# How to evaluate the cost of the green hydrogen business case?

## Assessing green hydrogen production costs

June 2022

# Preface

**Low carbon hydrogen is needed at scale in order to achieve the legally binding targets set out in the Paris Agreement. There has been a lot of momentum around low carbon hydrogen as it attracts the attention of governments, investors and energy companies. This is now accelerating in Europe with energy security being at risk due to geopolitical tensions and war right next to the EU.**

Why the sudden interest in hydrogen? Hydrogen is a diverse energy source which can be used as a fuel, heat source and feedstock across many applications. It provides the opportunity to supply low carbon gas at scale, and green hydrogen in particular can both support greater renewable penetration by acting as a storage vector for excess or low cost intermittent renewable power.

Above all however, the accelerating interest and momentum of  green hydrogen, particularly in Europe, over the last months has less to do with the long term ambitions on net zero and more with the geopolitical situation in 2022. With war raging and energy security severely compromised, green hydrogen offers a future strategic alternative to fossil fuel imports.

A further implication of this shift from contributing to long-term net-zero targets to short and medium term energy security is that capacity expansion of green hydrogen production cannot wait any longer. Realizing the highest capacity at as low as possible costs is vital with green hydrogen becoming a cornerstone for future European energy security.

Green hydrogen addresses the two key issues within European energy policy and economy at the same time. Together with other shifts in the European energy market, it can enhance European energy security, while at the same time it can contribute to the decarbonization and reaching net-zero targets given its versatile nature as energy carrier.

Energy is only valuable if it is provided at a time, and in a form, that it is required by consumers and industry, and typically molecules (e.g. hydrogen) are easier and cheaper to store at scale and for longer periods than electrons (electricity).

Hydrogen provides an alternative energy source in areas where electrification is otherwise too complex, costly, or undesired by consumers. However, it is not a silver bullet and despite the drive in progress, there are still a whole host of challenges to overcome before hydrogen can take its place as a low carbon energy source on the world stage.

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# Key takeaways

## Sustainable hydrogen is critical for the decarbonization of European industry

Ambitious climate goals require drastic interventions for the industrials to reach sector-specific targets. The industrial sector are beginning to develop strategies and explore site specific decarbonisation options and hydrogen can be a key component as a fuel, high temperature heat, and as a feedstock in industries such as ammonia, methanol, and refineries.

The EU's carbon-free hydrogen targets are a key pillar in the European industry's decarbonization goals. They should guarantee a minimum of 10MT of green hydrogen production for demand sectors to adjust to.

## Extensive additional investments are required as forecasted demand for renewable hydrogen strongly outmatches supply in spite of European targets

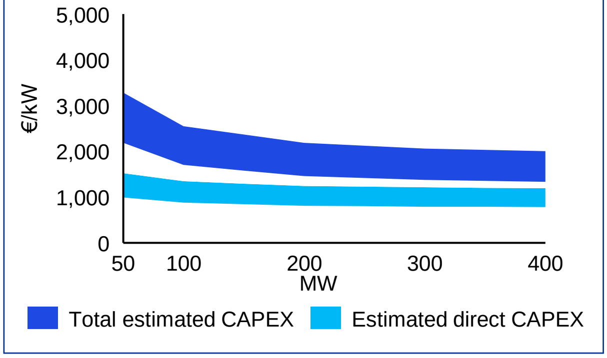
The European sustainable hydrogen strategy is ambitious but will still not be able to cover the expected demand in 2030. Therefore, if industries continue to implement sustainable hydrogen solutions, additional supply and therefore investment in production capacity is required.

## Detailed understanding of cost structure and investments are key to the business case of hydrogen

By assessing business cases from current electrolyzer projects, it can be concluded that companies may not accurately estimating the costs related to the business case. For example, not all relevant CAPEX items are taken into account, resulting in a misinterpretation of investment requirements.

In addition, by assessing a wide variety of projects, there appears to be a significant level of economies of scale related to the size of the project and the corresponding CAPEX (see underneath).

**PEM electrolyzer total and direct CAPEX per installed capacity, 2022**
€/kW capacity, indicative

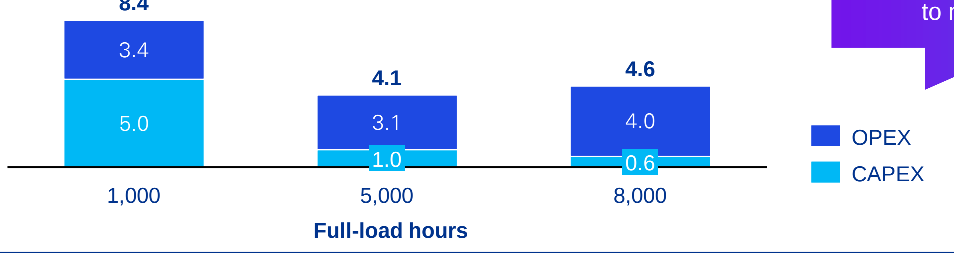



## Comprehensive power sourcing strategy is required to ensure green and reasonably cheap power

Importantly, using a large amount of asset capacity utilization (or technically called full-load hours) heavily impacts the production costs for grid-connected electrolyzers as for Europe the power price increases steeply and availability of green power can be low. Hence, full-load hours should be limited to 5,000 hours to not operate during relatively expensive hours.

Most important to the business case with grid-connected electrolyzers: determine the full-load hours or capacity factor resulting in the lowest levelized cost. For Europe, this generally means limiting the full-load hours to max. 5,000 hours.

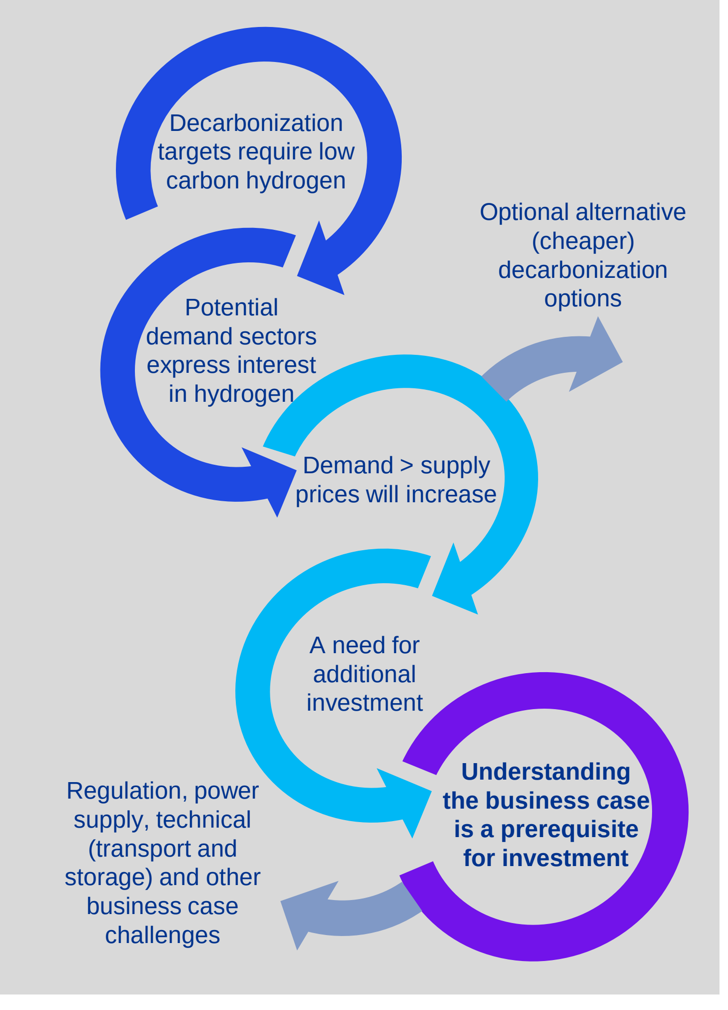
**Total levelised costs of hydrogen production through PEM electrolysis**
€/kg $H_2$, indicative scenarios given the most favorable CAPEX assumptions




Source: ISPT; IRENA; EU Horizon 2020; IEA; Hydrogen Council; ICCT; research papers; KPMG analysis.

# Contents



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Note: (a) KPMG AG Wirtschaftsprüfungsgesellschaft.

