Chapter 2
Hydrogen molecule market
September 2020

FUEL CELLS AND HYDROGEN OBSERVATORY

This report is based on data gathered as part of the Fuel Cells and Hydrogen Observatory as at 31 December 2019. 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.

This report was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking as part of the Fuel Cells and Hydrogen Observatory. Copies of this document can be downloaded from https://www.fchobservatory.eu/

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Executive Summary

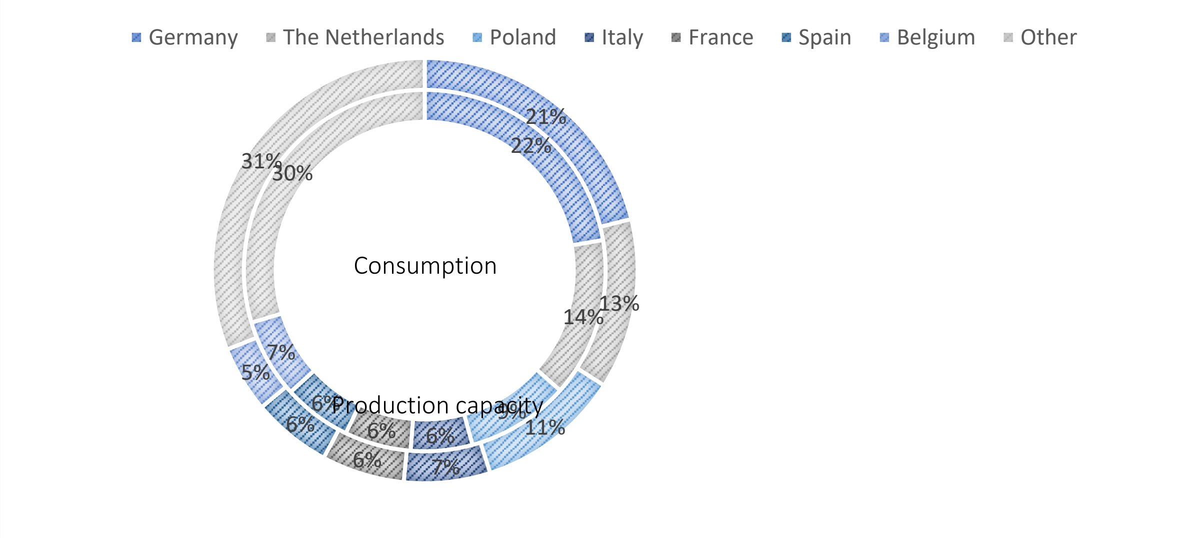
Purpose:	*The purpose of the hydrogen molecule market analysis is to track changes in the structure of hydrogen supply and demand in Europe. This report is mainly focused on presenting the current landscape - that will allow for future year-on-year comparisons, in order to assess the progress Europe is making with regards to deployment of clean hydrogen production capacities as well as development of demand for clean hydrogen from emerging new hydrogen applications in the mobility sector or in industry.*
Scope:	*The following report summarizes the hydrogen molecule market landscape and contains data about* ***hydrogen production and consumption in the EEA countries*** *(EU countries, together with Switzerland, Norway, Iceland and Liechtenstein). Hydrogen production capacity is presented by country and by 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 available at the end of 2019.*
Key Findings:	*Hydrogen market (on both the demand and supply side) is dominated by ammonia and refining industries with three countries (DE, NL, PL) responsible for almost half hydrogen consumption. Today hydrogen is overwhelmingly produced by reforming of fossil fuels (mostly natural gas). Clean hydrogen production capacities are insignificant with blue hydrogen capacities at below 1% and green hydrogen production capacity below 0.1% of total.*

Total hydrogen production capacity in the EEA countries at the end of 2018 has been estimated at ***9.9 Mt per year*** *(excluding by-product hydrogen in the coke oven gas). The corresponding consumption of hydrogen has been estimated at* ***8.3 Mt (327 TWh$_{HHV}$)****, which means an average capacity utilization of 84%.*

The biggest share of hydrogen demand comes from the refineries, which were responsible for 45% of total hydrogen use, followed by the ammonia industry with 34%. Together these two sectors consumed almost 4/5 of total hydrogen consumption in the EEA. About 12% is consumed by the chemical industry, with almost half of that used for methanol production. On-site captive hydrogen production is by far the most common method of hydrogen supply, comprising around two thirds of all hydrogen production. ***Emerging hydrogen applications, like the transportation sector, comprise a miniscule portion of the market (<0.1% in 2018).***

Germany is, by a significant margin, the largest European market for hydrogen, with 21% of total European hydrogen production capacity and 22% of total demand. Together with the Netherlands and Poland, those three countries are responsible for almost half of the hydrogen market.

Figure 1. Total hydrogen production capacity and consumption by country in 2018
Source: own elaboration.



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

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

- *Air Liquide Cryocap installation in Port Jerome, France, capturing CO_2 from hydrogen supplied to Exxon refinery, with a capacity of around 50,000 Nm^3/h.*
- *Shell refinery in Rotterdam, where CO_2 from hydrogen production is captured as part of the OCAP project, operated by Linde.*

Total share of hydrogen production from fossil fuels with CCS/CCU (blue hydrogen) in all hydrogen production capacity (excluding by-product) is around 0.7%.

*At the end of 2018, we have identified around 70 ongoing power-to-gas projects using renewable energy for hydrogen production. Total power of those electrolysers was around **58 MW**, which means a capacity to generate **1.1 t of green H_2 per hour (<0.1% of total production capacity)**.*

1. Hydrogen production capacity

1.1. Summary

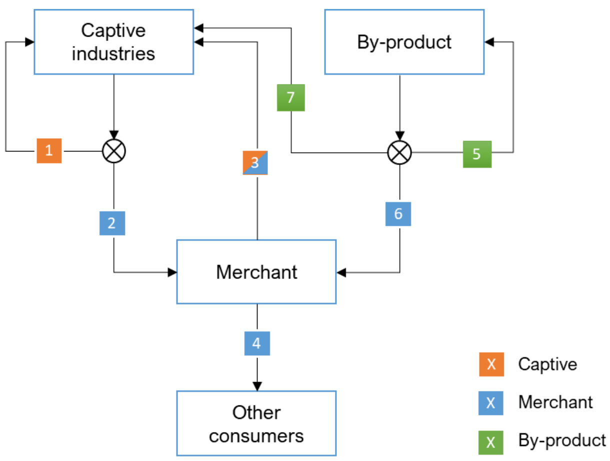
Hydrogen production capacity analysis has been undertaken, building on similar work completed previously as part of the Roads2HyCom project and ongoing work by the Hydrogen Analysis Resource Centre (HyARC). It includes a total of **454 hydrogen production sites***, which have been categorised by:*

- *type of production (captive, merchant, by-product),*
- *technology,*
- *application (only for captive H_2 production capacity),*
- *country.*

The hydrogen production plants have been divided into three main categories: captive production facilities[1], merchant production facilities[2] and plants where production of hydrogen is a by-product of other processes. It should be noted though, that it 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 its 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 we have defined the boundaries between the three hydrogen production types as follows:

Figure 2. Definition of hydrogen production types by availability



[1] On-site production of Hydrogen for own consumption.
[2] Hydrogen production dedicated for sales.

