BCCI workshop on 12 November 2020:
Increasing energy efficiency and Hydrogen Economy - the contribution of the chemical industry to a 'climate-neutral economy'

Production of „green" Hydrogen - technical, economic, environmental aspects

cefic

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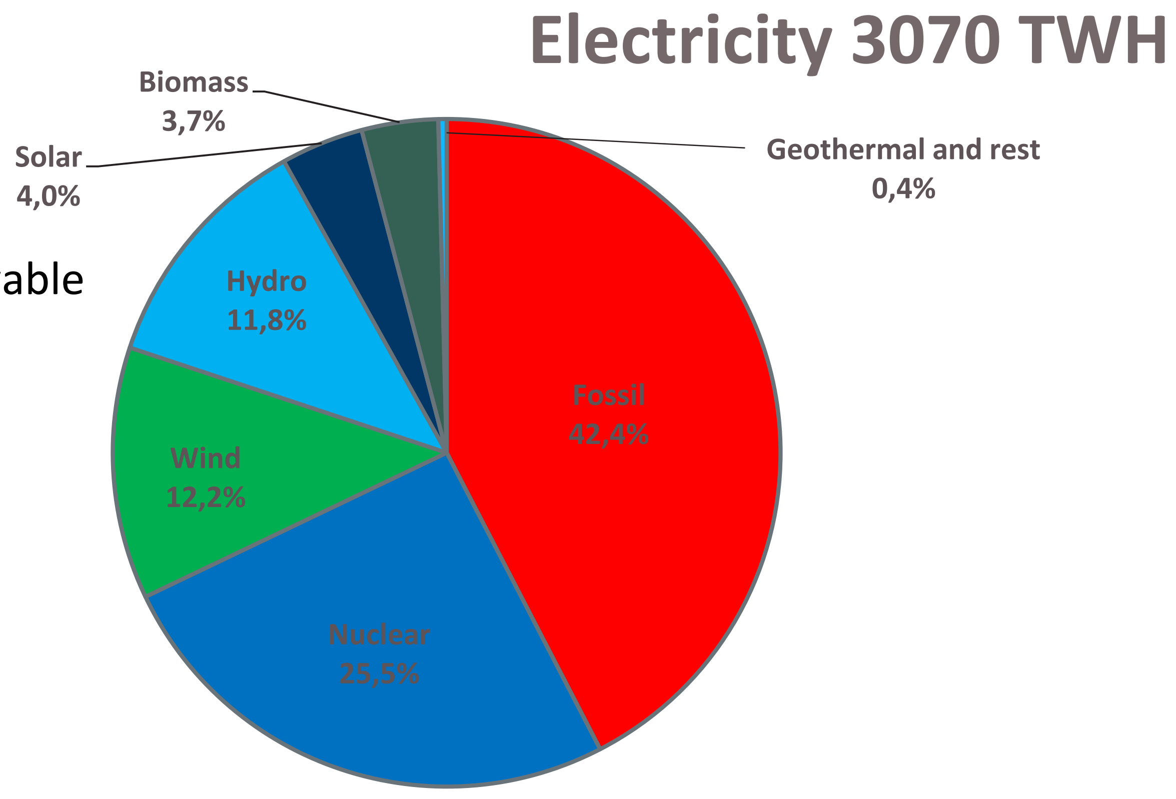
EU electricity production (2018)

