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THE CURRENT H2 MARKET IN EU

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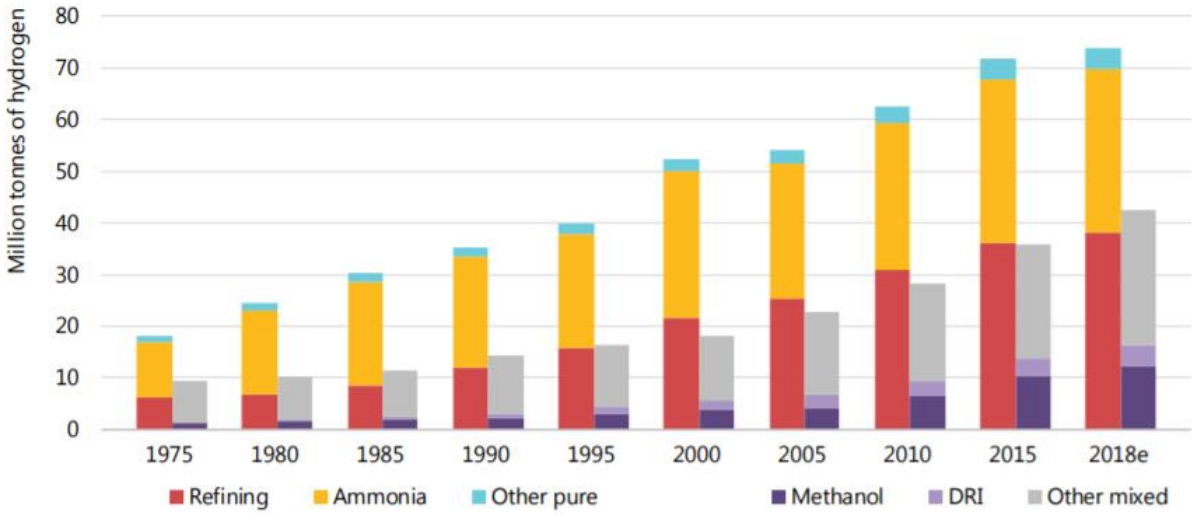
H2 WORLD-WIDE DEMAND

- IEA report on the future of hydrogen estimates world demand for H2 at 70 Mton/year in pure form + additional 45 Mton/year (2018)



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.

H2 VIA STEAM REFORMING

- Most commonly applied technology for H2 production = steam reforming of methane. Main steps
  - Primary reformer : $CH_4 + H_2O \rightarrow CO + 3H_2$

    Strongly endothermic ΔH_r= 206 kJ/mol)
  - Secondary reformer : $CO + H_2O \rightarrow CO_2 + H_2$

    Mildly exothermic ΔHr= -41 kJ/mol
  - **Remark : the net effect is to create one CO2 molecule per 4 H2 molecules.**
  - Step 3 : absorption of CO2 via aqueous ethanol amine solution (or other absorbant liquid) or PSA
- CO2 emissions for H2 production via SMR of median plant are about 9 ton CO2/ton H2.

H2 VIA STEAM REFORMING

- Important concept : syngas number

  SN = (mol H2- mol CO2)(Mol CO + mol CO2)

- SN number for conventional H2 via SMR is 3
- It is possible to replace the second reformer by an authotermal reformer (which uses pure O2). This leads to lower syngas numbers that can be useful if focus is not only on H2, eg methanol (CH30H) needs SN=2

  $CO + 2\ H_2 \rightarrow CH_3OH$

  $CO_2 + 3\ H_2 \rightarrow CH_3OH + 3H_2O$

- CO2 Emissions for CH3OH production for median plant : 0.2-0.3 ton CO2/ton CH30H
- H2 can via steam reforming also be produced from coal or biomass but CO2 to H2 ratios than from steam reforming.

H2 as a byproduct : main processes

- H2 is produced as a byproduct in refineries and in steam crackers.
- Main producer of H2 in refinery is catalytic reformer : main objective of catalytic reformer is to increase the octane number of gasoline.
- H2 is also produced as a byproduct in steam crackers. Production presents less than 1 % of output of a steam cracker and purity is typically less than 70 %wt (rest being methane).
- H2 is produced as byproduct in chlorine production.

