HYDROGEN EUROPE

CLEAN HYDROGEN

MONITOR 2021

Hydrogen Europe

FOREWORD

We cannot achieve climate neutrality without hydrogen

The past year has seen ever-increasing momentum for the hydrogen industry in Europe. From being viewed as an innovative niche technology, hydrogen has become a key pillar in the European Union's (EU) energy and climate policy and is recognised as a key enabler in the EU's efforts to transition to a climate-neutral society by 2050.

As an energy vector, hydrogen can unlock the full potential of renewables, providing a means to transfer energy across sectors, time, and place flexibly. Using hydrogen technologies, we can contribute to the decarbonisation of economies, notably within industry and transport, thus making renewables relevant in new areas not accessible in the past. Furthermore, with hydrogen, we can store excess electricity generated from renewable power, thus providing grid balancing or seasonal storage whilst making the overall energy system of the future more efficient.

Europe is leading within hydrogen technologies, and we must maintain this leadership position and seize the current momentum. The EU has set ambitious hydrogen targets for 2030, and I am certain that with this 2nd edition of Hydrogen Europe's Clean Hydrogen Monitor, stakeholders from across the globe have a unique reference point to inform and update themselves on the latest hydrogen-related developments across the European continent.

Our hydrogen ambitions are within reach. Now it's time to turn ambition into concrete action via the development of a regulatory and incentives framework that will facilitate the push for clean hydrogen to reach "fossil parity", contribute to fighting climate change, creating numerous new future jobs and ultimately empower generations with clean energy forever. The time for hydrogen is now!

Jon André Løkke
President
Hydrogen Europe

It's coming closer!

As you read this foreword, the vision of a hydrogen economy that contributes to massive mitigation of climate effects is taking shape.

After years of maturing fundamental technological applications over the whole value chain, after clear proposals on how to implement them in "real life", **we now find ourselves in the midst of a disruptive change of our energy and economic system.**

This system was based, in the past, on a linear idea; it was based on the growing use of fossil energy to fuel economic growth. The link between fossil exploitation and growth has been stopped already due to the ever-larger role of renewable energy.

Hydrogen allows us to implement ever-more circular elements into our energy, industry, mobility and heating systems, even as we continue to sustain economic growth. It enables us to harvest much more results from the renewable revolution.

Climate, circularity and a real reset are the driving forces for the hydrogen revolution, and we already see how decision-makers are increasingly committing to taking this new course.

What are the possibilities?
How much should we invest?
Will there be a balance between public funding and private investment?
Which technology is ready enough?
Will we overcome the chicken and egg dilemma?
What are the volumes that we can expect?
Which concrete projects will be implemented at what time?

If you want to answer these questions, you should have a look at our annual data collection. This hydrogen monitor is the most comprehensive and deepest analysis of the hydrogen sector in Europe.

We hope it can act as a compass to guide you on your own hydrogen journey.

Stay at the forefront of these developments, enjoy this document of change. And if you wish, help us with your contributions to make it even better every year.

Europe wants to become the first climate-neutral continent on earth. **Hydrogen is the hero net zero.** Hydrogen is ready! Are you?

Jorgo Chatzimarkakis
CEO
Hydrogen Europe

TABLE OF CONTENTS

Our goal remains to provide you, our readers, with key facts and figures that may guide your business or policy decisions when dealing with this sector.

Hydrogen Europe

ABOUT THE AUTHORS:

Chapter 1: Matus Muron and Grzegorz Pawelec
Chapter 2: Grzegorz Pawelec
Chapter 3: Matus Muron
Chapter 4: Joana Fonseca
Chapter 5: Alexandru Floristean and Bastien Bonnet-Cantalloube
Chapter 6: Priscilla Ferrari de Carvalho and Grzegorz Pawelec
Chapter 7: Matus Muron

Coordinator and Reviewer: Alexandru Floristean
Editors: Amy Allsop and Michela Bortolotti

WWW.HYDROGENEUROPE.EU

Visual design: Tomasz Peukert (peukert@madebymade.pl)

INTRODUCTION

The second edition of the yearly Clean Hydrogen Monitor continues our ambition to shed light on some of the key indicators affecting the nascent (and growing) market for clean hydrogen.

Similar to last years' edition, the focus of our report is on hydrogen, which contributes to the achievement of the EU's climate ambitions, particularly the goal of ensuring net-zero emissions by 2050.

This means, in practice, presenting quantitative and qualitative indicators which shed light on **the state-of-play of the introduction of renewable and low-carbon hydrogen as a replacement to fossil fuel-based** "grey" hydrogen, but also, but also as a replacement to other fossil fuels in all sectors where hydrogen can play a significant role in achieving a net-zero economy, such as the replacement of coal in the steel sector, of heavy fuel oil and liquified natural gas in the maritime sector, diesel and petrol in the transport sector, of kerosene in aviation, of natural gas in heating and other industrial uses.

In order to achieve this goal, we have structured our report in the following manner:

- Chapter 1 contains information on the current hydrogen production capacity and demand in the European Union, European Free Trade Agreement (EFTA) countries and the UK
- Chapter 2 analyses the hydrogen production costs with a strong focus on renewable hydrogen
- Chapter 3 presents the plans for producing renewable and low-carbon hydrogen in Europe
- Chapter 4 analyses the plans to consume renewable hydrogen by industry
- Chapter 5 looks at the EU policies which have a direct and strong impact on the adoption of clean hydrogen in Europe
- Chapter 6 presents the Funding opportunities available to hydrogen in the short and medium-term, in particular from EU funding instruments as well as from the implementation of the Recovery and Resilience Facility
- Chapter 7 looks deeper into national policies and incentives that can already support the uptake of clean hydrogen and hydrogen technologies.

As a yearly report, we intend to track developments and, especially, to highlight the changes that have occurred since our last edition. As such, some chapters of our report (for example, our presentation of EU policies) should not be understood as comprehensive but as an "update" of the most important developments since our last edition.

We hope that you will find our report insightful and wish you a very pleasant read.

1

HYDROGEN DEMAND AND SUPPLY IN THE EU

The following chapter contains information about current hydrogen production capacity and demand in the European Union, EFTA, and the UK. The information presented in this document refers to data as of the end of 2019 unless otherwise specified.

The hydrogen production section of this report provides information about current production capacities, expressed in million tonnes (Mt) per year or MW of all identified hydrogen production plants in Europe, divided by:

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

The hydrogen demand section of this report provides information about the quantities of hydrogen (expressed in million tonnes) that were consumed by different end-use sectors in 2019.

For more detailed data on each country, see the Fuel Cell and Hydrogen Observatory database at: https://fchobservatory.eu

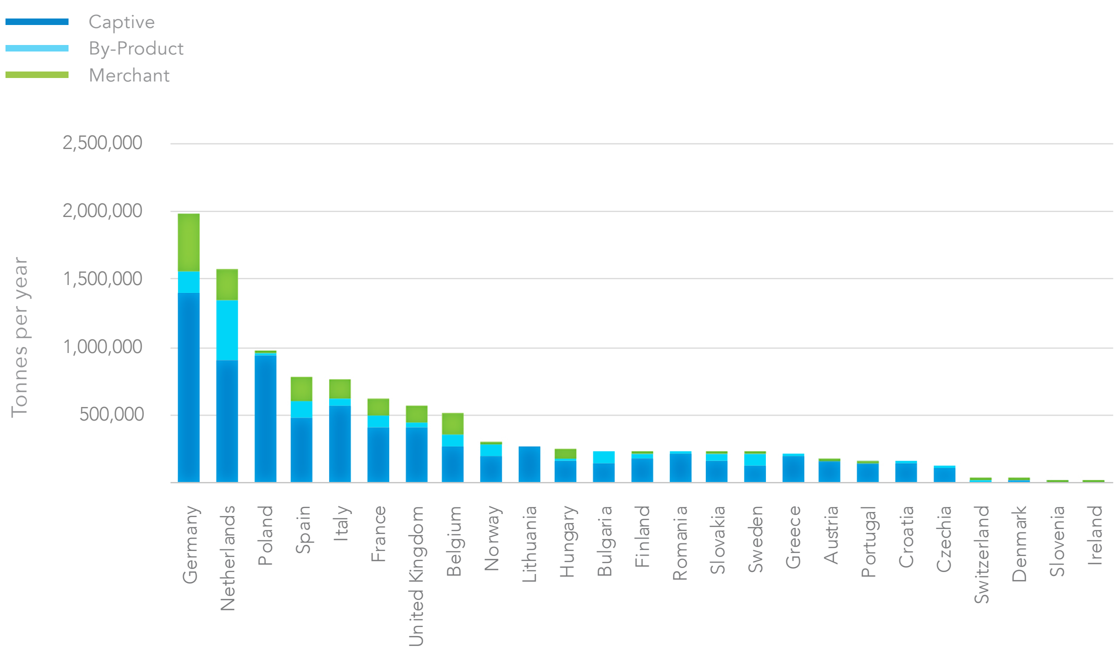
1.1 HYDROGEN PRODUCTION CAPACITY

In total, **536 hydrogen production sites** have been identified to be in operation in Europe at the end of 2019, with a total production capacity of **12.1 Mt per year**. Excluding by-product hydrogen generated as part of coke oven gas (COG), the **hydrogen production capacity** amounts to a total of **10.5 Mt of hydrogen per year** spread across **504 production points**. Based on the estimated size of the hydrogen consumption in 2019 (see the following subchapter), the **average production capacity utilisation in 2019 was 80%.**

For reference, the **EU Hydrogen Strategy has defined a renewable hydrogen production target for 2030 at 10 million tonnes.** This is almost equivalent to the total current hydrogen production capacity that has been developed over several decades.

Countries with the largest hydrogen production capacity are **Germany, Netherlands, Poland, and Spain.** These four countries account for **50% of the total EU, EFTA, and the UK** hydrogen production capacity. Figure 1 provides an overview of total hydrogen production capacity by country and by production type.

Figure 1 Total hydrogen production capacity by country



Source: Fuel Cells and Hydrogen Observatory

Figure 2 provides an overview of hydrogen production capacity (excluding coke oven gas hydrogen) as of 2019 split between different production technologies. The **"thermal"** production methods (reforming, partial oxidation, by-product production from refining operations, and by-product production from ethylene and styrene) constitute **95.5%** of total capacity. **By-product electrolysis** (i.e., capacity from chlor-alkali and sodium chlorate processes) accounts for **3.9%. Reforming with carbon capture** provides **0.5%** of total hydrogen production capacity. **Power-to-hydrogen** accounted for only **0.1%** of total hydrogen production capacity as of 2019.

This report further splits these volumes and provides information on conventional hydrogen production capacity, reforming with carbon capture, and power-to-hydrogen facilities more specifically. The thermal and by-product electrolysis categories form the conventional category used below.

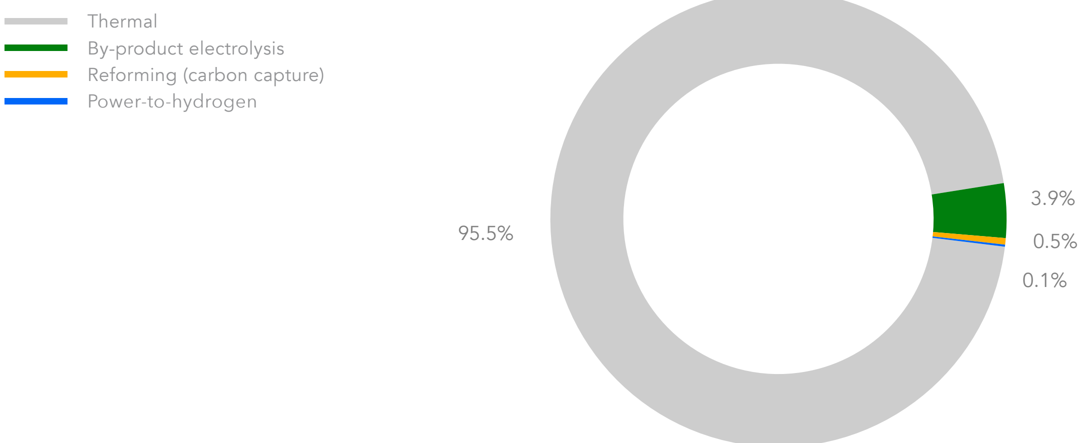
1.1.1 CONVENTIONAL PRODUCTION CAPACITY

The conventional hydrogen production capacity includes reforming, partial oxidation, by-product production from refining operations, by-product production from ethylene and styrene, and by-product electrolysis from chlor-alkali and sodium chlorate processes.

The most common technology for producing hydrogen is steam reforming of natural gas (SMR). Less common are partial oxidation (POX) and autothermal reforming (ATR). They are widely used for all applications ranging from refining, ammonia production, or any other large scale hydrogen production. Even though natural gas is the most common feed, steam reforming is also used with other feeds, including liquid hydrocarbons like LPG or naphtha.

The conventional hydrogen production capacity adds up to 10.5 Mt of hydrogen per year spread across 406 production points[1] .

Figure 2 Hydrogen generation capacity by technology



Source: Fuel Cells and Hydrogen Observatory

[1] Excluding by-product hydrogen generated as part of coke oven gas (COG)

Conventional production capacity is divided into three main categories: captive production facilities[2], merchant production facilities[3], and plants, where hydrogen production is a by-product of other processes. The boundaries between the three hydrogen production types used for this report are explained in the Methodological Note at the end of the report. Figure 4 visualises the share of the different categories. Captive production capacity accounted for 72% of total conventional hydrogen production capacity. Most of the captive hydrogen production capacity is for refining, ammonia production, and chemical industries. The by-product production capacity includes hydrogen from refining[4], ethylene, styrene, chlor-alkali process, and sodium chlorate production.

Captive hydrogen production

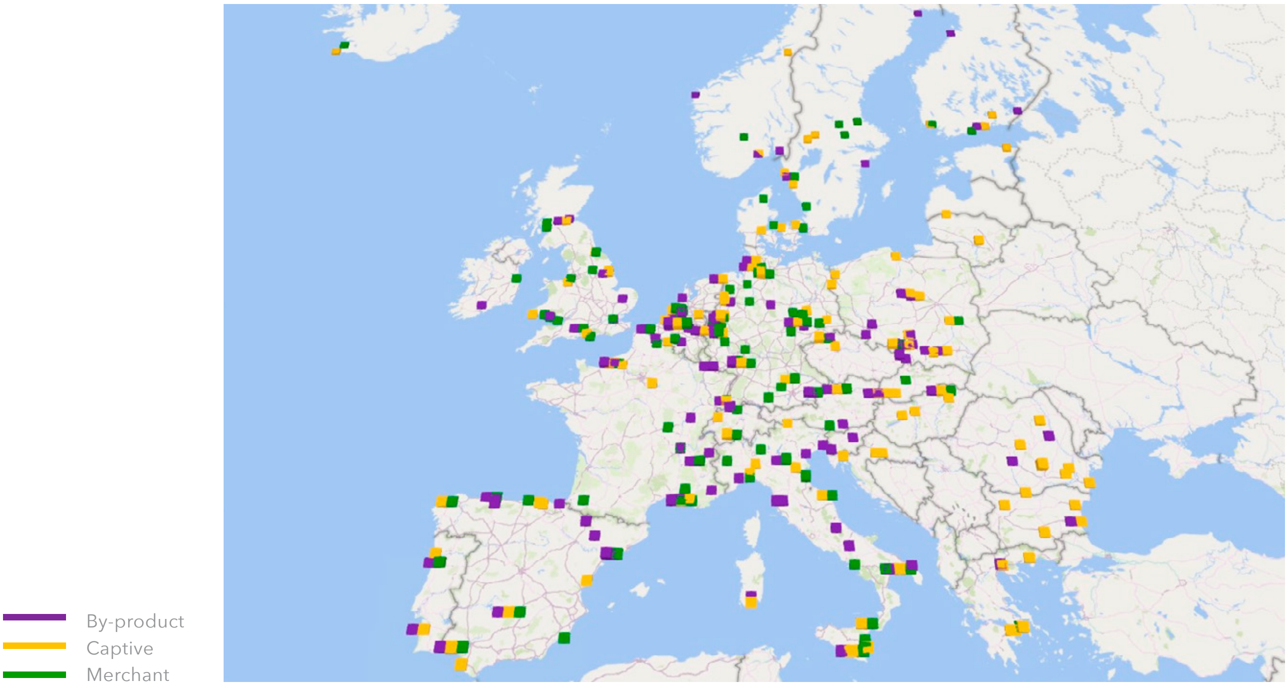
On-site captive hydrogen production is the most common method of hydrogen supply. Two-thirds of all hydrogen production capacity (7.6 Mt per year in 157 production plants[5]) were dedicated for on-site captive consumption as of 2019. Ammonia and refineries both account for 3.4 Mt each, 0.7 Mt is dedicated to methanol and other chemicals, and additional smaller capacities are allocated for facilities where a high volume of hydrogen consumption justifies an investment in a dedicated hydrogen generation unit.

Hydrogen production as a by-product

Hydrogen as a by-product[6] of other processes is produced at 143 plants. Total by-product hydrogen production capacity has been estimated at 1.5 Mt per year (around 14% of total production capacity), including:

- 0.65 Mt per year of by-product hydrogen capacity from refining processes[7]

Figure 3 Identified conventional hydrogen production sites



[2] On-site hydrogen production of hydrogen for own consumption.
[3] Hydrogen production dedicated for sales.
[4] The by-product refining share is significantly larger in reality, but accurate data is not yet available for all refineries. The rest of these amounts are thus captured as part of captive hydrogen production capacity.
[5] Excluding water electrolysis
[6] Excluding by-product hydrogen generated as part of coke oven gas (COG)
[7] The by-product refining share is significantly larger in reality, but accurate data is not yet available for all refineries. The rest of these amounts are thus captured as part of captive hydrogen production capacity.

- 0.4 Mt per year of by-product hydrogen capacity from ethylene production
- 0.21 Mt per year of by-product hydrogen capacity from the chlor-alkali process
- 0.15 Mt per year of by-product hydrogen capacity from styrene production
- 0.04 Mt per year of by-product hydrogen capacity from sodium chlorate production.

The largest amount of by-product hydrogen production capacity is in refineries from catalytic reforming and other processes.

Another potentially significant source of hydrogen is coke oven gas. Coke oven gas is used to enrich the calorific value of the other process gases for use in blast furnace stoves, at the reheating furnaces of the hot strip mills, for the under firing of coke ovens, and other high-temperature processes. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and used in power plants[8]. While hydrogen generally comprises 55%-65% of coke oven gas, it is extracted and separated from the mix in rare cases. Therefore, while it is important to mention, it is not included in the hydrogen production capacity numbers above.

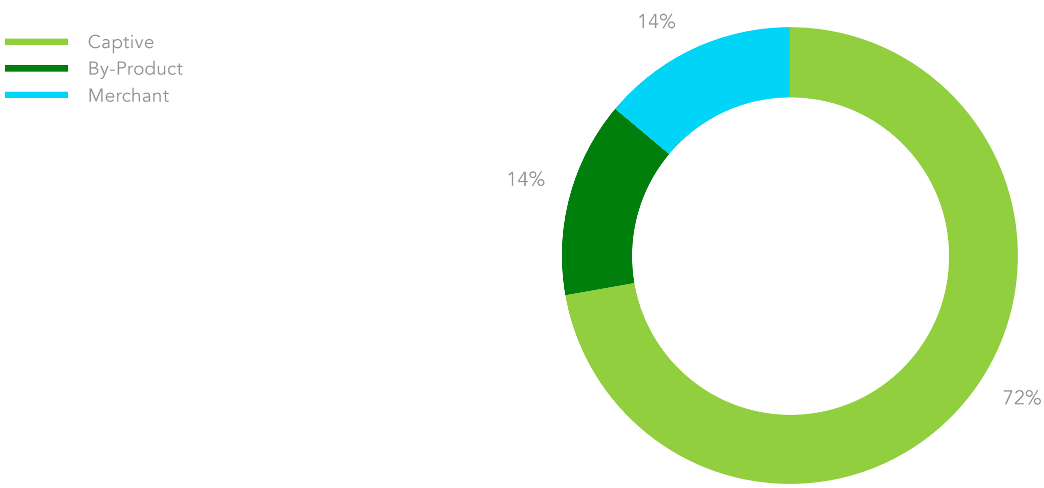
Merchant hydrogen production

Another large group of conventional hydrogen production are merchant plants which produce hydrogen mostly for external sales. This report estimates that there were 106 conventional merchant hydrogen plants operational in Europe in 2019[9]. They represent 14% of the total hydrogen production capacity (1.5 Mt per year).

Merchant hydrogen plants can be divided into two main sub-categories. In the first category are plants dedicated to supplying a single large-scale consumer with only excess capacity available to supply the retail hydrogen market. In the second category are small and medium scale hydrogen production sites designed to supply retail customers primarily. While merchant plants dedicated to a single large consumer are comparable in size to captive hydrogen production facilities, purely merchant plants supplying retail customers tend to be significantly smaller.[10]

The merchant hydrogen market in Europe is led by four companies: Air Liquide, Air Products, Linde, and Messer. Their assets constitute 90% of capacity and 81% of total merchant hydrogen production plants.

Figure 4 Structure of conventional hydrogen production capacity by type



[8] R. Remus, M. A. A. Monsonet, S. Roudier y L. D. Sancho, «Best Available Techniques (BAT) Reference Document for Iron and Steel Production,» JRC Reference Report, 2013.
[9] Excluding water electrolysis
[10] D. Pichota, L. Granadosa, T. Morela, A. Schullera, R. Dubettiera, F. Lockwood, "Start-up of Port-Jérôme CRYOCAP Plant: Optimized Cryogenic CO2 Capture from H2 Plants", Energy Procedia 114 (2017) 2682 – 2689.

1.1.2 REFORMING WITH CARBON CAPTURE

In 2019, out of the 504 identified hydrogen production plants, only three were using carbon capture technologies:

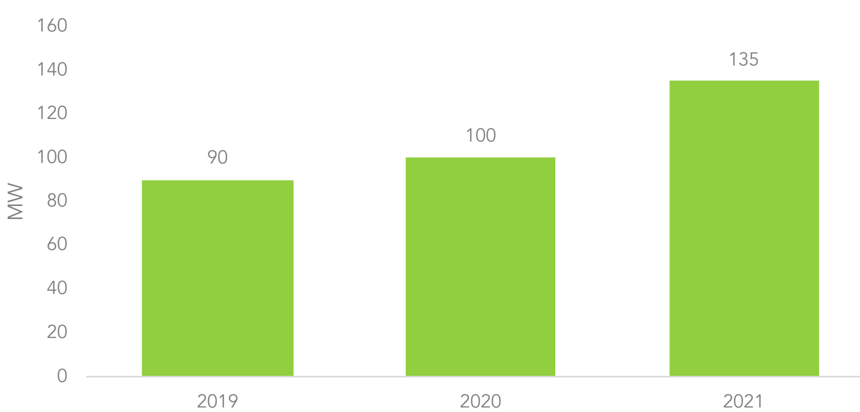
- Air Liquide CRYOCAP installation in Port Jerome, France, capturing CO2 from the hydrogen production plant, which supplies hydrogen to an Exxon refinery. The CRYOCAP technology uses cryogenic purification to separate CO2 from the PSA off-gas. The captured and liquefied CO2 is delivered to the local beverage industry. The installation is capable of capturing up to 3,000 tonnes of CO2 per day, but its utilised capture is significantly smaller.
- Shell refinery in Rotterdam, where CO2 from hydrogen production is captured as part of the OCAP project[11]
- Grupo Sappio hydrogen production unit in Mantova, Italy, with a hydrogen production capacity of around 1,500 Nm3/h

The total share of reforming with carbon capture from methane with CCS/CCU (also known as "blue" hydrogen) in all hydrogen production capacity was **0.5% of the total**.

1.1.3 POWER-TO-HYDROGEN PRODUCTION CAPACITY

While power-to-hydrogen technology has been available and utilised for decades, it is only now emerging as a future large-scale hydrogen production technology. Traditionally, power-to-hydrogen has been employed in some industries where hydrogen demand exceeded the economic feasibility of hydrogen deliveries in cylinders or tube trailers. However, the demand was insufficient to invest in a steam methane reformer and associated on-site infrastructure. The most common examples include electrolysers installed for captive hydrogen production at food processing facilities (fat hardening), glass manufacturers, merchant production, or power plants where hydrogen is used for cooling purposes.

Figure 5 Cumulative installed power-to-hydrogen capacity in EU, EFTA, UK (MW)

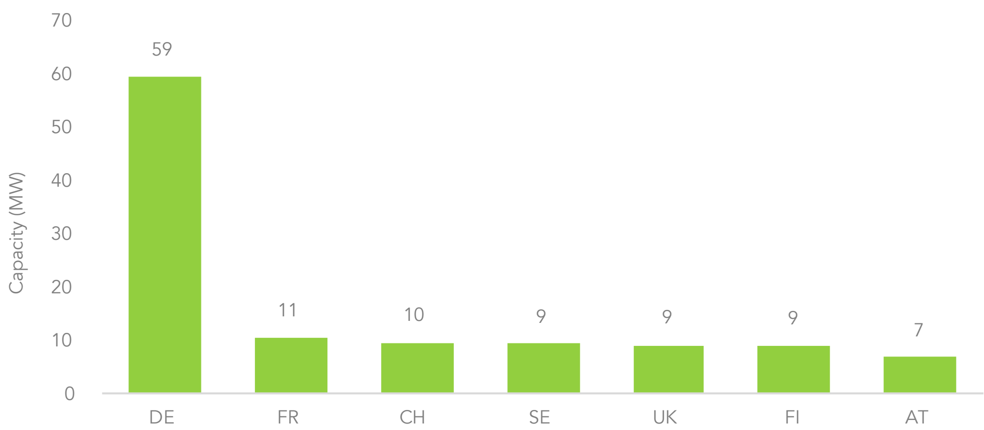


Source: Hydrogen Europe

[11] More information available at: https://www.ocap.nl/

As of August 2021, Hydrogen Europe identified 129 PtH sites in operation in the EU, EFTA, and UK amounting to 135 MWel. So far, they are a marginal part of the market, constituting only 0.1% of total installed hydrogen production capacity. A large number of these installations have been built as demonstration projects, but several commercial multi-MW projects became operational in 2019. Figure 5 shows the cumulative installed power-to-hydrogen capacity from 2019 to 2021. The total installed capacity has increased by 45 MW between 2019 and 2021. Chapter 3 will provide further information on planned PtH projects in the short, medium, and long term. Hydrogen Europe acknowledges that there are numerous smaller operational power-to-hydrogen facilities in the tens or hundreds of kW range that have not been included in the numbers below. Use cases of the identified projects range from refining, merchant sales, industrial manufacturing, mobility, and others. Germany accounts for 44% of the identified capacity and 29% of projects in the EU, EFTA, and the UK. Other countries with significant installed capacity are France with 11 MW, Switzerland with 10 MW, Sweden, United Kingdom, and Finland with 9 MW each, and Austria with 7 MW.

Figure 6 Countries with the highest installed PtH capacity in 2021



Source: Hydrogen Europe

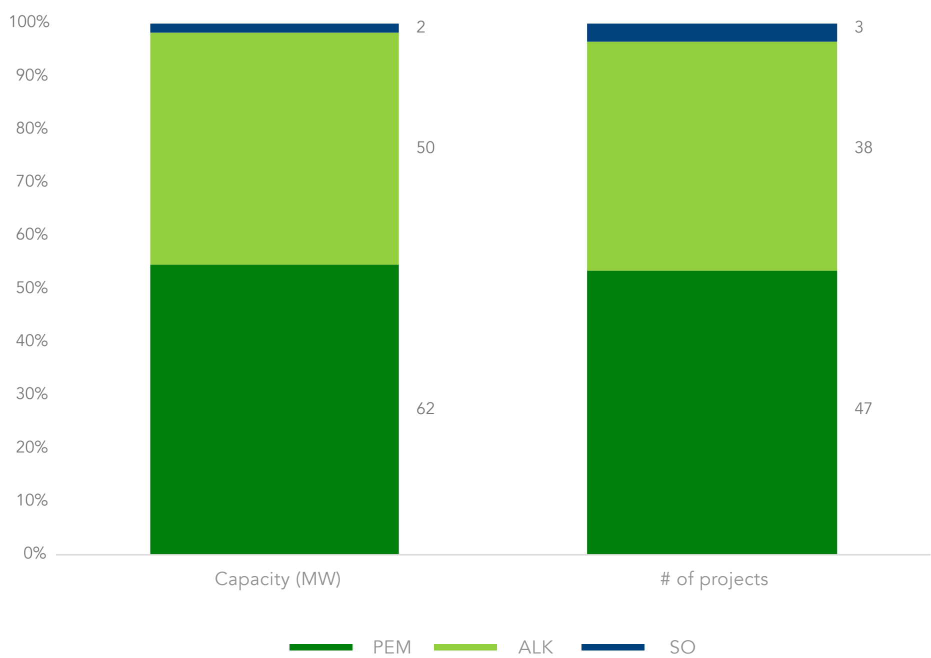
Figure 7 provides details on the electrolyser technology data available for 89 projects representing 114 MW of the operational PtH capacity. PEM electrolysers constitute 55% or 62 MW of currently operational capacity, while ALK accounts for 44% or 50 MW.[12] The numbers are largely similar in terms of projects, with 47 projects or 53% using PEM technology and 38 projects or 43% using ALK technology.[13]

Figure 8 provides details about the electricity connection of operational PtH projects. They are dominated by grid connections providing 65% or 85 MW of PtH capacity and 68% or 88 projects. Direct connection to a renewable energy source accounts for 31% or 34 MW of capacity and 28% or 36 projects. Projects with both a direct and grid connection are less common for the time being, with only five MW split among five projects.

Figure 9 provides details about the electricity source of operational PtH projects regardless of whether they use a direct or a grid connection. The electricity source information is available for 116 MW and 101 projects. 46% or 53 MW come from unspecified renewable sources. Wind constitutes 29% or 34 MW. The "other" category refers to grid mix or electricity from incineration plants and comprises 15% or 17 MW of capacity. Overall, 85% of PtH capacity and 94% of projects are powered by renewable electricity either directly or via a power purchase agreement.

Figure 7

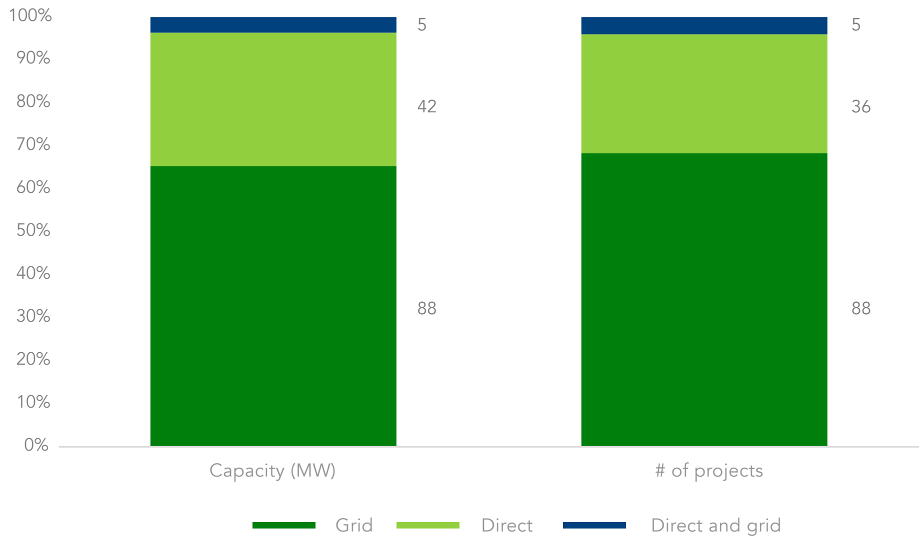
Operational electrolyser technology by capacity and projects



Source: Hydrogen Europe

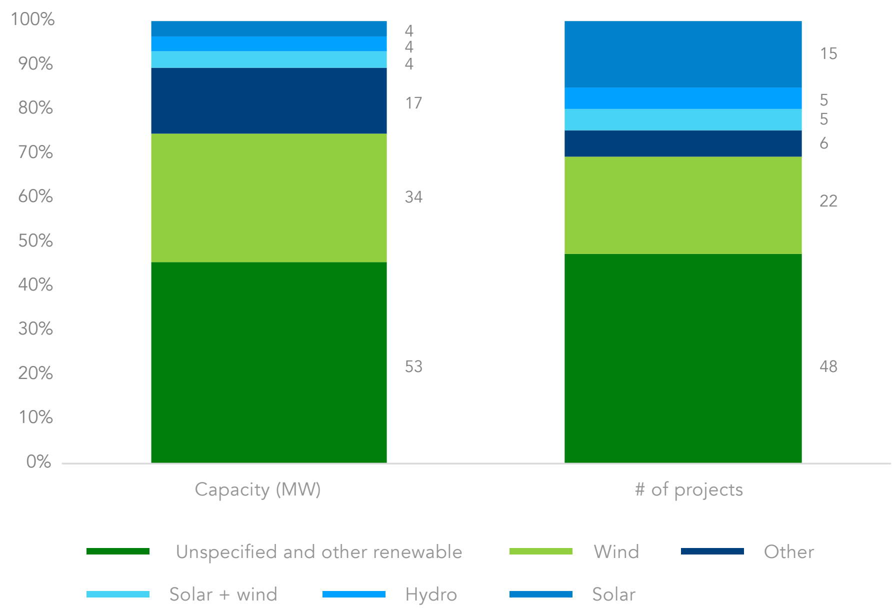
[12] Numbers may not sum to 100% due to rounding
[13] Numbers may not sum to 100% due to rounding

Figure 8 Electricity connection of operational PtH projects



Source: Hydrogen Europe

Figure 9 Electricity source of operational electrolysers



Source: Hydrogen Europe

1.2 HYDROGEN DEMAND

1.2.1 DEMAND BY SECTOR

The biggest share of hydrogen demand comes from refineries, which were responsible for 49% of total hydrogen use (~4.1 Mt), followed by the ammonia industry with 31% (~2.6 Mt).

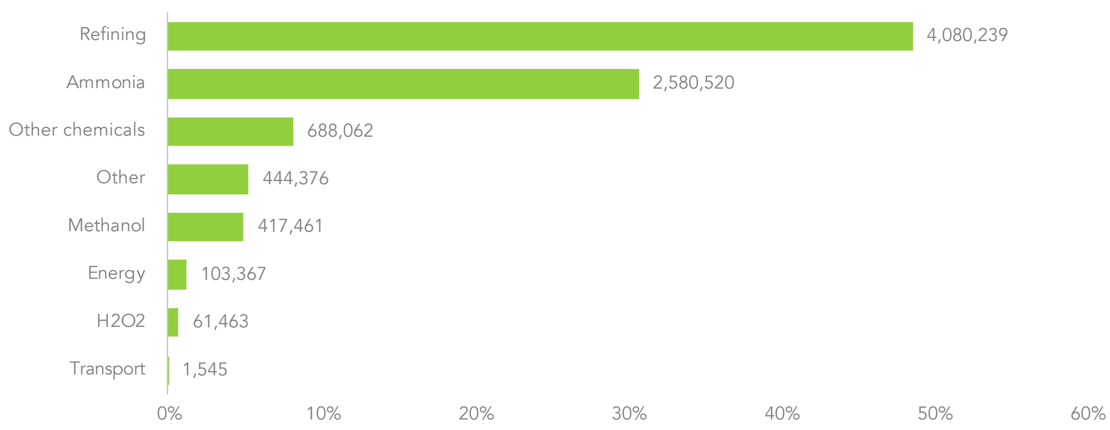
Total demand for hydrogen in 2019 has been estimated at 8.4 Mt. The biggest share of hydrogen demand comes from refineries, which were responsible for 49% of total hydrogen use (~4.1 Mt), followed by the ammonia industry with 31% (~2.6 Mt). Together these two sectors consumed almost 80% of total hydrogen consumption in the EU, EFTA, and UK. The chemical industry consumes about 13%.

Emerging hydrogen applications for clean hydrogen, like the transportation sector, comprised in 2019 only a minuscule portion of the market (<0.1%).

REFINING

The 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 relates to several processes such as hydrogenation, hydrodesulfurisation, hydrodenitrification, and hydrodemetalization. Hydrocracking involves transforming 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, this report estimates that the total hydrogen demand from the oil refining and petrochemical industry was 4.1 Mt in 2019.

Figure 10 Total demand for hydrogen in 2019 by application



Source: Fuel Cells and Hydrogen Observatory

AMMONIA

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 2019 has been estimated at 2.6 Mt.

CHEMICAL INDUSTRY

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

Total demand for hydrogen from the chemical industry (excluding ammonia production) has been estimated at 1.2 Mt in 2019.

Refining, ammonia production, and other chemical industries are together responsible for around 92% of the 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% H2) is used commonly as an inert protective atmosphere in conventional batch annealing in annealing furnaces. Batch annealing with 100 % hydrogen is also possible, resulting in better productivity, improved mechanical properties, and surface and product quality. Using hydrogen for the Direct Reduction of Iron (DRI) is another important future driver of hydrogen consumption in steel production, with the Hybrit project in Sweden having produced its first hydrogen reduced sponge iron in 2021. For more details on future industrial demand for low-carbon hydrogen in steel production, please consult Chapter 4.

OTHER

There are several other uses of hydrogen. In glass manufacturing, hydrogen is used as an inerting or protective gas. In food processing, hydrogen is used for margarine production by hydrogenating fatty acids in vegetable oils. It is also used for energy by either burning it in boilers, using it in combined heat and power units, using it in a fuel cell to generate heat and electricity, or using it for generator cooling. It is also used as a fuel either in a fuel cell or by burning it in a combustion engine, but these applications are only starting to become commonplace.

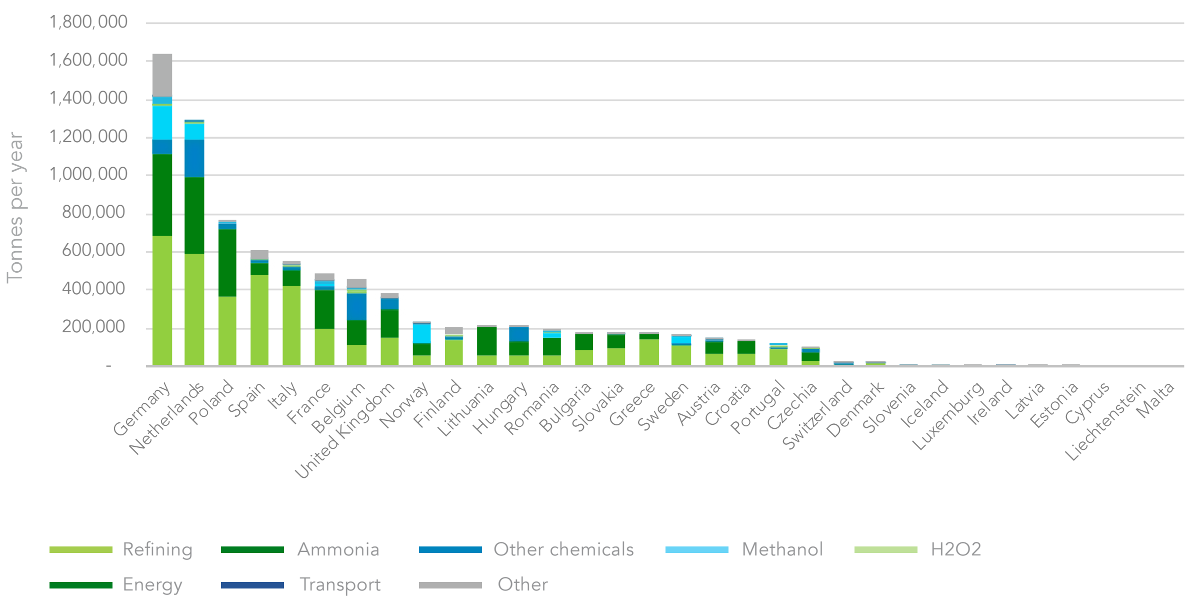
1.2.2 DEMAND PER COUNTRY

More than half of the total EU, EEA and UK hydrogen consumption takes place in just four countries: Germany (20%), the Netherlands (15%), Poland (9%), and Spain (7%).

Similarly to the overall results for the entire geographic scope of this report, in most countries, the dominant hydrogen demand comes from the refining industry. In some countries like Spain, Italy, Finland, Greece, or Portugal, refining is responsible for most domestic hydrogen consumption. In the case of Poland and Lithuania, a significant percentage of hydrogen demand comes from the ammonia industry.

More than half of the total EU, EEA and UK hydrogen consumption takes place in just four countries: Germany (20%), the Netherlands (15%), Poland (9%), and Spain (7%).

Figure 11 Total demand for hydrogen in 2019 by country



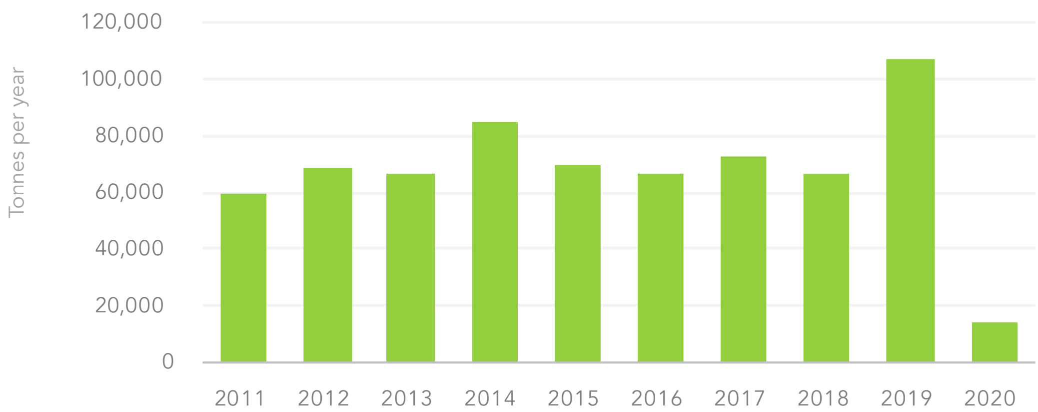
Source: Fuel Cells and Hydrogen Observatory

1.3 INTERNATIONAL TRADE OF HYDROGEN BY EU COUNTRIES

This sub-chapter refers to data for 2020, unlike most of the used data in the chapters above that refers to 2019. As in previous years, only a relatively small portion of annual hydrogen production was subject to international trade in 2020. The total amount of hydrogen exported in 2020 by EU countries both to other EU member states as well as externally amounted to 0.013 Mt, which is less than 0.2% of total hydrogen consumption. This figure is very low compared to previous years. From 2010 to 2018, EU countries usually exported between 0.06 and 0.08 Mt of hydrogen while the year 2019 saw a record volume of export of over 0.1 Mt. Compared to those years, the volume of hydrogen trade in 2020 fell by over 80%. This could have been due to Covid-19, but given the relatively small volumes concerned, any variation from several industrial sites supplied through pipelines from a plant in a different country could have had that kind of effect.

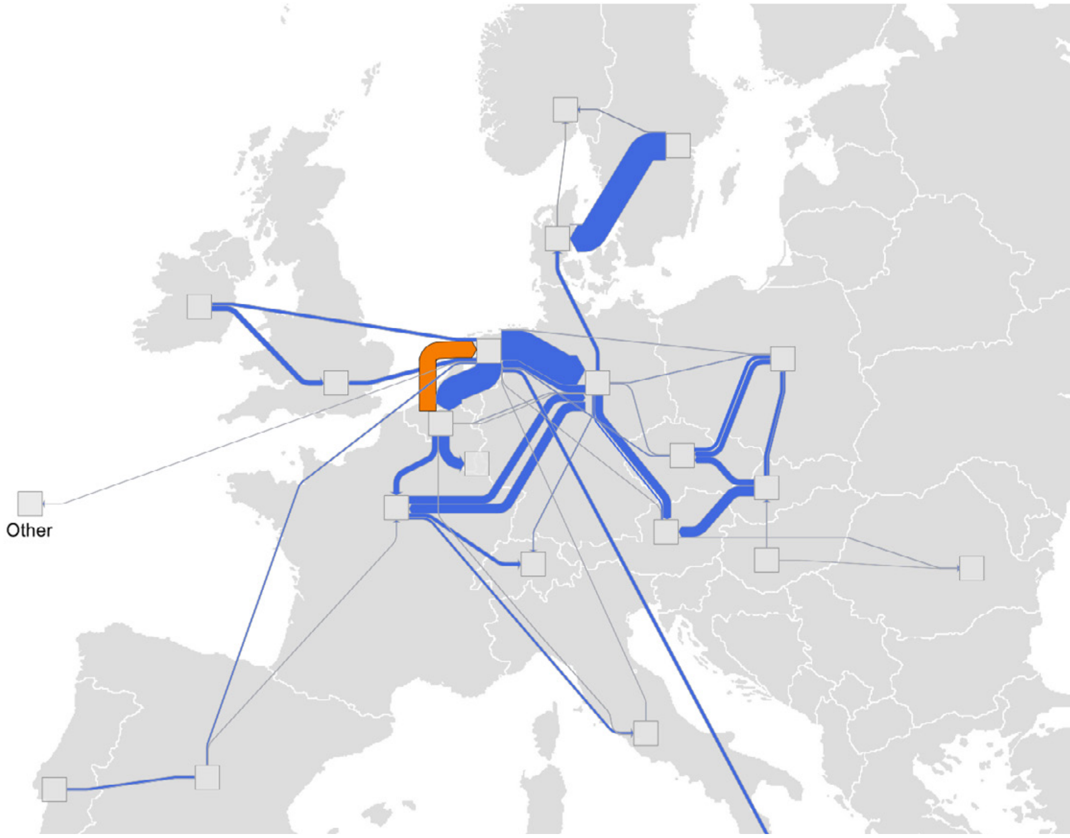
Most of this trade occurred within the EU, with only 696 tonnes (5%) exported to countries outside of the EU in 2020. Hydrogen imports from outside of the EU are equally unimportant, with only around 87 tonnes imported into the EU in 2020, of which 2/3 were from Switzerland.