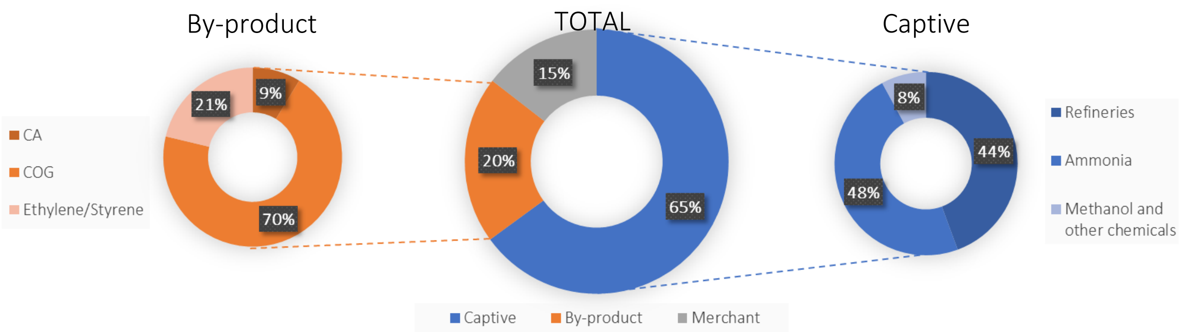
Where:

1. *Captive hydrogen production on-site used exclusively for own consumption within the same facility.*
2. *Excess hydrogen production capacity in dedicated installations, that can be valorised and sold to external hydrogen merchant companies for resale. This has been applied only to installations, 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 we could identify that the installation was serving a single customer those installations were categorised as captive. In other cases, it was categorised as merchant.*
4. *Hydrogen produced for retail purposes and sold in relatively small volumes, 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 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.*

Total hydrogen production capacity in the covered European countries at the end of 2018 has been estimated at ***11.5 Mt per year (31,573 MTD)****. Excluding the coke oven gas hydrogen from this, the remaining hydrogen generation capacity is around* ***9.9 Mt per year****.*

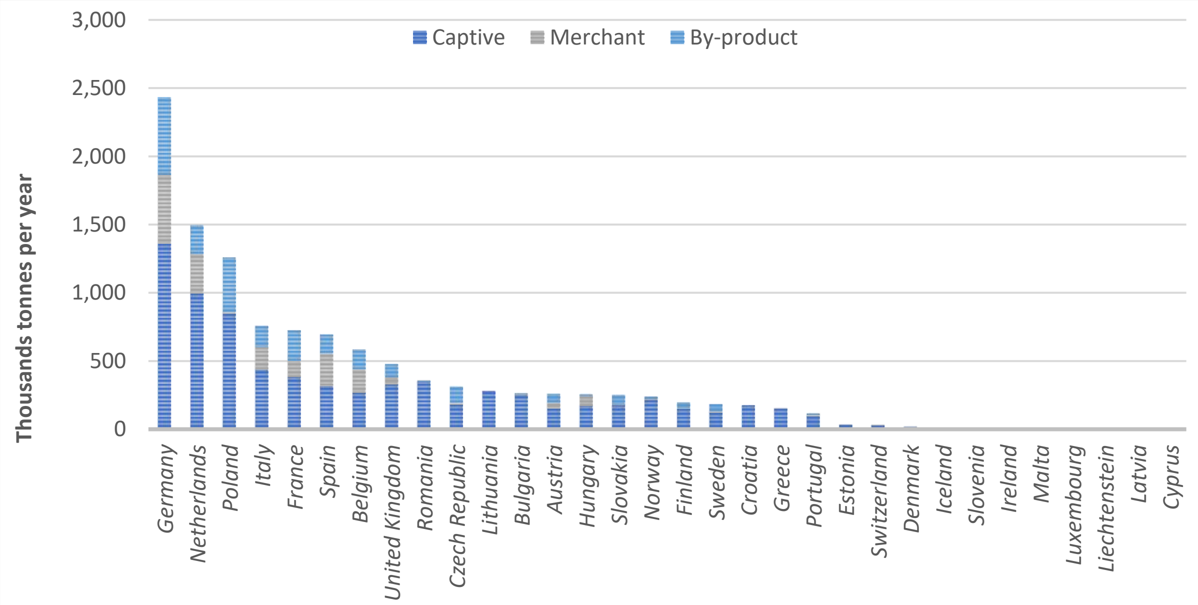
Almost two thirds of all hydrogen production capacity were designated for captive production. In reality it is even more than that, as a large portion of the merchant plants are dedicated entirely to supplying large industrial customers on-site, with only a small proportion of production capacity available to supply the wider market. Around one fifth of total hydrogen production capacity is made up by by-product hydrogen, of which 70% is coke oven gas hydrogen.

Figure 3. Structure of hydrogen production capacity
Source: own elaboration.



With almost 2.5 Mt of hydrogen per year (21% of total), Germany has by far the largest hydrogen production capacity of all the analysed countries, leading the next country - the Netherlands, with 1.5 Mt - by almost 1 million tonnes. Other countries with significant hydrogen production capacity are Poland (1.3 Mt, 11%), Italy (0.8 Mt, 7%), France and Spain (0.7 Mt, 6%), and Belgium (0.6 Mt, 5%).

Figure 4. Total hydrogen production capacity by country
Source: own elaboration.



1.2. Captive production

On-site captive hydrogen production is by far the most common method of hydrogen supply for large hydrogen consumers. This is mainly the case for refineries, ammonia plants, 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).

1.2.1. Refining

The oil refining sector is the biggest hydrogen 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 a number of processes such as hydrogenation, hydrodesulphurization, hydrodenitrification and hydrodemetalization. Hydrocracking involves the transformation of long and unsaturated products into products with a lower molecular weight than the feed.

Hydrocracking is by far the most common hydrogen consuming process, needing around 300 Nm^3 H_2/t of product. Hydrotreating processes usually require only around 20-50 Nm^3 H_2/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 Nm^3 H_2/t crude oil [1].

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

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

- *reforming operations for hydrotreating,*
- *steam reforming or autothermal reforming of light ends or natural gas,*
- *partial oxidation (gasification) of heavy oil fractions.*

Refineries with the simplest configuration may produce sufficient quantities of 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 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) [2].

*Our estimation of total production capacity of HGU's installed at refineries (excluding merchant plants, even if dedicated to supply H_2 to refineries) is approximately **380 t H_2 per hour (9,100 metric tonnes per day)**.*

Germany has the largest share with 19% of total EEA hydrogen production capacity in refineries, followed by the Netherlands (12%), Italy (10%), Spain (9.5%) and Poland (8%).

Figure 5. Identified HGU's installed at refineries.
Source: CONCAWE, Fuels Europe, OGJ Worldwide Refining Study.

