Petrochemicals Europe views on the (Green) Hydrogen Economy. Some basic data and what can be the opportunities for petrochemicals in this new economy.

EXECUTIVE SUMMARY

In the 2019 Cefic Vision on Hydrogen, Cefic expects hydrogen to play a pivotal role in reducing the carbon footprint of Europe's energy and feedstock supply within the transition to climate neutrality. The future of the European chemical industry – especially in the transition towards climate neutrality – will be closely intertwined with developments like a hydrogen economy.

The petrochemical industry is a large producer and consumer of hydrogen. On a local level, production and consumption are typically well-balanced today. Beyond its preferred use as a chemical raw material, hydrogen can also be used as an energy carrier as an enabler of electrification which does not release CO2 if combusted for energy generation. Given the high energy intensity of the petrochemical industry, hydrogen could therefore play a key role in the decarbonization of the petrochemical industry if it is provided from emission-free production processes, which also includes CCS options and at competitive cost. This requires an appropriate infrastructure as well as a favourable regulation around its production, storage and distribution.

This paper focuses on the specific role of petrochemicals in relation to (green) hydrogen by articulating the functionality and quantities of hydrogen in the industry today with the objective to create better insight in potential opportunities.

1. Introduction

The European chemical industry is already a major hydrogen consumer and producer today.

For the vision to become reality, the European Union requires a Hydrogen Strategy, which creates legal and investment certainty for a competitive industry in order to pave the way for a successful deployment of climate-friendly hydrogen[1], which has the following aims:

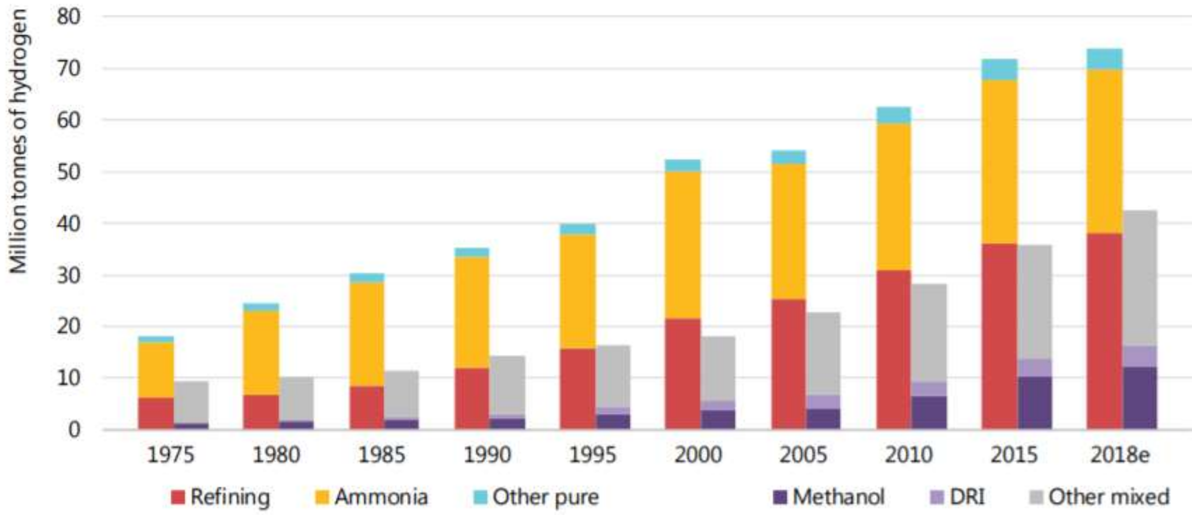
1. A rapid **reduction in cost** of producing climate-friendly hydrogen.
2. The **right balance between promotion and affordability.**
3. **A solid and credible certification framework**, including clear and comprehensive definitions for different types of hydrogen. Certification should be clear and avoid double penalties or double incentives when accounted for.
4. **A competitive market. Striking the right balance between promotion and affordability.**
5. **Infrastructure** should be carefully planned to safeguard various **gas quality** requirements (H2 and H2/Natural Gas mixtures), allow safe and efficient transport and build on the potential of hydrogen as a storage solution.
6. Strong **research and innovation support** to encourage progress on technologies.
   For more details, reader is referred to the complete Cefic position paper on hydrogen that can be found on the Cefic website.