# The need for sustainable hydrogen

# Ambitious climate goals require drastic interventions for the industry to reach industry-specific $CO_2$ targets

## As industry accounts for ~20% of European emissions, it requires a clearly defined pathway to decarbonize

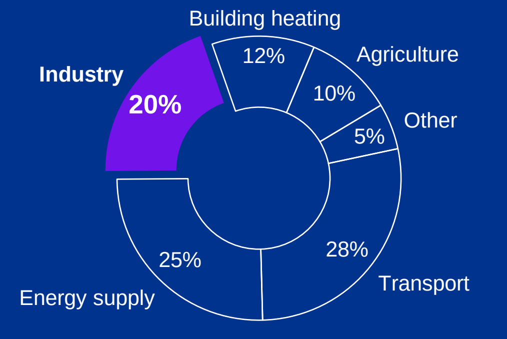
As governments are trying to limit climate change to 1.5°C following the Paris Agreement, countries are struggling with how to execute this effectively. The (energy) transition requires various decarbonization solutions to decrease emissions within different sectors (see figure 1 for the emissions split between industries). The (heavy) industry sector, which currently relies mainly on sources of fossil fuels, will need to shift to more sustainable sources of energy.

While sector-specific targets for decarbonization are being developed or are already in place (figure 2), the challenge of decarbonization differs per sector. It will consequently follow different pathways to reach carbon neutrality.

For some sectors in particular, where fossil fuels are the primary source of energy and feedstock, the costs and technical ease in switching to sustainable sources will be high. These sectors (e.g. steel or ammonia production) are harder-to-abate and require unique solutions.

In recent years, most industrial companies have focused on energy efficiency measures.

**Figure 1. Europe's $CO_2$ emissions by segment**
%, 2019

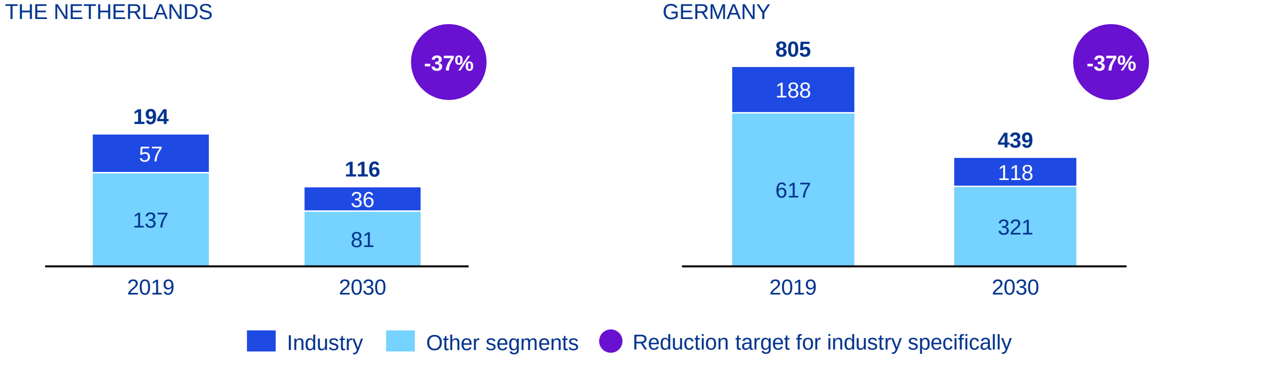



Source: EEA.

Nevertheless, the increasingly significant demand for CO2 reduction requires even less carbon-intensive products and processes. At a high level, there are three main decarbonization approaches for harder-to-abate sectors: (1) electrification, (2) carbon capture (& storage), and (3) sustainable hydrogen.

The latter option, hydrogen, is already a widely used raw material among some industry sub-sectors. These sub-sectors require more minor adjustments, and subsequently downstream investment, to adopt on a broader scale than other decarbonization options. Moreover, new energy and non-energy applications for sustainable hydrogen are outlined on the next page.

**Figure 2. Industrial $CO_2$ reduction targets in the Netherlands and Germany**
$CO_2$ emissions, 2019 and 2030 targets, Mt $CO_2$




Source: Bloomberg; CBS; Statista; KPMG analysis.

Source: Energy Transitions Commission; KPMG analysis.

# The EU's carbon-free hydrogen targets are a key pillar in the European industry's decarbonization goals

## Ambitious industry decarbonization targets foster a wide range of sustainable hydrogen applications

The European Union has defined concrete targets for ramping up the European sustainable hydrogen market up to 2050. However, there is still significant uncertainty about the actual future demand for sustainable hydrogen.

**2021-2025**

As a first step, the decarbonization of existing hydrogen production will be realized by 2025 by producing carbon-free and low hydrogen via steam methane reforming (SMR) or Autothermal Reforming (ATR) combined with carbon capture and storage technologies and electrolysis. The EU aims for 6 GW of installed electrolysis capacity by 2025, producing up to 1 Mt of sustainable hydrogen when operated 24 hours a day and 365 days per year with renewable electricity.

**2025-2030**

In a second step, the EU targets 40 GW of installed electrolysis capacity in member countries, producing 10 Mt of sustainable hydrogen, and an additional 40 GW in European non-EU countries and North Africa. In parallel, a hydrogen pipeline network across Europe may allow unimpeded cross-border trade and connect industrial clusters in Northern Europe with wind and solar energy-rich regions in Southern and Eastern Europe and North Africa.

With carbon-free hydrogen reaching cost competitiveness (compared to conventional hydrogen) in this phase, the main fields of application are displacing existing grey hydrogen demand, and use in steel production and heavy-duty parts for train and maritime transportation. Furthermore, sustainable hydrogen is expected to become increasingly crucial as a long term energy storage option, in power grid balancing and industrial, and in residential heating applications likely to be focused in regions within proximity of industrial chubs.

**2030-2050**

To achieve climate neutrality, the EU considers 500 GW of installed electrolysis capacity to be required by 2050. All previously-mentioned applications will become mature in this phase, and large-scale sustainable hydrogen production and cost competitiveness are expected to enable the decarbonization of hard-to-decarbonize industries and buildings. Furthermore, the sustainable hydrogen-based economy will allow synthetic fuels based on carbon-neutral CO2 to penetrate a broader range of sectors, especially aviation and maritime applications. To add to that, import of hydrogen is going to be important to fulfill all demand. Partnerships with energy export regions such as the middle east will be key.

**Figure 3. Sustainable hydrogen targets of the European Union' Green Deal' hydrogen strategy, July 2020**


Source: European Commission (2020).

# Current applications for sustainable hydrogen mainly lie in industrial usage as feedstock and as an energy source

## New hydrogen applications will strongly increase demand in the future

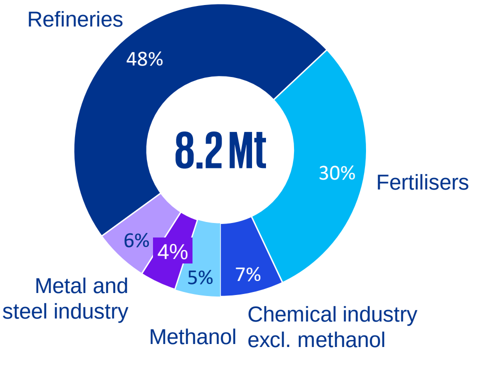
Hydrogen is already an essential feedstock for the chemical industry. Ammonia and methanol production, and refineries are currently the three significant fields of application for hydrogen. To decarbonize these processes, the hydrogen produced via SMR and ATR from natural gas needs to be replaced by zero carbon hydrogen through electrolysis and carbon capture technologies. In addition to that, new industrial applications for hydrogen as a feedstock in sectors with hard-to-abate emissions, such as the steel industry, will further increase the demand for sustainable hydrogen.

In other sectors, for example, mobility and industrial heating, the required amount of sustainable hydrogen depends on further technological developments, political regulations and incentivization such as subsidies for specific applications. For example, whilst battery electric vehicles (BEVs) are likely to win the battle for passenger vehicles and light vans, the market for heavy goods vehicles and depot style uses cases remains undecided, with hydrogen likely to play a role.

In addition, for (domestic) heating solutions, the role of sustainable hydrogen will be highly dependent on political intervention and subsidies stimulated by delivery challenges facing deployment of alternative decarbonisation options such as heat pumps. For industrial applications, the main substitute is grey hydrogen. In comparison, for (domestic) heating, sustainable hydrogen will have to compete with natural gas, air and ground source heat pumps, and district heating.

