.

    2 | Equipment manufacturers also need to improve their financial robustness to cope with the quality problems they encounter. Indeed, European equipment manufacturers are experiencing real financial difficulties, as the market is not yet mature, while they are not being delivered on time with major quality deficiencies. These issues are being addressed but remain difficult to resolve due to the lack of operational projects. Nevertheless, the European industry seems to be under less pressure since American interest is now more directed toward the development of CCUS rather than electrolysis technologies.

C. While, underestimated, infrastructure development is key for ensuring the supply of electricity, improving system flexibility, and lowering hydrogen transportation costs

The development of the electrical system is essential to ensure the supply of electricity to hydrogen production plants.

- **The transmission grid is not dimensioned to supply electrolyzers.** According to RTE, demand for new connections is growing and being driven by electrolyzers – which represented 15GW of demand in 2022 for industrial use or the production of e-fuels in France. Although 16.5GW of consumer applications have been accepted (including 40% for hydrogen – mainly in industrial port areas), not all applications are accepted due to long lead times or lack of funding. In fact, the customer pays 70% of the costs, while the rest is taken on by the local authority – and it can take up to seven years for a 4000-volt connection.
- **The development of a new mutualized approach to determine the best connection solution for the community is therefore a key factor in rapidly adapting the grid to needs.** For example, RTE responds to existing requests, but also anticipates connections of future applicants by over-dimensioning installations. This new approach requires RTE to take on a certain amount of risk, as part of the financing comes from its own funds, with customers investing in proportion to their consumption.

Improved storage and transport infrastructures ares not considered as main levers according to 24% of respondents. Storage facilities, followed by import and export pipelines, are nevertheless an interesting lever to activate with 17% of respondents thinking they are key elements of the value chain to be developed in the coming years. Accelerating the deployment of local infrastructure is essential to mitigate project risks and support demand. By contrast, long-distance transport technologies are not sufficiently mature to be competitive in the medium term, and therefore do not constitute a priority lever.

Massive storage and pipelines need to be developed to improve system flexibility and lower transportation costs, but developing these facilities will remain difficult to coordinate.

- **Firstly, storage infrastructure is the best technical solution for improving flexibility in hydrogen production** – and thus reducing costs. Mature technologies cannot produce hydrogen with the required flexibility because rapid variations in production damage equipment and reduce the life of electrolyzers. In this way, massive underground storage appears to be the least costly solution, while liquid storage is a very expensive option due to its high energy consumption. For example, the Netherlands is developing the first 216 GWh salt cavern for hydrogen storage. While according to Terega, the development of these storage infrastructures does not require a lot of foresight, as it is possible to accelerate the natural development of salt caverns within four years. Today, there are very few projects for the development of aquifer cavities because infrastructure developers must make equity advances due to the lack of demand.
- **Secondly, pipelines should be developed, and existing natural gas pipelines repurposed and refurbished to save costs.** Approximately 31% of respondents think that pipeline revamping is a key piece of the value chain to be developed in the future. According to GRT Gaz and RTE, more than 50% of a future large-scale hydrogen transport network could correspond to pipelines converted in France. According to GRT Gaz, revamping existing pipelines will cost 1/3 of the price of building new ones. However, the reuse and adaptation of natural gas pipelines and massive storage is complex to implement due to the high transportation needs of natural gas, which are also increasing thanks to geopolitical events that are preventing the use of networks from being interrupted in order to make the necessary adaptations. Nevertheless, it is possible to inject 10-15% hydrogen into existing pipelines, but the hydrogen delivered will only be suitable for boiler use – or will require an additional purification step at extra cost. Therefore, the construction of new

pipeline infrastructures seems more realistic.

- **Finally, hydrogen production plants must be located in areas where renewable energy is widely available with an existing or surplus electrical support infrastructure.** This can help avoid high investment in transmission interconnections and reduce constraints on the electrical grid in the long term. For industrial needs, a compromise needs to be found between renewables and hydrogen demand locations, while considering different forms of possible transportation, such as transporting semi-finite products could be an optimized solution in some cases.

