Foreword

Hydrogen Europe is proud to present to you the “European Clean Hydrogen Monitor”!

It’s the first of its kind overview showing the state of play with regards to hydrogen technologies in Europe. On an annual basis there will be an update serving as a basis for your investment or political decisions.

Our Mission Is – No Emission!

From day 1 Hydrogen Europe promoted clean hydrogen and clean hydrogen technologies as enablers of a decarbonised energy system. We strongly support the adoption of very ambitious climate targets for 2030 and the objective of carbon neutrality in the EU by 2050. Clean hydrogen can help to realise this transition of our energy system in multiple sectors, from energy production, storage and distribution, to end-uses in transport, industry, heating and others.

Clean Hydrogen Technologies Can and Will Replace

not just fossil-based hydrogen in current (industrial) uses, but also other fossil-based energies such as petrol, diesel and hydrocarbon fuels in the transport sector, coal/coke in the steel sector, natural gas in the heating sector, and other polluting and emitting fuels and feedstocks.

We Are Talking About a Systemic Change.

The use of clean hydrogen needs adaptations in production schemes, in the infrastructure and in the deployment of hydrogen by the end users. This cannot – of course –be done in a day. Yet, we should not wait for the implementation of the different hydrogen strategies on private, municipal, regional, national or European level until other geographies worldwide race ahead.
HYDROGEN FOR CLIMATE ACTION REQUIRES A DEEP AND OBJECTIVE UNDERSTANDING OF THE FACTS PERTAINING TO:

- the current status of the sector in terms of production and consumption (clean or otherwise),
- the competitive gap between renewable hydrogen and its fossil alternatives,
- the plans for further development of (clean) pathways for hydrogen production and use (despite the competitive gap) and
- the policies that incentivise the adoption of clean hydrogen technologies over fossil-based fuels and feedstocks.

On an annual basis his report aims to provide a thorough and objective understanding with updates, monitor changes and, importantly, highlight trends that will eventually grow to characterise the sector.

We are sure that this report will be used by decision makers in the public and private sector in order to speed up the adoption of clean hydrogen technologies and make our transition to a zero-carbon economy smoother, easier, faster and less costly.

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The intention of the report is to provide the Clean Hydrogen Sector with objective facts and figures relevant to the development of a Clean Hydrogen market.

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HYDROGEN DEMAND AND SUPPLY IN THE EU

The following chapter contains information about current hydrogen supply and demand in the European Economic Area (the EU-27 plus the UK, Norway, Switzerland and Iceland). All data presented in the document referring to supply and demand for hydrogen represents data for 2018.

The hydrogen supply section of the report provides information about the current production capacities, expressed in metric tonnes per day (MTD), of all identified hydrogen generation plants in Europe, divided by:

- country of production,
- type of production (for own consumption, merchant or by-product)
- production technology, with a special focus on clean hydrogen production capacities.

The hydrogen demand section of the report provides information about the quantities of hydrogen (expressed in tonnes or TWh\textsubscript{HHV}) consumed by different end-use sectors in 2018.
For more detailed data on each country, see the Fuel Cell and Hydrogen Observatory database at: https://fchobservatory.eu
1.1 HYDROGEN GENERATION CAPACITY

1.1.1 PRODUCTION CAPACITY BY TYPE

In total, 457 hydrogen production sites, have been identified to be in operation in Europe at the end of 2018. These are divided into three main types: captive production facilities, merchant production facilities and plants where the production of hydrogen is a by-product of other processes. The boundaries between the three hydrogen production types used are explained in the Methodological Note, found at the end of the report.

More than half of the total hydrogen consumption takes place in just four countries: Germany (22%), the Netherlands (14%), Poland (9%) and Belgium (7%).

Figure 1

Identified hydrogen production sites

Source: Hydrogen Europe.

1 On-site production of Hydrogen for own consumption.
2 Hydrogen production for sales.
Total hydrogen production capacity in Europe at the end of 2018 was around 11.5 million tonnes (Mt) per year. Excluding by-product hydrogen, generated as part of coke oven gas (COG), the total pure hydrogen production capacity adds up to a total of 9.9 Mt of hydrogen per year (27 thousand MTD). Based on the estimated size of hydrogen consumption in 2018 (see the following subchapter), the average production capacity utilisation in 2019 was 84%.

On-site captive hydrogen production is by far the most common method of hydrogen supply, with almost two-thirds of all hydrogen production capacity (7.5 Mt per year or 20.5 thousand MTD in 140 production plants) being dedicated to own consumption. This is the case for refineries, ammonia, methanol, hydrogen peroxide production plants and other facilities, where a high volume of hydrogen consumption justifies investment in a dedicated Hydrogen Generation Unit (HGU).

Another large group are merchant plants, which produce hydrogen mostly for sales. We estimate that there were 184 merchant hydrogen plants operational in Europe in 2018. Even though these are more numerous than captive plants, because of their smaller average capacity they only represent 15% of total hydrogen production capacity (1.7 million tonnes per year or 4,584 MTD).

Merchant hydrogen plants can be divided into two main sub-categories:
- plants dedicated to supplying a single large-scale consumer, with only excess capacity available to supply the retail hydrogen market
- small and medium scale hydrogen production sites designed to supply mostly retail customers.

While the first type can be comparable in scale to the largest captive hydrogen production facilities, the installations designed with the hydrogen retail market in mind are an order of magnitude smaller in terms of their maximum capacity.

The merchant hydrogen market in Europe is dominated by 4 companies: Air Liquide, Air Products, Linde Gas, and Messer, who, together with their subsidiaries, own a combined 87% of total merchant hydrogen production capacity.
Hydrogen as a by-product of other processes is produced at 133 different plants. Total by-product hydrogen production capacity has been estimated at 2.36 Mt per year (around 20% of total production capacity), including:

- 1.6 Mt of hydrogen mixed in coke oven gas (COG),
- 0.21 Mt of hydrogen produced by the Chlor-alkali industry,
- 0.38 Mt of hydrogen produced by the ethylene industry,
- 0.12 Mt by-product hydrogen from the styrene industry.

By far the largest part of by-product hydrogen exists as a mixture with coke oven gas. In this case, the output gas is not pure hydrogen but rather a mixture of hydrogen (55%-65%) and methane, carbon monoxide, CO2 and nitrogen. Coke oven gas is used to enrich the calorific value of other process gases for use in blast furnace stoves, and at the reheating furnaces of hot strip mills and other high-temperature processes, or for the under firing of coke ovens. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and also at power plants. Only in rare cases is hydrogen extracted from COG utilised as a separate product stream.

1.1.2 PRODUCTION CAPACITY BY TECHNOLOGY

The most common technology for producing hydrogen is steam reforming of natural gas (SMR), or less commonly partial oxidation (POX) or autothermal reforming (ATR). SMR and natural gas are widely used for all applications, be it oil refining, ammonia synthesis or any other bulk hydrogen production. Although natural gas is the most common feed, steam reforming is also used with other feeds, including liquid hydrocarbons like LPG or naphtha. In total over 92% of all hydrogen production plants use fossil fuels as feedstock. In the case of large captive production plants, it’s close to 100%

In 2018, out of the 228 identified hydrogen production plants which were using fossil fuels as feedstock, only two were using carbon capture technologies:

- Air Liquide CRYOCAP installation in Port Jerome, France, capturing CO2 from a hydrogen production plant that supplies hydrogen to an Exxon refinery. The facility has a capacity of around 50,000 Nm3 of clean hydrogen per hour (4,500 kg/h). The CRYOCAP technology uses cryogenic purification to separate the CO2 from the PSA off-gas. Not only does the technology allow more than 97% of the CO2 to be captured, it also increases the hydrogen output by 10% to 15%. The captured and liquefied CO2 is delivered to the local beverage industry. While the installation is capable of capturing up to 3,000 tonnes of CO2 per day, currently only around 55% of CO2 capturing capacity is being utilised due to insufficient demand for CO2.4
- Shell refinery in Rotterdam, where CO2 from hydrogen production is captured as part of the OCAP project, operated by Linde.5

The total share of low-carbon hydrogen production from fossil fuels with CCS/CCU (known also as “blue” hydrogen) in all hydrogen production capacity (excluding by-product) is around 0.7%.

Hydrogen can, of course, also be produced with electricity via water electrolysis. There are a significant number of electrolysers installed in Europe. Traditionally, electrolysers have been employed whenever the volume of hydrogen demand is high enough to warrant building a dedicated installation onsite, instead of using external supplies in cylinders or tube trailers, but not high enough to

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3. More information available at: https://www.ocap.nl/
invest in an SMR and hydrogen purification (most commonly via Pressure Swing Adsorption – PSA), especially whenever high purity grade hydrogen is required or where natural gas is unavailable. This includes for example electrolyzers installed for captive hydrogen production at food processing facilities (fat hardening) or power plants where hydrogen is used for cooling purposes. According to the EU Joint Research Centre (JRC) the total installed capacity of electrolyzers in Europe is around 1 GW, which amounts to around 1.6% of total hydrogen production capacity. The existing electrolyzers are quite numerous and relatively small scale (rarely exceeding the tens or hundreds of kW). As such, a detailed breakdown of their size and location is not possible in this report. No detailed information as to the origin of electricity used for hydrogen production in these plants is available. Yet, as these electrolyzers are installed for industrial purposes, that need to be fully dispatchable, it is reasonable to assume they are powered with grid electricity and not intermittent renewable sources. The carbon footprint of produced hydrogen is thus dependant on the carbon intensity of the electricity grid the electrolyzers are connected to. Beside this traditional usage of electrolyzers, we see emerging so-called Power-to-hydrogen (PtH) projects, where low carbon or renewable electricity is used to produce clean hydrogen via water electrolysis. So far, these are still a marginal part of the market. The installations have, up until now, mostly been built as part of R&D or demonstration plants, not planned for long-term commercial operations, and are usually decommissioned after 2-3 years of operation. Nevertheless, as of the end of 2018, we estimate that there were around 70 PtH projects in operation producing renewable hydrogen, mostly for mobility applications or energy storage for...
renewable energy grid balancing. Almost half of those projects were running in Germany. The total power of those electrolysers was around 58 MW, which means a capacity to generate 1.1 t of clean H₂ per hour (<0.1% of total production capacity). In total, at the end of 2018 the estimated clean hydrogen production capacity, including renewable and low carbon hydrogen, amounted to 76 thousand tonnes per year, which represents less than 1% of the total hydrogen production capacity of all identified hydrogen production plants.

Figure 4

Hydrogen generation capacity by technology

Source: Hydrogen Europe.
1.1.3 PRODUCTION CAPACITY BY COUNTRY

With almost 2.5 Mt of hydrogen per year (21% of the total), Germany has by far the largest hydrogen production capacity in the EU, ahead of the next country - the Netherlands, which produces 1.5 Mt per year. Other countries with significant hydrogen production capacity are Poland (1.3 Mt, 11%), Italy (0.8 Mt, 7%), France and Spain (0.7 Mt, 6%), and Belgium (0.6 Mt, 5%).

The structure of production by type and technology in different countries resembles the overall structure, with captive production dominating in most countries. One of the outliers is Poland. Even though this country is third overall in terms of total hydrogen production capacities, there is relatively little merchant hydrogen production capacity. Most of the traded hydrogen on the Polish market comes either from excess capacity in hydrogen generation units in chemical plants and refineries, or by-product hydrogen, or is imported from abroad – mostly from Germany and Czechia.

Figure 5 Total hydrogen production capacity by country

Source: Hydrogen Europe.
1.2 HYDROGEN DEMAND

1.2.1 DEMAND BY SECTOR

Total demand for hydrogen in 2018 has been estimated at 8.3 Mt (327 TWh\textsubscript{HHV}). The biggest share of hydrogen demand comes from refineries, which were responsible for 45% of total hydrogen use (3.7 Mt), followed by the ammonia industry with 34% (2.8 Mt). Together these two sectors accounted for almost 4/5 of total hydrogen consumption in the EEA. About 12% was consumed by the chemical industry – mostly for methanol production.

Emerging hydrogen applications for clean hydrogen, like the transportation sector, so far comprise a minuscule portion of the market (<0.1% in 2018).

Figure 6

Total demand for hydrogen in 2018 by application

Petroleum Refining

The oil refining sector is the biggest hydrogen consumer in the EU. Hydrogen in refineries is used for hydrotreating and hydrocracking processes. Hydrotreatment is one of the key stages of the diesel refining process and refers to a number of processes, such as hydrogenation, hydrodesulphurization, hydrodenitrification and hydrodemetalization. Hydrocracking involves the transformation of long and unsaturated products into products with a lower molecular weight than the feed. Based on gathered information about hydrogen production capacities at refineries, together with information about their capacity utilisation, we estimate that the total hydrogen demand from the oil refining and petrochemical industry, in 2018, amounted to 3.7 Mt (148 TWh\textsubscript{HHV}).
**AMMONIA**

Next to refineries, the ammonia industry is the second largest hydrogen consuming sector in the EU. The ammonia production process involves a synthesis of hydrogen with nitrogen, with a consumption of 175-180 kg of hydrogen per t of ammonia. Total demand for hydrogen by the ammonia industry in 2018 has been estimated at 2.8 Mt (112 TWh\textsubscript{HHV}).

**CHEMICAL INDUSTRY**

Other than ammonia, hydrogen is a required feedstock or intermediate product necessary for the production of a significant number of other chemical products, including methanol and hydrogen peroxide, but also cyclohexane, aniline, caprolactam, oxo alcohols, toluene diisocyanate (TDI), hexamethylenedianiline, adipic acid, hydrochloric acid, tetrahydrofuran and others.

Total demand for hydrogen (excluding ammonia manufacturing) in 2018 from the chemical industry has been estimated at around 1.0 Mt (40.8 TWh\textsubscript{HHV}).

Together, oil refining and chemical industries are responsible for around 93% of total demand for hydrogen. The remaining demand comes from the following applications:

- **Steel manufacturing and metals processing**
  A mixture of hydrogen and nitrogen (5% to 7% H\textsubscript{2}) is used commonly as an inert protective atmosphere in conventional batch annealing in annealing furnaces. Batch annealing with 100% hydrogen is also possible and results in better productivity, improved mechanical properties, surface and product quality.

- **Food processing**
  By hydrogenating unsaturated fatty acids in vegetable oils, hydrogen is used in the production of margarine. Hydrogenation is usually carried out by dispersing hydrogen gas in the oil, in the presence of a finely divided nickel catalyst supported by diatomaceous earth.

- **Energy sector**
  While hydrogen can be used in a fuel cell to generate heat and energy with high efficiency, currently hydrogen use in the energy sector mostly consists of:
  - Burning hydrogen in boilers or CHP units for heat or heat and power generation, mostly done onsite where hydrogen is generated as a by-product of other processes (chlor-alkali).
  - Using hydrogen for generator cooling.
    The hydrogen demand depends on the installed power of turbines, their age and technical condition – especially the condition of the generator’s hydrogen seals. Depending on those factors, and the resulting hydrogen demand, some power plants have their own HGU’s and only use external suppliers to cover additional needs, while others obtain all of the required hydrogen from external sources.

- **Transportation**
  Hydrogen can also be used as a fuel, both directly in fuel cells or an internal combustion engine, or indirectly when renewable hydrogen is used to synthesise other more complex synthetic fuels. While this application currently forms an insignificant part of hydrogen consumption (below 0.1%), it is expected to grow in the future.
1.2.2 DEMAND PER COUNTRY

More than half of total EEA hydrogen consumption takes place in just four countries: Germany (22%), the Netherlands (14%), Poland (9%) and Belgium (7%).

Across the entire EEA, in most countries the dominant hydrogen demand comes from the oil refining industry. In some countries like Spain, Italy, Finland, Greece and Portugal, oil refining is responsible for almost all hydrogen consumption. In the case of Poland and Lithuania, the largest portion of hydrogen demand comes from the ammonia industry.

Norway is also an interesting case. Although there are two relatively big refineries, neither of them uses hydrocracking and therefore has no need for dedicated hydrogen production. As a result, most demand for hydrogen in Norway comes from Shell’s Tjeldbergodden methanol plant.

Figure 7

Total demand for hydrogen in 2018 by country (in TWhHHV)

Source: Hydrogen Europe.
1.3 INTERNATIONAL HYDROGEN TRADE BY EU COUNTRIES

A relatively small portion of annual hydrogen production is subject to international trade. In 2019 the total amount of hydrogen exported by EU countries both to other EU member states and externally, amounted to 107 thousand tonnes, which is slightly more than 1% of total hydrogen consumption. Most of this trade happens within the EU, with only 1,000 – 2,000 tonnes per year exported to countries outside the EU. Hydrogen imports from outside of the EU are equally unimportant, with only around 8 thousand tonnes imported into the EU in 2019, of which half was from Switzerland.

Over 90% of all hydrogen trade between EU countries involves The Netherlands, Belgium and France, which are interconnected with a hydrogen pipeline network, owned and operated by Air Liquide. The pipeline network makes it not only possible but also economically viable to transport large amounts of hydrogen. Excluding trade between those three countries, most of the remaining hydrogen exports by EU member states in 2019 went from the Netherlands and France to Germany, and from Sweden to Denmark. Trade between all the other EU countries rarely exceeded 2,000 tonnes per year.

Source: EUROSTAT international trade database.
Figure 9

Exports of hydrogen by EU member states in 2019

Source: Hydrogen Europe, based on EUROSTAT international trade database.

For visibility purposes the figure only shows flows of hydrogen of more than 10 tonnes per year.
The volume of trade has an obvious correlation with the price of hydrogen. In cases where trade concerns only small amounts of hydrogen, it is usually high purity grade hydrogen 5.0 (99.999%) or higher, sold in small quantities in pressurized containers for such applications as laboratory analysis. The price of such highly pure hydrogen can reach up to €30/kg. Higher volumes are distributed using cylinder packs or tube trailers, with a much lower price of €5 – 15/kg. Prices of hydrogen distributed via pipelines are set by SMR production costs and are usually below €2/kg.

Figure 10 Average 2019 hydrogen price in international trade, depending on annual volume of trade (in € per kg)

Source: Hydrogen Europe based on Eurostat data.
1.4 SUMMARY

As has been shown, current (2018) hydrogen production capacities in the EEA are around 10 Mt per year, with the corresponding annual demand for hydrogen at around 8.3Mt (327 TWhHHV).

As can be expected, the current state of both the supply and demand side is a consequence of historical developments on the hydrogen market, where hydrogen is mostly used as a feedstock for oil refining and the ammonia and methanol manufacturing industry. As a result, the vast majority of hydrogen production happens at large scale production plants dedicated exclusively to supplying these industries. As currently the cheapest method of bulk hydrogen production is hydrocarbon reforming, over 90% of hydrogen is produced from natural gas and other fossil fuels.

Clean hydrogen (renewable or low-carbon) production capacities are lower than 1% of total hydrogen production, with the new emerging hydrogen end-uses, like zero-emission mobility, having equally small shares of the hydrogen demand market. For reference, the EU Hydrogen Strategy has defined a renewable hydrogen production target for 2030 at around 10 million tonnes: the equivalent of total current hydrogen production capacities, which have been build up over decades. These quantities clearly show the extent of the challenge that lies ahead for the EU, and is a call for urgent action with regards to not only deploying new electrolysers for hydrogen production but also to the rapid development of new renewable energy sources across the EU, both solar PV and offshore wind. Furthermore, as not all current (fossil) production can be expected to be shut down in the next decade, the implementation of the EU Hydrogen strategy will require stimulating demand for Clean Hydrogen in emerging sectors such as the transport sector and steelmaking in addition to the replacement of current feedstock.