Figure 12 Hydrogen exports reported by EU countries



Source: EUROSTAT international trade database

Figure 13 Exports of hydrogen by EU member states in 2020[14]



Source: Hydrogen Europe, based on EUROSTAT international trade database

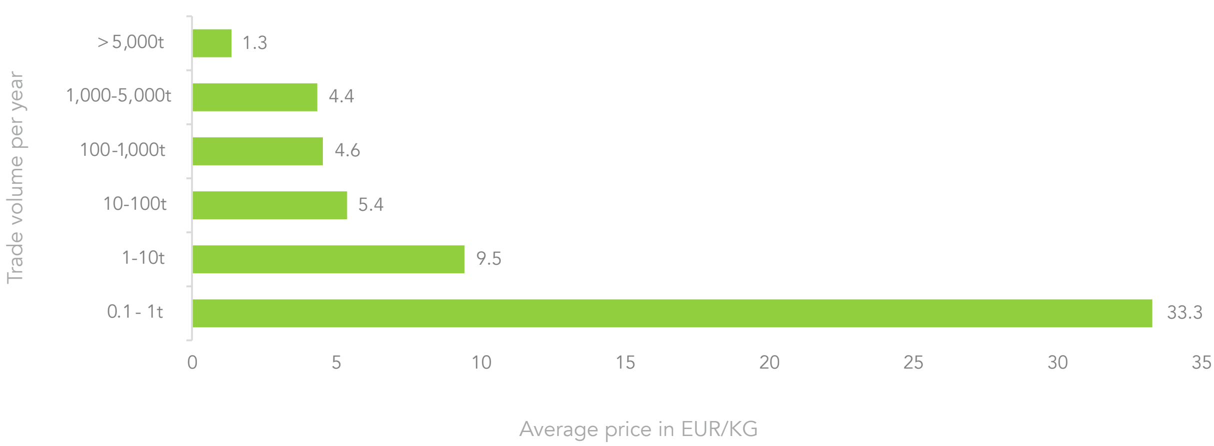
[14] For visibility purposes the figure only shows flows of hydrogen of more than 10 tonnes per year. The exports from Belgium to the Netherlands (shown in orange) have been scaled down by a factor of 10x.

By far the biggest exporter of hydrogen in 2020 in the EU was Belgium with over 6 thousand tonnes (44% of total EU hydrogen exports), followed by the Netherlands (3,500 tonnes and 25%) and Germany (1,100 tonnes and 8%). Over 55% of all trade between EU countries involves The Netherlands, Belgium and France, which are interconnected with a hydrogen pipeline network, owned and operated by Air Liquide.

Excluding trade between those three countries, most of the remaining hydrogen exports by EU member states in 2020 went from the Netherlands to Germany (1,000 tonnes) and from Sweden to Denmark (900 tonnes). Trade between all the other EU countries rarely exceeded 100-200 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 pressurised containers for such applications like laboratory analysis. The price of such highly pure hydrogen can exceed 30 EUR/kg. Higher volumes are distributed with cylinders or tube trailers with a much lower price of 5 – 15 EUR/kg. Hydrogen prices distributed via pipelines are set by SMR production costs, which in 2020, due to low natural gas prices, were around 1.0 – 1.2 EUR/kg. The significant increase in methane prices in 2021 is likely to have an important impact on this indicator; however, data relative to hydrogen prices in 2021 was not available at the time of drafting this report.

Figure 14 Average 2020 hydrogen price in international trade, depending on annual volume of trade



Source: Hydrogen Europe based on Eurostat data

2

LEVELIZED HYDROGEN PRODUCTION COSTS IN THE EU

The following chapter contains an estimation of current (2020) electrolytic and renewable hydrogen production costs in the EU, as well as a brief assessment of the development of those costs over the past years and expected near-future developments.

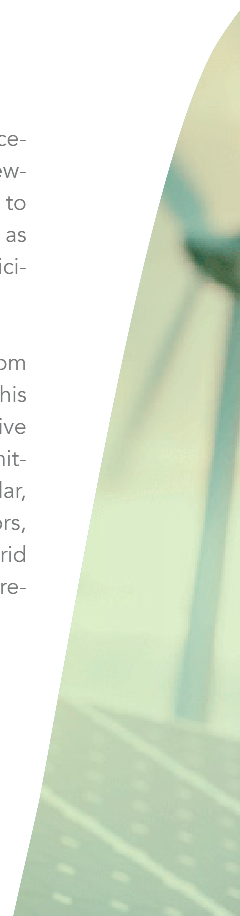
The goal of this analysis is to track the development of those costs to compare them with several benchmarks, most crucially – the costs of hydrogen production using the incumbent fossil-fuel technology, which is steam methane reforming without CCS (so-called "grey" or "fossil" hydrogen).

Therefore, the ultimate purpose of this analysis is to help calculate the current cost gap that needs to be bridged to make unsubsidised electrolytic hydrogen production competitive in the EU.
The production costs were estimated for two scenarios:

- Electrolyser using grid electricity.
- A direct, physical connection between a renewable electricity source (RES) and the electrolyser.

While 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 and as carbon-intensive as the electricity supplied to it by the grid.

Although electricity supplied by the grids is far from being fully decarbonised in many EU countries, 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 which can result in renewable energy curtailment.



The ultimate purpose of this analysis is to help calculate the current cost gap that needs to be bridged in order to make unsubsidized electrolytic hydrogen production competitive in the EU

Located strategically, electrolysers can produce hydrogen at times when the renewable production exceeds grid export capacity avoiding curtailment of wind and solar energy, especially if hydrogen infrastructures (transport and/or storage) are made available. When addressing long-term (structural) congestions, strategically placed, large scale electrolysis installations would not only benefit from the economies of scale but could help balance the entire grid and not only a single RES. In cases where Power-to-Hydrogen (PtH) installations would be dispatched by the TSO/DSO specifically to address the RES curtailment issue, it would make sense for the produced hydrogen to be viewed as entirely renewable, even when connected to a high carbon-intensive electricity grid.

Electrolysers can also serve as a variable load, following signals from electricity transmission system operators to provide frequency reserves such as FCR or as an FRR, voltage control and even synthetic inertia, as today other technologies already offer (e.g., power generators, demand response, battery storage). Some of these capabilities have been tested and demonstrated in various European projects.

In the coming years, grid-connected PtH plants should be able to produce 100% renewable hydrogen using grid electricity and 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, such a scenario was not included in the quantitative analysis at this point.

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.

The analysis in this chapter is based on data for which a complete yearly dataset is available, i.e., 2020. As 2021 saw a significant increase of both natural gas prices as well as electricity prices across Europe, driven by a surge in demand for energy, bottlenecks on the supply side and partially by higher CO2 prices, the landscape for hydrogen production costs and their competitive position against fossil fuels is likely to look very different in next year's analysis.

Table 1 Key distinctions between the two hydrogen production scenarios

Criteria	Grid connected electrolysis	Direct connection to RES
Carbon intensity	Carbon intensity of the grid (based on most recent EEA[15] assessment)	Zero-carbon (100% renewable)
Electricity costs	Wholesale electricity price (based on data obtained from the ENTSO-e Transparency Portal)	RES Levelized cost of electricity (own estimation of LCOE based on most recent IRENA RES deployment costs data)
Network costs, taxes and fees	Applicable (based on data obtained from Eurostat)	Not applicable
Scale	10.0 MW electrolysis	10.0 MW electrolysis
Capacity factor	4,000 off-peak hours	Equal to the capacity factor of the RES it is connected to.[16]

Source: Hydrogen Europe

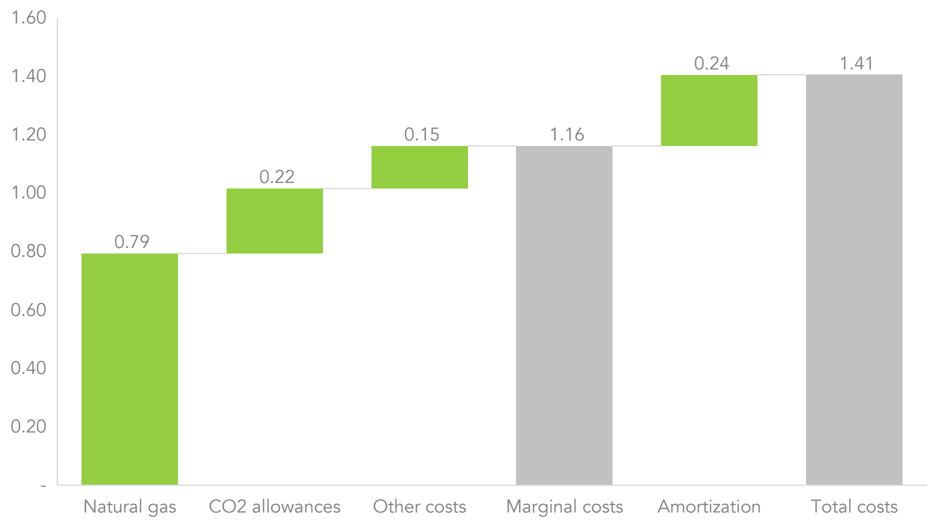
[15] EEA = European Environment Agency (https://www.eea.europa.eu/)
[16] Only in case when the electrolyser's power is equal to that of the RES. When the size of an electrolyser is smaller than RES, its capacity factor can be significantly increased.

2.1 SMR BENCHMARK

As has been noted in the market analysis section, currently 'grey' hydrogen, produced from fossil fuels – most commonly from natural gas via steam methane reforming - accounts for an overwhelming portion of hydrogen production in the EU (and worldwide). Replacing that fossil fuel made hydrogen, therefore, presents the most immediate market opportunity for renewable hydrogen. As a result, production costs of hydrogen through the SMR process provide a useful price benchmark for all alternative, clean hydrogen production technologies.

In 2020 we estimate that, on average, the levelized production costs of hydrogen by SMR in the EU-27 were approximately **1.41 EUR/kg of H2**. Furthermore, as SMR plants are already operational (and in many cases long amortised), marginal - not levelized - costs may, in many cases, be a better benchmark. Excluding the impact of CAPEX (amortisation), estimated grey hydrogen marginal production costs in the EU-27 in 2020 were around **1.16 EUR/kg**.

Figure 15 Average hydrogen production costs via SMR in the EU-27 in 2020 (in EUR/kg)



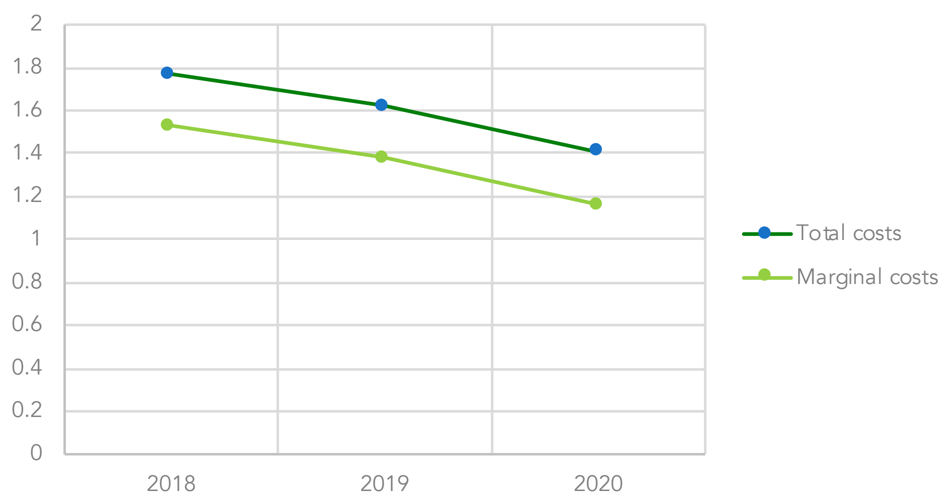
Source: Hydrogen Europe.

Even though costs of CO_2 allowances were starting to rise in 2020, a decrease in natural gas prices, which occurred as a result of the economic downturn caused by the COVID-19 pandemic, more than made up for the CO_2 allowances price rise. As a result, grey hydrogen production costs in 2020 were significantly lower than in previous years.

However, it should be noted that replacing grey hydrogen is by far not the only business case for clean hydrogen. In the case of numerous other applications – most notably in the road mobility sector – the break-even price for hydrogen might be significantly higher than the grey hydrogen production price level. Furthermore, existing and proposed legislation, e.g., the RED II directive, create additional demand for clean hydrogen, for which clean hydrogen no longer competes with grey hydrogen.

Replacing grey hydrogen is by far not the only business case for clean hydrogen. In the case of numerous other applications – most notably in the road mobility sector – the break-even price for hydrogen might be significantly higher than the grey hydrogen production price level.

Figure 16 Average hydrogen production costs via SMR in the EU-27 in 2018-2020 (in EUR/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.

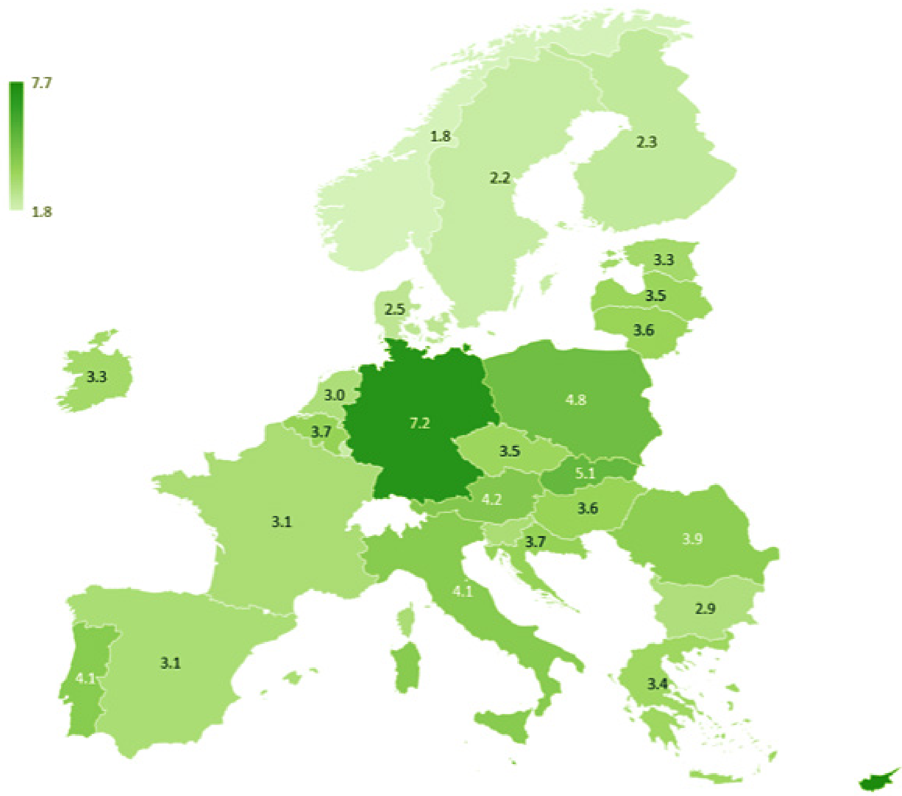
2.2 GRID-CONNECTED ELECTROLYSIS

2.2.1 COSTS OF PRODUCTION

The hydrogen production costs using grid electricity in the EU (together with Norway) in 2020 **have been estimated in the range of 1.8-7.7 EUR/kg** (compared to 2.6 – 9.5 in 2019), with the average for all countries being **3.75 EUR/kg** and a median of 3.5 EUR/kg (4.7 and 4.2 respectively in 2019).

The highest costs of grid electricity hydrogen production are in Cyprus (7.7 EUR/kg) and Germany (7.2 EUR/kg), followed by Malta with 6.3 EUR/kg. On the other end of the spectrum are the Scandinavian countries: Norway (1.8 EUR/kg), Sweden (2.0 EUR/kg), Finland (2.3 EUR/kg) and Denmark (2.5 EUR/kg). The only other country outside of Scandinavia where the costs of producing hydrogen using grid electricity are as low is Luxemburg, with costs estimated at 2.3 EUR/kg.

Figure 17 Map of grid-connected electrolysis hydrogen production costs in the EU in 2020



Source: Hydrogen Europe

There are at least a couple of reasons why such large differences between countries exist. The most obvious one is the difference between wholesale electricity prices, which has the biggest contribution to the final cost of hydrogen in most countries. High wholesale electricity prices explain to a large extent the high hydrogen cost in Cyprus and Malta, where the wholesale electricity prices are among the highest in Europe. Yet, in the case of Germany, the hydrogen production costs are one of the highest even though it has one of the lowest wholesale electricity prices in Europe. The reason why hydrogen production costs in Germany are so high is high taxes charged on top of wholesale electricity price, which in this case constitute around 58% of the total cost, while in Bulgaria, Luxembourg, and Malta, the contribution of taxes to the final hydrogen production costs are only around 1-3%.

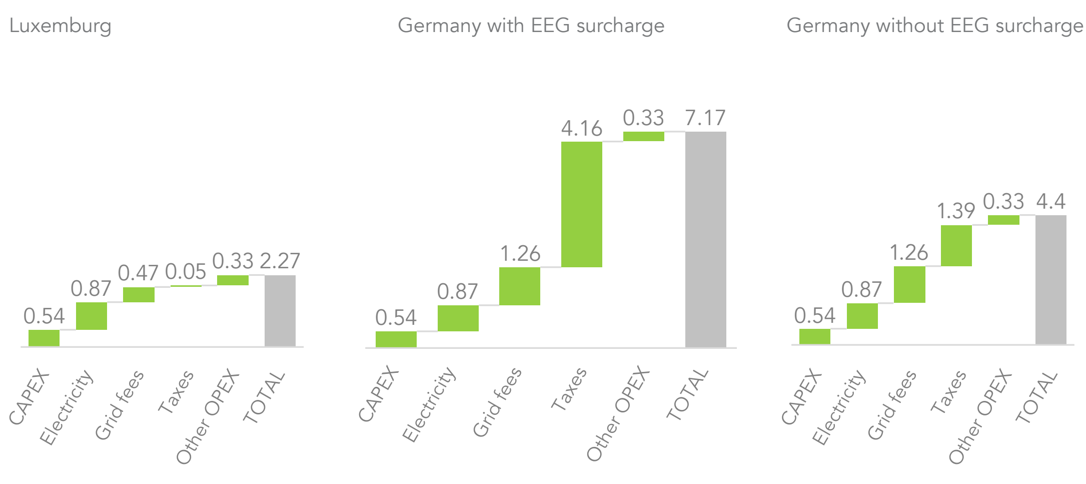
It is especially interesting to compare costs in Germany to those in Luxembourg. As Luxembourg is participating in a single energy grid with Germany, it enjoys the same low wholesale electricity prices as Germany, thanks to high penetration of cheap renewables. However, most of the balancing costs are borne by the German end-users, with very low taxes and grid fees applied in Luxembourg. As a result, it is one of the cheapest countries to produce hydrogen with grid-connected electrolysis in the EU, with total costs more than three times lower than Germany, which has the same electricity prices.

It should also be noted that one of the key contributors to grid fees in Germany is the renewable energy surcharge (EEG surcharge). If the electricity supplied via the grid were of renewable origin, this surcharge would not apply, significantly reducing the impact of grid fees on hydrogen production costs in Germany and lowering the total production costs to around 4.4 EUR/kg (close to EU average).

The following figure shows calculated hydrogen generation costs in the EU, based on wholesale electricity prices and network costs and fees for 2020.[17] The above calculations were based on the assumption that the electrolyser would run on average around 4,000 hours per year, in off-peak hours, when the wholesale electricity prices are lowest. This is close to optimum for most EU countries. If

Figure 18

Comparison of hydrogen production costs via grid-connected electrolysis in Germany and Luxembourg

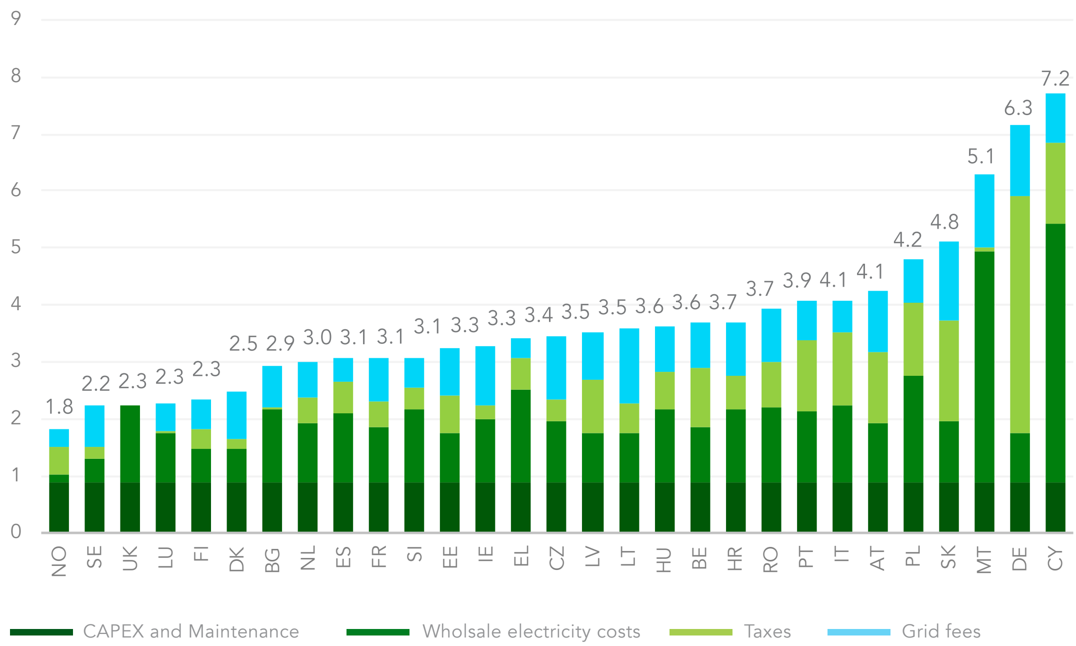


Source: Hydrogen Europe

[17] 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.

Figure 19

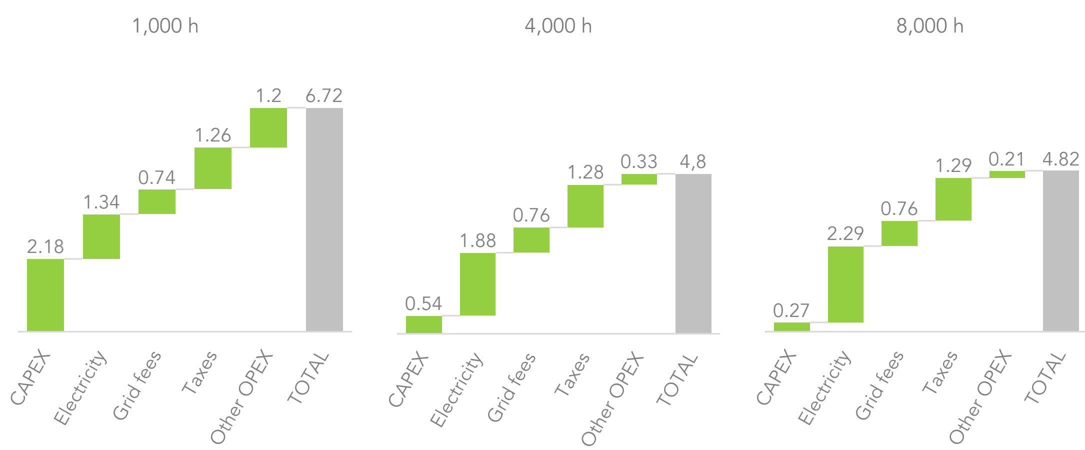
Grid-connected electrolysis hydrogen production costs in the EU in 2020 (in EUR/kg)



Source: Hydrogen Europe

Figure 20

Comparison of hydrogen production costs (in EUR/kg) with grid-connected electrolysis in Poland, depending on the number of operating hours.



Source: Hydrogen Europe

[18] In case of Poland, it would result in average price of 26.5 EUR/MWh compared to 36.4 EUR/MWh in the 4,000 hour per year base case.

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.

one increased 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. Reversely, limiting the operational time only to a few hours each day could drive the average price of electricity down[18]. 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 in the figure below (on the example of Poland).

2.2.2 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, it would make sense for the carbon intensity of the produced hydrogen to be counted as zero. Another way of ensuring a renewable character of 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 is 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 2019[19], the carbon footprint of hydrogen ranges from 0 kgCO2/kgH2 in Iceland to 37.6 kgCO2/kgH2 in Poland. **Production of hydrogen using the EU-27 average electricity mix in 2020 would have resulted in emissions of 12.8 kgCO2/kgH2** (last year's edition showed that, in 2019, this figure was 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 that of renewable hydrogen (i.e., zero).

In a number of other countries, including **Norway, Sweden 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 on the EU level**, including the one set in EU taxonomy on sustainable finance[20] and the RED II for renewable transport fuels of non-biological origin (RFNBO) – which has been set at least 70% GHG savings compared to fossil fuel benchmark (equivalent to 3.384 kg CO2 per kg of H2).

In all those countries, with the addition of Lithuania and Luxembourg, 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 the standard value achievable with exiting SMR installations with CCS retrofit.[21]

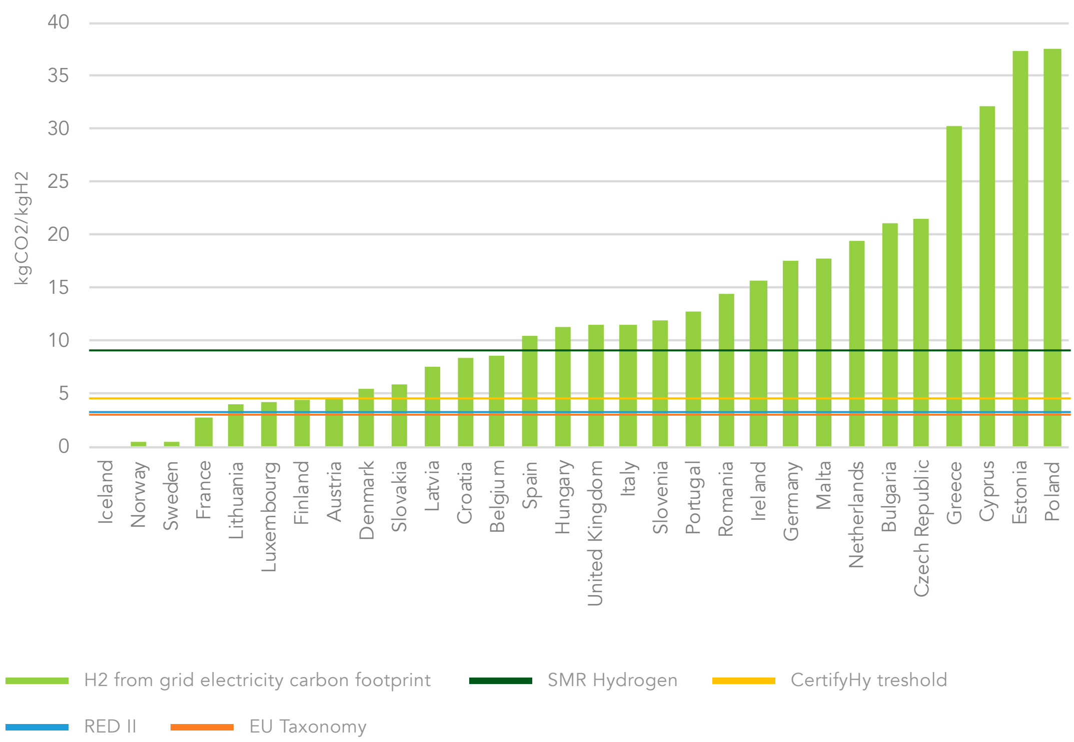
Norway, Sweden and France, the carbon intensity of grid electricity is low enough that even without PPA's and Certificates of Origin, the produced hydrogen's carbon footprint would be low enough to meet all hydrogen emission benchmarks set on the EU level

[19] Because of lack of data from EEA, in case of Norway the carbon intensity of grid electricity is based on: https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf
[20] 3.0 tonnes of CO2 per tonne of hydrogen
[21] With a retrofit CCS capture rate of around 60%. For more information see https://www.certifhy.eu/.

In all those countries, with the addition of Austria, Belgium, Croatia, Denmark, Latvia, Finland, and Slovakia, the carbon intensity of hydrogen from grid electricity would be lower than the average "grey" hydrogen emission intensity (around 9.0 kgCO2 per kgH2).

In all the remaining countries, hydrogen production from grid electricity, including the average EU-27 energy mix, would be more carbon-intensive than hydrogen from Steam Methane Reforming (SMR) without CCS.

Figure 21 Carbon intensity of hydrogen produced from grid electricity, compared to selected benchmarks



Source: Hydrogen Europe, based on EEA data.

Note:
SMR Hydrogen: 9.0 kg CO2 / kg H2 (75.0 gCO2/ MJLHV),
EU Taxonomy threshold for sustainable hydrogen manufacturing: 3 kg CO2 / kg H2 (25 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).

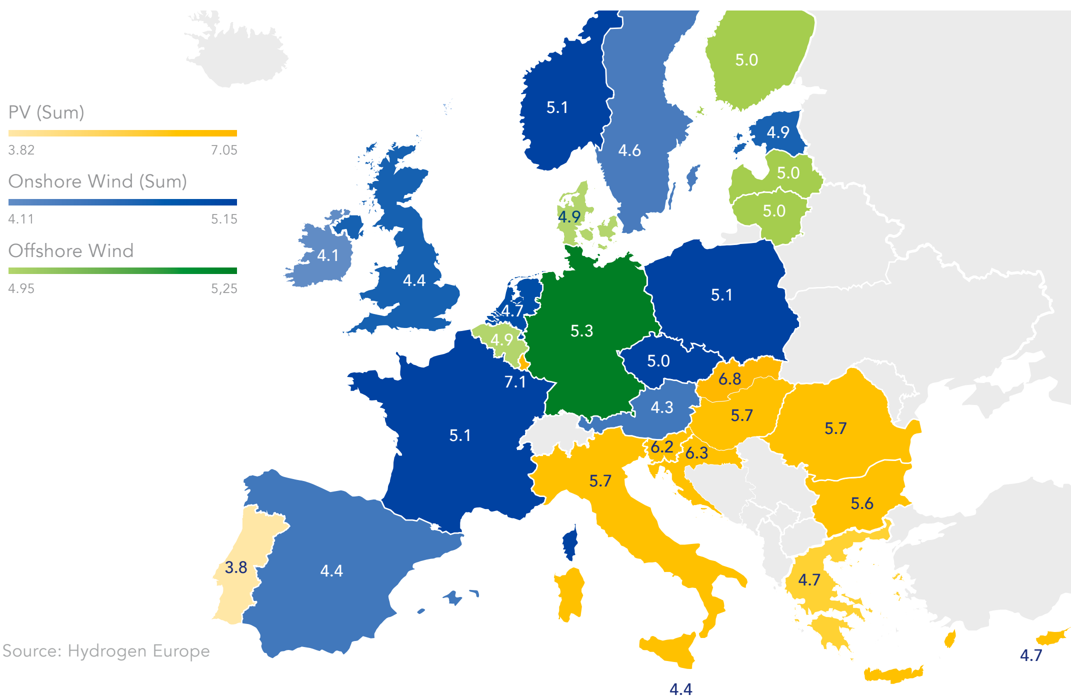
2.3 DIRECT CONNECTION TO A RENEWABLE ENERGY SOURCE

> the ever-decreasing costs of renewable electricity make it possible to produce renewable hydrogen at prices that are not far off from being competitive in most EU countries.

Production of hydrogen via electrolysis with a direct connection to a renewable energy source avoids a number the 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 make it possible to produce renewable hydrogen at prices that are not far off from being competitive in most EU countries.[22]

Considering the average solar irradiation and wind conditions in the EU Member States and Norway and the UK, estimated renewable hydrogen production costs vary from 3.8 EUR/kg (from solar PV in Portugal) to 7.1 EUR/kg (from solar PV in Luxembourg). In southern European countries, the cheapest pathway of renewable hydrogen production is solar PV. In contrast, for northern European countries, in most cases, the cheapest option is onshore wind except for Belgium and Germany, Denmark, Finland, Latvia and Lithuania, where, on average, offshore wind is the cheapest option.

Figure 22 Average renewable hydrogen production costs in the EU (with UK and Norway) in 2020 (in EUR/kg), using the lowest-cost RES technology for a given country



Source: Hydrogen Europe

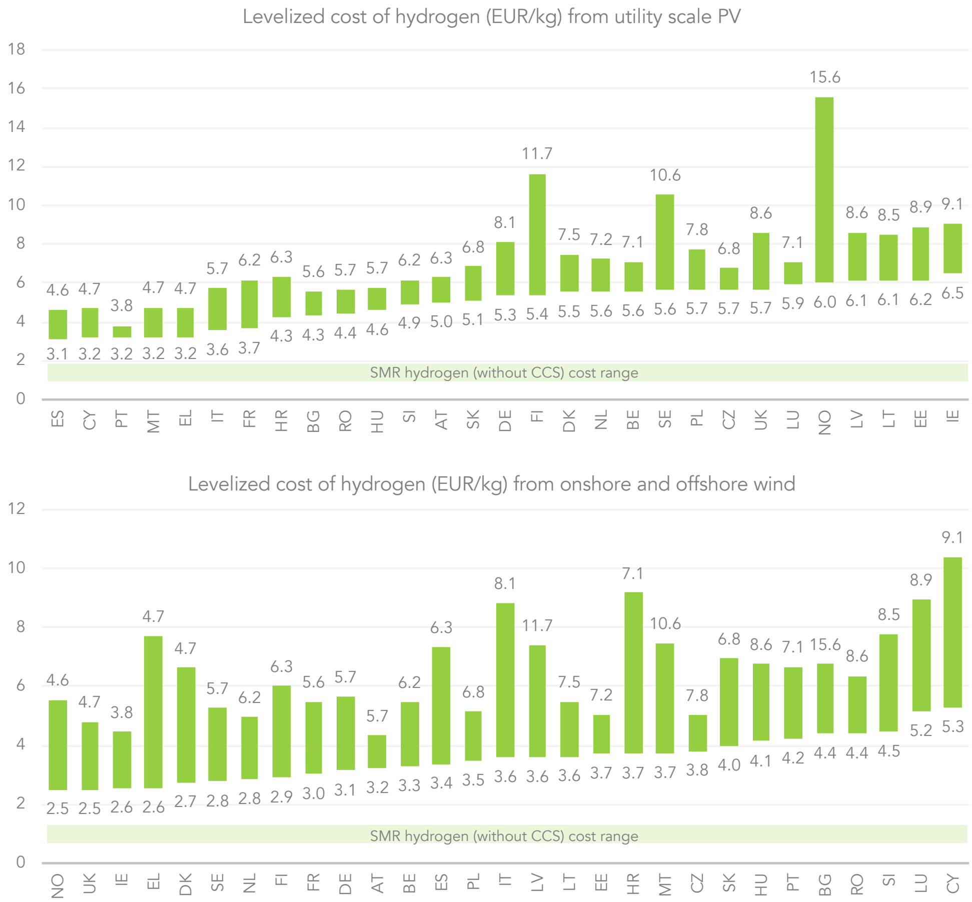
[22] For detailed techno-economic assumptions used for production costs estimations see the Methodological Note.

However, it should be stressed that the costs have been calculated based on **average wind and solar conditions for each country**[23]. Especially for large countries like Germany, Spain or France, this can be misleading as there are areas with significantly better than average wind or solar conditions, where renewable hydrogen production with direct connection to the RES source would also be significantly less expensive than on average. This has been illustrated on the following two graphs, in which the lower end of the cost range has been estimated assuming the best irradiation or wind conditions available in a given country.[24]

Based on this analysis, it can be noted that the **renewable hydrogen production costs in the EU can be as low as 3.0 EUR/kg (PV in the South of Europe) and as low as 2.5 EUR/kg in countries with good wind conditions (mostly Northern Europe).** The estimated levels of renewable hydrogen production costs are in most countries still 2-3 times higher than the current benchmark, set by fossil hy-

Figure 23

Levelized costs of renewable hydrogen production in EU countries (with UK and Norway) in 2020, 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.

[23] It also does not include other potentially cheap renewable energy sources like hydro power in Austria, Slovenia or Scandinavia.
[24] For solar PV the best available conditions were estimated of a maximum capacity factor for a NUTS-2 region in country based on their 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 adopted based on the JRC ENSPRESSO database.

drogen produced via steam reforming without CCS, which, depending on natural gas prices, can be as low as 1.2 – 2.0 EUR/kg.

Based on this analysis, it can be noted that the renewable hydrogen production costs in the EU can be as low as 3.0 EUR/kg (PV in the South of Europe) and as low as 2.5 EUR/kg in countries with good wind conditions (mostly Northern Europe).

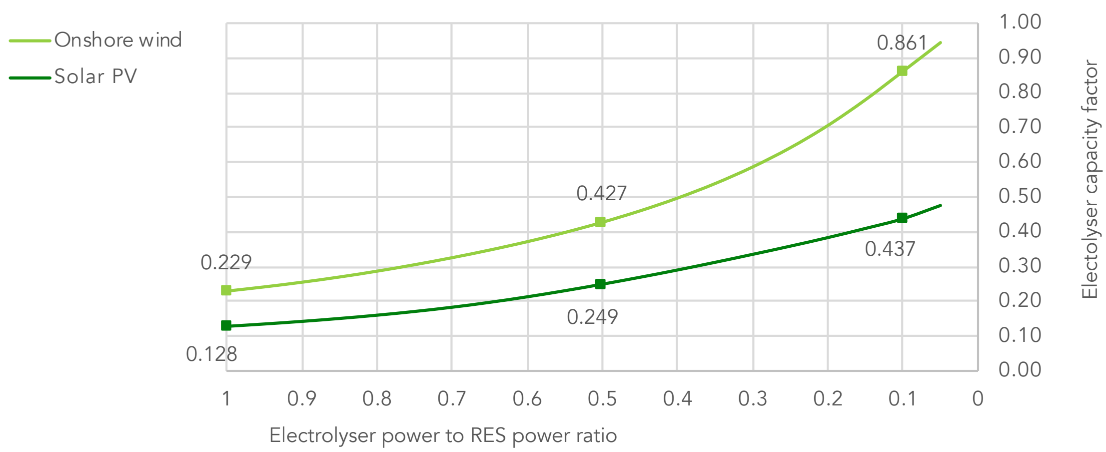
The estimated levels of renewable hydrogen production costs are in most countries still 2-3 times higher than the current benchmark, set by fossil hydrogen produced via steam reforming without CCS, which, depending on natural gas prices, can be as low as 1.2 – 2.0 EUR/kg.

Further cost optimisation can be done by combining complementary renewable energy sources like PV and wind, which enables to increase the capacity factor of the electrolyser and thus reducing the impact of CAPEX on the total levelized cost of hydrogen.

Similar positive effects can be achieved by downscaling the electrolyser compared to the RES it is connected to. Employing this strategy would require that the 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 24 illustrates, using the example of France, the relationship between the electrolyser capacity factor and the power of electrolyser relative to the renewable energy source it is connected to (assuming the electrolyser is prioritised oversupplying 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 France is around 1,150 h full load equivalent for solar PV and 2,000 h for onshore wind (on average for the country). Reducing

Figure 24 Relationship of capacity factor and power of electrolyser relative to RES, example: France



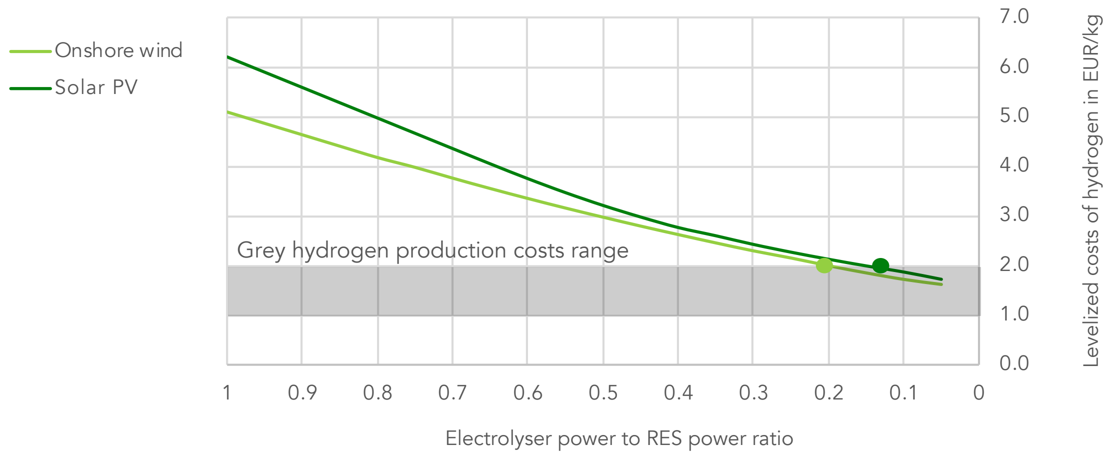
Source: Hydrogen Europe

the electrolyser power to half of that of the RES (ratio of 0.5), the capacity factor increases to around 2,200 h for solar PV and 3,700 for onshore wind. In the 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 3,800 hours and around 7,500h for onshore wind.

Taking advantage of this optimisation strategy could drive the costs of renewable hydrogen low enough to be cost-competitive with grey hydrogen. Keeping with the example of France, as can be seen on the figure below, with an electrolyser-to-res power ratio of 0.15 or below for solar PV or 0.20 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.[24]

This optimisation strategy would also have additional benefits from the point of view of the RES investor and the electric grid operator. Reducing the amount of energy supplied to the grid decreases the stress on the electricity grid. It 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. It would also allow the RES plant to optimise revenues by prioritising the dispatching of electricity to the grid when prices are high and prioritising hydrogen production when electricity prices are low.

Figure 25 Relationship of the LCOH and power of electrolyser relative to RES, example: France



Source: Hydrogen Europe

[24] Please note this is true for average solar irradiation in France. Situation in southern France would be by far more favourable for solar PV for example.

2.4 RENEWABLE HYDROGEN PRODUCTION COSTS DEVELOPMENTS

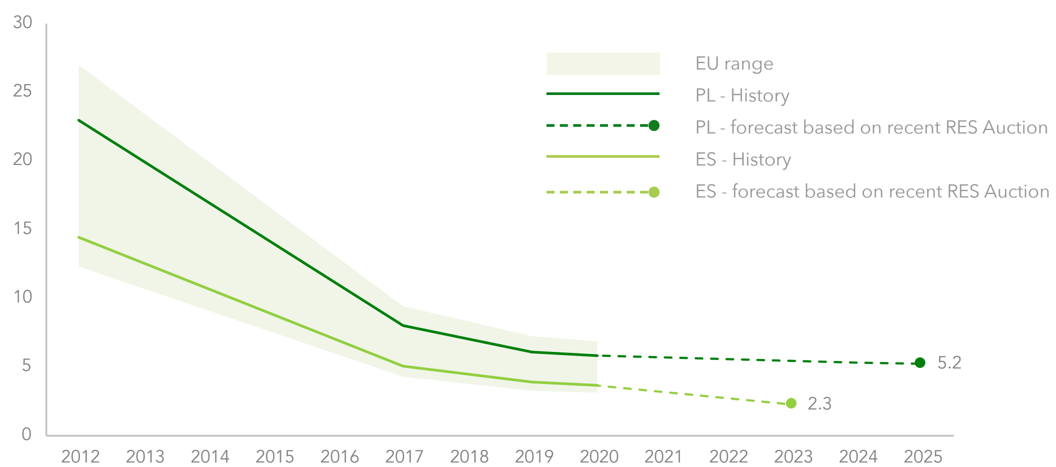
While renewable hydrogen production costs are still higher than for hydrogen produced from fossil fuels, 2020 saw a continuation of the downwards trend of renewable hydrogen production costs.