D. Alternatives to electrolysis – Developing other low-carbon production technologies - including geological hydrogen - is being considered to a lesser degree but the sector remains open to possible innovations that could help better deploy hydrogen (32%)

The development of geological hydrogen holds great promise for achieving a competitive LCOH. With the potential to cut costs, some projects are expecting prices of €0.75/kg. In this way, geological hydrogen is generating a growth in interest worldwide. Millions have been raised recently by Australian explorers such as HyTerra and Gold Hydrogen. Additionally, Breakthrough Energy invested $91m in the American start-up Koloma.

However, as a long-term solution, geological hydrogen must not delay the development of electrolysis, which has low stranded costs. Research is still in its earliest stages and there are a lot of uncertainties on deposit estimations, which require the use of the oil industry's approach to specific, measurable, achievable, realistic, and time-bound objectives. Moreover, there is a lot of uncertainty on the acceptability of extraction methods, which could be considered as non-sustainable. Electrolyzers will be amortized within 10 to 15 years, which is the duration necessary for the exploration and establishment of infrastructure adapted to the exploitation of geological hydrogen.

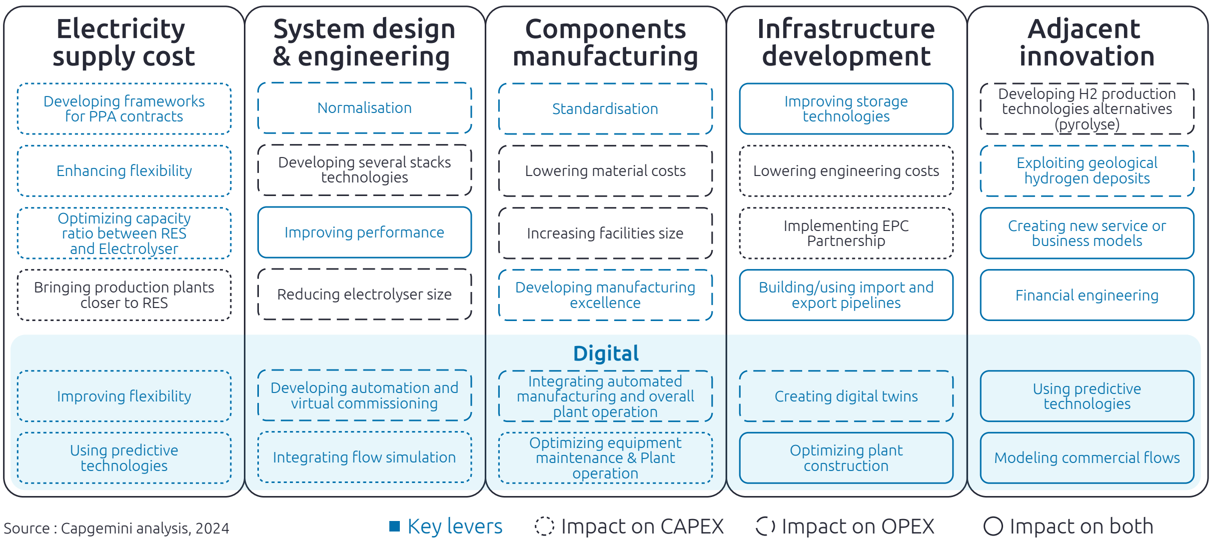
Finally, it's important to remain cautious about the announced costs of geological hydrogen since they may be underestimated (hidden costs). Geological hydrogen is not necessarily pure, which may require a costly purification step. There is also the need to manage the other gases discharged by the process.

Producing hydrogen from biomass is also being considered. Biomass gasification and pyrolysis are the main technologies under development. Biomass gasification involves feeding pre-treated biomass into a gasifier, which reacts with oxygen and steam under conditions of higher temperatures (generally >900°C) to produce a mixture of gases containing H_2, CO, and CO_2. Pyrolysis, on the other hand, consists of chemically decomposing an organic compound by raising its temperature to over 200°C in the absence of oxygen, producing other gases and compounds depending on the reaction conditions. Biomass pyrolysis produces solid biochar, liquid bio-oil, and other non-condensable gaseous products, as well as hydrogen. Although they have great potential, these technologies still need to solve technological issues before becoming a competitive production route. They also suffer from the increasing pressure on biomass resources for other applications (biogas).