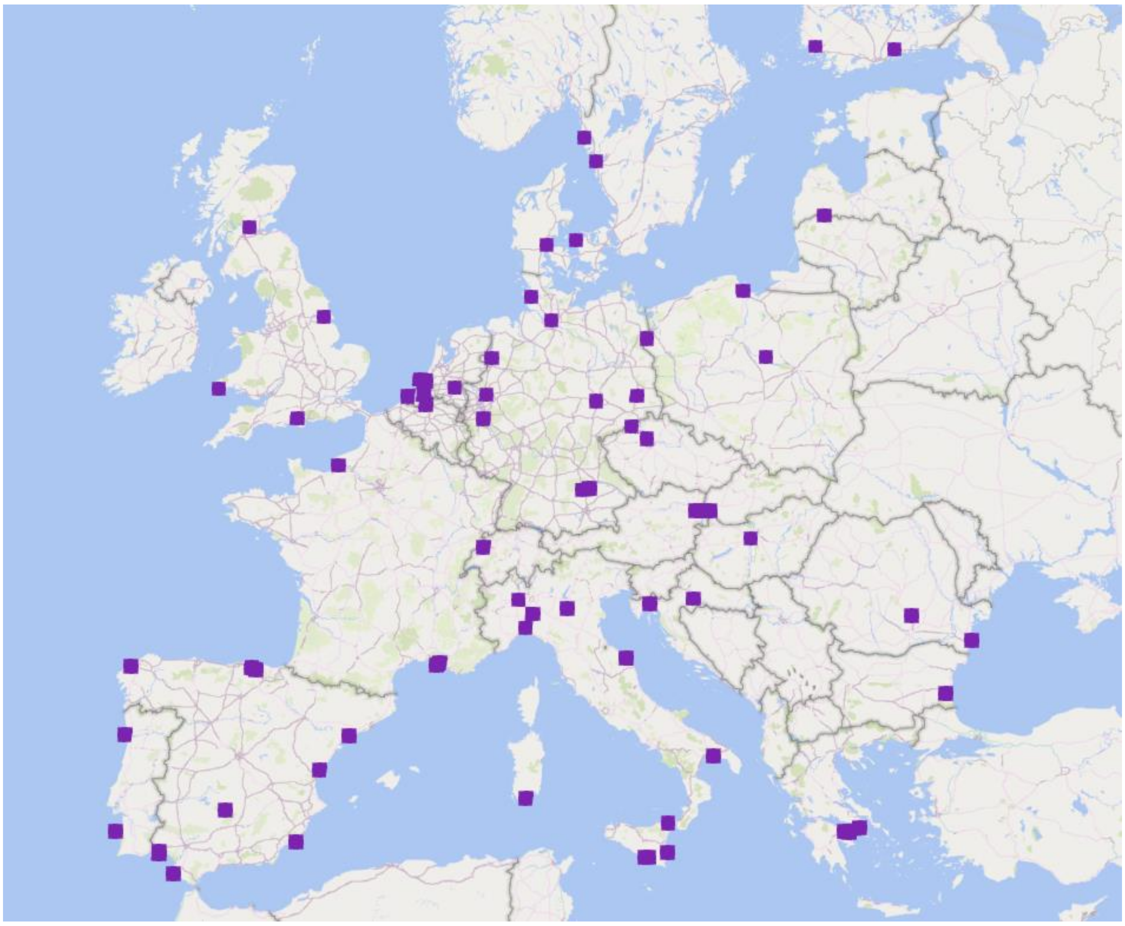
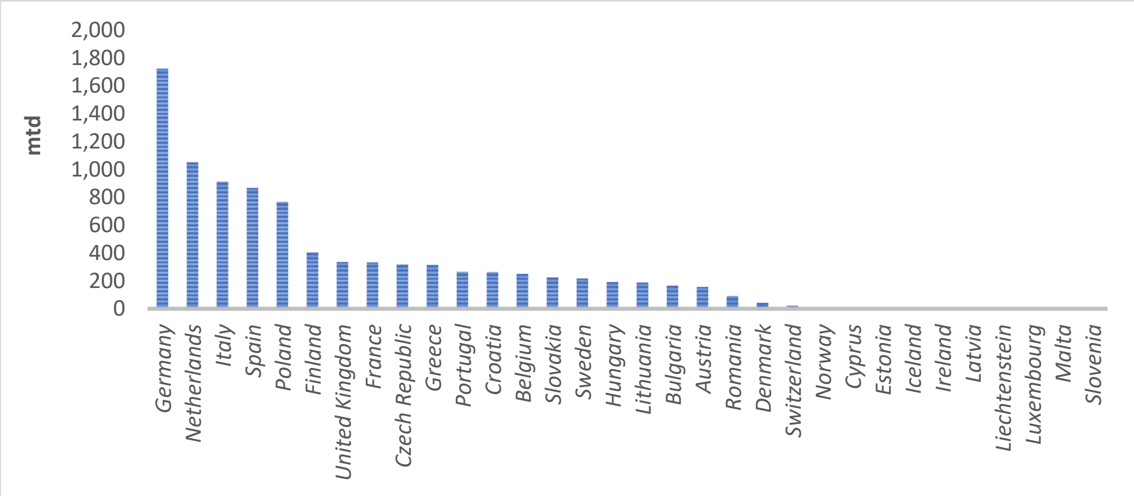


Figure 6. Total hydrogen production capacity of refineries HGU's by country (in metric tonnes per day)
Source: CONCAWE, Fuels Europe, OGJ Worldwide Refining Study.



1.2.2. Ammonia

Next to refineries, the ammonia industry is the second largest hydrogen consuming sector in the EU. 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.

Total ammonia production capacity in the analysed countries is about 20.7 Mt per year. Based on this we estimate that a total ammonia-related hydrogen production capacity in Europe is approximately ***3.7 Mt per year*** *with around 3.6 Mt run directly as part of the ammonia plant, and 0.1 Mt in external merchant plants.*

Again, Germany has the largest share with 15% of all Europe's hydrogen production capacity dedicated to ammonia production, closely followed by Poland (15%) and the Netherlands (14%), Romania (8%), France (7%) and the United Kingdom (6%).

Out of the 43 identified hydrogen production facilities dedicated to supply ammonia plants 41 where captive installations with the remaining 2 merchant plants operated by Linde and Air Liquide. All of them were using either steam methane reforming or partial oxidation (POX) to generate hydrogen.

Figure 7. Identified HGU dedicated to supply ammonia plants
Source: Fertilizers Europe.

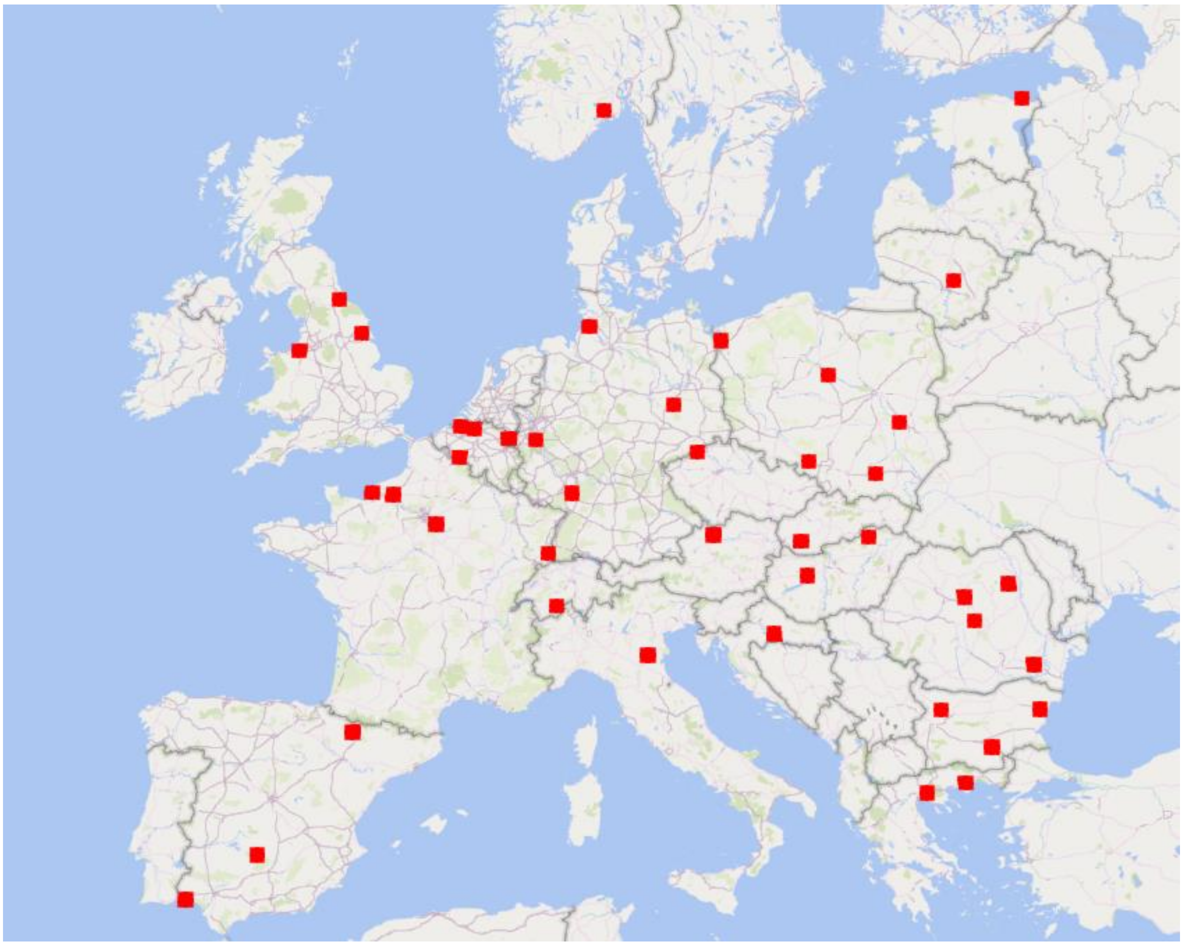
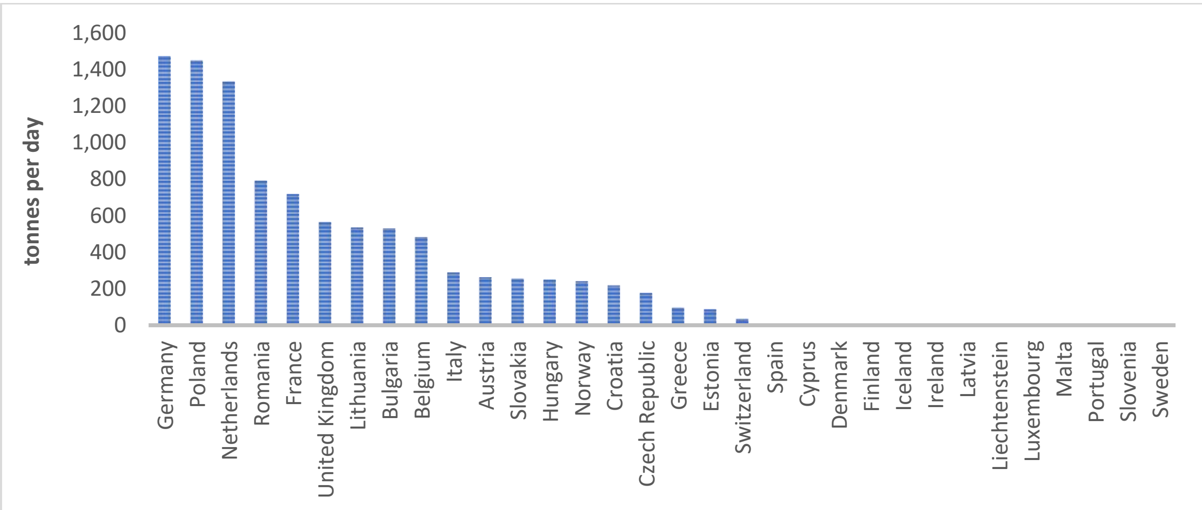