The fall in production costs applies for key RES technologies – i.e., solar PV as well as onshore and offshore wind. In all cases, the reasons for the production costs reduction are similar - the continuous fall of renewable energy costs coupled with a reduction of electrolyser CAPEX, supported by rising electrolyser efficiency.

In 2012 production of renewable hydrogen from solar PV in the EU was on average close to 27 EUR/kg. In 2020 the median for EU countries was around 6.8 EUR/kg, which means over 75% cost reduction during this period. The production costs in the most favourable locations in the EU (Portugal and Spain) fell by a similar fraction from around 12 EUR/kg in 2012 to 3.1 EUR/kg in 2020. Based on recent RES auction results in some EU countries, one should reasonably expect the downwards trend to continue in the coming years. Looking at the example of Spain, the RES auction organised in 2020 allowed the Spanish Government to successfully contract over 2 GW of additional solar PV capacity, with prices ranging from 14.89 EUR/MWh to 28.90 EUR/MWh. Using the lower of those values would allow producing renewable hydrogen at around 2.3 EUR/kg (at current electrolyser CAPEX levels). Similarly, low levels of solar PV electricity auction prices were recently obtained in Portugal as well. In Northern and Central European countries, renewable hydrogen produced from solar PV will remain relatively high in the immediate future, with the recent RES auction in Poland indicating a possible production cost level in the next couple of years of around 5 EUR/kg.

Figure 26

Renewable hydrogen production costs (in EUR/kg) via water electrolysis with solar PV over the 2012-2020 period and expected developments in selected countries based on recent RES auction results



Source: Hydrogen Europe

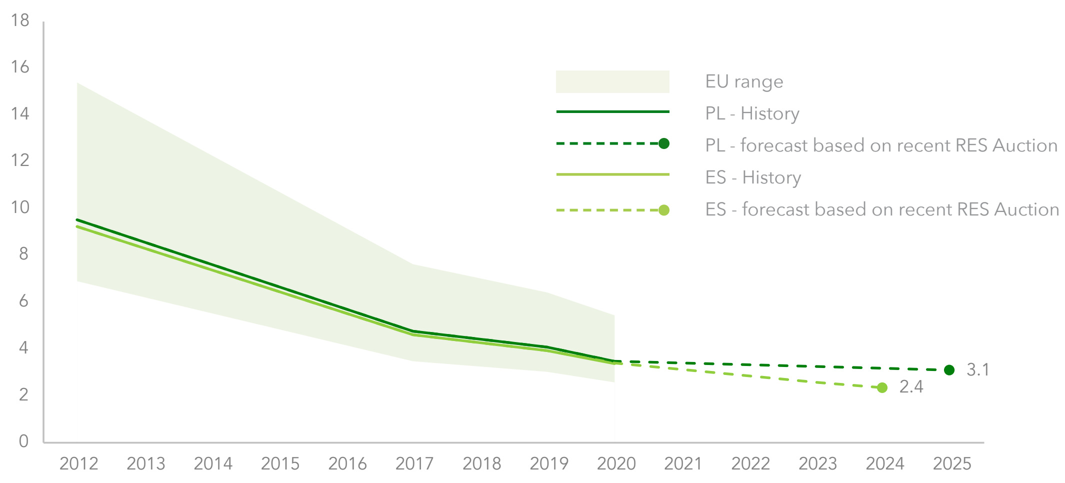
Hydrogen produced from onshore wind saw a similar fall in production costs over since 2012. The median of "green" hydrogen production costs from onshore wind in EU countries fell by almost 65% in this period – from around 15 EUR/kg in 2012 to around 5.5 EUR/kg in 2020. At the same time, the production costs in areas with the most favourable wind conditions in Europe fell from around 7 EUR/kg in 2012 to 2.6 EUR/kg in 2020.

As is the case with solar PV, recent RES auction in some EU countries suggests the continuation of the downwards trend of renewable hydrogen production costs from onshore wind. The RES auction organised by the Spanish Government at the end of 2020 allowed to successfully contract almost 1 GW of additional onshore wind capacity, with prices ranging from 20.0 EUR/MWh to 28.89 EUR/MWh with a delivery date in 2024. Using the lower of those values would allow producing renewable hydrogen at around 2.4 EUR/kg (at current electrolyser CAPEX levels). Similar, price levels are being also achieved in other EU countries. For example, the recent RES auction in Poland returned a winning bid price for onshore wind of 179 PLN/MWh (~40 EUR/MWh), which would enable "green" hydrogen production costs of around 3.1 EUR/kg.

In the case of offshore wind, the median of renewable hydrogen production costs in Europe fell from around 10 EUR/kg in 2012 by almost 50% to around 5.2 EUR/kg in 2020. At the same time, the production costs in areas with the most favourable offshore wind conditions in Europe fell from around 8.1 EUR/kg in 2012 to 4.3 EUR/kg in 2020.

Figure 27

Renewable hydrogen production costs (in EUR/kg) via water electrolysis with the onshore wind over the 2012-2020 period and expected developments in selected countries based on recent RES auction results

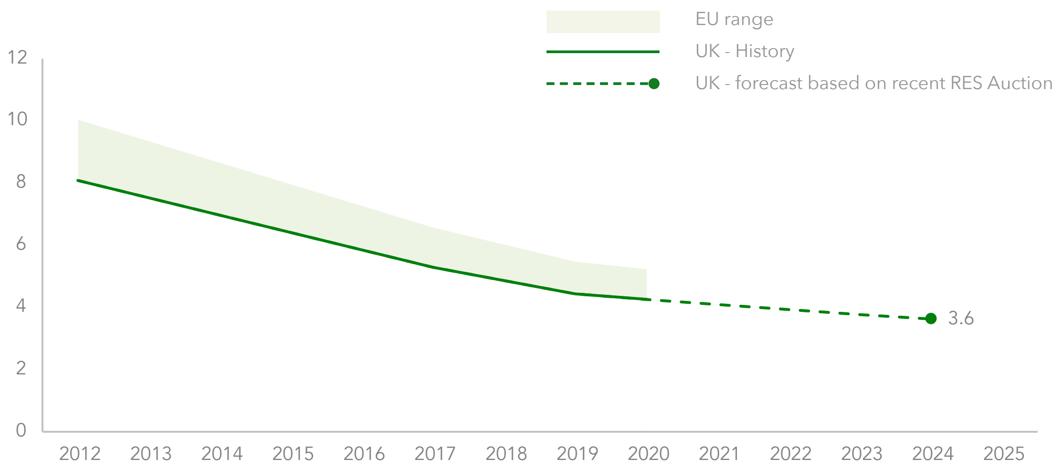


Source: Hydrogen Europe.
Note: the upper boundary of the EU range is defined as the median for all EU countries (+ UK and NO) and the lower boundary as the production costs in assuming the most favourable solar irradiation conditions available in the EU.

The most recent auction organised by the UK Government has cleared at the record low price of 39.65 GBP/MWh for delivery in 2023/24 and 41.611 GBP/MWh in 2024/25 (2012 prices). In 2020 prices, this would enable "green" hydrogen production costs of around 3.6 EUR/kg by 2024.

Figure 28

Renewable hydrogen production costs (in EUR/kg) via water electrolysis with the offshore wind over the 2012-2020 period and expected developments in selected countries based on recent RES auction results



Source: Hydrogen Europe.
Note: the upper boundary of the EU range is defined as the median for all EU countries (+ UK and NO) and the lower boundary as the production costs in assuming the most favourable solar irradiation conditions available in the EU.

2.3 SUMMARY

Lowering renewable hydrogen production costs is essential if hydrogen delivers on its role as an enabler in the ongoing EU-wide decarbonisation effort. It is especially crucial in areas with a limited regulatory push, and renewable hydrogen has to compete with its fossil-fuel equivalent or directly with fossil fuels (e.g., replacing natural gas for heating).

Low natural gas prices in 2020 made that extremely challenging driving marginal costs of SMR based hydrogen down to around **1.1 EUR/kg**. Such a low production price level is still unachievable for renewable hydrogen production based in Europe.
Yet, for other applications, like those **in the transportation sector**, or whenever there is a clear regulatory push to phase out the use of fossil fuels, the break-even cost is more favourable, with fuel cell (FC) cars cost parity with diesel projected at commercial FCEV production volumes and a hydrogen cost of up to €5/kg. Considering distribution and refuelling infrastructure costs, **the break-even cost translates into hydrogen production costs of around €3-3.5/kg.**

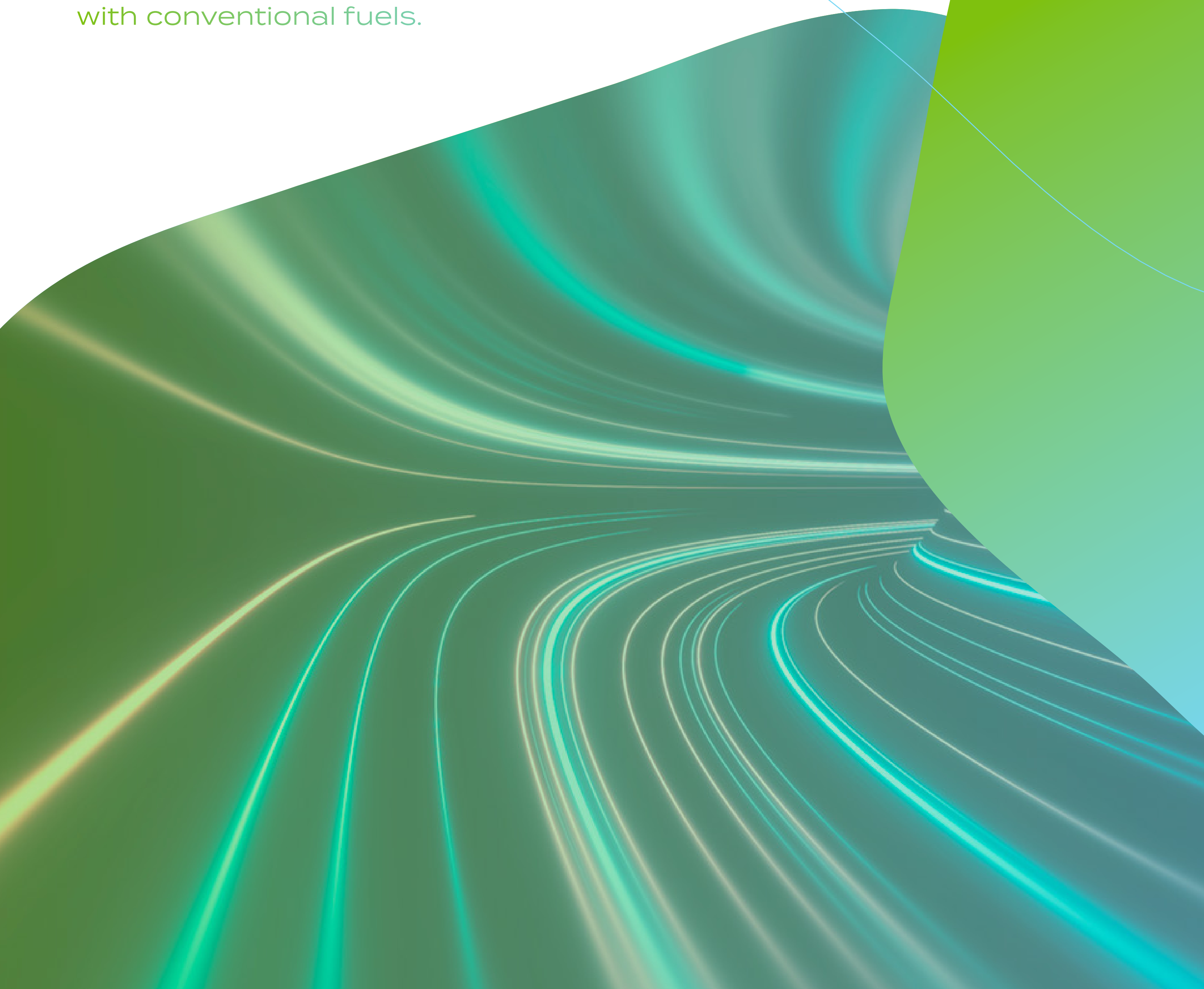
As this report has shown, **the price levels presented in this chapter are at the limit of what was possible in 2020.** There are countries and regions in Europe where producing renewable hydrogen at the necessary cost level is, theoretically, possible. Most notably, in southern Europe with cheap solar PV energy, the estimated lowest possible production costs in the best locations are around 3.1 EUR/kg. In the case of countries in northern Europe, where the onshore wind is in most cases the cheapest technology for renewable energy generation, in regions with favourable wind conditions, the cost of producing renewable hydrogen can be as low as 2.5 EUR/kg. 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, for hydrogen to become a cornerstone of the decarbonised European economy, cheap renewable hydrogen should, ideally, be available in all EU countries and not only in limited regions with highly favourable RES generation potential. As the analysis has shown, the average (and not best available) renewable hydrogen production costs in Europe remain relatively high, with a median for all EU countries at 5.1 EUR/kg. While **this represents a decrease of around 0.3 EUR/kg compared to last year,** further cost reductions are needed.

The production cost reduction will be assisted by the expected further decrease of renewable energy costs and the increased R&D effort envisaged under the Horizon Europe framework, focused on increasing energy efficiency and cost reductions along the whole value chain. The key element, however, required to unlock low renewable hydrogen production costs is scaling up electrolyser manufacturing and hydrogen production projects. Here, we see a crucial role to be played by the European Clean Hydrogen Alliance, hydrogen IPCEI's, EIB, and funds like the ETS Innovation Fund.

One should also not forget about alternative ways of renewable and low carbon hydrogen production methods, which this report doesn't cover but which also offer significant opportunities for cheap, clean hydrogen production, including not only alternative renewable energy sources like hydro-energy, but also emerging technologies like direct solar-to-hydrogen photoelectrochemical cells, as well as the thermal conversion of biomass or waste into hydrogen, pyrolysis and nuclear energy.

In the transportation sector the break-even cost translates into hydrogen production costs of around €3-3.5/kg.

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 chapter 1, hydrogen produced via water electrolysis (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 renewable hydrogen). At the same time, as discussed in Chapter 1, electricity-based hydrogen production constitutes a very small share of overall hydrogen production at this moment.

Therefore, **it is important to track the development of hydrogen production and infrastructure projects to assess the progress of the hydrogen sector as an enabler of a zero-emission energy system.**

The following chapter presents an aggregation of planned:

- power-to-hydrogen (PtH) projects across Europe,
- selection of reforming projects with carbon capture,
- the most significant hydrogen transmission initiatives,
- most important industrial development initiatives such as European Clean Hydrogen Alliance and the Hydrogen IPCEI process

The purpose of the chapter is to provide information on planned hydrogen production and infrastructure assets and to track hydrogen developments for comparison with national and European targets, strategies, and roadmaps.

Hydrogen Europe has collected the data and information in this chapter from both public and restricted sources. While the intention is to provide an accurate snapshot of planned developments, this overview likely does not reflect all projects currently planned (e.g., some may not have been made public at all). As the projects that have been used to generate the overview are still evolving, the presented numbers will continue to change.

For more details on the methodology, please consult the Methodological Annexe.

3.1 PLANNED POWER-TO-HYDROGEN PROJECTS

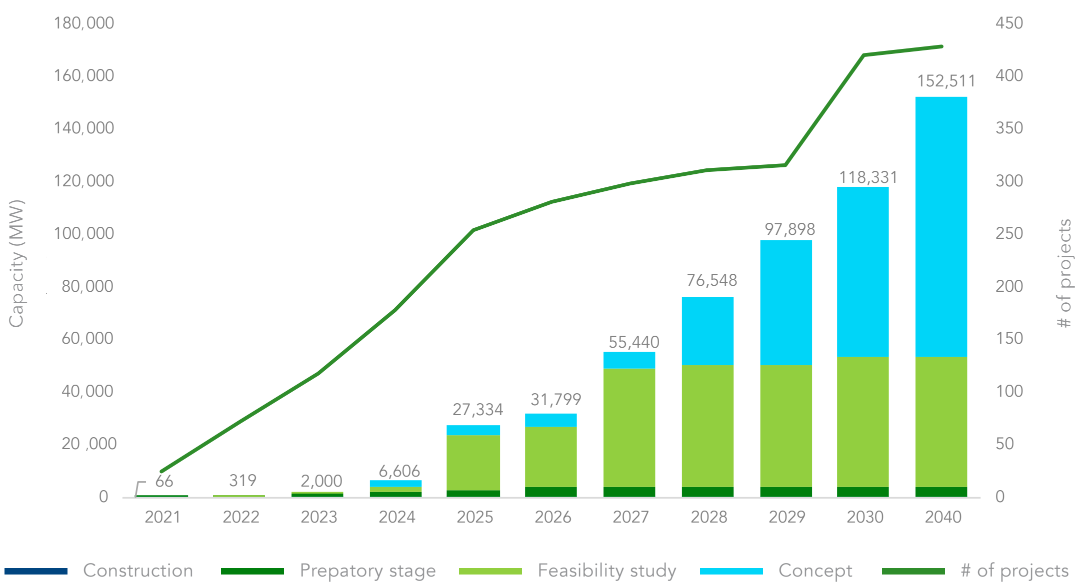
The total planned capacity of PtH projects[25] in Europe[26] is 152,511 MW of electrolyser installed power by 2040 (429 projects) with an extra 3,459 MW (53 projects) with an unspecified start date.

The total planned capacity of PtH projects[25] in Europe[26] is 152,511 MW of electrolyser installed power by 2040 (429 projects) with an extra 3,459 MW (53 projects) with an unspecified start date. There are 420 PtH projects with an announced start date amounting to **118,331 MW by 2030**. In the medium term, 179 planned projects are amounting to 6,606 MW by 2024. Figure 29 presents cumulative planned PtH projects by year up to 2040. Based on available information, 66 MW of additional PtH capacity is planned to come online by the end of 2021, 319 MW by 2022, et cetera.

The period leading up to 2030 is a very important medium-term objective due to both European Hydrogen Strategy (EHS) and 2030 climate targets. For 2021 – 2030, **the average tracked capacity growth rate is 103% annually.** This is an impressive annual increase, which, if achieved, would result in 118 GW of installed water electrolysis capacity by 2030 and **reach the 40 GW objective** set by the **European Hydrogen Strategy already in 2027.**

Figure 29

Cumulative planned PtH projects by year 2021 - 2040 in MW and # of projects

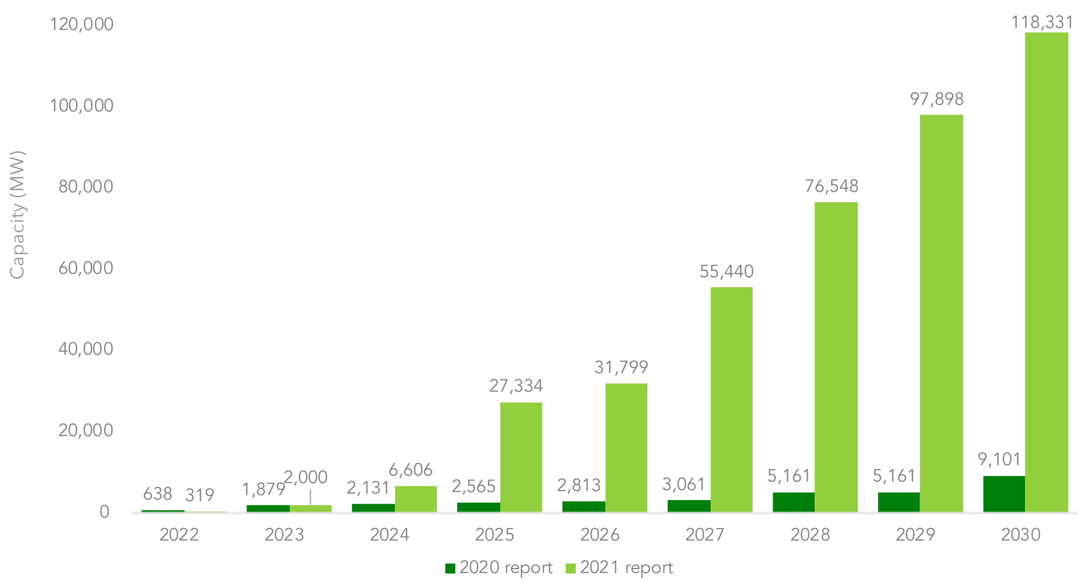


Source: Hydrogen Europe.

[25] The term "project" refers to an individual project or a project phase. One project can have multiple phases that gradually enlarge its capacity. For the purposes of this report, each phase of a project with three phases of 10 MW, 100 MW, and 300 MW in the same location and with the same project partners is counted as separate project.
[26] Europe refers to EU, EFTA, and UK

Compared with 9,101 MW by 2030 and 101 projects published in the Clean Hydrogen Monitor 2020, the data collected for this report represent a 1200% increase in planned capacity and 316% in terms of planned projects by 2030. The impressive increase reflects the commitment from the governments and the industry to decarbonise industry, transport, and heating using power-to-hydrogen technology. Figure 30 illustrates this development.

Figure 30 Comparison of planned PtH project capacity announcements



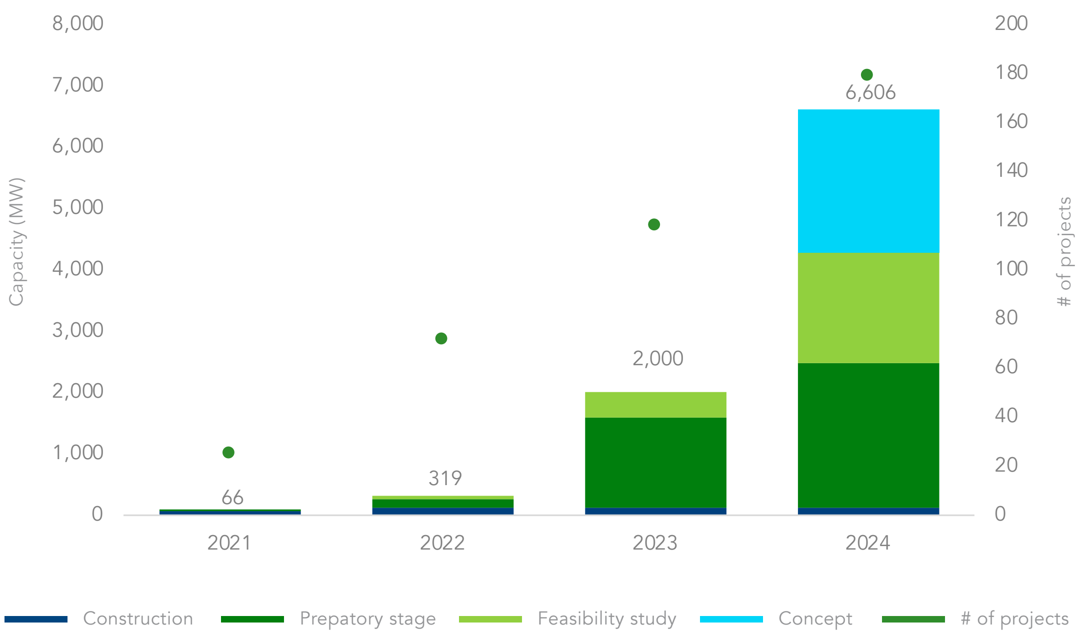
Source: Hydrogen Europe.

In the short term, by 2024, the situation has also significantly improved from last year, with **total planned capacity by 2024 increasing from 2,131 to 6,606 MW**. As of the writing of this report, should all planned projects by 2024 be realised, EHS's 6 GW objective would be reached by 2024. While project announcements continue, the focus will be on the realisation and execution of the announcements in the next years. Figure 31 demonstrates the short-term development of projects. Out of the 319 MW planned to come online by 2022, excluding the 135 MW already in operation and not visualised, 135 MW are under construction, 140 MW are in the preparatory stage, and 44 MW are undergoing feasibility studies. As expected, the current status of projects planning to be online by 2024 differs from the 2022 composition as the pipeline is less concrete further in the future. Out of the 6,606 MW planned to be operational by then, 135 MW are under construction, 2,345 MW are in a preparatory stage, 1,809 MW are undergoing a feasibility study, and 2,316 MW are still only a concept.

If all these projects were realised by 2024, there would be 6,741 MW of operational PtH capacity.

Figure 31

PtH projects by year and project stage 2021 - 2024 in MW and # of projects



Source: Hydrogen Europe.

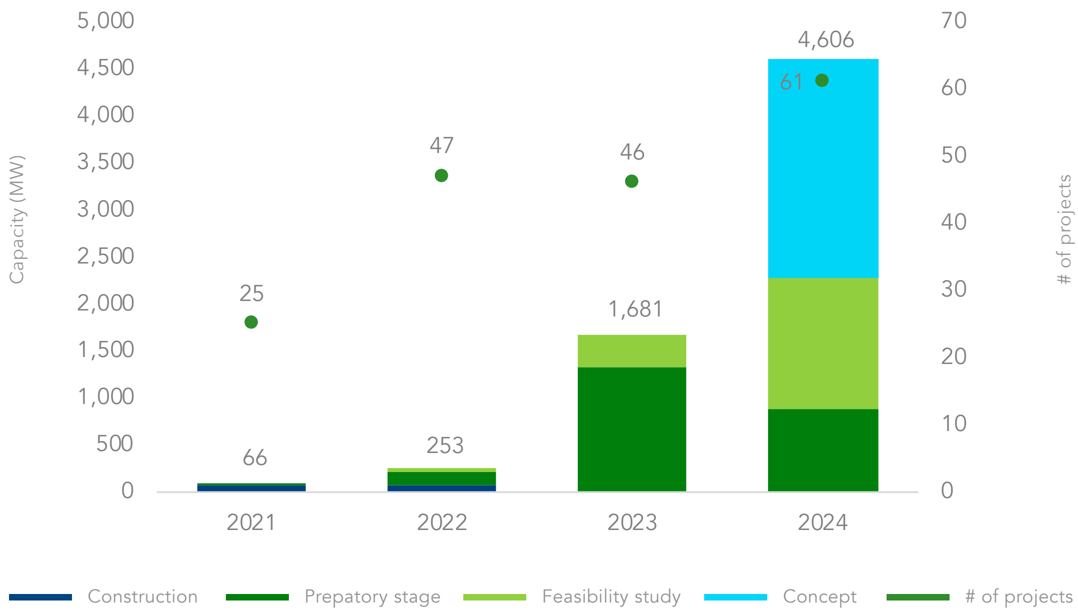
The gap between EHS 6 GW target by 2024 and cumulative planned PtH capacity has disappeared compared to last year's expectations due to persistent support for the development of clean hydrogen from European, national, regional levels as well from producers, consumers, infrastructure operators, and other participants in the hydrogen ecosystem. Continuing clarification on the regulatory treatment of hydrogen on both European and national levels, the interest and support in the IPCEI process, the popularity of the European Clean Hydrogen Alliance, and the emergence of new funding instruments have and will continue to contribute to additional project announcements and deployments. The emphasis will have to be on the realisation of those announcements.

Annual capacity additions

The average annual addition between 2021 and 2030 is 11,833 MW of PtH capacity, with additions of over 20,000 MW in 2025, 2027, 2028, 2029, and 2030. The 118,331 MW with announced dates between 2021 and 2030 are split between 420 projects at an average project size of 282 MW.

Figure 32 provides an annual addition perspective for 2021 – 2024. The average annual addition is 1,651 MW of PtH capacity, with the largest expected additions coming in 2023 and 2024. While the expected average project size in 2022 is 5.4 MW, the expected average project size two years later in 2024 is 76 MW. Should these projects be realised, this would result in the average project size increasing 14 times within two years.

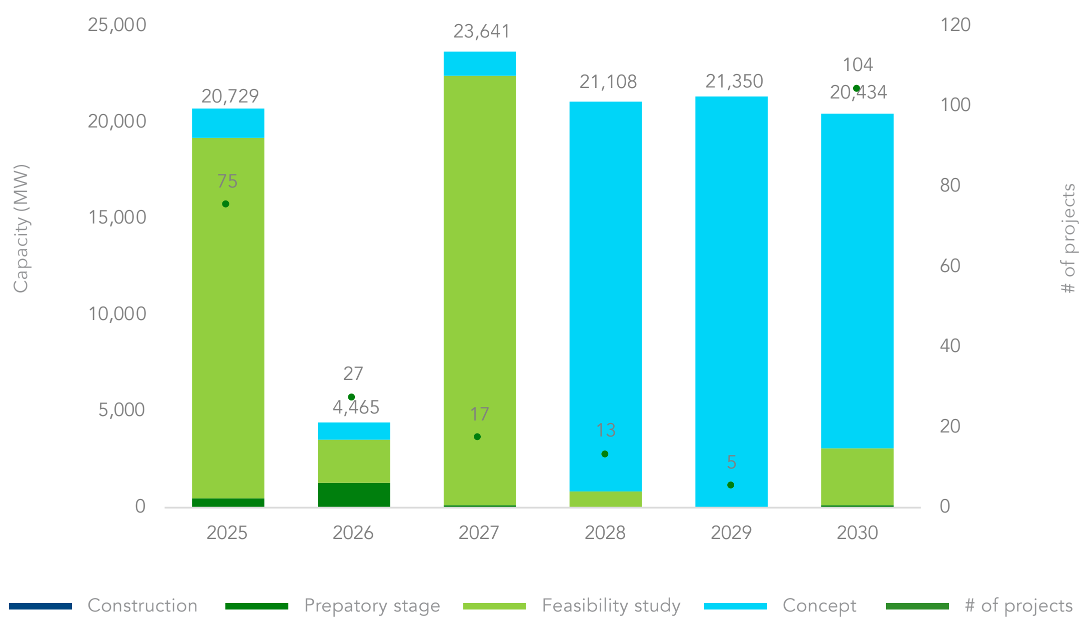
Figure 32 Planned PtH projects added by year 2021 - 2024 in MW and number of projects



Source: Hydrogen Europe.

Figure 33 provides an annual addition perspective for 2025 – 2030. The average annual addition is 18,621 MW of PtH capacity, with the largest expected additions planned for 2027 and 2029. The 111,726 MW are split between 241 projects with an impressive 464 MW per project. The average project sizes differ significantly between the different years. In 2025, the 20,729 MW is split between 75 projects averaging 276 MW per project. In 2027, the 23,641 MW of new additions result from only seventeen new projects resulting in an average project size in 2027 of 1,390 MW. This trend is even more obvious in 2029 when five new projects are planning to add 21,350 MW of PtH capacity. The results suggest that project developers will be increasing their project ambitions to build multi-GW projects in the second half of the decade. Many of the projects being built at this time are expansions of existing installations. Based on the data, 104 projects are supposed to come online in 2030. This is due to a large number of indicative dates when some projects in earlier stages of development have only indicated 2030 instead of a more specific operation date.

Figure 33 PtH projects added by the year 2025 - 2030 in MW and number of projects



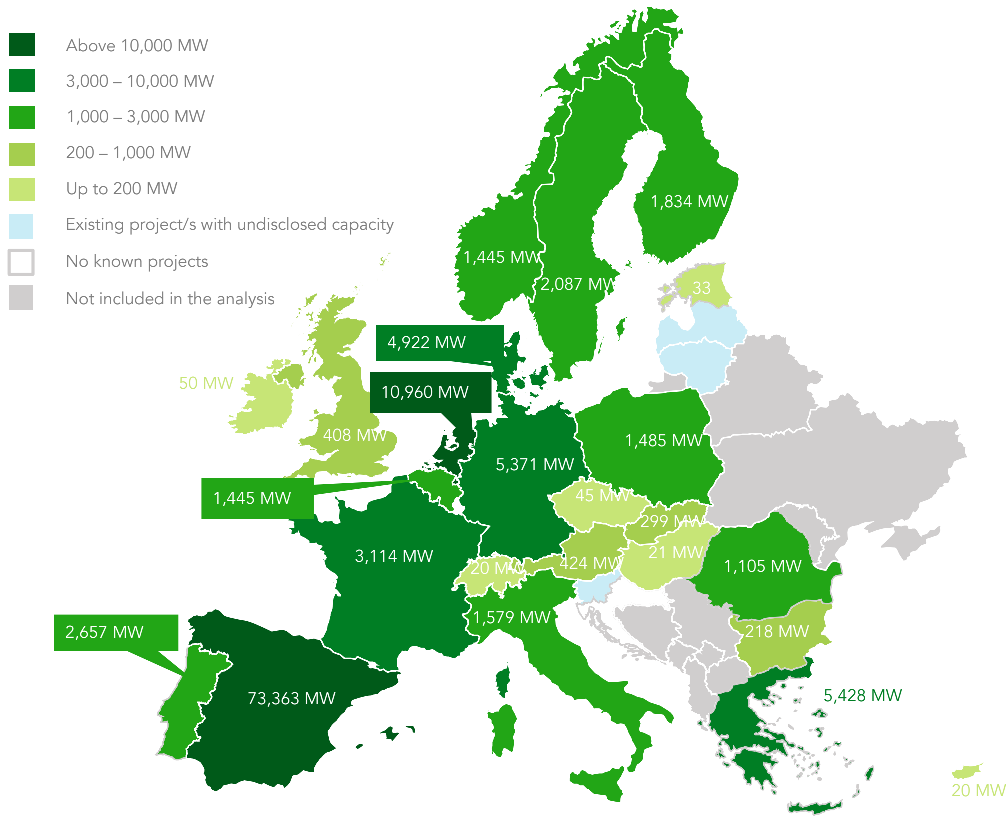
Source: Hydrogen Europe.

COUNTRY PERSPECTIVE

The country with the highest planned PtH capacity by 2030 is Spain with 73,363[27] MW followed by the Netherlands with 10,960 MW, Greece with 5,428 MW, Germany with 5,371 MW, Denmark with 4,922 MW, France with 3,114 MW, and Portugal with 2,657 MW. Together, these seven countries would represent 89% of planned PtH capacity in Europe and 59% of planned projects.

The plans for future PtH projects differ country by country, especially when it comes to the size and number of projects. The largest planned PtH addition by 2030 is planned in Spain, where its 73,363 MW split between 51 projects results in an average project size of 1,112 MW. This is markedly different from Germany, where its 5,371 MW split between 58 projects results in an average project size of 93 MW. Italy is another country with numerous smaller projects, where this report identified 28 PtH projects amounting to 1,579 MW of capacity with an average project size of 56 MW.

Figure 34 Map of PtH capacity additions by country 2021 - 2030 in MW



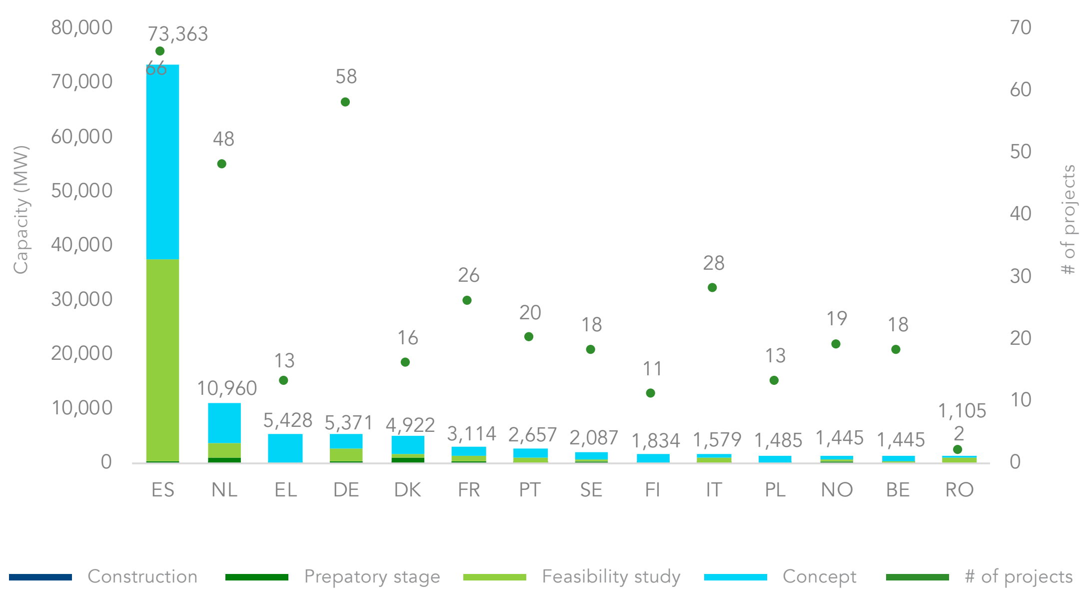
Source: Hydrogen Europe

[27] Spain remains the outlier in our project tracking due to a single project that plans to deploy 69 GW of electrolysis by 2030 alone

Spain's more than 73 GW are primarily due to a single large project aiming to deploy 69 GW of electrolysis by 2030. In addition, there are also several 100+ MW projects focused on industrial clusters. The second-largest project pipeline by 2030 is in the Netherlands with 10 GW of electrolysis compared to the objective in its hydrogen strategy of 3-4 GW by 2030. The planned Greek PtH capacity is largely based on a single integrated project aimed at decarbonising specific regions.

Germany's current project pipeline of 5,371 MW by 2030 sets Germany at 107% of its 5 GW 2030 target. As of the writing of this report, Denmark has the fifth-highest planned PtH pipeline by 2030, with 4,922 MW to be deployed split between 16 projects.

Figure 35 PtH capacity additions and # of projects by country by 2030



Source: Hydrogen Europe.

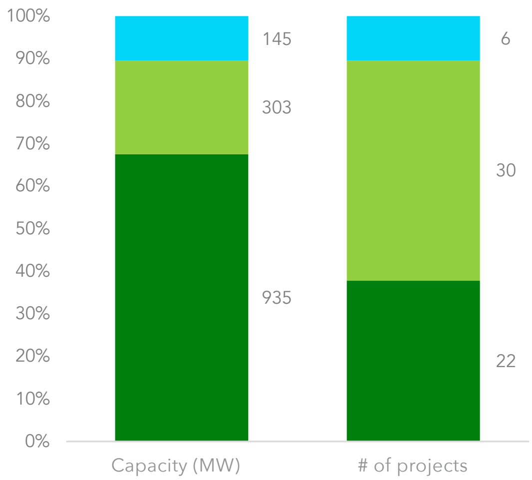
ELECTROLYSER TECHNOLOGY

58 out of 179 planned projects by 2024 and 1,382 MW of capacity out of 6,606 MW have announced their electrolyser technology. 68% of the capacity and 38% of those projects plan to use alkaline electrolysis at an average project size of 42 MW. Proton exchange membrane electrolysis is more popular for smaller projects as it is planned to be used in 22% of capacity but 52% of projects at an average project size of 10 MW.

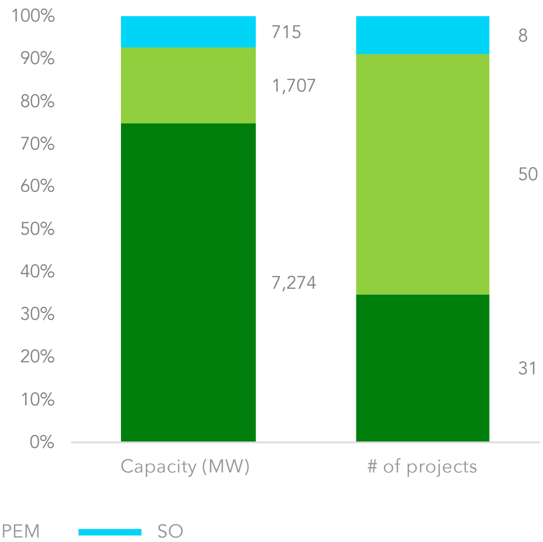
For the longer-term outlook by 2030, electrolyser technology is known for only 89 out of the 420 projects and 9,696 MW out of 118,331 MW of electrolyser capacity. 75% of the capacity and 35% of those projects plan to use alkaline electrolysis at an average project size of 235 MW. Proton exchange membrane electrolysis will continue to be used for smaller projects as it is planned to be used in 18% of capacity but 56% of projects at an average project size of 34 MW.[28] The medium to long-term trend indicates that larger projects rely mostly on alkaline technology while smaller projects rely on PEM technology. The future market growth, deployments, cost reductions across electrolysis technologies, and future development of emerging electrolysis technologies will shape the deployments and will likely differ from the snapshot presented today.

Figure 36, 37

Electrolyser composition of planned projects in MW and # of projects by 2024



Electrolyser composition of planned projects in MW and # of projects by 2030[29]



[28] Figures may not round up to 100% due to automatic rounding
[29] Figures may not round up to 100% due to automatic rounding

ELECTRICITY CONNECTION

One of the key considerations for every PtH project developer is the electricity supply. That means both whether the project has (i) a direct connection to its electricity source, (ii) a grid connection, or (iii) both and what is the source of the electricity planned to be consumed.

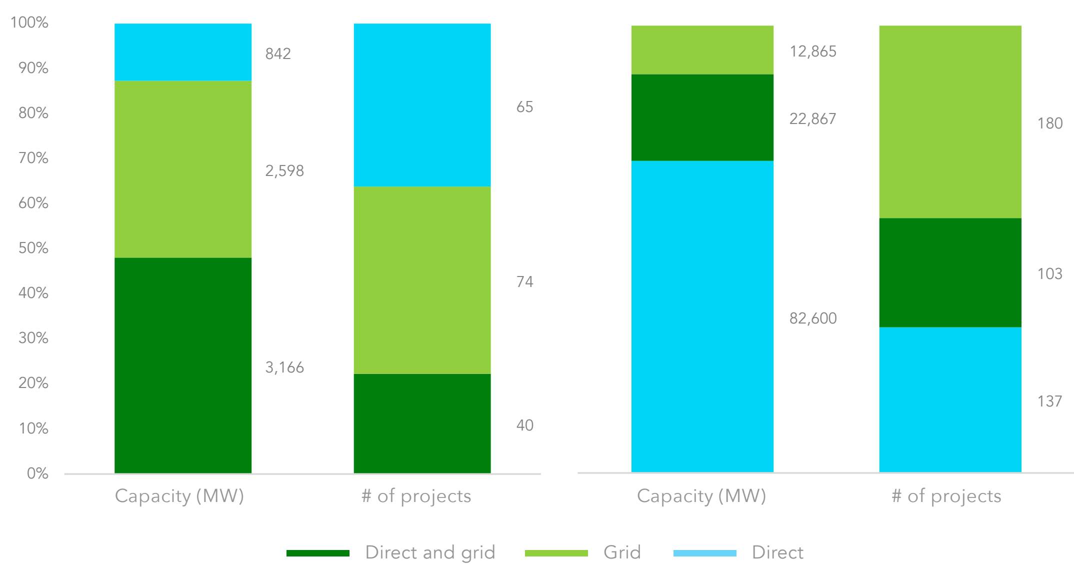
For the 6,606 MW currently planned by 2024, 3,166 MW or 48% of the capacity and 40 or 22% of the projects is planned to have both a direct and a grid connection. 2,598 MW or 39% of the capacity, and 74 or 41% of the projects are planning only to have a grid connection. By 2024, only a direct connection is currently planned for 842 MW or 13% of the capacity and 65 or 36% of projects. Overall, 87% of the planned capacity and 64% of projects are planning to be connected to the electricity grid. While large scale PtH capacity increases will go hand in with large scale additional development of renewable generation capacities, these figures point to the importance of grid-connected electrolysis, at least in short to medium term.

The situation significantly changes when looking to announced projects by 2030. For the planned 118,331 MW by 2030, 82,600 MW or 70% of the capacity and 137 or 33% of the projects planned indicate a direct connection to their electricity source. 22,867 MW or 19% of the capacity, and 103 or 25% of the projects are planning to have both a direct and a grid connection. By 2030, 12,865 MW or 11% of the capacity and 180 or 43% of projects are planning only to have a grid connection. While developers plan to rely heavily on grid electricity by 2024, future deployments of large scale PtH installations plan to develop significant renewable generation capacities for their internal use. The average project size by 2030 is 603 MW for directly connected projects, 222 MW for projects with both a direct and a grid connection, and 71 MW for grid-connected projects

Figure 38, 39

Electricity supply connection in MW and # of projects by 2024

Electricity supply connection in MW and # of projects by 2030



Source: Hydrogen Europe.