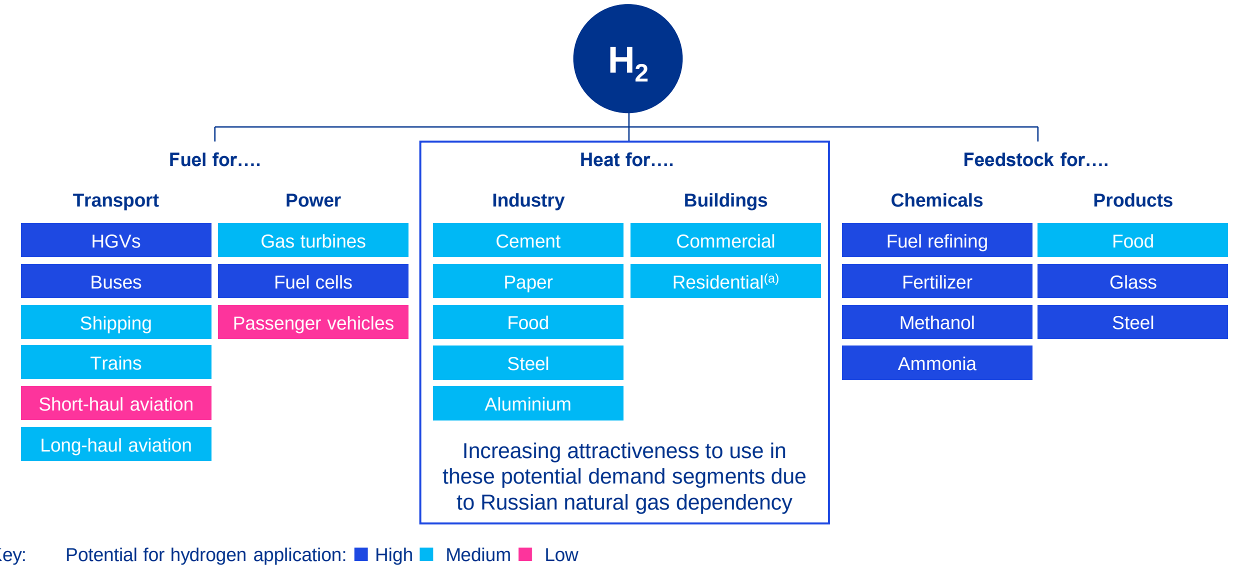
**Figure 4. Current hydrogen demand in Europe**

%, 2019




Source: Prognos AG (2020); Kakoulaki et al. (2020); KPMG analysis.

**Figure 5. Future offtake of sustainable hydrogen demand**




Key: Potential for hydrogen application: High, Medium, Low

Note: (a) Depending on housing stock and proximity to industrial hubs.

Source: KPMG analysis.

# More than ever, industry experts believe green hydrogen (and especially in the EU) will fulfill an important role

## Short/mid-term: lack of midstream infrastructure will require production co-located with demand (in the EU)

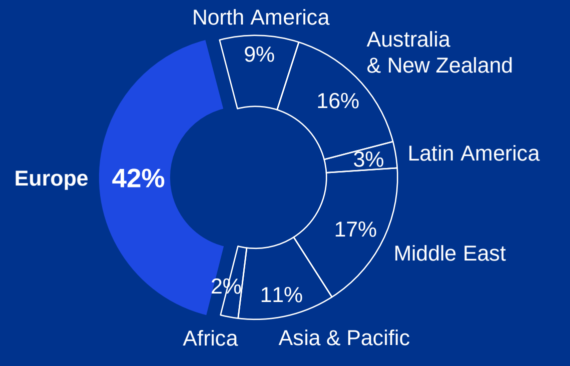
KPMG has performed a survey to understand the market sentiment among industrial hydrogen experts.

Outcomes show a considerable variation in what region may take a leading role in sustainable hydrogen production. By 2035, the EU is expected to lead in hydrogen production, with most experts believing over half of the hydrogen production is green. Whilst Australia is expected to have a higher green hydrogen share, Europe is expected to lead by total volume.

Reason for Europe to be at the forefront of hydrogen production currently mainly results from the lack of midstream infrastructure, meaning supply has to be co-located with demand. Hence, production will have to be located largely in Europe due to progress with policy and subsidies creating the demand.

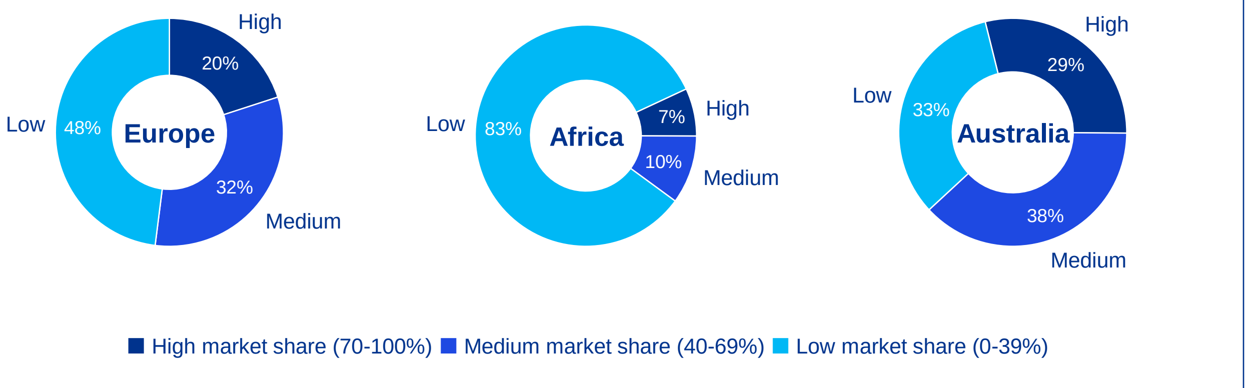
Market participants believe Europe to become the green hydrogen hub, which will set a base for accelerating further adoption in Africa and other regions. Current hydrogen targets, as previously discussed, are of much importance. Market experts likely expect much from the EU in terms of sustainable production.

**Figure 6. Leading hydrogen producing regions, KPMG survey trends towards 2035,**
survey feedback, 2021




Source: KPMG questionnaire by the KPMG Global hydrogen team, KPMG analysis.

**Figure 7. Expected market share of green hydrogen in the total hydrogen mix across continents by 2035,**
survey feedback, % of respondents, 2021




Note: The survey had been conducted in October 2021 and consists of 452 respondents. 60% of respondents is from Europe, 14% North America, 12% Australia and 16% from other regions.
Source: KPMG questionnaire by the KPMG Global hydrogen team, KPMG analysis.

# The need for investment in sustainable hydrogen production

# Current demand forecasts for renewable hydrogen strongly outmatch EU sustainable hydrogen production targets

## Risks underlie the EU's sustainable hydrogen production targets for 2030

The EU has set a target for an installed electrolysis capacity of at least 40 GW by 2030, which should, according to the EU, produce 10 Mt of sustainable hydrogen per year. In addition, 40 GW of capacity from neighboring countries (in North Africa, for example) would supply the additional sustainable hydrogen. According to a current overview by the European Commission, 22+ GW of electrolysis capacity is planned to be built in the next 5+ years resulting in half of the EU targets for 2030 being fulfilled.

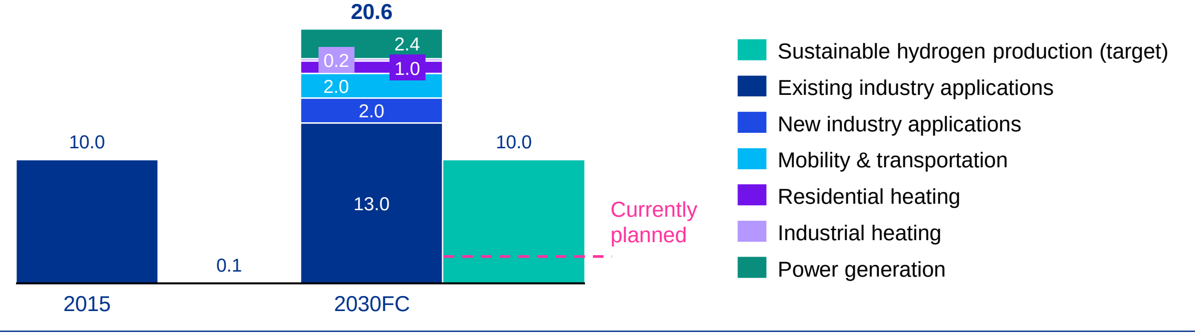
There are some major risks underlying these targets:

1. The current pipeline consists of a number of large projects which have yet to move beyond concept stage and first need to undergo a feasibility study. For example, White Dragon, a project in Greece, is planning to realize 4.65 GW of green sustainable hydrogen capacity. Reliance on these large projects represents a delivery risk against these ambitious targets.
2. Progress in policies to both incentivize supply, as well as demand for sustainable hydrogen. Additionally, standards and certification required to clearly define boundaries ($CO_2$ footprint) of different types of hydrogen.
3. Reliance on imports combined with lack of midstream infrastructure to transport large volumes of hydrogen across continents.
4. More importantly, there are a few questionable assumptions within the 10 Mt EU production target :
   – The presented target of 40 GW assumes that electrolyzers will operate 24 hours per day, 365 days per year (the number of operating hours, or asset utilization, is known as full-load hours). Current projects expect to operate fewer full-load hours due to the limited supply of renewable electricity and for some business cases, the avoidance of high power prices, as discussed later.
   – In addition, to reach 10 Mt with a 40 GW capacity, and efficiency of 95% must be assumed. This equals 35 MWh of energy consumption per tonne of hydrogen, while the theoretical thermo-dynamic minimum is 33.3 MWh per tonne. Current electrolyzers operate at efficiencies of 65%-75%, depending on how much energy is consumed in compressing and purifying the hydrogen produced.

