Chapter 2

2022 Hydrogen Supply Capacity and Demand

March 2022

FUEL CELLS AND HYDROGEN OBSERVATORY

Co-funded by the European Union

Clean Hydrogen Partnership

Disclaimer

This report is based on data gathered for the Fuel Cells and Hydrogen Observatory by March 2022. The data aim to reflect the situation in hydrogen supply and demand as of the end of 2020.[1] The authors believe that this information comes from reliable sources, but do not guarantee the accuracy or completion of this information. The Observatory and information gathered within it will continue to be revised. These revisions will take place annually and can also be done on a case-by-case basis. As a result, the information used as of writing of this report might differ from the changing data in the Observatory.

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This report was prepared for the Clean Hydrogen Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from https://www.fchobservatory.eu/

The Fuel Cells and Hydrogen Observatory has been prepared for the Clean Hydrogen JU under a public procurement contract.

[1] The data only reflects end of 2020 as some of the sources did not have 2021 data available during the data collection process.

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Executive Summary

Purpose: The purpose of the hydrogen supply and demand data stream is to provide an overview of the hydrogen market in Europe and to track industry's progress in deploying clean hydrogen technologies.

Scope: Data about hydrogen production capacity and consumption in EU countries, together with Switzerland, Norway, Iceland, and the United Kingdom. Hydrogen production capacity is presented by country and by production technology, whereas the hydrogen consumption data is presented by country and by end-use sector. The analysis undertaken for this report was completed using data reflecting end of 2020.

Key Findings: The current hydrogen market (on both the demand and supply side) is dominated by refining and ammonia industries with four countries (DE, NL, PL, ES) responsible for more than half of hydrogen consumption. Hydrogen is overwhelmingly produced by reforming of fossil fuels (mostly natural gas). Clean hydrogen production capacities are currently insignificant with hydrogen produced from natural gas coupled with carbon capture at 0.42% and hydrogen produced from water electrolysis at 0.14% of total production capacity.

Total hydrogen production capacity in the included countries at the end of 2020 has been estimated at **30,927 tonnes per day** or **11.4 Mt per year.** If by-product hydrogen from coke oven gas is included the total is **33,026 tonnes per day** which equates to **12.2 Mt** per year. The corresponding consumption of hydrogen has been estimated at **8.6 Mt (341 TWh_{HHV}),** which means an average capacity utilization of 76%.

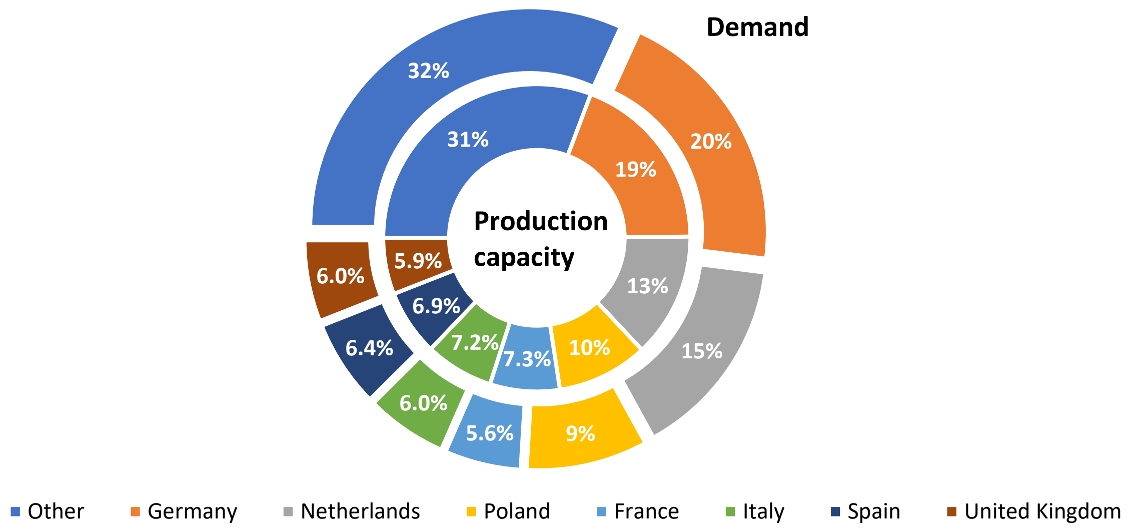
The biggest share of hydrogen demand comes from refineries, which were responsible for 50% of total hydrogen use, followed by the ammonia industry with 29%. Together these two sectors consumed almost 4/5 of total hydrogen consumption in the covered European countries. About 12% was consumed by the chemical industry including methanol production constituting 5%. **Emerging hydrogen applications, like the transportation sector remained steady consuming only 0.02% of the total.**

On-site captive hydrogen production was by far the most common method of hydrogen supply, comprising **25,105 tonnes per day (81%)** of all hydrogen production capacity with merchant production of **3,575 tonnes per day** (**12%**) and by-product production of **2,203 tonnes per day (7%).**[2]

Germany was, by a significant margin, **the largest European market for hydrogen, with 19% of total European hydrogen production capacity** and **20% of total demand**. Together with the Netherlands, Poland, and Spain, these four countries were responsible for 51% of the hydrogen demand and 48% of production capacity.[3]

[2] Excluding by-product hydrogen in coke oven gas
[3] Excluding by-product hydrogen in coke oven gas

Figure 1: Total hydrogen production capacity and consumption by country in 2020
Source: Fuel Cells and Hydrogen Observatory



The most common method of producing hydrogen is steam reforming of natural gas (SMR). Less common are partial oxidation (POX) and autothermal reforming (ATR). SMR and natural gas are widely used for all applications including oil refining, ammonia synthesis, or any other bulk hydrogen production. Even though natural gas is the most common feedstock, steam reforming is also used with other feedstocks, which include also liquid hydrocarbons like LPG or naphtha.

Out of the 338 identified hydrogen production plants which were using fossil fuels as feedstock, only three were using carbon capture technologies:

- Grupo Sappio hydrogen production unit in Mantova, Italy with a capacity of around 1,500 Nm3/h that started operating in 2016.
- Air Liquide Cryocap installation in Port Jerome, France, capturing CO2 from hydrogen supplied to an Exxon refinery, with a capacity of around 50,000 Nm3/h that started operating in 2015.
- Shell refinery in Rotterdam, Netherlands where CO2 from hydrogen production is captured and sold for agricultural use as part of the OCAP project since 2004.

Total share of hydrogen production from fossil fuels with CCS/CCU was approximately 131 tonnes per day equating to 0.42% of the total hydrogen generation capacity.[4]

By the end of 2020, the authors identified and track 114 operational power-to-hydrogen (water electrolytic) projects in EU, EFTA, and UK. Total power of the electrolysers from those 114 projects was **99 MW** equalling to hydrogen generation capacity of ~**44 t of electrolytic hydrogen per day (0.14% of total production capacity)**. This represents an 11% increase in operational power-to-hydrogen capacity between 2019 and 2020 caused by **19 new projects adding 7 MW of capacity**. Compared to 2018, it represents a 31% increase in capacity over two years. Electrolyzer deployment is increasing rapidly with approximately **36 MW** of **new electrolyzer capacity** being expected to have been deployed **in 2021.**

[4] Excluding by-product hydrogen in coke oven gas

1. Hydrogen production capacity

1.1. Summary

The assessment of hydrogen production capacity in EU, EFTA, and UK builds on work completed by the Roads2HyCom project and ongoing work by the Hydrogen Analysis Resource Centre (HyARC). The annual updates capture closing and new facilities as well as further specify and improve on the collected information by contacting asset owners, industry associations, and statistical offices.[5] Results of this data collection include **535 hydrogen production sites**, which have been categorised by:

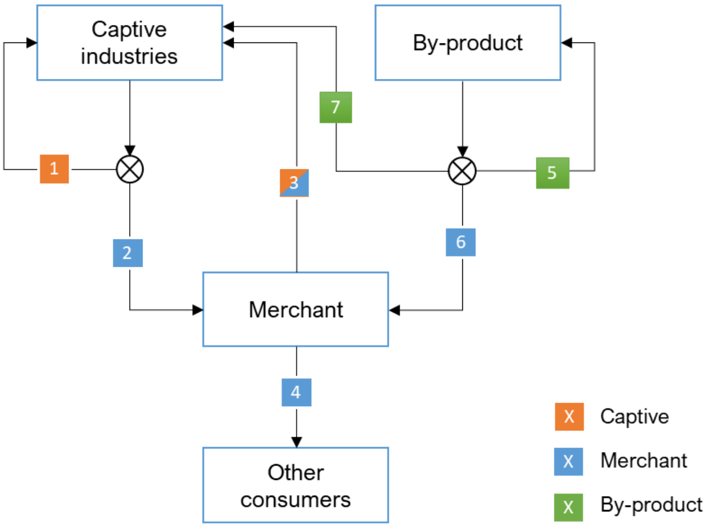
- type of production (captive, merchant, by-product);
- technology;
- application (only for captive hydrogen production capacity);
- country.