[29] Figures may not round up to 100% due to automatic rounding

ELECTRICITY SOURCE

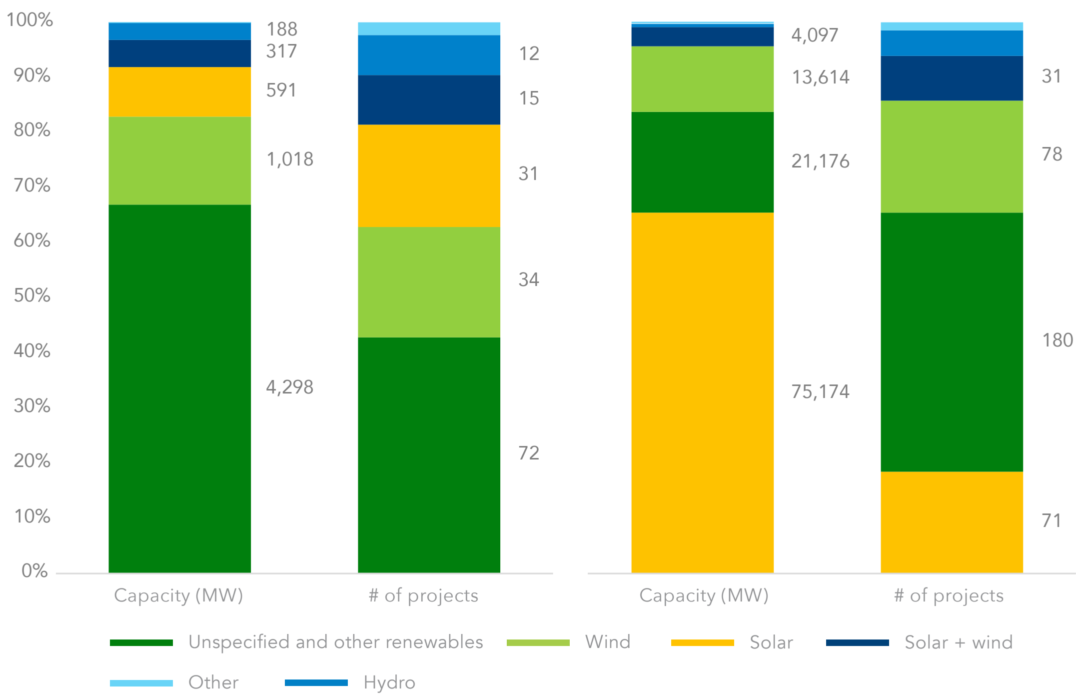
Regarding the electricity source, both capacity and number of projects planned by 2024 are dominated by unspecified and other renewables. These projects have indicated that they will be powered by renewable energy but have not specified exact generation sources.[30] The grid-connected projects plan to purchase power purchase agreements while directly connected projects are either developing new electricity generation capacity as a part of the project or are locating the PtH facility close to an already existing renewable generation site. The unspecified and other renewables comprise 4,257 MW or 68% of the announced capacity by 2024 and 72 or 43% of projects. The second-largest electricity source by 2024 will be wind projects with 1,018 MW or 16% share of capacity and 34 or 20% of projects. The remaining 16% of capacity is also dominated by renewable energy sources, including solar, a combination of solar and wind, and hydro.

The 2030 perspective is dominated by new additional PtH capacity connected to solar generation capacity. The 75 GW represents 65% of the 2030 capacity and 19% of the projects. While these are impressive numbers, it is important to point out that they are dominated by a single large and very ambitious project in Spain that accounts for 69 GW of electrolyser capacity alone. The second-largest category is Unspecified and other renewables representing 21,176 MW or 18% of the capacity and 180 or 47% of all projects. This represents an average size of 118 MW per project and outlines a trend that many of the PtH projects in lower hundreds of MW have not secured their electricity supply or are planning on signing a grid PPA. Wind has the third largest capacity with almost 14 GW or 12% of capacity and 78 or 20% of projects.

Figure 40, 41

Electricity source for projects in MW and # of projects by 2024[31]

Electricity source for projects in MW and # of rojects by 2030



Source: Hydrogen Europe.

[30] The category Unspecified and other renewable also includes ocean energy
[31] Other includes waste, grid mix, biomass, and nuclear

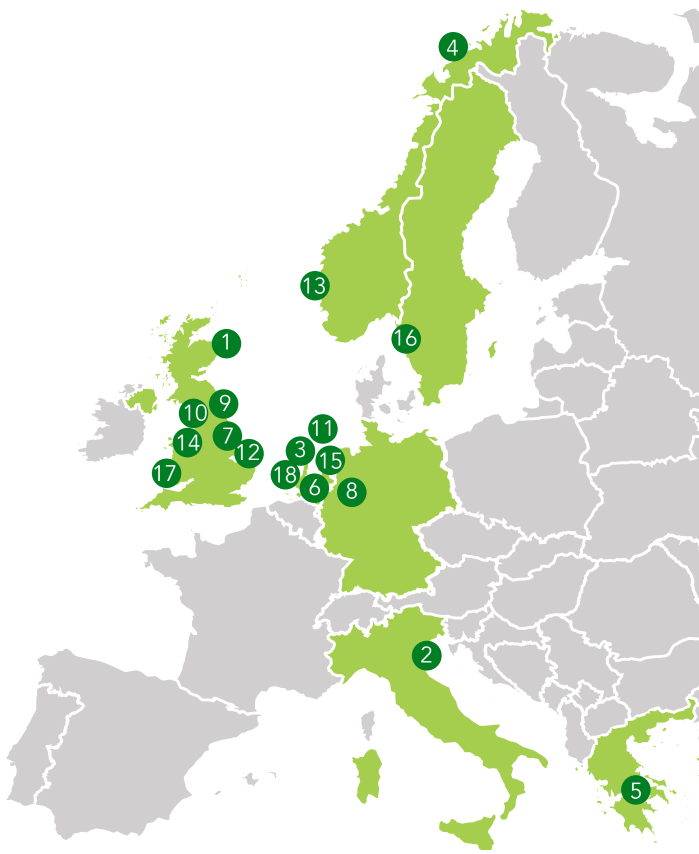
3.2 REFORMING WITH CARBON CAPTURE

As the planned PtH projects have already been presented above, this section of the report presents the projects intending to produce hydrogen via reforming combined with carbon capture.

Last year's Clean Hydrogen Monitor identified a selection of 12 projects under development intending to produce hydrogen by reforming and capturing the associated CO2 emissions. This year's report identified a selection of 18 projects. There are more projects in development that have not been included in this selection. Some of them are small demonstration projects, while others have not yet been publicly announced. Out of these 18 identified projects, seven are located in the UK, five in the Netherlands, two in Norway, one in Italy, and one each in Germany, Greece and Sweden.

Figure 42 Selection of announced projects based on reforming with carbon capture

1. Acorn CCS / H2
2. Adriatic Blue
3. Aramis (Blue H2 Den Helder)
4. Barents Blue
5. Blue Med
6. H2 Magnum
7. H2H Saltend
8. H2morrow
9. H2 Teeside
10. H21 North of England
11. H-Vision
12. Humber Zero
13. HyDemo
14. HyNet
15. Porthos
16. Preem CCS
17. South Wales Ind. Cluster
18. Zeeland Refinery CCS



Selection of countries with announced projects to produce hydrogen from reforming with carbon capture

Source: Hydrogen Europe

The projects mentioned above vary in terms of both hydrogen production technology as well as carbon capture solutions. Some projects, such as H21 North of England, include constructing a new 12.15 GW auto-thermal reforming hydrogen generation based on natural gas coupled with CCS.[33] In others, such as the Porthos project in the Netherlands, its development allows the involved project partners to retrofit an already existing hydrogen production with CCUS [34] [35]. In the HyDemo project in Norway, a 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.[36]

Some industrial areas, such as the Humber region, include multiple projects for producing hydrogen with reforming and carbon capture. Humber is one of the most carbon-intensive industrial clusters in England, with emissions of around 14 million tonnes of CO2 per year.[37] The two active low-carbon hydrogen production projects include H2H Saltend and Humber Zero. Project's 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 operating with a 600 MW capacity during the first phase, with the CO2 preliminarily destined to be stored at the "Endurance" aquifer on the UK continental shelf.[38] The Humber Zero project is located just south of H2H Saltend. Its project partners plan to reduce their emissions by decarbonising a refinery and a local power plant. The project will include the development of a regional hydrogen hub with local production of both renewable hydrogen and hydrogen produced by reforming with carbon capture. Produced volumes will be used by the power plant and local industry.[39] [40]

North of the H2H Saltend, the H2 Teeside in the Teeside industrial cluster is planned to be developed in two phases, reaching a full capacity of 1,000 MW to produce hydrogen by reforming with carbon capture by 2030.[41] Even further north in Scotland,[42] the Acorn CCS/H2 planned to be operational by 2025 is designed to have an initial production capacity of 200 MW of hydrogen to contribute to the decarbonisation of Scotland. In the western UK, the Liverpool-Manchester HyNET project will operate between the Northwest of England and North Wales, generating, storing, and distributing up to 4,600 MW of hydrogen by 2030. The first phase of the project is planned to be already operating by 2025.[43]

In Germany, the companies involved in the H2morrow project will produce low-carbon hydrogen from Norwegian natural gas delivered through the gas grid.[44]

In the Netherlands, the H-Vision project aims to produce low-carbon hydrogen in Rotterdam by 2026 with further scale-up by 2032. The objective is to develop a low-carbon hydrogen production capacity of 1,500 MW, developed in two phases of 750 MW each.[45] The H2 Magnum project located in Eemshaven, planned to be operational by 2027, plans to convert an existing gas power plant into a hydrogen-powered plant while developing significant capacities of hydrogen produced by reforming with carbon capture.[46]

---

[33] https://together.northerngasnetworks.co.uk/wp-content/uploads/2019/03/H21-NoE-Exec-Sum-Print-Final.pdf
[34] https://www.porthosco2.nl/en/
[35] https://www.topsectorenergie.nl/sites/default/files/uploads/TKI%20Gas/publicaties/Overview%20Hydrogen%20projects%20in%20he%20Netherlands%20versie%201mei2020.pdf
[36] https://www.uib.no/sites/w3.uib.no/files/attachments/eikaas_equinor_february_2020_uib.pdf
[37] https://www.zerocarbonhumber.co.uk/
[38] https://www.equinor.com/en/what-we-do/h2hsaltend.html
[39] https://www.humberzero.co.uk/2021/03/17/huge-boost-for-ground-breaking-humber-zero-project/
[40] https://www.humberzero.co.uk/
[41] https://www.icis.com/explore/resources/news/2021/03/18/10619081/bp-announces-1gw-blue-hydrogen-project
[42] https://theacornproject.uk/wp-content/uploads/2020/09/Hydrogen-in-Scotland-The-role-of-Acorn-Hydrogen-in-Enabling-UK-Net-Zero.pdf
[43] https://hynet.co.uk/
[44] https://oge.net/en/press-releases/2019/equinor-and-open-grid-europe-present-joint-h2morrow-project-to-support-deep-decarbonization-of-german-industry
[45] https://www.h-vision.nl/en
[46] https://www.equinor.com/en/news/evaluating-conversion-natural-gas-hydrogen.html

The Adriatic Blue project in Italy plans to utilise depleted offshore gas reservoirs in Northern Italy for storing CO2, allowing low-carbon hydrogen production in the Ravenna industrial complex. As the first large low-carbon hydrogen production project in Southern Europe, it could provide the low-carbon hydrogen supply needed to decarbonise various local industrial sites[47] by 2026.[48]
In Sweden, the Preem CCS pilot plans to capture carbon from a reformer at the refinery at Lysekil. After the testing program, the project should operate at full scale by 2025.[49]

Overall, the year-on-year increase of planned reforming projects with carbon capture demonstrates the existing momentum for this production technology. The key indicator for hydrogen produced via reforming with carbon capture will be the projects' development progress in the subsequent years.

[47] https://www.eni.com/assets/documents/investor/2020/ita/Transcript-eni-strategy-presentation-28-feb-2020.pdf
[47] https://www.eni.com/assets/documents/investor/2020/eng/3q-2020/2020-third-quarter-results.pdf
[48] https://www.akersolutions.com/news/news-archive/2020/aker-solutions-starts-ccs-test-program-at-preem-refinery-in-sweden/

3.3 HYDROGEN TRANSMISSION AND DISTRIBUTION INFRASTRUCTURE

For hydrogen to access the various end-uses across Europe, basic infrastructure will have to be developed between production and consumption points, especially since many of the most economical production locations will be far from large scale consumption. 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 and FCHO), the development of an EU-wide hydrogen pipeline network is required to jumpstart the hydrogen economy further, as this is by far the cheapest mode of transport for large quantities of hydrogen.[49] The hydrogen economy will require a similar transmission and distribution ecosystem to the current natural gas infrastructure, complemented by trucks and ships. While blending hydrogen into the existing natural gas pipelines may be an important intermediary step in the early 2020s, retrofitting existing gas infrastructure to carry pure hydrogen will be necessary for the long run. This chapter provides an overview of the plans to develop dedicated (pure) hydrogen transmission and distribution networks.

Together with the rapid development of national hydrogen strategies come also transmission and distribution projects. Some of the largest infrastructure initiatives include the European Hydrogen Backbone by a group of EU gas infrastructure companies and two national initiatives in Germany and the Netherlands. These plans include both retrofitting existing natural gas pipelines and partially building an entirely new hydrogen infrastructure to accommodate growing hydrogen demand.

European Hydrogen Backbone

As the most comprehensive current hydrogen infrastructure initiative, 23 European gas infrastructure companies developed an in-depth analysis that evaluated the cost-effectiveness and proposed developing a pan-European hydrogen infrastructure, the European Hydrogen Backbone. The analysis covers 19 EU member states in addition to the United Kingdom and Switzerland. The analysis assumes the utilisation of both renewable hydrogen and hydrogen produced by reforming natural gas coupled with carbon capture. The European Hydrogen Backbone Initiative envisages an 11,600 km hydrogen network by 2030 that would initially focus on connecting the emerging hydrogen valleys and clusters. By 2040, it envisages developing into a pan-European network of 39,700 km, with 69% originating from repurposed existing infrastructure and 31% new pipelines. Additional network development is also expected after 2040.[50]

According to the European Hydrogen Backbone initiative, most hydrogen transmission projects will first develop in industrial clusters, ports, and cities in the north of the continent (Belgium, Netherlands, North-West Germany) by 2030. In addition, other network additions or repurposing is planned in France (Dunkerque, the Seine Valley from Le Havre to Paris, Lyon, Lacq, Marseille), Spain (the Basque Country, Asturias, Castille and Léon, Aragon, and connection between Barcelona and Valencia), Italy with both repurposed and new infrastructure from Sicily to Milan, and in Scandinavia with mostly new pipelines in Denmark, Finland, and Sweden.[51]
By 2035, the hydrogen network is expected to grow from regional networks connecting industrial clusters to a (trans) national scale by connecting countries. These include connecting the northwest Europe cluster to Scandinavian, French, and German networks, a connection between France and Spain, and connecting the Italian infrastructure through Slovenia to Austria, Hungary, and Slovakia.

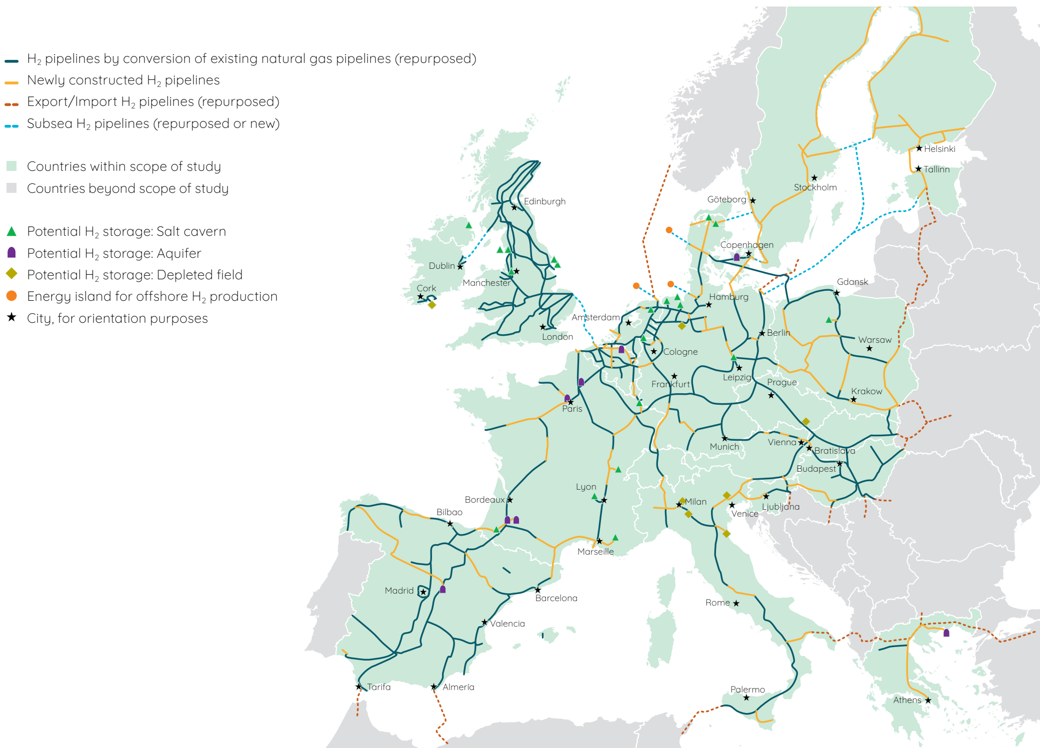
[49] https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf
[50] https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf
[51] https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf

By 2040, this vision envisages a truly pan-European dedicated hydrogen transmission infrastructure stretching from Sicily to Northern Sweden and Galicia to Eastern Finland. The network would also be able to accommodate significant hydrogen imports from Morocco, Algeria, and Tunisia in the South, Turkey in the Southeast, Ukraine in the East, and Norway in the North.

Such developments would directly impact Europe's decarbonisation. They would allow the necessary sector coupling in the North Sea, the Baltic Sea, and other regions that would otherwise struggle with integrating massive new renewable resources.[52] In Central Europe, this infrastructure and associated supply of clean hydrogen would enable decarbonisation of the local heavy industry.

The group of gas infrastructure companies estimate CAPEX for this expansion to be between €43-81 bn by 2040 with between 63% to 77% of total investment dedicated to pipelines and between 37% and 23% to compression equipment. The estimated levelized cost of transporting hydrogen along an average stretch of the backbone amounts to €0.11-0.21/kg of hydrogen per 1,000km with €0.16/kg in the "medium" case. The study estimates CAPEX costs for repurposing a natural gas pipeline to hydrogen at €0.4 million/km for a 28-37 inch diameter pipeline in the study's medium scenario, which is 18% of the cost of the new pipeline at €2.2 million/km. The study concludes that repurposing existing natural gas pipelines to transport hydrogen is the most cost-effective solution for long-distance transportation.

Figure 43 European Hydrogen Backbone 2021



Source: European Hydrogen Backbone Initiative (supported by Guidehouse)

[52] https://northseawindpowerhub.eu/wp-content/uploads/2020/04/NSWPHIntegration-routes-offshore-wind-2050.pdf

Dutch hydrogen backbone

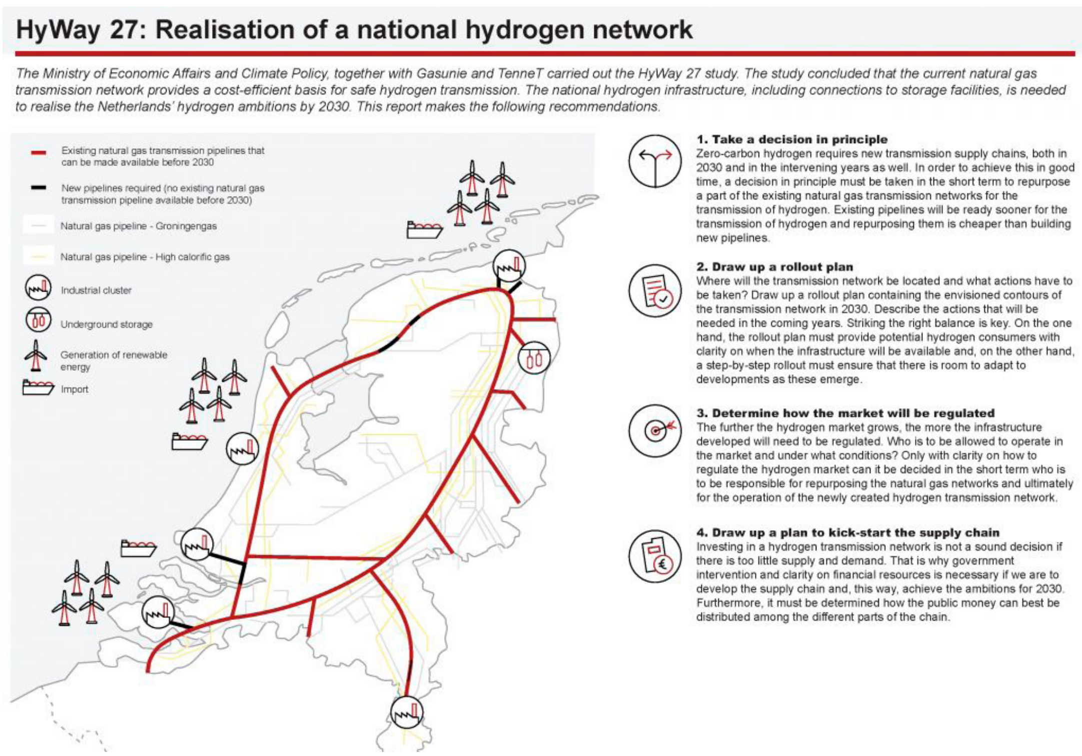
The Netherlands is one of the first movers in Europe when it comes to developing a hydrogen economy. The government set to review the use of the natural gas grid for hydrogen transmission. The HyWay 27 study carried out by the Ministry of Economic Affairs and Climate Policy, Gasunie, and TenneT, was published in June 2021 set out to answer the following three questions:

(i) Do we need a transmission network for hydrogen, and if so, when?
(ii) Can the existing natural gas grid be used for the transmission of hydrogen?
(iii) What kind of government intervention will be needed to create a transmission network?

The study confirmed the importance of CO2-free hydrogen for developing a climate-neutral economy and the importance of developing national hydrogen transport to give hydrogen a significant position in the Dutch energy system. It also sees short-term demand from the industry while in the longer term, it identifies mobility, buildings, and electricity sector as additional use cases.

The report recommended that: (i). a decision is taken to repurpose parts of the existing transmission grid in the short term, (ii). rollout plan is created for the hydrogen transmission network development (iii). regulatory requirements of the hydrogen market, including the hydrogen transmission network, are assessed and (iv) a plan to kickstart the supply chain is developed.

Figure 44 Proposed Dutch national hydrogen network



Source: Gasunie

[53] https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand
[54] https://www.fnb-gas.de/media/fnb_gas_2020_nep_entwurf_de.pdf

The Ministry of Economic Affairs and Climate Policy received the study results positively and indicated that it would decide to repurpose part of the existing natural gas transmission. As a result, the Ministry of Economic Affairs and Climate has asked Gasunie to start with the development of this national hydrogen network.[53] Gasunie continues developing the Dutch hydrogen backbone by repurposing existing gas pipelines as these become available due to declining demand for natural gas and considers the construction of new hydrogen pipelines to connect the main industrial clusters in the Netherlands to reach 1,400 km by 2030.[54]

The current development timeline first envisages the development of regional backbones by 2024-2026, focused on the main industrial clusters accounting for most of the Netherland's 1.3 million tons of hydrogen consumed annually.[55] This includes a connection to Northern Germany. The connection between the individual industrial clusters, including Zeeland, Rotterdam, Amsterdam, Limburg, and the northern Netherlands, is planned by 2026-2028. The interconnection to the European Hydrogen Backbone is envisioned for 2028-2030.

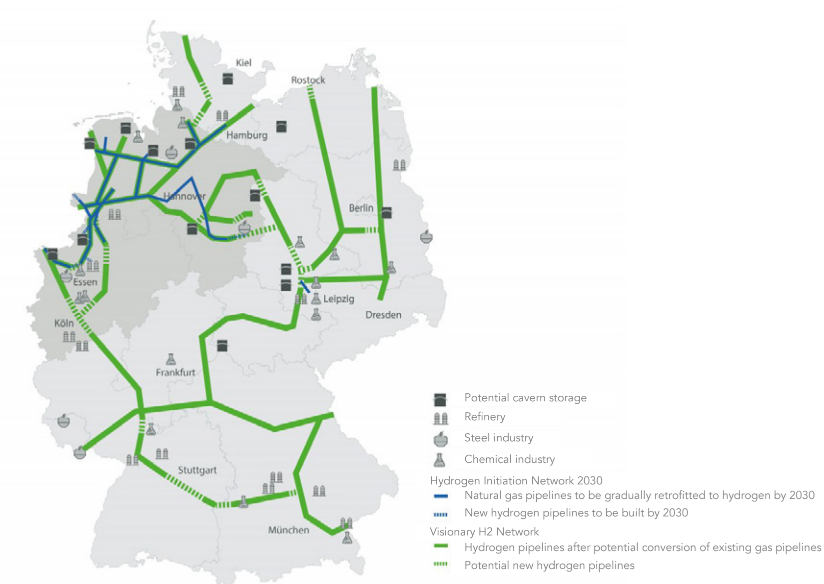
[53] https://www.rijksoverheid.nl/actueel/nieuws/2021/06/30/staatssecretaris-yesilgoz-zegerius-zet-eerste-stap-voor-ontwikkeling-landelijk-waterstofnet
[54] https://www.gasunienewenergy.nl/projecten/waterstofbackbone/hydrogen-backbone
[55] https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand

German visionary hydrogen network map (2020-2030) [41]

The initial German hydrogen infrastructure plans have been first concisely articulated in 2020 in the Gas Network Development Plan 2020-2030 as reported in Clean Hydrogen Monitor 2020. Figure 45 displays the network as envisaged last year. 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.[56] Parts of this network have already been included in the national preselection of projects for hydrogen IPCEI in Germany.

The planning for Gas Network Development Plan 2022-2032 has continued to build on the previous scenario by incorporating the newest projects, plans, and demands from gas consumers. The new version of the future German hydrogen infrastructure will be developed based on findings from the Gas Network Development Plan 2022-2032, which will be articulated over the course of 2021 and finalised in 2022.

Figure 45 German initiation and visionary hydrogen networks



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

[56] https://www.fnb-gas.de/media/fnb_gas_2020_nep_entwurf_de.pdf

3.4 INDUSTRIAL DEVELOPMENT INITIATIVES

European Clean Hydrogen Alliance

The European Clean Hydrogen Alliance is an initiative of the European Commission that brings together all the stakeholders involved in hydrogen deployment to create a pipeline of investment projects by 2030 and identify their enabling conditions. The Alliance has currently more than 1,500 members representing the European industry, research organisations, public authorities, and civil society. The operational work of the Alliance relies on six thematic roundtables that reflect the activities of the entire hydrogen value chain. Hydrogen Europe is one of the seven facilitating organisations of the Alliance. It supports the coordination of the six roundtables under the supervision of the European Commission. The members of the Alliance have submitted more than 1,000 deployment projects so far across production, transmission, and end-use. Two-thirds of hydrogen production and consumption projects are scheduled to begin operations within three years, underlining that the deployment phase has already started. 84% of the production projects plan to use electrolysers, and most of those expect to be powered by renewable electricity. Several geographic clusters for hydrogen production and consumption are emerging and will require transmission & distribution infrastructure to connect them.

The European Commission is analysing the submitted projects, and the project pipeline will be presented at the end of 2021. A report will also reflect the discussions of the roundtables on the bottlenecks that need to be addressed in terms of market and end-use, administrative and regulatory, supply chain, and technology. Funding issues are significant enabling conditions of the projects. As a result, a Funding Compass has already been made available to the members of the Alliance to identify funding opportunities at national and EU levels.

Important Projects of Common European Interest (IPCEI) – Hydrogen

IPCEIs are an EU industry policy tool that can provide state aid to integrated projects across EU borders, making them particularly suitable for supporting hydrogen deployment efforts. The industry has made substantial proposals on this topic since 2019. Member States have responded by organising numerous calls for expression of interest and signing the Manifesto to develop the European "H2 systems and technology" value chain at the end of 2020. The 22 Member States (plus Norway) that signed it agreed on the importance of promoting cross-border collaboration and on working on large-scale joint investment projects via IPCEIs.

Two IPCEI waves have been prepared by Member states, one on Technology and another on Industry. They bring together 128 projects selected by the Member states. These include production, infrastructure, and end-use projects of different nature (R&D, first industrial deployment, and energy and transport projects of “great importance”). Member states have launched an informal prenotification process with the European Commission at the beginning of September intending to finetune future notifications and facilitate a smooth adoption of these projects by the European Commission in 2022. Additional IPCEI waves are currently being considered and could be launched by the end of 2021.

4

PLANNED HYDROGEN CONSUMPTION IN INDUSTRY

The projects presented in this chapter reflect plans to replace fossil fuels such as coal and gas and unabated "grey" hydrogen in the industry with low-carbon hydrogen.[57]

This includes the consumption of hydrogen:

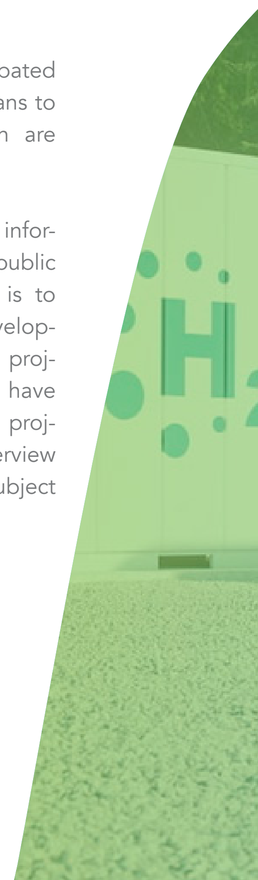
- as a feedstock in the refining industry,
- in the steel sector,
- in ammonia and methanol production as well as
- in the synthesis of e-fuels.[58]

The scope of the work also includes industry projects where low-carbon hydrogen is used to replace natural gas or other fossil fuels in industrial burners, resulting in emission reduction in energy-intensive industrial processes like the production of cement, ceramics and others.

Projects aimed at consuming low-carbon hydrogen for mobility or in the energy sector are not included in the analysis of this chapter.

Projects (or industries) that only use unabated "grey" hydrogen[59] in their process without plans to replace that consumption with clean hydrogen are not within the scope of this chapter.

Hydrogen Europe has collected the data and information presented in this chapter from both public and restricted sources. While the intention is to provide an accurate snapshot of planned developments, this overview likely does not reflect all projects currently planned (e.g., some may not have been made public at all). Furthermore, as the projects that have been used to generate the overview are still evolving, the numbers presented are subject to change.



[57] The EU's definition of "low-carbon hydrogen" includes both what is commonly known as "green" or renewable hydrogen, which is produced from renewable energy, as well as non-renewable, low-carbon hydrogen, which includes electricity-based hydrogen (PtH) produced from low-GHG electricity as well as what is sometimes referred to as "blue" hydrogen, (i.e. natural gas based hydrogen with carbon capture and storage (CCS) or usage (CCU)).
[58] Because ammonia and methanol are already tracked as separate sectors, they are not included as e-fuels even though they can be considered one
[59] This chapter uses the term clean hydrogen interchangeably with the above-mentioned definition of low-carbon hydrogen.

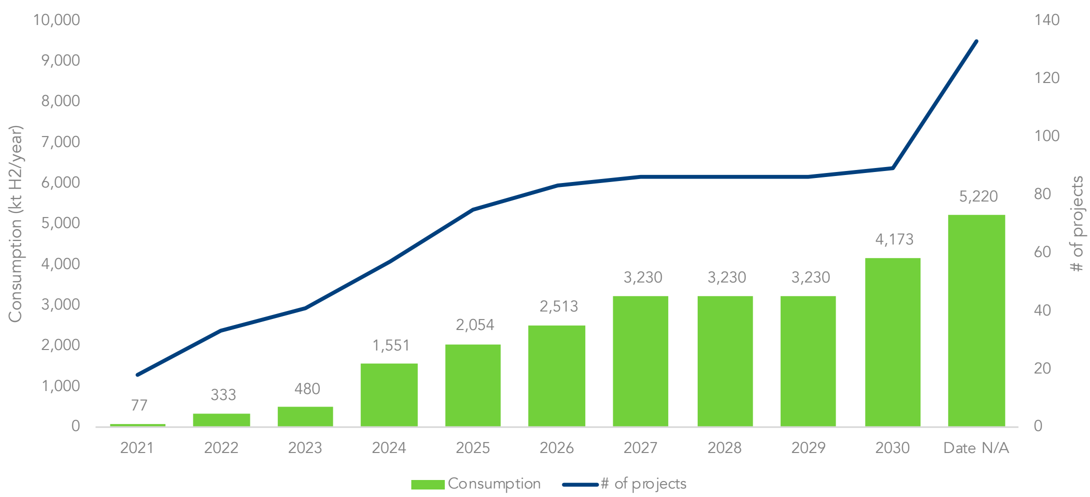
Clean hydrogen consumption in industry is expected to be, in the space of a decade, at least 67 times the expected amount in 2021

CONSUMPTION OF LOW-CARBON HYDROGEN IN INDUSTRY

The total planned consumption of low-carbon hydrogen in the industrial projects tracked amounts to 5.2 Mt H2/year by 2030[60]. The hydrogen production technology announced encompasses in terms of consumption: 84% PtH, 9% reforming with carbon capture projects and 7% both or a different/unknown source of low-carbon hydrogen. While only 19 projects are already in operation, the clean hydrogen consumption in the industry is expected to be, in the space of a decade, at least 67 times the expected amount in 2021. Although several tracked projects have not yet announced their start date, for the purposes of this chapter, it is assumed that they will become operational by 2030.

Clean hydrogen consumption in the industry is expected to be, in the space of a decade, at least 67 times the expected amount in 2021.

Figure 46 Cumulative planned low-carbon hydrogen consumption projects by 2021-2030 in kt H2/year and # of projects

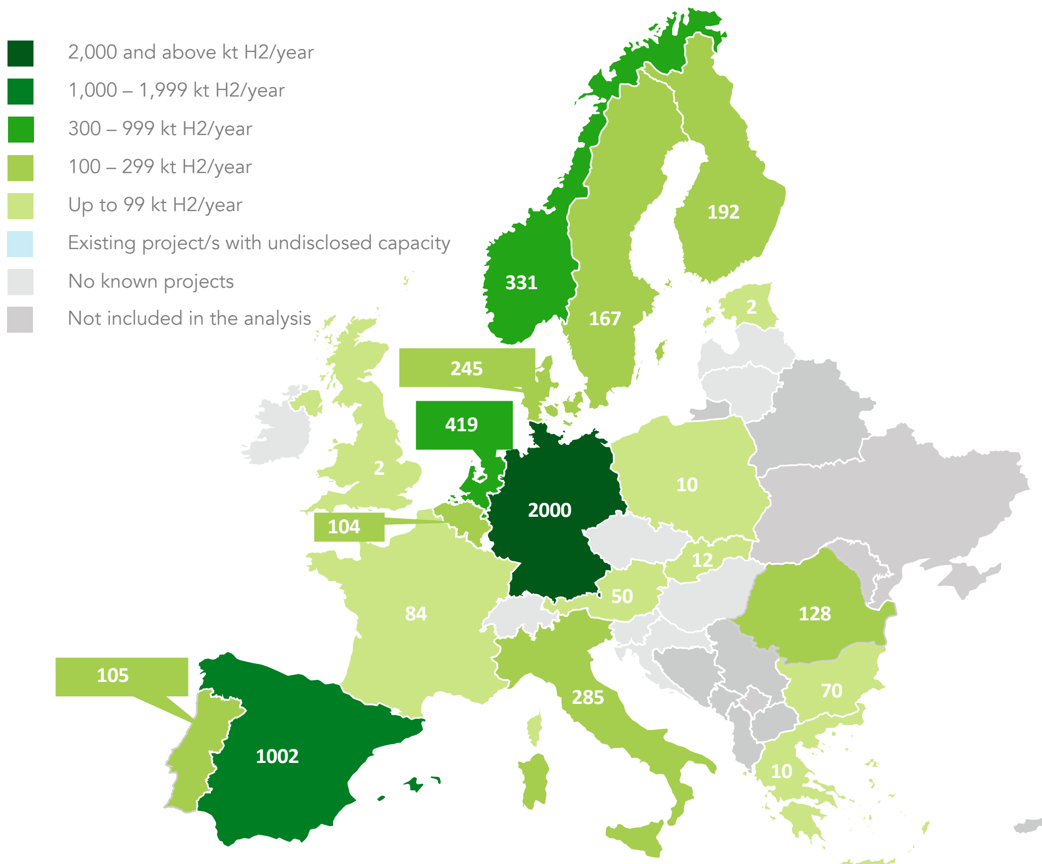


Source: Hydrogen Europe

[60] Although a number of announced projects do not commit to a firm date of completion, we assume those to be completed by 2030 for the purpose of this chapter.

Germany stands out as the country with the highest amount of planned low-carbon consumption by industry: 2,000 kt H2/year, amounting, by 2030, to 20% of the total number of projects and 38% of the total hydrogen consumption. Spain comes second with 1,002 kt H2/year of planned consumption in 2030, followed by the Netherlands with 419 kt H2/year and Norway with 331 kt H2/year.

Figure 47 Map of total planned clean hydrogen consumption by country in ktH2/year by 2030

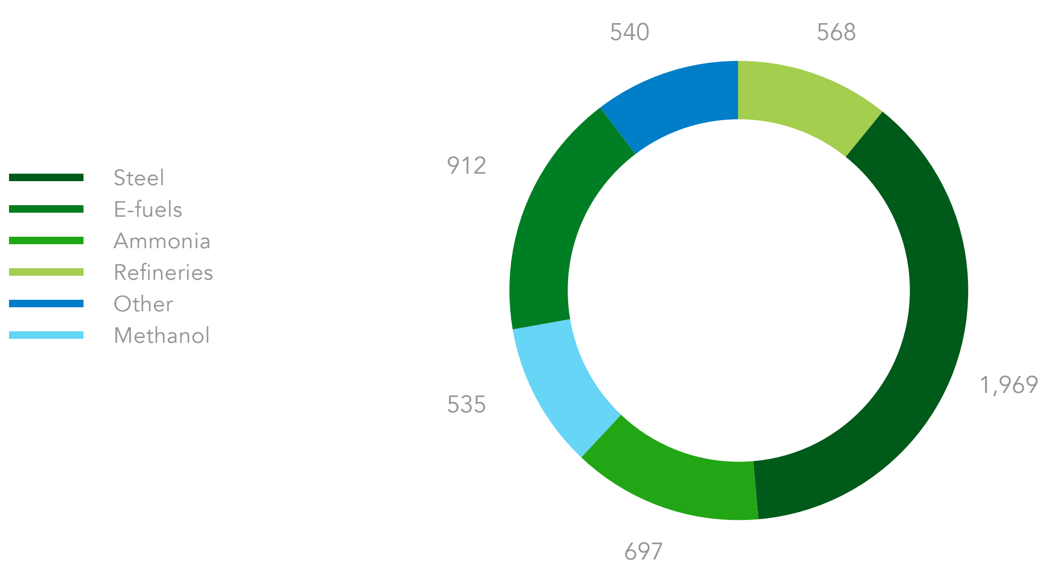


Source: Hydrogen Europe

At 1,969 kt H2/year, the steel industry presents the highest share of low-carbon hydrogen planned to be consumed by the industry, 38% by 2030. Although the conventional production methods for steel are not hydrogen demanding, new emerging CO2-free technologies are, which causes the hydrogen demand from this sector to rise. 18% of the total clean hydrogen consumption is planned to be applied to the production of e-fuels, 13% to ammonia production, 11% to refining projects, 10% to methanol production and 10% to other projects, which includes industrial heat in different facilities.

Considering the projects announced so far, 66% of total hydrogen consumption in industry plans to rely on on-site or on dedicated contracted off-site hydrogen production, as in these industries, a high volume of hydrogen consumption justifies investment in a dedicated Hydrogen Generation Unit (HGU) or merchant partnerships with specific production installations.

Figure 48 Hydrogen consumption in kt H2/year for the different industry sectors



Source: Hydrogen Europe

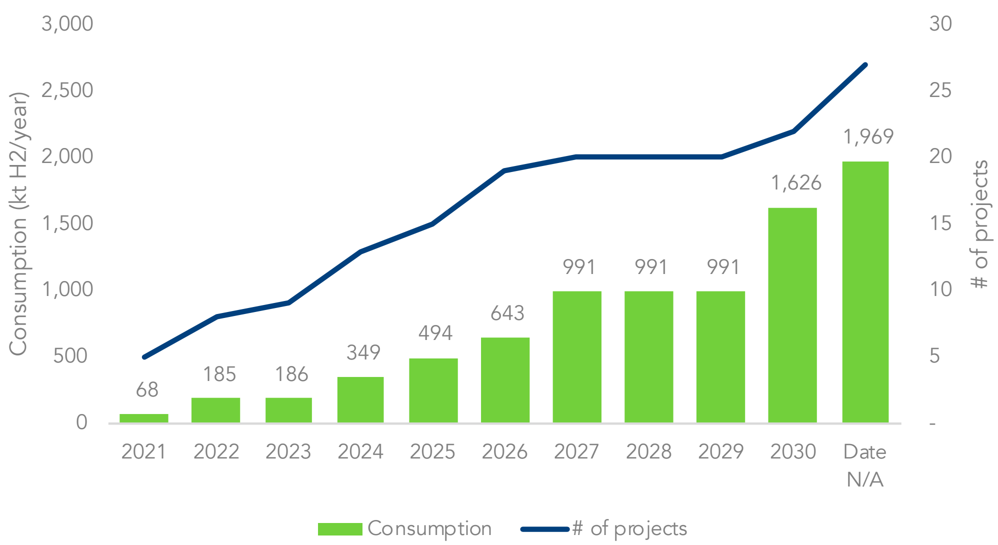
4.1 CLEAN HYDROGEN IN STEEL

The steel industry is one the biggest CO2 emitters due to the high amount of energy required and the result of the use of coke coal as raw material. Two main routes are typically used to produce steel. The most conventional one integrates a blast furnace (BF) and a basic oxygen furnace (BOF). Coal is used as a reductant to transform iron ore into steel. The second route uses an electric furnace arc (EAF), powered by electricity, to produce steel from steel scrap and direct reduced iron (DRI) in different proportions. While the EAF route is already less carbon-intensive than the BF/BOF method, emissions still occur when natural gas is used as a reductant to produce the DRI pellets. Replacing the natural gas with low-carbon hydrogen, combined with the supply of renewable electricity to power the EAF, will help decarbonize the entire steel production process. Projects following this method are already ongoing. A prime example is Hybrit which has already delivered the first CO2-free steel to the first buyer, Volvo.

While in 2019 the steel production split in Europe was around 58% BF/BOF and 42% EAF61, many facilities are transitioning into less emission-intensive technology, which is reflected in many projects already planned to use low-carbon hydrogen in the steel industry. Higher costs for the EAF route are not as much associated with higher CAPEX values as higher operational costs due to hydrogen prices, electricity prices and acquisition of scrap. To produce one tonne of steel, 51-72 kg of hydrogen can be required. Without cost on carbon emissions, low-carbon hydrogen would need a price of 0.9 €/kg to break even. Considering that the BF/BOF route can have CO2 emissions of around 1.6-2.2 tonne per tonne of steel, a carbon cost of 29€/CO2e and a hydrogen price of 2 €/kg would be enough for the DRI-H2 EAF route to break even.

Figure 49

Cumulative planned consumption projects in steel by 2021-2030 in kt H2/year and # of projects



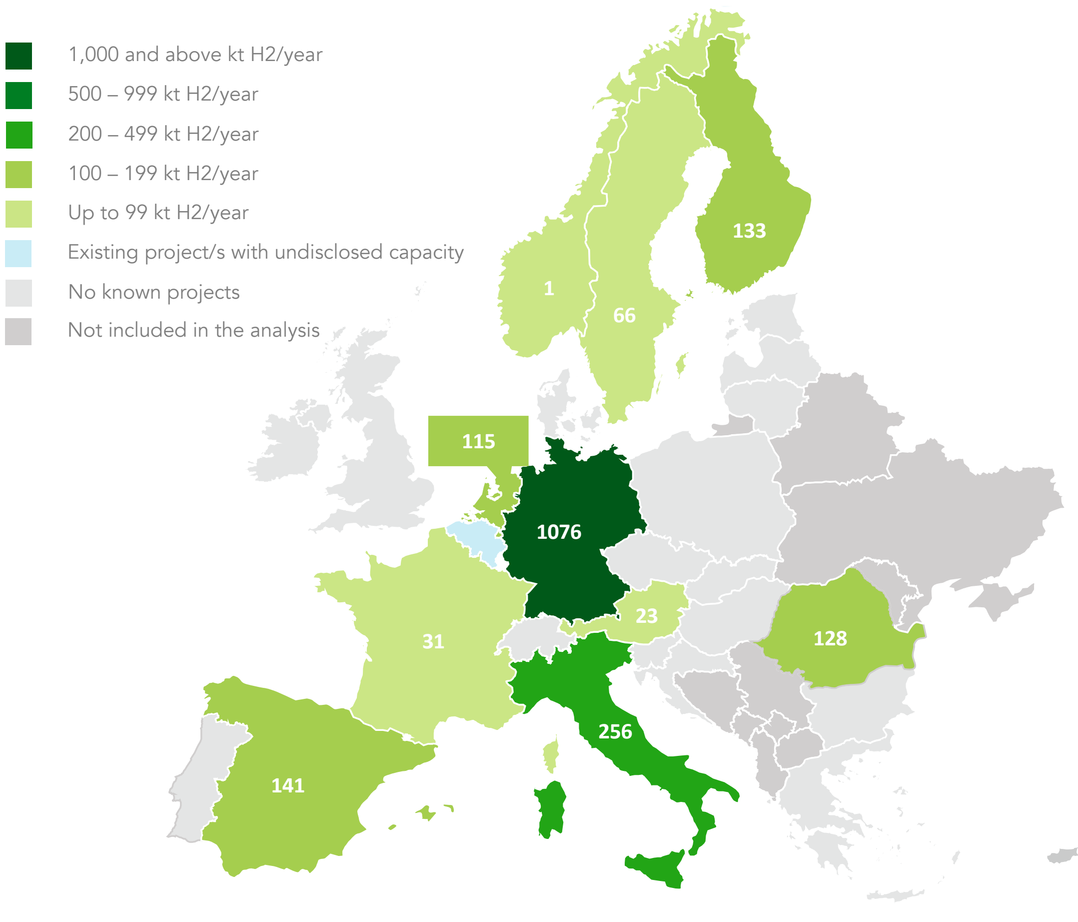
Source: Hydrogen Europe

[61] World Steel in Figures 2021

By 2030, 1,969 kt H2/year of low-carbon hydrogen is expected to be consumed by the steel industry, including projects without an announced operation date. From 2021 to 2027, the consumption in this industry is expected to increase, on average, 56.3% annually, even though no significant growth is seen between 2022 and 2023. Between 2027 and 2029, low-carbon consumption in steel is also expected to remain constant at 991 kt H2/year. In 2030 a planned consumption of 635 kt H2/year is planned to be added.