Figure 8. Hydrogen production capacity of plants dedicated to supply ammonia plants.
Source: Fertilizers Europe.



1.2.3. Other captive hydrogen production plants

Together the captive hydrogen production sites located in refineries or ammonia plants comprise around 92% 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.

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

1st step: $CH_4 + H_2O \rightarrow CO + 3\ H_2$ *and* $CO + H_2O \rightarrow CO_2 + H_2$

2nd step: $3\ H_2 + CO_2 \rightarrow CH_3OH + H_2O$

This production consumes about 1400 m^3 H_2*/t of methanol [1]. Methanol is an important chemical raw material used for the production of formaldehyde, acetic acid and MTBE or fatty acid methyl esters (FAME), adhesives and solvents.*

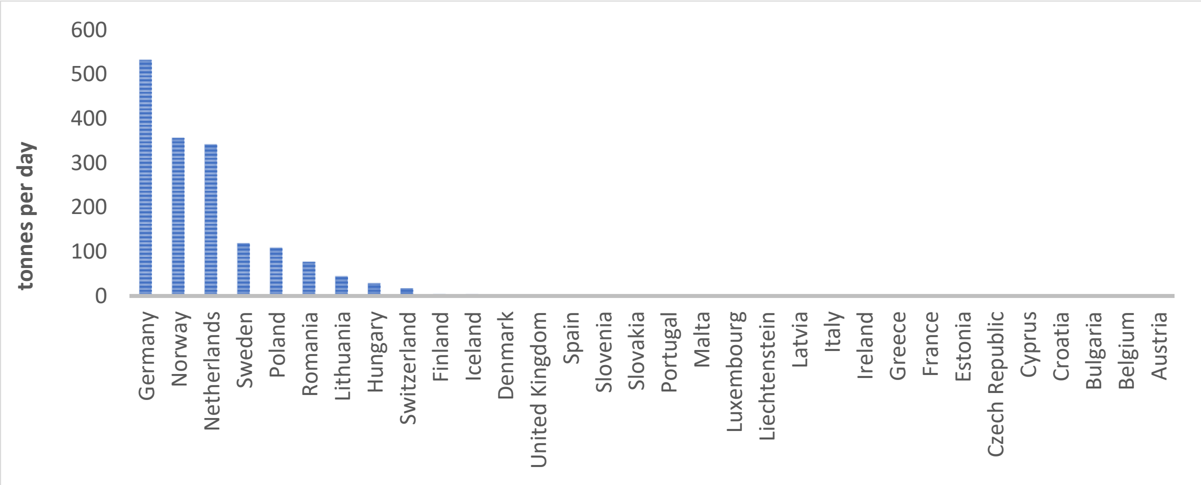
Other uses of hydrogen in the chemical industry include the production of such high-volume chemical products as hydrogen peroxide, for which hydrogen consumption is approx. 735 m^3 H_2*/t [1], hydrogen chloride, aniline, cyclohexane, TDI and oxo-alcohols. In most of cases, production of those chemicals takes place at large integrated chemical or petrochemical plants.*

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

One notable exception is the 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 H_2 *from water electrolysis, which is then reacted with* CO_2 *from flue gases to produce methanol [3].*

Figure 9. Identified HGU dedicated to supply hydrogen to methanol industry or other chemical plants, excluding ammonia
Source: own research.

Figure 10. Captive hydrogen production capacity for methanol industry or other chemical plants, excluding ammonia. Source: own research.



1.3. Merchant hydrogen production

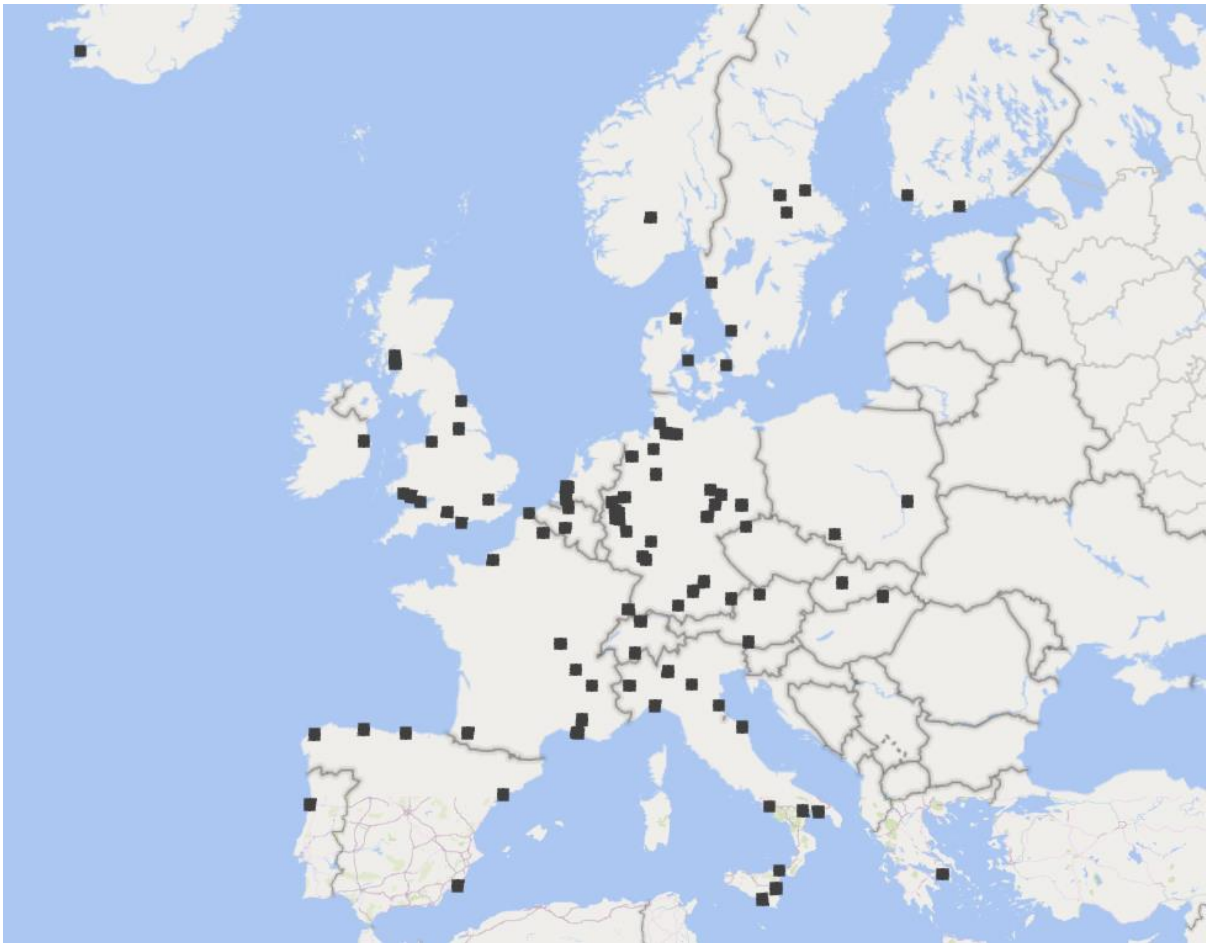
The merchant hydrogen plants can be divided into two main categories:

- *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.