In addition to this, as electrolysers will be in many cases be deployed near the renewable energy source (avoiding grid congestion) and away from large scale end-users, there is also a need to develop hydrogen transportation infrastructure that would allow for large scale hydrogen trade across the whole EU. As the analysis in this chapter has shown, currently only around 1% of total hydrogen demand is subject to intra-EU trade between member states. On the other hand, the analysis of bulk hydrogen imports/exports value shows that when transported via pipelines the transportation of hydrogen can be achieved at relatively limited costs.

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9 Excluding by-product hydrogen, generated as part of coke oven gas (COG).
The EU Hydrogen Strategy has defined a renewable hydrogen production target for 2030 at around 10 million tonnes: the equivalent of total current hydrogen production capacities, which have been build up over decades.
The ultimate purpose of this analysis is therefore to help calculate the current cost gap that needs to be bridged in order to make unsubsidised electrolytic hydrogen production competitive in the EU.

The production costs were estimated for two scenarios:
- Electrolyser using grid electricity.
- Direct, physical connection between a renewable electricity source (RES) and the electrolyser.

Undoubtedly, in the direct connection scenario, 100% of the electrolyser’s output is renewable. In the case of an electrolyser connected to the grid, by default, the produced hydrogen is as renewable as the electricity supplied to it by the grid.
The goal of this analysis is to track the development of those costs in order to compare them with a number of benchmarks.
Although in many EU countries electricity supplied by the grids is far from being fully decarbonised, this scenario has merit even in high carbon intensive electricity grids. An increasing amount of intermittent renewable energy sources, like wind and solar, can pose several challenges for the grid operators, including load and generation imbalances and grid congestion issues. Both of these can result in renewable energy curtailment. Power-to-hydrogen (PtH) projects are a key technology that can help overcome those challenges, which is especially useful in addressing long term, seasonal energy supply imbalances, but also in managing congestions on distribution grids.

When addressing long-term (structural) congestions, strategically placed, large scale electrolysis installations would not only benefit from economies of scale but could also help balance the entire grid and not only a single RES. In cases where PtH installations would be dispatched by the TSO/DSO specifically to address the RES curtailment issue, the produced hydrogen could be viewed as entirely renewable, even when connected to a high carbon intensive electricity grid.

Furthermore, in the coming years, grid connected PtH plants should be able to produce 100% renewable hydrogen using grid electricity together with a combination of Power Purchase Agreements (PPA), signed with a renewable energy producer, and Certificates of Origin (GO) to prove the renewable character of the electricity consumed. Nevertheless, since the legal framework and market conditions for such a scenario are not yet in place, this scenario was not included in the quantitative analysis at this point.

The following table summarizes the parameters used in the two analysed scenarios for hydrogen production.

For both scenarios, key techno-economic parameters of the electrolysis were adopted based on current state-of-the-art 10,000 kW alkaline electrolysis. For detailed techno-economic assumptions see the Methodological Note.

### Table 1: Key distinctions between the two hydrogen production scenarios

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Grid connected electrolysis</th>
<th>Direct connection to RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon intensity</td>
<td>Carbon intensity of the grid</td>
<td>Zero-carbon (100% renewable)</td>
</tr>
<tr>
<td>Electricity costs</td>
<td>Wholesale electricity price</td>
<td>RES Levelized cost of electricity (LCOE)</td>
</tr>
<tr>
<td>Network costs, taxes and fees</td>
<td>Applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Scale</td>
<td>Large</td>
<td>Smaller (does not necessarily mean small)</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>Result of an optimisation of running time and wholesale energy price. Around 4,000 h full load equivalent.</td>
<td>Equal to the capacity factor of the RES it is connected to.</td>
</tr>
</tbody>
</table>

Source: Hydrogen Europe.

\[1\] Only in case when the electrolyser's power is equal to that of the RES. When the size of an electrolyser is smaller than RES, its capacity factor can be significantly increased.
2.1 GRID CONNECTED ELECTРОLYSIS

2.1.1 COSTS OF PRODUCTION

The hydrogen production costs using grid electricity in the EU (together with Norway and the UK) in 2019 have been estimated in the range of €2.6 – 9.5/kg, with the average for all countries being €4.7/kg and a median of €4.2/kg. By far the highest costs of grid electricity hydrogen production are in Denmark, where the costs are higher by a full €1/kg than the second highest country Cyprus (€8.5/kg) and €2.1/kg higher than third highest, Germany (€7.4/kg). On the other end of the spectrum are the other Scandinavian countries: Sweden (€3.2/kg) and Norway and Finland (€3.4/kg). The country where the costs of producing hydrogen using grid electricity are the lowest is Luxemburg, with costs estimated at only €2.6/kg.

Figure 11 Map of grid connected electrolysis hydrogen production costs in the EU in 2019

Source: Hydrogen Europe.
There are at least two reasons why such large differences between countries exist. The most obvious reason is the difference between wholesale electricity prices, which make the biggest contribution to the final cost of hydrogen in most countries. High wholesale electricity prices explain to a large extent the high hydrogen costs in Cyprus and Malta, where the wholesale electricity prices are among the highest in Europe. Yet two of the three countries with the highest hydrogen costs, i.e. Denmark and Germany, are at the same time, among the countries with the lowest wholesale electricity price Europe. The reason why the hydrogen production costs are so high in these two countries (DK and DE) are high taxes charged on top of the wholesale electricity price. This impact is especially profound in the case of Denmark, where electricity taxes are responsible for 2/3 of total hydrogen production costs, while in Bulgaria, Luxembourg and Malta the contribution of taxes to the final hydrogen production costs is only around 1%.

The following figure show calculated hydrogen generation costs in the EU, based on wholesale electricity prices and network costs and fees for 2019.11

Luxembourg is an interesting case in itself. As the country is participating in a single energy grid with Germany, it enjoys the same low wholesale electricity prices as Germany, thanks to high penetration of cheap renewables, but most of the balancing costs are being borne by the German end-users, with very low taxes and grid fees applied in Luxembourg. As a result it is, by far, the cheapest country to produce hydrogen with grid connected electrolysis in the EU, with total costs more than 2.8 times lower than in Germany, which has the same electricity prices, and 3.5 times lower than in Denmark.

The above calculations were based on the assumption that the electrolyser would run for on average around 4,000 hours per year, in off-peak hours, when the electricity price is the lowest. This is close to optimum for most EU countries. If one would increase the number of operating hours, the impact of CAPEX on final hydrogen production costs would decrease, yet as more and more of the electricity would have to be bought in peak hours, at higher prices, the additional costs of electricity consumption would more than offset any gains resulting from a higher electrolyser capacity factor.

Figure 12

Grid connected electrolysis hydrogen production costs in the EU in 2019 (in € per kg)

Source: Hydrogen Europe.

11 Source: ENTSO-e transparency portal for wholesale electricity prices and EUROSTAT for electricity network costs, fees and taxes for 20,000 – 69,999 MWh energy consumption band.
Inversely, limiting the operational time only to a few hours each day, could drive the average price of electricity down (in the case of Germany, even in to negative territory for around 400 hours per year). In this case however, as lower amounts of hydrogen would be produced, the impact of CAPEX on the final cost would increase – again offsetting any gains from lower electricity prices. This relationship is depicted on the figure below (in the example of Germany).

**Figure 13**
Comparison of hydrogen production costs with grid connected electrolysis in selected EU countries in 2019 (in € per kg)

<table>
<thead>
<tr>
<th>Country</th>
<th>Luxembourg</th>
<th>Germany</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>Electricity</td>
<td>1.55</td>
<td>1.55</td>
<td>1.69</td>
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<td>Grid fees</td>
<td>0.32</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>Taxes</td>
<td>0.03</td>
<td>0.03</td>
<td>0.72</td>
</tr>
<tr>
<td>Other OPEX</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2.6</td>
<td>2.6</td>
<td>9.54</td>
</tr>
</tbody>
</table>

Source: Hydrogen Europe.

**Figure 14**
Comparison of hydrogen production costs with grid connected electrolysis in Germany, depending on number of operating hours. (in € per kg)

<table>
<thead>
<tr>
<th>Hours</th>
<th>1,000 h</th>
<th>4,000 h</th>
<th>8,000 h</th>
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<tbody>
<tr>
<td>CAPEX</td>
<td>2.17</td>
<td>0.54</td>
<td>0.27</td>
</tr>
<tr>
<td>Electricity</td>
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<td>1.55</td>
<td>2.15</td>
</tr>
<tr>
<td>Grid fees</td>
<td>1.23</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Taxes</td>
<td>0.6</td>
<td>0.15</td>
<td>0.07</td>
</tr>
<tr>
<td>Other OPEX</td>
<td>8.45</td>
<td>7.40</td>
<td>7.67</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8.45</td>
<td>7.40</td>
<td>7.67</td>
</tr>
</tbody>
</table>

Source: Hydrogen Europe.
2.1.2 CARBON INTENSITY

As previously mentioned, if a grid connected electrolyser would be dispatched by the TSO/DSO, and would use electricity that would otherwise be curtailed, the carbon intensity of the produced hydrogen would be zero. Another way of ensuring a renewable character for hydrogen produced with grid connected electrolysis would be to use electricity based on a PPA with a renewable energy source together with GOs.

If none of those conditions would be met, the carbon intensity of hydrogen would depend on the carbon intensity of the grid it is connected to. Assuming average grid electricity carbon intensities of European countries, as estimated by the European Environment Agency (EEA) for 2017, the carbon footprint of hydrogen ranges from 0 kgCO₂/kgH₂ in Iceland to 46.1 kgCO₂/kgH₂ in Estonia. Production of hydrogen using the EU-27 average electricity mix would result in emissions of 14.8 kgCO₂/kgH₂.

For Iceland, because the electricity grid is almost 100% decarbonised, hydrogen produced from grid electricity has a carbon footprint that is effectively equal to renewable hydrogen.

In a number of other countries, including Norway, Sweden, Latvia, Lithuania, Luxembourg and France, the carbon intensity of grid electricity is low enough that even without PPA's and Certificates of Origin the produced hydrogen's carbon footprint would be low enough to meet all hydrogen emission benchmarks set at the EU level, including the one set in the RED II for renewable transport fuels of non-biological origin (RFNBO), which is at least 70% GHG savings compared to a fossil fuel benchmark (equivalent to 3.384 kg CO₂ per kg of H₂).

In all those countries, with the addition of Finland, the carbon intensity of hydrogen from grid electricity would be lower than the CERTIFHy threshold for low-carbon hydrogen, set at 36.4 gCO₂/MJ (4.4 kgCO₂ per kg H₂). In other words, the carbon footprint of that hydrogen would be lower than is standard value achievable with exiting SMR installations with CCS retrofit.¹²

In all those countries, with the addition of Austria and Slovakia, the carbon intensity of hydrogen from grid electricity would be lower than the threshold defined in the EU Taxonomy for sustainable finance for manufacturing of taxonomy eligible hydrogen (5.8 kgCO₂/kgH₂, with the average carbon intensity of electricity produced and used for hydrogen manufacturing at or below 100 gCO₂e/kWh¹³).

In all those countries, with the addition of Denmark and Belgium, the carbon intensity of hydrogen from grid electricity would be lower than EU ETS benchmark for hydrogen manufacturing (8.85 kgCO₂ per kgH₂).

In all the remaining countries, production of hydrogen from grid electricity, including also the average EU-27 energy mix, would be more carbon intensive than the EU ETS benchmark for hydrogen production hydrogen. In other words, it would be more carbon intensive than hydrogen from Steam Methane Reforming (SMR) without CCS (commonly referred to as “grey” hydrogen).

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¹² With a retrofit CCS capture rate of around 60%. For more information see https://www.certifhy.eu/.
Figure 15  Carbon intensity of hydrogen produced from grid electricity, compared to selected benchmarks

Source: Hydrogen Europe, based on EEA data.

Note:
EU ETS Benchmark: 8.85 kg CO2 / kg H2 (73.8 gCO2/ MJLHV),
EU Taxonomy threshold for sustainable hydrogen manufacturing: 5.8 kg CO2 / kg H2 (48.3 gCO2/ MJLHV),
CertifHy threshold for low carbon hydrogen: 4.4 kg CO2 / kg H2 (36.4 gCO2/ MJLHV),
RED II threshold for RFNBO: 3.384 kg CO2 / kg H2 (28.2 gCO2/MJLHV).
2.2 DIRECT CONNECTION TO A RENEWABLE ENERGY SOURCE

Production of hydrogen via electrolysis with direct connection to a renewable energy source avoids a number of electricity cost items like network costs and taxes. On the other hand, the electrolyser capacity factor is limited by the capacity factor of the renewable source it is connected to. Especially in the case of solar PV in Central and Northern Europe, this may potentially translate into a very low capacity factor of just around 1,000 full load equivalent hours per year. Yet, even with potentially lower capacity factors, compared to grid powered electrolysis, the ever-decreasing costs of renewable electricity are making it possible to produce renewable hydrogen at prices that are not far from being competitive in most EU countries.\(^\text{14}\)

Taking into account average solar irradiation and average wind conditions in EU Member States, as well as Norway and the UK, estimated renewable hydrogen production costs with direct connection vary from €3.5/kg (from solar PV in Portugal) to €6.5/kg (from onshore wind in Luxemburg). In southern European countries the cheapest pathway to green hydrogen production is solar PV, while for northern European countries in most cases the cheapest option is onshore wind, with the exception of Belgium and Germany, where on average offshore wind is the cheapest option.

Figure 16

Lowest available green hydrogen production costs given average wind and solar conditions in the EU in 2019 (in € per kg)

Source: Hydrogen Europe.

\(^{14}\) For detailed techno-economic assumptions used for production costs estimations see the Methodological Note.
It should be stressed however that the costs have been calculated based on average wind and solar conditions for each country. Especially for large countries like Germany, this can be misleading as there are areas with significantly better than average wind or solar conditions, where production of renewable hydrogen with direct connection to the RES source would also be significantly less expensive than the average. This has been illustrated on the following two graphs, where the lower end of the cost range has been estimated assuming the best irradiation or wind conditions available in a given country.

Based on this analysis it can be noted that renewable hydrogen production costs in the EU can be as low as €2.9/kg (PV in South of Europe) and, in the German example, as low as €3.5/kg.

The estimated levels of renewable hydrogen production costs are in most countries still 2-3 times higher than the current benchmark, set by fossil hydrogen produced via steam reforming without CCS, which, depending on natural gas prices, can be as low as €1.5 – 2.0 EUR/kg.

Figure 17
Levelized costs of green hydrogen production in EU countries in 2019, using solar PV or wind power

Note: the costs range for each technology is defined by the best wind/irradiation conditions (lower end of the cost range) in a given country and the average conditions available in this country (upper end of the range).
Source: Hydrogen Europe.

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15 It also does not include other potentially cheap renewable energy sources like hydro power in Austria, Slovenia or Scandinavia.
16 For solar PV the best available conditions were based on an estimated maximum capacity factor for a NUTS-2 region in a country based on the global tracking with 0.85 performance dataset, while for wind the best available conditions were assumed based on the maximum wind capacity factor available for any NUTS-2 region. Both values were based on the JRC ENSPRESSO database.
Further cost optimisation can be done by combining complementary renewable energy sources like PV and wind, which enables an increased capacity factor for the electrolyser and thus reduces the impact of CAPEX on total levelized cost of hydrogen.

Similar positive effects can be achieved by down-scaling the electrolyser compared to the RES it is connected to. Employing this strategy would require that excess renewable electricity that could not be used for hydrogen production would have to be supplied to the grid (or consumed in another way), but the electrolyser capacity factor could be increased to more than 4,000 h p.a. full load equivalent for solar PV and even more than 8,000 h for onshore wind.

Figure 18 illustrates, using the example of Spain, the relationship between the electrolyser capacity factor and the power of the electrolyser relative to the renewable energy source it is connected to (assuming the electrolyser is prioritised over supplying energy to the grid). As can be seen on the graph when the electrolyser power is equal to RES (ratio of 1) the electrolyser's capacity factor is equal to that of the RES, which in the case of Spain is around 1,500h full load equivalent for solar PV and 2,400h for onshore wind. Reducing the electrolyser power to half of that of the RES (ratio of 0.5), the capacity factor increases to around 2,800h for solar PV and 4,200 for onshore wind. In extreme case, where the electrolyser power would only be 10% of that of the RES (ratio of 0.1), the capacity for the solar PV case would increase to 4,050 hours and almost 8,000 for onshore wind.

Figure 18 Relationship of capacity factor and power of electrolyser relative to RES, example: Spain

Source: Hydrogen Europe based on JRC EMHIRES Database.
Taking advantage of this optimization strategy could drive the costs of green hydrogen low enough for it to be cost-competitive with grey hydrogen. Remaining with the example of Spain, as can be seen on the figure below, with a electrolyser-to-RES power ratio of 0.35 or below for solar PV or 0.2 or below for onshore wind renewable hydrogen production costs would fall below €2.0 EUR/kg – so within a range of being able to compete with hydrogen produced from fossil fuels without CCS/CCU.

This optimisation strategy would also have additional benefits from the point of view of the RES investor, as well as the electricity grid operator. Reducing the amount of energy supplied to the grid decreases the stress on the electricity grid and makes it possible to construct larger RES than the local grid connection capacity would normally allow for. Additionally, being connected to the grid and having an onsite electrolyser would enable the RES operator to provide valuable grid balancing services to the grid operator, in the form of demand side response or uptake of excess renewable electricity from other sources.

Figure 19

Relationship of capacity factor and power of electrolyser relative to RES, example: Spain

Source: Hydrogen Europe.
2.3 SUMMARY

If hydrogen is to realise its potential to be an energy vector in a decarbonised economy it needs to be produced on a mass scale in a sustainable way. But in order for that to happen, clean hydrogen needs to become cost-competitive with conventional fuels.

Today, neither renewable hydrogen nor low-carbon hydrogen, notably fossil-based hydrogen with carbon capture, are cost-competitive against fossil-based hydrogen. Estimated costs today for fossil-based hydrogen are around €1.5/kg for the EU, highly dependent on natural gas prices, disregarding the cost of CO2. Estimated costs today for fossil-based hydrogen with carbon capture and storage are around €2 EUR/kg.17

This means that in order for renewable hydrogen to become the fuel of choice for industry it need to not only be produced but delivered to the end users at a cost of €1.5-2.0/kg. For other applications, like those in the transportation sector, the break-even cost is more favourable, with fuel cell (FC) cars cost parity with diesel projected at commercial FCEV production volumes and at a hydrogen cost of up to €5/kg. Taking into account distribution and refuelling infrastructure costs, this translates into hydrogen production costs of around €3-3.5/kg.

As this report has shown, these price levels are at the limit of what is possible today. There are countries and regions in Europe, where producing renewable hydrogen at the necessary cost level is possible, most notably in southern Europe with cheap solar PV energy or, in the case of countries in northern Europe, with onshore wind in regions with favourable wind conditions. Costs could be brought down further with the use of a combination of wind and solar, or with other optimisation strategies aimed at increasing the electrolyser capacity factor, as described in this chapter.