With a total consumption of 1,076 kt H2/year of clean hydrogen in 8 projects, Germany has the highest planned consumption of clean hydrogen in the steel sector, which is not surprising considering that Germany is the biggest steel manufacturer in Europe. Italy plans to consume approx. 256 kt H2/year clean hydrogen in steel, followed by Spain, Finland and Romania with 141, 133 and 128 kt H2/year, respectively. Together, these countries represent 88% of the total planned clean hydrogen consumption in the steel sector.

Figure 50 Map of total planned clean hydrogen consumption in steel production by country in kt H2/year by 2030



Source: Hydrogen Europe

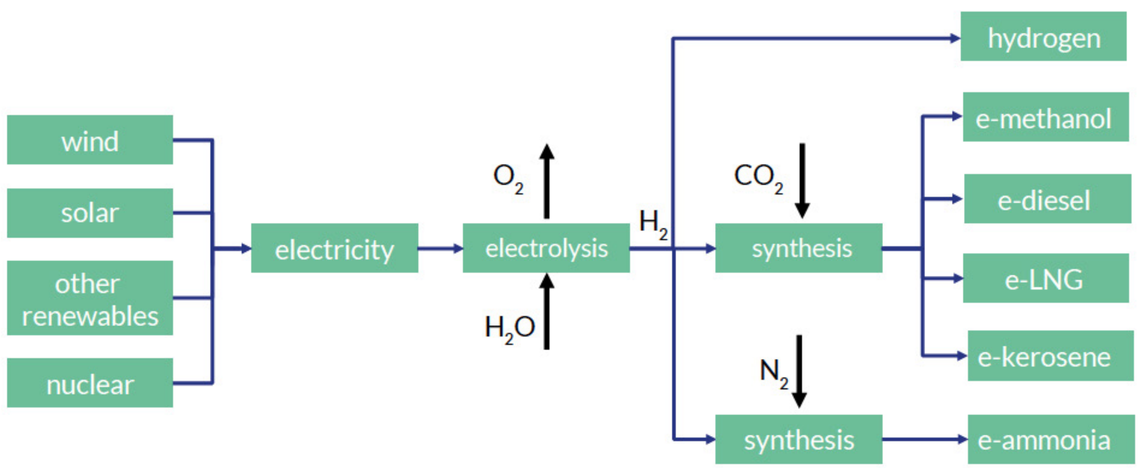
4.2 CLEAN HYDROGEN IN E-FUELS

With constant pressure to reduce emissions in the entire mobility sector, alternative "green" fuels are needed to help decarbonize hard-to-electrify vehicles (e.g., aviation and maritime sectors). E-fuels are synthetic hydrogen-based fuels that can be burned in internal combustion engines. Provided that carbon is captured from the atmosphere, renewable electricity is used during the synthesis. The hydrogen source is low-carbon; e-fuels such as e-methanol, e-ammonia, e-diesel, e-L(N)G, and e-kerosene are great alternatives to reduce emissions in mobility. Carbon dioxide is still emitted during the combustion of e-fuels but provided the conditions expressed above are met; the CO2 emissions should correspond to the amounts of carbon dioxide taken out of the atmosphere and used in the production process as a feedstock.

Significant consumption of clean hydrogen for e-fuels production is only expected in 2024, where 85% of the total planned (announced as of the time of writing) consumption in this sector is expected to be deployed. Between 2024 and 2030, the planned consumption is expected to grow from 771 kt H2/year to 912 kt H2/year if projects without announced operation dates are included in this time frame.

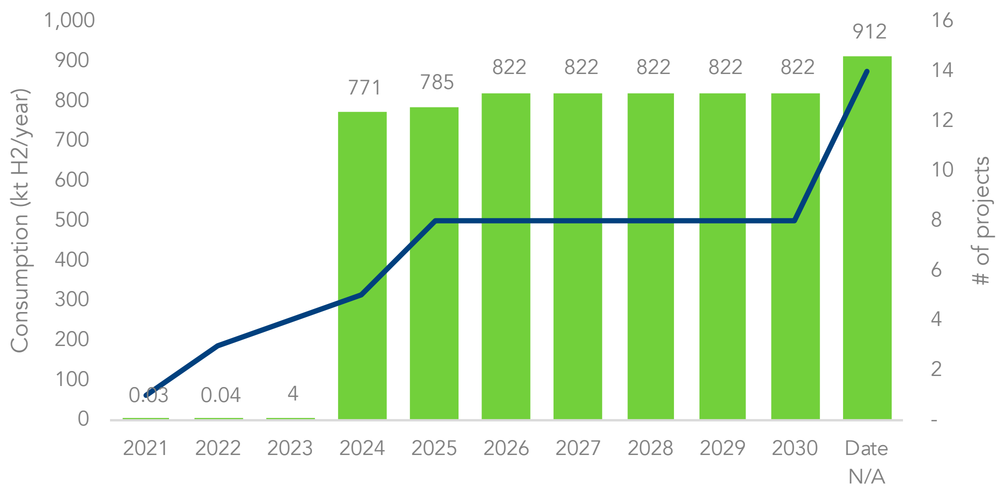
Most of the planned production of e-fuels is concentrated in Spain, with 84% of the total consumption at 767 ktH2/year. Smaller projects are also seen in Germany, Norway, Sweden, Austria and Belgium.

Figure 51 Schematic representation of the role of hydrogen and relevant e-fuels.



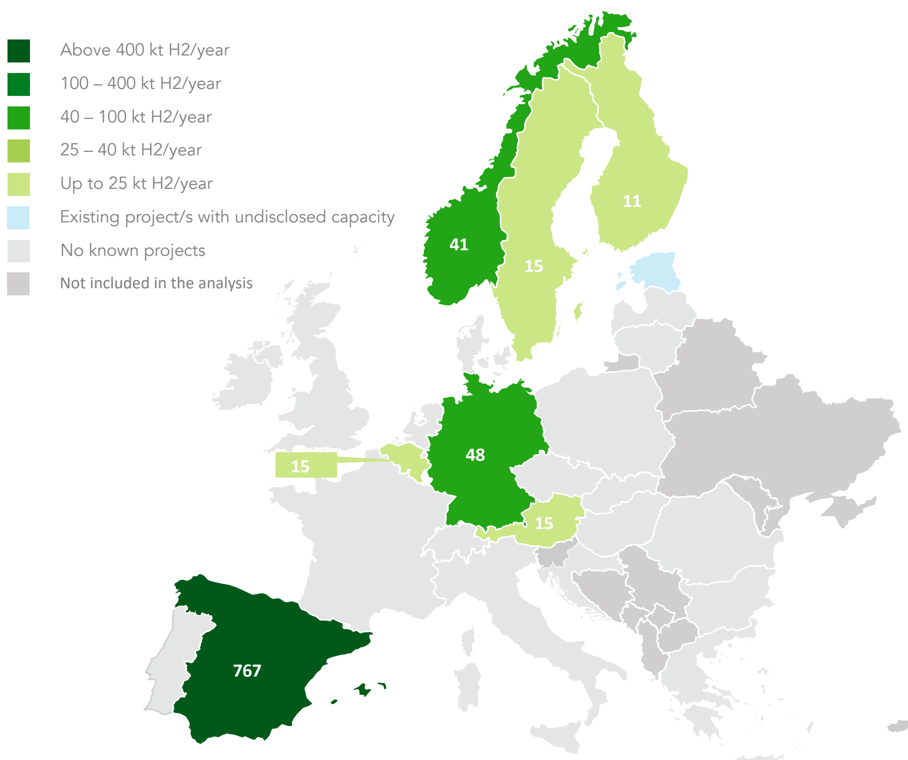
Source: TNO

Figure 52 Cumulative planned consumption projects in e-fuels production by 2021-2030 in kt H2/year and # of projects



Source: Hydrogen Europe

Figure 53 Map of total planned clean hydrogen consumption in e-fuels production by country in kt H2/year by 2030



Source: Hydrogen Europe

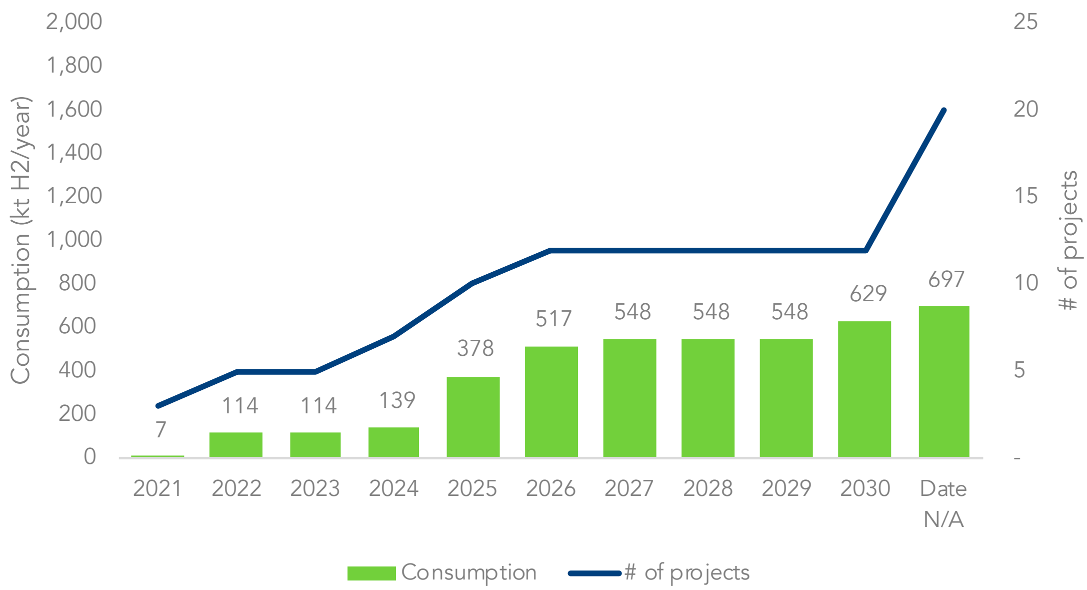
4.3 CLEAN HYDROGEN IN AMMONIA

With a total demand for hydrogen estimated at 2.6 Mt (102 TWhHHV) in 2019, the ammonia industry is the second-largest hydrogen consuming sector in the EU. When producing one tonne of ammonia, 175-180 kg of hydrogen are necessary.

Although it is normally used as a feedstock for fertilizer production, ammonia has also been seen as a potential energy carrier and/or fuel, already considered a suitable e-fuel for maritime applications. The widespread adoption of clean hydrogen in industries where hydrogen is already part of the process is, often, dependent on reaching cost parity with fossil fuel hydrogen, also known as break-even price, which in turn is very much reliant on climate policies, including prices on the CO2 emissions of industry. With fossil fuel hydrogen prices around 1.5 €/kg in Europe, carbon pricing is still needed to help low-carbon hydrogen break even in the ammonia sector. For example, with low-carbon hydrogen at 2 €/kg, a carbon price of 56 €/tonne CO2e is needed to break even.

Low-carbon ammonia projects planned to be operational until 2030 amount to a total hydrogen consumption of 697 kt H2/year, with 54% planned to be already in operation in 2025. Considering all ammonia production projects planning to replace fossil-fuel hydrogen with low-carbon hydrogen, 6.5 Mt of CO2 emissions could be avoided annually by 2030 from this sector alone.

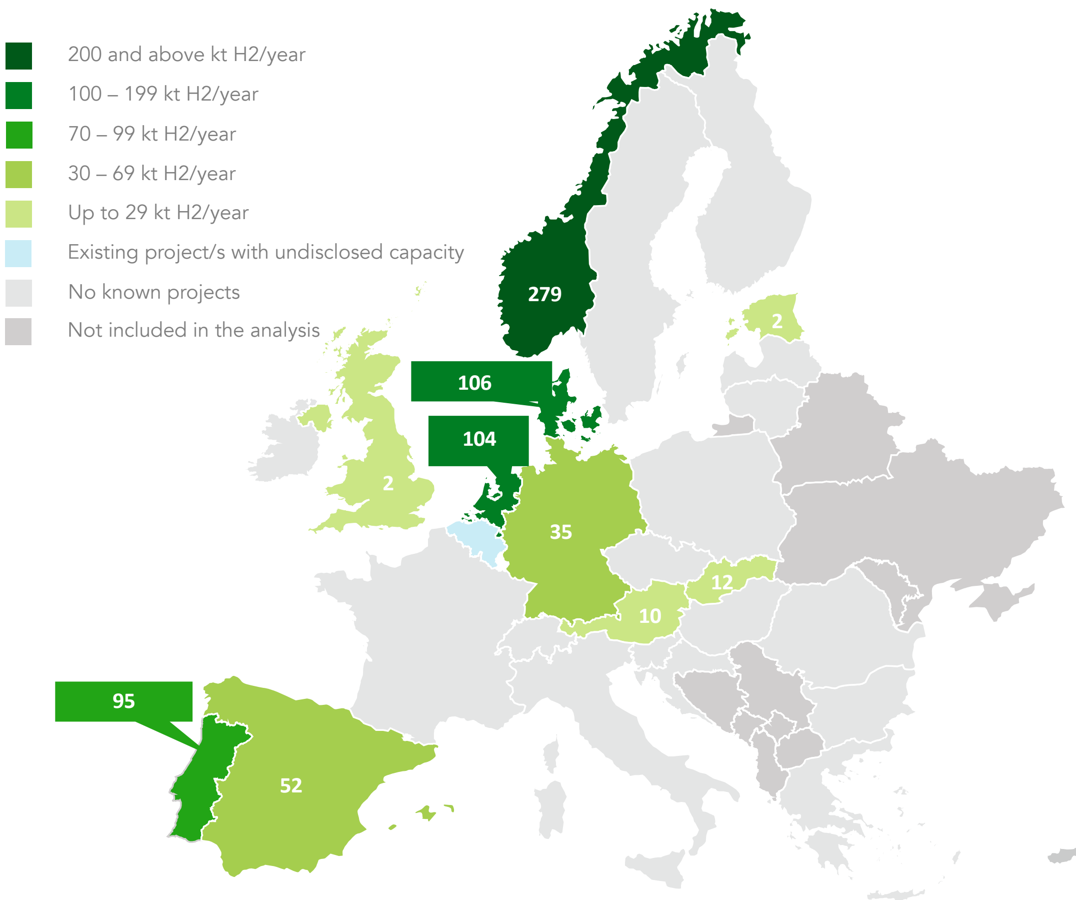
Figure 54 Cumulative planned consumption projects in ammonia production by 2021-2030 in kt H2/year and # of projects



Source: Hydrogen Europe

Norway stands out as the country with the highest planned consumption of low-carbon hydrogen for ammonia production, with a total of 279 kt H2/year, representing 40% of the total planned clean hydrogen consumption in the sector. Other notable countries include the Netherlands, with 104 kt H2/year consumption and Denmark with 106 kt H2/year consumption.

Figure 55 Map of total planned clean hydrogen consumption in ammonia production by country in kt H2/year by 2030



Source: Hydrogen Europe

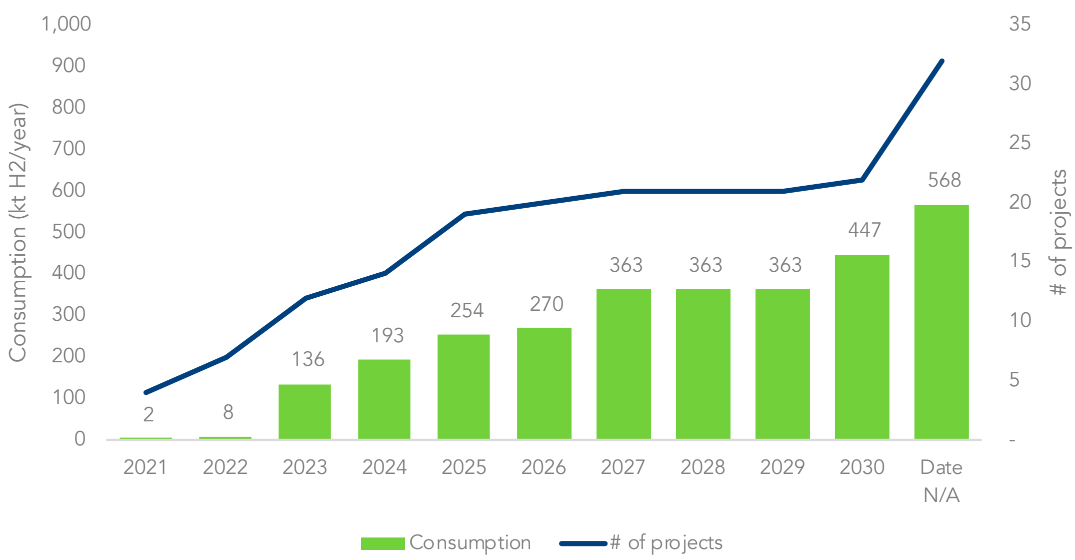
4.4 CLEAN HYDROGEN IN REFINING

Hydrogen in refining is used for hydrotreating and hydrocracking processes. Hydrotreatment is one of the key stages of the diesel refining process. It refers to several processes, such as hydrogenation, hydrodesulfurization, hydrodenitrification and hydrodemetalization. Hydrocracking involves transforming long and unsaturated products into products with a lower molecular weight than the feed.
As the oil refining sector is the biggest hydrogen consumer in the EU, the replacement of fossil fuel hydrogen with low-carbon hydrogen results in CO2 emissions reduction. Similar to the ammonia industry, the break-even price for refineries would be 1.5 €/kg if no CO2 costs are considered. With carbon costs of 56 €/kg, clean hydrogen at 2 €/kg would reach cost parity with fossil fuel hydrogen.

Around 11% of the total low-carbon hydrogen consumption planned by 2030 concerns replacing fossil-fuel-based hydrogen with low-carbon hydrogen in refining, with a total consumption of 568 kt H2/year expected by 2030 in this sector. Significant deployment is expected to start in 2023, with 136 kt H2/year cumulative consumption. Between 2023 and 2027, clean hydrogen consumption in refining is expected to grow gradually, with an average annual growth of 28%. Considering the totality of refining projects planning to replace fossil-fuel hydrogen with low-carbon hydrogen, 4.7 Mt of CO2 emissions could be avoided annually in this sector by 2030.

Figure 56

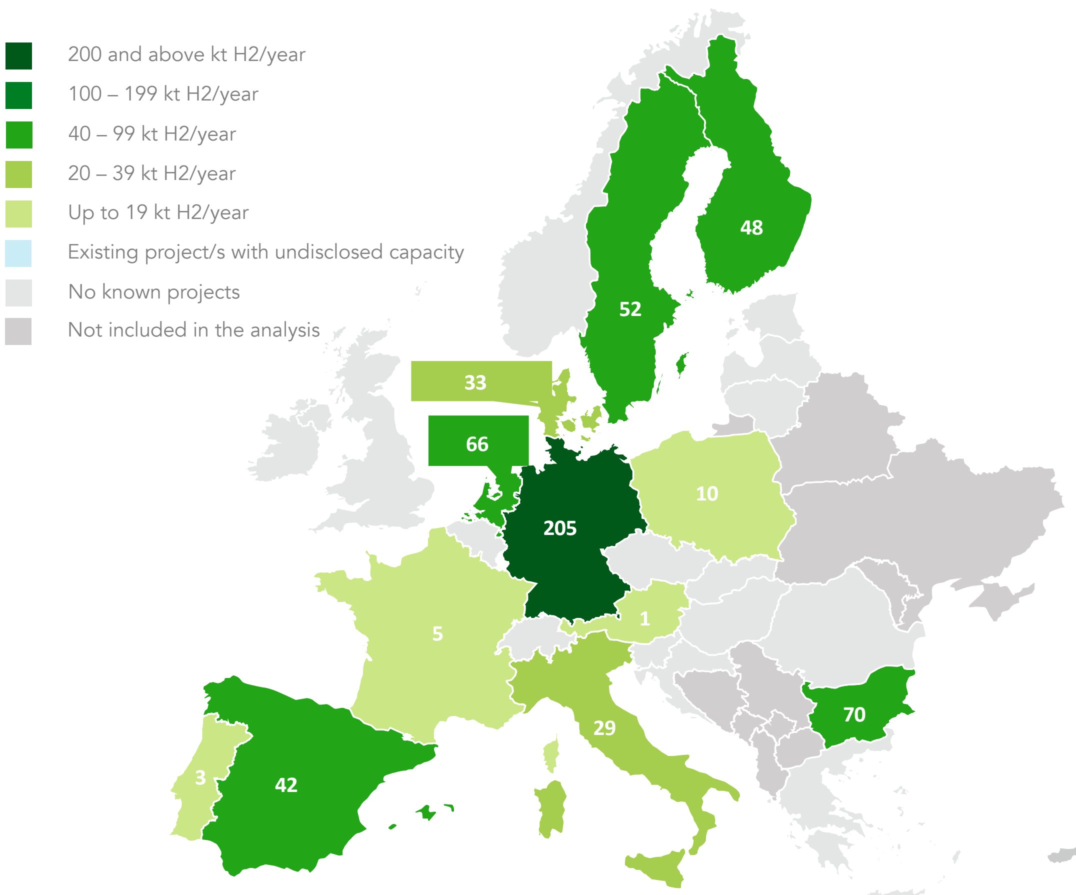
Cumulative planned consumption projects in refining by 2021-2030 in kt H2/year and # of projects



Source: Hydrogen Europe

The country with the highest projected consumption of clean hydrogen in refining is Germany, with nine projects and 205 kt H2/year of hydrogen consumption, followed by Bulgaria with only one project accounting for a total of 70 kt H2/year consumption and the Netherlands with three projects and a 66 kt H2/year total consumption. Sweden and Finland both present one project planned, with 52 kt H2/year and 48 kt H2/year planned consumption, respectively, and Spain, with three projects, plans for a consumption of 42 kt H2/year.

Figure 57 Map of total planned clean hydrogen consumption in refining by country in kt H2/year by 2030



Source: Hydrogen Europe

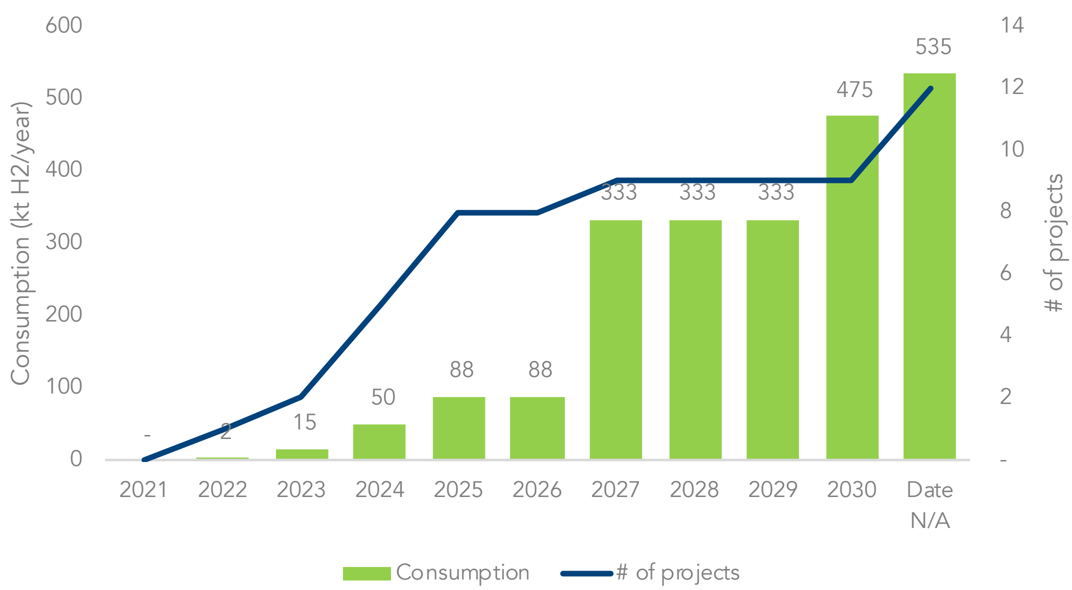
4.4 CLEAN HYDROGEN IN METHANOL

Similar to ammonia, methanol can have different uses as a chemical product or an e-fuel. To produce e-methanol, carbon dioxide and hydrogen are both needed as feedstock, making this process a common end-use for the currently planned low-carbon hydrogen production.

Total planned consumption of clean hydrogen for the specific production of e-methanol accounts for 535 kt H2/year until 2030, 10% of the total planned consumption in the industry. 46% of the total planned consumption is expected to be deployed only in 2027. An additional consumption of 202 kt H2/year is only expected three years later in 2030.

Figure 58

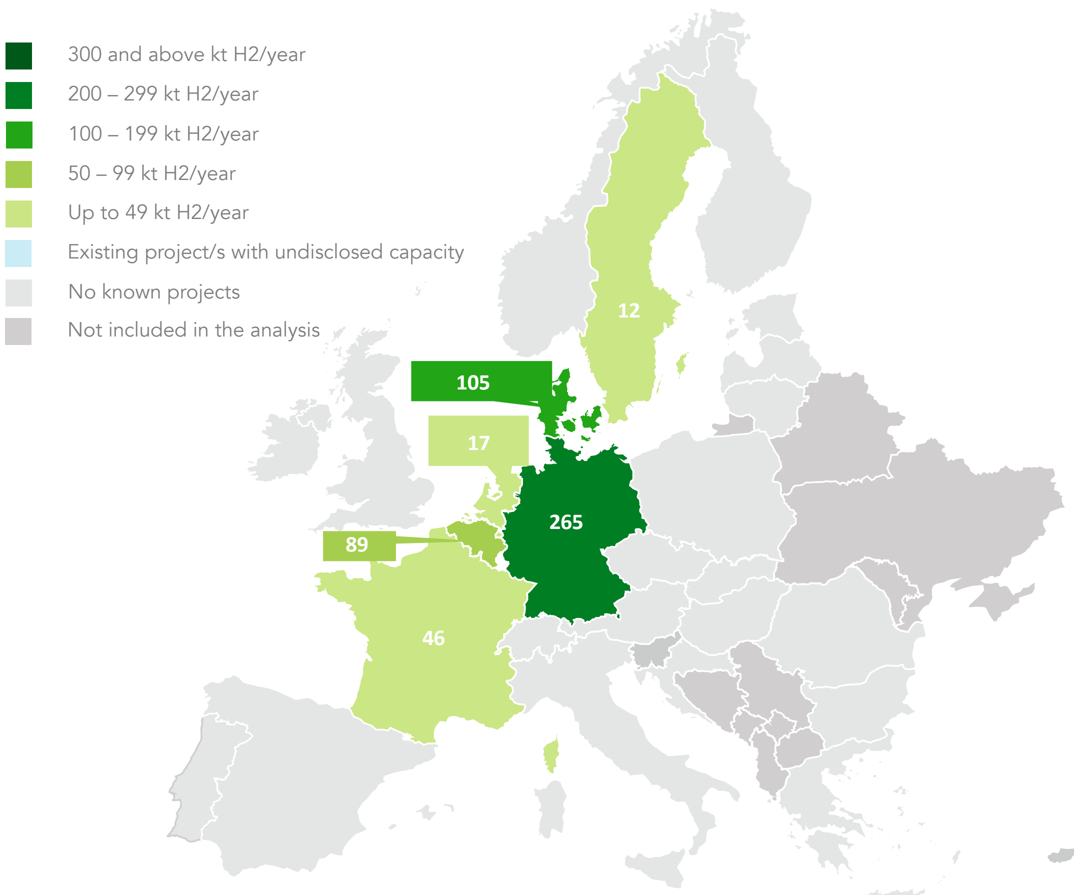
Cumulative planned consumption projects in methanol production by 2021-2030 in kt H2/year and # of projects



Source: Hydrogen Europe

With a total consumption of 265 kt H2/year in 3 planned projects, Germany is the country with the highest amount of hydrogen consumption for methanol production. Other countries, like Denmark with 105 kt H2/year, Belgium with 89 kt H2/year, France with 46 kt H2/year, the Netherlands with 17 kt H2/year, and Sweden with 12 kt H2/year are also planning to move forward in this sector.

Figure 59 Map of total planned clean hydrogen consumption in methanol production by country in kt H2/year by 2030



Source: Hydrogen Europe

5

EU POLICIES AND INCENTIVES

The EU's climate obligations and ambitions, in particular, the commitment to ensure net carbon neutrality by 2050 and to ensure a reduction of at least 55% GHG emission reduction by 2030, are reshaping most aspects of EU policy and legislation.

Entire areas of EU Policy, particularly Energy, Mobility, Taxation, Industrial Policy, Climate and Environmental protection, et cetera are being re-designed to shift our economies away from carbon-emitting energy sources and carriers.
This revision of the policy and legislative environment has had an immense impact on the hydrogen market, an impact that will only continue to grow in the next years as legislative proposals become law.

As navigating the plethora of EU soft and binding laws can seem daunting and complex, this chapter aims to briefly explain the hydrogen-related content of EU legislative acts and non-binding strategy papers.

Given the nature of this report as a yearly publication, this chapter aims to **present the relevant acts adopted, launched, or presented at the EU level in the past year rather than** provide a full and comprehensive overview of EU legislation and policy.

Therefore, the chapter below aims to present the main policy developments affecting Hydrogen that have taken place in the past year, focusing on legislative developments (both adopted legal acts as well as legislative proposals) as well as non-legislative measures such as policy strategies. In the sections below, we will aim to synthesize the main EU-level political and legislative initiatives of the past year, from those merely announced to those entered into force.

For a complete picture or historical overview, please review the 2020 edition of the Clean Hydrogen Monitor.

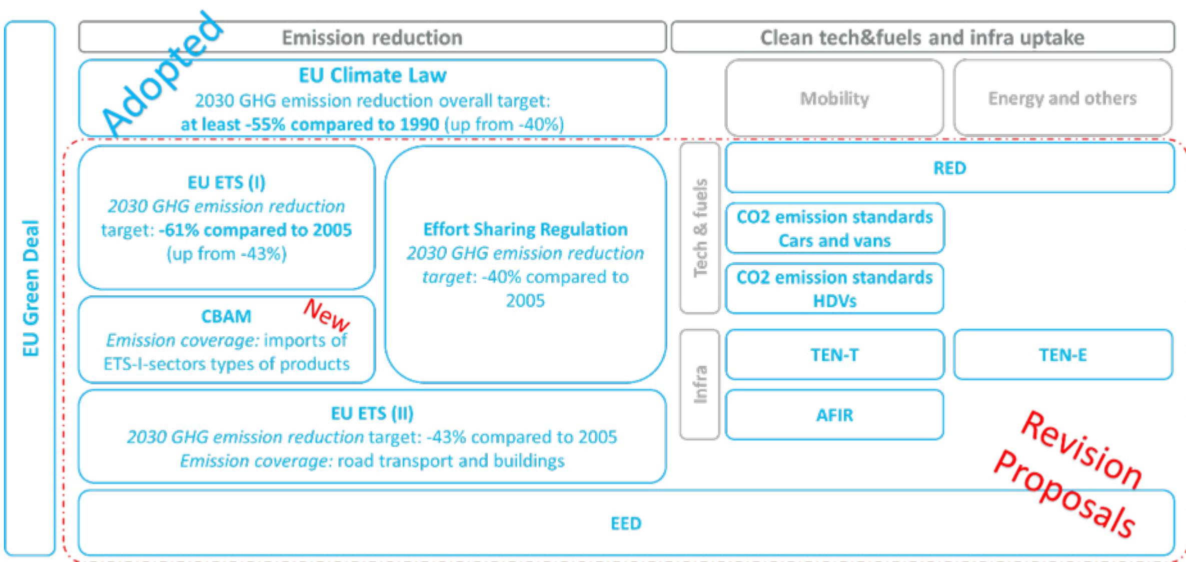
As navigating the plethora of EU soft and binding law can seem daunting and complex, this chapter aims to briefly explain the content and relevance relative to hydrogen of EU legislative acts and non-binding strategy papers.

5.1 LEGISLATIVE ACTS AND PROPOSALS ADOPTED/ PRESENTED IN 2020 AND 2021

The adoption of the European Hydrogen Strategy on 8th July 2020[62] marked an important shift in EU policy regarding the development of an EU wide clean hydrogen market. Since then, it has become increasingly clear that the EU is aiming to and willing to enact legislation supporting the development of an emerging clean hydrogen market in Europe.

While the foundations for the legislative environment affecting hydrogen were already in place[63], the developments which took place following the adoption of the European Hydrogen Strategy[64] on the 8th of July 2020 have the potential to be truly transformational for the Clean Hydrogen sector. Figure 60 below presents just a few of such developments which are likely to have a major impact.

Figure 60 Main Energy and Climate Legislative acts and proposals affecting Hydrogen released or proposed in 2020 and 2021



Source: Hydrogen Europe

[62] See Clean Hydrogen Monitor 2020 (https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/Clean-Hydrogen-Monitor-2020.pdf) for a full analysis of the European Hydrogen Strategy
[63] for a foundational baseline, please consult the Clean Hydrogen Monitor 2020 as well as the Fuel Cells and Hydrogen Observatory (www.fchobservatory.eu)
[64] COM(2020) 301 final, A hydrogen strategy for a climate-neutral Europe available at: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

5.1.1 EU CLIMATE LAW – A BINDING LEGAL ACT

On 30 June 2021, the (revised) **EU Climate Law**[65] was formally adopted. This short (only ten pages of legal text) but monumental EU Regulation sets the binding objective of climate neutrality (net-zero emissions) in the EU by 2050. Furthermore, it sets a new EU target of reducing greenhouse gas emissions by at least 55% by 2030[66] (up from 40%) and lays down that the transition to climate neutrality is to be "irreversible". This has set the stage for the "fit-for-55" legislative proposal package, which we will present below.

The transition to climate neutrality is to be "irreversible"

The impact that the EU Climate Law has on the development of the hydrogen market cannot be understated. As a carbon-free energy carrier and as a zero/low carbon[67] fuel, hydrogen is indispensable to any scenario for reaching net-carbon neutrality.[68] While lesser GHG emission reduction targets may have been achieved without or with smaller amounts of (low carbon) hydrogen, only an energy system built around electricity and hydrogen (with a complementary role for advanced biofuels) can realistically achieve the targets of the EU Climate Law. By setting a binding and irreversible objective of climate neutrality, the EU Climate Law effectively guaranteed the adoption of (low carbon) hydrogen in the EU

Represents perhaps the most fundamental change to the EU legislative acquis since the completion of the EU single market.

5.1.2 THE FIT FOR-55 PACKAGE AND LEGISLATIVE PROPOSALS

The **Fit-for-55 legislative** package, proposed by the European Commission on 14th July 2021, represents perhaps the most fundamental change to the EU legislative acquis since the completion of the EU single market. The package touches upon almost all aspects of the EU economy, especially in energy, industry and mobility. In this report, we will limit ourselves to a short presentation of the legislative proposals within the Fit-for-55 package with the highest potential impact on the Hydrogen market and highlight those provisions which are most relevant

Revision of the Renewable Energy Directive (RED)

The European Commission's (EC) revised proposal for the RED raises the renewable energy target from 32-40%. Particularly important for Hydrogen, the proposal includes:

- minimum binding targets for the use of renewable hydrogen in the industry: 50% of hydrogen consumption must be achieved with renewable fuels of non-biological origin (RFNBOs)
- minimum binding targets for the use of RFNBOs in the transport sector, including renewable hydrogen consumed in refineries: at least 2,6% of the total consumption of energy for the transport sector.
- specific provisions introduced to mainstream renewable energy in heating and cooling so that the 1.1 percentage point annual increase in heating and cooling becomes a binding baseline, on top of which each country will have a specific indicative top-up. Such an increase can be achieved in multiple ways, including the use of renewable hydrogen for heating.
- an indicative target of at least a 49 % share of energy from renewable sources in the buildings sector
- provisions extending the scope of the Union Database to cover the tracing of liquid and gaseous renewable fuels and recycled carbon fuels as well as their life cycle GHG emissions
- other provisions affecting hydrogen directly and indirectly

If adopted in its current form, the **revised Renewable Energy Directive** generates demand for renewable-only Hydrogen of at least 4.9 Mt and, as such, **represents one of the main drivers for the widespread adoption of renewable hydrogen in the EU.**

[65] Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality
[66] Compared to 1990 levels
[67] If produced from renewable or low-carbon sources
[68] See, for example, IEA's Net Zero by 2050 - a Roadmap for the Global Energy Sector, available at https://www.iea.org/reports/net-zero-by-2050

EU Emissions Trading Scheme (ETS)

The EU ETS is also slated to undergo a major revision. The main change is that the **emissions covered by the ETS should deliver 61% GHG emissions reduction by 2030** (up from 43%). This higher target will be achieved by combining a higher Linear Reduction Factor (LRF) and a one-off reduction of the cap. This increased ambition of the carbon market will likely trigger the clean switch across multiple applications driven by higher CO2 prices (e.g. in Ammonia, steel and cement production). This is a positive step to incentivise the ramp of clean hydrogen in all sectors covered by the ETS.

Production of electrolytic hydrogen will be included under the EU ETS, making them eligible for free allowances, a move that will further support the business case for such facilities

Furthermore, free allocation is made conditional on installations' decarbonisation efforts. Installations covered by energy audit obligations will be required to implement report recommendations or other measures leading to equivalent GHG reduction; otherwise, free allocation will be reduced by 25%. The proposal specifies that the requirements hold for investments with a pay-back period no longer than five years.

Sectors covered by the proposed **Carbon Border Adjustment Mechanism (CBAM)** - steel, aluminium, cement, fertilizers, and electricity – would have a 10-year transition period to adapt to the new regime before free allocation is fully phased out. Free allocation in sectors covered by the CBAM would decline by 10% yearly, starting in 2026 and would be zero by 2035.

Free allocation of allowances will also be phased out for the aviation sector by 2026 (for intra-EU flights). Extra-European flights are to be subject to offset under the international CORSIA scheme (transport).

Importantly, the EU ETS proposal includes producing electrolytic hydrogen under the EU emissions trading scheme, making renewable and low-carbon facilities eligible for free allowances. This will further improve their economics as allowance sales will boost their revenues.

The current **ETS scheme will be extended to most maritime transport**. The same rules on auctioning, transfer, surrender and cancellation of allowances, penalties and registries would apply to emissions from intra-EU voyages while at berth in an EU port and half of the emissions from extra-EU voyages. Surrender obligations will be gradually phased between 2021-2025. As of 2026, shipping companies will have to surrender 100% of their verified emissions. Shipowners will have to surrender units for 20% of verified emissions reported for 2023, 45% for 2024, 70% for 2025, and 100% by 2026. Non-surrendered allowances during the phase-in period would be cancelled. Last but not least, **the extension of the ETS to road transport and buildings** in a separate ETS without free allowances was confirmed. The cap of the new ETS for road transport and buildings will be set from 2026 onwards, alongside a linear reduction factor in line with a 45% emissions reduction in these sectors by 2030 compared to 2005. A price-based cost-containment mechanism will avoid price spikes, and a new and separate MSR for the two sectors will start operating in 2027.

The **Innovation and Modernisation Funds** are strengthened as additional auctioned allowances from the current ETS will feed into their budgets. However, 100% of ETS revenues must be used for climate-related purposes.

- **Modernisation Fund.** An additional 2.5% of the cap is auctioned to fund the transition in MS with below-average GDP per capita in 2016-18. The fund cannot finance investment in any type of fossil fuel. (this used to apply only to solid fossil fuels)
- **Innovation Fund.** 200 mln allowances are added to the Fund, 150 from the transport and buildings ETS. The scope of the fund includes support of the project via carbon contracts for difference (CCfDs).
- **The Social Climate Fund** will mobilise €72.2 billion for 2025-2032 to support households and transport users affected by the new EU ETS. The purpose of the fund is to help the

Member States in more vulnerable situations.
- In the buildings sector, it will support investments in energy efficiency, renovation, clean heating and cooling and integration of renewable energy.
- In the transport sector, it will support all investments in zero or low emission mobility.

Carbon Border Adjustment Mechanism (CBAM)

While several hydrogen consuming sectors (e.g., cement, steel, and fertilizers) are included within the scope of the proposed CBAM (alongside electricity and aluminium), hydrogen itself (N.B. which is not subject to any meaningful international trade at the moment) is not and neither are chemicals or petrochemicals.

In line with the CBAM, importers will have a payment obligation, starting from 2026, at a level that would create a level based on CO2 prices under the ETS for the corresponding goods, minus the free allocations still being received by those sectors. Following a transitional period, free allocation will be phased out gradually, which will begin with the initial payment obligation for importers.
The Commission proposes a 10-year transition period before free allocations are fully phased out. The share of free permits for the sectors affected will still be 100% in 2025 and will gradually decline by 10% each year to reach zero in 2035. When free allocations are maintained, the CBAM will only apply to those emissions above the free allocation received by domestic producers. The methodology for calculating the reduction in the number of CBAM certificates to be surrendered by importers to reflect free allocation will be determined by implementing acts.

Importers that fail to declare the emissions embedded in imports will be subject to a default value, which will be the average carbon intensity for comparable products in the country of origin.

Energy Tax Directive

The proposed revision to the Energy Taxation Directive heavily incentivised a switch to renewable and low-carbon hydrogen and derived fuels by setting out minimal taxation rates compared to unabated fossil fuels.

The revision aims to tax energy content rather than volume and places energy products in different tax categories based on their environmental performance when setting minimum excise rates, a ranking of which must be maintained when MS set actual rates. This will ensure that the environmental impact of individual fuels is better reflected, helping businesses and consumers alike make cleaner choices. In essence, how energy products are categorised for taxation purposes has been simplified to ensure that fuels most harmful to the environment are taxed the most.

Some of the so-called fossil fuel subsidies delivered through exemptions for certain products and home heating will be phased out. This will ensure that fossil fuels are no longer taxed below minimum rates. Member States will be able to support vulnerable households and protect against energy poverty. Moreover, fossil fuels used as fuel for intra-EU air transport, maritime transport and fishing should no longer be fully exempt from energy taxation in the EU – a crucial measure given the role of these sectors in energy consumption and pollution.

The proposal foresees preferential tax rates for renewable and low-carbon hydrogen (during a 10y transition period for the latter), incentivising the use of clean hydrogen in multiple applications, not least in maritime and aviation.

- Conventional fossil fuels, such as gas oil and petrol, and non-sustainable biofuels will be subject to the highest minimum rate of €10.75/GJ when used as a motor fuel and €0.9/GJ when used for heating.
- Natural gas, LPG, and non-renewable fuels of

non-biological origin (i.e., fossil hydrogen): while fossil-based, they can still support decarbonisation in the short and medium-term. Two-thirds of the reference rate will apply to this category for a transitional period of 10 years – i.e., a minimum rate of €7.17/GJ when used for motor fuel and €0.6/GJ when used for heating - before being taxed at the same rate as conventional fossil fuels.

- Sustainable but not advanced biofuels: to reflect these products' potential in supporting decarbonisation, half of the reference rate applies – i.e., a minimum of €5.38/GJ when used as motor fuel and €0.45/GJ when used for heating.
- The lowest minimum rate of €0.15/GJ applies to electricity - regardless of its use and regardless of the primary energy source used for its production (which will also be exempt)*
- Advanced sustainable biofuels and biogas, and renewable fuels of non-biological origin such as renewable hydrogen will also be subject to the lowest minimum rate of €0.15/GJ
- Low-carbon hydrogen and related fuels will also benefit from that same rate for a transitional period of 10 years.