2. Global Overview of the current hydrogen market

In the 'Future of Hydrogen' report[2], IEA estimates the worldwide Industrial demand hydrogen at 70 Mt H2/year, used in pure form mostly for oil refining and chemicals manufacturing as captive (internal) use. A further 45 Mt H2/year is used in the industry without prior separation from other gases (see figure 1).

[1] For "climate-friendly hydrogen", Cefic means hydrogen produced with a low greenhouse gas (GHG) emissions compared to unabated hydrogen from natural gas with Steam Methane Reforming (SMR), e.g. with fossil-free energy or from natural gas with CO2 emissions either captured or transformed into solid carbon. In communications reference is often made to different colours of hydrogen (green, blue, grey). See appendix 1. In this nomenclature, climate friendly hydrogen corresponds to green and blue hydrogen, but also any other form of hydrogen with very low GHG emissions such as turquoise hydrogen or hydrogen made using electricity from nuclear power plants.

Figure 1: Hydrogen Global annual demand since 1975 -as published in IEA report Future of Hydrogen.[2]



Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

Around 70 MtH_2/yr is used today in pure form, mostly for oil refining and ammonia manufacture for fertilisers; a further 45 MtH_2 is used in industry without prior separation from other gases.

3. European Overview of the current hydrogen market

In the European Union (EU) it is estimated that 9.6 Mt/y (or 108 Billion Nm3) [3] is used every year, mostly in refining and chemical industries as captive/dedicated ('internal') use. This estimate contrasts to the Eurostat hydrogen production data: according to the 2019 Eurostat data, dedicated hydrogen production is limited to 1.4 Mton/year (15 Billion Nm3/year). Of this 1.4 Mton/year, it is estimated that more than 95% is produced via steam reforming of methane. Sales of hydrogen listed in Eurostat database are only 0.8 Mton (9 billion Nm3) or slightly more than half of the listed production.

Below, some insight is provided in the discrepancy between the assumed hydrogen consumption figures and the reported production figures under Eurostat.

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[3] IEA: The Future of Hydrogen. Seizing today's opportunities. Report prepared by the IEA for the G20 Japan, June 2019.

[3] The FCP hydrogen Europe Roadmap estimates current demand of hydrogen as part of the energy mix is 325 TWh in 2015. Conversion from TWh to Nm3 is obtained assuming a heating value of 2.,99 kWh/Nm³

4. Hydrogen production in Europe

On purpose produced hydrogen is largely produced and used on site (captive use) and scarcely sold on the market, the freely traded hydrogen represents only some 4% of the total hydrogen consumption (Yergin et al. 2009)[4] .

As mentioned above, hydrogen production as listed in Eurostat amounts to around 1.4 Mton in 2019 (Eurostat data are in Nm3: production is listed as 15.4 billion Nm3). The biggest producing country in Europe is Germany with 0.4 Mton/year (4.5 billion Nm3).

However, there are other production units (see 4.1-4.3) whose hydrogen production is not reported under Eurostat NACE code 20111150. This is because this production effectively never enters to external market for consumption.

4.1 Fertilizers

Practically all fertilizers plant in Europe (with one or two exceptions) produce their own hydrogen in steam reformers. These are an integral part of the ammonia plant. Their hydrogen production is not included in the Eurostat database. Only the production of hydrogen from the ones that buy their hydrogen from a third party is included in Eurostat data.

4.2 Refineries

As for refineries, Concawe[5] estimates consumption is about 4.8 Mton/year of hydrogen. Half of this hydrogen is produced in gasoline reformers as a byproduct of the production of gasoline (and again not included in the Eurostat production figures). For the other half, about 1.9 Mton/year is coming from steam reformers, and about 0.5 Mton/year from POX units[6]. As for the 1.9 Mton/year, about 1/3 is made internally within the refinery (0.6 Mton/year) and 2/3 is imported from steam reformers operated by third parties (like Air Liquide, Linde, …) (1.3 Mton/year included in the figures of Eurostat).