Yet this is currently possible only in a limited number of locations with the most favourable solar irradiation or wind conditions in Europe. For hydrogen to become a cornerstone of a fossil fuel-free economy, low renewable hydrogen production costs need to be achievable in most EU countries, whereas, as the analysis has shown, those are on average currently between €5-6/kg.

It is very important to add that the calculations presented in this chapter use electricity price data which may, in practice, be unavailable to hydrogen production projects. Most notably, the requirements imposed by the “additionality” principle in the Renewable Energy Directive place significant burdens on the hydrogen producer and increases the electricity price that a hydrogen producer has to pay. This further increases the cost gap and prohibits the building of a business case.

Further cost reductions are clearly needed and can be achieved by a combination of the expected further rapid decrease of renewable energy costs and a set of additional measures, including:

- Increasing R&D efforts for hydrogen technologies, focused on increasing energy efficiency and cost reductions along the whole value chain.
- Scaling up hydrogen production via the EU Clean Hydrogen Alliance, Hydrogen IPCEI and funds like the ETS Innovation Fund.
- Scaling-up of electrolyser and fuel cell equipment manufacturing.
- Building up of hydrogen transportation infrastructure, especially hydrogen pipelines as the cheapest energy transportation mode.
- Eliminating legal barriers (e.g. double taxation, additionality, etc.).

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17 The EU Hydrogen Strategy.
If hydrogen is to realise its potential to be an energy vector in a decarbonised economy it needs to be produced on a mass scale in a sustainable way. But in order for that to happen, clean hydrogen needs to become cost-competitive with conventional fuels.
3

PLANNED HYDROGEN PRODUCTION AND INFRASTRUCTURE

As discussed in the chapter above, electricity-based hydrogen (also known as Power-to-Hydrogen or PtH) has the potential to be generated with very low or zero emissions, depending on the carbon intensity of the electricity used.

If renewable electricity is used or procured, it also gains renewable character (becoming what is known as “green” hydrogen). At the same time, as shown in Chapter 1, electricity-based hydrogen production takes a very small share of overall Hydrogen production at this moment.

As such, as a means of ensuring a sustainable development of the hydrogen sector as an enabler of a low/zero emission energy system, it becomes important to track the development of Power-to-Hydrogen (PtH) projects as well other low-carbon means of production across Europe.

The following chapter presents an aggregation of planned:
- Power-to-Hydrogen (PtH) projects across Europe.
- Low-carbon hydrogen production projects.
- Significant hydrogen transmission projects and initiatives.
- Hydrogen related Important Projects of Common European Interest (IPCEIs).
The data and information in this chapter have been collected by Hydrogen Europe from both public and restricted sources. While the intention is to provide an accurate snapshot of planned developments, it is likely that this overview does not reflect all projects currently planned (e.g., as some may not have been made public at all). As the projects that have been used to generate the overview are still evolving, the numbers presented are subject to change.

For more details on the methodology, please consult the Methodological Annex.
3.1 PLANNED POWER-TO-HYDROGEN PROJECTS

The total planned capacity of PtH projects is 20,011 MW of electrolyser installed power by 2040 (106 projects) with an extra 1,278 MW (45 projects) with an unspecified start date. There are 101 PtH projects with an announced start date, which together amount to 9,101 MW by 2030. In the medium term, there are 79 planned projects amounting to 2,131 MW by 2024.

The average tracked capacity growth rate is **63% annually for the period 2020 – 2030**. This is an impressive annual increase, but it is still insufficient to reach the goals that European Commission set out in its European Hydrogen Strategy of 6 GW of renewable hydrogen electrolysers by 2024 and 40 GW by 2030.

The currently known list of PtH projects would reach only 36% of the 2024 objective and only 23% of the 2030 objective.

Yet, this gap should not be perceived as evidence of EU Hydrogen Strategy targets being unrealistic. Most of the tracked projects have been developed despite persisting regulatory gaps and unfavourable economic conditions. The implementation of the EU Hydrogen Strategy, the introduction of new policies, in combination with initiatives like the European Clean Hydrogen Alliance, as well as the emergence of new funding instruments like the ETS Innovation Fund and the Next Generation EU.
programme, have the potential to facilitate deployment of the projects necessary to reach the 6 GW and 40 GW targets by 2024 and 2030 respectively.

The average annual addition between 2020 and 2030 is 827 MW. As 2030 is considered as an aspirational target and an important milestone, multiple large-scale projects have expressed their intention to be operating by the end of 2030 contributing an additional 3,940 MW of electrolysers in that year.

The 20,011 MW with announced dates between 2020 and 2040 are split between 106 projects, with an average project size of 189 MW. In addition, there are a further 45 projects with a total capacity of 1,278 MW (28 MW per project on average) and an unknown launch date.

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18 2031+ projects include a very large electrolysis installation that will likely be implemented in phases, but its only current estimate is being operational by 2040.
The country with the highest number of announced electrolyser capacity is the Netherlands with 12,909 MW, followed by Spain with 2,252 MW, Germany with 1,548 MW, Denmark with 1,454 MW, France with 1,172 MW, and Portugal with 1,001 MW. These six countries together represent 96% of planned PtH capacity and 66% of planned projects. Other notable countries include the United Kingdom with 229 MW and Bulgaria with 218 MW.

As previously mentioned, the Netherlands has ambitious plans for developing 12,909 MW of electrolysis by 2040 and 2,596 MW by 2030. This is due to several 100+ MW projects up to 2030 as well as a multi-GW project planned for 2040. The Dutch 2030 objective is 3-4 GW. The currently announced projects already comprise 87% of 3 GW and 65% of its 4 GW 2030 target. Spain’s currently announced projects amount to 1,352 MW by 2030 comprising 34% of Spain’s draft 4 GW 2030 objective, backed by an intention to mobilise 9 billion EUR worth of investments.
Germany’s current project pipeline of 1,405 MW by 2030 sets Germany at 28% of its 5 GW 2030 target. Given the activity of the German hydrogen market with 24 planned projects by 2030 and sizeable committed funding of 9 billion EUR, it is likely that project announcements will continue.

Portugal’s strategy outlines 2-2.5 GW by 2030 while its currently planned projects amount to 991 MW by 2030 with additional 10 MW without an announced start date. This positions Portugal at 40% to 50% of its target but backed by plans to spend 7 – 9 billion EUR on hydrogen activities, 85% of which will be coming from the private sector.

France’s currently announced projects amount to 839 MW by 2030, with an additional 333 MW having an unknown start date. These comprise 13% of the country’s 6.5 GW 2030 target. Given its recent international hydrogen activity and having committed €7 billion between 2020 – 2030, France still has potential to reach its target.

Planned PtH capacity and the number of projects for the 10 most active PtH markets can be observed below in Figure 23. The number and size of projects differ significantly across countries, with Germany’s 1,548 MW composed of 34 projects reaching 46 MW average project capacity, while Denmark’s 1,454 MW is spread across eight projects with an average project size of 182 MW.

Figure 23
PtH projects in 10 countries 2020 - 2040 in MW and # of projects

Source: Hydrogen Europe.
45 out of the 151 projects included in the analysis have already announced their electrolyser technology. More than two thirds of those projects plan to use the proton exchange membrane (PEM) technology, with 27.1% choosing alkaline electrolysis. The remaining 4.4% will involve solid oxide electrolysis (SO). However, as PEM is often chosen for relatively small projects, its share in total capacity is only 21.4%, while 76.0% of the capacity will be provided by alkaline and 2.5% by SO.19

The electricity source for new PtH capacity has been announced for 82 of the 151 projects with 17,616 MW of electrolysis. Within this sample, 77% of announced PtH capacity and 39% of projects with disclosed electricity source will be provided by wind power. Solar generation constitutes 14% of the announced capacity and 18% of the number of projects. A combination of solar and wind is considered in 22% of projects.

Figure 24, 25

Electricity source of known projects in MW and # of projects

Source: Hydrogen Europe.

19 Figures may not round up to 100% due to automatic rounding
20 Figures may not round up to 100% due to automatic rounding
21 Figures may not round up to 100% due to automatic rounding
3.2 LOW-CARBON HYDROGEN PROJECT OVERVIEW

The EU’s definition of “low-carbon hydrogen” includes both electricity-based hydrogen (PtH) with a GHG emission factor below a certain threshold (yet to be determined) and fossil-based hydrogen with carbon capture. As all PtH projects (most of which will use renewable electricity) have already been presented above, this section of the report presents the projects planned to produce low-carbon hydrogen from fossil natural gas combined with CCS / CCU.

There are multiple low-carbon hydrogen projects under development across Europe. Figure 27 provides an overview of 12 of those low-carbon hydrogen production projects. Five are located in the UK, three in the Netherlands, and one each in Germany, Sweden, Norway, and Italy.

Figure 26
Selection of announced low-carbon hydrogen production projects

1. Acorn CCS / H2
2. Aramis (Blue H2 Den Helder)
3. H21 North of England
4. H2morrow
5. H-Vision
6. HyDemo
7. H2H Saltend
8. HyNet
9. Porthos
10. Preem CCS
11. CCS Ravenna Hub
12. Humber Zero

Source: Hydrogen Europe
The above-mentioned projects vary in terms of both hydrogen production technology and carbon capture solutions. Some projects, such as H21 North of England includes construction of a new 12.15 GW auto-thermal reforming hydrogen generation based on natural gas coupled with CCS. In other projects, such as the Porthos project in the Netherlands, the involved project partners are going to retrofit an already existing hydrogen production plant and industrial processes with CCUS. In the HyDemo project in Norway, new production of liquified hydrogen for maritime applications will be coupled with CO2 storage that is being developed off the coast of Norway, as part of another project called Northern Lights.

Some industrial areas, such as the Humber region, include multiple low-carbon hydrogen production projects. Humber is one of the most carbon-intensive industrial clusters in England, with emissions of around 14 million tonnes of CO2 per year. The two active low-carbon hydrogen production projects include H2H Saltend and Humber Zero. Projects partners in the H2H Saltend, in the Hull area, plan to launch the decarbonisation of the entire region by building their own CCS solution at the Saltend Chemicals park, with the CO2 preliminarily destined to be stored at the “Endurance” aquifer on the UK continental shelf, saving 0.9 million tonnes of CO2 per year in the first phase of the project. The Humber Zero project is located just south of H2H Saltend. Project partners plan to reduce their GHG emissions by decarbonizing a refinery and the power plant it supplies. The project is going to include the development of a regional hydrogen hub with local production of both green and low-carbon hydrogen to be used by the power plant and local industry. The first phase of hydrogen production is planned to be operational by 2025 and the project participants plan to abate up to 8 million tonnes of CO2 per year.

In Germany, the companies involved in the H2morrow project will produce low-carbon hydrogen from Norwegian natural gas delivered through the gas grid. The goal of the project is to provide 8.6 TWh of hydrogen per year by 2030, potentially abating up to 1.9 million tonnes of CO2 per year.

In the Netherlands, the H-Vision project aims to produce low-carbon hydrogen in Rotterdam by the mid-2020s with further scale-up by 2030. The objective is to develop low-carbon hydrogen production capacity of 3,200 MW (around 20% of the energy demand of the industry in the port area), abating around 2.2 million tonnes of CO2 by 2026 and 4.3 million tonnes by 2031. The CO2 capture potential in the different case scenarios amount to between 2-10 MTPA and is dependent on the Porthos project mentioned earlier.

In the Ravenna CCS project in Italy, depleted offshore gas reservoirs in Northern Italy are being considered for storing CO2, allowing low-carbon hydrogen production in the Ravenna industrial complex. As a first large low-carbon hydrogen production project in Southern Europe, it could provide low-carbon hydrogen supply needed to decarbonise various local industrial sites by the late 2020s.
3.3 HYDROGEN TRANSMISSION AND DISTRIBUTION INFRASTRUCTURE

For hydrogen to access the various end-uses across Europe, a basic infrastructure will have to be developed between production and consumption points. While there are already thousands of tonnes of hydrogen traded and distributed around Europe today via local dedicated hydrogen pipelines or trucks (see Chapter 1), the development of an EU-wide hydrogen pipeline network is required to further jumpstart the hydrogen economy, as this is by far the cheapest mode of transport for large quantities of gas. The hydrogen economy will require similar transmission and distribution ecosystem to the current natural gas infrastructure, complemented by trucks and ships. While blending hydrogen gas into the existing natural gas pipelines will be important in the early 2020s, retrofitting existing gas infrastructure to carry pure hydrogen will be necessary. That infrastructure does not currently exist beside dedicated pipelines in a limited number of industrial areas.31 This chapter provides an overview of the plans to develop dedicated (pure) hydrogen transmission and distribution networks.

There have been several infrastructure initiatives including the European Hydrogen Backbone by a group of EU Gas TSOs and two national initiatives by Germany and the Netherlands. All these initiatives include both retrofitting existing natural gas pipelines and partially building an entirely new hydrogen infrastructure to accommodate growing hydrogen demand.

European Hydrogen Backbone32

As the most comprehensive current hydrogen infrastructure initiative, 11 European gas infrastructure TSOs33 developed an in-depth analysis that evaluated the cost-effectiveness and proposed the development of a pan-European hydrogen infrastructure, the European Hydrogen Backbone. The analysis covers 10 EU countries and assumes utilization of both low-carbon hydrogen by mid-2020s and green hydrogen by late-2020s. The European Hydrogen Backbone Initiative envisages a 6,800 km hydrogen network by 2030 and a 22,900 km network by 2040, 75% of which would consist of retrofitted natural gas infrastructure. (Figure 27)

According to the European Hydrogen Backbone initiative, most hydrogen infrastructure projects will first develop in industrial clusters, ports, and cities in the north of the continent (Belgium, Netherlands, North-West Germany) by 2030. Other considered network additions or retrofits include France and Spain (Lacq, Marseille, Fos, Lyon, The Basque Country, Castile and Léon, Aragon, Asturias) or Denmark and Sweden (Jutland and Göteborg respectively). By 2035, the hydrogen network will grow from regional networks to a (trans)national scale with the addition of an interconnection between Denmark and Germany and extending the north-south corridor in France to Marseille. By 2040, the network will become pan-European and

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33 Enagás, Energinet, Fluxys Belgium, Gazunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga
eventually incorporate green hydrogen imports from North Africa, the North Sea, and possibly Ukraine. An example of this progression could be hydrogen valleys around Valencia, Barcelona, and other Spanish industrial clusters. These would be subsequently integrated with the rest of Spain through both retrofits and newly constructed H2 pipelines before connecting the Spanish network internationally, for example to Marseille, France.

The group of TSOs estimate CAPEX for this expansion to be between €27-62bn by 2040 with 60% of total investment dedicated to pipelines and 40% to compression equipment. The estimated levelized cost of transporting hydrogen is €0.09-0.17/kg of hydrogen per 1000km². The study concludes that retrofitting existing natural gas pipelines to transport hydrogen is the most cost-effective solution for building up an EU-wide pipeline network. It estimates that the construction of a hydrogen pipeline would be 10-50% more expensive than constructing a new natural gas pipeline while retrofitting a natural gas pipeline would only require 10-25% of the CAPEX required for new hydrogen pipeline. If built as planned, the European Hydrogen Backbone would be capable of transporting 1,130 TWh (28.7 million tonnes) of hydrogen per year by 2040 and enable imports of hydrogen from outside the EU. For comparison, the EU Hydrogen Strategy aims for 394 TWh (10 million tonnes) of renewable hydrogen by 2030.
Dutch hydrogen backbone

The Netherlands is one of the most ambitious countries regarding the development of a hydrogen economy. Gasunie, a Dutch natural gas TSO, is planning a hydrogen network to connect demand and supply in the country, starting with five regional industrial clusters, which will then be integrated into a national hydrogen backbone infrastructure by around 2025. According to the plans, the Dutch national infrastructure is to be integrated into the European hydrogen infrastructure by the late 2020s. Foreign imports of hydrogen and storage facilities are also envisaged in the plan. The pipeline infrastructure will have a capacity to transport between 55-120 TWh of hydrogen per year by 2030. This will require the creation of around a 1,100 km hydrogen network, of which up to 90% will be retrofitted existing natural gas pipelines.

The demand for hydrogen in the Netherlands is mainly driven by regional industrial clusters, which account for around 15 TWh of hydrogen demand per year and are located around the entire country (Zeeland, IJmond, Rijnmond, Limburg, Eemshaven). Additionally, the IJmond and Rijnmond regions are collaborating with regional industrial companies to develop local hydrogen backbones. Future steps include connecting the hydrogen pipeline network with Belgium (Rotterdam – Antwerp) and Germany (to Northern Germany and the Ruhr area), connecting it to the future European hydrogen infrastructure.

Further information will be presented in late 2020 in the HyWay 27 study, which is co-authored by Gasunie, Tennet, and the Dutch Ministry of Economic Affairs and Climate. It will outline the conditions under which the existing gas network can be retrofitted in time for investment decisions to be taken by the Rotterdam and Northern Dutch regions in 2021.
German visionary hydrogen network map (2020-2030)  

The major German gas transmission system operators, through consultations with market partners, developed a “visionary hydrogen system scenario” that could be developed mostly through natural gas pipeline retrofits. This envisaged hydrogen network would have a total length of around 5,900 km and would connect current and expected hydrogen production and consumption points in the country, including cavern storage facilities, industrial clusters, and regions with green hydrogen production potential. Given that most green hydrogen production potential and storage capacity is in the north, the TSOs foresee a gradual development of the network from and north towards major industrial centres in the south.

Figure 29

Disclaimer: The map serves as a graphic representation, which does not claim to be complete regarding the depicted storage capacities or end-users
Translated from German

Source: Netzentwicklungsplan Gas 2020-2030, FNB Gas

42 Idem (p.180)
Other planned transmission and distribution projects

In addition to the initiatives, reports, and studies discussed above, several hydrogen infrastructure projects have been announced. These include the MosaHYc (Mosel Saar HYdrogen Conversion) project, which is a cooperation between a French TSO and a German DSO operating in the region, which aims to convert existing natural gas pipelines into a 70 km hydrogen infrastructure between Saarland, Grand Est, and Luxembourg. The completion of this project would connect Völklingen (Germany), Carling (France), Bouzonville (France), and Perl (Germany). Project partners plan to transport up to 20,000 m³/h (60 MWLHV) of pure hydrogen and hope that this project will become the cornerstone of a future hydrogen valley between the three countries.

Another announced infrastructure project is the German Get H2 Nukleus project, which is the first step on a wider nationwide H2 infrastructure development plan. The project is located around Lingen and aims to establish a regional hydrogen infrastructure that would distribute renewable hydrogen to the industrial end-user, including two refineries. One of the key features of the project is that the developed H2 infrastructure will be public and will allow for future connection of new H2 producers and end-users.

Source: Open Grid Europe

3.4 IMPORTANT PROJECTS OF COMMON EUROPEAN INTEREST (IPCEI) ON HYDROGEN

In addition to the projects and plans presented above, several large-scale initiatives that cover the entire hydrogen value chain, from production, through transport, to consumption, have been announced. The projects are being developed as part of the preparatory process of the hydrogen-dedicated Important Project of Common European Interest (IPCEI) and were presented at the Hydrogen 4 Climate Action Conference on 9th of October 2019 in Brussels.