32.1% is renewable



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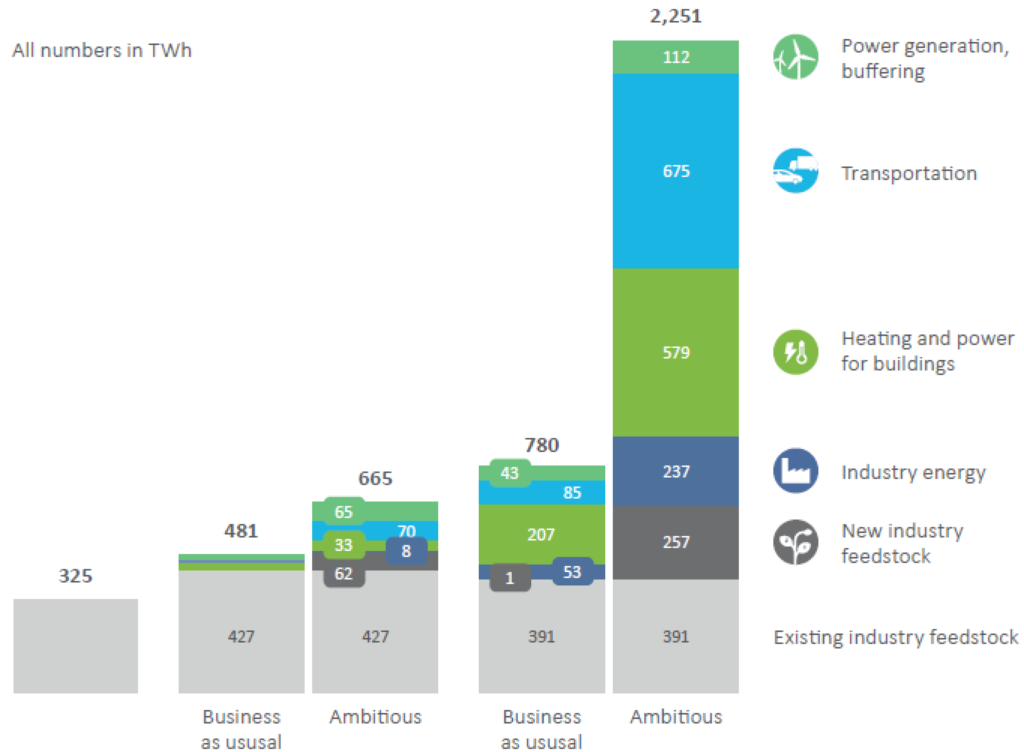
Ambitions for the use of Hydrogen

European Union 'Hydrogen roadmap Europe, a Sustainable Pathway for the European Energy Transition (FCH JU, 2019)



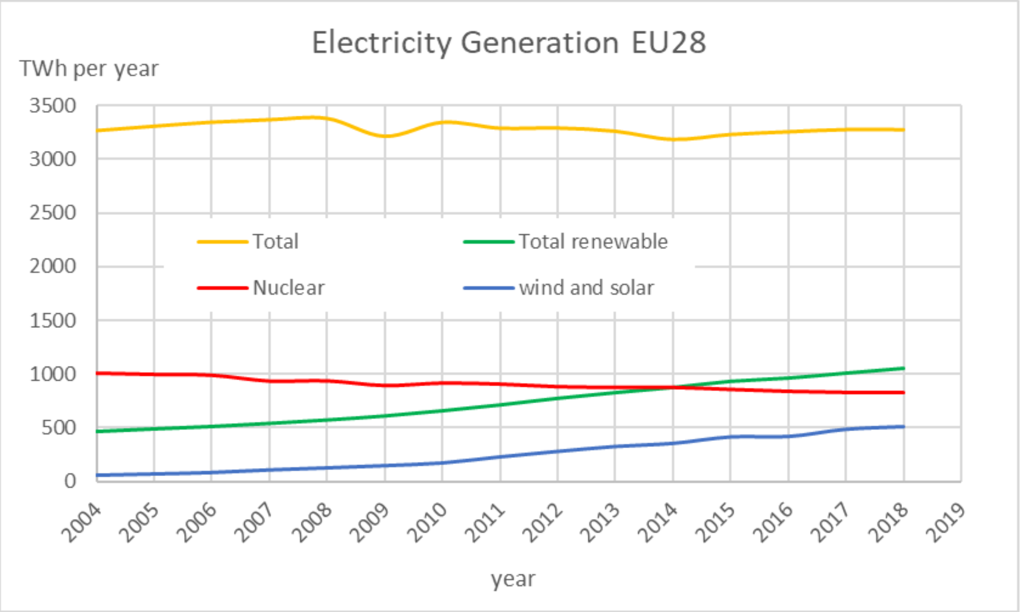
2015	2030		2050		Year
14,100	11,500		9,300		Final energy demand [TWh]
2%	2%	6%	8%	24%	Thereof H_2

Hydrogen consumption and ambitions

- Todays production approx. 325 TWh
  - equals approx. 8 million ton H_2/year (H2 strategy mentions 9.8 Mt)
- Based on the Hydrogen for Europe roadmap in 2050 we could need 19 – 55 Mt H_2
- If all this hydrogen has to be produced via water electrolysis it would require some 1235 – 3575 TWh of carbon neutral electricity in 2050 – up to about the total amount of the EU electricity production of today
- By 2050: Electricity would need to supply hydrogen manufacturing (24%) and in addition many other applications totalling to some 9.300 TWh final energy demand (around 10 times the renewable electricity supply of today).