In conclusion, the European sustainable hydrogen strategy is ambitious in terms of GW capacity but will still not be able to cover the expected demand for MT hydrogen in 2030. Therefore, if industries continue to implement sustainable hydrogen solutions, additional supply and investment in production capacity are required.

**Figure 8. Hydrogen demand in Europe per segment**
2015-2030FC (Mt $H_2$), ambitious scenario

The European Commission is working on an obligation to the European Renewable Energy Directive (RED). At least 50% of the hydrogen used in industry (refineries are exempt) must be green from electrolysis by 2030.




Source: Energeia; European Commission; Zauner 2019; KPMG analysis.

# Supply shortage and carbon prices increase the attractiveness of investments in sustainable hydrogen

## The projected under-capacity in sustainable hydrogen production will drive prices

Business cases for investing in green hydrogen strongly depend on the price paid for renewable hydrogen. Currently, grey and green hydrogen prices are expected to change significantly for several reasons. As there is no defined market for green hydrogen, it is too early to tell how prices will develop. In forthcoming KPMG  Thought Leadership materials, the potential routes to a green hydrogen market development will be discussed.

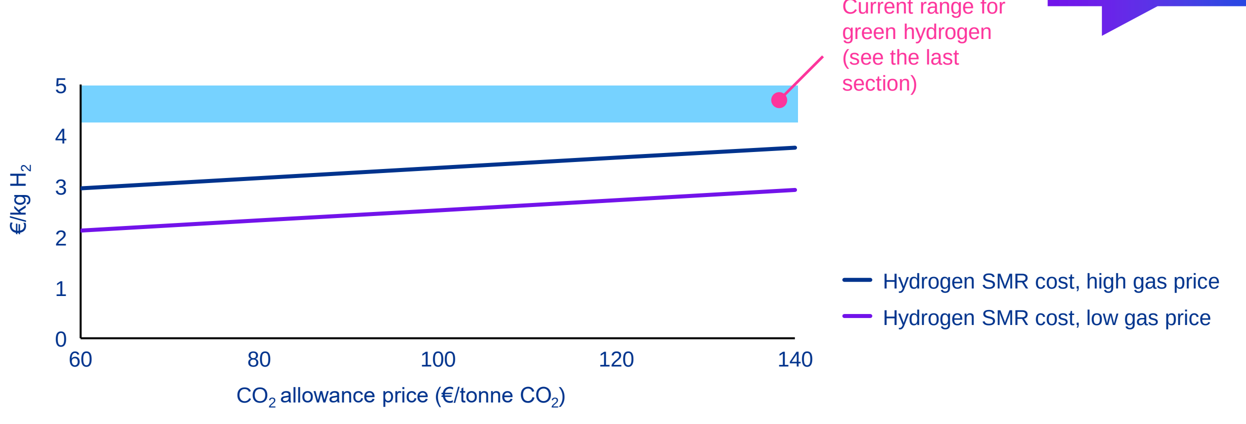
**Green hydrogen prices**
The production costs of commercially produced green hydrogen are dependent on many variables (see the next chapter). However, one particular development can already be foreseen. The industry's commitments to decarbonize will require large quantities of hydrogen, and the supply shortage discussed previously is likely to drive sustainable hydrogen prices.

**Fossil-based hydrogen prices**
Conventional and carbon-intensive hydrogen produced via the SMR process remains a cheaper option in production cost. Nevertheless, traditional hydrogen production has become more expensive lately as natural gas prices, the main cost driver for fossil-based hydrogen, have increased. Even though power prices, the main cost driver for green hydrogen, correlate with natural gas prices through the merit-order scheme, they have only seen a minor increase compared to natural gas prices. In addition, CO2 allowance prices are expected to increase in the coming years, impacting the price of natural gas-based hydrogen production.

**Outlook**
For the reasons discussed above, in addition to future electrolyzer cost reductions, it can be expected that the production cost gap between fossil-based and green hydrogen will close, making business cases for investments in green hydrogen production more attractive.

Not taking the current spot price, but a hedged average natural gas price, into account.

**Figure 9. Total production costs of hydrogen production through SMR**
€/kg $H_2$, indicative




Note: Low gas price is set at €0.28/m$^3$, high gas price is set at €0.50/m$^3$. SMR production is assumed to emit 10kg $CO_2$/kg $H_2$. Power price ranges between €50-€70/MWh.

Source: IEA; Ycharts; Hydrogen for Climate Action; KPMG analysis.

# To improve business dynamics for green hydrogen, a bottom-up investment plan is needed

## Formulating a clear business case for hydrogen is still challenging

Facilitating the scale-up of green hydrogen requires consideration of several factors, including creating large-scale value chains from the generation of renewable energy, electrolysis, storage and distribution to end-users. Due to the current usage of hydrogen in the industry, part of the value chain for green hydrogen is already facilitated. Still, the lack of mature transport possibilities require onsite production, limiting production options. The more considerable barrier to green hydrogen in terms of industrial use is that it is only starting to become commercially viable.

Nevertheless, as illustrated, many ‘favorable’ commercial conditions are developing around green hydrogen. This results in more attractive green hydrogen business cases than before. Investors, therefore, require advice on how to assess a green hydrogen business case and decide whether to invest or not.

Though some energy giants are making the first move to invest in green hydrogen production, the broad range of hydrogen applications does allow a far wider spectrum of (industrial) companies and financial investors to invest. This paper outlines the main factors to consider when assessing a green hydrogen investment case and the underlying assumptions and figures in current industry projections.

Following the reasoning outlined in this paper, the required total investment may be much higher than the investment requirement based on assumptions made by the European Commission. This results from the different expectations in efficiency and full-load hours, impacting the expected output per installed capacity.

The study does not discuss potential cost reductions resulting from the technological advancements required to realize the energy transition, nor does it detail indirect uncertainties like the availability of green power or regulations. In addition, transport costs or developments in competitive markets will not be deliberated. Instead, future series will outline these critical factors to the business case in more detail.

**The investment requirement is expected to be between…**

**65-100**
€billion

… when the EU is aiming for 40 GW of installed capacity, given the current KPMG CAPEX estimations

**Or even…**

**140-215**
€billion

… if the EU is aiming for 10 Mt of sustainable hydrogen production, given the current KPMG CAPEX and adjusted full-load hour estimations