The 2014 Communication from the Commission on the Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest created the opportunity to prepare an IPCEI dedicated to the hydrogen sector. The case for it was further strengthened in 2019 by the inclusion of hydrogen technologies and systems as one of the key Strategic Value Chains for a future-ready EU Industry.

IPCEIs are about disruptive and ambitious research and innovation, beyond the state of the art in the sector, followed by first industrial deployment. There are multiple projects that are being developed with the IPCEI framework in mind. 8 of those projects are highlighted in the map below.

Source: Hydrogen Europe based on https://www.hydrogen4climateaction.eu/
projects below cover 17 EU Member states and include 43 GW of renewable energy deployment for green hydrogen production that would enable CO2 savings of 37 Mt per year.

The “Green Flamingo’s” 15 project partners from Portugal, Netherlands, Germany, and Denmark aim to develop an Iberian green hydrogen export hub connected to the Port of Rotterdam via a maritime route. They intend to leverage existing infrastructure, local solar resources, and local hydrogen demand in the Port of Sines to jumpstart Portuguese hydrogen economy by developing 5 GW of electrolyzers powered by solar and wind, building a refuelling station network, and providing hydrogen as a fuel for ships.\(^{46,47}\)

The “Green Octopus” project connecting with Green Flamingo spans France, Belgium, the Netherlands, Germany, and Denmark. Its 20 project partners plan to produce several GWs of green hydrogen, build twenty hydrogen refuelling stations, construct and serve 25 hydrogen ships, as well as contribute to decarbonisation of the various industry clusters including steel, refining, and chemicals.\(^{48}\)

The “Green Spider” connects Spain, France, and Germany and it intends to generate renewable hydrogen in Spain and transport this to industrial and consumption centres further north. If implemented as planned, it will provide an additional 1 GW of electrolyser capacity, hydrogen storage, 20 hydrogen refuelling stations, and 800 km of additional hydrogen transportation infrastructure, and also deploy FC vehicles.\(^{49}\)

The “Blue Danube” project in Central and Southern Europe consists of planned operations of 12 companies in nine countries. It hopes to produce renewable hydrogen using 2 GW of electrolyser capacity and transport this to countries along the Danube, developing key hydrogen infrastructure in the region.\(^{50}\)

The “Silver Frog” project consists of six companies from Belgium, Germany, Italy, Hungary, and Denmark, who aim to produce large quantities of renewable hydrogen from renewable energy via an additional 10 GW of electrolysis capacity, and transport it to steel, refining, and chemical industries via existing gas infrastructure.\(^{51}\)

“Blue Dolphin” is a maritime focused project covering seven companies from Italy, Spain, the Netherlands, Belgium, and Germany, that aim to adapt four ports and two shipyards to hydrogen use in maritime. They expect to develop an additional 0.6 GW of electrolyser capacity as well as six tankers, 10 passenger ships, and 30 barges.\(^{52}\)

The “Black Horse” project focuses on zero emission mobility and includes 20 companies from the four Visegrad countries of Slovakia, Czechia, Poland, and Hungary. The project partners aim to make hydrogen trucks commercially viable for transportation companies and in the process develop up to 16.5 GW of additional electrolyser capacity, build 270 hydrogen refuelling stations, and enable 10,000 heavy duty vehicles on European roads by replacing diesel vehicles with FCEVs.\(^{53}\)

Eight companies that are a part of the “White Dragon” project aim to replace the current use of lignite in Greece with extensive solar installations and 1.5 GW of solar oxide fuel cells, producing hydrogen, power, and heat. They aim to feed heat into the existing district heating systems and transport excess hydrogen through existing international natural gas infrastructure.

More information about these and other projects can be found at: https://www.hydrogen4climateaction.eu/
EU POLICIES, LEGISLATION, AND INCENTIVES

Clean Energy Package implementation, the European Green Deal, the new Multiannual Financial Framework (MFF) and a one-of-a-kind Recovery Plan... The European energy landscape has gone through many changes lately.

New policies and initiatives deeply affect the energy sector, and hydrogen is no exception. On the contrary, the carbon-free energy carrier has increasingly been the focus of policymakers over the recent period, not least under the EU’s Recovery Plan and the Commission’s hydrogen strategy. These efforts aim to build on the institution’s ambition to make hydrogen a cost-effective decarbonisation solution, complementing electrification, and an enabler of EU energy and climate targets for 2030 and 2050.

Let us first dig into the latest main policy developments that shaped the hydrogen industry, before offering a prospective near future for hydrogen in the European policy environment.
New policies and initiatives deeply affect the energy sector, and hydrogen is not spared. On the contrary, the carbon-free energy carrier has increasingly been under the focus of policymakers in the recent period.
4.1 THE EU’S CONTEMPORARY ENERGY POLICY FRAMEWORK

The purpose of this first section is to outline and synthesise the main EU-level political and legislative milestones of the past few years, from those merely announced to those that have entered into force, which shape the EU’s energy and climate political landscape and the regulatory framework affecting the hydrogen sector. The focus in this report will be on the main policy developments between December 2018 and Summer 2020.

Figure 32 EU policy timeline on past developments

The basis of the EU’s contemporary energy policy framework (June 2019 and anterior)

Clean Energy Package Adoption (2019)
Governance Regulation (EU) 2018/1999
EU Green Deal – Commission’s Communication
EU’s Recovery Plan – Council’s agreement
EU’s Recovery Plan – (updated MFF and Next Generation EU) – Commission’s proposal
European Climate Law – Commission’s proposal
Just Transition Fund – Commission’s proposal
New Industrial Strategy for Europe – Commission’s Communication
EU’s Hydrogen Strategy and European Clean Hydrogen Alliance – Commission’s Communication
EU’s Energy System Integration Strategy – Commission’s Communication
2030 Target Plan – Commission’s Impact Assessment

The European Green Deal and follow-up actions

from the EU Green Deal Communication in December 2019 until the Commission’s 2030 target impact assessment in September 2020
The Clean Energy Package includes a number of major legal texts, such as the Renewable Energy Directive (Recast) and the Governance Regulation, that fundamentally shape today’s European energy system and greatly influence the hydrogen sector.

4.1.1. LAYING DOWN THE BASIS: ENERGY UNION, CLEAN ENERGY PACKAGE, AND THE EU ETS

The ‘Energy Union’, since 2015, is the strategy that models the EU’s contemporary energy policy and regulatory framework. It is organised around five essential pillars: energy security, the internal energy market, energy efficiency, decarbonisation, and research & innovation.

In June 2019, the final elements of the Clean Energy for All Europeans Package (or ‘Clean Energy Package’) were adopted. This set of legislation aims to implement the goals of the Energy Union strategy, facilitate the transition away from fossil fuels towards cleaner energy, and deliver on the EU’s Paris Agreement commitments for reducing greenhouse gas emissions.

The Regulation on the Governance of the Energy Union and Climate Action (EU) 2018/1999 (or Governance Regulation) outlines the framework for the EU’s energy policy. It sets an EU trajectory to reach Energy Union objectives, and flanks Member States’ national efforts, notably via their respective integrated National Energy and Climate Plans (NECPs). The latest versions of final NECPs, based on earlier recommendations from the European Commission, were released this summer by Member States. They address the various Energy Union dimensions and objectives and the different energy consuming sectors. These documents, where hydrogen technologies are quasi-systematically considered, will steer national policy for the period 2021-2030 in order to reach EU’s 2030 energy and climate targets (cf. Chapter 5 for information on NECPs).
Under the European Green Deal, the Governance Regulation will be amended, and its climate ambitions will be reinforced, through the European Climate Law. This sets higher greenhouse gas reduction targets for 2030 and climate neutrality by 2050 (cf. the next subsection 4.1.2). Hydrogen's potential as a decarbonisation solution of the energy system could thereby be reinforced.

· The revised **Renewable Energy Directive** (2018/2001/EU), also known as RED II, lays out a legislative framework for the development of renewable energy sources, from their generation and distribution to their end-uses. Its current version sets a 32% target of renewable energy sources in the EU’s gross final consumption by 2030 and, thereby, aims to boost renewables production and consumption. Importantly, it also sets an indicative target for increasing renewable content in the heating and cooling sector by an annual 1.2% / year as well as a renewable fuel obligation (14%) on fuel suppliers in the transport sector. Since the share of renewables in the energy mix is expected to significantly increase over the years to 2030 and beyond, hydrogen could act as a catalyst to integrate higher shares of additional (variable) renewable energy sources and thereby represent a notable business opportunity. The renewable energy target could indeed support the ramping up of hydrogen technologies, since those enable higher renewable integration into the power grid by acting as a Power-to-X and energy storage solution, as well as a higher share of renewable gases in the gas grid and the heating and cooling sector, and higher integration of renewable energy in the transport sector (through the use of renewable hydrogen as a fuel, as an ingredient for e-fuels, and as an intermediary product for the production of conventional fuels).


The **EU Emission Trading System** (ETS) is another key energy policy instrument meant to help the EU reach its decarbonisation target (i.e. 40% of greenhouse gas emission reduction overall by 2030, with a potential upward revision to 55%, as proposed by the EU Commission on 16 September 2020). Flanked by Directive 2003/87/EC, the EU ETS predates the Clean Energy Package and is fully independent from the 2019 legislation. However, this ‘cap and trade’ instrument complements the legislative framework defined in the Clean Energy Package. The ETS consists of a closed, regulated market where a determined number of ‘emission allowances’ (or quotas) are traded. This number is reduced regularly, with the aim of raising the allowance price by means of market forces (here, a negative supply shock). The system covers around 11,000 installations from power production to energy-intensive industrial plants, such as steel and chemical manufacturing. The ETS entered into force in 2005 and covers some of the aviation sector since 2012 (intra-EU flights only). The system was revised and enhanced in 2015 and 2018 with a Market Stability Reserve that aims to avoid an allowance surplus on the market. Although partly credited for the decline of coal power generation in the EU, carbon prices under the ETS have been too low to trigger, on their own, significant technological changes towards zero emission solutions in the sectors under its scope.

Overall, the ETS covers about 45% of the EU's...
greenhouse gas emissions, while the reduction efforts of the other share of EU greenhouse gas emissions are defined under the ‘Effort Sharing’ Regulation (EU) 2018/842. Under the previous 2030 reduction target for greenhouse gas emission of 40%, the objective was to reduce emissions under the ETS by 43% and under the Effort Sharing Regulation by 30%, both compared to 2005 levels. The different sectors in this Effort Sharing basket of emissions are regulated by Member States but there are a number of EU regulations facilitating the reduction (e.g. the CO2 emission performance standards for passenger cars and vans, the CO2 emission performance standards for new heavy-duty vehicles and upcoming legislative initiatives for maritime and aviation).55

The ETS concerns many ‘hydrogen-relevant’ sectors, from SMR hydrogen production plants to steelmaking, chemicals, aviation and (potentially) the maritime sector. In spite of its great potential to directly influence the carbon price and foster the emergence of clean technologies such as renewable and low-carbon hydrogen, low allowance price levels have so far kept the scheme from providing enough incentives for a ‘clean switch’ in those ‘hydrogen-relevant’ sectors. Yet, plans under the European Green Deal to reform the ETS by integrating more sectors and ensuring a more constant drop for allocated allowances, to effectively steer prices upwards on the carbon market, may offer some opportunities for hydrogen, if the CO2 price is high enough. Not only could this help clean hydrogen to reach cost-competitiveness with fossil fuel-based hydrogen and competing technologies, it could also foster the use of clean hydrogen in a more diverse range of sectors (cf. section 4.2). In addition to the market effects described above, the revenues from the ETS allowance auctioning system will offer financing opportunities via two distinct funds:

- The Innovation Fund (IF): worth an estimated €10 billion up to 2030 (depending on CO2 price), the IF will fund (inter alia), notably via grants for different pillars: 1) innovative low-carbon technologies and processes in energy intensive industries (e.g. renewable and low-carbon hydrogen in refineries, steel, cement, and other energy intensive industries, where hydrogen is used, 2) the construction and operation of carbon capture and storage (CCS) and utilisation (CCU), 3) energy storage, and 4) innovative renewable energy generation. The first call for proposals for large-scale projects is open until 29 October 202056. All pillars of the Innovation Fund aim to support technologies where hydrogen has significant potential for development and where the introduction of clean hydrogen can lead to significant GHG Reduction.

- The Modernisation Fund, which funds projects in several areas: 1) the generation and use of energy from renewable sources, 2) energy efficiency, 3) energy storage, 4) the modernisation of energy networks, including district heating, pipelines and grids, and 5) a just transition in carbon-dependent regions (redeployment, re-skilling and upskilling of workers, education, job-seeking initiatives and start-ups) in the ten lowest-income EU countries (Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia). Hydrogen is one of the eligible technologies, in particular under the first and third pillars.

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Indeed, 93% of the EU population sees climate change as a serious problem. This helps to explain the shift from the Energy Union mantra to a more intense focus on climate challenges in energy politics. The European Green Deal is the first of the European Commission’s twin priorities, namely the green and digital transitions. It aims to introduce a political and legislative framework to reach climate-neutrality by 2050 and provides the strategy and means to achieve this objective. Economic areas and aims addressed are far-reaching, from a ‘clean and circular economy in the industry’ to ‘a fair, healthy and environmentally friendly food system’ as indicated in the figure below.

Figure 34: The European Green Deal and follow-up actions

The European Green Deal and follow-up actions

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Amongst many initiatives incorporated in the European Green Deal, the following plans are expected to affect the hydrogen industry most.

1. The **European Climate Law** embodies a plan to enshrine in law the 2050 target for carbon neutrality in the EU, and to increase the greenhouse gas reduction target from 40% to 50-55% by 2030 compared with 1990 levels. The European Parliament Committee on Environment, Public Health and Food Safety voted in September 2020 for an even more ambitious upgrade: this requires a 60% greenhouse gas reduction by 2030 and an intermediary target for 2040. Based on an impact assessment released the same month, President von der Leyen declared during her 2020 State of Union on 16 September that the Commission would go forward with a 55% reduction target for 2030, with a view to formally adopting this objective by the end of the year. To enshrine the renewed ambitions, the first European Climate Law proposal was published in March 2020 by the European Commission, following the EU Green Deal announcement in December 2019. This will update the framework for EU-level climate action by amending the Clean Energy Package’s Governance Regulation. The reach of this legislation will be broad and substantial. A legislative revision process, which will aim to align current legislations with the updated ambition, is already ongoing. The legal texts that will be affected by these revisions – The Renewable Energy Directive (RED II) and the Energy Efficiency Directive are two examples – cover a series of sectors presenting business opportunities for hydrogen, from an increased use of renewable fuels in transport to incentives for stationary hydrogen fuel cell systems. The revisions, expected by June 2021, will therefore necessarily impact the hydrogen industry globally, and could boost the scaling up of renewable hydrogen further in a wide range of applications. The legislative proposal for a European Climate Law was

![Figure 35 European Green Deal vision](source: European Commission, COM(2019) 640 final, 2019)
submitted to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions for further consideration under the ordinary legislative procedure.

- Under the Green Deal, the Commission wants industrial policy to deliver for the development and integration of low-carbon solutions: through policies and financial instruments at EU and national level, as well as via the private sector. A new **EU Industrial Strategy**\(^58\), also published in March 2020, shows the path forward with a clear focus on EU sovereignty protection, the development of key strategic value chains, and the achievement of the EU’s climate targets. The development of European value chains of clean technologies like hydrogen will be further supported. Chief measures on the agenda include the revision of State aid rules by 2021 in a number of priority areas, not least energy and environment as well as Important Projects of Common European Interest (IPCEI). The Strategy also foresees (for the first time) the creation of a European Clean Hydrogen Alliance.\(^59\)

- **The Energy System Integration Strategy**\(^60\) is a milestone amongst all EU Green Deal Strategies. Published in July 2020, it aims to pave the way towards a European, integrated, and decarbonised energy system. It plans to enable the achievement of the Green Deal targets, not least carbon neutrality by 2050, and encompasses the objectives of the Energy Union. To reach these targets, the Strategy articulates an action plan based on six pillars, which notably include the promotion of ‘renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sectors,’ with detailed measures. Among other solutions, it highlights hydrogen as a way to decarbonise sectors where electrification is hardest (especially heavy-duty vehicles, aviation, maritime transport, and energy-intensive industries). It also points to hydrogen’s potential ‘nodal role’ in an ‘integrated energy system,’ which would enable seasonal energy storage and the transformation and use of local renewable energy production for a series of end-uses. Overall, the Strategy rests on three overarching principles: 1) circularity and energy efficiency; 2) electrification of end-use sectors; and 3) the complementary use of renewable and low-carbon fuels (where hydrogen is widely promoted). Concretely, the Strategy plans for the coherent revision of both TEN-E and TEN-T, the review of Ten-year Network (electricity and gas grid) Development plans (TYNDP), and a series of hydrogen-specific measures detailed in a complementary Hydrogen Strategy.

- Jointly with its Energy System Integration Strategy, the European Commission published a dedicated **Hydrogen Strategy**, laying out a vision vis-à-vis hydrogen and its role as an energy carrier in a European integrated energy system. This details a 3-phase roadmap for hydrogen development with clear milestones: 6 GW of renewable hydrogen electrolysers and 1 Mt of production by 2024 and 40 GW of renewable hydrogen electrolysers and 10 Mt of production by 2030 in the EU with an additional 40 GW of electrolysers installed outside Europe. As of 2030, hydrogen technologies are expected to reach maturity, to be deployed at large scale, to play an increasingly important role in Europe’s energy system (i.e. hydrogen could account for up to more than 23% in the 2050 energy mix). Main policy measures that will be tackled under the EU’s Hydrogen Strategy include: (i) the determination of a terminology of hydrogen types and a reference to European-wide criteria for renewable and low-carbon hydrogen certification, (ii) the introduction of minimum shares or quotas of renewable hydrogen in specific end-uses, (iii) the development of a pilot scheme –

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\(^59\) More details on the European Clean Hydrogen Alliance are provided further below in the paragraph on the EU’s Hydrogen Strategy.

preferably at EU level – for a Carbon Contracts for Difference (CCfD) programme, and (iv) the inclusion of hydrogen in energy infrastructure policies and legislations, such as within TYNDP planning and TEN-E, TEN-T and AFID revisions. The strategy will be supported by the European Clean Hydrogen Alliance (ECH2A), formally kicked-off at the same time as the publication of the EU Communication. ECH2A aims to link the private sector with public institutions and other relevant stakeholders, to enable and prioritise investments in line with the Strategy. This broad coordination forum will help large investment projects, including Important Projects of Common European Interest (IPCEI) reach maturity in a coordinated manner, in line with EU strategies.

The European Green Deal Call bolsters research and innovation projects in relation to Green Deal objectives. It takes place under the current EU research and innovation programme – Horizon 2020 – and additional research and innovation initiatives will be funded under the next programme – Horizon Europe. It will support “pilot applications, demonstration projects and innovative products, innovation for better governance of the green and digital transition, and social and value chain innovation.” This is structured in 10 call areas. The second area has a special focus on hydrogen: it will provide support for the development and demonstration of a 100 MW electrolyser. On top of that, other call areas are of particular relevance for hydrogen technologies, whether it be with the decarbonisation of the industry (call area 3), the improvement of buildings’ energy efficiency (call area 4), or the greening of ports and airports (call area 5). The Call was formally launched on 17 September 2020 via a press release. It will be open for submissions until 26 January 2021 via the European Commission’s funding and tenders portal[^63], with selected projects expected to start in autumn 2021.