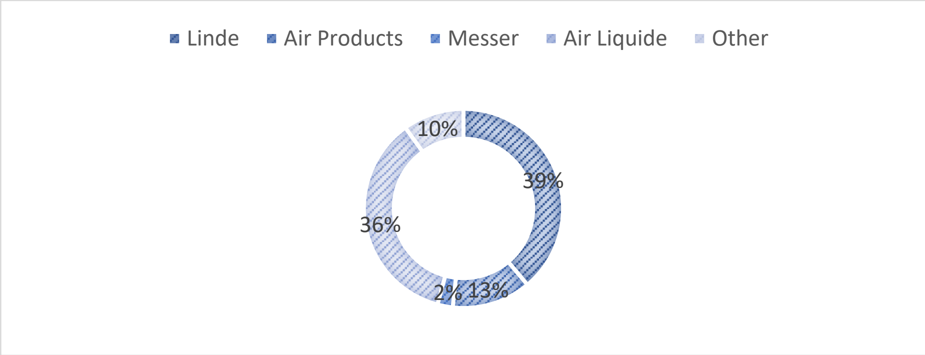
*We estimate that there were around 113 merchant hydrogen plants operational in Europe in 2018. **Total capacity of those plants has been estimated at 4,246 t/day (around 1.5 Mt per year)**.*

Figure 11. Identified merchant hydrogen plants
Source: [1] updated based on HyARC database and own research.



The merchant hydrogen market in Europe is dominated by 4 groups: Linde Gas, Air Liquide, Air Products and Messer, who own a combined 87% of total merchant hydrogen production capacity.

Figure 12. Structure of ownership of European merchant hydrogen production plants by capacity
Source: own research.



As was the case with captive hydrogen production, most merchant hydrogen production capacity is located in Germany (29%), the Netherlands (21%), Belgium (11%) and Italy (11%), Spain (8%) and France (8%).

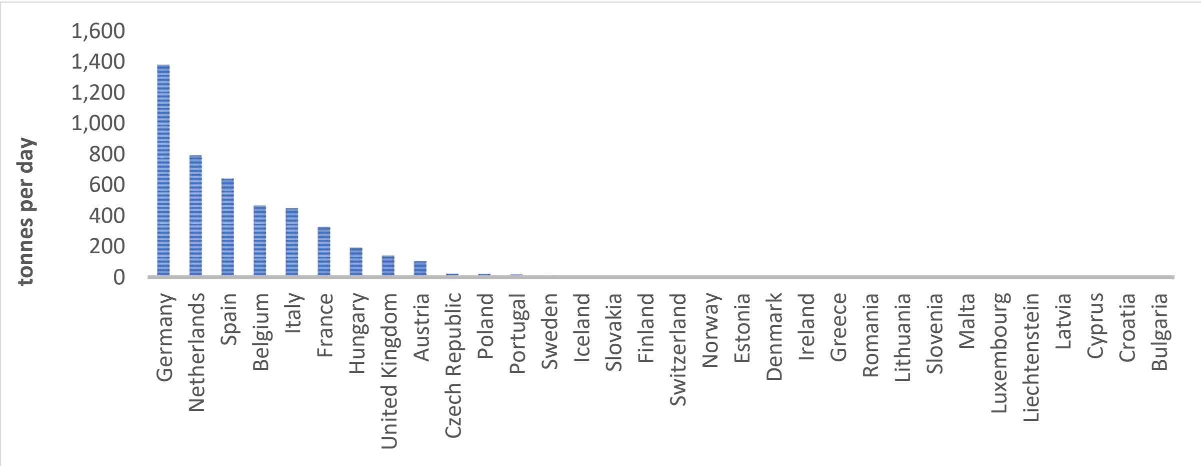


Figure 13. Merchant hydrogen production capacity.
Source: own research.

From a technology perspective, while most production capacity is still fossil fuel based, a portion of the merchant hydrogen (below 10%) also comes from by-product production from the chlor-alkali industry and coke oven gas.

1.4. By-product hydrogen production

By-product hydrogen production capacity, by which we mean hydrogen produced as a by-product of other processes, has been estimated at **2.36 Mt per year**, including:

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

The hydrogen production rate for ethylene and styrene production processes is around 190 Nm^3 H_2/t ethylene and 220 Nm^3 H_2/t of styrene [1]. By-product hydrogen from those industries is almost universally used on site as a feedstock to other chemical or petrochemical processes further downstream.

The by-product production rate from the chlor-alkali industry is around 300 to 270 Nm^3 H_2/t chlorine [1]. 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 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. In the case of the chlor-alkali plant in Cologne, Germany, some by-product hydrogen is also used as a fuel for FCEV buses.

The biggest potential source of by-product hydrogen is coke oven gas (COG), where hydrogen production rate is about 450 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 and at the reheating furnaces of the hot strip mills and other high temperature processes or for the under firing of coke ovens. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and also is used in power plants [4].

Other, smaller by-product hydrogen sources include:

- *Acetylene production: 3,400 – 3,740 Nm^3 H_2/t product*
- *Cyanide production: 2,470 m3 H_2/t of product (Degussa´s BMA process) [1].*

Figure 14. Identified by-product hydrogen production plants
Source: based on information from Petrochemicals Europe, Eurochlor and own research.