The tax for aviation fuel will be introduced gradually before reaching the final minimum rate after a 10-year transitional period (i.e., ten years after entry into force, a minimum rate of €10.75/GJ will apply). Shipping fuels will be subject to a low minimum tax rate to avoid 'bunker evasion' (economic incentive to purchase fuel outside the EU). Alternatives to fossil fuels used for air and maritime transport (such as Advanced sustainable biofuels and biogas and renewable fuels of non-biological origin such as renewable hydrogen) will not be taxed for a 10-year transitional period.

Renewable fuels of non-biological origin such as renewable hydrogen will also be subject to the lowest minimum rate of €0.15/GJ

Box 1 Applying excise tax on electricity – A continued loophole for fossil fuels to escape excise taxation?

Electricity is the least taxed energy product, irrespective of the production method (i.e. even when produced from coal or gas). The Impact Assessment accompanying the Commission proposal states that this choice has been made as a result of the technical difficulties that would have come with a differentiated level of taxation for electricity based on its carbon footprint.
This logic appears to be inconsistent with the rest of the directive, as for Hydrogen, RFNBOs, and Biogas/Natural Gas, taxation is differentiated according to the environmental footprint, i.e. a large tax is applied for fossil hydrogen, a lower one for low-carbon hydrogen and an even lower for renewable hydrogen)

Additionally, the fossil fuels used for the production of electricity are exempt from taxation under the proposal. Even though the Directive does give the possibility for MS to tax fossil fuels used for the production of electricity, this possibility is left at the discretion of MS.

Source: Hydrogen Europe

Alternative Fuels Infrastructure Regulation (AFIR – formerly AFID

The AFIR proposal, as a directly applicable Regulation, sets binding targets for the development of hydrogen refuelling infrastructure along the TEN-T core network, the TEN-T comprehensive network and urban nodes while also taking into consideration the role of multimodal hubs. It **promotes the roll-out of hydrogen refuelling stations at a maximum distance of 150km in-between stations.**

In order to take into account the specificities for heavy-duty vehicles, as well as cars and light-duty transport, it requires a minimum daily capacity of 2 t of H /day and at least a 700-bar dispenser.

Additionally, liquid hydrogen shall be made available at publicly accessible refuelling stations with a maximum distance of 450 km in-between them.
While it stops short of targets for hydrogen infrastructure for ships, at ports and airports, it does state that National Policy Frameworks, prepared by the Member States by 2025, should contain deployment plans for alternative fuels infrastructure in inland waterway transport, maritime ports, and airports.

CO2 Standards Regulation for Cars and Vans

The proposal to revise the CO2 Standards Regulations for light-duty vehicles maintains its 2025 target sets an increased emission GHG reduction target for cars and vans by 2030, this time differentiating between cars (55% reduction) and vans (50% reduction), which represents a strong policy incentive for the adoption of zero-emission vehicles, both BEVs and FCEVs.

In addition, the proposal includes a new target for 100% emission reductions in 2035, effectively signalling the phase-out of the internal combustion engine under the current account scheme (tank to wheel) in favour of zero tailpipe emission vehicles. This would mean that, if adopted, all new cars sold in the EU after 2035 must be either BEVs and FCEVs.

FuelEU Maritime

The promotion of hydrogen and hydrogen derived fuels in the maritime sector is enabled by clear targets to reduce emissions, starting in 2025 set on shipping companies. The targets themselves are based on the fleet average GHG (CO2+CH4+N2O) intensity of the energy used onboard by ships in 2020 based on a lifecycle assessment. From this reference point, the emission level is reduced by:

- 2% from 1 January 2025
- 6% from 1 January 2030
- 13% from 1 January 2035
- 26% from 1 January 2040
- 59% from 1 January 2045
- 75% from 1 January 2050.

The obligations apply to ships above 5,000 gross tonnages. The scope is aligned with the extended EU ETS extension to the maritime sector (see ETS revision), namely all intra-EU voyages and stays within a port of call covered. Half of the voyages between EU and non-EU ports of call will also be included. The pooling of Fuel-EU certificates allowing shippers to balance compliance at a fleet level will be allowed. Penalties for non-compliance are set at a high level (creating a strong incentive for compliance), and the compliance deficit will be allocated to the EU ETS.

> The CO2 emission standards proposal includes a new target for 100% emission reductions in 2035, effectively signalling the phase-out of the internal combustion engine

RefuelEU Aviation

The Refuel EU Aviation is a Regulation that is set to apply as of 1'st January 2023. It sets an obligation on fuel suppliers to provide sustainable aviation fuels to airlines at all EU airports. This obligation only considers Sustainable Aviation Fuels such as biofuels, advanced biofuels and RFNBOs, which are chemically identical to the fossil fuels they are replacing. After 2030, it introduced a minimum share of e-fuels (RFNBOs) within the obligation.

The targets set by the regulation are:

- From 1/1/25, a minimum 2% SAF
- From 1/1/30, minimum 5% SAF, of which a minimum of 0.7% of synthetic aviation fuels
- From 1/1/35, minimum 20% SAF, of which a minimum of 5% of synthetic aviation fuels
- From 1/1/40, minimum 32% SAF, of which a minimum of 8% of synthetic aviation fuels
- From 1/1/45, minimum 38% SAF, of which a minimum of 11% of synthetic aviation fuels
- From 1/1/50, minimum 63% SAF, of which a minimum of 28% of synthetic aviation

A transitional period until the end of 2029 will apply, during which fuel suppliers may supply the minimum share (2%) of sustainable aviation fuel as a weighted average over all the aviation fuel they supplied across Union airports for that reporting period (instead of the minimum 2% for each airport).

5.1.3 TRANS-EUROPEAN NETWORK – ENERGY (TEN-E) PROPOSAL

Although not part of the Fit-for-55 package, the proposal for the revision of the TEN-E Regulation, which was published in December 2020, also represents a highly relevant, important legislative proposal that lays the groundwork for the mainstreaming of Hydrogen in the European Energy System by revising the 2013 version.

Formerly, the legislation considered four energy infrastructure categories: electricity, gas, oil, and carbon dioxide. The 2020 proposal brought the main change in that respect, as it proposed the following five categories: electricity, smart gas grid, hydrogen, electrolysers, and carbon dioxide. **The hydrogen sector is now fully considered, and natural gas and oil infrastructure projects are excluded from future PCI lists.** The Regulation foresees the planning for the conversion of Europe's natural gas infrastructure to hydrogen and the emergence of the hydrogen backbone. Furthermore, all future infrastructure investments must be fit-for-purpose and fully aligned with the objectives of the European Green Deal.

5.2 NON-BINDING POLICIES AND STRATEGIES

In the EU's legislative process, non-binding policy documents, strategies, communications, white papers and other soft law examples play an important role in setting a long-term vision for the direction that will be eventually be taken by EU law.

Although not as directly impactful as the legislative acts and proposals presented in the sub-sections above, non-legislative acts are also important to understand, should someone be interested in understanding the role that hydrogen may play in the EU over the long term.

Renovation Wave

The European Commission published its Renovation Wave on October 14, 2020. This strategy aims to help improve the energy performance of buildings and provides a roadmap of EU targets to achieve by 2030, accompanied by a series of policy measures. Buildings are responsible for about 40% of the EU's energy consumption and 36% of greenhouse gas (GHG) emissions.

The main targets are:
- 60% reduction in buildings' GHG emissions;
- 14% reduction in buildings' final energy consumption;
- 18% reduction of the energy consumption for heating and cooling (H&C);
- Double the renovation rate by 2030.

Looking at heating fuels and technologies, hydrogen and fuel cells are not mentioned in the strategy. Yet, there is no particular focus and details on specific priority technologies to decarbonise heating and cooling (H&C) in buildings in the strategy ('electrification' is not mentioned either and 'heat pump' only once, for example).

Decarbonisation of Heating and Cooling (H&C) remains a priority area, with an increased share of renewable heat and an increased replacement rate of heat equipment foreseen. Therefore, the integration of renewables will be a key focus – the synergies offered by linking H&C and transport infrastructure are underlined.

The strategy links back to the subsequent revision of RED II (now released), where the use of decarbonised gases is a major aspect, particularly when offering synergies with local agricultural and industrial sectors, which could provide opportunities for hydrogen hydrogen-based gases.

In a nutshell, the legislative proposals to look out for in priority to follow up on this strategy's ambitions and to know more on the regulation of hydrogen in residential applications are the RED II and ETS revisions (out since July 2021) and the EPBD and Ecodesign revisions (Q4 2021).

Offshore Renewable Strategy

The European Commission published its Offshore Renewable Strategy on November 19, 2020.
In a nutshell, the strategy:
- Aims to reach 300 GW of offshore wind installed capacity by 2050 and for 40 GW for ocean energies;
- Estimates required investments at around €800bn (2/3 for grid infrastructure, 1/3 for offshore energy generation);
- Wants to give a push to cross-border co-

operation via hybrid projects, consisting of cross-border offshore renewable energy plants with potentially various grid connection settings (tackled under TEN-E revision), in the perspective of a future 'fully meshed off-shore energy system,' where independent system operators could emerge;

- Plans to create an offshore bidding zone for hybrid projects, what is thought to be the 'right framework' for the development of large-scale offshore projects, including those in hydrogen production;
- Identifies some main funding schemes (InvestEU, RRF, CEF) for infrastructure and energy production project development.

With direct high-voltage current (HVDC), offshore hydrogen production and hydrogen pipelines are considered the most promising means of delivering offshore energy to consumption centres onshore. While the power grid extension is considered, the lack of offshore grid or lengthy grid development is highlighted, and onshore needs should be considered under grid planning exercise, particularly when linking offshore energy to hydrogen production.

The role of PtX (including hydrogen and ammonia) in energy system integration is recalled and linked with Energy System Integration and Hydrogen Strategies. Indeed, PtX could be used to partially make up for the limits of large-scale deployment of HVDC, reinforcing a potential role for hydrogen infrastructure in offshore grid planning.

Finally, the strategy considers the synergies between hydrogen, grid connection, and maritime sector: 'In the medium to the longer-term, on-site conversion of renewable electricity into hydrogen (i.e., hydrogen offshore production directly by the offshore renewable plant) and its shipping or onsite fuelling will become relevant.'

Overall, hydrogen is highly featured as an energy carrier that can play a "nodal role" in an 'integrated energy system' – as the EC Energy System Integration puts it – and here, in the deployment of offshore renewables.

Sustainable and Smart Mobility Strategy (SSMS)

The European Commission published the Sustainable and Smart Mobility Strategy on 9 December 2020.

It provides a vision of the European transport system and transport policies, especially in the perspective of decarbonisation of the sector. Indeed, to achieve carbon neutrality by 2050, EU transport greenhouse gas emissions will have to be cut by 90% emissions by 2050. The Strategy lays out the European Commission roadmap to achieve these goals in the next ten years. Moreover, with transport as a major end-use for hydrogen, the Strategy is highly relevant for the hydrogen sector. In a nutshell, the Strategy adopts an integrated approach by looking at demand, supply, infrastructure, and fuels in the transport sector.

The European Commission's Strategy foresees a total of 30 million zero-emission cars and 80,000 zero-emission lorries by 2030. It plans that nearly all cars, vans, buses, and new heavy-duty vehicles will be zero-emission by 2050. Hydrogen and renewable and low-carbon fuels are quasi systematically mentioned therein aside from electrification as solutions to decarbonise the various transport modes. The Commission's vision for transport strives to be technology-neutral while prioritising energy-efficient solutions by 'looking at the whole-life cycle.'

It adds that RED II revision could add minimum shares or quotas to incentivise the deployment of sustainable fuels (which it did, cf. RED II revision analysis under Fit for 55 Package section), possibly incentivising hydrogen deployment. It is mentioned several times, too, that upcoming key files such as Alternative Fuels Infrastructure Directive (AFID) and TEN-T revision proposals should be aligned with energy system integration and hydrogen strategies. Regarding road transport, the Strategy provides the Commission's first clear targets for hydrogen refuelling stations: 500 in 2025 and 1,000 in 2030, up from 144 currently. Whereas the need identified by the industry is larger (1,500 HRS would be needed by 2030 for the heavy-duty sector), target-based rolling out of hydrogen refuelling infrastructure across the TEN-T will help incentivise the switch to hydrogen mobility solutions and tackle the chicken-and-egg-problem. The Strategy also forecasts a substantial share of hydrogen (31-40%) and e-fuels (10-17%) in the road transport sector in 2050.

In addition, the creation of a new Alliance on Renewable and Low-Carbon Fuels Value Chain will be considered, where hydrogen and hydrogen-made fuels would undoubtedly represent a key element.

Industrial Strategy

Under its EU Green Deal, the Commission wants the industrial policy to deliver the development and integration of low-carbon solutions through policies and financial instruments at the EU and national level and via the private sector. The logic is that those who move first and move fastest will hold a greater competitive advantage. The latest European Industrial Strategy (published in March 2020) focuses on the Commission's green and digital goals and on strengthening Europe's sovereignty. In addition, the Commission published a revised version of its Industrial Strategy in May 2021, focusing on 'strategic autonomy' and recovery.

Those who move first and move fastest will hold a greater competitive advantage

The Commission perceives hydrogen as a key breakthrough technology where the EU should have frontrunners in developing commercial applications. Hydrogen is one of the six strategic sectors the Commission provides a detailed supply risk analysis for. It stresses external dependencies, especially for raw materials (PGM) and fuel cell and electrolysers assemblies. In this respect, alliances such as European Clean Hydrogen Alliance and the European Raw Material Alliance and IPCEIs have a key role to play in helping to secure supply and foster domestic production and communicate on risks and bottlenecks for technology ramp-up. The Commission is also considering launching an Alliance on Zero Emission Aviation, along with the Renewable and Low-Carbon Fuels Alliance, where hydrogen could play a main role.

The Commission perceives hydrogen as a key breakthrough technology where the EU should have frontrunners in developing commercial applications.

5.3 EXPECTATIONS FOR THE FUTURE PERIOD (Q3 AND Q4 2021 AND 2022)

After the "Fit for 55" package was released on 14 July, 14 December could also mark a key day in EU energy, climate, and transport policies. Indeed, regarding the energy and climate dimension, the Commission plans to publish revisions of the Third Energy Package for gas and the Energy Performance of Buildings Directive (EPBD). Those should be accompanied by plans to reduce methane emissions in the energy sector, a Commission Communication on Restoring sustainable carbon cycles and a Council Recommendation to address the social and labour aspects of the climate transition.

The Commission also intends to present an 'Efficient and green mobility package,' comprising revisions of the Regulation on the trans-European transport network (TEN-T) and the Directive on Intelligent Transport Systems and a new EU urban mobility framework and rail freight corridors initiative.

A sustainable products policy initiative, including a revision of the Ecodesign Directive, should be released as well.

For the hydrogen sector, **the revision of the Third Gas Package will be the milestone** to revise gas market rules and a major chance to make it fit for the ramping up of hydrogen production, transport, and use. **The initiative's title, 'Hydrogen and Decarbonised Gas package,' indicates the new leading role that hydrogen is set to play.** The revision will indeed aim to 'facilitate the market entry of renewable and low-carbon gases and remove any undue regulatory barriers.'

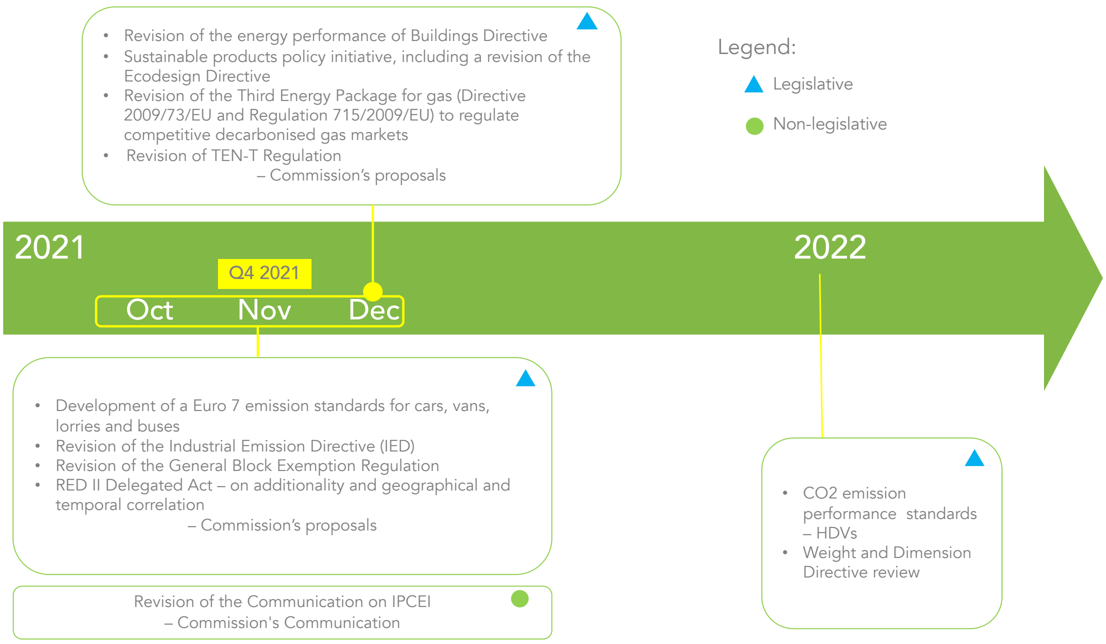
The publication of the Renewable Energy Directive's delegated act on additionality, geographic and temporal correlation, a crucial act for enabling (or prohibiting) renewable hydrogen projects from being implemented in practice, was still expected at the time of writing.

Finally, the revision of the TEN-T regulation will be an opportunity for the Commission to align guidelines on transport infrastructure funding with transport objectives under the EU Green Deal, not least the 90% emission reduction target by 2050. As set out in the 2020 Sustainable and Smart Mobility Strategy, it should ensure that new guidelines are consistent with the 'do no significant harm' principle and that transport corridors are completed on time. In addition, it should provide further opportunities for the uptake of clean transportation modes, including for hydrogen technologies, such as support for hydrogen refuelling stations deployment, consistent with both the AFIR and the revised TEN-E.

Renewable Energy Directive's delegated act on additionality, geographic and temporal correlation, a crucial act for enabling (or prohibiting) renewable hydrogen projects from being implemented in practice, was still expected at the time of writing

[57] European Commission, Special Eurobarometer 490 – Report, 2019. Accessible via: https://ec.europa.eu/clima/sites/clima/files/support/docs/report_2019_en.pdf

Figure 61 Upcoming legislative proposals with a significant impact on hydrogen deployment



Source: Hydrogen Europe

6

FUNDING OPPORTUNITIES

As climate objectives become more and more urgent and the need for action more immediate, so do the expectations of hydrogen and the role it should play to accelerate decarbonisation efforts.

It is becoming increasingly clear that, to meet growing expectations, the hydrogen projects, plans and ambitions presented in the chapters above need to become a reality and take their place within the broader energy system**. However, for these projects to become a reality at the scale they are needed, they require a sustainable business model backed up by funding and investments.**

This chapter attempts to shed some light on some of the most important, immediate funding opportunities that will be made available for hydrogen technologies. It is structured along two sub-chapters focusing on:

- EU funding programmes and
- Relevant investments under the Recovery and Resilience Facility (RRF) and national recovery plans (RRPs)

For projects to become a reality at the scale they are needed, they require a sustainable business model backed up by funding and investments.

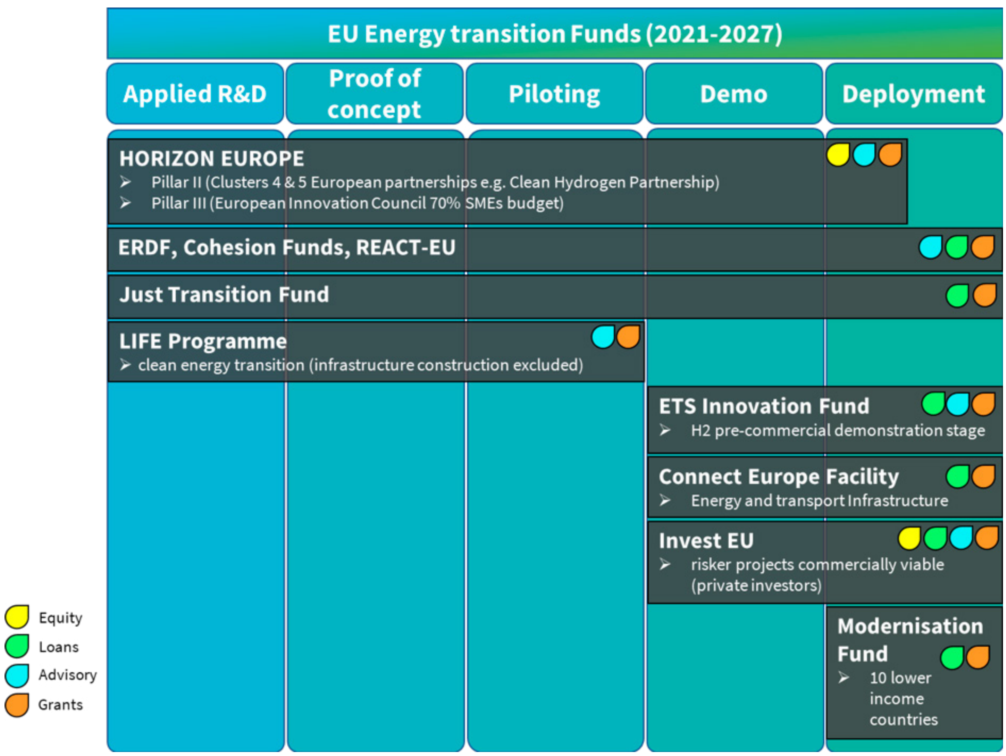
6.1 EU FUNDING OPPORTUNITIES

For the EU to meet the increased climate ambition of 55% GHG emission reduction by 2030 and the climate neutrality by 2050, at least 30% of the 2021-2027 budget of the EU will be spent on fighting climate change, which represents the highest share ever. As a result, a large number of EU funding instruments can support hydrogen projects along the entire value chain - ranging from the production of renewable and low-carbon hydrogen to its transmission and distribution and application in various sectors.

The following sections briefly describe key EU funds available in the current Multiannual Financial Framework, indicating what type of hydrogen-related investments could potentially be funded through those instruments. Further, more detailed information on the described EU funds, including funding rates, conditions for applications, payment modalities, award criteria, are available through the **Hydrogen Public Funding Compass**.[69]

First presented at the European Hydrogen Forum 2021, the Hydrogen Public Funding Compass is an online guide designed to serve as an entry point to access information on the most important EU funding programmes for renewables and low carbon hydrogen. Prepared by the European Commission and Hydrogen Europe, the tool covers EU funding programmes and funds financed by the 2021-2027 long-term EU budget and NextGenerationEU and national funding programmes and funds available at the EU country level.

Figure 62 Overview of EU energy transition funds available for the 2021-2027 period.



Source: Hydrogen Europe

[69] https://ec.europa.eu/growth/industry/hydrogen/funding-guide/eu-programmes-funds_en

The guide is a 'work in progress' by nature since, at the time of writing, upcoming programmes and calls for proposal could not be included yet. It is intended for regular updates, with frequency still to be decided according to the timeline when new Programmes specifically concerning the renewable and low carbon hydrogen value chain will be adopted.

Access to the Hydrogen Public Funding Compass is available at the **following link**.

6.1.1 ETS INNOVATION FUND

The Innovation Fund is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies, including hydrogen, accelerating their introduction to the market.

The Innovation Fund is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies, including hydrogen, accelerating their introduction to the market.

As the fund budget is related to revenues from the ETS, at current carbon emission allowances prices, the Innovation Funds budget is already at a sizeable EUR 20 billion – to be spent until 2030. With the initial proposals included in the Fit-for-55 package Innovation Fund might be further reinforced in the coming years.

The fund is open to projects for breakthrough technologies for all energy-intensive industry sectors covered by Annexe I to the EU ETS Directive, including products substituting carbon-intensive ones, renewable energy, energy storage, carbon capture and storage (CCS) and carbon capture and utilisation (CCU). Furthermore, for renewable energy and energy storage project categories, the fund could support not only projects deployment but also innovative projects involving equipment manufacturing – making it possible to fund hydrogen applications production and applications in various sectors and potentially electrolyser manufacturing projects.

As the fund allows for a high degree of flexibility as to how to define project boundaries, hydrogen transmission and distribution projects could be funded as well either indirectly or even directly, assuming they are integrated within a larger production or end-use project, which would generate GHG emission savings (which a standalone infrastructure project would not).
Expected large scale GHG emission savings resulting from funded projects make the Innovation Fund unsuitable for pure research projects. For similar reasons, pilot projects, unless large scale and expected to operate for a 10-year timeframe, are also not a good fit for the fund. Some flexibility might be allowed for small-scale projects.

In future, the Innovation Fund is expected to also include support in the form of a carbon contract for difference type instruments.

6.1.2 HORIZON EUROPE AND CLEAN HYDROGEN JU

Horizon Europe can support a wide range of hydrogen RDI activities:

- Research and innovation projects (including basic and applied research, technology development and integration, testing, demonstration, and validation on a small-scale prototype in a laboratory or simulated environment)
- Innovation actions (including prototyping, testing, demonstrating, piloting, large-scale product validation and market replication)
- Innovation and market deployment (activities necessary to deploy innovation in the market, including the scaling-up of companies)

The cluster 'Climate, energy and mobility" of Pillar II is relevant for hydrogen activities, especially the dedicated Public-Private Partnership Clean Hydrogen for Europe. In addition, the Environmental investment centre (EIC) support for the deployment of innovative solutions in Pillar III and other clusters, PPPs and Missions of Pillar II, and the research infrastructure programme in Pillar I may provide additional opportunities for hydrogen RDI activities.

The Clean Hydrogen Joint Undertaking (successor to the Fuel Cell and Hydrogen Joint Undertaking) can finance research and innovation projects, innovation actions and innovation and market deployment, relating to the different parts of the hydrogen value chain:

- Clean hydrogen production. E.g., electrolysis and other modes of production, integration of electrolysis in the energy system, decarbonisation of industry.
- Distribution. E.g., Delivery of hydrogen at

low cost (large scale storage, pipeline and non-pipeline transport, liquid carriers, key technologies for distribution) and hydrogen infrastructure (HRS) development.
- End-uses. E.g., Competitive hydrogen vehicles (building blocks, HDV, maritime/ports, aviation/airports, rail), Heat & power (stationary FC, turbines & burners), Decarbonisation of industry.

The Clean Hydrogen JU also addresses R&I needs in the hydrogen supply chain (e.g., scale-up of manufacturing), cross-cutting issues (ex: recycling, LCA, safety, et cetera) and the integration of ecosystems combining multiple applications (hydrogen valleys).

Other key partnerships launched under Horizon Europe and potentially interesting for hydrogen project funding are:
- The European Partnership for Clean Aviation;
- The European Partnership for transforming Europe's rail system;
- Zero-emission waterborne transport;
- Zero-emission road transport;
- Built4People;
- Clean steel – low-carbon steelmaking;
- Process4Planet.

6.1.3 MODERNISATION FUND

The Modernisation Fund (MF) is a dedicated funding programme to support ten lower-income EU Member States in their transition to climate neutrality by helping modernise their energy systems and improve energy efficiency. It is recognised in the European Green Deal Investment Plan as one of the key funding instruments contributing to the objectives of the European Green Deal.

Looking from the hydrogen sector perspective, the following activities could be funded via the MF as priority investments:

1. Generation and use of electricity from renewable sources
   a. Production of renewable hydrogen from renewable electricity;
   b. Use of hydrogen produced from renewable electricity;
   c Zero direct emission mobile assets based on renewables (e.g., electric hydrogen-fuelled trains, trucks or cars).

2. Improvement of energy efficiency
   a. High-efficiency hydrogen combined heat and power (CHP) investments, provided a share of electricity is cogenerated at high efficiency on an annual basis;
   b. Utilization of by-product hydrogen streams.

3. Energy storage:
   a. Power-to-hydrogen projects with grid stabilization purpose;
   b. Flexible power generation for longer dark doldrum periods;
   c. Hybrid solutions for off-grid islands;
   d. Back-up solutions / emergency systems;
   e. Underground hydrogen storage;
   f. Natural gas infrastructure projects to facilitate the use of low carbon/renewable hydrogen in an existing gas network;
   g. Infrastructure for the transmission and distribution of green hydrogen, including hydrogen refuelling stations.

Given a strong focus of the JTF both on climate change mitigation and job creation, the Just Transition Fund can be used to finance most hydrogen project archetypes, including key equipment manufacturing plants

Furthermore, the following types of investments could be funded as part of the non-priority envelope:

1. Low carbon hydrogen production from waste feedstocks or gaseous fuels
2. Hydrogen production from nuclear energy
3. New hydrogen district heating and cooling systems, bringing GHG emission savings and efficiency improvements
4. Renewable hydrogen heat only projects (not CHP).

It should be noted that the above list is non-exhaustive and also not binding for the Member States – i.e. Member States cannot expand the scope of eligible investments beyond what is allowed by the MF Regulation but can always narrow it down to fit with their National Climate and Energy Plans or other strategies.

In order to ensure that investments will contribute to 2030 climate objectives, investment proposals must comprise mature technology. In general, the proposed technologies must be proven in an operational environment under comparable conditions and scale and with available appropriate references. This excludes R&D type projects.

6.1.4 JUST TRANSITION FUND

Just Transition Fund (JTF) was established to address the social, economic and environmental consequences of reaching the Union's 2030 climate target and achieving climate neutrality by 2050.

Given a strong focus of the JTF both on climate change mitigation and job creation, the Just Transition Fund can be used to finance most hydrogen project archetypes, including key equipment manufacturing plants**.** On the other hand, due to the strong focus on job creation and aid in energy transition, the JTF is more suited to fund implementation projects than pilot or demonstration projects, even though the latter are not explicitly ruled out.

More specifically, as Investments related to the production, processing, transport, distribution, storage or combustion of fossil fuels cannot be funded through the JTF, **the fund can support predominantly renewable hydrogen production and use.** Furthermore, to be eligible for funding, waste-to-hydrogen projects need to respect the waste hierarchy defined in the Waste Framework Directive – i.e., the processed waste feedstock needs to be either biodegradable and/or unrecyclable.

In the case of infrastructure projects, industry application and energy roundtables, the fund allows for the support of investments in the deployment of technology and systems and infrastructures for affordable clean energy, including energy storage technologies, and GHG emission reduction.

Both fleet deployment and refuelling infrastructure deployment projects are eligible for the mobility applications, provided they have a local character.

For the investment archetypes defined by the buildings roundtable, only district heating projects are eligible if the heat production installations are supplied exclusively by renewable energy sources. Investments in research and innovation activities, including universities and public research organisations, and fostering the transfer of advanced technologies are also eligible for funding.

It should be noted, though, that described scope of activities eligible for support from the JTF only defines general eligibility rules; for a specific project to be eligible for the support, it has also to be part of the sectors and the types of operations envisaged in the EC-approved, territorial just transition plan relevant for the region where the investment is planned.

6.1.5 CONNECTING EUROPE FACILITY – TRANSPORT AND ENERGY

The Connecting Europe Facility (CEF) is a key EU funding instrument for targeted infrastructure investment at the European level. It supports the development of high performing, sustainable and efficiently interconnected trans-European networks in transport, energy and digital services.

CEF investments fill the missing links in Europe's energy, transport and digital backbone, and the facility is divided into three distinct instruments. The revision of the CEF Regulation, which underpins this programme, is in the process of being finalised by the European institutions and is expected to come into force retroactively from 1 January 2021.

CEF for Energy (CEF-E) is an envelope of CEF that supports the implementation of Trans-European Networks for Energy Regulation (TEN-E), a policy framework focused on linking the energy infrastructure of EU countries. Nine priority corridors and three priority thematic areas have been identified in the TEN-E framework to address the energy infrastructure needs at the regional and European levels. CEF supports implementing Projects of Common Interest (PCIs) in these priority corridors and thematic areas.

CEF-E is suited to demonstration projects, studies, and co-financing of the development of energy infrastructure. As noted above, CEF-E is based on the TEN-E Regulation. However, the current status quo, namely the TEN-E Regulation from 2013, does not recognise hydrogen infrastructure, electrolysers, or smart gas grids as eligible projects. However, it does recognise CO2 pipelines as eligible. **The proposed revision of the TEN-E Regulation will, however, significantly change the PCI categories criteria. The Commission's proposal envisages supporting the roll-out of electrolysers, hydrogen infrastructure, and smart gas grids as separate PCI categories** following negotiations once the other institutions (EU Parliament and the Council) establish their respective positions towards 2021, with a political agreement expect by early to mid-2022.

The Connecting Europe Facility for Transport (CEF-T) is the funding instrument meant to realise the European transport infrastructure policy. The instrument contributes to implementing the Trans-European Transport Network (TEN-T) framework by financing key projects to upgrade infrastructure and remove existing bottlenecks whilst promoting sustainable and innovative mobility solutions. These projects cover all EU Member States and all transport modes (road, rail, maritime, inland waterways, air) and support transport co-modality, logistics, and innovation. Furthermore, it aims at supporting investments in building new transport infrastructure in Europe or rehabilitating and upgrading the existing one.

Because of a relatively low funding rate with a requirement of blending with external private financing, CEF-T is best suited for funding large scale, mature hydrogen infrastructure projects, which are close to the market and have a low funding gap.

6.1.6 EUROPEAN REGIONAL DEVELOPMENT FUND, COHESION FUND AND REACT-EU

Both ERDF and CF have specific targets of 30% and 37%, respectively, to support innovation and entrepreneurship in the transition to a climate-neutral economy[70]. This means that although hydrogen is not explicitly mentioned in the objectives or the key priorities of the funds, each of those funds is potentially interesting for the hydrogen sector. **t**
However, opportunities for funding hydrogen projects will strongly depend on the Member States and priorities identified in the national programmes. This means that hydrogen-related projects need to be explored on a case-by-case basis, whether they could fit into the priorities of the relevant programmes of the Member States or region where the potential beneficiary is located.

6.1.7 INVESTEU

InvestEU is composed of the InvestEU Fund, InvestEU Advisory Hub and InvestEU portal. The instrument is expected to mobilise more than €372 billion of public and private investment through an EU budget guarantee of €26.2 billion. It is centrally managed by the Commission, with EIB acting as its main financial partner, expected to deliver on 75% of the EU guarantee.

[70] REACT-EU is providing additional funds to ERDF and has therefore the same objectives.

Investment in clean hydrogen is part of the main policy priority under the Sustainable Infrastructure window.

InvestEU could provide repayable support for projects targeting the use of low-carbon hydrogen, production and supply (at commercial scale) and on-site storage to develop the energy sector and the deployment of low carbon technologies. Support may also be given for the deployment for all modes of transport of recharging and refuelling infrastructure for electricity, hydrogen and liquefied or compressed natural gas blended highly with bio-methane (>50 %). Investments in infrastructure supporting the production or use of hydrogen are considered critical infrastructure under the InvestEU Fund.

For further details on the type of projects that might receive funding from InvestEU, you can consult the policy window section of the InvestEU investment guidelines.[71]

6.1.8 LIFE

The new LIFE programme will be divided into four sub-programmes, out of which climate change and mitigation and clean energy transition sub-programmes will be available to fund hydrogen-related projects.

LIFE programme's sub-programme on clean energy transition will be based around the following areas of intervention: building a national, regional and local policy framework supporting the clean energy transition; accelerating technology roll-out, digitalisation, new services and business models and enhancement of the related professional skills on the market; attracting private finance for sustainable energy; supporting the development of local and regional investment projects, and involving and empowering citizens in the clean energy transition.
The Programme is suited for small demonstration projects and governance projects and projects by acting as a catalyst for large-scale deployments of technical and policy solutions. On the other hand, LIFE is not meant to support large infrastructure construction (over EUR 500k).

Investments in infrastructure supporting the production or use of hydrogen are considered critical infrastructure under the InvestEU Fund

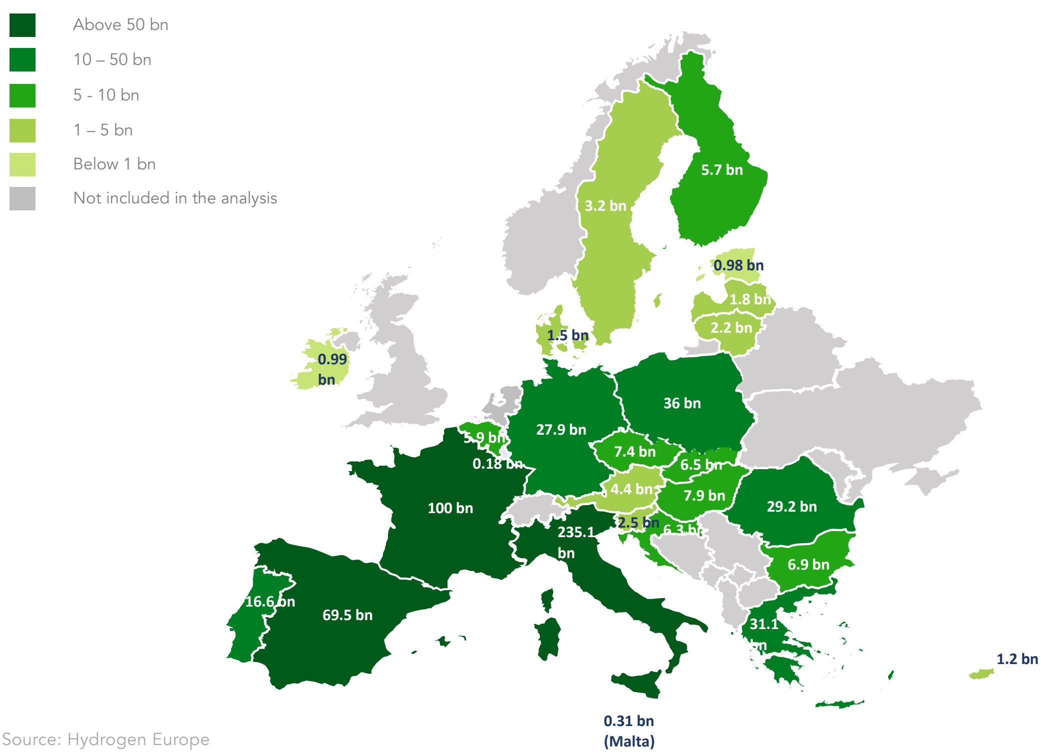
[71] Source: https://ec.europa.eu/growth/industry/hydrogen/funding-guide/investeu_en

6.2 RECOVERY AND RESILIENCE FACILITY AND NATIONAL PLANS

This section analyses the Recovery and Resilience Facility (RRF) and national recovery plans (RRPs) presented by the EU countries to repair damages from the pandemic. It provides an overview of the instrument; and the plans of allocations to hydrogen - including a breakdown of the allocations along the hydrogen value chain – at both the EU and Member States level; it presents the targets and deadlines associated with the plans. Several countries, including those with the highest planned investments in hydrogen technology, are analysed in more detail. The chapter concludes with remarks of and a glimpse into the future of hydrogen in the EU.

In the wake of the coronavirus pandemic, the European Union created the Recovery and Resilience Facility to help Member States repair economic and social damages by financially supporting investments and reforms. The RRF, designed to boost the recovery of Member States post-COVID, is at the centre of the NextGenerationEU, the largest stimulus package ever implemented in Europe. Aiming at a sustainable recovery, the temporary instrument makes available 672.5 billion euros in grants and loans. Importantly, it mandates that at least 37% of the total allocation should be dedicated to the "green" transition[72].

Figure 63 Total Funds Distribution in RRPs (in billion EUR)



Source: Hydrogen Europe

[72] Contributions to the "green transition" are "(...) reforms and investments in green technologies and capacities, including in biodiversity, energy efficiency, building renovation and the circular economy, while contributing to the Union's climate targets, fostering sustainable growth, creating jobs and preserving energy security", as in paragraph 11 of the Regulation, 2021/241 of the European Parliament and of the Council of 12 February 2021. For more details of the components that contribute to the "green transition" please see Annexe VI of the Regulation.

To access the funds, Member States must submit draft Recovery and Resilience Plans (RRPs) to the European Commission, which must specify the investments, reforms and targets they aim to achieve. After submission, the Commission assesses the plans and, once the Commissions' concerns and comments are addressed, it submits them to the European Council for approval.

When analysing data for this report (August – September 2021), the Commission endorsed 18 of the 25 plans formally submitted to it. The two countries that did not submit a plan are Bulgaria and the Netherlands[73]. Considering all formally submitted and draft plans -, the total RRF funds mobilised for the recovery in each country range from - 93.3 million (Luxembourg) to 191.5 billion euros (Italy) -, to be spent between 2021-2026. Suppose one considers national investments triggered by the plans and other public funds, both national and from EU sources other than the RRF but included in the plans themselves. In that case, the total value of the recovery plans ranges from 183.1 million (Luxembourg) to over 235.1 billion euros (Italy). Belgium, Bulgaria and Greece also plan investments funded with private resources – increasing their plans to 9.6, 10.3 and 90.9 billion euros, respectively. Figure 63 illustrates the distribution of the total funds from the RRPs, including all public funds included in the RRPs presented by each Member State.

The plans are structured along with so-called "flagship areas" for investment and reforms. Among these, the areas "Power up" [of technologies and renewables] and" Recharge and Refuel" [of sustainable transport and charging stations] are, in particular, very closely linked with the Commission's priorities to promote a climate-neutral Europe.

As hydrogen is an essential part of the net-zero emission energy system, they also have a particularly close relationship with the European Hydrogen Strategy[74] and the European Clean Hydrogen Alliance, which aim to support the same goal. Box 2 shows the Commission's hydrogen-related targets by 2030.

As a result of this close link, Member States have, as expected, included hydrogen investments in their recovery and resilience plans, investments that this chapter closely analyses.

Please note that the following analysis of hydrogen investments in RRPs is based on all plans published up to this date (August-September 2021). It includes final plans - as adopted - plans that were officially submitted but not yet adopted and the Bulgarian draft as was published on 2 July 2021. The Netherlands did not publish a draft of the plan yet. Be aware that plans which have not been formally finalised and adopted might undergo significant changes (see Figure 64). The analysis also includes funds from both the Recovery and Resilience Facility and national public funds and funds from other EU sources, when applicable[75].

Box 2 The Commission´s Targets in the 2030 horizon

The Commission's ambition is to ensure the installation of at least 6 GW of electrolysers by 2025 and at least 40 GW of electrolysers in Europe, in addition to 40 GW in Europe's neighborhood with export to the EU by 2030. The strategy aims to secure the production of up to 1 million tonnes of renewable hydrogen by 2025 and 10 million tonnes by 2030 in the EU, as well as the deployment of 500 hydrogen stations by 2025 and 500 additional ones by 2030.

[73] Bulgaria has a draft in preparation and the Netherlands did not publish a draft of the plan.
[74] A hydrogen strategy for a climate-neutral Europe, but see also the Annual Sustainable Growth Strategy 2021.
[75] Austria, Bulgaria, Czechia, Finland, France, Germany, Hungary, Italy and Luxembourg include national public funds and funds from other EU sources additionally to the RRF in their recovery plans.

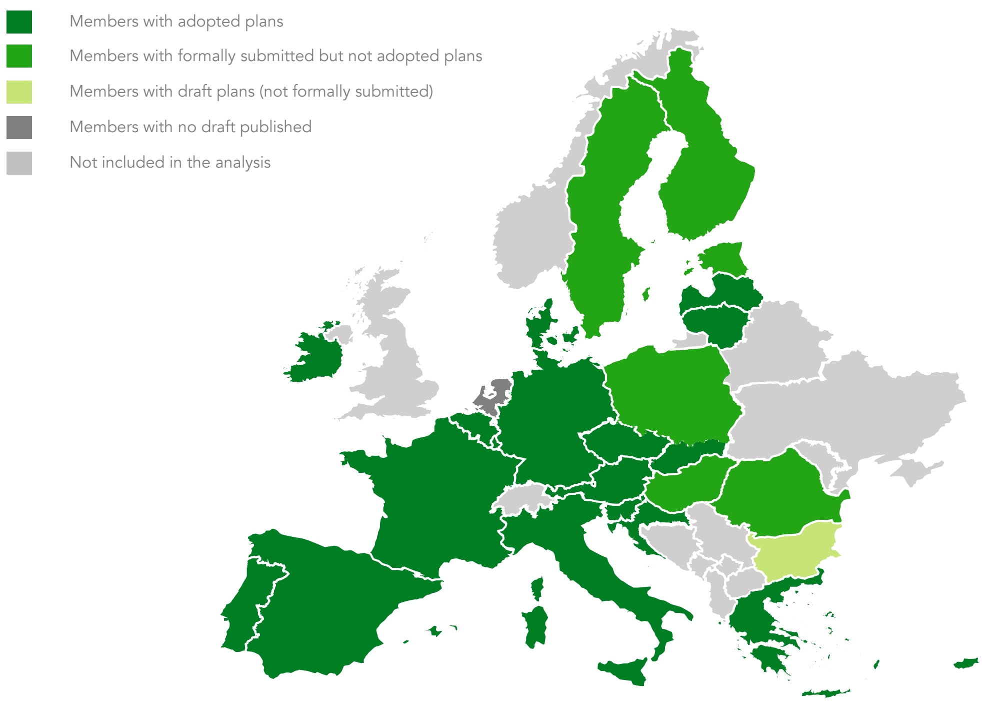
In their plans, Member States take different approaches to allocate investments and structuring their RRPs. This is also true for the planned investments in hydrogen technologies. While some Member States[73] present their plans with a high degree of granularity, from which it is possible to determine the precise funds which are dedicated exclusively to hydrogen technologies, others[74] take a more general approach and provide only funding categories which encompass funding and investments for multiple technologies, among which hydrogen. In this analysis, both types of hydrogen-related allocations are included. They are named 'exclusive' and 'non-exclusive', respectively, to designate the allocation type presented by each Member State. Please be aware that non-exclusive funds do not contain proportions or indications of the specific amount directed for hydrogen. Finally, a small number of Member States[75] do not mention hydrogen at all in their plans.