Foreseen by the Green Deal as an instrument to support Member States (in particular those which are most dependent on fossil fuels) in their energy transition towards climate neutrality, the **Just Transition Fund (JTF)** has been significantly enhanced by the EU’s Recovery Plan. As a result, we tackle the JTF in the next section.

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[^63]: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/programmes/h2020
4.1.3 THE EU RECOVERY PLAN

The current seven-year EU budget or Multiannual Financial Framework (MFF) comes to an end in 2020. Negotiations on the next budget design for the period 2021-2027 were shaken by the COVID-19 crisis. As a reaction, the European Commission proposed an updated MFF topped up by an EU Recovery Plan, dubbed Next Generation EU (NGEU), to relaunch the economy. The European Council reached a compromise on the matter in July 2020.

As co-legislators, the Council of the EU and the European Parliament must now seal a final agreement. Allocations shall be used to support the green and digital transitions. With a total approximating €1.800 billion (European Council compromise), both the MFF and NGEU will impact the hydrogen industry by providing extra funding means under existing legislation or legislative proposals.

(e.g. InvestEU and the Just Transition Mechanism), which will be amended, and by creating new support instruments (e.g. the Recovery and Resilience Facility). The MFF and the NGEU are interlinked, i.e. they support and complement each other’s programmes. The NGEU is structured around three pillars (‘Supporting Member States’ recovery’, ‘Kick-starting the economy and helping private investment’, and ‘Learning the lessons from the crisis’), each containing a series of programmes, as detailed in Figure 3. Programmes under Pillars 1 and 2 are those that matter most for the hydrogen industry.

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**Figure 36** The EU Recovery Plan
The new **Recovery and Resilience Facility** aims to “support investments and reforms essential to a lasting recovery, to improve the economic and social resilience of Member States, and to support the green and digital transitions.” It is the largest funding scheme under the NG EU, amounting to a total of €672.5 billion, of which €360 billion in loans and €312.5 billion in grants (European Council agreement). EU support is anchored in national Recovery and Resilience Plans, to be assessed by the Commission against 7 criteria, including their contribution to the ‘green transition’ (i.e. Green Deal targets) and to ‘country-specific recommendations under the European Semester’. Allocations can be used, for instance, to address priorities and challenges identified in the NECPs as well as those of the ‘green transition’. The Commission also emphasised the need to primarily support key European value chains, in line with its EU Industrial Strategy, of which hydrogen has been repeatedly mentioned as part. Hydrogen is therefore eligible for funding and would benefit from support from the Recovery and Resilience Facility, provided the technology is integrated into national Recovery and Resilience Plans prepared by Member States. Countries with high ambitions on hydrogen in their NECPs are expected to also aim high on hydrogen in their Recovery and Resilience plans. Austria, France, Germany, the Netherlands, and Portugal already feature hydrogen prominently in their national plans and strategies (cf. Chapter 5 for more information).

The EU Recovery Plan updates the **InvestEU** programmes and creates a new Strategic Investment Facility, which is a fifth investment window under InvestEU. This “proposed flag-ship investment programme to kick-start the European economy” consists of an EU budget guarantee meant to improve financing conditions, via loans for instance (Commission’s

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**Figure 37** The three pillars of the EU’s Recovery Plan

- **Investing in a green, digital and resilient Europe**
  - **Supporting Member States to recover**
    - Recovery and Resilience Facility
    - Recovery Assistance for Cohesion and the Territories of Europe – REACT-EU
    - Reinforced rural development programmes
    - Reinforced Just Transition Mechanism
  - Within European Semester framework
    - Supporting investments and reforms
    - Supporting a just transition
  - **Kick-starting the economy and helping private investment**
    - Solvency Support Instrument
    - Strategic Investment Facility
    - Strengthened InvestEU programme
    - Supporting key sectors and technologies
    - Investing in key value chains
    - Solvency support for viable companies
  - **Learning the lessons from the crisis**
    - New Health programme
    - Reinforced rescEU
    - Reinforced programmes for research, innovation and external action
    - Supporting key programmes for future crises
    - Supporting global partners

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Source: European Commission, The EU budget powering the Recovery Plan for Europe – Factsheet, May 2020
proposal). InvestEU, especially with its ‘Strategic Investment’ window, puts a clear focus on supporting industry in the development of key value chains and strategic technologies, in line with the Commission’s Industrial Strategy. Hydrogen, a technology that is “key for the clean energy transition”, has clearly been identified by the Commission as a strategic and priority value chain to support under the Strategic Investment Facility. The Facility also aims at supplying further backing to the European Clean Hydrogen Alliance. Other windows, such as ‘Sustainable Infrastructure’, will also provide many funding opportunities for hydrogen, from production (production of renewable energies and alternative and clean synthetic fuels) to distribution (infrastructure modernisation, with potential natural gas pipeline retrofits) and end-uses like transport (fleet renewal with clean vehicles, alternative fuels, or infrastructure deployment) and industry (decarbonisation of heavy industries such as steelmaking).

· The Just Transition Mechanism, proposed as part of the Green Deal in January 2020, plans financial support for the most vulnerable sectors and regions directly affected by the green transition. In the European Council text, the Just Transition Mechanism is comprised of 1) a €17.5-billion Just Transition Fund (financed by NGEU and the next MFF) aiming to alleviate the socio-economic impacts of the transition, supporting re-skilling, helping SMEs to create new economic opportunities, and investing in the clean energy transition with direct grants, 2) a Just Transition Scheme consisting of an additional investment scheme under InvestEU, to support the financing of the transition towards a climate-neutral economy (therefore by means of guarantees) equipped with an €1.8-billion envelope from InvestEU and aiming to mobilise investments, and 3) a public sector loan facility to mobilise between €25 and €30 billion in public investment to support communities in affected regions and reduce the socio-economic costs of the transition, via both loans and grants. Financed projects would have to be ‘consistent’ with NECPs and help implement measures planned in NECPs. As with InvestEU, funding will be channelled mostly through the European Investment Bank (EIB) based on countries’ territorial just transition plans and assessed by the Commission. The scheme makes hydrogen eligible for funds and could provide development potential for the energy carrier – notably in carbon-intensive regions – as long as it is integrated into national and regional plans. Indeed, development opportunities for hydrogen are substantial in those regions whose economies are more dependent on gas and carbon-intensive sectors, such as Poland (expected to benefit most from the scheme, in financial terms). Besides, just as with Recovery and Resilience Plans, countries with high ambitions on hydrogen in NECPs are likely to reflect this level of ambition in their just transition plans.

· The EU Recovery Plan boosts Cohesion Policy with REACT-EU, a new temporary support instrument. This will bolster already-existing Cohesion Policy funds – the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the Fund for European Aid to the Most Deprived (FEAD) – with an additional €47.5 billion on the period 2020-2022. Funding is accessible mainly via grants and, increasingly, through financial instruments (loans, microcredit, guarantees, equity stakes, financing of working capital in SMEs). The ERDF, which aims to make up for interregional inequalities, could provide most funding opportunities for hydrogen, not least in areas like energy efficiency, cogeneration, or sustainable transport. Indeed, the development of the hydrogen industry could support national and regional efforts to boost the economy. 

Please find more information on upcoming policy developments in Section 4.2 of this chapter.
and help to reach decarbonisation targets in regions and sectors where most obstacles lie.

**Rural Development Programmes** are reinforced under the recovery effort, compared to earlier MFF proposals. The European Agricultural Fund for Rural Development (EAFRD), the funding instrument of the EU’s Common Agricultural Policy (CAP), is strengthened by an additional €7.5 billion, which would take its total 2021-2027 budget to around €85 billion (European Council compromise). This is mostly provided through grants based on the assessment of national Rural Development Programmes. Member States can for instance receive “agri-environment-climate payments” for ambitious commitments that go beyond relevant minimum requirements for fertiliser, established in national law. Considering the criteria set at national level, bio-fertilisers and clean-hydrogen-based fertilisers could benefit from a wide range of financial instruments available under the fund, from guarantees to direct grants.

The new **Solvency Support Instrument** is designed to “help mobilise private resources to provide urgent support to European companies that would otherwise be viable to address immediate liquidity and solvency concerns.” It will work as a €66-billion guarantee built on the EU budget and channelled through the EIB to generate around €300 billion of investments in solvency support in equity and loans (Commission’s proposal). Industries in the hydrogen value chain facing difficulties of this kind will be eligible for support.

### 4.1.4 CONCLUSION

The EU laid the ground for its contemporary energy and climate policy with the establishment of the Energy Union in 2015. The Clean Energy Package, finally adopted in 2019, aims to develop Energy Union strategy by transferring its principles and objectives into law. Building on political momentum, the new Commission announced in late 2019 its European Green Deal, which sets carbon neutrality by 2050 in the EU as the fundamental landmark. In this perspective, it aims (i) to put into law the carbon-neutrality target, (ii) to give a roadmap on the path to take and milestones to reach for 2030 and 2050, and (iii) to both review energy and climate targets upwards (for instance via a legislative reviewing process due in June 2021) and propose new legislation to align the updated ambitions.

In May 2020, in the aftermaths of the COVID-19 crisis, the European Commission proposed a €1,850-billion EU Recovery Plan, made up of an updated (reduced) 7-year EU budget and a recovery fund dubbed Next Generation EU. This financial support will help strengthen measures previously planned under the Green Deal, such as the Hydrogen Strategy and the Just Transition Fund.

In a nutshell, the EU decided on a vision for its energy system in 2015 with the Energy Union strategy, which the 2019 Clean Energy Package aimed to turn into action. Both the Green Deal in late 2019 and the EU Recovery Plan in 2020 updated this vision through higher climate ambitions, which entail both the revision of existing legislations and the definition of a new regulatory framework.

Member States have faced and will still face national implementation of the energy system’s updated EU regulatory framework. A great deal of legislation under the Clean Energy Package will have to be transposed into national law over the coming months, not least the revised Renewable Energy Directive in June 2021.
The political developments outlined above offer many opportunities for clean hydrogen. Indeed, reaching climate neutrality by 2050 has become the fundamental goal of today’s energy and climate policy. Hydrogen has gained its own political momentum, demonstrated by an EU Hydrogen Strategy as well as an increasing number of national hydrogen plans, and can act as an enabler to decarbonise the economy and reach climate targets. The framework for its uptake is expected to be increasingly tackled through upcoming legislation.

Please see Chapter 5 – Section 2 for more information on national hydrogen strategies.
4.2 EXPECTATION FOR FUTURE POLICY DEVELOPMENTS

The European Commission’s Energy Systems Integration Communication and accompanying Hydrogen Strategy published on 8 July 2020, and the Council agreement on the Recovery Package the same month, are landmark policy developments for hydrogen’s role within the EU energy system and related funding opportunities. More initiatives are forthcoming, either new strategies and legislations under the Green Deal or revisions of existing directives and regulations. This section aims to present a brief overview of the legislative and non-legislative agenda relevant to Hydrogen over the coming period.

Figure 38 EU policy timeline on upcoming developments (from Q4 2020 until 2022)
4.2.1 NON-LEGISLATIVE POLICY INITIATIVES

According to its adjusted 2020 Work Programme, the European Commission will publish a series of new strategies under the European Green Deal:

- **Renovation Wave**\(^{67}\): building on the Clean Energy Package, the amending Directive on the Energy Performance of Buildings, and NECPs, the Renovation Wave Strategy will “tackle the underlying barriers for improving the energy efficiency of the EU building stock.” The action plan could for instance outline which technologies will be privileged for residential heating and influence the future of cogeneration and hydrogen fuel cell heating systems. Incentives – both financial and regulatory – are expected to bring buildings’ energy consumption down and reduce the sector’s greenhouse gas emissions. Among other technologies, hydrogen stationary fuel cell applications could gather some support, as they help to integrate renewable energy into the building’s energy mix.

- **Offshore Renewable Energy**\(^{68}\): the Strategy will aim to “make it easier for the different forms of offshore renewable energy – notably offshore wind, but also tidal and ocean energy – to fulfil their potential in the most efficient and competitive way, while also respecting the environment.” Noteworthy synergies are expected as the Commission detailed that planning and deployment of offshore renewable electricity will be done “taking into account the potential for on-site or nearby hydrogen production.” This makes the Strategy highly relevant for the upscaling of hydrogen, which can play a key role in the integration of intermittent power generated offshore.

- **Sustainable and Smart Mobility** (Q4 2020): Transport Commissioner Adina Valean has outlined in a speech the 4 upcoming main areas of the strategy: 1) Boosting the uptake of clean vehicles and alternative fuels for road, maritime and aviation, 2) Increasing the share of more sustainable transport modes such as rail and inland waterways, and improving the transport system’s efficiency, 3) Incentivising the right consumer choices and low-emission practices, and 4), Investing in low- and zero-emissions solutions, including infrastructure. The strategy will include two legislative documents tackling the upscaling of alternative fuels in aviation and maritime transport: ReFuelEU Aviation - Sustainable Aviation Fuels, and FuelEU Maritime - Green European Maritime Space. The Strategy will have the twin green and digital transitions at its core and also “will address the use of hydrogen in the transport sector.” Indeed, hydrogen can help to decarbonise mobility, especially long-haul and heavy transport. It is therefore expected to receive deployment support.

- **Renewed Sustainable Finance Strategy** (Q4 2020): The Strategy will aim to help increase private investment in sustainable projects and activities, through a roadmap of new actions, to be presented in late 2020. Along with the EU sustainable finance taxonomy, it “will guide investments in hydrogen across key economic sectors by promoting activities and projects that will provide a substantial contribution to decarbonisation,” the Commission announced in its hydrogen strategy. A clear distinction of hydrogen types is expected, as well as financial incentives for increased investments in hydrogen based on those types.

Other upcoming non-legislative initiatives to follow include a **Communication on Horizon Europe research and innovation missions**\(^{68}\), an **EU Methane Strategy**\(^{70}\), a **Chemicals Strategy for sustainability**\(^{71}\), and a **European Climate Pact**\(^{72}\). A potential **EU Clean Steel Strategy** (mentioned in the New Industrial Strategy) could also be relevant for hydrogen, as it could provide opportunities for its development in steelmaking industrial processes, where decarbonisation potential is substantial.
4.2.2 LEGISLATIVE REVISION

Under the European Green Deal, the legislative reviewing process aims to align energy and climate policies with updated EU ambitions, not least the 2050 carbon neutrality objective and the revised (potentially up to) 55% greenhouse gas reduction target by 2030. The contribution of the EU’s energy policy to the EU’s climate policy can be structured around 3 objectives: (i) renewables integration, (ii) energy efficiency improvements, and (iii) CO2 reductions. The revised legislation each time falls under one of the highlighted objectives. This interdependence creates the need to revise each one as soon as the ambition of any of the other two changes.

The state aid legal framework will also be revised as part of this exercise, which is to be completed by June 2021. A TEN-E Regulation recast is expected earlier, in December 2020, along with the transport policy initiatives mentioned earlier (i.e. the strategy for sustainable and smart mobility and the two accompanying legislative documents on the maritime and aviation sectors). For some of the legislation, Commission roadmaps are already open and public consultations dates have been determined. Here are some key elements to which attention should be drawn, organised according to the three above-mentioned objectives:

- Renewable energy integration
  - Whereas the Renewable Energy Directive (recast) from 2018 is to still be implemented in national legislation by 30 June 2021, a new version is expected as part of the legislative revision process. 2030 target shares for renewable energy sources as part of final energy consumption and final energy consumption in transport, for instance, are expected to be raised, in order to be aligned with the upgraded overall 2030 target for greenhouse gas emissions reduction. As well as target revisions, the reviewed legislation could provide additional incentives – legal and financial – to deploy more renewable energy sources capacities and to make 2030 objectives reachable. Following the recent policy developments that gave a clearer focus on hydrogen potential (e.g. the EU Hydrogen Strategy), hydrogen is expected to be seen as a key enabler for higher renewables integration in the various sectors covered by the RED.

- The revision of the Alternative Fuels Infrastructure Directive (AFID) aims to “set requirements for greatly expanding the EU’s network of recharging and refuelling stations for alternative vehicle fuels – mainly electric batteries, natural gas (CNG/LNG) and hydrogen. The goal is to install a sufficient number of points in all countries that are easy to access and use.” A public consultation ended in June 2020 and an updated Directive is expected in the first quarter of 2021. Similarly, the revision of the TEN-T Regulation will aim to adapt the European transport network to increased mobility flows and new challenges, primarily the twin digital and green transitions. While it will be reviewed in consistency with the revision of the TEN-E Regulation, the updated TEN-T Regulation is expected to give a boost to the planning and development of sustainable transport infrastructure, notably via increased deployment of hydrogen refuelling stations.

- Energy efficiency improvements
  - Energy efficiency is the ‘first principle’ of the EU’s Energy System Integration Strategy. In this perspective, it is a priority action field at the core of the European energy system’s reform. To align with Green Deal objectives, the 2018 amending version of the Energy Efficiency Directive will also be revised by 30 June 2021, in line with related initiatives such as the Renovation Wave Strategy, to
be published in October 2020. Reforms could include the revision of the Primary Energy Factor (PEF), ‘to fully recognise energy efficiency savings via renewable electricity and heat’. The PEF bridges primary energy consumption and final energy consumption and enables the calculation of energy savings in primary energy terms. As a result, cogeneration or combined heat and power (CHP) technologies (including fuel cells and microCHP) could receive further support for deployment in this perspective.

- **CO2 reductions**

  - The EU ETS Directive 2003/87/EC is designed to achieve a greenhouse gas emission reduction of 43% compared to 2005 levels for the EU emissions it covers (i.e. about 45% of total EU emissions). The Directive will be revised to align its rules with the ambition reflected in the new 55% greenhouse gas reduction target for 2030. As for its scope, the Commission gave some details regarding its ETS reform plans under the Green Deal: the inclusion of the maritime sector, the reduction of free allowances allocated to airlines, and the redefinition of the Linear Reduction Factor (LRF) determining the number of emission allowances on the market, should be the main changes. In September, the European Parliament voted to support the Commission’s plan on maritime transport. Inclusion of road transport and buildings is also being studied. Concerning the use of funds, revenues from the auctioning of emission allowances could feed into the EU budget, as suggested by the Commission in its MFF proposal.

  - The Energy Taxation Directive is a key instrument that could use fiscal means to incentivise more sustainable assets and investments. The upcoming Sustainable Finance Strategy (to be published in the last quarter of 2020) should give some insights as to what could be expected in the 2021 revised version of the Directive. Based on the Commission’s assessment of the Directive’s current version, the legislation does not properly tackle tax exemptions allocated to fossil fuels and does not ‘adequately promote greenhouse gas emission reductions, energy efficiency, or alternative fuels (hydrogen, synthetic fuels, e-fuels, advanced biofuels, electricity, etc.).’ As a low-carbon / carbon-free energy carrier, clean hydrogen could benefit from a revised system that would see competing fossil-based energies taxed based on their GHG emissions.

  - In the transport sector, Regulation (EU) 2019/631 on CO2 emission performance standards for passenger cars and vans will be revised by the Commission. The review will focus on the following aspects: ‘real world representativeness of the CO2 emission and energy consumption values, deployment of ZLEV [zero- and low-emissions vehicles], roll-out of recharging and refuelling infrastructure, the role of synthetic and advanced alternative fuels produced with renewable energy, emission reductions observed for the existing fleet, the ZLEV incentive mechanism, impacts for consumers, aspects related to the just transition, 2030 targets, and identification of a pathway for emission reductions beyond 2030’. CO2 emission reduction targets could be increased to align with the updated 2030 targets. The revision could include additional incentives for manufacturers to develop and upscale production and sales of FCEVs and other clean vehicles.