5 To implement these levers, digital technology – which is currently underestimated by the players involved – is quite useful as it can improve design, manufacturing excellence/commissioning, operations, and prediction

Players see digital as useful for Hydrogen Management Systems (74%), system design and cost estimates (48%), operational excellence (40%) and traceability (48%). But a digital presence was seen as key for only 1% of respondents for carrying out a project. The integration of digital services is not seen as essential in a project at all (1%).

Figure 12: Although it is not highlighted, digital is a key enabler to reduce hydrogen cost and carry out projects at scale



Source : Capgemini analysis, 2024

During the design phase, digital technologies can improve electrolyzer efficiency and hydrogen production flexibility, along with enabling more accurate technology choices and dimensioning. For example, the use of digital twins enabled the company Univers (ex-Envision Digital) to select the most cost-effective design for off-grid PV green hydrogen production: Modelling showed that lower availability reduced CAPEX, with 96% availability and a CAPEX of €370/kW when compared with the two other scenarios (availability of 98.5% for €390/kW of CAPEX and availability of 99.5% for €440/kW of CAPEX). In addition, generative AI combined with system simulations can lead to design innovations and unexpected gains. It facilitates automated design optimisation, enabling rapid exploration of countless variants and configurations. This not only speeds up the product development process, but also improves performance and functionality.

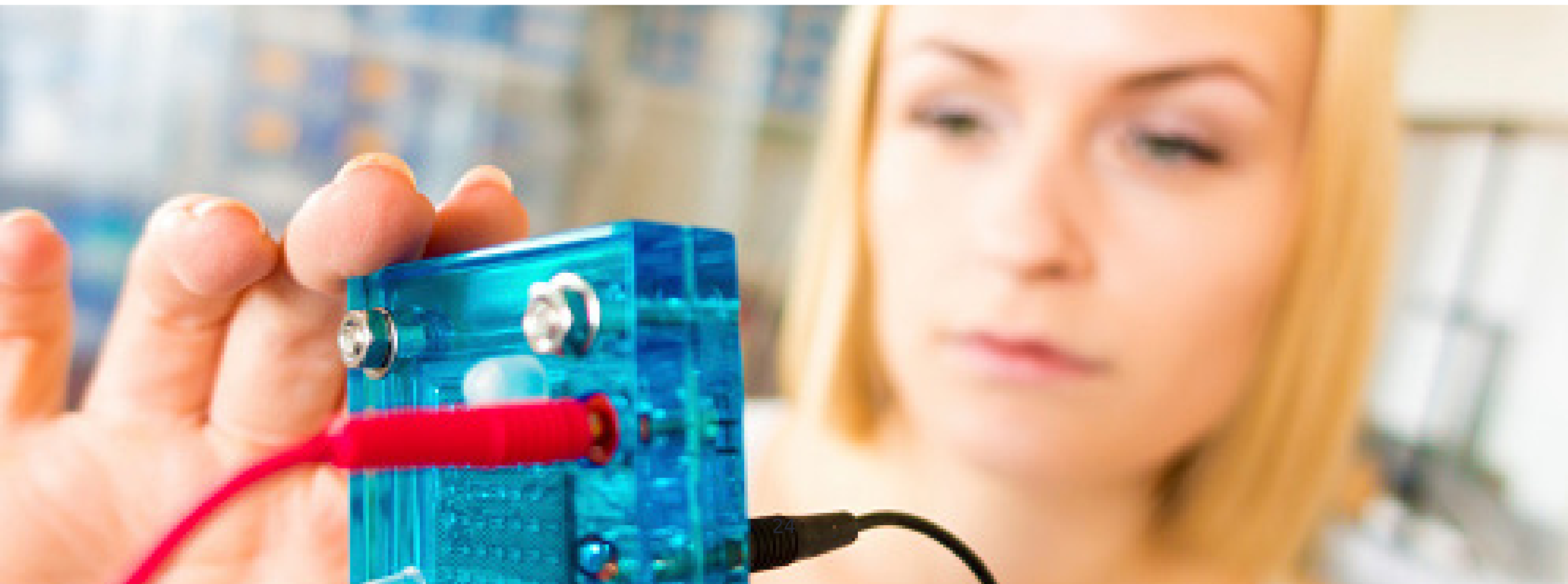
Automation, virtual commissioning, and flow simulation can reduce manufacturing and commissioning costs for hydrogen production. Lean production management can cut production costs by 10-15% and simulation has demonstrated its potential in the aeronautical sector with 30 to 90% gains in production lead-times and 20-30% gains in production output.