The hydrogen production plants have been divided into three main categories: captive production facilities[6], merchant production facilities[7], and plants where production of hydrogen is a by-product of other processes. It should be noted though, that in some cases, the boundaries between different hydrogen streams are extremely blurry. The reason is that in many cases many types of installations are clustered within the same area and it is not uncommon for an industrial park to contain all three types of installations. In this case, the flow of hydrogen between installations is more a result of current capacity utilization than a fixed design and can therefore change over time. For example, a captive hydrogen generation unit (HGU) can be used to supply hydrogen to merchant companies during times when it is underutilized for its primary purpose. As a result, the amount of hydrogen that can be used for merchant supply from excess hydrogen from captive industries, varies depending on the actual demand for hydrogen from its primary use.

For the purpose of this analysis the authors defined the boundaries between the three hydrogen production types as follows:

[5] The hydrogen supply capacity market is largely stable so differences compared to previous years primarily reflect methodological changes as well as continuously improving accuracy of the supply capacity data rather than market trends. The methodological changes compared to the September 2021 report include classifying by-product hydrogen production capacity in refineries as captive and reducing the potential of hydrogen production capacity from coke production. In terms of improving data accuracy, the most significant improvement occurred in the production capacities in refineries which lead to a significant increase in captive refining production capacity.
[6] On-site production of hydrogen for own consumption.
[7] Hydrogen production dedicated for sales.

Figure 2: Definition of hydrogen production types by availability
Source: Author's own elaboration



Where:

1. Captive hydrogen production on-site used exclusively for own consumption within the same facility.[8]
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 supply hydrogen merchants.
3. Hydrogen produced in large industrial installations usually dedicated to serve a single customer or an industrial cluster. Usually produced in close vicinity or distributed with pipelines. Whenever it was possible to verify that the installation was serving a single customer those installations were categorised as captive. In other cases, they were categorised as merchant.
4. Hydrogen produced for retail purposes and sold in relatively small volumes, that does not warrant building its own HGU. Usually distributed in compressed form, in cylinders or using tube trailers (200 bar), in few cases liquefied, also mostly using trucks.
5. By-product hydrogen that is vented to the atmosphere or used as feedstock for internal processes or for on-site energy generation.[9]
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.

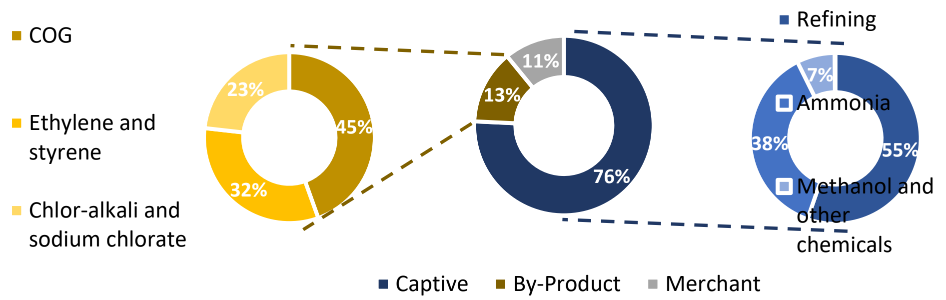
Total hydrogen production capacity in the covered European countries at the end of 2020 has been estimated at **33,026 tonnes per day**. Excluding coke oven gas hydrogen, the remaining capacity is **30,927 t per day**.

Seventy six percent (76%) of all hydrogen production capacity was designated for **captive production**. In reality it is even more than that, as a large portion of the merchant plants are dedicated entirely to supplying large industrial customers on-site, with only a small proportion of production capacity

[8] Hydrogen produced during various refining processes and used onsite is considered captive in our methodology
[9] Hydrogen produced during various refining processes and used onsite is an exception and is considered captive in our methodology

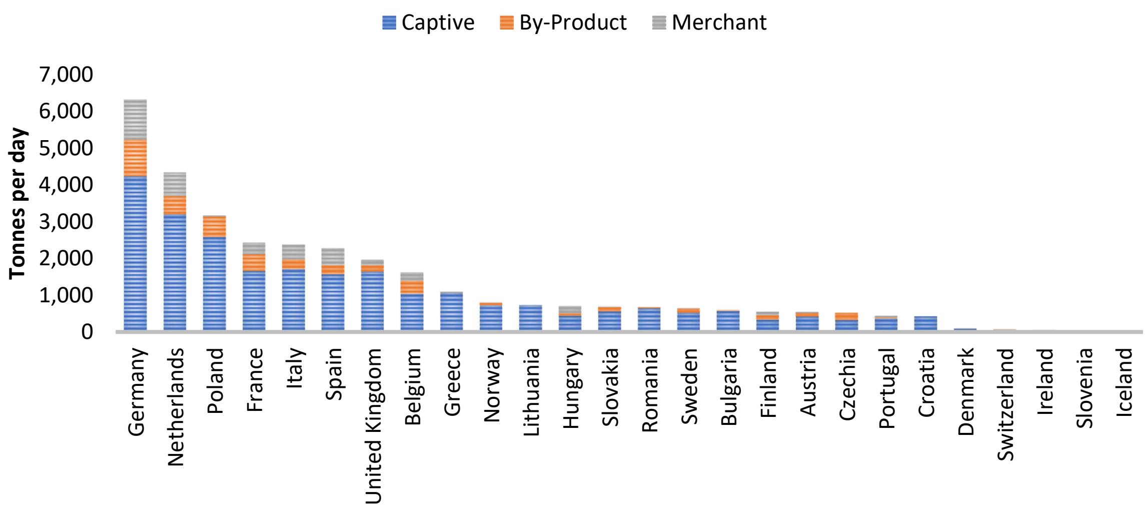
available to supply the wider market. **By-product hydrogen provides 13%** of total hydrogen production capacity, of which 49% is hydrogen from coke oven gas.[10]

Figure 3: Structure of hydrogen production capacity
Source: Fuel Cells and Hydrogen Observatory



With almost **6,323 t per day (19% of total), Germany has by far the largest hydrogen production capacity from among the analysed countries.** The Netherlands follows with 4,336 t per day (13% of total. Other countries with significant hydrogen production capacity are Poland (3,166 t per day, 10%), France (2,425, 7%), Italy (2,379, 7%), Spain (2,283, 7%), and United Kingdom (1,968, 6%).[11]

Figure 4: Total hydrogen production capacity by country
Source: Fuel Cells and Hydrogen Observatory



1.2. Captive production

On-site captive hydrogen production is by far the most common method of hydrogen supply for large hydrogen consumers. These include refineries as well as ammonia, methanol, and hydrogen peroxide production plants. In all those cases, the high volume of hydrogen consumed, justifies the investment in a dedicated HGU. The predominant technology for this type of installations is hydrocarbon reforming – mostly steam methane reforming (SMR). The capacity numbers in this section also include by-product

[10] The total by-product capacity has decreased from 26% to 13% compared to the September 2021 report due to two methodological changes. Identified by-product hydrogen production capacity in refineries was moved from the by-product section to the captive section and hydrogen production capacity from coke production was reduced from 450 to 207 Nm^3 H^2/t of product.
[11] Numbers include by-product hydrogen in coke oven gas

hydrogen production capacity at refineries. Hydrogen is produced at refineries as a by-product of different refining processes. Since it is mostly used on-site, it methodologically belongs to captive production.

1.2.1. Refining

The total captive hydrogen production capacity installed at refineries (excluding merchant plants, even if dedicated to supply hydrogen to refineries) is approximately **13,886 t per day** split between **92 facilities.**[12]

Germany has the largest share with 15% of total EU, EFTA, and UK hydrogen production capacity in refineries, followed by the Netherlands (11%), Italy (10%), Spain, (9%), Poland (8%), and the United Kingdom (7%).

The oil refining sector is the biggest hydrogen producer and consumer in the EU. Hydrogen in refineries is used for the purpose of hydrotreating and hydrocracking processes. Hydrotreatment is one of the key stages of the diesel refining process and relates to several processes such as hydrogenation, hydrodesulphurization, hydrodenitrification, and hydrodemetalization. Hydrocracking involves the transformation of long and unsaturated products into products with a lower molecular weight than the feed.

Hydrocracking is by far the most common hydrogen consuming process, needing around 300 Nm3 H2/t of product. Hydrotreating processes usually require only around 20-50 Nm3 H2/t of product. It is also important to note that refineries not only consume but also produce hydrogen at various stages of crude oil refining, with the most hydrogen yield being generated during catalytic reformulation which produces hydrogen at a rate of 200 Nm3 H2/t crude oil[13].

The volume of production can be substantial to the point that refineries that do not use hydrocracking can be self-sufficient in terms of hydrogen consumption and do not require any additional dedicated hydrogen production.

All large EU refineries use fossil fuels (most commonly natural gas) as a feedstock to produce hydrogen through one of the following processes:

- steam reforming or autothermal reforming of light ends or natural gas;
- partial oxidation (gasification) of heavy oil fractions;
- reforming processes which produce hydrogen as a by-product.