  - The Commission will also review CO2 emission performance standards for new heavy-duty vehicles by assessing ‘the effectiveness’ of the Regulation (EU) 2019/1242 by 2022. This review will cover for instance: ‘2030 target and possible targets for 2035
and 2040; inclusion of other types of heavy-duty vehicles, including buses, coaches, trailers, vocational vehicles and considerations of EMS (European modular system); ZLEV incentive mechanism; real world representativeness of the CO2 emission and energy consumption values; role of synthetic and advanced alternative fuels produced with renewable energy; possible introduction of a form of pooling; level of the excess emission premium.’ In the light of higher climate ambitions, this review could boost incentives for clean and low-carbon vehicles such as hydrogen buses and trucks.

Finally, actions mentioned under the EU Hydrogen Strategy are expected to be translated into legislative proposals, including the introduction of both a common low-carbon threshold/standard for the promotion of hydrogen production installations based on their full life-cycle GHG performance and of comprehensive terminology and European-wide criteria for the certification of renewable and low carbon hydrogen (by June 2021), and the review of the legislative framework to design a competitive decarbonised gas market, fit for renewable gases, including to empower gas customers with enhanced information and rights (2021).
5

NATIONAL POLICIES AND INCENTIVES

This chapter tackles national-level policies relevant for the hydrogen industry. It encompasses both implemented measures – i.e. the current legal framework for hydrogen refuelling stations, hydrogen concentration in the gas network, etc. – and announced plans, such as the national hydrogen strategies.

It covers the Member States of the European Union, as well as the UK, Iceland, Norway, and Switzerland. The aim of this chapter is to provide an overview of the key policies and initiatives at national level, and to draw cross-country comparisons. It deals with national and regional hydrogen strategies, the National Energy and Climate Plans (NECPs), and the current national policy landscape for hydrogen.
The growing number of countries that published national hydrogen strategies shows the increased interest and ambitions regarding hydrogen technologies.
5.1 NATIONAL HYDROGEN STRATEGIES

Hydrogen has undoubtedly gained substantial momentum in the recent period. The growing number of countries that published national hydrogen strategies shows the increased interest and ambitions regarding hydrogen technologies. This section provides an overview of these strategies and what they mean for the development of the hydrogen sector going forward.

5.1.1 EUROPEAN NATIONAL HYDROGEN STRATEGIES

By early September 2020, five EU and EEA countries had released national hydrogen strategies (France, Germany, the Netherlands, Portugal, Spain, and Norway) in 2020. More EU countries are expected to follow shortly (Austria, Estonia, Luxembourg, Poland, Slovakia, among others).

As well as national plans, certain regions have published their own hydrogen strategies, notably in those countries that have already published a national strategy, namely France, Germany and the Netherlands.

Figure 39 State of publication of National Hydrogen Strategies in EU/EEA Member States
FRANCE

National level:

France was the first EU country to publish a national hydrogen strategy in 2018 with its Hydrogen deployment plan for the energy transition. In September 2020, the government released a second strategy that significantly upgrades the ambition: from €150 million of public funding per year to €7 billion over the period 2020-2030, i.e. about €700 million per year. Besides, about half of the total amount is to be spent on the first three years. The landmark target of the strategy is reaching an electrolyser capacity of 6.5 GW by 2030 – a far more ambitious objectives than under the previous plan (1-10 MW by 2023 and 10-100 MW by 2028 for Power-to-Gas demonstrators). The 2020 strategy gives a clear focus to the role of decarbonised hydrogen (i.e. renewables-based, leaving the door open for nuclear energy) in the decarbonisation of the industry and of heavy mobility (especially Light Commercial Vehicles, trucks, regional trains, and then ships and planes). To do so, the government plans to help the hydrogen industry to scale up, not least by setting up a premium-based support mechanism to bolster investment and operations after tenders. It will also launch several calls for projects to finance hydrogen applications and the hydrogen value chain, such as hydrogen fuel cells and tanks, and research projects. Sectoral targets detailed in the 2018 plan and later confirmed in the PPE (Programmation pluriannuelle de l’énergie, France’s multiannual energy plan) remain valid: a 10% integration share of decarbonised hydrogen in the industrial hydrogen mix by 2023 and 20-40% by 2028; 5,000 light-duty vehicles; 200 heavy-duty vehicles; 100 hydrogen refuelling stations (fed by local production, and up from ca. 30 at the end of 2019) by 2023 and 20,000-50,000 light-duty vehicles; 800-2,000 heavy-duty vehicles; 400-1,000 hydrogen refuelling stations by 2028, in the transport sector.

Regional level:

In 2018, the Bourgogne Franche-Comté region published a hydrogen roadmap. It plans for a €90-million budget dedicated to hydrogen development over the next decade, adding up to €12 million already invested since 2012. Funding is distributed as follows: €18 million to industrial projects, €18 million to stationary and mobility projects, about €50 million for trains, €2 million to vocational training and research, and €2 million to the animation of the sector, markets, and studies.

Table 2 Main Targets of the French Hydrogen Plan

<table>
<thead>
<tr>
<th></th>
<th>2023</th>
<th>2028</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td>Electrolyser capacity in GW</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Passenger cars and LCVs</td>
<td>5,000</td>
<td>20,000 - 50,000</td>
</tr>
<tr>
<td></td>
<td>HDVs</td>
<td>200</td>
<td>800 - 2,000</td>
</tr>
<tr>
<td></td>
<td>Hydrogen refuelling stations</td>
<td>100</td>
<td>400 - 1,000</td>
</tr>
<tr>
<td><strong>Industry</strong></td>
<td>Decarbonised hydrogen share of hydrogen mixed in the industry in %</td>
<td>10</td>
<td>20 - 40</td>
</tr>
</tbody>
</table>
The document ENRGHy\textsuperscript{76} completes the roadmap and answers a 2016 national call for ‘Hydrogen Territories’ in France. The region, standing amongst the call’s awardees, will access to funding for 7 experimental projects, from research in storage (ISTHY) and fuel cells for mobility (HYBAN), to the deployment of a renewable hydrogen refuelling station with the purchase of 5 hydrogen buses (EOLBUS), a methanation project allying PtG technology (HyCAUNAIS), the installation of a distribution channel supplying local hydrogen production (VHyCtor), a hydroelectricity-powered electrolyser feeding in local clean mobility solutions (NewM-HyLL), and a stationary application for a data centre (HyDATA). Besides, the budget share dedicated to trains will enable the purchase of three hydrogen train sets from Alstom.

The Occitanie Region has launched its Green Hydrogen Plan\textsuperscript{77} in 2019, which will be worth €150 million over the period 2019-2030 and which should generate €1 billion of investment. By 2024, this plan will support the acquisition of 3 Regiolis hydrogen train sets (€33 million committed in 2019); the construction of 20 green hydrogen production/distribution stations; the construction of a hydrogen production plant “Lucia” (Port-la-Nouvelle) and 2 industrial electrolysers (HyPort in Blagnac and Tarbes); and the acquisition of 600 hydrogen vehicles (heavy, commercial, and light). This capacity will be further boosted by 2030 with: the construction of 2 green hydrogen production plants; the construction of 55 green hydrogen production/distribution stations; the construction of 10 electrolysers; and the acquisition of 3,250 hydrogen vehicles.

The Pays de la Loire regional council adopted its Hydrogen Plan under its recovery plan\textsuperscript{78} in early July 2020. It plans to fund hydrogen development with a €100-million budget for the period until 2030. Concretely, it ambitions to deploy an electrolyser production capacity with its associated distribution network and end-uses. It will aim to have 15 hydrogen production and refuelling stations and to help professional purchases of 500 hydrogen vehicles; the target is 13,000 by 2030. Other projects include a hydrogen coach line, the trial of a regional train (TER) powered by hydrogen and of a maritime shuttle, or the integration of hydrogen technologies in the Nantes Saint-Nazaire Grand Port.

The Auvergne-Rhône Alpes region is an awardee of the 2017 European Blending Call with its Zero Emission Valley\textsuperscript{79} programme, which acts as the region’s development plan for hydrogen. Targets for the next ten years include 20 hydrogen refuelling stations (by 2023), 15 electrolyisers, and 1,000 light-duty and tourism vehicles. It will be supplied with a funding of €15 million from the region and €10 million from European funds. It will aim to mobilise €70 million over the whole period.

**GERMANY**

National level:

The country released its National Hydrogen strategy\textsuperscript{80} in June 2020. By 2030, national consumption in Germany was predicted to be 90-110 TWh. By then, Germany aims to build up 5-GW electrolysis production capacity (i.e. 14 TWh of hydrogen production; provided by 20-TWh RES production) and 10-GW capacity by 2040.

To help develop the value chain from production and distribution to end-uses, a cross-cutting €9 billion of public funding is made available: €7 billion dedicated to market upscaling of hydrogen.
technology in Germany under the Future Package (Zukunftspaket) and €2 billion to international partnerships.

The vision articulates two main stages: 1) market upscaling and laying the foundations for the home market from 2020 until 2023, 2) consolidating the home market and shaping the hydrogen dimension at EU and international levels from 2024 to 2030.

The sectoral focus is primarily on the industry, whose needs could reach 80 TWh of hydrogen in steelmaking and 22 TWh for refining and ammonia production by 2050. In this regard, hydrogen, among other technologies helping to decarbonise the industry, will benefit from already-existing funding programmes, topping up the €7-billion package. €1 billion was made available under the National Decarbonisation Programme to decarbonise production processes, in 2020-2023. This is complemented by the €650 million of funding from 2020 to 2024 under the Innovation Pact for Climate Protection to decarbonise industrial production (e.g. steel and chemical industries).

Mobility is another priority sector for the strategy, where hydrogen will benefit from extensive support programmes such as €3.6 billion in grants for clean vehicle purchase or €3.4 billion in grants for the construction of tanking and charging infrastructure, both for 2020-2030 under the Energy and Climate Fund.

Regional level:

In November 2019, an alliance of five German Länder (Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony and Schleswig-Holstein) published a Hydrogen Strategy for North Germany. This aims among other things to take advantage of the region’s wind energy generation capacity, its seaports, and the expertise of its local industrial and research players, to develop the hydrogen sector. The installation of 500-MW electrolyser capacity by 2025 and 5 GW by 2030 is also planned. It should be noted that this target for electrolyser capacity by 2030 reveals a lack of consistency between the regional initiative and the more recent national hydrogen strategy, which aims

### Table 3 Main Targets of the German Hydrogen Plan

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolyser capacity in GW</td>
<td>5</td>
<td>10</td>
<td>/</td>
</tr>
<tr>
<td>Hydrogen production in TWh</td>
<td>14</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Hydrogen demand in TWh</td>
<td>90 - 110</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td><strong>Industry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen demand for steelmaking</td>
<td>/</td>
<td>/</td>
<td>80</td>
</tr>
<tr>
<td>Hydrogen demand for refining and ammonia production in TWh</td>
<td>/</td>
<td>/</td>
<td>22</td>
</tr>
</tbody>
</table>

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81 Ministries of Economy and Transport of the North German Coastal States, Hydrogen Strategy for North Germany, 2019. Accessible via: https://www.hamburg.de/contentblob/13874168/e484c76e44486905abd9220bbdd64a8f/data/hydrogen-strategy-for-north-germany.pdf
for the same capacity by the end of the decade.

**THE NETHERLANDS**

National level:

The Dutch Government published its national strategy\(^{82}\) in April 2020. It plans for the development of a 500-MW electrolyser capacity by 2025 and 3-4 GW by 2030.

In the transport sector, the Netherlands will aim to deploy 15,000 FCEVs, 3,000 heavy-duty vehicles, and 50 hydrogen refuelling stations by 2025. By 2030, the FCEV fleet should increase to 300,000, and there should be a minimum blending rate of 14% of sustainable fuel in aviation fuel. By 2050, that rate would be raised to 100%.

The Netherlands is also particularly interested in making use of its developed gas grid to enable the deployment of hydrogen. Concretely, a four-year programme starting this year is tasked with identifying safety issues and proposing solutions to tackle them. In the meantime, a blending obligation for hydrogen on the natural gas grid and the possible coexistence of both private and public distribution networks for hydrogen will be considered.

Regional level:

In April 2019, the Dutch provinces of Groningen and Drenthe teamed up to set up a Hydrogen Valley in the Northern Netherlands. With a budget of €2.8 billion, the valley gathers 50 partners from around the world and intends to realise 33 diverse projects, from small-scale (1 MW) to large-scale (1 GW) production, to distribution and all end-uses. Blue hydrogen will be part of the plan to scale up hydrogen technology and to help reduce green hydrogen costs eventually. Part of the budget will therefore be dedicated to financing a 1.2-GW blue hydrogen production plant and 100-MW clusters for green hydrogen production.

**PORTUGAL**

After a public consultation ending on 6 July 2020, the Portuguese national hydrogen strategy\(^{83}\) was formally adopted by the Council of Ministers on 14 August 2020. This 3-phase plan is inspired by the EU hydrogen strategy’s timeline: 1) Phase 1 (2020-2023): establishment of the regulatory framework and first projects, 2) Phase 2 (2024-2030): consol-

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**Table 4 Main Targets of the Dutch Hydrogen Plan**

<table>
<thead>
<tr>
<th></th>
<th>2025</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolyser capacity in GW</td>
<td>0.5</td>
<td>3 – 4</td>
<td>/</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger cars and LCVs</td>
<td>15,000</td>
<td>300,000</td>
<td>/</td>
</tr>
<tr>
<td>HDVs</td>
<td>3,000</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Hydrogen refuelling stations</td>
<td>50</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Blending rate of sustainable fuels in aviation fuels in %</td>
<td>/</td>
<td>14</td>
<td>100</td>
</tr>
</tbody>
</table>

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idation and roll-out of projects at national level, and 3) Phase 3 (2030-2050): full development of the national hydrogen market. The Portuguese Hydrogen strategy aims to mobilise €7 to €9 billion of investments, of which 85% from the private sector, by 2030 that would fund the effort to ramp up hydrogen solutions. Contrary to the French and German strategies, which detail public funding amounts in support of the industry, Portugal provides an estimate of mobilised investments.

The strategy outlines a series of hydrogen development targets for 2030. By 2030, hydrogen should amount to 5% of the country's final energy consumption, 2 to 2.5 GW of electrolyser capacity should be installed (including via a 1-GW project on the industrial site of Sines worth €1.5 billion), and a 10 to 15% ratio of hydrogen in natural gas networks should be achieved. In the transport sector, hydrogen should account for 5% in road transport fuel consumption, and 50 to 100 refuelling stations should be built. Finally, hydrogen should amount to 5% of energy consumption in the industrial sector.

Table 5 Main Targets of the Portuguese Hydrogen Plan

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
</tr>
<tr>
<td>Electrolyser capacity in GW</td>
<td>2 - 2.5</td>
</tr>
<tr>
<td>Share of hydrogen in final energy consumption in %</td>
<td>5</td>
</tr>
<tr>
<td><strong>Distribution</strong></td>
<td></td>
</tr>
<tr>
<td>Blending ratio of hydrogen in natural gas grid in %</td>
<td>10 - 15</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td></td>
</tr>
<tr>
<td>Share of hydrogen in road transport fuel consumption in %</td>
<td>5</td>
</tr>
<tr>
<td>Share of hydrogen in fuel for domestic maritime transport %</td>
<td>3 - 5</td>
</tr>
<tr>
<td>Hydrogen refuelling stations</td>
<td>50 - 100</td>
</tr>
<tr>
<td><strong>Industry</strong></td>
<td></td>
</tr>
<tr>
<td>Share of decarbonised hydrogen within the industry's energy mix in %</td>
<td>5</td>
</tr>
</tbody>
</table>
Spain

The Spanish government also released a strategy. It plans to mobilise close to €9 billion worth of investments for the period until 2030 to develop the hydrogen sector, notably with the target to build up 4 GW of electrolyser capacity by then. As with Portugal’s strategy, the indicated amount in support of the hydrogen industry is an estimate of mobilised public and private investments by 2030.

The Spanish Government will strive to have 25% of renewable hydrogen within the industrial hydrogen mix. In the transport sector, 150 to 200 buses and 5,000 to 7,500 LDVs and HDVs for freight transport should be on the road. In addition, 100 to 150 hydrogen refuelling stations and two commercial hydrogen train lines should be operational by the end of the decade.

Table 6 Main Targets of the Spanish Hydrogen Plan

<table>
<thead>
<tr>
<th>Production</th>
<th>Electrolyser capacity in GW</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>Buses 150 - 200</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>LDVs and HDVs 5,000 - 7,500</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td>Hydrogen refuelling stations 100 - 150</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Commercial hydrogen train lines 2</td>
<td>2</td>
</tr>
<tr>
<td>Industry</td>
<td>Decarbonised hydrogen share within hydrogen mixed in % 25</td>
<td>25</td>
</tr>
</tbody>
</table>

Norway

Norway’s National Hydrogen Strategy (2020), in the same spirit as Australia’s and New Zealand’s, provides a vision of hydrogen development and the strategic importance to act in, yet without supplying concrete targets.

Other Member States

National hydrogen strategies are currently being drafted by the Austrian, Estonian, Luxembourgian, Polish, and Slovak governments.

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5.1.2. Non-European National Hydrogen Strategies

Outside the EU, Australia, Japan, New Zealand, Norway, and South Korea have also released strategies for the development of hydrogen.

Japan

As early as 2017, Japan provided a detailed and ambitious strategy for the deployment of hydrogen technologies, for which it seeing itself as a pioneer. The country adopts a stance where it considers importing increasingly large amounts of hydrogen from abroad and plans to become a world leader in hydrogen end-use technologies, especially in mobility. In this respect, Japan will aim for a fleet of 200,000 FCEVs by 2025 and 800,000 by 2030. 320 hydrogen refuelling stations would also be installed by 2025 and 900 by 2030.

South Korea

Via its Hydrogen Economy Roadmap (2019), South Korea adopts a similar approach to Japan, with a notable focus on hydrogen mobility deployment. It plans for a 100,000 strong FCEV fleet in 2025. 310 hydrogen refuelling stations should be installed as soon as 2022. Regarding hydrogen distribution, the country plans to establish hydrogen pipelines near sources of by-product hydrogen production (Ulsan, Yeosu, and Daesan) by 2022 and to consider the construction of high-pressure hydrogen pipelines nationwide by 2030. Finally, South Korea maps out a detailed forecast for power generation with hydrogen fuel cell systems: from 308 MW in 2018 to 1.5 GW in 2022 and 15 GW in 2040.

Australia

Australia’s National Hydrogen Strategy (2019) offers a national vision for hydrogen and its potential role in the country’s energy system transition and economic development. Given Australia’s federal structure, much room is given for states and territories to detail initiatives taken at their level, such as funding schemes. Compared with other countries, the focus is not on quantitative targets for hydrogen development but rather on the rationale behind a national plan for hydrogen. The strategy emphasis the need to work on safety standards and on an incentivising legal framework. Finally, Australia positions itself as a future world major hydrogen producer and exporter.