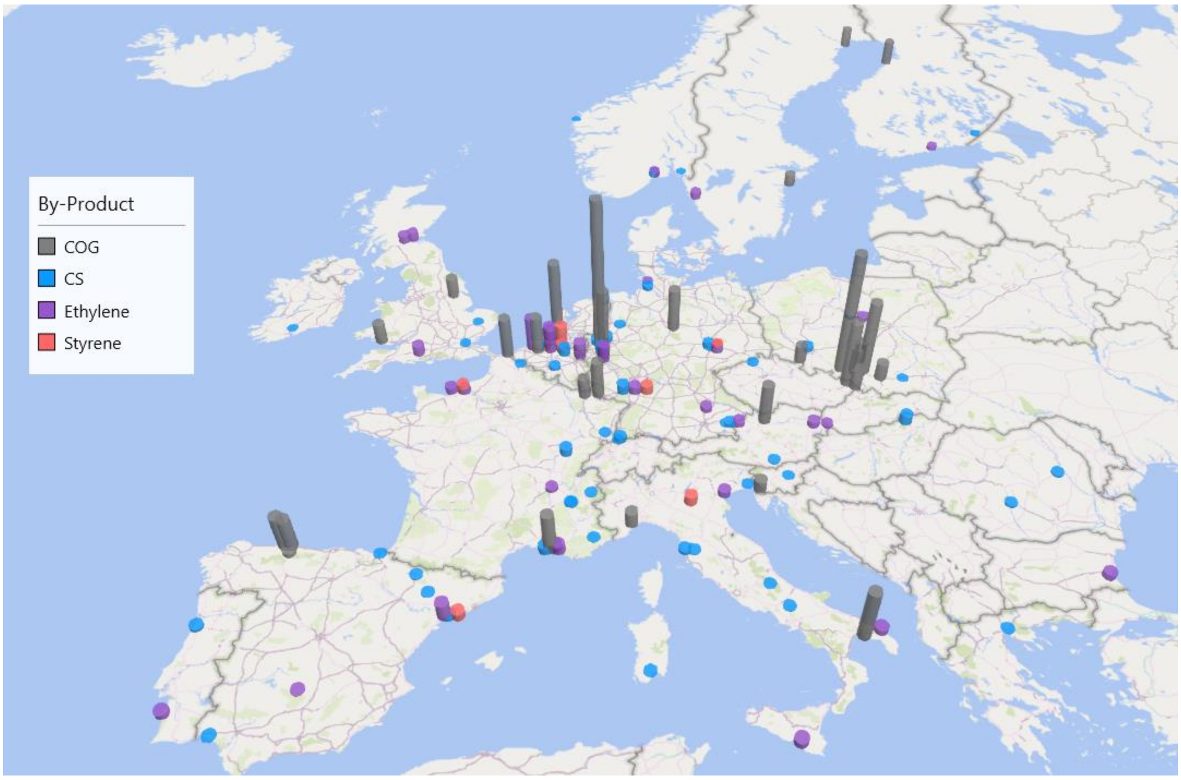
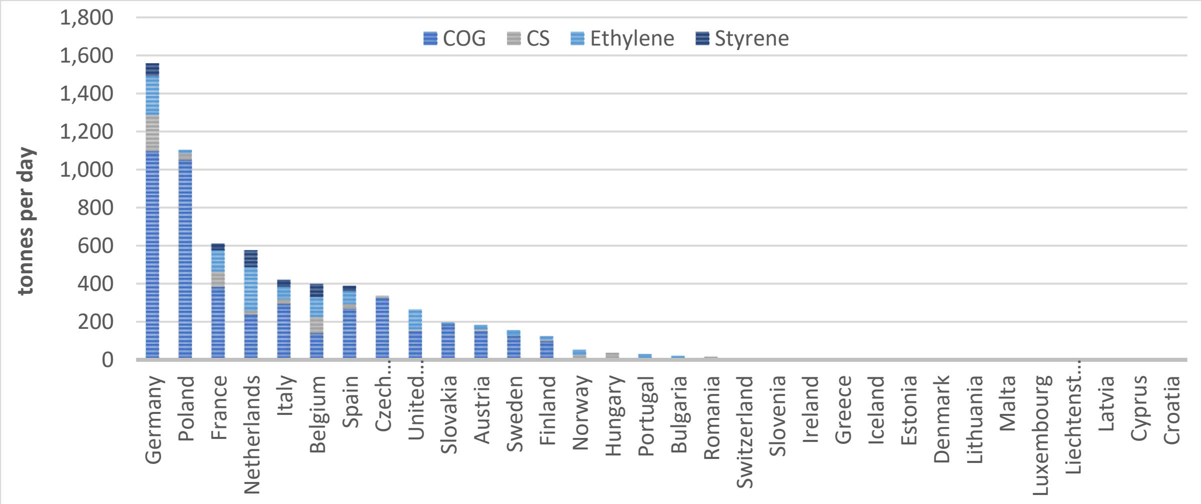


Figure 15. Merchant hydrogen production capacity.
Source: estimation based on data from based on information from Petrochemicals Europe, Eurochlor and own research.



1.5. Clean hydrogen production capacity

Total hydrogen production capacity in the covered European countries at the end of 2018 has been estimated at ***11.5 Mt per year (31,573 MTD)****. Excluding the coke oven gas hydrogen from this, the remaining hydrogen generation capacity is around* ***9.9 Mt per year****.*

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

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

- *Air Liquide Cryocap installation in Port Jerome, France, capturing CO_2 from hydrogen supplied to Exxon refinery, with a capacity of around 50,000 Nm^3/h.*
- *Shell refinery in Rotterdam, where CO_2 from hydrogen production is captured as part of the OCAP project, operated by Linde.*

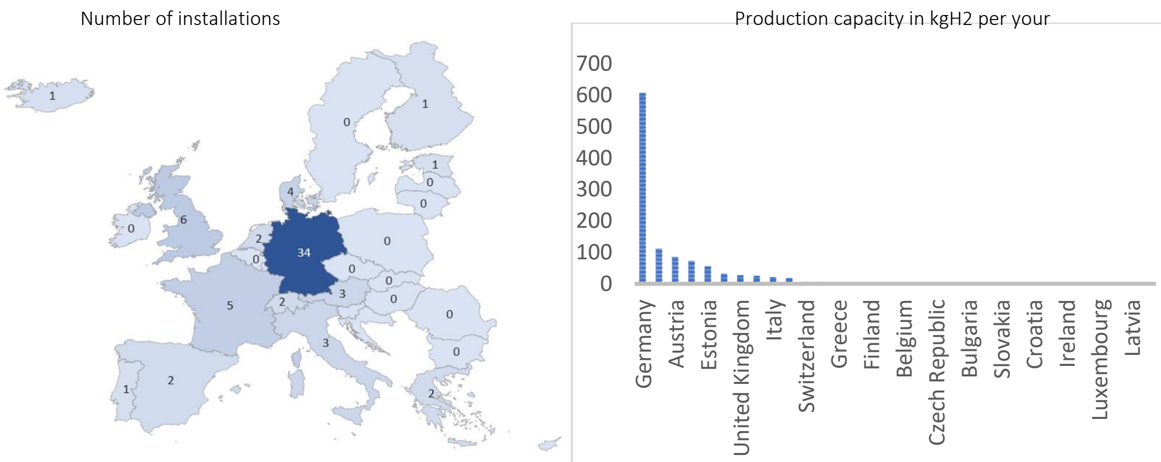
Total share of hydrogen production from fossil fuels with CCS/CCU (blue hydrogen) in all hydrogen production capacity (excluding by-product) is around 0.7%.

Hydrogen can, of course, be also produced with electricity by splitting water via water electrolysis. There is a significant number of electrolysers installed in Europe. Usually electrolysers have been employed whenever the volume of hydrogen demand is 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. According to the JRC [5] the total installed *capacity of electrolysers in Europe is around 1 GW, which would amount to around 1.4% of total hydrogen production capacity. But since those electrolysers are quite numerous and relatively small scale (rarely exceeding the tens or hundreds of kW range), they are extremely hard to track and have been excluded from detailed analysis.*

On the other hand, besides the established hydrogen use cases, mentioned above, there is an increased activity in development of power-to-gas (hydrogen) projects, where low carbon or renewable electricity is used to produced clean hydrogen via water electrolysis. Clean hydrogen is then used as an energy carrier itself or synthesised further to produce synthetic methane or liquid fuels.

*Those installations were mostly built as part of R&D or demonstration plants, not planned for long-term commercial operations and were usually decommissioned after 2-3 years of operation. Nevertheless, as of 2018/2019, we estimate that there were around 70 ongoing power-to-gas projects, producing renewable hydrogen mostly for mobility applications or energy storage for renewable energy grid balancing. Almost half of those projects are running in Germany. Total power of those electrolysers was around **58 MW**, which means a capacity to generate clean hydrogen of **1.1 t of clean H_2 per hour (<0.1% of total production capacity)**.*

Figure 16. Number and hydrogen production capacity of power-to-gas projects in 2018
Source: own elaboration.



2. Demand for Hydrogen

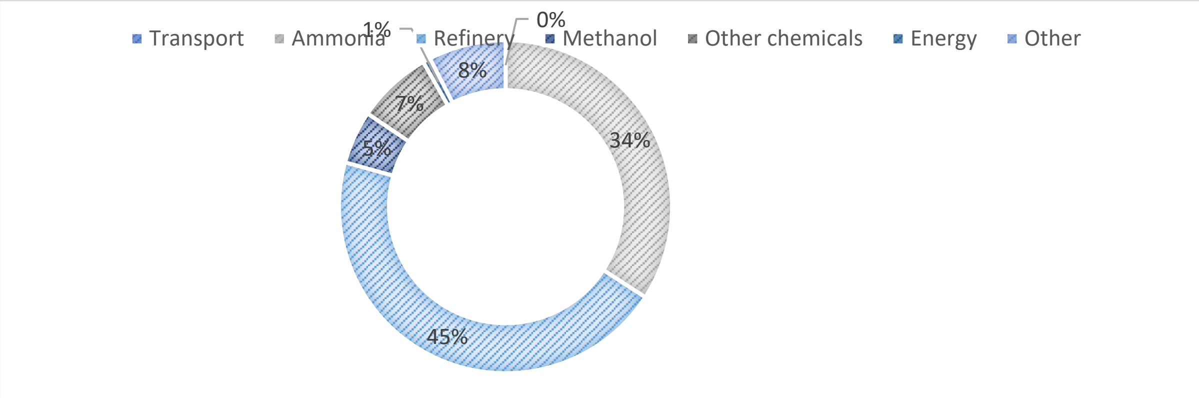
2.1. Summary

Hydrogen consumption data has been estimated mostly based on available statistical information, gathered and merged from a number of sources, including EUROSTAT as primary data source, supplemented by information published or received from a number of trade associations (Eurochlor, Fertilizers EUROPE, Fuels Europe, CONCAWE, Petrochemicals Europe, Cefic).