Another difference concerns the scope of investments that are planned in hydrogen technologies: while some RRPs include robust plans containing investments in multiple parts of the value chain which seek to develop hydrogen on many fronts (e.g., production, distribution and end-use, in multiple sectors), others focus on only specific parts of the value chain.

Furthermore, while some RRPs include detailed targets and deadlines associated with investments in hydrogen technologies (some of which contain a clear link to their respective national hydrogen strategies), others, in contrast, present broader goals without associated quantitative targets.

Figure 64

Status of Recovery and Resilience Plans, as of the moment of drafting



Source: Hydrogen Europe

[73] Austria, Belgium, Estonia, France, Germany, Italy, Lithuania, Poland, Romania and Spain
[74] Bulgaria, Croatia, Cyprus, Czechia, Denmark, Finland, Greece, Hungary, Latvia, Portugal, Slovakia and Slovenia.
[75] Ireland, Luxembourg, Malta and Sweden.

6.2.1 TOTAL ALLOCATIONS FOR HYDROGEN IN RECOVERY AND RESILIENCE PLANS

In total, the cumulative amount of funds available for hydrogen from all RRPs reaches over 54 billion euros

In total, the cumulative amount of funds available for hydrogen from all RRPs reaches over 54 billion euros, of which 42 billion are allocated to categories which include investments in multiple technologies among which hydrogen may be funded, as well as 12 billion which are dedicated exclusively for hydrogen technologies. Figure 65 shows the distribution of total hydrogen funds (both exclusive and non-exclusive) of 26 EU Members (EU 27 excl. The Netherlands).

At the Member States level, the total funds for hydrogen in RRPs (both exclusive and non-exclusive) range from roughly 5 million (Slovenia) euros to over 14 billion euros (France).[76]

Overall, France, Spain, Germany and Italy are the Member States with the largest absolute value of funds (both exclusive and non-exclusive) made available for hydrogen, dedicating 14.3, 9.4, 7.9, 7.8 billion euros, respectively.

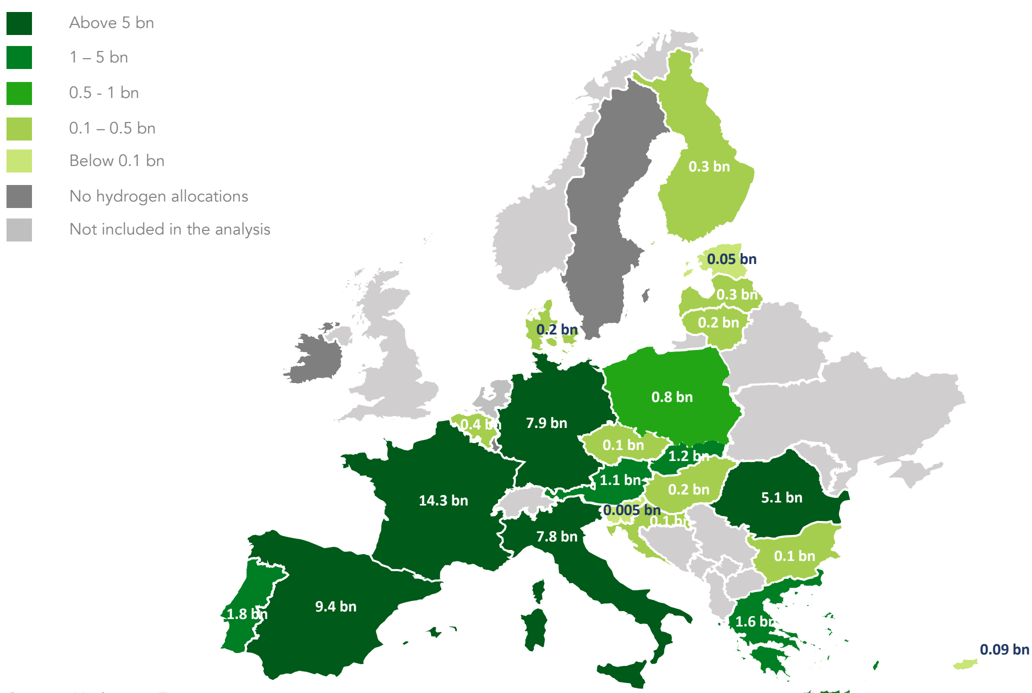
Among the Member States which dedicate **exclusive funds to hydrogen**, Italy and Germany lead the ranking, dedicating 3.6 and 2.7 billion euros respectively in investments exclusively to hydrogen technology.

Among the Member States, which include hydrogen among broader categories involving multiple technologies (non-exclusive funds), France, Spain and Germany lead the list allocating 12.3, 7.9 and 5.2 billion euros respectively for hydrogen, alongside other technologies.

Figure 66 illustrates the absolute amount and the breakdown by allocation type of funds available for hydrogen for all Member States. Figure 67 zooms in on countries with less than 1 billion euros of funds allocated to hydrogen.

Figure 65

Total Hydrogen Funds Distribution in RRPs (in billion EUR)

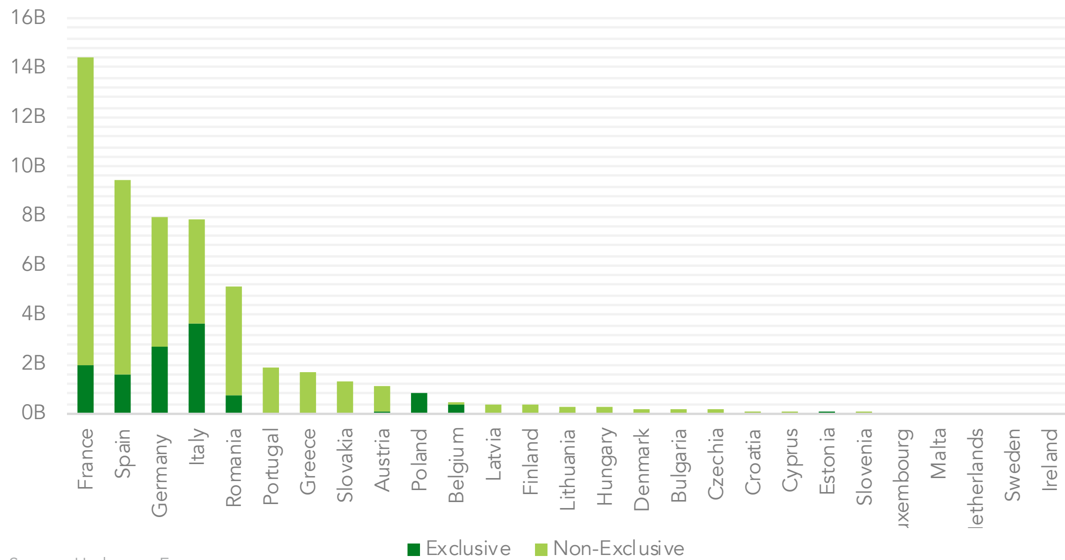


Source: Hydrogen Europe

[76] If one considers private investments as well, the total hydrogen funds of Greece reach over 2 billion euros.

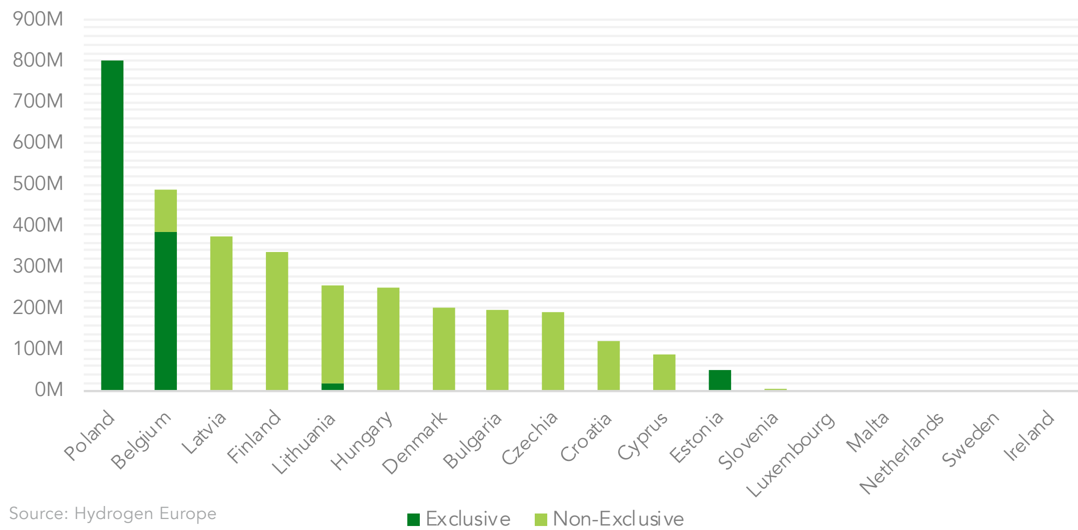
When analysing hydrogen allocations in relative terms (i.e., as a share of the country RRP allocation – including both RRF funds, national public investments and funds from other EU sources), the ranking looks different, with Germany appearing to be the Member State with the highest relative allocation of funds for hydrogen (both exclusive and non-exclusive), comprising almost one-third of its resources - 28.6%. Not too far behind, Austria makes available 24.5% of its resources for hydrogen, followed by Latvia with 20.6%, Slovakia with 19.2%, Romania with 17.7% and France with 14.4%.

Figure 66 Breakdown of Hydrogen Funds by Allocation Type (in billion EUR)



Source: Hydrogen Europe

Figure 67 Breakdown of Hydrogen Funds by Allocation Type (in million EUR)

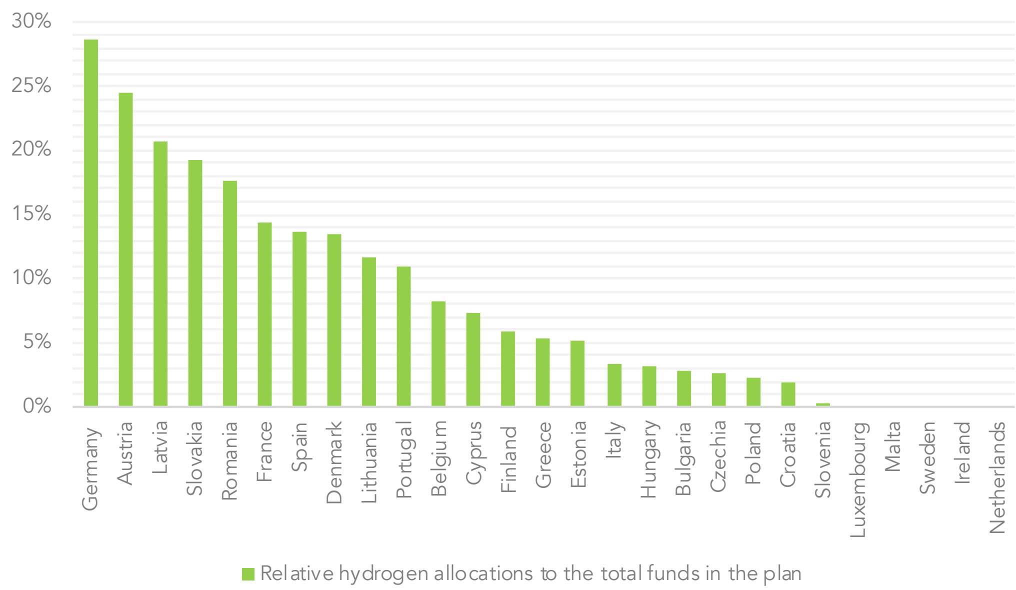


Source: Hydrogen Europe

This shows that, while Western European countries appear to have the highest allocations for hydrogen, in relative terms, Central and Eastern countries are also among the Member States with a strong focus on hydrogen investments. Figure 68 shows the share of total hydrogen funds in relation to the total funds in the RRPs.

The upcoming section zooms in on the allocation of investments and the various parts of the hydrogen value chain at both the EU-level and national level, detailing some of the most ambitious targets and plans for hydrogen presented in the recovery plans.

Figure 68 Total Hydrogen Funds Relatively to the Total Funds in the RRPs (%)



Source: Hydrogen Europe

6.2.2 RRP ALLOCATIONS ALONG THE HYDROGEN VALUE CHAIN

Building a hydrogen market requires investments to be made along the entire value chain, including in:

(i) **production** of hydrogen (specifically, hydrogen production that does not aim at any specific application or end-use – includes investments in electrolysers and other technologies to produce it and increase installed production capacity),

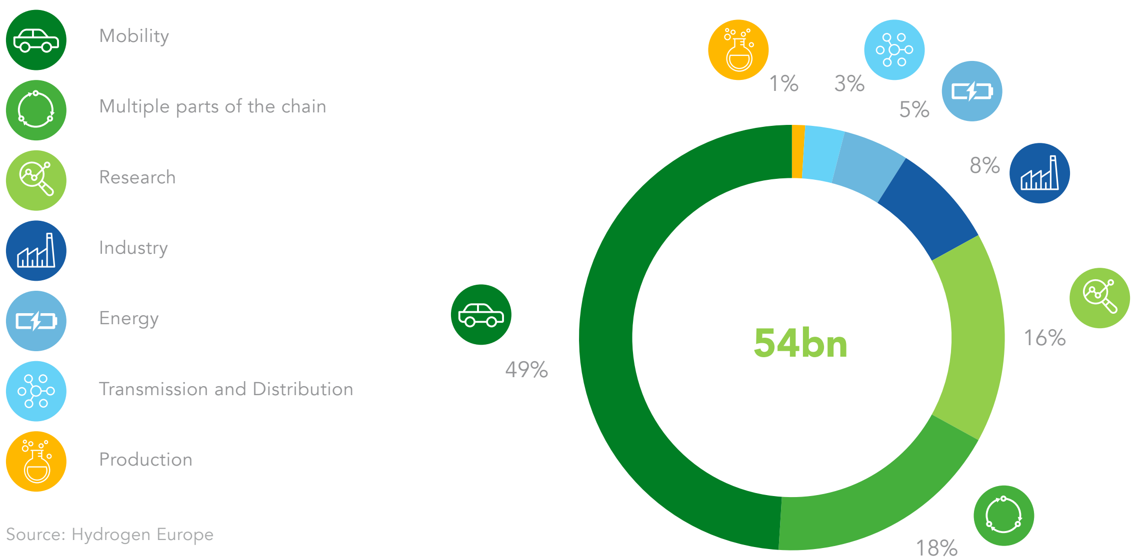
(ii) **in transmission and distribution** – (i.e., infrastructure to transmit and distribute hydrogen via pipelines and HRS to supply hydrogen-powered transportation – includes investments in stations and pilot projects to assist light and heavy vehicles on the road, trains and hydrogen distribution in ports to assist ships) –, as well as in

(iii) multiple **end-use sectors** such as **mobility** (e.g., governmental incentives as tax exemptions and financing schemes for the acquisition of FCEVs and investments in complementary refuelling stations[77]), in the **industry** (i.e., investments in electrolysis capacity to produce renewable hydrogen for the specific consumption in the chemical industry and other 'hard-to-abate' sectors) and in the energy sector (e.g., developing energy storage facilities and applications in the electricity system).

Furthermore, future development requires investments in (iv) **research and development** – aiming at future innovative production and consumption of hydrogen in multiple sectors (e.g., includes investments in pilot projects to develop new production technologies and hydrogen applications in sectors that have a scarce hydrogen supply and consumption, such as aviation).

Investments are also commonly grouped and presented as funds dedicated to (v) **multiple parts of the value chain** (e.g., when a certain allocation is planned for hydrogen production and further research).

Figure 69 Total Hydrogen Funds Allocation per Part of the Value Chain



Source: Hydrogen Europe

[77] Hydrogen refueling stations are mostly going to be found in the category (II) transmission and distribution, however, Croatia and Germany also associate investments in refueling infrastructure to the (iii) end-use mobility, to complement the mechanism of incentives for hydrogen-vehicles.
[78] However, if when analyzing only hydrogen exclusive allocations, the allocation to hydrogen mobility represents only 4,5% of the total funds allocated exclusively to hydrogen (see below).
[79] Untargeted production refers to investments to produce hydrogen without aiming at any specific application or end-use, in contrast to e.g., producing hydrogen for applications in industry.

EU-level analysis

When analysing RRPs investments from the perspective of the value chain, it can be observed that, at the EU-level, most of the RRPs allocations relevant to hydrogen (both exclusive and non-exclusive) are destined to Mobility applications, representing almost 50% of the total planned investments, or 26.7 billion euros[78]. Figure 69 illustrates the share of total hydrogen relevant funds to each part of the value chain.

Funds allocated to more than one part of the chain are also common, representing around 18% of the total. These investments could not be attributed to only one specific part of the value chain as they aim to enable a broader strategy to develop hydrogen on multiple fronts.

Allocations to Research account for 16% of the investments, followed by industrial and energy applications that represent less than 10% of the funds.
An even smaller share of investments is allocated exclusively to hydrogen transmission and distribution and (untargeted)[79] hydrogen production. Together they constitute almost 4% of the total.

When looking only at funds dedicated exclusively to hydrogen, the scenario is considerably different. Figure 70 shows the share of exclusive hydrogen funds per part of the value chain.

Investments in multiple parts of the chain represent over 50% of the total or around 6.2 billion euros. Industrial applications and research follow, each with roughly 17% of the total.

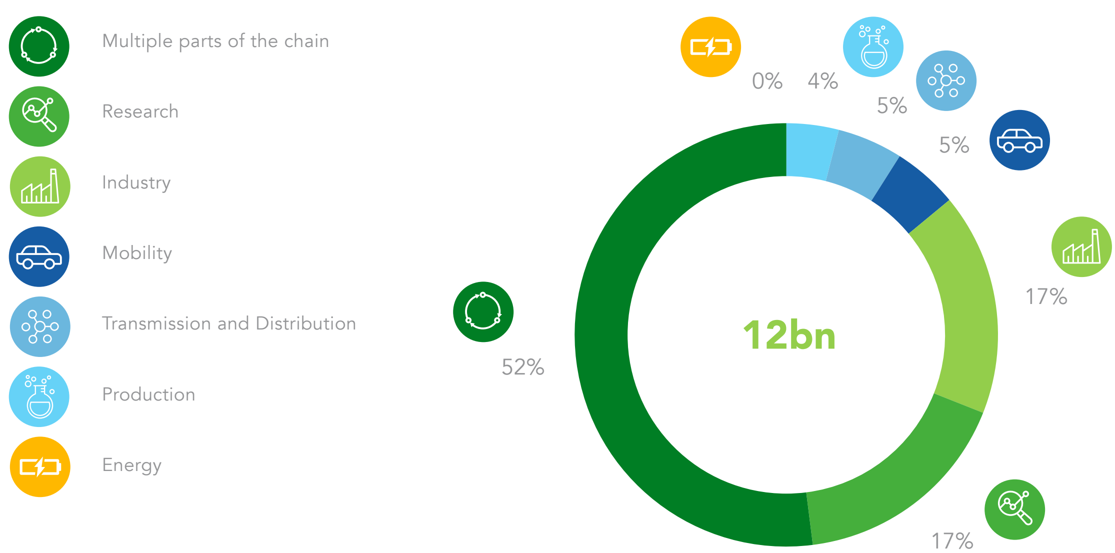
When considering exclusive allocations only, mobility represents only around 4.5% of the investments, similarly to allocations dedicated to both the production and transmission and distribution parts of the chain. There are no funds dedicated exclusively to the development of hydrogen for energy applications.

Member State-level comparison

Analysing Member States' Total allocations that also may include hydrogen (i.e., exclusive and non-exclusive funds) from a value chain perspective, it can be observed that:

- Italy has the largest exclusive allocation for **production**, investing 500 million euros in

Figure 70 Exclusive Hydrogen Funds Allocations per Part of the Value Chain



Source: Hydrogen Europe

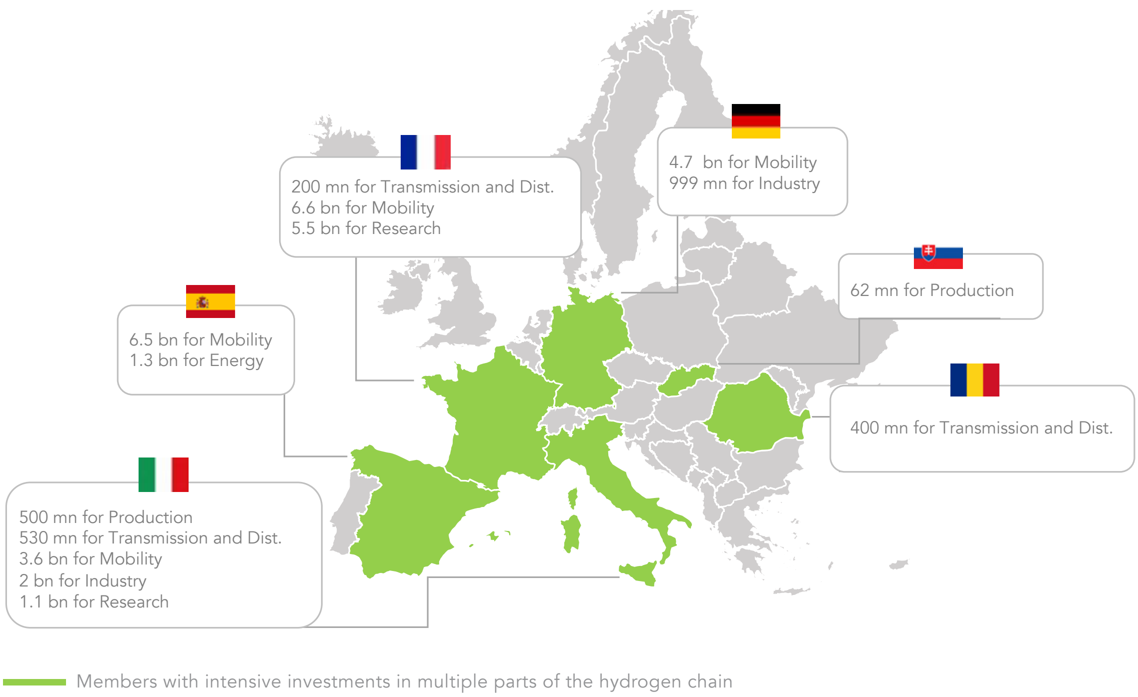
hydrogen production in no longer used industrial areas, followed by Slovakia with 62 million.

- Italy is also the Member that most invests in **transmission and distribution** with 530 million euros, essentially for light vehicles refuelling stations and pilot projects to construct stations in road corridors and rail lines to assist hydrogen-powered heavy trucks and rail transportation. Romania and France follow with respectively 400 and 200 million.
- Italians also have the highest allocation for **industrial applications**, aiming to implement renewable hydrogen in 'hard-to-abate' sectors through RRP investments totalling 2 billion euros. In this category, Italy is followed by Germany, which plans to invest 999 million in the industrial end-use of hydrogen.
- In **energy** applications, Spain is the country that most invests in this part of the value chain, with around 1.3 billion euros allocated for electricity storage.
- In terms of **research**, France is planning to invest 5.5 billion, which is written to include the development of hydrogen as a fuel for applications in transportation and the space sector. Italy comes next with 1.1 billion planned investments in research, including a dimension comprising hydrogen production, transmission and distribution, development of technologies for industrial needs, mobility applications (e.g., fuel cells for trucks) and storage.

Figure 72 shows an overview for a selection of countries (i.e., those with high total allocations, both exclusive and non-exclusive) along each part of the hydrogen value chain.

At least half of the Member States include funding allocations that are already planned to involve more than one part of the value chain; therefore, it has not been possible to accurately attribute these allocations to a particular part of the hydrogen value

Figure 72 Allocations to different parts of the value chain (selection)[80] (in EUR)



Source: Hydrogen Europe

[80] This selection only includes investments in the 25th percentile of the distribution of each hydrogen value chain category, that is, after analysing the distribution of hydrogen-related funds in each category of the chain, the 25% largest investments in each category of the chain were selected and presented in the figure.

chain. France, for example, has an investment category of 2 billion euros dedicated to Production, Mobility, Industry and Research in hydrogen. Spain and Germany also make investments planned to encompass multiple parts of the value chain of around 1.5 billion each, as does Austria, with 1.1 billion.

The allocations of France and Germany include a total of around 3 billion euros for the implementation of Important Projects of Common European Interest (IPCEI), which apply to multiple parts of the value chain, as do the 1.5 billion allocated by Spain with the purpose to support the implementation of the Spanish national hydrogen strategy (which includes, except for Transmission and Distribution, all parts of the value chain). Figure 73 illustrates an overview of the largest investments (exclusive and non-exclusive) in multiple parts of the hydrogen chain (i.e., those that could not have been attributed to a single part of the value chain).

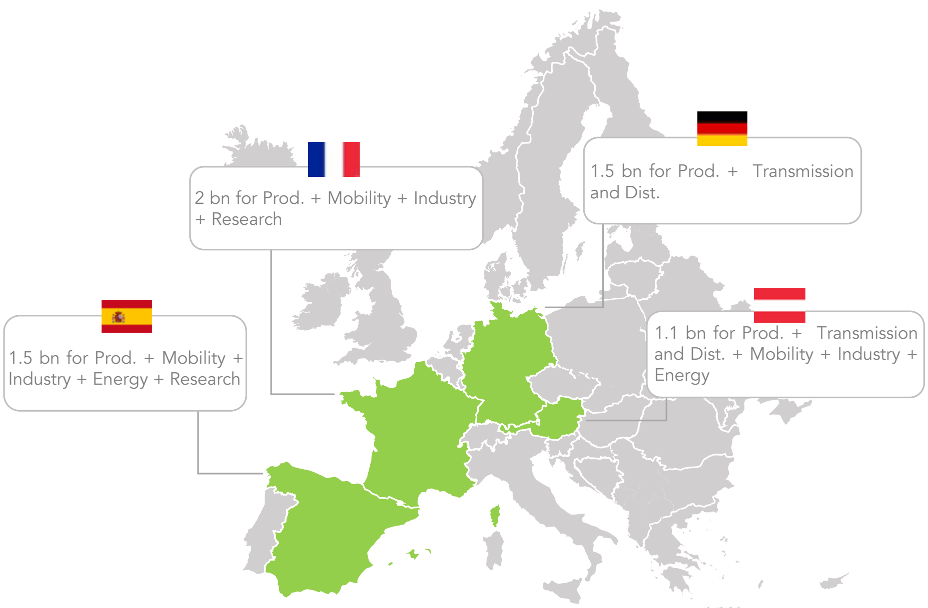
6.2.3 TARGETS AND DEADLINES ASSOCIATED WITH RRP INVESTMENTS IN HYDROGEN TECHNOLOGIES

As mentioned in the introduction to this chapter, not all countries associate their planned investments in hydrogen with clear targets and deadlines. When they do, the targets are often embedded in national hydrogen strategies (e.g., the production targets of France, Germany, Italy and Spain). In such cases, the RRPs funds contribute to the financing of the targets under the national strategies.

When an association between the planned allocations and specific targets and deadlines is made, it is most often in relation to the Production, Transmission and Distribution, and Mobility parts of the value chain.

Figure 73

Allocations that could not be attributed to a single part of the value chain (selection)[81] (in EUR)



Members with intensive investments in multiple parts of the hydrogen chain

Source: Hydrogen Europe

[81] Investments in the 25th percentile of the distribution of the hydrogen value chain category, that is, after analysing the distribution of hydrogen-related funds that could not be attributed to a single category of the chain, the 25% largest investments were selected and presented in the figure.

Regarding **production** capacity of renewable hydrogen, France, Germany, Italy and Spain set themselves ambitious targets of 6.5 GW, 5 GW, 5 GW and 4 GW by 2030, respectively. These targets are financed by both the RRP and by funds associated with the national hydrogen strategies. Slovakia targets 20 MW of electrolysis capacity to be installed by 2026. Portugal targets up to 2.5 GW of installed electrolysis capacity by 2030.

Concerning concrete targets associated with allocating funds to hydrogen **transmission and distribution**, Italy, the largest investor in this part of the chain, sets a target to build 40 hydrogen refuelling stations to assist heavy trucks. Slovakia also stands out by aiming to construct at least 3,029 charging and hydrogen refuelling stations by 2026, of which it is not clear precisely how many hydrogen refuelling stations. The country, however, has currently no filling stations for hydrogen-powered vehicles. Among the countries with the highest allocations towards **mobility** applications, Spain intends to promote at least 5,000-7,000 hydrogen-powered vehicles, in addition to 150-200 fuel cell buses. Germany has measures to support 560,000 electric vehicles by 2022, 4,000 purely electric vehicles by 2024, 2,800 alternative-drive buses and 280 trains, all including – among others - hydrogen-powered technologies. In its turn, Italy intends to promote 3,360 low-emission buses and 53 trains by 2026, including – among others - hydrogen-powered technologies.

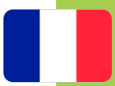
6.2.4 A CLOSER LOOK AT THE MOST AMBITIOUS PLANS

Overall, France, Germany, Italy, Spain and Romania are the Member States with the highest allocations (in absolute terms) to hydrogen in their respective RRPs. The upcoming section takes a closer look at the RRPs of each of these countries. It highlights the main figures, provides an overview of all the funds available for hydrogen, details the largest exclusive and non-exclusive investments, the targets, connections to national strategies and gives a glimpse of the future course of the hydrogen value chain in each country.

France, Germany, Italy, Spain and Romania are the Member States with the highest allocations (in absolute terms) to hydrogen in their respective RRPs

FRANCE

Box 3 Highlights of the French Recovery and Resilience Plan



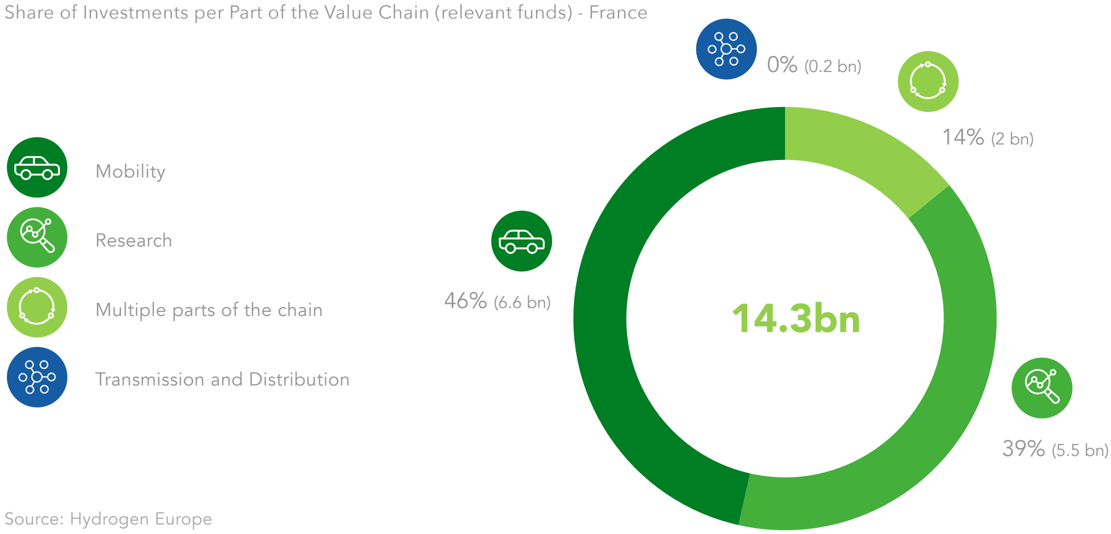
- 14.3 bn for investments that also include hydrogen - the highest non-exclusive allocation among the plans
- 2 bn exclusively to hydrogen technologies in multiple parts of the chain – of which 1.5 bn are directed to IPCEI projects
- 6.6 bn for Mobility applications and 5.5 bn for Research
- 6.5 GW of renewable hydrogen production by 2030 supported by the RRP
- Mobilisation of additional 5 bn EUR by 2030 to boost the hydrogen acceleration plan

Source: Hydrogen Europe

France makes available (both exclusively and non-exclusively) over 14.3 billion euros which can be used, among other technologies, for hydrogen. This represents 14.4% of the total amount of the plan. Out of the 14 billion available, 2 billion euros are dedicated exclusively to hydrogen technologies, and the rest (over 12 billion euros) are non-exclusive (meaning they encompass categories that aim to fund multiple technologies, including hydrogen). Overall, relevant planned investments are strongly aimed towards Mobility and Research but also include, except for energy applications, investments in all parts of the value chain. Hydrogen allocations in the plan aim to support the 6.5 GW target of renewable hydrogen production capacity in the country by 2030, an additional 5 billion euros will be mobilised by 2030 to support hydrogen development (see below).

Figure 74 presents the share of investments per part of the value chain planned in the French recovery plan.

Figure 74 Share of Investments per Part of the Value Chain (relevant funds) - France



Source: Hydrogen Europe

[82] The plan does not specify how much of these funds, precisely, will be dedicated to electrification and hydrogen trains for non-electrified lines respectively.

The main investments

Investments dedicated exclusively to hydrogen technologies (amounting to 2 billion euros) are largely destined for hydrogen IPCEI projects (1.5 billion). Bearing in mind the challenges to develop 'carbon-free' hydrogen in the country, France aims at improving the competitive gap of hydrogen produced by electrolysis, arising mainly from the cost to acquire electricity, against that of hydrogen produced from steam methane reforming. The 2 billion euros allocated are meant to support electrolyser producers to gain market visibility and reduce the unitary cost of electrolysers. By developing 'carbon-free' hydrogen, France states in its plan that it intends to promote the decarbonisation of industry and heavy mobility with hydrogen-powered vehicles and other hydrogen solutions. The financing of electrolysers and installations to decarbonise industrial sites will happen through calls for tenders. France also intends to promote the integration of the hydrogen value chain at the European level, including the launch of a priority research program (PRR) named "Hydrogen Applications".

The 1.5 billion euros dedicated for IPCEI projects aim to support the research and design, industrialization (e.g., investing in electrolysers, fuel cells, tanks and materials), and, alongside the PRR mentioned above, the integration of the hydrogen value chain at the European level.

The 2 billion exclusive allocations to hydrogen will be used between 2021-2022, and the projects aim to be implemented mainly by 2023. The investments in the hydrogen chain are part of the national strategy to accelerate hydrogen, and the plan mentions that an additional 5 billion euros will be mobilised by 2030 to boost hydrogen development further.

Within the category of non-exclusive hydrogen funds, 6.6 billion euros represent investments in clean Mobility (this amounts to 46% of the total funds that could potentially be used to support hydrogen technologies). The allocation for Mobility includes 4.7 billion to improve and modernize the rail sector in France by upgrading the infrastructure and quality of the services, including hydrogen equipment for some of the lines[82]. The remaining 1.9 billion euros are to be used to purchase clean vehicles, including FCEVs, provided as an 'ecological bonus'. The funds include both support for heavy and light-duty vehicles for both private use and corporations. However, the 'ecological bonus' for light vehicles will be gradually decreased as the competitive position of clean vehicles improves in relation to conventional vehicles. The amount will be spent on the already ongoing measures up until 2022.

The 5.2 billion euros of the investments in Research are dedicated, among other things, to developing sustainable fuels for applications in transportation, aiming at projects finishing up until 2026.

Targets and deadlines

France sets clear production goals for clean hydrogen, intending to achieve 6.5 GW of capacity to produce renewable hydrogen by 2030. Aiming at contributing to this goal, the RRP funds target a 140 MW per year in electrolysers installed by 2026, 12,000 tonnes of Hydrogen produced by 2023 and cumulative 100,000 tonnes by 2026.

To sum up

In sum, the French recovery funds for hydrogen are linked to the 'carbon-free hydrogen strategy' approved in September 2020 and running up until 2030. Even though allocating funds towards multiple parts of the hydrogen value chain (including in comprehensive hydrogen IPCEIs), in the next few years, the country appears to concentrate its hydrogen recovery funds on research laboratories and on industry applications, fostering innovation to create a competitive advantage of renewable and low-carbon hydrogen.

GERMANY

Box 4 Highlights of the German Recovery and Resilience Plan

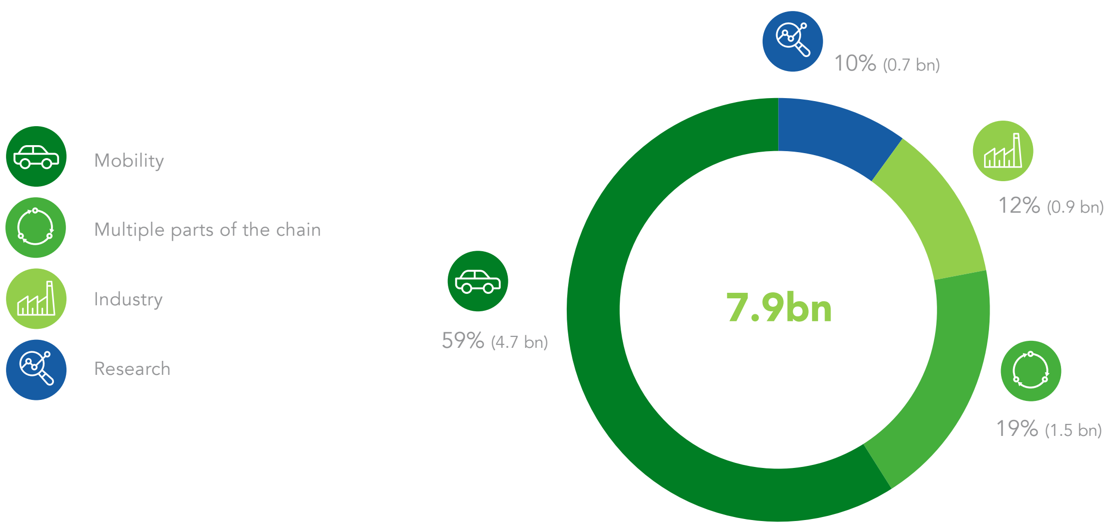
- 7.9 bn for investments that also include hydrogen - or 28.6% of the total plan - the highest relative allocation among the plans
- 2.7 bn exclusively to hydrogen technologies in different parts of the chain - of which 1.5 bn are directed to IPCEI projects
- 4.7 bn for Mobility applications
- 5 GW of renewable hydrogen production by 2030 supported by the RRP – 500 MW for industrial needs

Source: Hydrogen Europe

Germany makes available (both exclusively and non-exclusively) over 7.9 billion euros for investments, including hydrogen, representing 28.6% of the total amount of the plan, the most ambitious investor in relative terms. Out of the 7.9 billion available, 2.7 billion euros are dedicated exclusively to hydrogen technologies, and the remaining 5.2 billion encompass other technologies.

Overall, relevant planned investments are strongly aimed towards mobility and include in other parts of the value chain. Hydrogen allocations in the plan aim to support the 5 GW target of renewable hydrogen in the country by 2030 and specifically 500 MW of capacity for industrial needs (see below).

Figure 75 Share of Investments per Part of the Value Chain (Total relevant funds) - Germany



Source: Hydrogen Europe

The main investments

Within the category of exclusive investments in hydrogen, 1.5 billion euros represent investments in IPCEI projects. Aiming at decreasing the marginal costs of producing renewable hydrogen and improving the German and European networks, to create a comprehensive cross-border hydrogen supply network, the investment intends to support both the production of electrolysers, hydrogen conversion, transportation, storage and the deployment of refuelling stations. By developing a supply network, Germany intends to expand the regionally limited hydrogen infrastructure. The plan mentions that small/medium-sized companies will receive special attention. The investments will be made gradually from 2022-2026 and are in line with the 'German National Hydrogen Strategy' (NWS).

Among the investments dedicated to hydrogen and other technologies, 4.1 billion euros are directed to Mobility applications. To reduce emissions in the transport sector by increasing the competitiveness of clean vehicles concerning combustion engines, the funds support the acquisition of buses and rail transportation with alternative drives and electric vehicles powered by fuel cell technology or other drives. It also includes an extension of the tax exemption for zero-emission vehicles of all classes. All funds will be spent by 2025. Germany also makes available around half a billion euros exclusively to hydrogen in Mobility applications - similarly to be spent until 2025. The latter supports stimulating the demand for hydrogen-powered vehicles, fuel cell applications in traffic and refuelling stations to promote hydrogen supply - in line with Germany's national hydrogen strategy.

Targets and deadlines

Germany has clear renewable hydrogen production goals, intending to achieve 5 GW of production capacity by 2030. The RRPs funds aim to contribute to this goal and achieve 500 MW of renewable hydrogen capacity for industrial needs.

Other quantitative targets include support for 560,000 electric vehicles by 2022, 2,800 alternative-drive buses and 280 trains, all including, among others, hydrogen-powered technologies.

To sum up

In sum, the German recovery plan is linked to the 'German National Hydrogen Strategy' announced in June 2020 and setting goals for 2030. Overall, in the next few years, the country will concentrate its hydrogen recovery funds to develop a hydrogen supply network in cross-border projects (comprehensive hydrogen IPCEIs) and mobility applications to reduce emissions in the sector by stimulating demand and infrastructure to support the use of hydrogen. In addition, Germany has planned investments in industrial applications to decarbonise the sector.

ITALY

Box 5 Highlights of the Italian Recovery and Resilience Plan

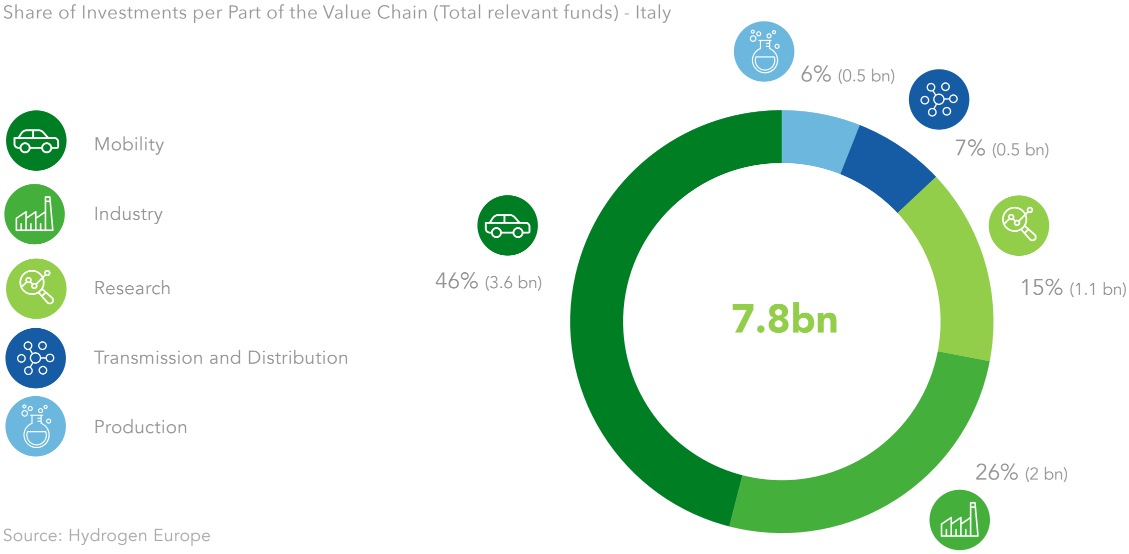
- 7.8 bn for investments that also include hydrogen
- 3.6 bn exclusively to hydrogen technologies in different parts of the chain – the highest exclusive allocation among the plans
- 3.6 bn for Mobility applications and 2 bn for Industry
- 5 GW of renewable hydrogen production by 2030 supported by the RRP

Source: Hydrogen Europe

Italy makes available (both exclusively and non-exclusively) over 7.8 billion euros for technologies, including hydrogen, representing 3.3% of the total amount of the plan. Out of the 7.8 billion available, around 3.6 billion are dedicated exclusively to hydrogen technologies, and 4.1 billion encompass other technologies as well as hydrogen. Overall, the relevant planned investments are aimed towards Mobility and Industry and include investments, except for Energy, in all parts of the value chain. Hydrogen allocations in the plan aim to support the 5 GW target of renewable hydrogen in the country by 2030 (see below).

Figure 76 presents the share of investments per part of the value chain planned in the Italian recovery plan.