Refineries with the simplest configuration may produce enough hydrogen only through catalytic reforming. Complex plants with extensive hydrotreating and/or hydrocracking operations typically require more hydrogen than is produced by their catalytic reforming units and it is those refineries that have dedicated HGU's. The feed of the hydrogen plant consists of hydrocarbons in the range from natural gas to heavy residue oils and coke. The conventional steam reforming process produces a

[12] While the identified production capacities change and become more accurate every year, the increase from last year's number of 9,376 t/d is mostly due to a change in methodology. In the report published in September 2021, the known volumes of hydrogen produced in refineries as a by-product of catalytic reforming or other processes were included in the by-product section. This report includes that capacity here in the captive section because while those hydrogen volumes are produced as a by-product, they are consumed on site as other captive production.

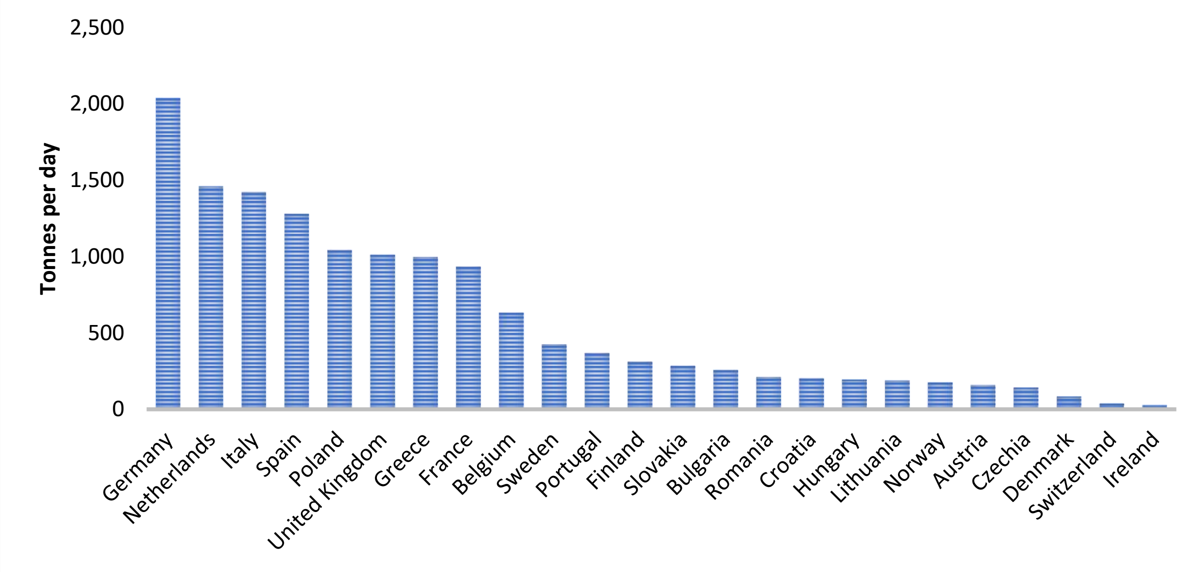
[13] G. Maisonnier, J. Perrin, R. Steinberger-Wilckens y S. C. Trümper, «European Hydrogen Infrastructure Atlas" and "Industrial Excess Hydrogen Analysis",» Roads2HyCom, 2007. < https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.477.3069&rep=rep1&type=pdf >

hydrogen product of a maximum of 97 – 98 % v/v purity and higher if a purification process is applied (99.9 – 99.999 % v/v).[14]

Figure 5: Captive hydrogen production installations for refining
Source: Fuel Cells and Hydrogen Observatory

[14] P. Barthe, M. Chaugny y L. Serge Roudier, «Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas,» JRC, 2015. <https://publications.jrc.ec.europa.eu/repository/handle/JRC94879 >

Figure 6: Captive hydrogen production capacity for refining by country
Source: Fuel Cells and Hydrogen Observatory



1.2.2. Ammonia

Next to refineries, the ammonia industry is the second largest hydrogen producing and consuming sector in the EU. Total ammonia-related hydrogen production capacity in Europe was approximately **9,382 t per day** split between **36 facilities**. All of them were using either steam methane reforming or partial oxidation (POX) to generate hydrogen.

Similarly to refining, Germany had the largest share with 15.8% of Europe's hydrogen production capacity dedicated to ammonia production, closely followed by the Netherlands (15.6%), Poland (15.5%), France (8%), and the United Kingdom (6%).

The ammonia production process involves a synthesis of hydrogen with nitrogen according to the following formula:

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$

This process consumes about 175-180 kg of hydrogen per t of ammonia.

Figure 7: Captive hydrogen production installations for ammonia plants
Source: Fuel Cells and Hydrogen Observatory

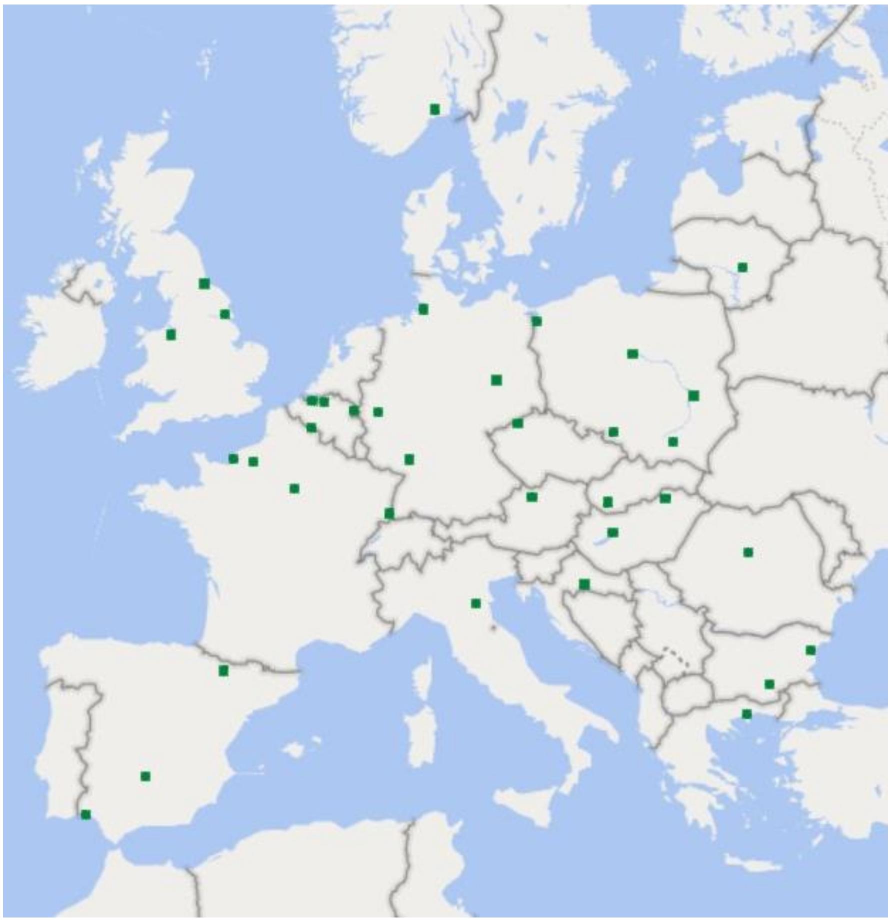
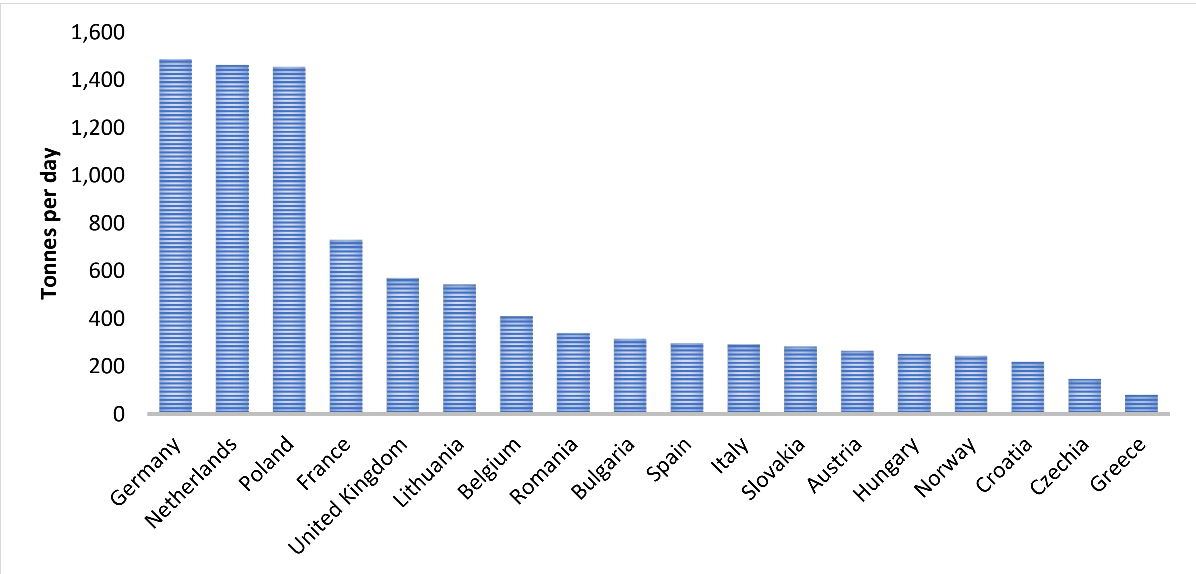