*Total demand for hydrogen in the analysed countries in 2018 has been estimated at **8.3 Mt (327 TWh_{HHV})**. The biggest share of hydrogen demand comes from the refineries, which were responsible for 45% of total hydrogen use, followed by the ammonia industry with 34%. Together these two sectors consumed almost 4/5 of total hydrogen consumption in the EEA. About 12% is consumed by the chemical industry, with almost half of that used for methanol production.*

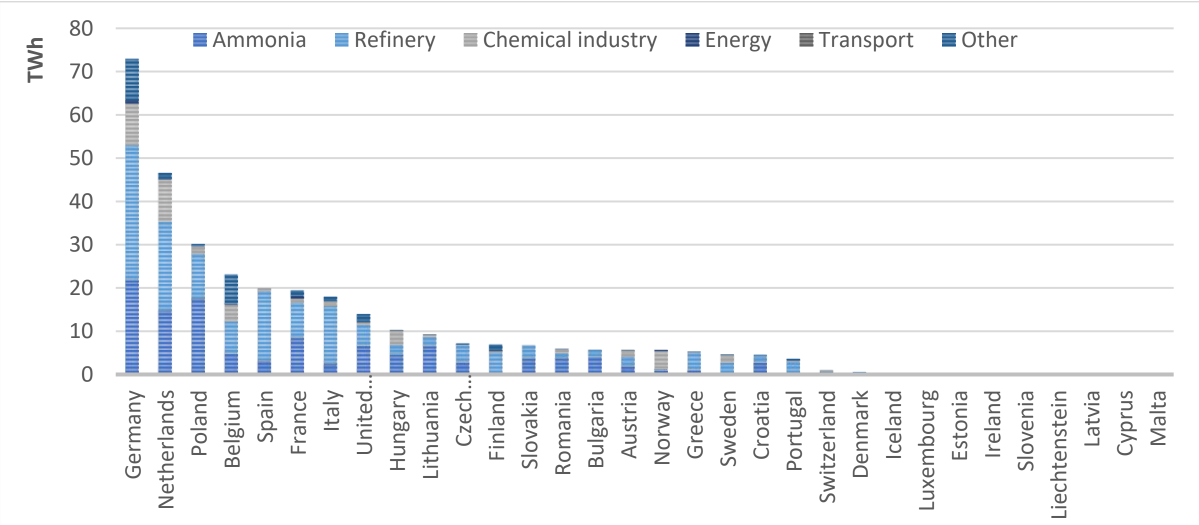
Emerging hydrogen applications, like the transportation sector, comprise a miniscule portion of the market (<0.1% in 2018).

Figure 17. Total demand for hydrogen in 2018 by application
Source: own elaboration.



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

Figure 18. Total demand for hydrogen in 2018 by country
Source: own elaboration.

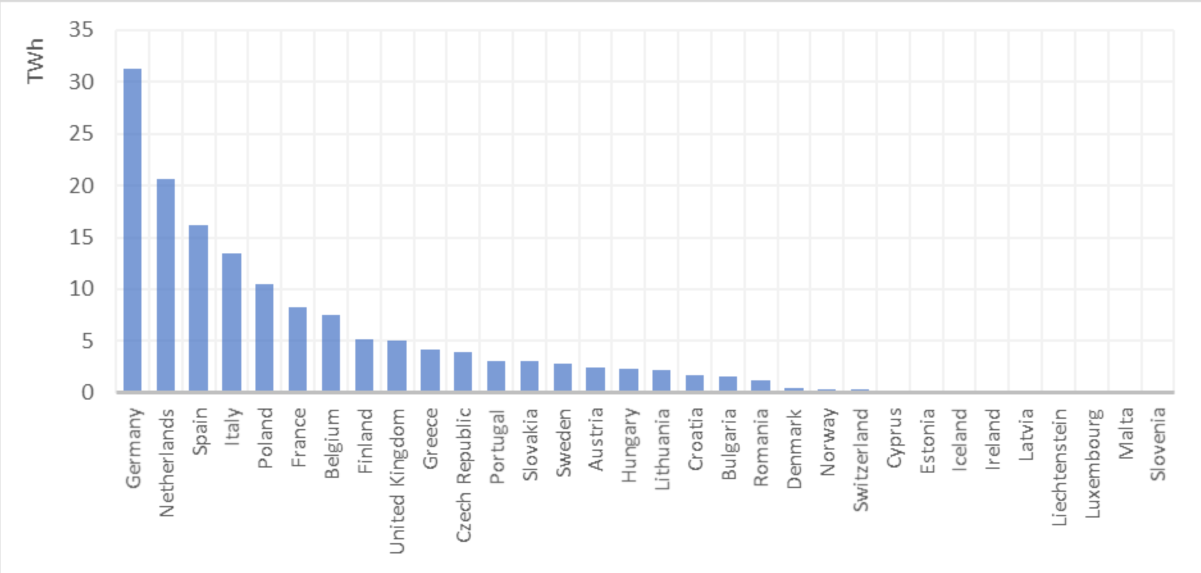


2.2. Refining industry

As mentioned, refineries use hydrogen mostly for hydrocracking and hydrotreating processes, including hydrodesulphurisation. As legislative requirements require ever lower sulphur content in fuels, so more desulphurisation is needed to achieve these targets, which drives up hydrogen consumption in the sector [2]. Similarly, as demand for distillates such as jet fuel, kerosene, high-quality lubricating oils and diesel increases 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 of the fact that the net hydrogen balance of a refinery depends strongly on the specific processes involved and mix of output products, it is extremely challenging to precisely estimate the actual demand for hydrogen, which cannot be simply calculated based on production volumes alone.

Nevertheless, based on gathered information about hydrogen production capacities at refineries, together with information about their capacity utilization, we estimate that the total hydrogen demand from the oil refining and petrochemical industry, in 2018, was ***3.7 Mt (148 TWh$_{HHV}$)****.*

Figure 19. Estimated hydrogen demand from the oil refining industry
Source: own elaboration.

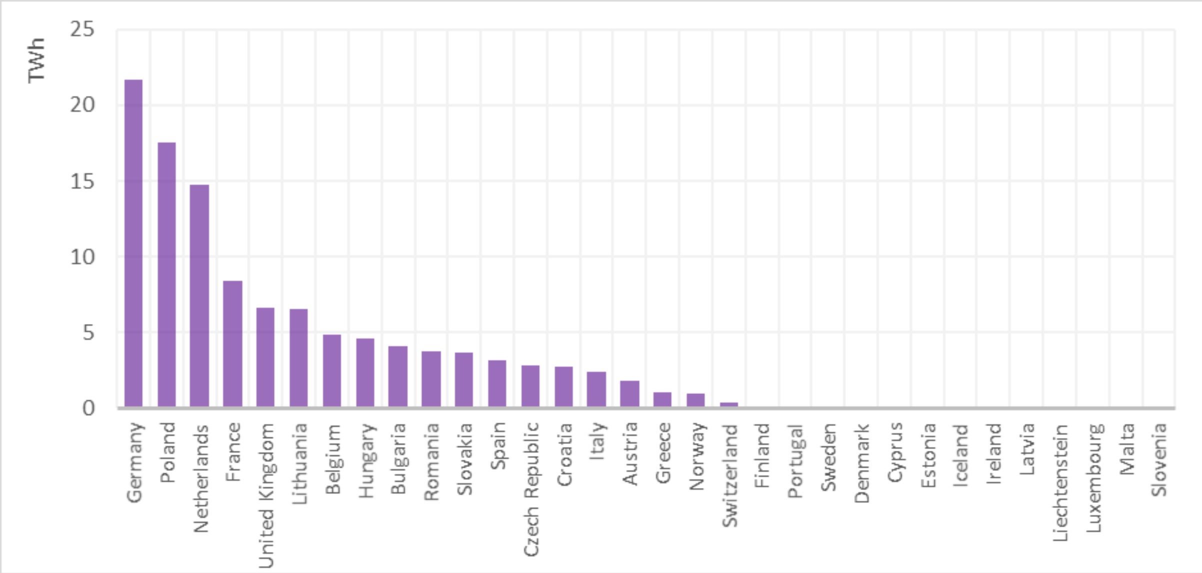


2.3. The chemical industry

In the chemical industry, the largest consumer 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 etc.