$2NaCl + 2\ H20 + electricity \rightarrow 2\ NaOH + Cl_2 + H_2$

Main uses of hydrogen

- In refining, H2 is used to desulfurise refinery streams and used for converting heavy hydrocarbons into lighter hydrocarbons.
- Fertilisers : $N_2 + 3\ H_2 \rightarrow 2\ NH_3$

- In the chemical industry can be used for hydrogenating double bonds (eg pyrolysis gasoline unit) but also for specific processes (cyclohexane, butanediol, butanol, TDA/TDI, …)
- In integrated sites (eg petrochemical sites), H2 produced in one process can be used by other process.
- But for rest, H2 produced in crackers is added to the site fuel gas and used as energy source.

PE analysis : H2 PRODUCTION

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,...)	**?**	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.

PE analysis : H2 DEMAND

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, …)	**?**	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)

EU COMMISSION AMBITION

- FCP EU H2 Roadmap estimates use for H2 at 9.6 Mton/year (108 Billion Nm3).
- EUROSTAT Production data (PRODCOM code 20111150 : 1.4 Mton/year in 2019 (15 Billion Nm3) of which about 60 % is reported to be sold. Biggest producing country is Germany: 0.4 Mton/year.
- EU ambition :H2 strategy communication document
  - By 2024 : up to 1 Million Ton of renewable H2 (at least 6 GW of electrolysers)
  - By 2030 : up to 10 Million Tonnes of renewable H2 (at least 40 GW of electrolysers)
  - Renewable defined as produced via electrolysis using green electricity or from biomass.

WHAT DOES EU AMBITION IMPLY

- On purpose production of H2 is today around 5.5 Mton/year. Big consumers are refineries and fertilizers
- There is additional production of about 3 Mton/year of H2 as a byproduct, that will probably remain at this level in the coming years.
- Even if of 5.5 Mton/year of on purpose produced H2 is replaced by renewable H2, new demand is required of about 4.5 Mton/year for ambition of 10 Mton/year of green H2.
- Question : What are the good applications for this extra H2 arriving on the market?

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HYDROGEN AS AN ENERGY CARRIER

- Hydrogen is a low-density energy carrier compared to existing liquid fuels. 10 kWh of energy =
  - 13.3 l of compressed H2 at 350 bar and 20° C
  - 7.7 l of compressed H2 at 700 bar and 20 ° C
  - 4.2 l of H2 of liquid h2 at 1 bar and -250° C
  - 1.7 l of LNG at 1 bar and -160° C
  - 1.1 l of gasoline
- There is a significant cost to compress or liquefy H2
  - 350 bar:10 % energy penalty
  - 800 bar: 25 % energy penalty
  - Liquid H2 : 30 % energy penalty + 10% energy penalty in transport
  - Liquid LNG : 5 % energy penalty + 3 % energy penalty in transport.
- Moreover, energy penalty for transport is a multiple of transport energy for methane and liquid fuels (eg 30 % energy penalty for transport via truck over 500 km (liquid or gas) or 5000 km via pipeline).
  - Source : EnergyVille, R. Belmans

H2 as a fuel?

Example of steam crackers : is it a good long-term solution?

- Steam cracker are important plants that provide building blocks for the whole chemical value chain. There are about 40 crackers in EU.
- Steam crackers are energy intensive and have high GHG emissions (from combustion of fuel gas in furnaces).
- Emissions from steam crackers in EU are about 30 Mton/year (represents about 20 % of emissions of the chemical industry).
- IF green H2 is available at competitive price, petrochemicals could replace some of their fuel gas by H2 and thereby reduce their GHG emissions without big investments (est 1 million ton H2 : impact GHG reduction by by about 20 %).
- However, alternative approach could to replace conventional by electrical furnaces (research ongoing). Need for renewable electricity will be almost double if going via green hydrogen.
  ➔ use of green H2 as energy carrier is not the right solution in the long run.

Comment on CCS

- Equipping a part of the existing H2 on purpose production plants with CCS (carbon capture and sequestration), could be a solution to achieve the EU GHG reduction ambitions in 2030 at a cost that may be lower than building today a new electrolyser plant.
- The EU recognises that retrofitting existing installations with CCS (or CCU) can help to grow H2 market in initial phase. However, investments will not happen in this technology is life time of investment is not at least 20 years.
- Remark : if CCS/CCU part of solutions allowed, even more ambitious demand growth for renewable H2 is required.