Digital solutions also reduce OPEX through automated manufacturing, overall plant operation and programming constraint studies, decision-support tools, and electrolyzer flexibility and lifetime simulations.

- The use of robots or cameras for testing increases the quality of manufacturing and therefore the lifespan of the equipment. In refineries, the overall design of the energy network can be optimized, and electrolyzers can be dimensioned more accurately - considering all operating constraints to avoid large design margins.
- Moreover, Capgemini developed a hydrogen system optimization tool (THySO) to generate safety, performance, and cost KPIs for managing a hydrogen production and storage facility using self-consumption of solar electricity.
- Simulation is used to maximize the flexibility of electrolyzers, whose nominal operating range is between 40-80%. This avoids damaging the machines due to the sensitivity of compressors and rectifiers.
- Additionally, numerical modelling tools improve risk management, which is insufficiently developed but essential for guaranteeing availability (and therefore cost levels). Good risk management (preventing explosions and fires) improves reliability – and therefore the availability – of production and distribution systems, while new entrants along the value chain are not trained in the required risk assessment. This is why there is a need to develop a global approach to risk management and demonstrate that risk analyses have been conducted throughout the value chain with tools for modelling accidental consequences and strengthening cybersecurity.

Certification via digital could facilitate market development, as Bureau Veritas highlighted with in the launched in January 2024 of a certification scheme dedicated to renewable hydrogen and help avoid high PPA aggregation costs. According to 49% of respondents, digital could play a role in hydrogen certification. Traceability is key for the deployment of the low-carbon industry and identifying the carbon content of each H_2 molecule, creating a market, and fostering the deployment of guarantee-of-origin.

Finally, digital has the potential to optimize the entire hydrogen supply chain (HSC) by defining the best locations for implementing production or storage units depending on the demand, availability of clean electricity, costs, and CO_2 emissions of modelized scenarios.



Conclusion

2024 is a crucial year for the hydrogen industry. While the targets for the development of low-carbon hydrogen are very ambitious, actual production is still a long way off (30MW in France, compared with the 2030 target of 6.5GW), particularly as hydrogen is still too expensive and uncompetitive.

The industry has many levers at its disposal to reduce costs (electricity purchasing strategies, equipment design, financial engineering, use of digital technology, etc.). But, at the same time, it is crucial that public support be more demand-driven (remuneration top-ups) and stable.

This paper outlines the major challenges we need to solve if we are to succeed in producing and marketing competitive, low-carbon hydrogen and making this vector a real tool for decarbonizing our economies. As a whole, the global hydrogen outlook is not all gloomy.

The recent definition of renewable hydrogen in Europe – with last year's adoption of the revised Renewable Energy Directive (REDIII) – is very good news for the development of hydrogen in Europe. The United States, which lags behind the EU, is in the process of adopting the same definition in order to develop its own hydrogen industry.

Similarly in Europe, the recent reform of the electricity markets is promoting the development of long-term contracts – PPAs in particular – which is a very good thing for securing the necessary volumes of low-carbon electricity for developers. What's more, while it's often said that there's no demand for hydrogen, it should be stressed that there really is – and plenty of it – particularly in the industrial sector.

This note of optimism – at least in Europe – suggests that we are on the right track for hydrogen to make a relevant contribution to our decarbonization objectives by 2030 – and especially by 2050.