Figure 8: Captive hydrogen production capacity for ammonia plants by country
Source: Fuel Cells and Hydrogen Observatory



1.2.3. Other captive hydrogen production plants

The captive hydrogen production sites located in refineries or ammonia plants comprise around 93% of total captive hydrogen production. Other than these processes, hydrogen is produced at scale also for the production of a number of other chemicals, including methanol and hydrogen peroxide. **Total captive hydrogen production capacity in Europe dedicated to methanol and other chemicals is approximately 1,837 t per day split between 26 facilities.**

The most common methanol production method is steam reforming of methane and subsequent synthesis, and follows the following process:

$$\textit{1st step: } CH_4 + H_2O \rightarrow CO + 3\ H_2 \textit{ and } CO + H_2O \rightarrow CO_2 + H_2$$
$$\textit{2nd step: } 3\ H_2 + CO_2 \rightarrow CH_3OH + H_2O$$

This production consumes about 1,400 Nm^3 H2/t of methanol.[15] Methanol is an important chemical raw material used to produce formaldehyde, acetic acid and MTBE or fatty acid methyl esters (FAME), adhesives and solvents.

Other uses of hydrogen in the chemical industry include the production of such high-volume chemical products as hydrogen peroxide, for which hydrogen consumption is approx. 735 Nm^3 H2/t[16], hydrogen chloride, aniline, cyclohexane, TDI, and oxo-alcohols. In most cases, production of those chemicals takes place at large integrated chemical or petrochemical plants.

As is the case with hydrogen produced for the refining or fertilizer industry, the overwhelming number of installations today use fossil fuels as feedstock for production of hydrogen.

One notable exception is Carbon Recycling International's George Olah Renewable Methanol Plant in Svartsengi (Iceland). The plant is able to produce 5 million litres of methanol per year and uses hydro and geothermal energy for producing hydrogen from water electrolysis, which is then reacted with CO_2 from flue gases to produce methanol.[17]

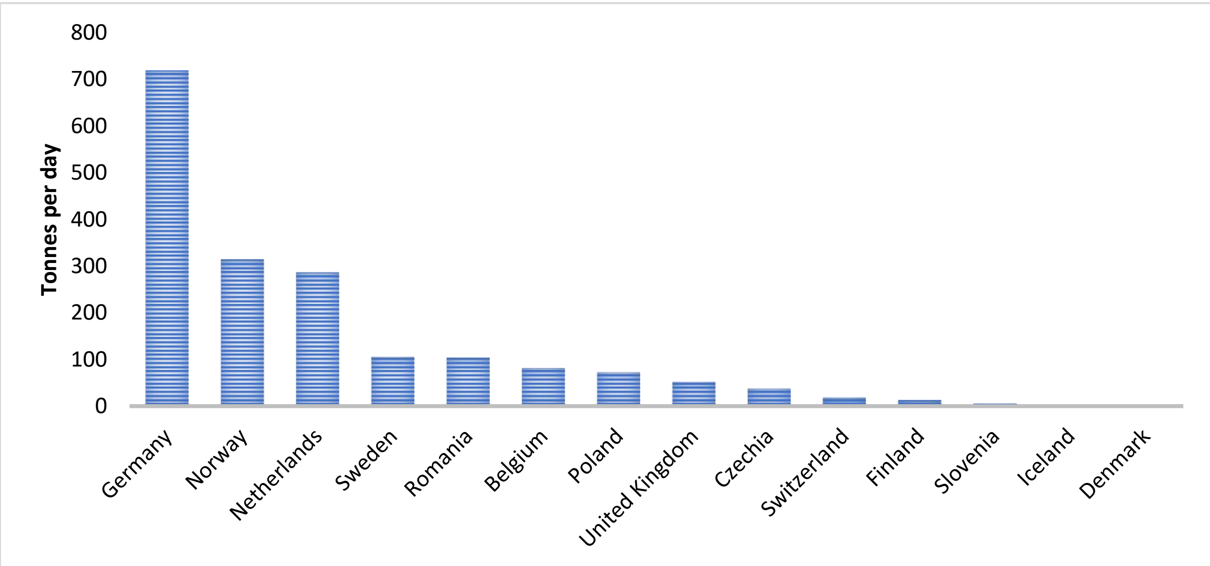
[15] G. Maisonnier, J. Perrin, R. Steinberger-Wilckens y S. C. Trümper, «European Hydrogen Infrastructure Atlas" and "Industrial Excess Hydrogen Analysis",» Roads2HyCom, 2007. < https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.477.3069&rep=rep1&type=pdf >

[16] Ibid.

[17] B. Rego de Vasconcelos y J.-M. Lavoie, «Recent Advances in Power-to-X Technology for the Production of Fuels and Chemicals,» Frontiers in Chemistry, 2019. < https://www.frontiersin.org/articles/10.3389/fchem.2019.00392/full >

Figure 9: Captive hydrogen production installations for methanol and other chemicals
Source: Fuel Cells and Hydrogen Observatory

Figure 10: Captive hydrogen production capacity for methanol or other chemical plants, excluding ammonia
Source: Fuel Cells and Hydrogen Observatory



1.3. Merchant hydrogen production

The report identified 105 merchant hydrogen plants operational in Europe in 2020. **Total capacity of those plants has been estimated at 3,575 t per day.**

The merchant hydrogen plants can be divided into two main categories:

- plants dedicated to supply a single large-scale consumer with only excess capacity available to supply the retail hydrogen market; and
- small and medium scale hydrogen production sites designed for the purpose of supplying mostly retail customers.

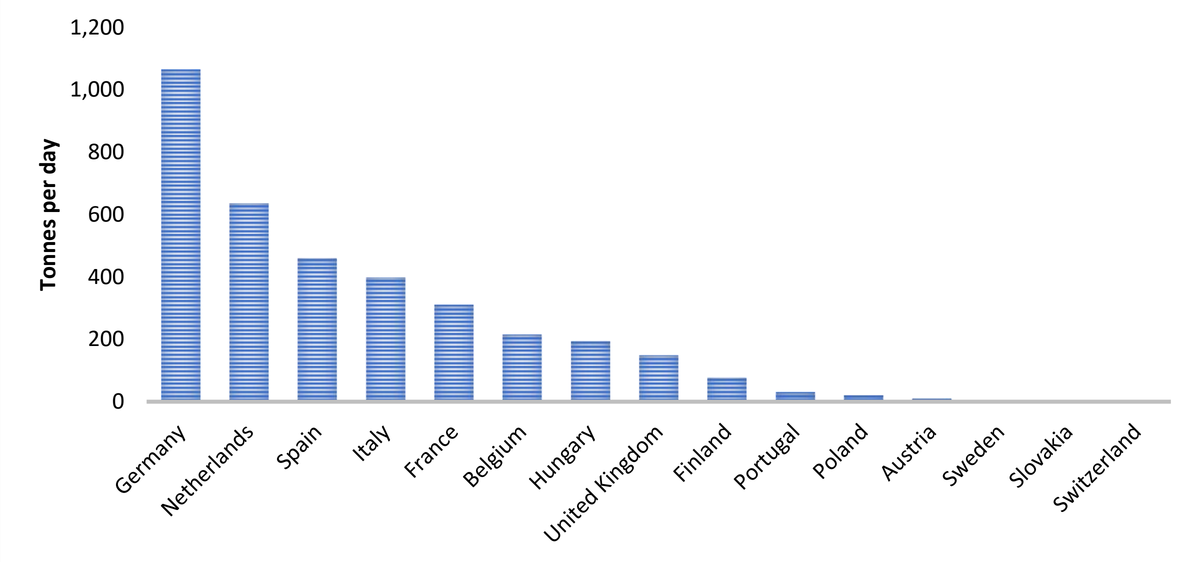
While the first type can be comparable in scale to the largest captive hydrogen production facilities, the installations designed with the hydrogen retail market in mind are an order of magnitude smaller in terms of their maximum capacity.

Figure 11: Identified merchant hydrogen plants
Source: Fuel Cells and Hydrogen Observatory

The merchant hydrogen market in Europe is dominated by 4 groups: Linde Gas, Air Liquide, Air Products and Messer, that own a combined 84% of plants and 90% of total merchant hydrogen production capacity.

As was the case with captive hydrogen production, most merchant hydrogen production capacity is located in Germany (30%), the Netherlands (18%), Spain (13%), Italy (11%), and France (9%).