Availability of “Carbon Neutral” Electricity

- Increase mainly realised by wind & sun
- Increase roughly 44 TWh/y
  - With this growth EU needs 50 years to get todays electricity demand carbon neutral
- Some European countries want to phase out nuclear
- If predicted hydrogen demand has to be produced from renewable electricity the challenge increases further
- Moreover, fossil energy users want to electrify - increasing the challenge even more

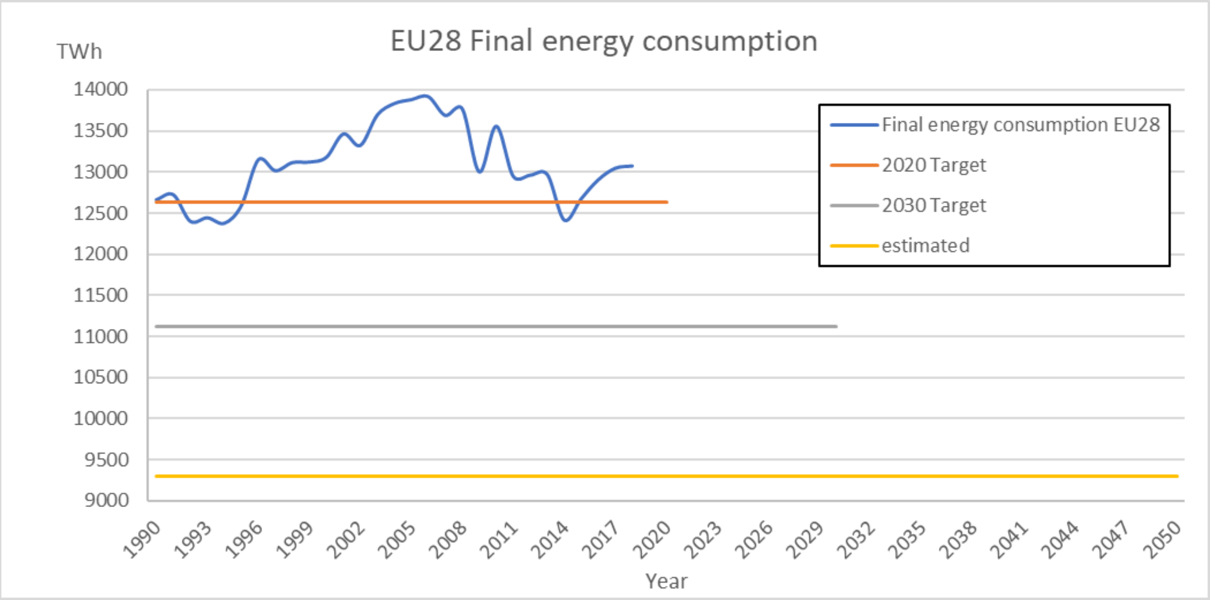


Even when also using all other H_2 sources: the amount of renewable electricity has to increase dramatically!

Hydrogen Strategy assumptions

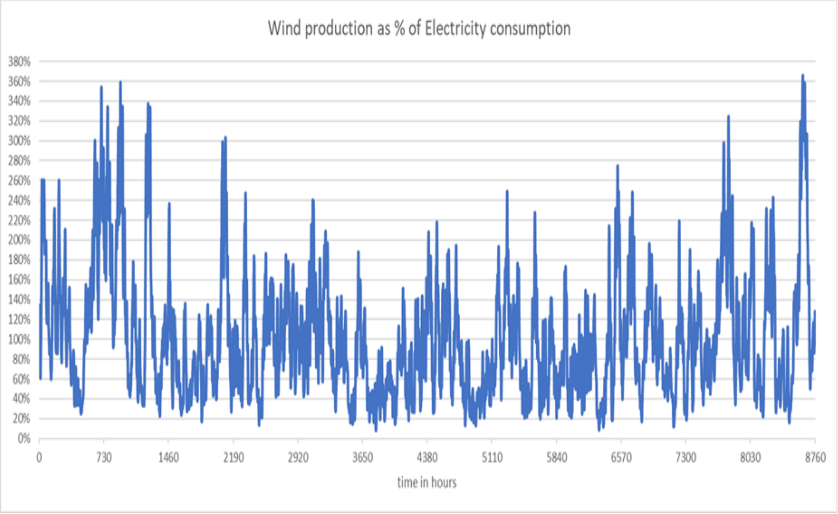
- Estimated decline of energy consumption
  - From 2018 to 2030 a decline of 1953 TWh required or 15%
  - From 2015 to 2050 a decline of 3771 TWh required or 29%
  - While we had an increase over the last 30 years