4.3 Steam Crackers, dehydrogenation, styrene production, Chlor-Alkali and Sodium Chlorate

There are also several other chemical production processes that produce Hydrogen as a byproduct (and therefore not included in Eurostat).

- The most important petrochemicals plants producing hydrogen are steam crackers. Steam crackers produce a variety of products ranging from hydrogen to heavy fuel, the main products being ethylene, propylene, butadiene and aromatics, but it also produces a hydrogen rich byproduct. The hydrogen stream leaving a cracker has a typical purity of 30 to 70 wt.% (the rest being mostly methane). Total amount of hydrogen in this hydrogen stream is estimated to be about 0.4 Mton/year for all EU crackers combined.
- There are various other petrochemical processes such as propane dehydrogenation and styrene production that also produce hydrogen as a byproduct. It is estimated that total hydrogen production of these petrochemical processes is less than 0.2 Mton/year.
- Finally, hydrogen is also produced in chlor-alkali plants. Production is estimated to be about 0.3 Mton/year.

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[4] Yergin et al. 2009: Daniel Yergin, David Hobbs, Lawrence Makovitch, Mary Lashley Barcella, Fueling North America's Energy Future: The Unconventional Natural Gas Revolution and the Carbon Agenda. IHS CERA Special Report. Cambridge, UK 2009

[5] Concawe: Scientific Division of the European Petroleum Refiners Association

[6] POX stands for Partial Oxidation. In such units, heavy fuel or residue stream of the refinery are converted to syngas (a mixture of CO, CO2 and hydrogen) from which hydrogen can be isolated.

Adding all the above numbers up, production of hydrogen in Europe counting refining, fertilizers and chemicals is estimated to be about 7.9 Mton/year, of which 2.9 Mton/year is produced as a byproduct, and hence not made on purpose.

Cefic is aware that there is also some production of hydrogen in steel manufacturing plants, but it is estimated that these quantities are small compared 7.9 Mton/year and the steel sector is better qualified to give insight in these numbers.

Source	Amount (Mt/yr)	Remark
On purpose (dedicated)	**5.5**	
Fertilizers	**3**	Fertilizers Europe estimate
Refineries	**1.1**	Concawe estimate
Dedicated production as listed in EUROSTAT	**1.4**	This number may include some hydrogen that is listed above under fertilizers and refineries
Byproduct (not on purpose)	**> 3.1-3.2**	
Refineries	**2.4**	Concawe estimate
Steam Crackers	**0.4**	Based on input to steam cracker ETS benchmark
Chlor-alkali	**0.3**	Euro Chlor estimate
Chemicals (excl. steam crackers and chlor-alkali)	**0.1-0.2**	Petrochemicals Europe estimate
Others (steel, …)	**information not available at Cefic**	Estimated to be small (<5 % of total hydrogen production in EU)
Total (on purpose and byproduct) (excluding others)	**8.6-8.8**	Low side of estimate reflects potential double counting of some on purpose produced hydrogen reported under fertilizers and refineries but also included in Eurostat data.

Table 1: overview of hydrogen production in Europe

5. European Hydrogen consumption

5.1 Hydrogen main consumers

The main consumers of hydrogen as a feedstock are

1. fertilizers (3 Mton/year),
2. refining (4.8 Mton/years) and
3. other chemicals (hydrogenation reactions: estimated to be maximum 0.5 Mton year).

In total that amounts to some 7.5 Mton/year of hydrogen consumption for feedstock purposes.

5.2 Hydrogen as a fuel. Current contribution to reducing CO2 emission

In integrated industrial complexes, the hydrogen produced in the steam crackers, PDH plants and even chlor-alkali plants is used to carry out hydrogenation reactions in other production plants within the industrial complex. But the rest of this (impure) hydrogen is mostly diluted in the site fuel gas and then burned to provide the heat required to operate the various plants on the site. This is also the case for non-integrated industrial complexes where hydrogen is produced as a byproduct.