Total demand for hydrogen by the ammonia industry in 2018, based on Eurostat data, can be estimated at ***2.8 Mt (112 TWh$_{HHV}$)****. Unfortunately, detailed statistics about ammonia production are not available for some EU Member States, due to confidentiality issues. In those cases, reported CO_2 emissions from ammonia production were used as a proxy.*

Figure 20. Estimated hydrogen demand from the ammonia industry
Source: own elaboration.



Furthermore, even though it dwarfs other applications, ammonia industry 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.*

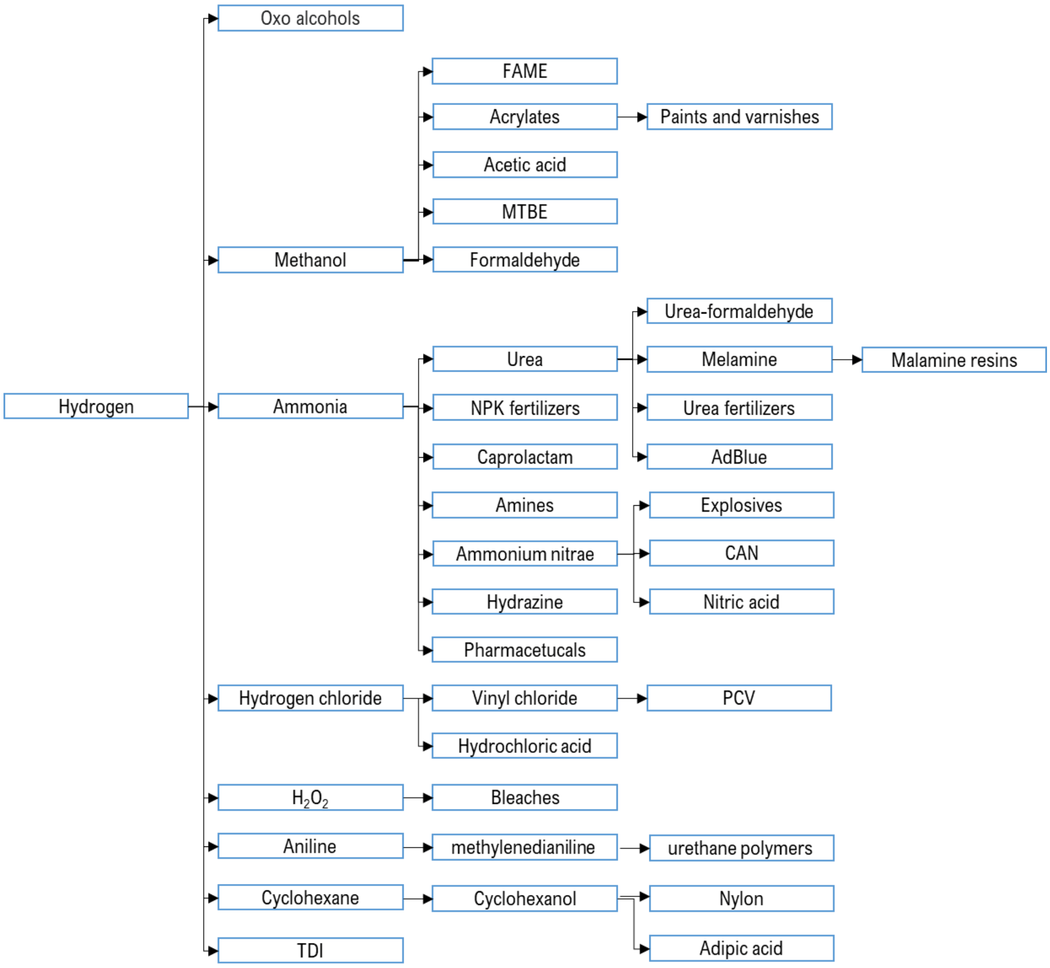
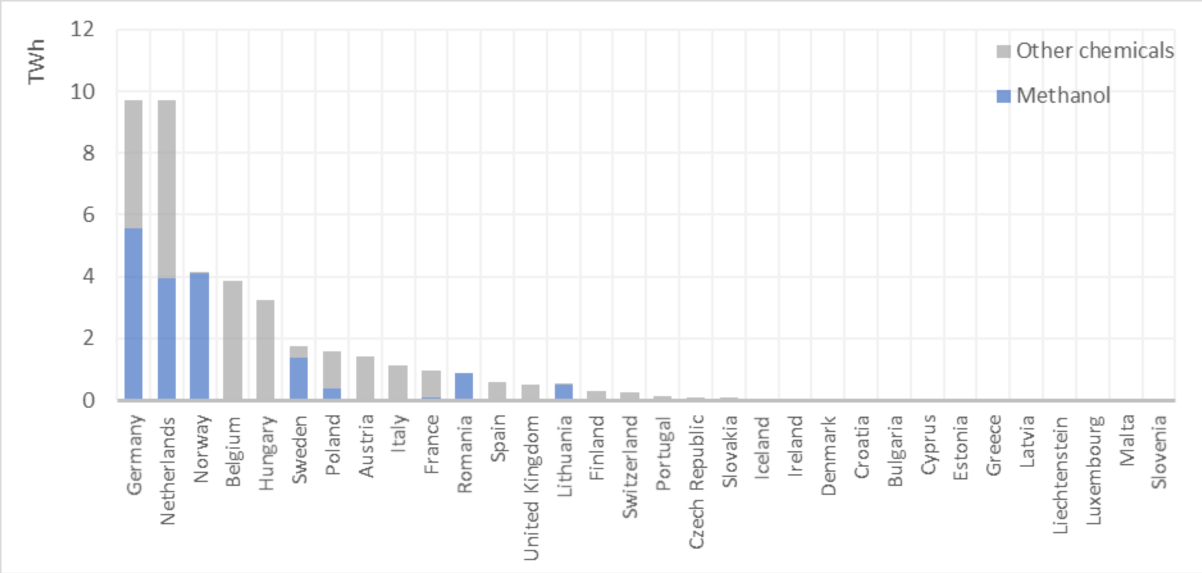


Figure 21. Chemical industry value chain dependant on hydrogen supply
Source: own elaboration.

*Total demand for hydrogen, in 2018, from the chemical industry (other than ammonia manufacturing) have been estimated at around **1.0 Mt (40.8 TWh$_{HHV}$)**, with almost half coming from Germany and the Netherlands.*

Figure 22. Estimated hydrogen demand from the chemical industry other than ammonia manufacturing
Source: own elaboration.



2.4. Other industries

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

Steel manufacturing and metals processing

Mixture of hydrogen and nitrogen (5% to 7% H_2) is used commonly as an inert protective atmosphere in conventional batch annealing in annealing furnaces. Batch annealing with 100 % hydrogen is also possible and results in better productivity, improved mechanical properties, surface and product quality.

Manufacture of Glass

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).*
- *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 a insignificant part of hydrogen consumption (below 0.1%), it is expected to grow in the future.

Appendix 1: List of acronyms

ATR	*Autothermal reforming*
BMA	*Blausäure (hydrogen cyanide) from Methan (methane) and Ammoniak (ammonia)*
CCS	*Carbon capture and storage*
CCU	*Carbon capture and utilisation*
CHP	*Combined heat and power*
COG	*Coke oven gas*
EEA	*European Economic Area*
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*
MTD	*Metric tons per day*
POX	*Partial oxidation*
PSA	*Pressure swing adsorption*
SMR	*Steam methane reforming*
TDI	*Toluene diisocyanate*

Appendix 2: References

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