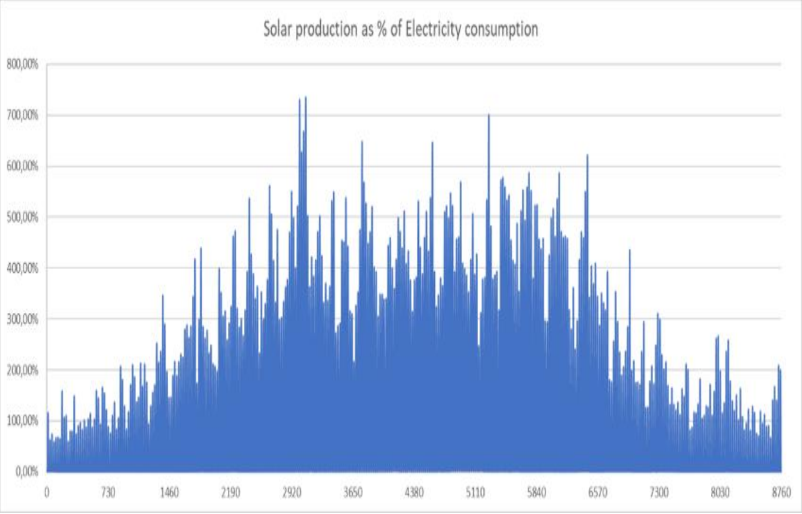
- For debate:
  - How realistic are the assumptions about energy efficiency?



Electricity consumption from wind and solar generation in DK, GER, NL, GB, BE, FR

- Wind and solar do not match today's electricity consumption
- If all required electricity be produced via wind or solar: economic challenge





Economic Efficiency ‘green’ HYDROGEN

Capital cost per megawatt is not much different from that for SMRs with carbon capture, presumed a lifetime of some 30 years.

Economic justification for electrolysers rather than SMRs considered partly as a route to diversity and principally as a means to reduce the curtailment of uncontrollable (intermittent) renewables such as wind and solar.

- Operating with wind and solar: The cost of hydrogen produced by electrolysis from renewables is sensitive to both the electricity cost and the utilisation of the electrolyser.

- IEA: Depending on local gas prices, electricity at USD 10–40/MWh and at full load hours of around 4,000 hours are needed for water electrolysis to become cost-competitive with natural gas with [carbon capture, utilisation and storage].

Economic Efficiency ‘green’ HYDROGEN

EU electricity from renewables is more expensive than $10–40/MWh, and a full load of 4,000 hours per year is a 46% load factor, a level of productivity reached by only a few EU wind farms, (by no solar sites?).