Figure 76 Share of Investments per Part of the Value Chain (Total relevant funds) - Italy



Source: Hydrogen Europe

The main investments

Within the category of exclusive investments in hydrogen technologies, 2 billion euros are dedicated for the decarbonisation of 'hard-to-abate' sectors (e.g., chemicals and petroleum refining) that are highly intense in energy and have no scalable electrification options. The investments intend to increase renewable hydrogen consumption in the industrial sector by promoting the transition away from "grey" hydrogen, already produced locally and used to produce basic chemicals (e.g., ammonia and methanol) and refining processes. Other 'hard-to-abate' sectors targeted include steel[83], concrete, glass and paper.

Within the category of non-exclusive funds, 3.6 billion euros are directed to Mobility applications. The investment is aimed to renew bus fleets and to purchase "green" trains in Italy, introducing low environmental impact vehicles, including - among others - hydrogen propulsion technologies and necessary infrastructure. It also aims at accelerating the 'National Strategic Plan for Sustainable Mobility' launched in 2017. Around one-third of the funds will be directed to the main Italian cities.

Italy also allocates 1.1 billion in research that includes, among other things, the development of hydrogen-related technologies for mobility applications (e.g., fuel cells for trucks and hydrogen transformation into green fuels).

Targets and deadlines

Italy has clear production goals, aiming at a 5 GW total electrolysis capacity by 2030. The RRP funds aim to contribute to this goal. Other quantitative targets laid out within the RRP include the construction of around 40 hydrogen refuelling stations to assist heavy trucks, purchasing 3,360 low-emission buses and 53 trains by 2026.

To sum up

The Italian recovery plan is also in line with the 'National Hydrogen Strategy Preliminary Guidelines' published in 2020 and setting goals up to 2030. It aims to support the development of a hydrogen economy in the country and to achieve decarbonisation goals. Even though Italy makes investments in multiple parts of the chain, in the next few years, it will concentrate the hydrogen recovery funds in industrial applications by shifting the consumption from "grey" to renewable hydrogen in industry and investing in hydrogen-based technologies as promoting low-emission public transportation.

[83] Italy is the second largest producer in Europe.

SPAIN

Box 6 Highlights of the Spanish Recovery and Resilience Plan

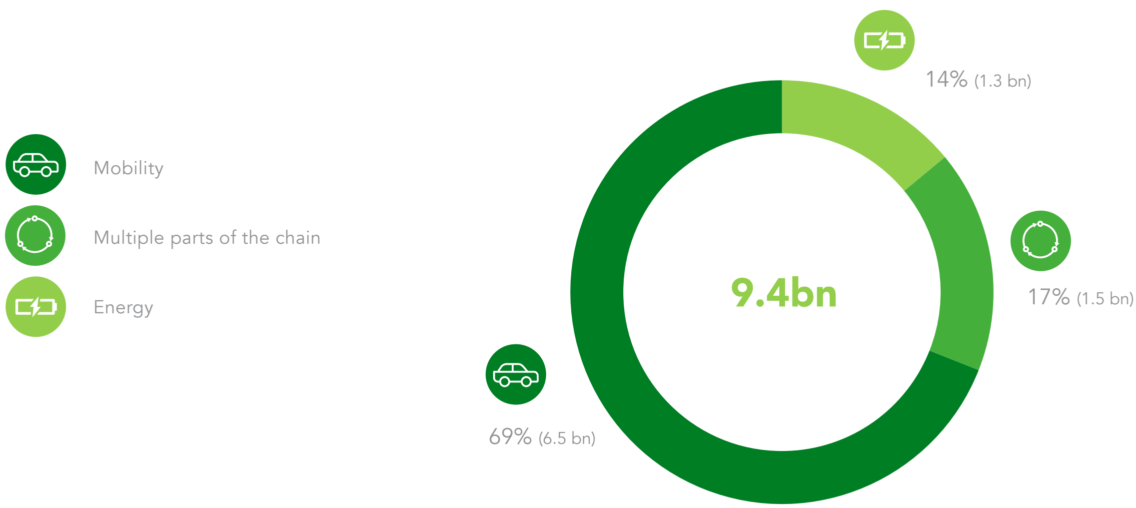
- 9.4 bn for investments that also include hydrogen
- 1.5 bn exclusively to hydrogen technologies in multiple parts of the chain
- 6.5 bn for Mobility applications
- 4 GW of renewable hydrogen production by 2030 + 5,000-7,000 light and heavy hydrogen vehicles supported by the RRP

Source: Hydrogen Europe

Spain makes available (both exclusively and non-exclusively) over 9.4 billion euros for investments that include hydrogen. This corresponds to 13.6% of the total amount of the plan, the second-most ambitious investor in absolute terms. Out of the 9.4 billion available, 1.5 billion are dedicated exclusively to hydrogen technologies, and 7.9 billion encompass other technologies alongside hydrogen. Overall, the relevant planned investments are strongly aimed towards mobility and include all parts of the chain except for Transmission and Distribution. Hydrogen allocations in the plan aim to support the 4 GW target of renewable hydrogen in the country by 2030 (see below).

Figure 77 presents the share of investments per part of the value chain planned in the Spanish recovery plan.

Figure 77 Investments per Part of the Value Chain (Total relevant funds) - Spain



Source: Hydrogen Europe

The main investments

Investments dedicated exclusively to hydrogen technologies (amounting to 1.5 billion euros) are directed to renewable hydrogen projects in multiple parts of the hydrogen chain. Aiming at replacing certain fuels and decarbonising several sectors in which renewable electricity or direct replacement by renewables is not feasible. The support intends to tackle the difference in costs of hydrogen in comparison to other fuels. The projects include the creation of technological clusters and pilot projects on a regional scale, industrial innovation, fair transition zones and competitive renewable energy, as well as regulations and incentives encompassing large-scale production, transformation and hydrogen use in heavy long-distance transportation, as energy storage, in high-temperature processes and hydrogen-intensive industries.

Within the category of non-exclusive funds, 6.5 billion euros are directed to Mobility applications to decarbonise urban and metropolitan transportation. The investment intends to transform the public transportation sector into a sustainable alternative to private vehicles by utilising low-emission fleets. The allocation includes support for the acquisition of fuel cell vehicles and promoting renewable hydrogen for mobility uses. It will focus on cities with over 50,000 inhabitants.

Targets and deadlines

Spain sets clear goals for production and mobility applications to be also supported by RRP funds. It aims at 4 GW of installed electrolysers by 2030, as well as the promotion of at least 5,000-7,000 light and heavy hydrogen-powered vehicles, 150-200 hydrogen fuel cell buses and achieving a minimal contribution of 25% of renewable hydrogen out of the total amount of hydrogen consumed in all industries, as a raw material and energy source.

To sum up

In sum, the Spanish recovery plan is set in line with the Spanish 'Renewable Hydrogen Roadmap' approved in 2020 and setting goals for 2030. Even though Spain makes investments in several hydrogen applications and multiple parts of the chain, in the short term, recovery funds will be concentrated on Mobility applications aimed at making the public transportation system more sustainable, including through the use of FCEVs.

Romania

Box 7 Highlights of the Romanian Recovery and Resilience Plan

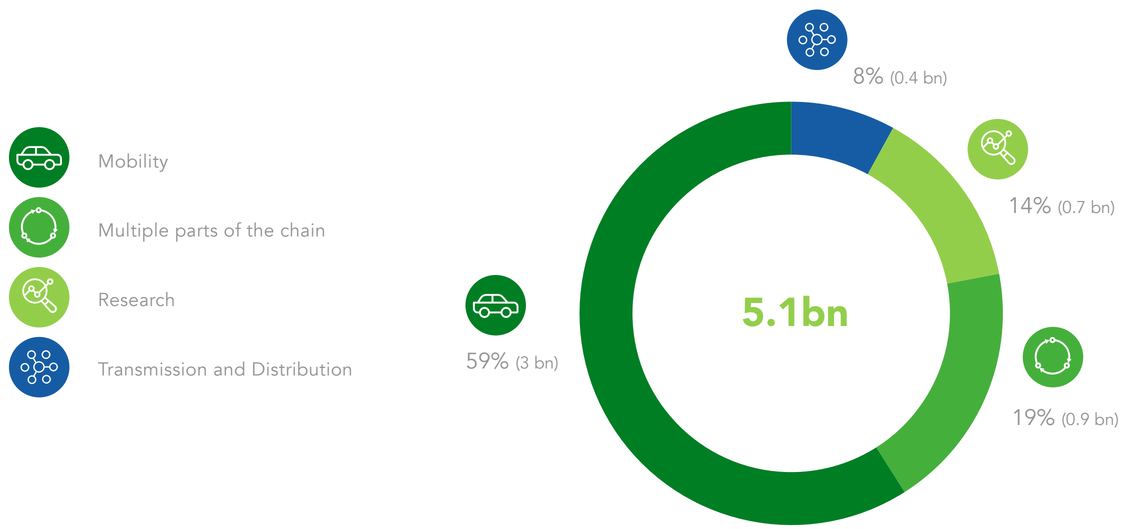
- 5.1 bn for investments that also include hydrogen
- 713 mn exclusively to the Research of hydrogen technologies
- 3 bn for Mobility applications
- 1,000 minibuses and 600 buses potentially powered by hydrogen financed by the RRP

Source: Hydrogen Europe

Although still in its draft form, the Romanian RRP makes available (both exclusively and non-exclusively) over 5.1 billion euros for investments, including hydrogen or 17.7% of the total amount of the plan. Out of the 5.1 billion available, 713 million are dedicated exclusively to hydrogen technologies, and 4.4 billion encompass other technologies. Overall, the relevant planned investments are strongly aimed towards mobility and include investments in different parts of the chain.

Figure 78 presents the share of investments per part of the value chain planned in the Romanian recovery plan.

Figure 78 Share of Investments per Part of the Value Chain (Total relevant Funds) – Romania



Source: Hydrogen Europe

The main investments

Investments dedicated exclusively to hydrogen technologies (amounting to 713 million euros) are directed to hydrogen research projects. Aiming to achieve deep decarbonisation in the country, the investment will be directed to demonstration projects in renewable hydrogen, research, development and facilitation of IPCEI projects, and vertically integrating projects from multiple industries, all using hydrogen. The demonstration projects intend to evaluate their economic and technical feasibility. The funds will be spent between 2021-2026.

Within the category of non-exclusive funds, 3 billion euros are directed to Mobility applications. This includes funds for the modernization and renewal of railway and road transportation, including, among other technologies, the acquisition of hydrogen-powered trains and minibuses. The investments intend to contribute to the modernisation of railway lines and increase road quality in rural areas. Romania also allocates almost 1 billion euros for both the acquisition of hydrogen-powered transportation and to build a hydrogen supply network, among other technologies and their associated infrastructure.

Targets and deadlines

Romania sets a number of goals for mobility applications financed by RRP funds. It aims to purchase 1,000 minibuses and 660 buses, electric or hydrogen-powered, as well as ten hydrogen-powered locomotives.

To sum up

The Romanian recovery plan is linked to the increased efforts to develop hydrogen in the country, including the design of a national hydrogen strategy. In the next few years, the recovery funds relevant to Hydrogen will be concentrated in sustainable mobility (modernizing and renewing public transportation fleets and constructing a supply network of refuelling stations). In addition, demonstration projects are also expected to set the country's future course of hydrogen development (including comprehensive hydrogen IPCEI projects).

6.2.5 IN A NUTSHELL

Across the EU, the recovery and resilience plans contain over 54 billion euros relevant for hydrogen; 12 billion of these represent investments exclusive to hydrogen, while the rest are dedicated to multiple technologies, including hydrogen. France, Germany, Italy, and Spain have the largest hydrogen allocations (exclusive and non-exclusive funds). Relative to the total amount of the plans, Germany, Austria, Latvia, Slovakia, Romania, and France have the most ambitious plans.

France's RRP stands out as the most ambitious investor in hydrogen. It has the largest absolute amount of funds relevant for hydrogen. It already plans to mobilise an additional 5 billion euros by 2030 to boost the national strategy to accelerate hydrogen. The French investments also encompass almost the entire chain.
Italy stands out as having the largest exclusive allocation in hydrogen across almost the whole value chain.

France, Germany, Italy and Spain have linked their planned investments in Hydrogen within their RRPs to their national hydrogen strategies. Investments in IPCEI projects related to hydrogen are also covered by the recovery funds of France, Germany, and Romania.

7

NATIONAL POLICIES AND INCENTIVES ON HYDROGEN TECHNOLOGIES

While it may seem from current news coverage that attention to hydrogen is rather recent, in fact, hydrogen has already been on the minds of many policymakers for years.

Countries have been adopting various hydrogen and fuel cell-related policies covering production, distribution, and end-use of hydrogen for some time now. Given the growing importance of hydrogen in decarbonisation efforts, more hydrogen related policies will be adopted.

This sub-chapter provides an overview of already enacted (in-force) hydrogen and fuel cell policies in countries across Europe. More specifically, it focuses on policies related to mobility, infrastructure, and industry. The methodology used for data collection and information about the geographic coverage can be found in the Methodological Annexe.

This chapter provides an overview of already enacted (in-force) hydrogen and fuel cell policies in countries across Europe

7.1 POLICIES INCENTIVISING THE UPTAKE OF HYDROGEN IN MOBILITY

Nine countries in Europe provide CAPEX support for the construction of HRS

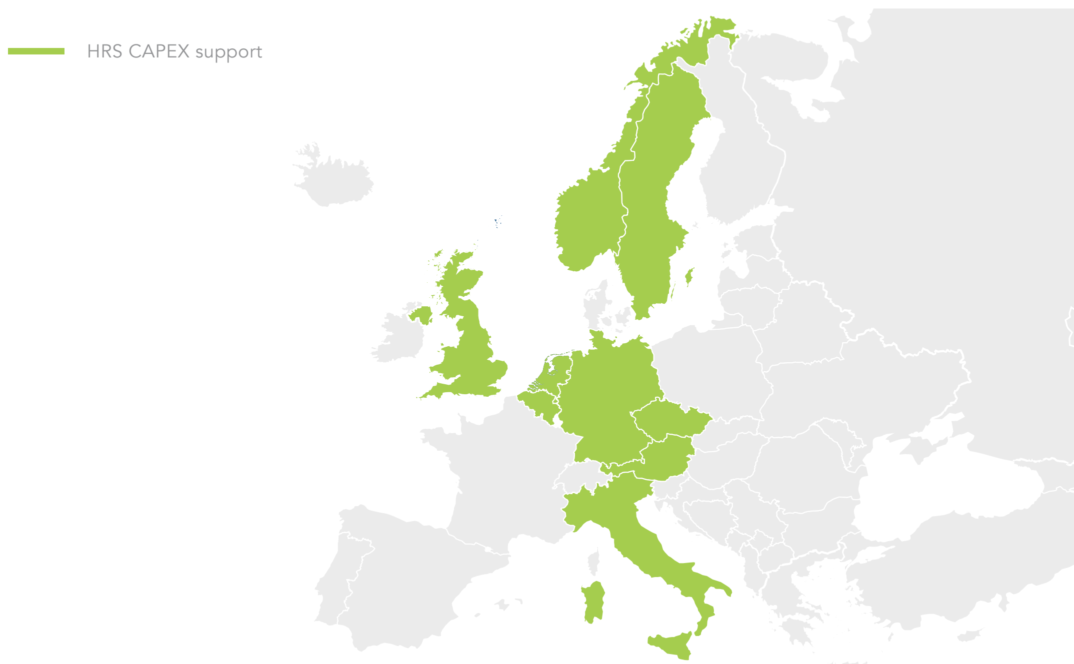
This section covers active policies regarding the support and development of hydrogen refuelling infrastructure and the deployment of FCEVs. This includes CAPEX support for Hydrogen Refuelling Stations (HRS), FCEV purchase subsidies, registration tax benefits for FCEV passenger cars and purchase subsidies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

7.1.1 HYDROGEN REFUELLING INFRASTRUCTURE

Similar to electric charging infrastructure, hydrogen refuelling infrastructure is essential for ensuring the decarbonisation of transport. A nationwide network of publicly accessible hydrogen refuelling stations, including high-capacity ones that will refuel tons of hydrogen/day, is needed to satisfy the demand from buses and heavy-duty vehicles. Such a network is a prerequisite for further expansion of hydrogen-based mobility. Some of the active policies to support the development of HRS include (i) targets or mandates, (ii) financial incentives in the form of CAPEX support, (iii) simplifying permitting rules, and (iv) common standards.

Nine countries in Europe provide CAPEX support for the construction of HRS, mainly countries in Central and Northern Europe. These include Austria, Belgium, Czechia, Germany, Italy, Netherlands, Norway, Sweden, and the United Kingdom.

Figure 79 Overview of HRS CAPEX policy support in Europe



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

The method of supporting HRS development differs across European countries. For example, 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 updating existing HRS and provision of new HRS.[84]

The Czech Republic recently began supporting HRS development through the Alternative fuel infrastructure support program – development support for hydrogen refuelling stations published in January 2020.[85]

In the Netherlands, HRS development qualifies for funding from the Dutch Enterprise Agency (RVO) through tax depreciation. The scheme aims to support mobility and transport projects that reduce emissions and are in the pre-commercial phase. Several HRS have financially benefited from this funding stream.[86]

The Italian National Strategic Plan for Sustainable Mobility from 2019 commits to co-funding alternative fuel infrastructure, including hydrogen up to 80%.

Austria provides a 20%-30% CAPEX subsidy for HRS as part of a mobility subsidy program. HRS operators have to prove that their hydrogen supply is 100% renewable to be eligible.

In Flanders, Belgium, Ecologiepremie+ allows companies to receive up to 30% CAPEX support for an HRS installation with onsite electrolysis that produces renewable hydrogen.

Czechia, Hungary, Lithuania, Netherlands, Portugal, Slovakia, and Switzerland provide purchase subsidies to battery electric vehicles but not to fuel cell electric vehicles.

7.1.2 FCEV ROAD TRANSPORT POLICIES

The size of the FCEV M1 fleet in 2021 is 2030 vehicles, representing about half of the number of BEVs in Europe in 2008.[77] Similarly to BEVs, FCEVs will also 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 supportive policies, such as purchase subsidies and registration tax benefits for passenger cars, buses, and heavy-duty vehicles.
Purchase subsidies and registration tax benefits are the most common policies used to support alternative vehicle sales. They have been used extensively for supporting BEVs. Both policies bridge the gap between the established and emerging technology by decreasing the capital investment of the new and required technology.[78]

Passenger cars

Twelve countries, shown in dark green in Figure 80, currently provide both purchase subsidies and registration tax benefits for FCEVs. Seventeen countries in total have purchase subsidies for FCEV passenger cars in effect. Four countries, Denmark, Czech Republic, Slovakia, and Hungary, have registration tax benefits but no purchase subsidies available.

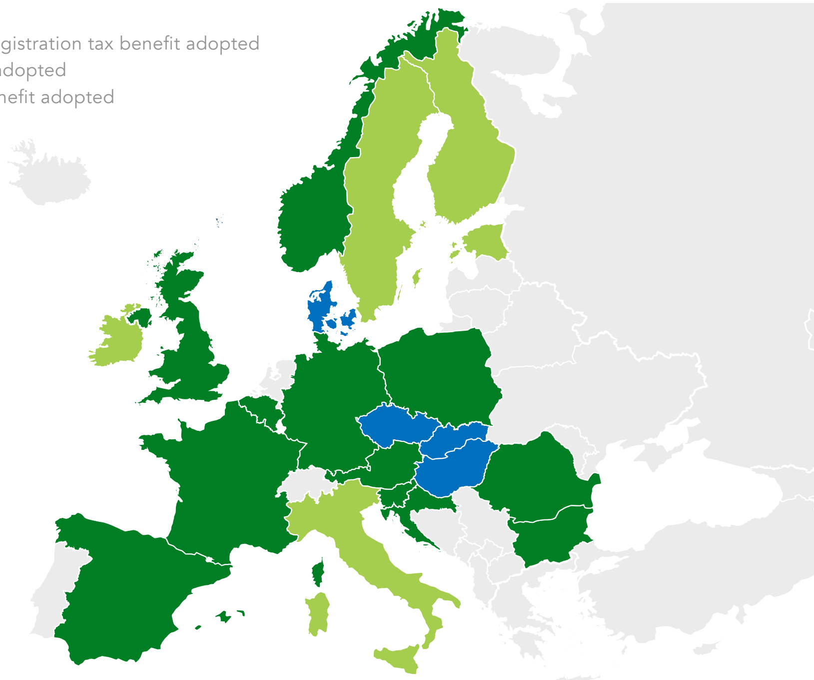
The amount of provided subsidy varies significantly between different member states from 2,000 EUR in Finland to 21,000 EUR in Poland. Figure 81 below provides an overview of the 14 countries with purchase subsidies for FCEV passenger cars and the maximum obtainable subsidy in each one in 000s EUR.

However, Czechia, Hungary, Lithuania, Netherlands, Portugal, Slovakia, and Switzerland provide purchase subsidies to battery electric vehicles but not to fuel cell electric vehicles.

[84] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/521147/supporting-fleet-uptake-of-hydrogen-fuel-cell-vehicles-guidance-note.pdf
[85] https://www.opd.cz/stranka/vyzva-81/
[86] https://www.rvo.nl/subsidie-en-financieringswijzer/dkti-transport

Figure 80 Overview of purchase subsidies and registration tax benefits adoption for FCEV passenger cars

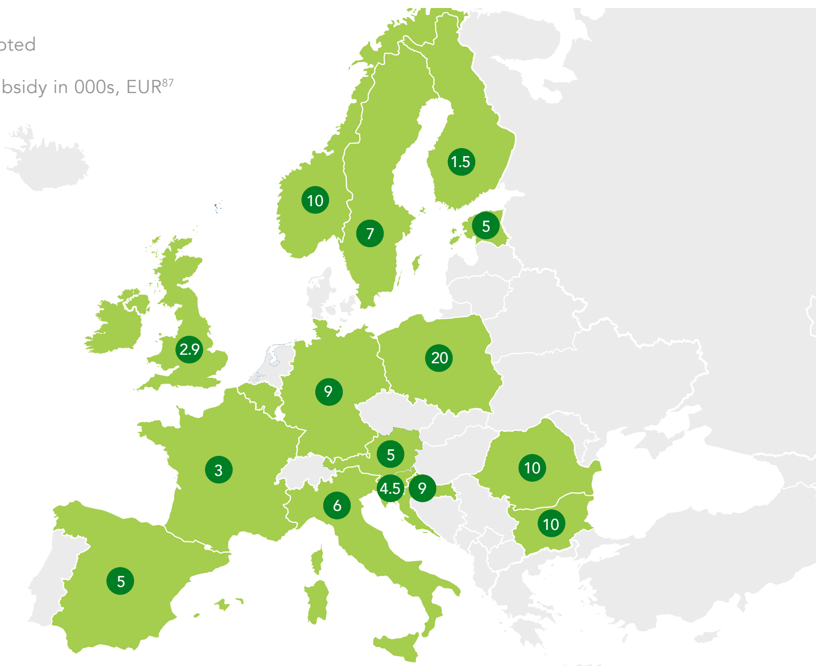
Purchase subsidy and registration tax benefit adopted
Only purchase subsidy adopted
Only registration tax benefit adopted



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

Figure 81 Purchase subsidies for FCEV passenger cars

Purchase subsidy adopted
5 Maximum purchase subsidy in 000s, EUR[87]



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

[87] Figures are for European Union in 2008 and European Union plus the UK in 2020. Sources are European Alternative Fuels Observatory and Fuel Cells and Hydrogen Observatory

Buses and heavy-duty vehicles

Fuel cell buses and heavy-duty vehicles are potentially a highly attractive replacement for diesel trucks and diesel buses. They can be refuelled in minutes and achieve a range of hundreds of kilometres.

Given hydrogen's versatility, there is a growing interest in zero-emission logistics in Europe, particularly from major retailers and their transport solutions providers. Yet, the policy landscape has responded only partially as purchase subsidies for fuel cell buses are available in only 12 countries. Moreover, purchase subsidies for heavy-duty vehicles are available in even fewer, 10.

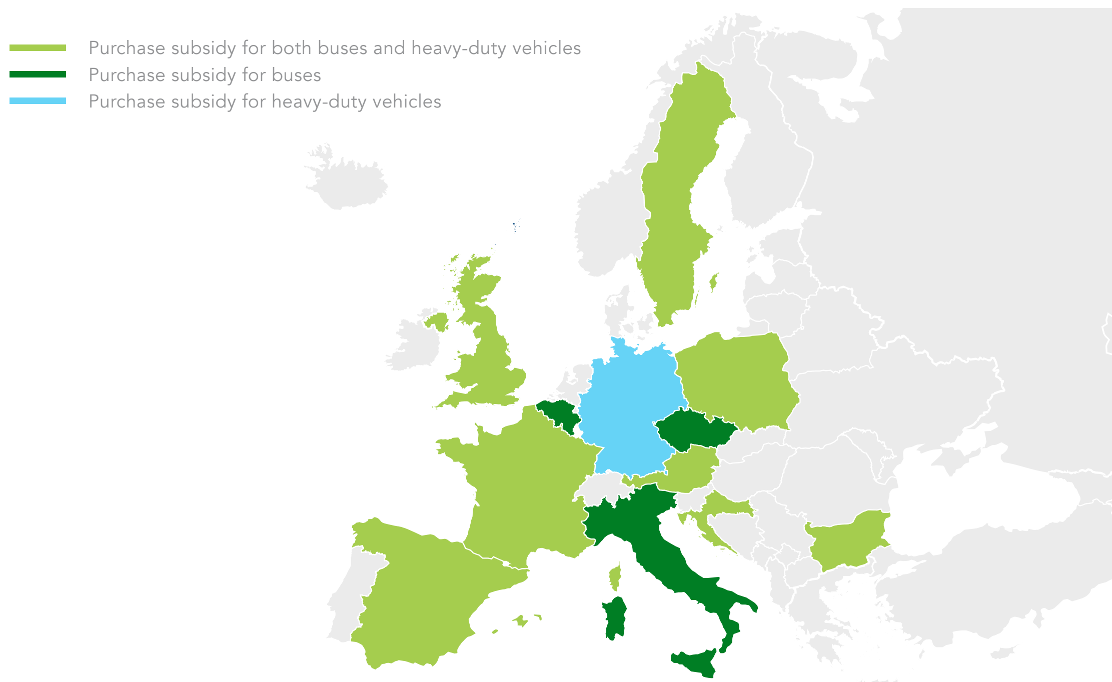
While for some countries, like Poland, Spain, and Ireland, the same policies and financial incentives apply for buses and HDVs, other countries have different policies.

In the UK, the active policy subsidises 75% of the CAPEX difference between FCEV bus and EuroV1 diesel bus while only up to 20% or 18,700 EUR for heavy-duty vehicles under a different scheme.
Austria subsidises buses depending on passenger seats with a maximum of 130,000 EUR for buses with more than 120 passengers. In comparison, heavy-duty FCEVs receive up to 50,000 EUR for vehicles above 12 tonnes.[88]

France provides 50,000 EUR for heavy-duty vehicles as of 2021 while providing 30,000 EUR for buses.

Sweden subsidises 10% of the purchase price for FCEV buses with more than 14 passengers. Bus operators can claim 20% of the price difference between FCEV and conventional buses. For heavy-duty vehicles in Sweden, the purchase subsidy amounts to a maximum of 20% of the investment. Irish government subsidies 40-60% of the price difference for HDVs and buses.

Figure 82 Overview of purchase subsidies and registration tax benefits adoption for FCEV buses and heavy-duty vehicles



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

[88] Fuel Cells and Hydrogen Observatory

7.2 POLICIES IMPACTING HYDROGEN PRODUCTION AND TRANSMISSION

Energy system integration, made possible using hydrogen as the missing link, is one of the main drivers of the hydrogen economy. The transport of hydrogen produced from renewable energy using a retrofitted or repurposed natural gas network or in a new hydrogen network could help unlock the full potential of renewable energy that would otherwise be curtailed.[89]

7.2.1 PRODUCTION SUPPORT

One of the most common policies to incentivise new technology adoption is CAPEX support. According to the FCHO, only eight countries provide CAPEX subsidies for renewable or low-carbon hydrogen production plants. However, these funding schemes are highly heterogeneous in terms of the means of support that they provide.

Only eight countries provide CAPEX subsidies for renewable or low-carbon hydrogen production plants

For example, the Energy Aid program in Finland supports the implementation of new technologies, including electrolysers, making them eligible to receive up to 40% investment subsidy. German funding program for market activation, part of the framework of National Innovation Program Hydrogen and Fuel Cell Technology, supports electrolytic hydrogen production for the transport sector by funding water electrolysis production projects with funding of up to 45% of the total investment for the plant.

In Austria, hydrogen production is eligible for funding from Kommunalkredit Public Consulting for up to 30% of relevant additional CAPEX costs compared to comparable technology.

The Flemish government in Belgium supports 20% to 40% of CAPEX for renewable or low-carbon hydrogen production projects over 3 million EUR via "Strategische ecologiesteun".

Hydrogen production projects are eligible for CAPEX funding in Denmark and Sweden through various industrial emission reduction initiatives. In addition, Bulgaria hopes to adopt CAPEX support for renewable hydrogen production as part of its Recovery and Resiliency Plan.

In addition to CAPEX subsidies, five countries (Denmark, France, Germany, Sweden, and Switzerland) try to incentivise electrolytic hydrogen production by providing reductions in electricity price components for the electricity exemptions via other means.

In France, electrolytic processes are exempted from the domestic tax on final electricity consumption. In addition, consumers with stable or counter-cyclical consumption profiles, such as some electrolysers, can benefit from a tariff reduction for using the public electricity network (TURPE) under specific conditions. In Sweden, all electrolytic processes, including electrolytic hydrogen production, are exempt from electricity tax.

In Denmark, electricity for hydrogen production is exempted from taxation. In Germany, electrolysers are exempt from grid charges based on the Energy Industry Act when they use grid electricity with renewable guarantees of origin.

[89] I.e., limitations of the electricity transmission and distribution system and the lack of storage capacity for renewable electricity are very often the main bottleneck standing in the way of further RES development, all of which are alleviated through the use of hydrogen. the introduction of hydrogen would make full use of the gas grid's immense energy storage capacities, and provide indirect renewable electricity transmission

In addition, according to the revised German Renewable Energy Sources Act (EEG) 2021, the EEG levy for electricity used for hydrogen production will be reduced to zero.

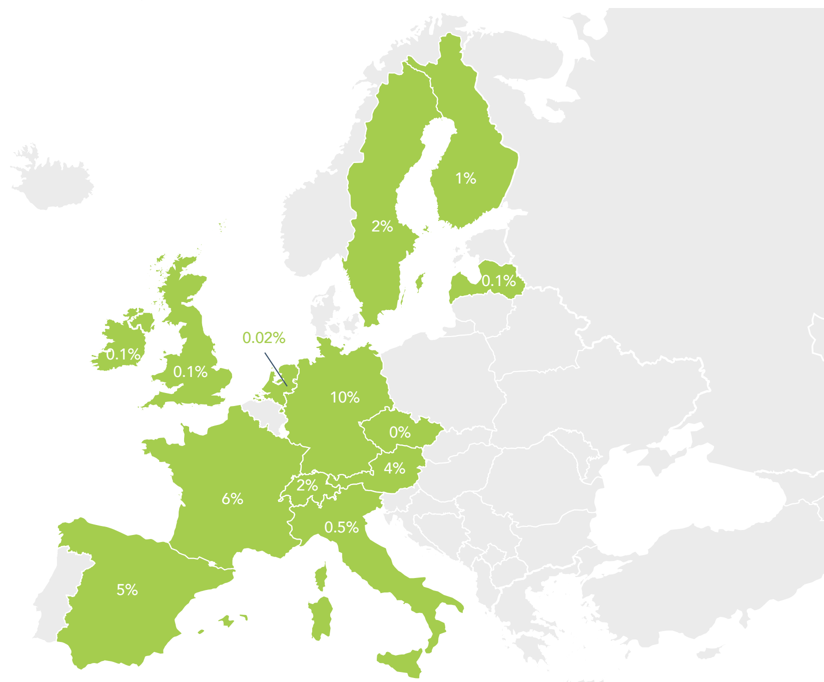
7.2.2 GAS GRID HYDROGEN CONCENTRATION

As hydrogen and natural gas have different chemical characteristics, blending hydrogen with natural gas also changes the characteristics of the mixture. Therefore, the blending of gas and hydrogen is viewed as an early step towards gradual gas grid decarbonisation.[90] Furthermore, injecting hydrogen into some natural gas distribution networks is already technically feasible today without a major overhaul of pipelines or appliances (e.g., if the mixture does not exceed 10-20% of hydrogen by volume).

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, at 10%, has the highest legal admitted concentration of hydrogen in transmission network. Czechia, on the other hand, imposes a legal limit of 0%. Figure 83 below presents the maximum permitted percentage of hydrogen (by volume) in various European countries' transmission networks, either legally or according to national safety regulations.

Figure 83 Countries with legal or safety limits on acceptable hydrogen concentration in TSO networks



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

[90] https://ec.europa.eu/info/sites/info/files/hydrogen_europe_-_vision_on_the_role_of_hydrogen_and_gas_infrastructure.pdf

7.3 POLICIES SUPPORTING THE INTRODUCTION OF HYDROGEN IN INDUSTRY

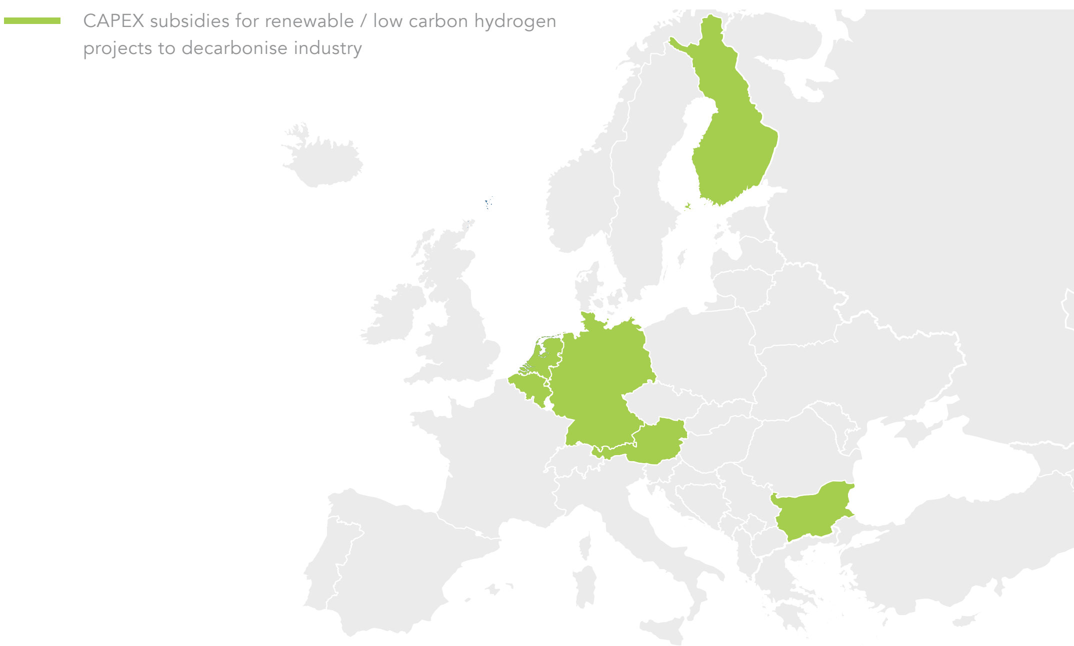
The current use of hydrogen spans various industries, including as a raw material in the chemical industry, for refining, as a reducing agent in the metallurgic industry, as a feedstock for the production of ammonia, methanol, and various polymers. In refineries, hydrogen is used for the processing of intermediate oil products. One of the main future opportunities for hydrogen is its use in these and other industrial processes that would have been difficult to decarbonise through different means.[91]

One of the methods of incentivising industry decarbonisation is **CAPEX subsidies** for the facilities' owners to encourage them to innovate and decarbonise their operations.

CAPEX subsidies for renewable and low-carbon hydrogen production projects in the industry are in effect in six countries Austria, Belgium, Bulgaria, Finland, Germany, and the Netherlands, for their use in industry.

Finland's Energy Aid program provides up to 40% of the initial investment to new technologies that achieve the reduction of greenhouse gas emissions and/or energy savings. This includes the production of hydrogen used in the industry via water electrolysis and using conventional hydrogen-producing coupled with carbon capture. The program is not limited to a specific industry and can be used across different industries.

Figure 84 CAPEX subsidies for renewable/low carbon hydrogen projects to decarbonize industry



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

[91] https://www.hydrogeneurope.eu/hydrogen-applications

The Netherlands's Energy Investment Allowance provides tax deductions up to 45% of CAPEX of energy-saving investments, including 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 Strategic Ecology support program.[92]

While Austria does not provide a specific policy, its Kommunalcredit Public Consulting can provide up to 30% of relevant additional CAPEX costs of 1.5 million EUR applicable for industrial hydrogen projects.

In Germany, the Environmental Innovation Program provides up to 30% investment grants for decarbonising industrial processes using new technologies, including hydrogen. More information, conditions, and links to the policies can be found on fchobservatory.eu.

[92] Fuel Cells and Hydrogen Observatory

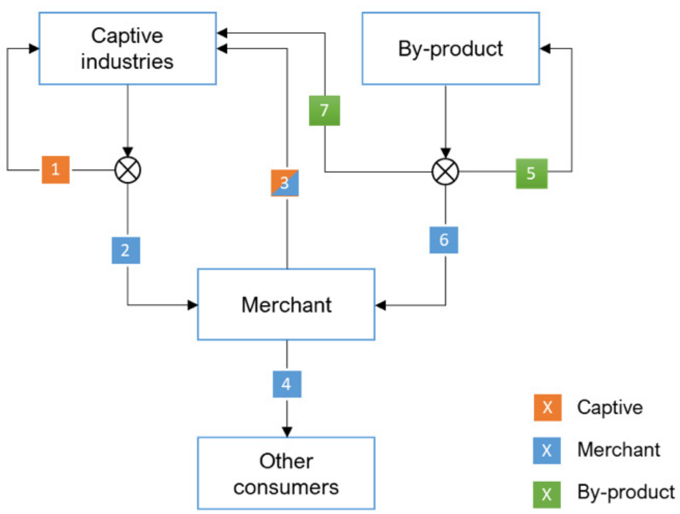
8

METHODOLOGICAL NOTE

CHAPTER 1: DEFINITION OF HYDROGEN PRODUCTION TYPES BY AVAILABILITY

Figure 85

Definition of hydrogen production types by availability



Source: Hydrogen Europe.

Where:

1. Captive hydrogen production onsite 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, which are dedicated to supplying hydrogen merchants.
3. Hydrogen produced in large industrial installations usually dedicated to serving a single customer or an industrial cluster. Usually produced in close vicinity or distributed with pipelines. Whenever it could be identified that the installation was serving a single customer, those installations were categorised as captive. In other cases, it was categorised as a merchant.
4. Hydrogen produced for retail purposes and sold in relatively small volumes. Usually distributed in a compressed form via cylinders or tube trailers (200 bar). In a few cases, it can be liquified and subsequently transported by trucks.
5. By-product hydrogen vented to the atmosphere or used as feedstock for internal processes or 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.

CHAPTER 2: LEVELIZED COST OF HYDROGEN ESTIMATIONS ASSUMPTIONS

Table 2

Assumptions for estimation of hydrogen production costs

Item	Unit	Value	Source
CAPEX	EUR/kW	600	[CHE SRIA 2021]
Economic life time	years	30	[BNEF 2019]
Energy consumption	kWh/kgH2	50.00	[CHE SRIA 2021]
Stack degradation[1]	per 1000 hrs	0.12%	[CHE SRIA 2021]
Other OPEX[2]	% CAPEX	4.00%	[CHE SRIA 2021]
Costs of capital	%	6.0% in real terms	-

Source: Hydrogen Europe based on updated Strategic Research and Innovation Agenda of the Clean Hydrogen for Europe partnership and BloombergNEF, "Hydrogen: The Economics of Production from Renewables", 2019.

Notes: 1) Stack degradation is 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 10 years with 8,000 operating hours per year.
2) Operation and maintenance costs averaged over the first ten years of the system. Potential stack replacements are included in O&M costs. Electricity costs are not included in O&M costs.

Table 3

Renewable energy capacity factors in the EU

	PV			Onshore wind			Offshore wind	
Entity	CF_avg	CF_top	CF_max	CF_avg	CF_top	CF_max	CF_avg	CF_max
Belgium	11.2	13.6	14.2	21.3	25.0	38.0	47.0	50.0
Bulgaria	14.3	17.9	18.4	16.9	23.0	27.0	34.0	36.0
Czechia	11.7	13.7	14.0	23.4	28.0	32.0		
Denmark	10.6	13.7	14.4	17.2	44.0	47.0	47.0	53.0
Germany	9.8	13.5	14.9	20.4	25.0	40.0	44.0	51.0
Estonia	8.9	12.9	12.9	23.7	33.0	33.0	46.0	49.0
Ireland	8.8	11.9	12.3	29.2	50.5	51.0	53.0	
Greece	16.9	22.1	25.1	21.2	35.0	51.0	29.0	42.0
Spain	17.2	21.8	25.6	27.2	29.4	36.8	30.7	46.4
France	12.9	16.7	21.8	22.9	32.0	42.0	42.0	48.0
Croatia	12.6	17.8	18.6	17.7	27.0	33.0	24.0	29.0
Italy	13.9	19.1	22.5	16.2	26.6	34.3	25.0	34.0
Cyprus	17.0	25.3	25.3	12.0	22.0	22.0	21.0	25.0
Latvia	9.2	13.0	13.0	15.3	34.1	34.1	46.0	48.8
Lithuania	9.4	12.9	12.9	21.2	33.9	33.9	46.0	46.7
Luxembourg	11.3	13.4	13.4	12.5	22.6	22.6		
Hungary	13.8	16.6	17.2	16.9	23.0	29.0		
Malta	16.8	25.2	25.2	27.0	32.8	32.8	30.0	30.6
Netherlands	11.0	13.4	14.3	25.0	36.7	45.1	47.0	49.8
Austria	12.7	14.5	15.9	27.5	34.0	39.0		
Poland	10.2	13.6	14.0	23.0	29.8	35.6	45.2	48.1
Portugal	20.9	24.2	25.3	22.2	24.9	28.2	33.9	38.6
Romania	14.0	16.7	18.0	19.6	22.6	27.0	35.7	38.7
Slovenia	12.9	16.1	16.2	14.5	24.1	26.5		
Slovakia	11.6	14.8	15.6	16.4	24.7	30.2		
Finland	6.8	12.9	14.7	19.1	36.0	44.0	46.0	49.0
Sweden	7.5	12.8	14.1	25.7	39.9	46.6	44.0	49.7
United Kingdom	9.3	12.4	14.0	27.2	39.7	52.4	48.6	55.6
Norway	5.1	10.5	13.2	22.7	49.5	52.4	41.4	48.9

Where: PV: PV: CF_avg – Average CF in 1986-2015 based on EMHIRESPV l CF_top – CF for top 10% locations l CF_max - max CF for ir_global_tracking with 0.85 performance ratio, Wind: CF_top - CF for top 10% locations l 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.

Table 4 Renewable energy generation cost assumpti

Item	Unit	PV	Wind Onshore	Wind Offshore	Source
Economic lifetime	years	25	25	25	[IRENA 2021]
CAPEX	EUR/kW	737	1,248	2,847	[IRENA 2021]
Fixed O&M	EUR/kW/year	13	20	70	[Frauenhofer ISE 2021]
Variable O&M	EUR/kWh	0.000	0.008	0.008	[Frauenhofer ISE 2021]

Source: Hydrogen Europe.

CHAPTER 3: PROJECT TRACKING METHODOLOGY AND GEOGRAPHIC SCOPE

The list of power-to-hydrogen, reforming with carbon capture, and infrastructure projects that form a basis for the analysis, have been collected by Hydrogen Europe from both public and restricted sources. It provides a snapshot of the current developments.

The authors collected this information to the best of their abilities. However, they cannot guarantee the 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 about the start date, capacity, technology, or other project information. 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 in all stages, including concept, feasibility studies, FEED, detailed design & permitting, and construction.

If the authors of this report refer to and provide details of specific projects, this information is either public or has been specifically authorised by the project partners.

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

CHAPTER 7. METHODOLOGY AND GEOGRAPHIC SCOPE

Methodology: Data have been collected by Hydrogen Europe through a network of national respondents for the FCH Observatory.

Geographical scope: Geographical coverage of the database consists of EU countries including Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden as well as Norway, Switzerland, and the United Kingdom.

A full list of National respondents can be found at the following link: https://fchobservatory.eu/index.php/about-us

Results in this chapter purposefully exclude some countries depending on the quantity and quality of the collected information.

Hydrogen Europe Industry Secretariat

Avenue de la Toison d' Or 56- 60
1060 Brussels
Belgium

secretariat@hydrogeneurope.eu
tel: +32 2 54 087 75

Hydrogen Europe

WWW.HYDROGENEUROPE.EU