To get an upper estimate on the amount of hydrogen fueled, it is assumed that all hydrogen used for hydrogenation reactions in the chemical industry comes from on-purpose hydrogen production (i.e. is accounted for in the Eurostat production data). All hydrogen produced in steam crackers, chlor-alkali processes and other chemical processes would then be assumed to be burned, and this gives about 0.9 Mton/year of hydrogen burned as fuel in chemical plants.

Diluting the produced hydrogen in the fuel gas of the site, reduces the CO2 emissions of the site. There would be no environmental gain to separate this hydrogen and sell it as a zero-emission fuel to a third party, because the site would then have to purchase additional natural gas, to compensate for the sold hydrogen. Overall CO2 emissions will stay the same, if not higher because extra energy will have to spent to purify the hydrogen to a higher purity for sale to third parties.

Demand	Amount Mt/yr	Remarks
Production of ammonia	**3**	Fertilizers Europe (estimate)
Refining	**4.8**	Concawe estimate Most of this is used for feedstock. May also include a small part that is used as fuel in the refinery
Used in chemical industry for hydrogenation reactions	**< 0.5**	Cefic estimate
Used as fuel in chemical industry	**<0.9**	Cefic estimate based on production of hydrogen as a byproduct
Others (steel, food, …)	**Information not available at Cefic**	Estimated to be small compared to total consumption in EU
Total (excluding others)	**8.7- 9.2**	The higher estimate is the sum of the numbers above, the lower estimate is based on assuming double counting H2 in the figure of hydrogenation (0.5) and fuel use (0.9)

Table 2: Consumption of hydrogen in Europe

5.3 Balancing consumption and production

The total estimated hydrogen consumption of refining and chemicals including fertilizers is estimated to amount to about 9 Mton/year of hydrogen. There is an additional consumption of hydrogen in the steel sector and other industrial sectors such as food, however they are believed to be small (steel have separate data) are excluded from this number.

This number seems relatively in line with the quoted 9.6 Mton/year demand as stated in the FCP European Hydrogen roadmap (see chapter 3), the small difference might be explained by a link to other applications where hydrogen is either fueled or where hydrogen is not used in its pure form. For these other applications, care is required as the hydrogen claimed in these applications is not produced on purpose but is a byproduct or intermediate to produce other materials. For instance, including MeOH as a hydrogen consumer is somewhat misleading as the process of producing methanol goes via steam reforming of methane or heavy refinery streams. In this process, syngas (a mixture of CO, CO2 and hydrogen) is produced that is then transformed in a next step to methanol. Hydrogen is not isolated from this syngas.

6. How to go from current hydrogen production to climate neutral hydrogen production.

From Table 1, it can be derived that the current demand for on purpose made hydrogen is estimated to be around 5.5 Mton/year.

This is the amount of hydrogen that could be made climate neutral either by installing a CCU/CCS installation on the existing steam reformers in Europe or building new electrolysis plants using green electricity which would replace existing steam reformers, assuming no new growth in the demand of hydrogen.

The total demand for hydrogen is higher as there is an additional 3.3 Mton of hydrogen that is produced as byproduct of other processes and to a large extent (2.6 Mton/year) used by refining and other chemical processes as feedstock, the rest being mostly used as fuel. However, the hydrogen produced as a byproduct, will remain available if demand for the main products in these processes remains. It is therefore reasonable to assume that there will remain a hydrogen production about 3.3 Mton/year as a byproduct of other products.

7. Outlook and European ambitions on renewable hydrogen – the role of CCU/CCS

In the European strategy for hydrogen, Europe aims to install a capacity of up to 10 Mton/year of renewable hydrogen production by 2030[7]. The EU preferred option is to install new electrolysis units but, in the strategy, it is accepted that, during a transition period, some of this hydrogen can be produced from conventional steam reformers to which a CCU/CCS unit would be added.