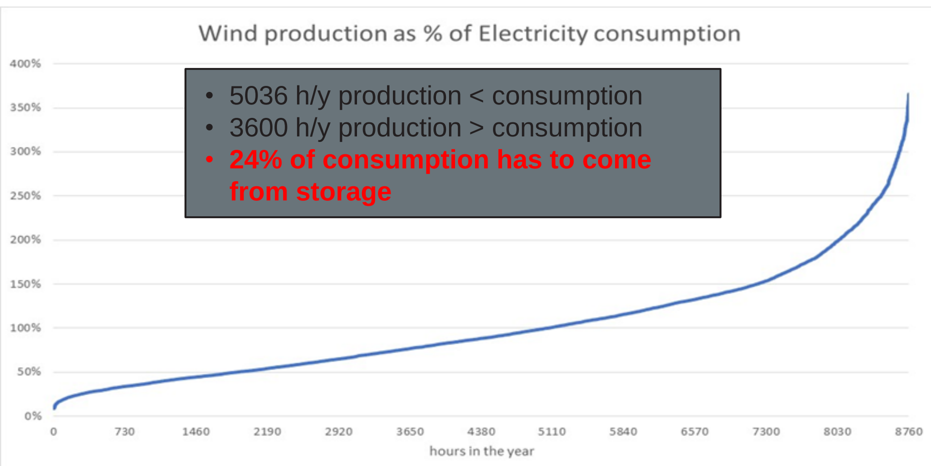
- Electrolysers dedicated to specific wind or solar sites are therefore unlikely, and the optimising of utilisation of centralized electrolysers serving several renewable installations appear more likely.
- Wind and solar output varies very considerably: the system will be faced with either **underutilisation of the electrolyser** or **unavoidable curtailment of the wind and solar sites** weakening the economic case for the production of hydrogen from electrolysers and renewable energy.

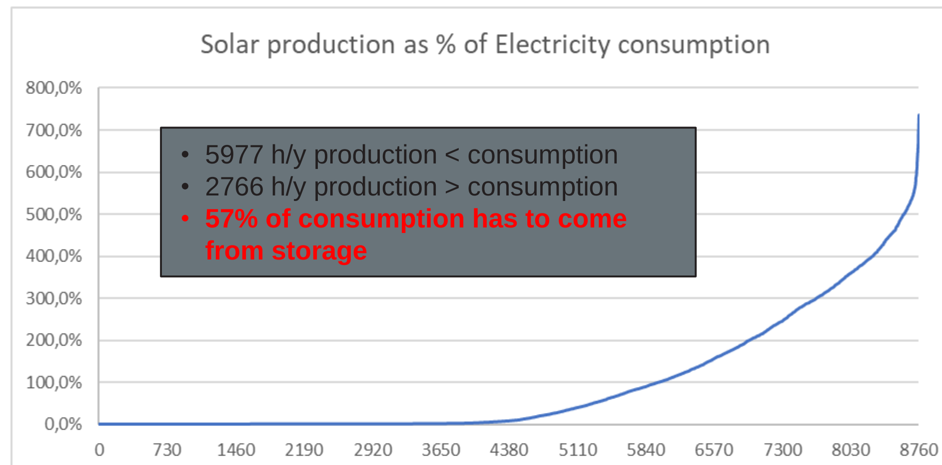
Electricity versus H_2

“electricity storage”

based on electricity consumption and wind and solar generation in DK, GER, NL, GB, BE, FR

- Wind and solar do not match today’s electricity consumption





- Large amounts of electricity have to be stored or consumption has to be able to follow production. Otherwise, other electricity generation systems have to create a back-up (nuclear, bio-mass, etc.)

Electricity versus H_2

"electricity storage"

- What is typically required for storage?
  - Wind is fluctuating between 8% and 366% of the consumption
  - Amount of required storage volume is approx. 12 days average daily consumption = 100 TWh for Europe (at todays electricity consumption)
    - As hydrogen, this means 6 million ton of hydrogen;
      at 700 bar this is 160 million m^3 (> 100000 Olympic swimming pools)
    - As Storage in batteries 1 billion batteries of 100 kWh (a Tesla car has a battery of 100 kWh)
    - As pumped Hydro (assume dH = 100 m) requires 408 billion m^3
    - Demand side response; this might help but large industrial consumers will not be able to operate between 8% and 366%; this would require massive over-capacities

Electricity versus H_2

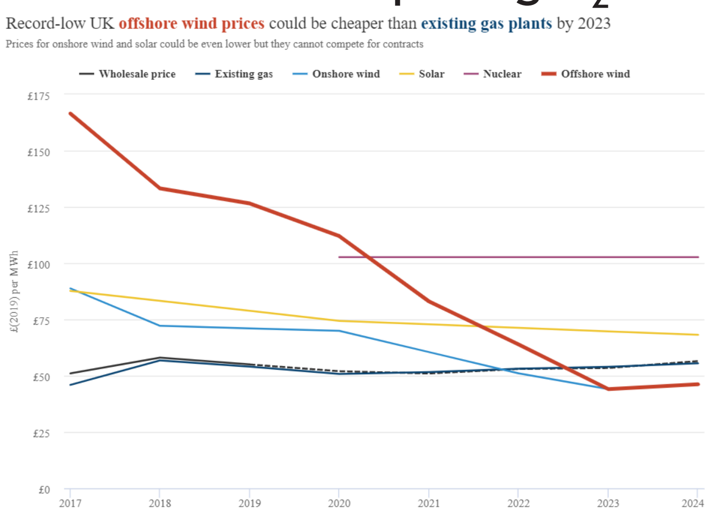
“electricity storage”