Figure 12: Merchant hydrogen production capacity.
Source: Fuel Cells and Hydrogen Observatory



From a technology perspective, while most production capacity is still fossil fuel based, 11% of the merchant hydrogen production capacity also comes from by-product production from the chlor-alkali and sodium chlorate processes.

1.4. By-product hydrogen production

By-product hydrogen production capacity, meaning hydrogen produced as a by-product of other processes, has been estimated at **4,303 t per day**[18], including:

- 2,099 t per day of hydrogen mixed in coke oven gas,
- 1,166 t per day of hydrogen produced during ethylene production,
- 580 t per day of hydrogen produced by the chlor-alkali process,
- 357 t per day of hydrogen produced during styrene production,
- 100 t per day of hydrogen produced by the sodium chlorate process.

The hydrogen production rate for ethylene and styrene production processes is around 190 Nm^3 H2/t ethylene and 220 Nm^3 H2/t of styrene.[19] By-product hydrogen from those industries is almost universally used on site as a feedstock for other chemical or petrochemical processes further downstream.

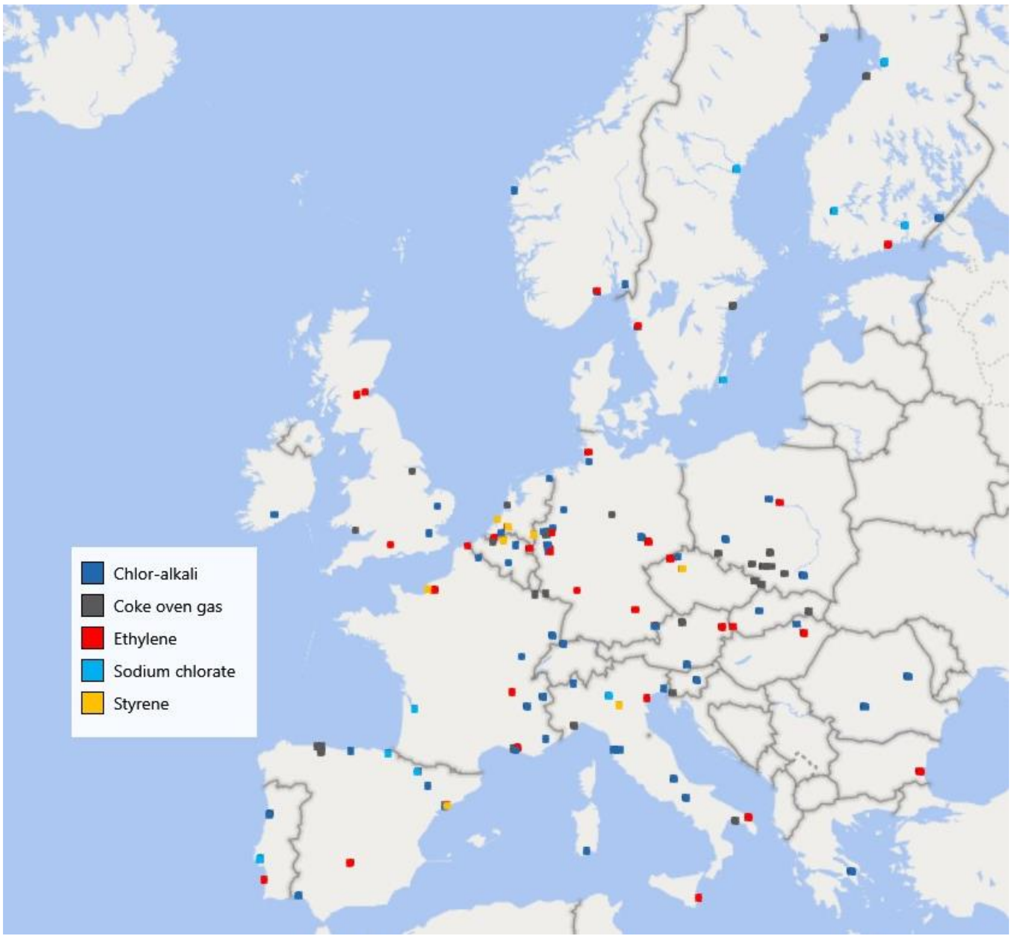
The by-product production rate from the chlor-alkali industry is around 300 to 270 Nm^3 H2/t chlorine.[20] On average, the industry vents around 15% of produced hydrogen into the atmosphere with the remaining 85% usually burned for heat or used in a CHP unit to generate both heat and power. Because

[18] The total by-product capacity has decreased significantly compared to the September 2021 report's 8,523 t per day due to two methodological changes. By-product hydrogen production capacity in refineries was moved from the by-product section to the captive section and hydrogen production from coke production was reduced from 450 to 207 Nm^3 H^2/t of product.
[19] G. Maisonnier, J. Perrin, R. Steinberger-Wilckens y S. C. Trümper, «European Hydrogen Infrastructure Atlas" and "Industrial Excess Hydrogen Analysis",» Roads2HyCom, 2007. < https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.477.3069&rep=rep1&type=pdf >
[20] Ibid.

by-product hydrogen from the chlor-alkali industry has high purity, if a pipeline network is available, by-product hydrogen can also be sold to other industrial users or sold to hydrogen merchants.

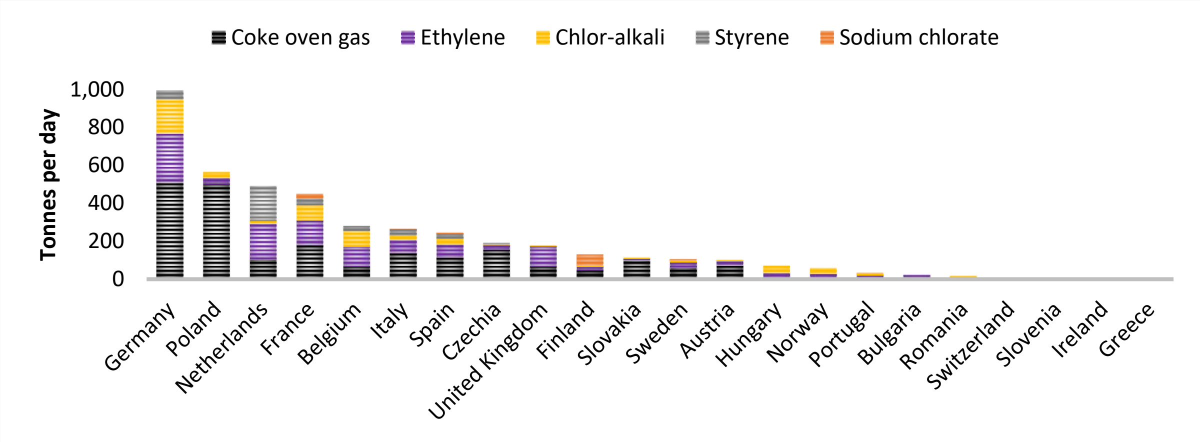
The biggest potential source of by-product hydrogen is coke oven gas (COG), where the hydrogen production rate is approximately 207 Nm^3 H^2/t of product. In this case though, the output gas is not pure hydrogen but rather a mixture of hydrogen (55%-65%) and methane, carbon monoxide, CO_2 and nitrogen. Coke oven gas is used to enrich the calorific value of the other process gases for use in blast furnace stoves, the reheating furnaces of hot strip mills, for other high temperature processes, or for the under-firing of coke ovens. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and is also used in power plants.[21] Other, smaller by-product hydrogen sources include acetylene and cyanide production.

Figure 13: Identified by-product hydrogen production plants
Source: Fuel Cells and Hydrogen Observatory



[21] 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. < https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf >

Figure 14: By-product hydrogen production capacity
Source: Fuel Cells and Hydrogen Observatory



1.5. Clean hydrogen production capacity

The most common method of producing hydrogen is steam reforming of natural gas (SMR). Less common are partial oxidation (POX) and autothermal reforming (ATR). SMR and natural gas is widely used for all applications including oil refining, ammonia synthesis, or any other bulk hydrogen production. Even though natural gas is the most common feedstock, steam reforming is also used with other feedstocks, which include also liquid hydrocarbons like LPG or naphtha.

Out of the 338 identified hydrogen production plants which were using fossil fuels as feedstock, only three were using **carbon capture** technologies:

- Grupo Sappio hydrogen production unit in Mantova, Italy with a capacity of around 1,500 Nm^3/h that started operating in 2016.
- Air Liquide Cryocap installation in Port Jerome, France, capturing CO_2 from hydrogen supplied to an Exxon refinery, with a capacity of around 50,000 Nm3/h that started operating in 2015.
- Shell refinery in Rotterdam, Netherlands where CO_2 from hydrogen production is captured and sold for agricultural use as part of the OCAP project since 2004.

The total share of hydrogen production capacity from fossil fuels with CCS/CCU is ~0.42% equating to 131 tonnes per day.