With respect to the consumption of hydrogen, no growth or limited growth in hydrogen demand is expected nor of fertilizers nor of the current usages of hydrogen in refining or petrochemicals, as growth rate in the EU of the production of fertilizers, refinery fuels such as gasoline and diesel and main petrochemicals is expected to be small .

This means that new applications will need to be developed to go from current demand of on purpose made hydrogen estimated to be about 5.5 Mton/year to 10 Mton/year of hydrogen in 2030.

This challenge further increases if the low carbon hydrogen produced by adding a CCU/CCS unit to an existing steam reformer unit would not be considered in the renewable hydrogen target of 10 Mton/year.

It is important to realize that building CCU/CCS unit will be capital intensive and complex to design/build. Even if industry would start to invest massively into this type of technology, such units would not be ready before 2025. And such investment decisions will not be taken if these units are not guaranteed to be allowed to stay in operation for at least 10 to 15 years.

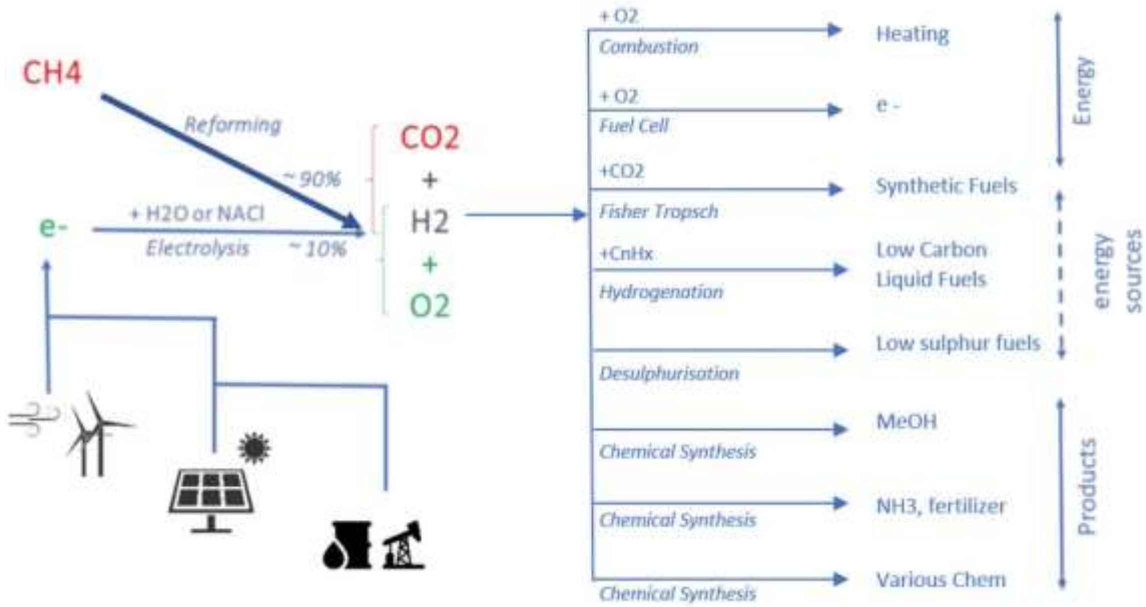
It is therefore strongly recommended that ambition in renewable hydrogen would be expressed as ambitions for renewable and low carbon hydrogen with a gradual shift in new units from low carbon hydrogen type of processes to electrolysis processes based on renewable energy.

[7] COM (2020) 301 final. A hydrogen strategy for a climate-neutral Europe.

8. Potential new outlets for hydrogen

An overview of the different uses of hydrogen is shown in Figure 2.

Figure 2: The main applications and consumption of hydrogen



The EU hydrogen strategy paper (see footnote 2) clearly outlines the transport sector as a potential for increasing hydrogen consumption. This could be in the form of compressed hydrogen, but it is also possible to convert this renewable hydrogen into liquid fuels such as ammonia (NH3), methanol (CH3OH) or synthetic fuels (using Fisher-Tropsch chemistry). Methanol and synthetic fuels are in this scenario produced using low carbon hydrogen on the one hand and CO2 that has been captured either from industry combustion gases (and possibly temporarily stored underground) or directly captured from the air.