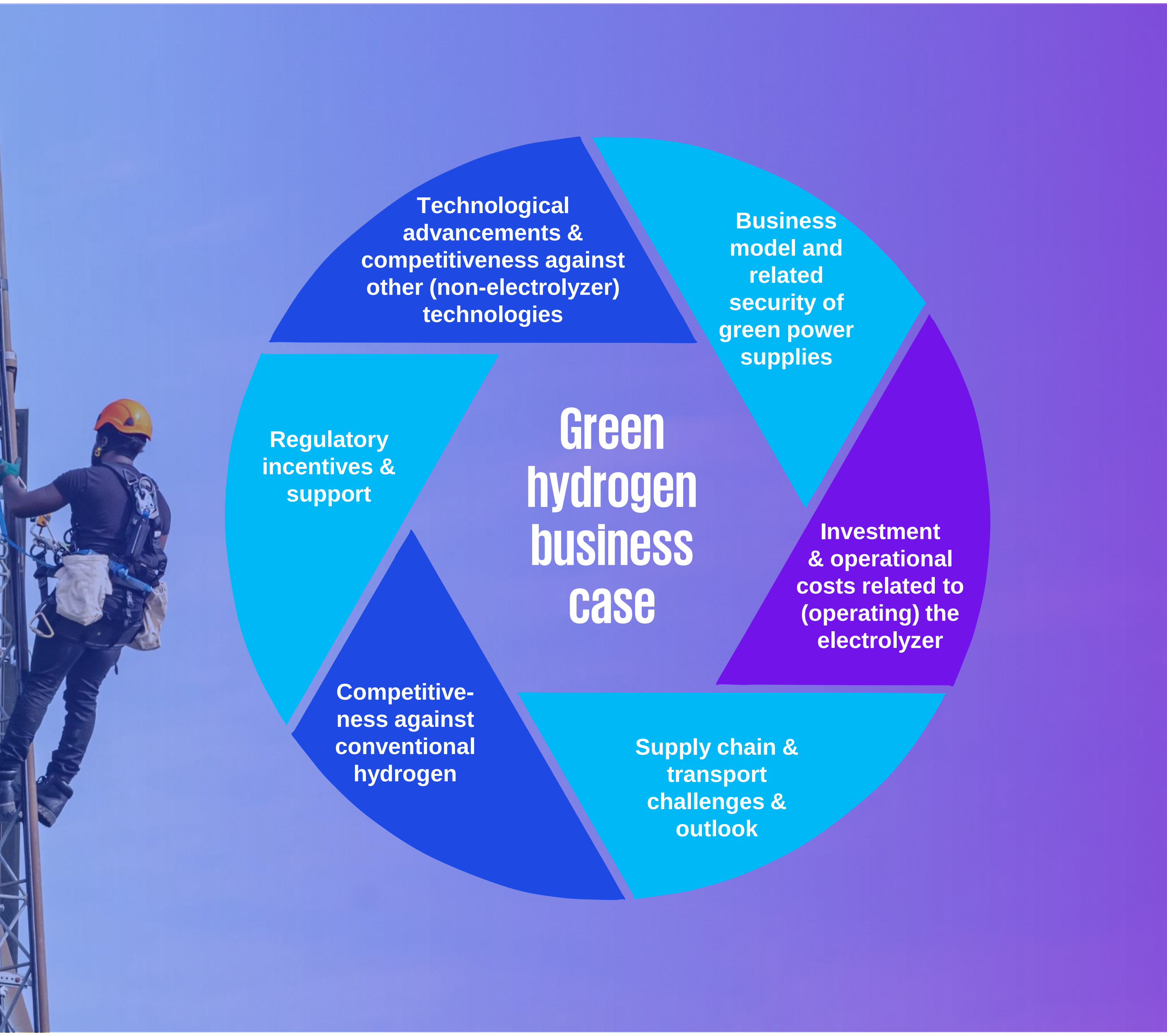
**Continue reading to understand how these investment requirements are calculated**

Source: Hydrogen for Climate Action; KPMG analysis.

# The business case requires a detailed assessment of many uncertainties…

**Figure 10. Key pillars to constructing a business case**




Key: ■ Discussed in detail throughout this paper ■ Touched upon by this paper, but requires more detail ■ Important, but not (yet) discussed in detail.
Source: KPMG analysis.

# Focusing on potential investment in PEM electrolyzers, being most appropriate for non-Scandinavian EU countries

## The alkaline electrolysis technology is already established and ready for commercial use; but is likely to be replaced in the medium term

Most European countries will require a certain amount of flexibility in the electrolyzer's operation for ramping-up and down due to intermittency of green power. As such, PEM is most suitable for adhering to these requirements.

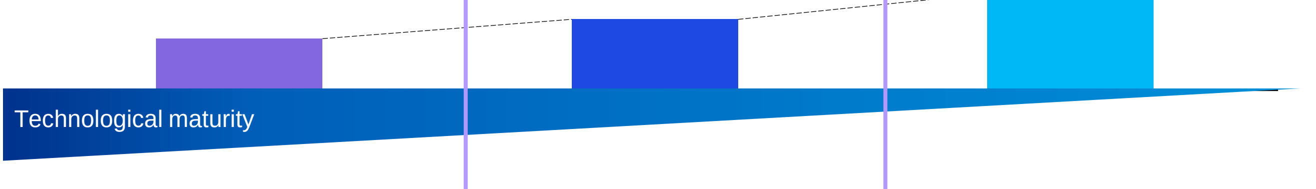
On the other hand, alkaline could be the better choice for countries having an abundance of green power supply (e.g. Scandinavian countries) where the electrolyzer can run on high full-load hours without flexibility requirement.

To add to the technological advancements, another hydrogen production techniques potentially allow for cheaper and more energy-efficient decarbonized hydrogen production. For example, upcoming sustainable gasification technologies allow for scalable and competitive production costs. These forthcoming technologies are not considered for this paper, though these might be a competitive alternative for electrolysis.

### Electrolyzer technologies

| | Alkaline electrolysis (AEL) | Proton exchange membrane (PEM) | High-temperature electrolysis (HTEL) |
|---|---|---|---|
| **Advantages:** | • Established, reliable technology<br>• Long service life (>50,000h)<br>• Tested on a large scale<br>• Relatively wide load range<br>• Little control effort with atmospheric AEL | • More efficient gas flow process<br>• Simple gas network coupling<br>• High level of flexibility and overload capacity<br>• Highly compact design<br>• Technological economies of scale | • Overall efficiency levels of 90% attainable<br>• Electricity consumption falls as temperature rises<br>• Heat recovery possible |
| **Disadvantages:** | • Some complex peripheral activities (e.g. gas cleaning)<br>• More complex gas connection (due to compressor)<br>• Low max. current densities<br>• Lower economies of scale | • Technologically less established (low production volumes)<br>• Greater material wear (service life <50,000h) | • Much shorter service life (>25,000h)<br>• Technology testing in progress<br>• Additional steam generators and compressors<br>• High maintenance costs (due to high temperatures) |

**Indicative average CAPEX**




Currently most suitable for most EU countries

Source: KPMG analysis.

# Assessing the business case

# To assess the green hydrogen business case, the cost structure should be evaluated in detail

## Both CAPEX and OPEX require detailed analysis for levelized costs to be calculated

The assessment of the hydrogen production business case is dependent on two main factors:

1. There has to be a particular demand for sustainable hydrogen resulting in an additional premium on the product. This requires an understanding of the supply- and demand-side dynamics, indicating if there is a market attraction for a differentiated sustainable alternative. This subject matter is covered throughout the previous section.
2. The average total production costs of green hydrogen must be as low as possible. A common way of expressing these total production costs for energy systems is by calculating the levelized costs.

The levelized cost method is an easy way of comparing energy systems fairly based on the total output compared to the total costs. The levelized cost sums up all cost items over the system's lifetime and divides these by the total output generated throughout its lifetime. The final result is an average cost of production per unit. Using this methodology, production methods and facilities can be compared against a benchmark.

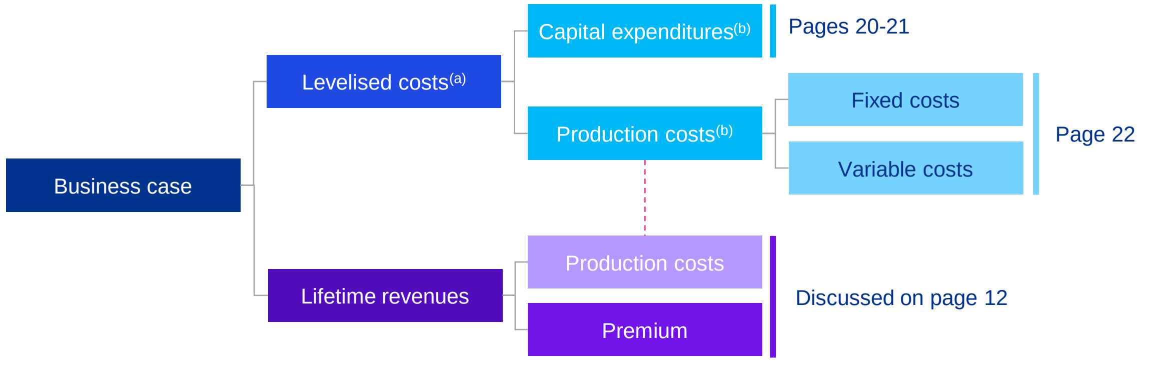
To calculate the levelized costs, a few additional key factors are required that cannot be expressed as a cost parameter. These parameters include (descending in order of importance):

— Full-load hours: Full-load hours are when the electrolyzer is operating at full load annually. This impacts the average CAPEX and the average fixed OPEX per hydrogen unit.