New Zealand

New Zealand’s 2019 Green Paper sets out a broad national ‘vision’ for the potential of hydrogen. Like Australia, the purpose is to explain the rationale behind hydrogen development and the opportunities this could offer. Amongst key elements mentioned, New Zealand could consider injecting up to 20% of hydrogen in its natural gas grid by 2035. The Green Paper should be complemented by an upcoming detailed roadmap.

5.1.3. Comparative Analysis of National Hydrogen Strategies

Overall, EU national strategies, along with those of South Korea and Japan, give detailed targets and measures on the future role of hydrogen in their national economies. Those of Australia, New Zealand, and Norway remain less quantitative and more general. The brief cross-country comparison that follows shows that national ambitions vary both globally and per application sector.

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**Production**

The 2020 strategies from Germany, the Netherlands, and France show significant and precise ambition in terms of targeted hydrogen production capacity. While the French government did not plan to consider large-scale PtG solutions before 2035 in its former plan, France, along with Germany and the Netherlands, will now respectively aim for 6.5 GW, 5 GW, and 3-4 GW electrolyser capacity by 2030. The Netherlands sets an intermediary target of 500 MW of electrolyser capacity by 2025 and Germany will strive towards 10 GW by 2040. Portugal hopes to deploy 2 to 2.5 GW of electrolyser capacity and Spain will aim for 4 GW by the end of the decade. In this aspect, European countries’ ambitions are higher and more detailed than countries like South Korea and Japan.

**DISTRIBUTION**

Portugal plans for a 10-15% ratio of hydrogen on the natural gas network by 2030, making it the only EU country that set itself a target of this kind. Germany, Spain, the Netherlands, and France are also studying the possibilities to retrofit and use of existing infrastructures, dedicating them either to pure hydrogen transport or to blending with natural gas. Construction of new networks of pipelines is also being considered. Similarly in this regard, South Korea plans to establish hydrogen pipelines near sources of by-product hydrogen production (Ulsan, Yeosu, and Daesan) by 2022 and to consider the construction of high-pressure hydrogen pipelines nationwide by 2030. Finally, New Zealand could consider injecting up to 20% of hydrogen into its natural gas grid by 2035.

**MOBILITY**

South Korea plans for a 100,000 strong FCEV fleet in 2025. Japan will aim for twice as much, while the Netherlands would have 15,000 vehicles on the road by then and France wants 5,000 light-duty vehicles by 2023. The Dutch are more ambitious on trucks (3,000 in 2025) than the French (200 in 2023). Regarding distribution, 320 hydrogen refuelling stations would be installed in Japan by 2025 and 310 as soon as 2022 in South Korea. France aims for 100 by 2023 and the Netherlands for 50 by 2025. In 2030, Japan wants to have deployed a significant 900 hydrogen refuelling stations. France gives itself more leeway and will aim somewhere between 400 and 1,000 installations by 2028, while Portuguese and Spanish targets are for, respectively, 50 to 100 stations and 100 to 150 stations by the end of the decade.

<table>
<thead>
<tr>
<th>Key production targets in national hydrogen strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyser capacity in GW (2025)</td>
</tr>
<tr>
<td>France</td>
</tr>
<tr>
<td>Germany</td>
</tr>
<tr>
<td>Netherlands</td>
</tr>
<tr>
<td>Portugal</td>
</tr>
<tr>
<td>Spain</td>
</tr>
<tr>
<td>EU</td>
</tr>
</tbody>
</table>

a: in 2024
### Table 8

**Key distribution targets in national hydrogen strategies**

<table>
<thead>
<tr>
<th></th>
<th>Ratio of hydrogen in natural gas networks in % (2030)</th>
<th>Considers injecting hydrogen into natural gas network (blending and/or pure hydrogen)</th>
<th>Considers construction of new pipelines dedicated to hydrogen distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>/</td>
<td>X</td>
<td>/</td>
</tr>
<tr>
<td>Germany</td>
<td>/</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Netherlands</td>
<td>/</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Portugal</td>
<td>10 – 15</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Spain</td>
<td>/</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>South Korea</td>
<td>/</td>
<td>/</td>
<td>X</td>
</tr>
<tr>
<td>Japan</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Australia</td>
<td>/</td>
<td>X</td>
<td>/</td>
</tr>
<tr>
<td>New Zealand</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>X</td>
<td>/</td>
</tr>
</tbody>
</table>

<sup>a</sup>: no formal target; by 2035 (see word document)

### Table 9

**Key mobility targets in national hydrogen strategies**

<table>
<thead>
<tr>
<th></th>
<th>Number of FCEVs (2025)</th>
<th>Number of hydrogen trucks (2025)</th>
<th>Number of hydrogen refuelling stations (2025)</th>
<th>Number of hydrogen refuelling stations (2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>5,000&lt;sup&gt;a&lt;/sup&gt;</td>
<td>200&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>400 – 1,000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Netherlands</td>
<td>15,000</td>
<td>3,000</td>
<td>50</td>
<td>/</td>
</tr>
<tr>
<td>Portugal</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>50 – 100</td>
</tr>
<tr>
<td>Spain</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>100 – 150</td>
</tr>
<tr>
<td>South Korea</td>
<td>100,000</td>
<td>/</td>
<td>/</td>
<td>310 – 1,200</td>
</tr>
<tr>
<td>Japan</td>
<td>200,000</td>
<td>/</td>
<td>/</td>
<td>900</td>
</tr>
</tbody>
</table>

<sup>a</sup>: in 2023  
<sup>b</sup>: in 2028
INDUSTRY

Spain and France (in its 2018 plan) are the only two countries that detail targets for decarbonisation of the hydrogen mix in the industrial sector. Spain plans for 25% of decarbonised hydrogen in the industrial hydrogen mix by 2030. France will aim for 10% by 2023 and 20-40% by 2028. For both countries, the decarbonisation of the industry is a top priority under their respective national hydrogen strategies. According to the Portuguese plan, green hydrogen should amount to 5% of energy consumption in the industrial sector by 2030. To reach this objective, the country will notably rely on its large-scale, €1.5 billion project on the industrial site of Sines, meant to deploy 1 GW of electrolyser capacity. Particular attention will be given to chemicals production (not least ammonia) using green hydrogen. The role of hydrogen in industry is also an important focus in Germany, where the government made available quite substantial funding and gave estimates on hydrogen consumption in the sector: 80 TWh in steelmaking and 22 TWh for refining and ammonia production by 2050.

ENERGY

Across countries, hydrogen is usually considered to have high potential for a series of energy uses, including energy storage, to increase flexibility in the energy (not least, power) mix, and the use of waste. For instance, Spain plans to adapt its legal framework to better integrate hydrogen as an enabler of improved management of electricity demand response. In this perspective, “hydrogen projects are expected to be operational by 2030 for electricity storage and/or the use of surplus renewable energy”. South Korea maps out a detailed forecast for power generation with hydrogen fuel cell systems: from 308 MW in 2018 to 1.5 GW in 2022 and 15 GW in 2040. This remains one of the application areas of hydrogen where France is the least ambitious – let us recall that the country did not foresee any need for large-scale PtG solutions before 2035 in its 2018 hydrogen plan and 2020 multiannual energy programme. The Spanish government sees a role for the molecule as part of the circular economy, by producing renewable hydrogen from waste and biogas in the agricultural sector. Finally, hydrogen use for the decarbonisation of heat in buildings is considered in Germany and the Netherlands.

Table 10

<table>
<thead>
<tr>
<th></th>
<th>Decarbonised hydrogen share within hydrogen mixed in the industry in % (2030)</th>
<th>Decarbonised hydrogen share within total industrial energy mix in % (2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>20 – 40(^a)</td>
<td>/</td>
</tr>
<tr>
<td>Portugal</td>
<td>/</td>
<td>5</td>
</tr>
<tr>
<td>Spain</td>
<td>25</td>
<td>/</td>
</tr>
</tbody>
</table>

\(^a\): in 2028
CROSS-CUTTING ASPECTS

Some major cross-cutting topics are tackled under national strategies too. All EU countries in the scope of this analysis wish to actively participate in the elaboration of the ICPEI tool for hydrogen projects and make use of it. For example, an IPCEI application could be submitted for the green hydrogen industrial project of Sines in Portugal. European countries also underline the importance of EU-level cooperation to realise the successful deployment of hydrogen, not least by working on European standards and a common Guarantees of Origin system. Besides, every nation that published a strategy acknowledges the key role of research to help advance the development and deployment of the technology, and details funding programmes to finance research activities. Among others, Germany launched a cross-ministry research campaign called “hydrogen technology 2030”. It will aim to organise and promote funding allocated to research (from €300 million to possibly over €500 million for 2020-2023) for a wide range of sectors, not least mobility and the steel and chemical industries.

Table 14 provides an overview of key targets in the hydrogen industry that were featured in national strategies. European countries lead the targets for planned electrolyser capacity, while South Korea and Japan adopt the perspective of hydrogen importer countries. It should be noted that more than half the 2030 EU-level target for electrolysis capacity of 40 GW is reached by compiling the targets of the five EU Member States that have published a hydrogen strategy. Both Asian nations are very ambitious on the deployment of hydrogen mobility and the associated infrastructure: they could install from a few hundred up to 1,000 hydrogen refuelling stations. France is the only European country that matches this level of ambition. Finally, although Germany and the Netherlands do see a role for hydrogen to play in the decarbonisation of their industry mix, only France, Portugal, and Spain provide targets.

<table>
<thead>
<tr>
<th>Electrolyser capacity in GW (2030)</th>
<th>Number of hydrogen refuelling stations (2030)</th>
<th>Decarbonised hydrogen share within hydrogen mixed in the industry in % (2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France  6.5</td>
<td>400 – 1,000a</td>
<td>20 – 40a</td>
</tr>
<tr>
<td>Germany  5</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Netherlands  3 - 4</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Portugal  2 - 2.5</td>
<td>50 – 100</td>
<td>5b</td>
</tr>
<tr>
<td>Spain  4</td>
<td>100 – 150</td>
<td>25</td>
</tr>
<tr>
<td>South Korea /</td>
<td>310 – 1,200</td>
<td>/</td>
</tr>
<tr>
<td>Japan /</td>
<td>900</td>
<td>/</td>
</tr>
<tr>
<td>EU  40</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

Table 11 Some key hydrogen targets featured in national hydrogen strategies

a: in 2028
b: within the total industrial energy mix
5.2 NATIONAL ENERGY AND CLIMATE PLANS (NECPs)

Under the Governance Regulation 2018/1999 (cf. Chapter 4), EU Member States are required to draft National Energy and Climate Plans (NECPs). In these documents, countries were asked to lay out the strategies and measures they plan to implement for the period 2021-2030 in order to comply with 2030 energy and climate targets at EU and national levels. NECPs are therefore relevant for the present and future development of hydrogen in EU countries. Organised in a harmonised structure, NECPs are often several hundred pages long and offer a comprehensive description of each country’s energy system. Although hydrogen technologies are mentioned in every plan but Finland’s, NECPs vary greatly as regards the ambition that governments set for hydrogen development in the coming decade and beyond. This section aims to give an overview of the role that hydrogen is allocated within the 27 NECPs, by offering a quantitative analysis of hydrogen mentions in NECPs. It then provides a qualitative analysis of the role of hydrogen across applications and of the ambition of policy measures, targets and funding aimed at supporting hydrogen across countries. Finally, it outlines some ‘key takes’ in a concise summary.

5.2.1. HOW PROMINENTLY IS HYDROGEN FEATURED IN NECPs?

‘Hydrogen’ and ‘fuel cells’ are mentioned 1,051 times across the 27 NECPs. The number of mentions per NECP is very unequal across Member States: from 116 in Austria’s NECP to none in Finland’s. Most Member States mention hydrogen at least 30 times and the average is 40 mentions. Although the number of hydrogen mentions is not a sufficient benchmark for the hydrogen ambitions of a specific country, it offers a partial, telling image of the place hydrogen could take in a national energy system.

Figure 40 gives an overview of the countries that mention hydrogen most often in their NECPs, based on a ratio of hydrogen mentions per NECP page, to allow for the great differences in these documents’ lengths. Unsurprisingly, countries that have published a national hydrogen strategy, or are in the process of releasing one, also mention hydrogen the most: Austria, the Netherlands, Portugal, France, and Germany lead the way, while Lithuania, Cyprus (which does not tackle hydrogen in its scenario ‘due to the lack of available data’) and Finland bring up the rear.

Figure 41 highlights the number of hydrogen applications tackled by each country. A third of Member States’ NECPs mention hydrogen when considering all technological applications, that is, from production and distribution to the main end-uses (i.e. mobility, industry, and energy uses). About two thirds of Member States’ NECPs cover at least four dimensions. Only two countries (HR, LT) foresee a potential for hydrogen in only two applications. This shows that the large majority of countries is treating hydrogen as a multi-application technology and, therefore, view it as a decarbonisation solution for various parts of their national energy system.
Figure 40
Ratio of hydrogen mentions per NECP page per Member State

Figure 41
Number of hydrogen applications tackled per Member State in their NECP
5.2.2. ROLE OF HYDROGEN ACROSS SECTORAL APPLICATIONS IN NECPS

The following analysis tackles the role of hydrogen in NECPs across the 5 main dimensions for hydrogen applications, as well as cross-cutting topics. It also details the main policy measures than Member States plan to set forth to develop the technology.

Hydrogen is treated in different ways depending on the country and on the sectoral application. Whereas Figure 41 gives an outlook on the number of hydrogen applications tackled by countries, Figure 42 highlights the sum of countries that foresee a role for hydrogen per specific sectoral application. Hydrogen in mobility is tackled by almost every Member State (25 out of 27), which demonstrates the high potential that countries foresee in the technology for the decarbonisation of this sector. Hydrogen in energy uses (24) and hydrogen production (21) are also addressed by a large majority of countries. Finally, 17 Member States mention aspects related to hydrogen distribution, while less than half of EU countries focus on the role of hydrogen in the industrial sector (12).

PRODUCTION

Hydrogen production usually refers to the generation of renewable and/or low-carbon hydrogen, which means the building of electrolyser capacity and the use of SMR technology topped by a CCS technology, respectively. Support schemes for the implementation of hydrogen production pilot projects are planned in several Member States (e.g. BE, BG, EL, HU, IT, and SI). Austria, Bulgaria, France, and the Netherlands provide estimates (or targets) for future production/consumption of hydrogen.

DISTRIBUTION

Looking at the distribution of hydrogen, many Member States are considering the injection of hydrogen into the gas grid, both by blending with natural gas or with pure hydrogen dedicated pipelines after a retrofit (AT, DE, MT, PT, RO), sometimes with precise targets (SI), or are planning on developing the necessary regulatory framework for hydrogen injection (e.g. PT, ES).
MOBILITY

This is the hydrogen application most often referred to in NECPs. Belgium (Wallonia region), Czechia, France, and Slovakia give estimates on the future number of FCEVs in their countries. Bulgaria, Hungary, Portugal, Slovakia, and Slovenia provide estimates (or targets) for the future use of hydrogen as a transport fuel. Yet there is a lack of clarity, or a deliberate omission, from some Member States on the role hydrogen fuel cells could have in electromobility. Biofuels, CNG, and LPG are often mentioned as a solution to raise the renewable energy share in transport, at the expense of hydrogen (e.g. HR, DK, EE).

INDUSTRY

Despite the small number of mentions, industry is, as well as mobility, a major application foreseen for hydrogen technologies’ development. Indeed, hydrogen is perceived to have significant potential to help with the decarbonisation of the sector. However, hydrogen’s role in industry is sometimes only detailed further in industry or sector-specific strategies (e.g. FI), which can help to explain the number of mentions. Overall, hydrogen is especially considered for energy-intensive processes, not least steelmaking, chemicals, refining, methanol, and ammonia. France and Slovenia provide estimates (or targets) on the future consumption of hydrogen by industry. Germany, Luxembourg, the Netherlands, Romania, Slovakia, Slovenia, and Sweden are also considering using blue and/or green hydrogen to decarbonise industry.

ENERGY

The development of hydrogen for energy uses, for instance to enable sector coupling and build up energy storage capacities, is considered to be strategic by almost all Member States. Across many Member States, it is seen as a potential means to cope with grid imbalances (especially in the perspective of an increasing renewable energy share in the mix) and to improve energy security (e.g. PL).

CHP is also regularly considered as a channel to boost RES integration in buildings – fuel cells are considered in some cases here (DK, SK). Finally, CCUS, in the context of ‘blue’ or low-carbon hydrogen production, is repeatedly mentioned to help decarbonise industry (BE, CZ, DE, LT, NL, SE).

CROSS-CUTTING ASPECTS

As regards cross-cutting topics on the role of hydrogen in national energy policies, EU Member States often mention the need to further work on Guarantees of Origin for hydrogen (AT, BE, BG, EL, FR, DE, LU, NL, ES, PT). Many also show interest in the ICPEI (e.g. AT, BE, IT, PT). Hydrogen is also recurrently identified as a research funding target, where both public funding and international cooperation could be needed. 9 Member States dedicate a specific section, box or paragraph to cross-cutting issues on hydrogen within their NECP (AT, CZ, FR, DE, HU, IE, LU, NL, and PL). Some countries mention work drafting national hydrogen strategies, whether this has been published (DE, FR, NL) or is under development (AT, EE, LU, PL, PT, ES). On this topic, Portugal and Spain have since then published their strategies, France released an updated version of its 2018 plan. Finally, the Pentalateral Energy Forum member countries (AT, BE, DE, FR, NL, LU, CH) present a “common chapter” in their respective NECPs, which considers hydrogen in the future energy system and plans for potential further cooperation on the technology’s development.
5.2.3. CONCLUSION

All Member States acknowledge the importance of developing uses of renewable and/or low-carbon hydrogen, at least in the long term, in their NECPs. The carbon-free energy carrier is mentioned in practically all plans, despite cross-country contrasts. Hydrogen is usually featured as a research funding target and as an important future technology in the mobility, industry, and energy sectors to reach energy and climate targets. Mobility is the sector where countries foresee the most potential for hydrogen.

Strictly based on the analysis of NECPs and the place and role they give to hydrogen, some Member States are more ‘H2-ambitious’ than others. Three country groups can be distinguished.

- A ‘leading group’: Austria, France, Germany, the Netherlands, and Portugal.
- A ‘fast follower group’: Belgium, Czechia, Hungary, Poland, Slovakia, and Slovenia.
- A ‘laggard group’ of the others.

Although repeatedly mentioned, hydrogen’s role is often not clearly translated into concrete (quantified) targets. Across countries, hydrogen is usually considered an important, sometimes key, technology for research and investment, but as still lacking maturity for wide-scale applications in the short-term, hence the occasional scarcity of concrete and detailed measures to help scale up the energy carrier. The period tackled by NECPs – i.e. 2021 to 2030 – is rather seen as a phase for 1) research and development of the technology (not least with the launch of demonstrators and through increased public funding), 2) the definition of a clear and incentivising legal framework, and 3) the reduction of total ownership costs and the upscaling of the technology’s value chain.

Overall, hydrogen is expected to play an increasingly significant role within national energy landscapes in the EU.

More information on the role of hydrogen in NECPs can be found in the study from the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) ‘Opportunities for Hydrogen Energy Technologies Considering National Energy & Climate Plans’ (2020).90

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5.3 NATIONAL POLICIES AND INCENTIVES ON HYDROGEN TECHNOLOGIES.