This type of chemistry is at the interface of the refining and the chemical industry.

However, in addition to methanol being used as a transport fuel it can also be used as a feedstock to make olefins and aromatics. Methanol to Olefins (MTO) processes are already operating mostly in Asia (although in China, most of the methanol feedstock is currently made from coal). MTO/MTP (Methanol to Propylene) could therefore form an interesting alternative to conventional steam cracking. Technologies are also under development to produce aromatics from methanol.

An alternative option would be to use renewable hydrogen as fuel gas in industrial installations. In this application, hydrogen would be used to supply heat for the process in the form of steam of direct heat input to the process. This would help to reduce GHG emissions from these industrial installations and initially it could even be done at reduced cost for the industrial installation if hydrogen would be blended into natural gas[8]. Petrochemical processes are by their nature energy intensive, e.g. a steam cracker typically consumes 30 GJ (or 0.6 t of methane) per ton of ethylene produced and could in principle adapt

[8] Blending with natural gas will however not lead to zero emissions, therefore at some stage transition to 100 % H2 fuelling would be required to achieve ambitions of net zero GHG emissions.

to replace some of the methane burned by climate friendly hydrogen, assuming the required amounts of hydrogen are available at a competitive price.

However, in the long run, rather than fueling hydrogen, it would be in principle preferential to generate this heat directly in an electrical boiler or furnace, unless there would be technical barriers preventing electrification or economic reasons that renders the H2 route more attractive. The amount of renewable energy required for producing (green) hydrogen via electrolysis and subsequently burning it, is estimated to be between 50 and 80 % higher than the electricity required for electrical heating. Hence, from a long-term perspective, with respect to total (green) electricity usage, state of the art electrical furnaces and boilers will be more efficient than fueling green hydrogen.[9] However, the development of electrical cracking furnaces is in its early R&D phase, technical as well as economic feasibility still needs to be proven, notably at scale.

Nonetheless, use as a fuel could however be an option in case of bottlenecks in the electricity distribution network and act as a buffer. Producing hydrogen from locally abundant renewable electricity and then converting it into synthetic fuels that are easier to transport could be economically more attractive than selling the respective electricity at a loss, or temporarily idling capacity.

In summary: whilst petrochemicals can initially consume some of the climate friendly hydrogen coming on the market, assuming it is available at competitive prices by using the hydrogen as fuel, this is seen as a transition route, not necessarily a solution in the long term. Potentially, petrochemicals could use the climate friendly hydrogen together with CO2 as building blocks to manufacture climate neutral products. However, as we will see in the next paragraph, apart from technology readiness of this type of chemistry, this route is not yet economically feasible.

9. <u>Drivers to develop Methanol based chemistry from CO2 and hydrogen</u>

This section addresses the application of hydrogen where there is growth potential for the petrochemical industry, namely methanol as a fuel and as feedstock for petrochemicals. What are the challenges to boost the hydrogen value chain to methanol?

Today, world production of methanol is about 50 Mton/year according to “The Future of Petrochemicals” EIA report published in 2018 (EU production of methanol is about 2 Mton/year). Most of this methanol is produced in large scale using natural gas and coal as feedstock.

The technology to produce methanol from CO2 and hydrogen is currently not yet fully mature. Moreover, given the current CO2 price in the range of 20-30 EURO/ton and current electricity prices, it is not possible to produce methanol at a price that is competitive with methanol put on the market produced in large scale methanol plants elsewhere in the world (250-450 EURO/ton). Conditions that could promote the CO2/H2 chemistry to olefins/aromatics are:

- Higher price for CO2.
- Action plan by EU so that cost related to CO2 emissions are included in the price that the consumer pays independent of whether the product is produced in EU or outside EU.