— System efficiency: The electrolyzer efficiency influences the levelized costs through the power required to produce a hydrogen unit.

— System lifetime: The longer the system can run, the lower the average CAPEX and fixed OPEX per hydrogen unit.

**Figure 11. A simplification of the green hydrogen production business case drivers based on levelized costs**
Indicative




Note: (a) Levelised costs are calculated as the total costs divided by the total output during the plant's lifetime.
(b) Levelised costs represent all costs over the total lifetime, therefore including the sum of OPEX and CAPEX over the total lifetime.

Source: KPMG analysis.

# To reduce levelized costs of hydrogen, asset utilization should be optimized rather than maximized

## Assessments of power prices throughout the year are key in determining the economically preferred full-load hours

Figure 12 below presents the production or levelized costs of a polymer electrolyte membrane (PEM) electrolyzer. These costs consist of the (in)direct CAPEX related to the electrolyzer and various OPEX costs for its operation. The case is calculated following a grid-connected business model. Including the majority of power procurement from PPA's will allow for a (more) stable power price. The following pages will discuss the costs to this business model and provide range estimates.

For every project, the number of load hours will greatly impact the production costs as power prices are the largest contributor. Therefore, the levelized costs should be assessed to determine the break-even point, which requires detailed information on local power prices.

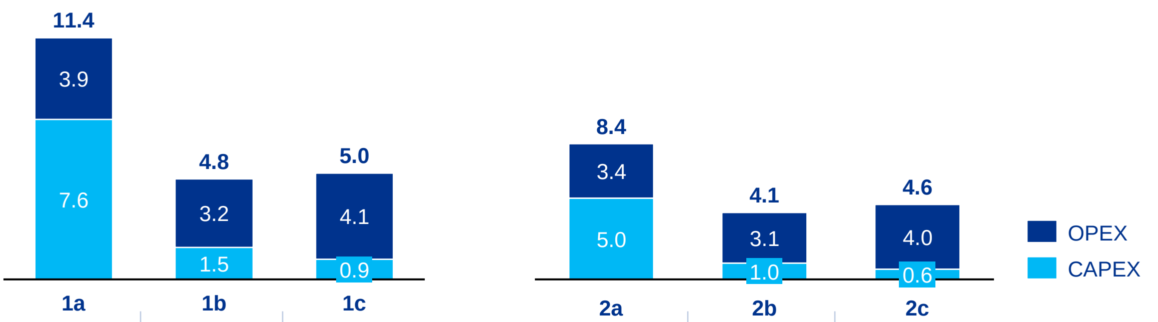
In theory, at certain additional full-load hours, the levelized costs increase due to power price increases. This is due to the volatile power supply from renewable energy generation installations. To enable full utilization, operators would have to make up for any shortfall in power supply by buying from spot markets at very high prices on short notice. Potentially, it is also feasible to close long-term agreements in order to avoid spot price fluctuations.

By assessing 10 different green hydrogen projects, an understanding has developed of what level full-load hours should be used. Majority of Europe-based electrolyzers should operate at a maximum of 5,000 – 6,000 full-load hours to obtain the lowest levelized costs. Depending on region, some projects allow for higher operation hours. Secondary research supports this finding and states that full-load hours of more than 4,000-5,000 hours/year often significantly increase production costs due to the increasing average power prices.

Using the parameters discussed throughout the following pages, scenarios 2b and 2c in figure 12 below illustrate that an increase in the average power price due to a rise in full-load hours can theoretically increase the levelized cost depending on the average power price increase. Projects in areas with stable power price conditions can operate at higher full-load hours, minimizing the CAPEX to below 25% of the levelized costs.

**Figure 12. Total levelised costs of hydrogen production through PEM electrolysis**

€/kg $H_2$, indicative scenarios given the most favorable CAPEX assumptions




| | 1a | 1b | 1c | 2a | 2b | 2c |
|---|---|---|---|---|---|---|
| Power price (€/MWh) | 20 | 50 | 70 | 20 | 50 | 70 |
| Full-load hours | 1,000 | 5,000 | 8,000 | 1,000 | 5,000 | 8,000 |
| Capacity (MW) | | 50 | | | 200 | |

Note: Assuming fixed OPEX to be 4% of CAPEX and power conversion to hydrogen to be 52 kWh/$H_2$. The electrolyzer lifetime (including stack) is equally set at 15 years. Though the PEM stacks will have to be replaced within 10 years, a larger share of the CAPEX has a much longer lifetime, thus balancing the overall lifetime at 15 years.

Source: ISPT; IRENA; EU Horizon 2020; IEA; Hydrogen Council; ICCT; research papers; KPMG analysis.

# A common pitfall is to focus solely on the direct CAPEX, underestimating the investment requirement

## Many CAPEX cost estimations focus on the direct costs, projecting limited economies of scale

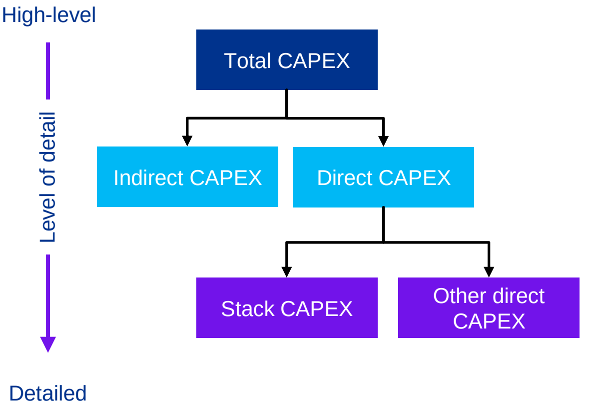
To understand financial support requirements, the electrolyzer CAPEX in the current situation needs to be assessed.

Based on KPMG professionals knowledge, there appears to be a large discrepancy between CAPEX estimations at major industrial projects. The underlying benchmark can act as a guide for whether all CAPEX items are included. In general, those projects that have not been in line with the total CAPEX benchmark have overlooked indirect CAPEX, resulting in a correlation on the direct CAPEX level but falling short on the indirect CAPEX level.

Although CAPEX is widely discussed in the relevant literature, many reports focus on direct CAPEX. Indirect CAPEX (e.g. engineering, project management, insurance) can represent a significant share of total CAPEX (see next page) but is often neglected in industry analyses.

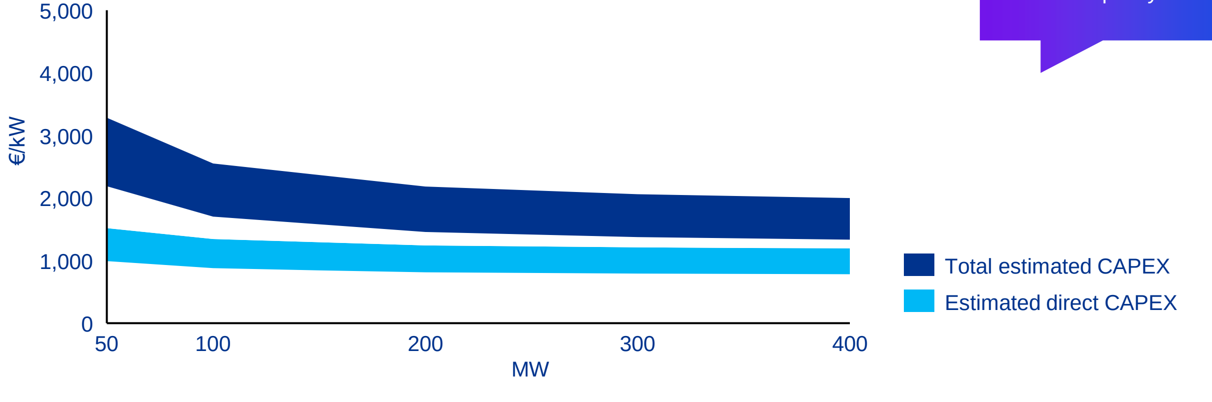
To add to figure 14, CAPEX estimations are expected to reduce soon, improving investment attractiveness given the current situation. Without any support, first movers would be disadvantaged.

**Figure 13. Schematic high-level breakdown of total CAPEX**




Economies of scale are mainly related to the indirect costs. These tend to be more variable relative to capacity.