Hydrogen can, of course, also be produced with electricity by splitting water via **water electrolysis**. There is a significant number of electrolysers installed in Europe. In the past, electrolysers have been employed whenever the volume of hydrogen demand was high enough to warrant building a dedicated installation onsite, instead of external supplies in cylinders or tube trailers, but not high enough to invest in an SMR + PSA unit, especially whenever high purity grade hydrogen is required. This includes for example electrolysers installed for captive hydrogen production at food processing facilities (fat hardening) or power plants where hydrogen is used for cooling purposes.

Power-to-hydrogen installations, where electricity is used to produce hydrogen via water electrolysis, have been proliferating in the last several years with increasing number of not only demonstration but also commercial projects being deployed.

By the end of 2020, the authors identified **114 operational power-to-gas (water electrolysis) projects**. Total power of those electrolysers was around **99 MW** equalling a hydrogen generation capacity of **~44**

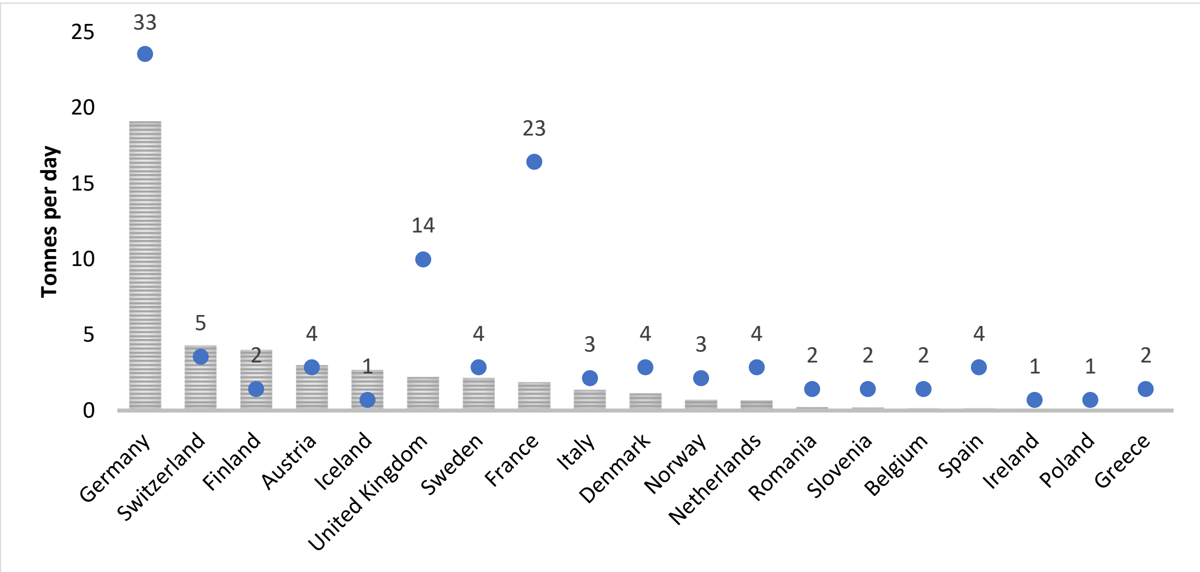
t of electrolytic hydrogen per day (0.14% of total production capacity).[22] [23] This represents an 11% increase in operational power-to-hydrogen capacity between 2019 and 2020 caused by **19 new projects adding 7 MW of capacity**. Compared to 2018, it represents a 31% increase in capacity over two years. While this report covers the year 2020, there was a significant planned deployment of **new electrolyzer capacity in 2021 of around 36 MW** with total expected PtH capacity in Europe reaching 135 MW or 60 t per day in 2021. That would represent a 36% increase compared to 2020 and 97% increase compared to 2018.

While some of the operational plants are commercial plants, others were built as part of R&D or demonstration plants destined to be decommissioned after only a few years of operations.

Most of them produce electrolytic hydrogen for on-site industrial consumption, merchant sales, mobility applications, or energy storage for renewable energy grid balancing.

Countries with the largest number of installations are Germany (33), France (22), United Kingdom (14). Countries with the largest installed water electrolytic production capacity are Germany with 19, Switzerland with 4.3, Finland with 4, and Austria with 3 t per day.

Figure 15: Hydrogen production capacity and number of installations using water electrolysis in 2020
Source: Fuel Cells and Hydrogen Observatory



[22] The production numbers from electrolysis reflect maximum technical production capacity. Actual production numbers are significantly lower due to the various operating conditions of the individual electrolysers.
[23] The 44 tons per day of water electrolysis capacity is additional to the captive, by-product, and merchant numbers provided in the sections before. All together they amount to the total displayed of 33,026 t per day if we include coke oven gas.

2. Demand for hydrogen

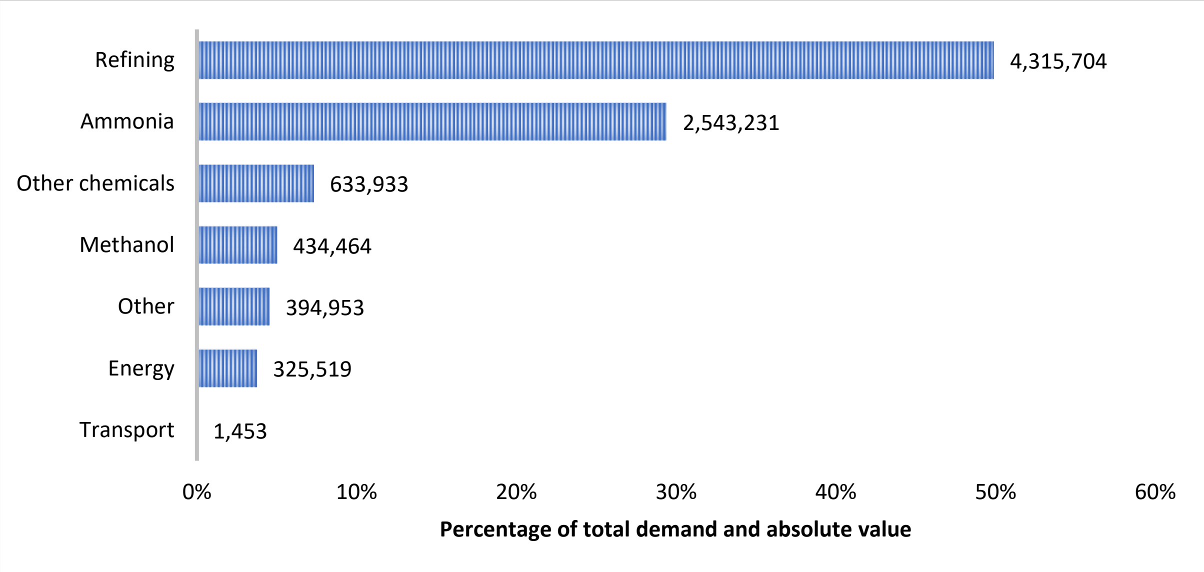
2.1. Summary

Total demand for hydrogen in the analysed countries in 2020 has been estimated at 8.6 Mt. The biggest share of hydrogen demand comes from refineries, which were responsible for 50% of total hydrogen use, followed by the ammonia industry with 29%. Together these two sectors consumed 79% of total hydrogen consumption in the EU, EFTA, and UK. About 12% is consumed by the chemical industry, with methanol production accounting for 5% of that.

Emerging hydrogen applications, like the transportation sector, comprised a very small portion of the market (0.02% in 2020).

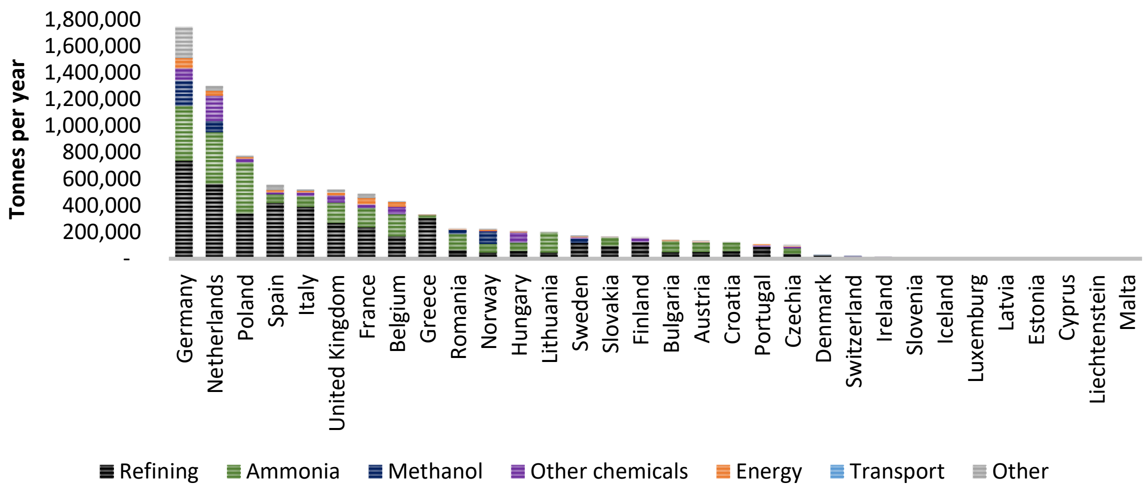
Hydrogen consumption data in this report has been collected and estimated based on available information gathered from a number of public and private sources. The external sources include EUROSTAT, a number of trade associations (Eurochlor, Fertilizers EUROPE, Fuels Europe, CONCAWE, Petrochemicals Europe, Cefic), and others.