Hydrogen has featured prominently in the news in 2020, but was on the minds of policymakers long before, as many countries have already adopted various hydrogen and fuel cell related policies covering the production, distribution, and end-use of hydrogen. Given the growing importance of hydrogen in decarbonisation efforts and its role in NECPs, more hydrogen related policy developments are expected in the coming months. As a prelude, this sub-chapter provides an overview of already enacted hydrogen and fuel cell policies in countries across Europe. More specifically it focuses on policies related to mobility, infrastructure, and industry. The methodological note and geographic coverage can be found in the Methodological Annex.

5.3.1. MOBILITY

This section covers policies on the support and development of hydrogen refuelling infrastructure and the deployment of FCEVs. That includes targets and CAPEX support for Hydrogen Refuelling Stations (HRS), purchase subsidies and registration tax benefits for FCEV passenger cars, and purchase subsidies for buses and heavy-duty vehicles.

Figure 43

Overview of HRS policy support in Europe

Source: Hydrogen Europe based on Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
Hydrogen refuelling infrastructure

As with electric charging infrastructure, hydrogen refuelling infrastructure is an essential part of the hydrogen mobility proposition. A nationwide network of publicly accessible hydrogen refuelling stations, including high capacity stations that will be able to refuel tonnes of hydrogen a day to satisfy demand from buses and heavy-duty vehicles, is a prerequisite for the further expansion of hydrogen-based mobility. Some of the adopted policies to support the development of HRS include targets or mandates, financial incentives in the form of CAPEX support, simplifying permitting rules, and common standards.

11 countries in Europe provide CAPEX support for the construction of HRS. Out of these, five enact policies that include both a target and support. Nine countries have implemented a target for the development of an HRS network but provide no financial support or incentives.

The method of supporting HRS development differs across European countries. In the UK, the CAPEX support is available from the Office for Low Emission Vehicles under the Hydrogen for Transport Advancement Programme (“HyTAP”) that provides financial support for upgrading existing HRS and the provision of new HRS. Czechia recently began supporting HRS development through the Alternative fuel infrastructure support program – development support for hydrogen refuelling stations that was published in January 2020. In the Netherlands, HRS development qualifies for funding from the Dutch Enterprise Agency (RVO) through tax depreciation, and several HRS have financially benefited from this funding stream. Nine countries in the scope of this report have HRS targets. Targets and mandates are a key policy instrument for incentivising, forcing, or encouraging public and private entities to advance publicly beneficial projects such as hydrogen refuelling infrastructure.

The HRS targets and their fulfilment differ widely across Europe. In Belgium, the targets are included in the National Policy Framework “Alternative fuels infrastructure” which specified a target of 22 HRS by 2020, 20 of those in Flanders. The current number of HRS in Belgium as of September 2020 is two. The Hungarian National Policy framework for the development of alternative fuels infrastructure from 2016 envisages two HRS by 2020, five by 2025, and 14 by 2030. There are currently no operating hydrogen refuelling stations in the country. The Spanish National Action Framework for Alternative Energy in Transport specified a target of 20 HRS in Spain by 2020. There are currently three HRS in Spain according to the FCH Observatory.

FCEV road transport policies

The size of the FCEV M1 fleet in 2020 is 1,538 vehicles, which is almost three times less than the number of BEVs in Europe in 2009. As with BEVs, FCEVs will require initial government support to establish themselves on the market. Some EU governments have or are planning to adopt policies supporting the deployment of FCEVs. This section will provide an overview of FCEV supporting policies, such as purchase subsidies and registration tax benefits for passenger cars, buses, and heavy-duty vehicles.

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92 https://www.opd.cz/stranka/vyzva-81/
93 https://www.rvo.nl/subsidie-en-financieringswijzer/dkti-transport
94 The subsidy is suspended
95 Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
96 Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
97 Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
98 Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
99 Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
100 Figures are for European Union in 2008 and European Union plus the UK in 2020
101 European Alternative Fuels Observatory
102 Fuel Cells and Hydrogen Observatory
Passenger cars

Purchase subsidies and registration tax benefits are some of the most common policies used to support alternative vehicles sales. They have been used extensively for supporting BEVs. Both policies bridge the gap between the established and emerging technologies by decreasing the capital investment needed for the new and required technology.  

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11 countries, in dark blue, currently provide both purchase subsidies and registration tax benefits for FCEVs. 14 countries, in light blue, have purchase subsidies for FCEV passenger cars in effect. 3 countries, Belgium, Ireland, and Latvia have registration tax benefits but not purchase subsidies available.

Figure 44

Overview of purchase subsidies and registration tax benefits adoption for FCEV passenger cars

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103 Fuel Cells and Hydrogen Observatory
The amount of subsidy provided varies significantly between different member states from €2,000 in Finland up to €21,000 in Poland. The Dutch program is only for entrepreneurs and the max available purchase subsidy 36% of the total price and 75,000 EUR. Figure 45 below provides an overview of the 14 countries with purchase subsidies for FCEV passenger cars and the maximum obtainable subsidy in each one in €000s.

Source: Hydrogen Europe based on Fuel Cells and Hydrogen Observatory (fchobservatory.eu)
Buses and heavy-duty vehicles

Fuel cell buses and heavy-duty vehicles are a potential drop-in replacement for diesel trucks and diesel buses as they can be refuelled in minutes and achieve a range of hundreds of kilometres. Given hydrogen’s versatility, there is growing interest in zero emission logistics in Europe, particularly from major retailers and their transport solutions providers. The policy landscape has so far responded only partially as purchase subsidies for fuel cell buses are available in nine countries while purchase subsidies for heavy-duty vehicles are available in five.

While in some countries, like Poland and the Netherlands, the same policies and financial incentives apply for buses, HDVs, and passenger cars, other countries have different policies. In the UK, the active policy subsidises 75% of the CAPEX difference between FCEV bus and EuroV1 diesel bus but only up to 20% or €9,200 for heavy-duty vehicles under a different scheme. Slovenia reimburses up to 80% of the purchase price or €500,000 for FCEV buses, but only up to €300,000 for heavy-duty vehicles. Austria subsidizes buses depending on the number of passenger seats, with a maximum of €130,000 for buses with more than 120 passengers, while heavy-duty FCEVs receive up to €50,000 for vehicles above 12 tonnes.106

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106 Fuel Cells and Hydrogen Observatory

Figure 46

Overview of purchase subsidies and registration tax benefits adoption for FCEV buses and heavy-duty vehicles

<table>
<thead>
<tr>
<th>Color</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep blue</td>
<td>Purchase subsidy for both buses and heavy duty vehicles</td>
</tr>
<tr>
<td>Green</td>
<td>Purchase subsidy only for buses</td>
</tr>
</tbody>
</table>

Source: Hydrogen Europe based on Fuel Cells and Hydrogen Observatory (fchobservatory.eu).
5.3.2. STATIONARY POWER

The use of fuel cells for stationary power is common, especially for emergency power supply and uninterruptible power supply, with an increasing number of applications for grid balancing as well as Combined Heat and Power (CHP). CHP systems provide heat as well as electricity for buildings at high efficiency. Fuel cells have also been designed for “Micro-CHP” applications, offering high flexibility, powering residential, commercial, and light industrial buildings, and supporting the increasing distributed energy paradigm. Micro-CHP systems in the residential and commercial sector support increasing the share of distributed energy. Figure 47 provides an overview of the seven countries that provide CAPEX support for CHP stationary power fuel cell applications across Europe.

In Italy, fuel cells are eligible for tax deduction in the amount of 65% of the CAPEX costs when replacing existing generators and achieving primary energy saving of more than 20%. The maximum deduction is limited to €100,000.\textsuperscript{107} In Germany the Federal Office of Economics and Export Control (BAFA) supports mini combined heat and power generators, including fuel cell CHP systems. The focus is on existing buildings requiring systems with electrical capacity of up to 20 kW. Given the relatively small scale, the base subsidy amount is capped at €3,500 with additional allowances if certain conditions are satisfied.\textsuperscript{108} The Dutch Energy investment allowance program provides tax deduction of 45% of CAPEX costs to companies investing in energy saving assets or renewable energy.\textsuperscript{109} In the UK, an Enhanced Capital Allowance Scheme and an Annual Investment Allowance provide CAPEX support for installing FC-based CHP systems.\textsuperscript{110}

Figure 47

CAPEX support for CHP stationary fuel cell applications

Source: Hydrogen Europe based on Fuel Cells and Hydrogen Observatory (fchobservatory.eu).

\textsuperscript{107} https://www.gazzettaufficiale.it/eli/gu/2017/12/29/17/12/302/so/62/sg/pdf
\textsuperscript{108} http://www.bafa.de/DE/Energie/Energieeffizienz/Kraft_Waerme_Kopplung/Mini_KWK/mini_kwk_node.html
\textsuperscript{109} https://english.rvo.nl/subsidies-programmes/energy-investment-allowance-eia
\textsuperscript{110} https://www.gov.uk/guidance/combined-heat-and-power-incentives
5.3.3. HYDROGEN AND THE GAS GRID

The sectoral integration of power and gas grids, using hydrogen as the medium, is one of the main premises of the hydrogen economy. The injection of hydrogen from renewable energy into a retrofitted natural gas network or in a new hydrogen network could help utilise renewable energy that would otherwise be curtailed, utilise the gas grid’s immense energy storage capacities, and provide indirect renewable electricity transmission.

Gas grid hydrogen concentration

While hydrogen and natural gas have different chemical characteristics, blending hydrogen with natural gas slightly changes these characteristics. Blending these two gases can also become an important early step towards gradual gas grid decarbonisation.\textsuperscript{111} Injecting hydrogen into some natural gas distribution networks is already technically feasible today without a major overhaul of pipelines or appliances, if containing 10-20% of hydrogen by volume. High pressure transmission infrastructure and a higher percentage of hydrogen in the gas grid will have to be studied to ensure the highest safety standards. To utilise high pressure hydrogen transmission infrastructure and higher than 20% concentration of hydrogen, transmission and distribution system operators must study and potentially adapt the appropriate transmission, storage, distribution, and end-use infrastructure.

In terms of policies, one of the key issues is the maximum legal or safely acceptable hydrogen concentration in the natural gas distribution or transmission network. Germany has the highest legal concentration of hydrogen in transmission network at 10% while in Czechia the legal limit is

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure48.png}
\caption{Countries with legal or safety limits on acceptable hydrogen concentration in TSO networks}
\end{figure}

\textsuperscript{111}https://ec.europa.eu/info/sites/info/files/hydrogen_europe_-_vision_on_the_role_of_hydrogen_and_gas_infrastructure.pdf
0%. Figure 34 below presents the maximum % of hydrogen allowed in various European countries’ transmission networks, either legally or according to national safety regulations.

### 5.3.4. INDUSTRY

Hydrogen is currently used by various industries, including as a raw material in the chemical industry, as a reductor agent in the metallurgic industry, and as a feedstock for production of ammonia and methanol and various polymers. In refineries, hydrogen is used for the processing of intermediate oil products. One of the main future opportunities for hydrogen is its use in the various industrial applications and processes that would have been difficult to decarbonise through different means.¹¹²

**CAPEX subsidies**

One of the methods of incentivising industry decarbonisation is CAPEX subsidies for facility owners, to encourage them to innovate, adopt change, and decarbonise their operations. CAPEX subsidies for renewable and low-carbon non-demonstration hydrogen production projects for use in industry are in place in six countries: Austria, Belgium, Bulgaria, Finland, Germany, and the Netherlands.

Finland’s Energy Aid program provides up to 40% of the initial investment to new technologies that achieve a reduction of greenhouse gas emissions and/or energy savings. Bulgaria’s various operational programs can be used for CAPEX subsidies for specific renewable hydrogen projects for industrial purposes. The Netherlands’s Energy Investment

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Allowance provides tax deductions up to 45% of energy saving investments, which can include industrial hydrogen applications. The Flemish government in Belgium encourages companies to make their processes more environmentally friendly and energy efficient by covering 20 to 40% of capital expenditure through its Ecology Bonus Flanders program.¹¹³
CHAPTER 1: DEFINITION OF HYDROGEN PRODUCTION TYPES BY AVAILABILITY

Figure 50

Definition of hydrogen production types by availability

Source: Hydrogen Europe.
CHAPTER 2: LEVELIZED COST OF HYDROGEN ESTIMATIONS ASSUMPTIONS

Table 12 Assumptions for estimation of hydrogen production costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>EUR/kW</td>
<td>600</td>
<td>[CHE SRIA 2020]</td>
</tr>
<tr>
<td>Economic life time</td>
<td>years</td>
<td>30</td>
<td>[BNEF 2019]</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>kWh/kgH2</td>
<td>50.00</td>
<td>[CHE SRIA 2020]</td>
</tr>
<tr>
<td>Stack degradation¹</td>
<td>per 1000 hrs</td>
<td>0.12%</td>
<td>[CHE SRIA 2020]</td>
</tr>
<tr>
<td>Other OPEX²</td>
<td>% CAPEX</td>
<td>2.00%</td>
<td>[CHE SRIA 2020]</td>
</tr>
<tr>
<td>Costs of capital</td>
<td>%</td>
<td>6.0% in real terms</td>
<td>-</td>
</tr>
</tbody>
</table>

Where:

1. Captive hydrogen production on-site used exclusively for own consumption within the same facility.
2. Excess hydrogen production capacity in dedicated installations that can be valorised and sold to external hydrogen merchant companies for resale. This has been applied only to installations dedicated to supplying hydrogen merchants.
3. Hydrogen produced in large industrial installations, usually dedicated to serve a single customer or an industrial cluster. Usually produced in close vicinity to or distributed with pipelines. Whenever we could identify that the installation was serving a single customer those installations were categorised as captive. In other cases, it was categorised as merchant.
4. Hydrogen produced for retail purposes and sold in relatively small volumes, which does not warrant building its own Hydrogen Generation Unit (HGU). Usually distributed in compressed form, in cylinders or using tube trailers (200 bar), in a few cases liquefied, also mostly using trucks.
5. By-product hydrogen that is vented to the atmosphere or used as feedstock for internal processes or for onsite energy generation.
6. By-product hydrogen that is purified and sold to merchants for further resale.
7. By-product hydrogen that is sold directly to nearby captive industry.

Notes: 1) Stack degradation defined as percentage efficiency loss when run at nominal capacity. For example, 0.125%/1,000h results in a 10% increase in energy consumption over a 10-year period with 8,000 operating hours per year.
2) Operation and maintenance cost averaged over the first 10 years of the system. Potential stack replacements are included in O&M cost. Electricity costs are not included in O&M cost.

Table 13 Renewable energy capacity factors in the EU

<table>
<thead>
<tr>
<th>Entity</th>
<th>PV CF_avg</th>
<th>PV CF_top</th>
<th>PV CF_max</th>
<th>Onshore wind CF_avg</th>
<th>Onshore wind CF_top</th>
<th>Offshore wind CF_avg</th>
<th>Offshore wind CF_max</th>
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<td>18.4</td>
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<td>27.0</td>
<td>34.0</td>
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<td>28.0</td>
<td>32.0</td>
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</tr>
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<td>44.0</td>
<td>47.0</td>
<td>47.0</td>
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<td>14.9</td>
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<td>25.0</td>
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<td>12.9</td>
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<td>33.0</td>
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<td>11.9</td>
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<td>29.4</td>
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<td>22.0</td>
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<td>27.5</td>
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<td>34.1</td>
<td>46.0</td>
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<td>29.8</td>
<td>35.6</td>
<td>45.2</td>
</tr>
<tr>
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<td>16.2</td>
<td>24.2</td>
<td>25.3</td>
<td>19.6</td>
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<td>28.2</td>
<td>33.9</td>
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<td>35.7</td>
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<td>46.0</td>
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<tr>
<td>Sweden</td>
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<td>14.1</td>
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<td>46.6</td>
<td>44.0</td>
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<td>39.7</td>
<td>52.4</td>
<td>48.6</td>
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<tr>
<td>Norway</td>
<td>8.0</td>
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<td>34.6</td>
<td>49.5</td>
<td>52.4</td>
<td>41.4</td>
</tr>
</tbody>
</table>

Where: PV: CF_avg – Average CF in 1986-2015 based on EMHIRES PV | CF_top – CF for top 10% locations | CF_max – max CF for ir_global_tracking with 0.85 performance ratio, Wind: CF_top – CF for top 10% locations | CF_max - maximum CF available.
Source: JRC EMHIRES and ENSPRESO dataset for wind and solar power generation, as well as JRC, “Wind potentials for EU and neighbouring countries”, 2018.
The list of Power-to-Hydrogen, low-carbon hydrogen, and infrastructure projects that form a basis for the analysis have been collected by Hydrogen Europe from public sources. It provides a snapshot of current developments. The authors collected this information to the best of their abilities but cannot guarantee absolute completeness or accuracy of the collected information. If only estimate ranges have been given for capacity or start dates, authors adopted the average provided value. The authors never made their own conclusions as to the start date, capacity, technology, or other project information. As a result, some missing information leads to inconsistencies e.g. between the sum of planned PtH capacity of all covered countries of 21,289 MW and the sum of planned PtH capacity between 2020 – 2040 of 20,011 MW. The difference between these two numbers is due to unavailable start dates for some projects with announced capacities. Distinctly different phases of large projects are being considered as separate projects.

The authors have adopted an inclusive approach when compiling this list of projects, to develop the most exhaustive compilation of European Power-to-Hydrogen projects. The authors are not judging the feasibility of announced facilities but reporting various public and private data points. As a result, this list includes projects at all stages, including concept, FEED, detailed design & permitting, and construction.

If the authors of this report refer to specific projects and provide any project details, this information is either public or a specific permission has been given by relevant project partners.

Geographical coverage of the database consists of the EU 27, Norway, Switzerland, and the United Kingdom. Results in this chapter purposefully exclude some countries depending on the quantity and quality of the collected information.

### Table 14: Renewable energy generation cost assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>PV</th>
<th>Wind Onshore</th>
<th>Wind Offshore</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic lifetime</td>
<td>years</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>[IRENA 2019]</td>
</tr>
<tr>
<td>CAPEX</td>
<td>EUR/kW</td>
<td>700</td>
<td>1,750</td>
<td>3,900</td>
<td>[IRENA 2019], [Fraunhofer ISE 2018]</td>
</tr>
<tr>
<td>Fixed O&amp;M</td>
<td>EUR/kW/year</td>
<td>18</td>
<td>30</td>
<td>100</td>
<td>[Fraunhofer ISE 2018]</td>
</tr>
<tr>
<td>Variable O&amp;M</td>
<td>EUR/kWh</td>
<td>0.000</td>
<td>0.005</td>
<td>0.005</td>
<td>[Fraunhofer ISE 2018]</td>
</tr>
</tbody>
</table>

Source: Hydrogen Europe.
CHAPTER 5. METHODOLOGY AND GEOGRAPHIC SCOPE FOR SUB-CHAPTER 5.3

Methodology: Data have been collected by Hydrogen Europe for the Fuel Cells and Hydrogen Observatory (www.FCHObservatory.eu) through a network of national respondents.

Geographical scope: Geographical coverage of the database consists of EU countries including Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden as well as Norway, Switzerland, and the United Kingdom. Results in this chapter purposefully exclude some countries depending on the quantity and quality of the collected information.