**Figure 14. PEM electrolyzer total and direct CAPEX per installed capacity, 2022**
€/kW capacity, indicative




Source: ISPT; IRENA; EU Horizon 2020; IEA; Hydrogen Council; ICCT; research papers; KPMG analysis.

# Direct CAPEX components are variable to the electrolyzer size, slightly limiting the economies of scale

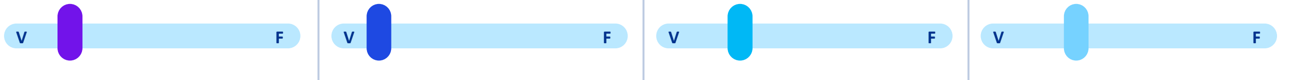
## Still, a significant share of CAPEX is indirect, which tends to be more fixed relative to capacity

Breaking down the total CAPEX of an electrolyzer into direct and indirect costs, direct costs appear to be largely variable, whereas indirect costs are likely to have some fixed elements. The economies of scale of direct CAPEX are relatively small compared to the total CAPEX benchmark. This is a result of the relatively high variable CAPEX characteristics like stacks, the costs of which tend to increase in a somewhat more linear manner. Including these variabilities determines the slope of the total CAPEX benchmark.

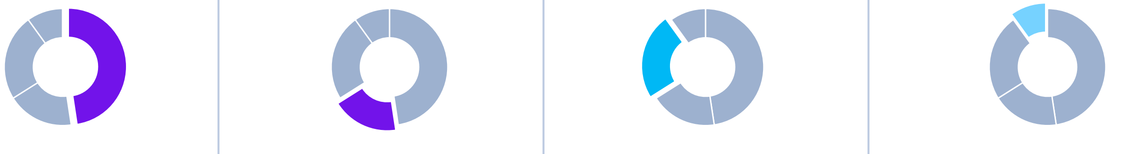
Both indirect CAPEX and direct CAPEX consist of many sub-costs that have to be included in a bottom-up approach.

**CAPEX items**

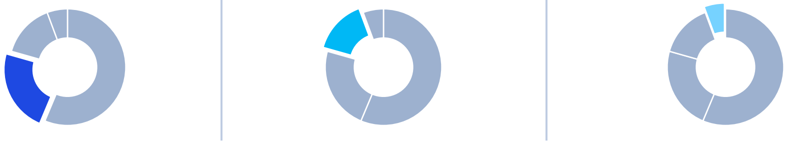
| Direct costs | Contingency[b] (accounted for as indirect) | General indirect costs | Indirect owner costs |
|---|---|---|---|
| — Stacks<br>— Civil, structural & architectural<br>— Power supply and electronics<br>— Balance of plants[a]<br>— Utilities and process automation | — Modelled as a fixed percentage of the direct costs | — Engineering<br>— Project management<br>— Construction supervision and management<br>— Commissioning | — Operator training<br>— Insurance<br>— Grid fees<br>— Owner project management<br>— Site supervisory teams<br>— Electricity consumption and lease during construction |




**200 MW estimate**



**1 GW estimate**



Key: V = Variable, F = Fixed.
Note: (a) Balance of plants are various supporting components to the system to produce hydrogen.
(b) Contingency is a budget saved in advance in case unexpected costs occur.
Source: ISPT; IRENA; EU Horizon 2020; IEA; Hydrogen Council; ICCT; research papers; KPMG analysis.

# Power prices are a key cost component and price variation during the year determines the optimal asset utilization

## The majority of levelized costs can be traced to the power prices in OPEX

Electrolyzer OPEX consists of two main elements: a fixed OPEX component and a variable OPEX component. The fixed OPEX, consisting of operation and maintenance costs, is often estimated at 2%-4% of direct CAPEX, depending on whether stack replacement is included. The variable costs consist mainly of power purchase costs and costs for purified water to a minor extent. Therefore, power procurement is essential in assessing the business case's overall feasibility.

Research papers often apply a relatively low power price assumption of ~€40/MWh. Given current developments in the power market, the KPMG benchmark for calculating the total levelized costs ranges between an average power price of ~€50/MWh and ~€70/MWh. Majority of current EU business cases appear to use similar ranges.

Load hours and efficiency levels also have a significant impact on the levelized costs and, as such, require detailed agreements with the power provider. As presented in figure 16, the European Union target assumes that electrolyzers will run close to the maximum full-load hours.

**Figure 15. Electrolyzer OPEX per MW capacity per full-load hour scenario[(a)], low power price**
€/kg $H_2$, indicative

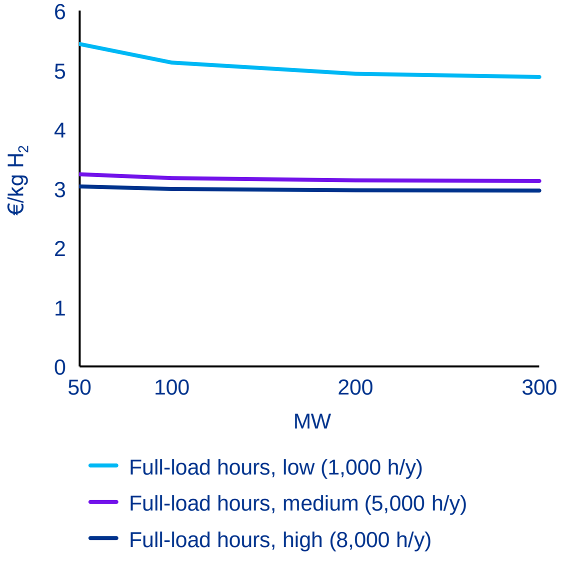
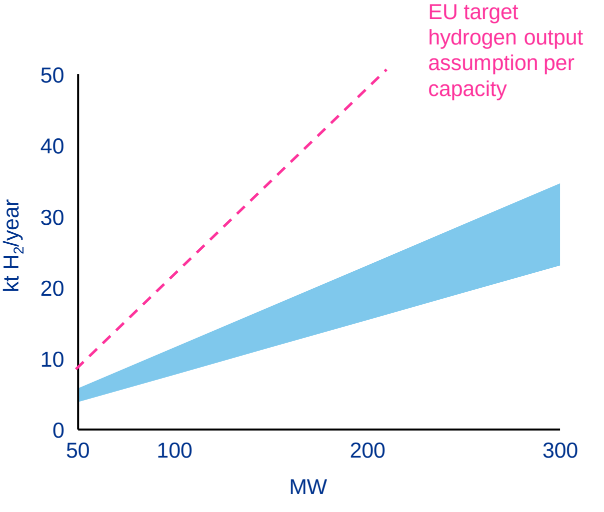



**Figure 16. Electrolyzer estimated hydrogen volume output per MW capacity[(b)]**
kt $H_2$/year, indicative




Note: (a) Assuming a low power price of €50/MWh and power conversion to hydrogen to be 52 kWh/$H_2$.
(b) Assuming between 4,000 and 6,000 full-load hours and power conversion to hydrogen to be 52 kWh/$H_2$.

Source: ISPT; IRENA; EU Horizon 2020; IEA; Hydrogen Council; ICCT; research papers; KPMG analysis.

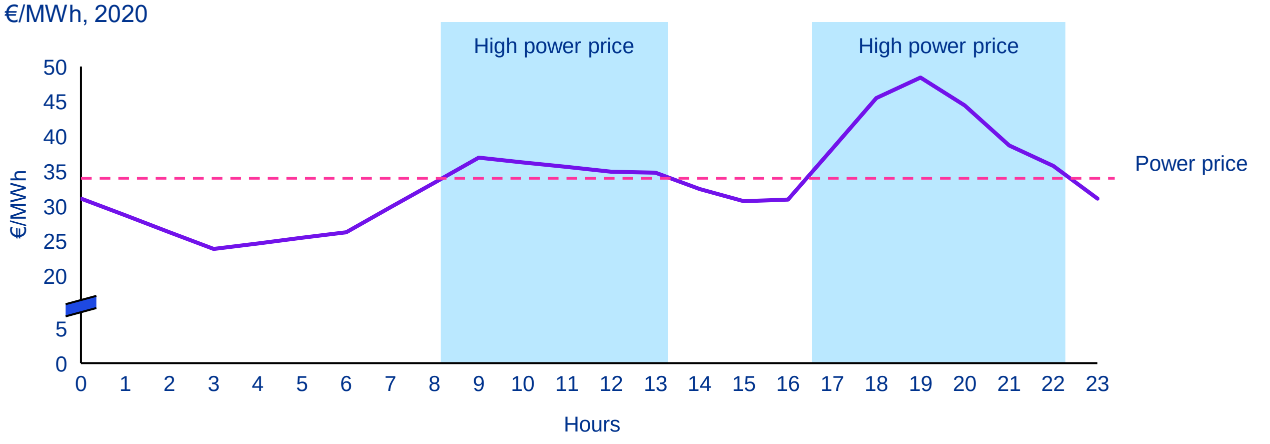
 | 

# Increases in power price volatility require a comprehensive procurement strategy for the electrolyzer

## As demand/supply varies during the day, hourly price difference arise...

Due to a wide variety of demand levels during the day, prices have significantly varied historically and will continue to do so in the future. Even though balancing mechanisms will increasingly be used, electrification will increase electricity demand during peak hours. The availability of supply will also increasingly vary due to renewable power systems.