Figure 16: Total demand for hydrogen in 2020 by application
Source: Fuel Cells and Hydrogen Observatory



More than half of total hydrogen consumption takes place in just four countries: Germany (20%), the Netherlands (15%), Poland (9%), and Spain (6%).

Figure 17: Total demand for hydrogen in 2020 by country
Source: Fuel Cells and Hydrogen Observatory



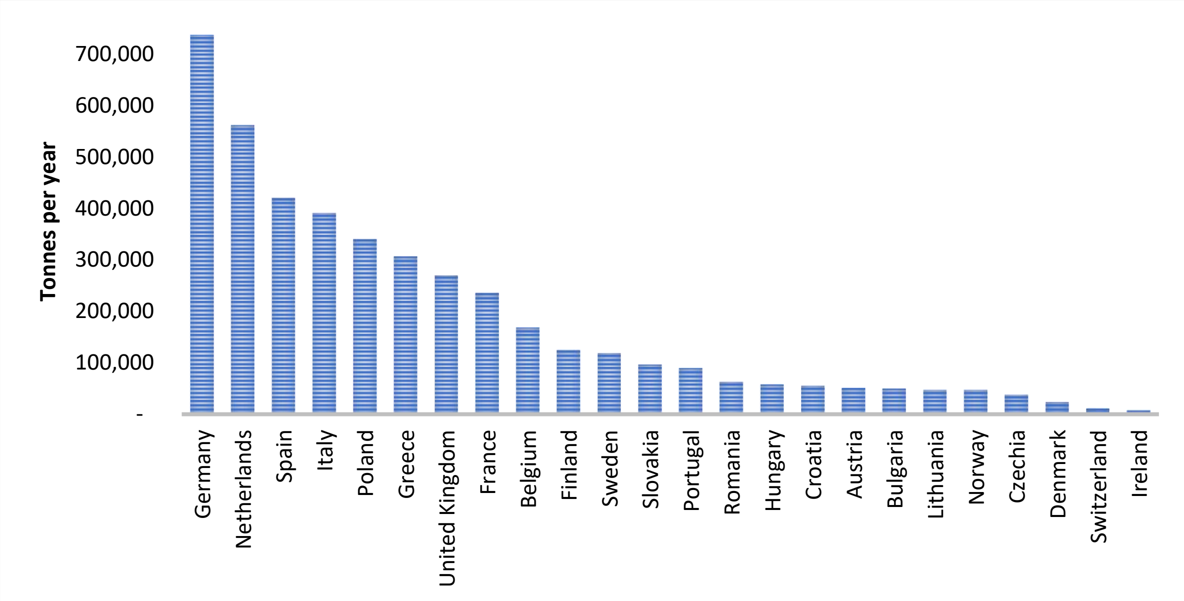
2.2. Refining industry

As mentioned in Section 1.2.1, refineries use hydrogen mostly for hydrocracking and hydrotreating processes, including hydrodesulphurisation. As legislative requirements require ever lower sulphur content in fuels, more desulphurisation is needed to achieve these targets, driving up hydrogen consumption in the sector.[24] Similarly, as demand for distillates such as jet fuel, kerosene, high-quality lubricating oils, and diesel continues to increase worldwide, so does the importance of hydrocracking. As a result, even though some refining processes generate hydrogen, most refineries are net consumers of it. Yet, because the net hydrogen balance of a refinery depends strongly on the specific processes involved and the mix of output products, it is extremely challenging to precisely estimate the actual demand for hydrogen, which cannot be calculated based on processing or production volumes alone.

Nevertheless, based on gathered information about hydrogen production capacities at refineries, together with information about their capacity utilization, this report estimates that the total hydrogen demand from oil refining was **4.3 Mt in 2020**.

[24] 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. < https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf >

Figure 18: Hydrogen demand in oil refining
Source: Fuel Cells and Hydrogen Observatory

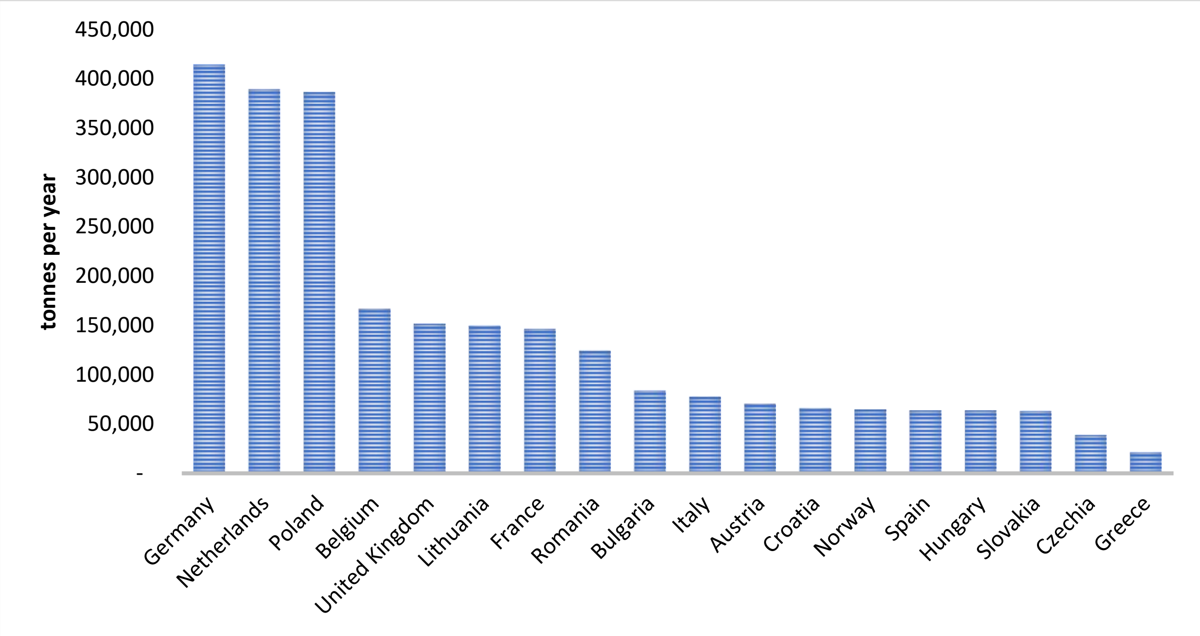


2.3. Chemical industry

In the chemical industry, the largest consumers of hydrogen are the ammonia manufacturers. Ammonia is used for the production of fertilizers and nitric oxide, which is an intermediate product for the production of nitric acid. In addition, ammonia is used for the production of sodium carbonate (soda ash), explosives, hydrogen cyanide, synthetic fabrics, and other products.

Total demand for hydrogen by the ammonia industry in 2020 was 2.5 Mt. Due to confidentiality issues, detailed statistics about ammonia production are not available for some EU Member States. In those cases, hydrogen production capacity in the ammonia industry in those countries and utilization rates were used instead.