[9] An issue that needs to be addressed both in the case of hydrogen fueling and electrical furnaces is the following. One of the byproducts that is generated in the cracking process is methane. This methane is currently used as fuel on the cracking furnaces, and in an energy efficient cracker, production of methane is roughly equal to fuel consumption on the furnaces So in both cases (hydrogen fueling or electric furnaces) a solution will have to be found for the methane produced.

- Abundant availability of green electricity at a competitive price.
- Support by EU of technological development in electrolyzers and CO_2/H_2 chemistry.
- Support by EU on OPEX for these operations.
- Schemes that require a certain amount of CO_2 based material in final products.
- Informing customers about positive contribution of CO_2 chemistry to achieving climate targets.

Conclusions

This paper aimed to provide a better and more quantified insight in today's use and production of H2 in the petrochemical industry and we also investigated the opportunities for (green) hydrogen in the petrochemical industry.

To get a clear supply-demand picture in Europe for hydrogen in the Petrochemicals industry is challenging due the significant amount of captive/dedicated use in its processes as well as the interlink between the various processes on sites such as in Verbunds. Various sources of information have been used and today the on-purpose production of hydrogen in Europe is estimated to be about 5.5 Mton/year. The main consumers of hydrogen are fertilizers (ammonia) and refineries. Today, Petrochemicals are only a minor net-producer and consumer of hydrogen (<0.5 Mton/year)

The EU has ambition to produce up to 10 Mton/year of renewable hydrogen by 2030. This means that significant new outlets for hydrogen need to be identified. Transport is one obvious identified market. Hydrogen can also be used in its pure form as combustion fuel in furnaces.

At an initial phase, petrochemical sites could replace some the natural gas used as fuel in furnaces by natural gas/hydrogen mixtures (provided this is available at competitive prices). This would help to reduce the greenhouse gas emissions in the short run. But in the long run, burning renewable hydrogen in furnaces is much less energy efficient than direct electrification of furnaces (which are still in early phases of development) and should therefore be seen as a transient solution and other outlets should be sought to achieve increased renewable H2 demand.

However, it is also possible to transform hydrogen into other types of fuel such as ammonia or using CO2 chemistry in methanol or synthetic liquids.

Methanol can then also be used as a feedstock to produce petrochemicals, the building stones of the chemical industry.

Today, research is still needed to optimize and scale up the electrolysis process to reduce production cost of hydrogen via electrolysis as well as research is required into the CO2/H2 chemistry to make synthetic fuels and methanol (or even directly petrochemicals without going via methanol).

It will also require the coming on-line of enough green electricity to produce the required green hydrogen.

In conclusion: in the long run, hydrogen is too valuable to be burned in furnaces and boilers unless there is no alternative. However, hydrogen jointly with CO2, offers interesting opportunities for the petrochemical industry as alternative feedstock to manufacture petrochemicals. On the other hand, some economic parameters need to change to make this type of chemistry competitive with the classical production process of methanol from natural gas or coal. This transition needs to be supported by the EU.

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About Cefic
Cefic, the European Chemical Industry Council, founded in 1972, is the voice of large, medium and small chemical companies across Europe, which provide 1.2 million jobs and account for 16% of world chemicals production.

Appendix 1: Different colors of hydrogen

In publications and discussions on the future of hydrogen, reference is often made to color of hydrogen.

- Green hydrogen is hydrogen on the basis of electrolysis of as green (renewable) as possible electricity.
- Blue hydrogen is hydrogen produced on basis of natural gas or coal with reuse (CCU) or storage of CO2.
- Grey (or black) hydrogen is hydrogen on the basis of a fossil feedstock, mostly natural gas or coal
- Brown hydrogen is hydrogen recovered from industrial processes where hydrogen is a byproduct.
- Turquoise hydrogen is hydrogen produced from pyrolysis of methane (no CO2 released, but C formed).

In general, there are no established colors for hydrogen from biomass, nuclear or different varieties of grid electricity.

When referring to climate friendly hydrogen, Cefic refers in the above terminology to green and blue hydrogen.