Greetings

A study carried out by Capgemini with the participation and support of EIT InnoEnergy

Capgemini

Capgemini is a global business and technology transformation partner, helping organizations to accelerate their dual transition to a digital and sustainable world, while creating tangible impact for enterprises and society.

It is a responsible and diverse group of 340,000 team members in more than 50 countries. With its strong over 55-year heritage, Capgemini is trusted by its clients to unlock the value of technology to address the entire breadth of their business needs. It delivers end-to-end services and solutions leveraging strengths from strategy and design to engineering, all fueled by its market leading capabilities in AI, cloud and data, combined with its deep industry expertise and partner ecosystem.

The Group reported 2023 global revenues of €22.5 billion.

Capgemini is active in the hydrogen industry, helping clients to tackle main challenges across the value value chain and position themselves in the low-carbon hydrogen market.

Capgemini provides support for :

- **Market positioning** by determining hydrogen strategy through due diligences, public funding strategies, market analyses and partnerships ;
- **Systems and equipment reliability and efficiency** by leveraging system simulations, testing, safety protocols and design to X ;
- **The scale up of the production of equipment to optimize costs** by building data backbone to implement smart manufacturing and factory digital twins ;

- **The track of the carbon content of H_2 molecule** by using life cycle assessments to evaluate the carbon content and create certificates to guarantee the content of the molecule.

With the support and participation of EIT InnoEnergy

EIT InnoEnergy, recognized as one of Europe's top investors in cleantech, was established in 2010 with the support of the European Institute of Innovation and Technology (EIT) and strong link to the European Commission which co-fund some activities. InnoEnergy accelerates, de-risks and boosts global business cases through its unique and trusted ecosystem of more than 1200 partners, 35 shareholders and a 200+ strong team with offices across Europe and in Boston, US. InnoEnergy's deal flow is in early-stage innovative technologies in cleantech, normally CAPEX heavy. InnoEnergy backs innovations across a range of areas. These include energy storage, transport and mobility, renewables, energy efficiency, hard to abate industries, smart grids and sustainable buildings and cities. InnoEnergy currently has a portfolio of 200 companies, three of which are unicorns, on track to generate €110 billion in revenue and save 2.1Gigatonnes of CO2e accumulatively by 2030.

InnoEnergy is active in four related areas bringing the technology and skills required to accelerate the energy transition: (1) Incubation for startups, (2) Innovation support for corporates, (3) strategic value chains, such as the European Green Hydrogen Acceleration Center (EGHAC) and (4) Human Capital.

To decarbonize industrial processes, EIT InnoEnergy has set-up the European Green Hydrogen Acceleration Center (EGHAC). The EGHAC has the goal to initiate, support and accelerate large scale industrial business initiatives which will have massive CO2 reduction impact and kickstart the creation of a green industrial and hydrogen economy. EGHAC focuses on the hard to abate industry sectors such as steel, fertilizer, mobility, petrochemicals, cement etc., with green hydrogen as a key decarbonization lever.

EGHAC has two major activities:

1. **to build companies** (venture builder) in hard to abate industries, with a special focus on green hydrogen. Our role is to derisk and shorten the time-to-market of industrial decarbonization initiatives as an investor but also a co-creator.
2. **to build out the investment portfolio of InnoEnergy** in hard to abate industries through investment in early-stage startups.

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About EIT InnoEnergy

EIT InnoEnergy operates at the centre of the energy transition and is the leading innovation engine in sustainable energy. It brings the technology, business model innovation and skills required to accelerate the green deal, progress towards Europe's decarbonisation and re-industrialisation goals, whilst also securing a reliable supply of clean energy.

InnoEnergy is the driving force behind three strategic European initiatives which include the European Battery Alliance (EBA), the European Green Hydrogen Acceleration Center (EGHAC) and the European Solar Photovoltaic Industry Alliance (ESIA). Today, InnoEnergy has a trusted ecosystem of 1200+ partners and 35 shareholders and a 200+ strong team with offices across Europe and in Boston, US.

More informations on www.innoenergy.com

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