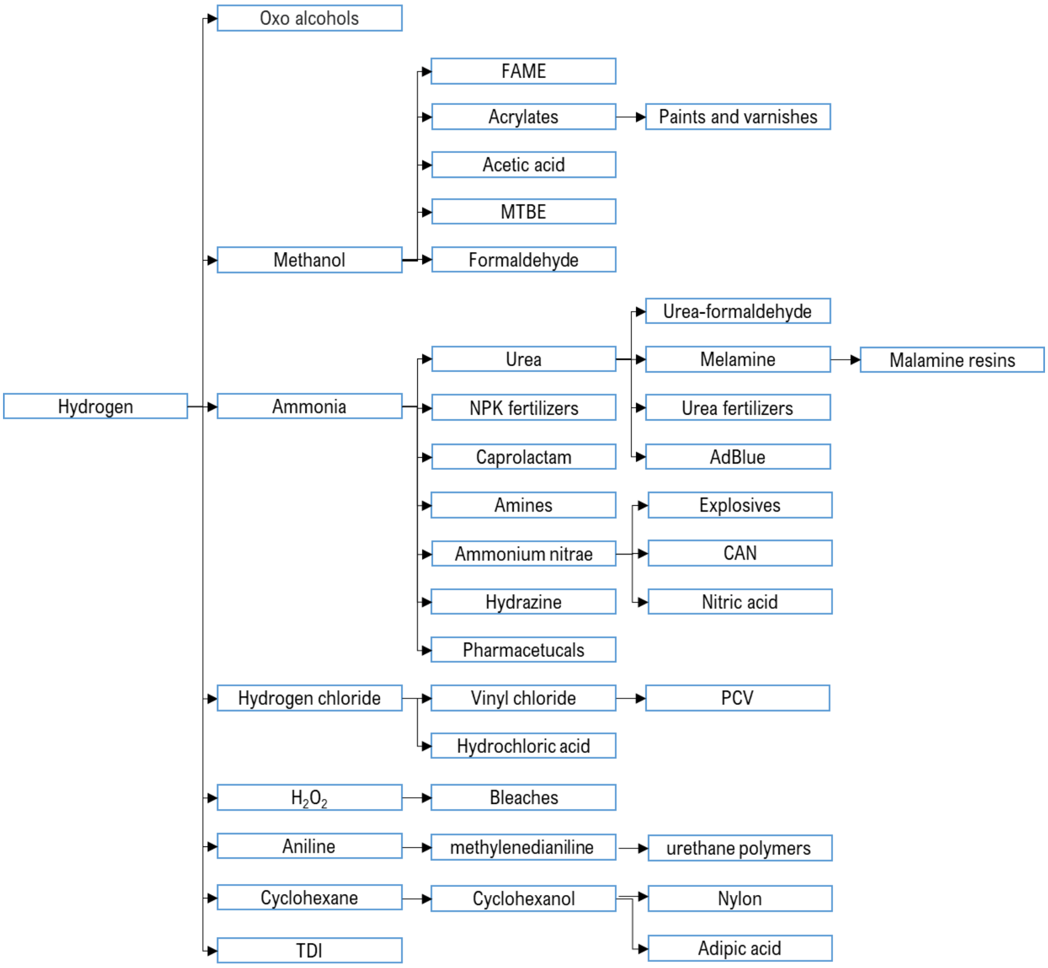
Figure 19: Hydrogen demand for ammonia
Source: Fuel Cells and Hydrogen Observatory



Even though the ammonia industry dwarfs other applications, it is by no means the only source of demand for hydrogen from the chemical industry. Other chemicals that require hydrogen input in their production process are (among others):

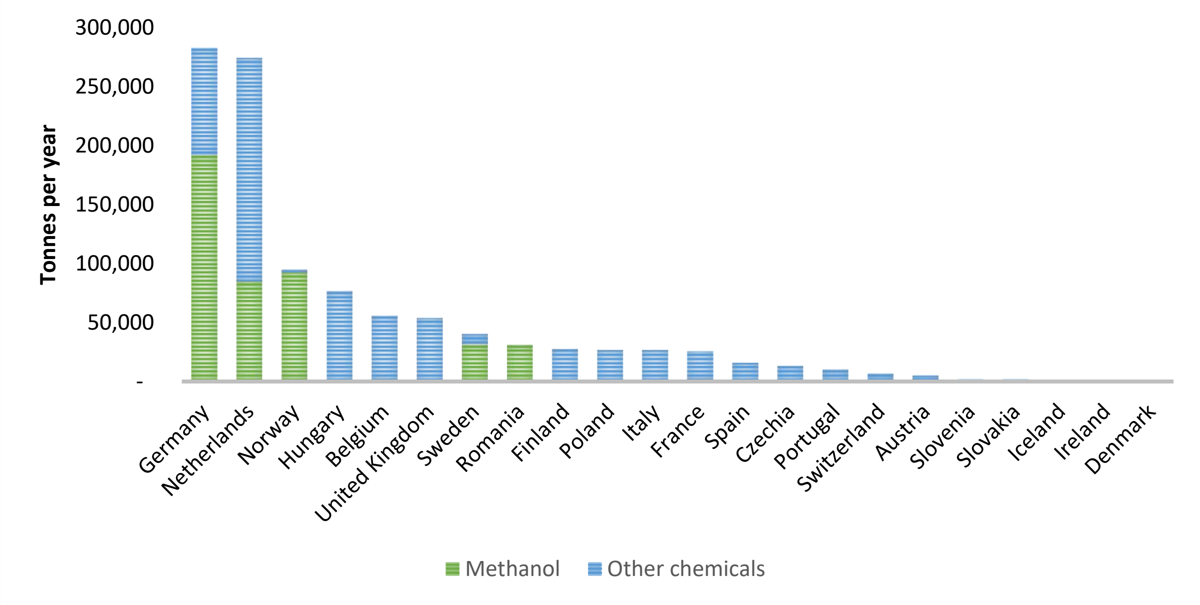
- Methanol
- Cyclohexane
- Aniline
- Caprolactam
- Hydrogen Peroxide
- Oxo Alcohols C8
- Oxo Alcohols C4
- Toluene Diiscocyanate (TDI)
- Hexamethylenediamine
- Adipic acid
- Hydrochloric acid
- Tetrahydrofuran

Figure 20: Hydrogen demand for ammonia
Source: Author's own elaboration



Total demand for hydrogen, in 2020, from the chemical industry, other than ammonia production, has been estimated at around 1.1 Mt, with more than half coming from Germany and the Netherlands.

Figure 21: Hydrogen demand for the chemical industry excluding ammonia
Source: Fuel Cells and Hydrogen Observatory



2.4. Other industries

The oil refining and chemical industries are responsible for 92% of total demand for hydrogen. The remaining demand comes from the following applications:

Steel manufacturing and metals processing

Mixture of hydrogen and nitrogen (5% to 7% hydrogen) is used commonly as an inert protective atmosphere in conventional batch annealing in annealing furnaces. Batch annealing with 100% hydrogen is also possible and results in better productivity, improved mechanical properties, surface, and product quality.

Glass manufacturing

In the glass industry, hydrogen is an inerting or protective gas in flat glass production. It is also used in the flame polishing process of glass products.

Food processing

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

Energy sector

While hydrogen can be used in a fuel cell to generate heat and energy with high efficiency, currently hydrogen use in the energy sector mostly consists of:

- Burning hydrogen in boilers or CHP units for heat or heat and power generation – mostly done onsite where hydrogen is generated as a by-product of other processes (chlor-alkali, ethylene).

- Using hydrogen for generator cooling. The amount of hydrogen demand depends on the installed power of turbines, their age and technical condition – especially the condition of the generator's hydrogen seals. Depending on those factors, and resulting hydrogen demand, some power plants have their own HGU's and only use external suppliers to cover additional needs, while other supply all of the required hydrogen from external sources.

Transportation

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

3. Conclusion

The purpose of this report is to provide an overview of the hydrogen market in Europe and to track industry's progress in deploying clean hydrogen technologies.

The power-to-hydrogen capacity in EU, EFTA, UK continued to grow with 11% added in **2020 reaching 99 MW** or 44 t per day. Numerous projects have been announced in 2019 and 2020. While this report covers the year 2020, there was a significant planned deployment of **new electrolyzer capacity in 2021 of around 36 MW** with total expected PtH capacity in Europe reaching 135 MW or 60 t per day in 2021. That would represent a 36% increase compared to 2020 and 97% increase compared to 2018.

Only **three operational hydrogen production plants with carbon capture** continue to operate in Europe.

The traditional hydrogen **supply capacity market is stable** so **changes** compared to previous years primarily **reflect methodological changes as well as continuously improving accuracy of the supply capacity data** rather than market trends. The methodological changes compared to the September 2021 report were described in the relevant parts of the report, but the main ones include classifying by-product hydrogen production capacity in refineries as captive and reducing the potential of hydrogen production capacity from coke production.

In terms of **demand**, hydrogen consumption in refining was revised and increased by 6% compared to last year. The increase reflects additional data becoming available in the refining sector and a trend of increasing hydrogen consumption in refining. Hydrogen demand for ammonia remained largely stable and its 1.4% decrease was caused mostly by lower utilizations during the COVID pandemic. Hydrogen consumption for methanol production increased by 4% mostly driven by changing capacity factors. The last significant change on the demand side concerns burning of hydrogen for energy where the value increased from 103 to 325 thousand tons per day due to a methodological change concerning by-product hydrogen from ethylene production and its burning on site.

4. Appendix 1: List of Acronyms

ATR	*Autothermal reforming*
CCS	*Carbon capture and storage*
CCU	*Carbon capture and utilisation*
CHP	*Combined heat and power*
COG	*Coke oven gas*
EEA	*European Economic Area*
EFTA	*European Free Trade Association*
EU	*European Union*
FAME	*Fatty acid methyl esters*
FCEV	*Fuel cell electric vehicle*
HGU	*Hydrogen Generation Unit*
HyARC	*Hydrogen Analysis Resource Centre*
JRC	*Joint Research Centre*
LPG	*Liquefied petroleum gas*
Mt	*Million tonnes*
MTBE	*Methyl tert-butyl ether*
POX	*Partial oxidation*
PSA	*Pressure swing adsorption*
SMR	*Steam methane reforming*
TDI	*Toluene diisocyanate*

5. Appendix 2: References

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The Pacific Northwest National Laboratory, «the Hydrogen Tools Portal, < https://h2tools.org/hyarc/hydrogen-data/merchant-hydrogen-plant-capacities-europe >