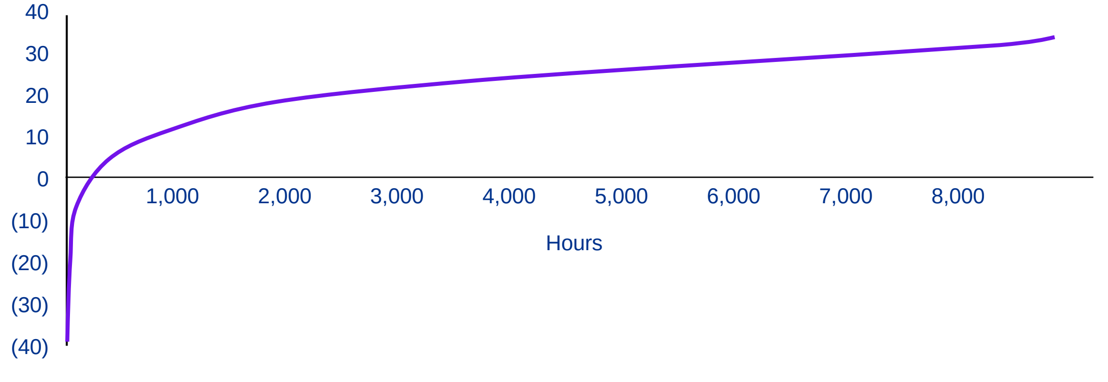
**Figure 17. Average power price during the day, UK**
€/MWh, 2020




## ...as such, the system's load hours have to be adjusted accordingly concerning the average power price

Due to the increasing price differences described above, an optimization assessment is required to determine if and when electrolyzers should stop operating in case power price are above a threshold. As shown below, the more full-load hours are used, the higher the average power price. In the long term, the issue of power price variations might vanish as soon as cheap electricity storage systems are available.

**Figure 18. Cumulative average power price, UK**
€/MWh, 2020




Source: Entsoe database; KPMG analysis.

# Conclusion

# The vast amount of uncertainties require tailor-made business case assessments

## Companies need to consider all relevant variables for deriving hydrogen (investment) strategy

In conclusion, the main relevant factors for all hydrogen investment cases can be aggregated into four categories:

**Technological readiness of hydrogen applications**
Due to ambitious decarbonization targets for different sectors, industrial companies, in particular, are forced to consider hydrogen as a tool to decarbonize. However, further technological development bears uncertainties, especially in the mid to long term.

**Hydrogen supply in Europe**
According to its hydrogen strategy, the planned electrolysis capacities in the EU will not ensure sufficient supply for all of the scheduled applications currently predicted by market outlooks. Therefore, a shortage of hydrogen will increase renewable hydrogen prices and result in more attractive business cases.

**Power and natural gas prices**
Power and natural gas prices increased strongly in 2021, resulting in rising prices for fossil-based hydrogen. As electricity prices have not increased as enormously as the gas prices, the price gap between green and grey hydrogen has reduced and made green hydrogen investment cases more attractive.

**CAPEX and OPEX considerations**
The CAPEX requirement should be assessed through a bottom-up approach, including all direct and indirect CAPEX. Furthermore, the optimal load hours strongly depend on renewable energy's direct availability, for example, wind parks and energy procurement strategies. To ensure full-load hours of >4,000 hours p.a. for electrolyzers, an energy procurement strategy must balance the higher investment cost in overcapacities of renewable generation (e.g. wind parks) vs. high power prices on the spot markets.

All these aspects assess hydrogen investment cases as complex and challenging. However, knowing and understanding these uncertainties is the first step in allowing a case-by-case analysis of investment opportunities, resulting in a data-based investment case for decision-making.

**Figure 17. Summary of uncertainties that have to be assessed for each business case**

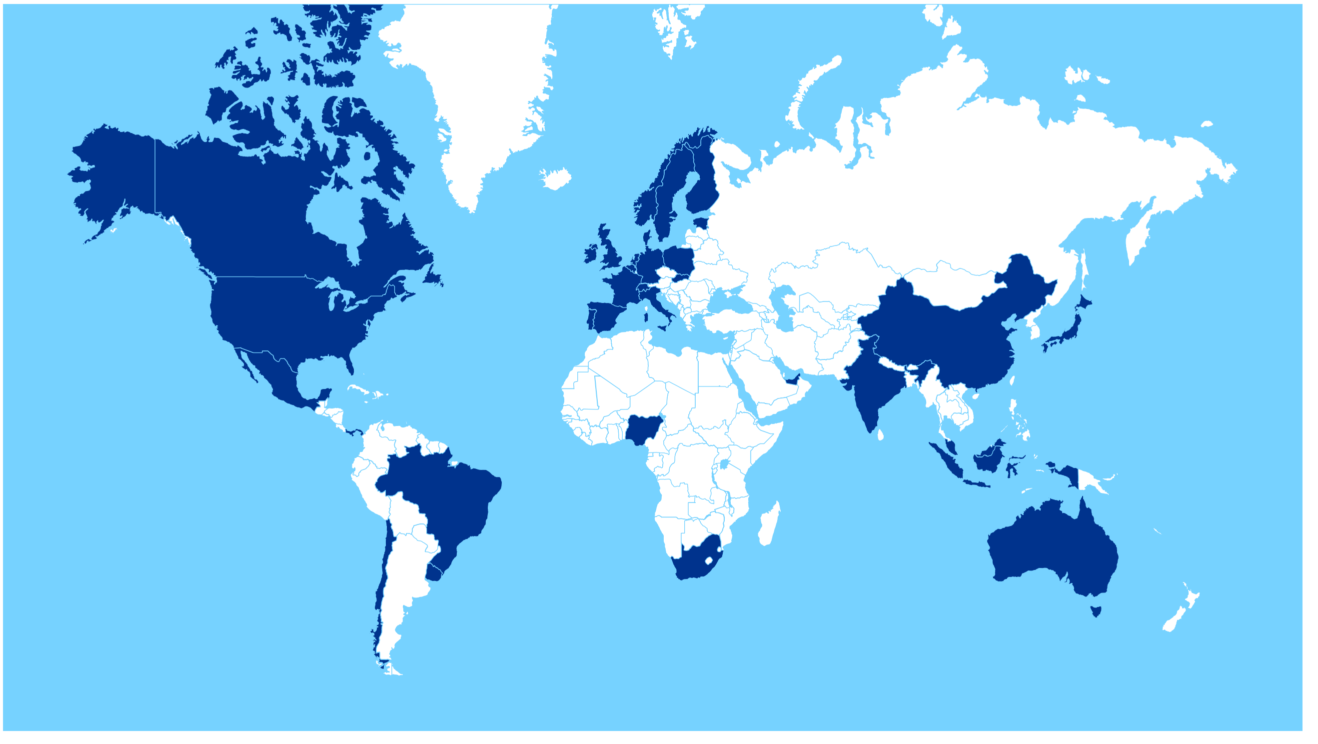
| Uncertainties in the ecosystem | Uncertainties in the investment figures | Unaddressed uncertainties (non-exhaustive) |
|---|---|---|
| • Technological readiness level | • Full-load hours | • Sufficient green power |
| • Green hydrogen capacity ramp-up | • (In-)direct CAPEX | • Clear differentiation in sustainable products |
| • Natural gas prices | • OPEX | • Hydrogen regulations |
| • Spot power prices | | |

# Appendix

# KPMG global hydrogen network

### 34 member countries and territories



| Providing in-depth and local hydrogen market insights | Sharing expertise across the hydrogen value chain | Collaborating on global KPMG hydrogen projects | Delivery access to 50+ resident hydrogen leads |
|---|---|---|---|

# Sourcing and notes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