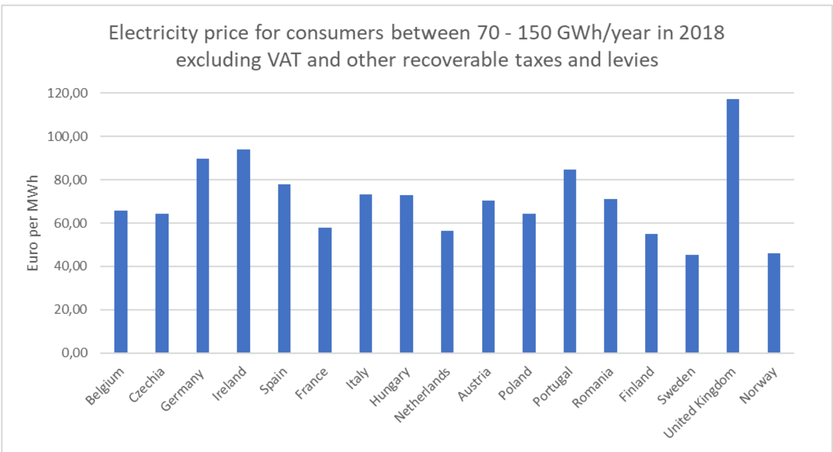
- If “electricity storage” is done via H_2, efficiency is rather low
  - One needs 65 kWh to produce high pressure H_2: efficiency is 52%
  - The H_2 has to be stored
  - After that, H_2 has to be converted into electricity: efficiency 50%
  - **Overall efficiency <26%: 3.9 TWh required to produce in the end 1 TWh Highly inefficient**

Levelling excess solar/wind electricity via H_2 storage and converting back to electricity is not very efficient. But it might be an option to store large amounts for long periods of limited wind/sun.

Some economics;
H_2 via electrolysis

- Electrolysis incl. compression requires approx. 65 - 68 kWh/kg H_2
- Electricity price for large consumers in Europe 45 -118 Euro/MWh
- Best wind contracts now approx. 50 Euro/MWh[1)]
- Variable cost per kg H_2 : 3 – 8 €/kg

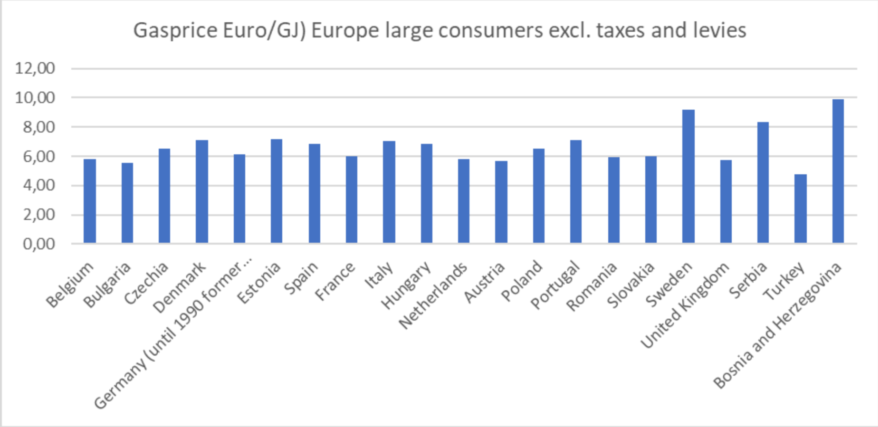




1) See: https://www.carbonbrief.org/analysis-record-low-uk-offshore-wind-cheaper-than-existing-gas-plants-by-2023

Some economics;
H_2 via methane reforming

- Gas input per kg H_2: 159.2 MJ/kg[1)]
- Electricity output: 1.1 kWh/kg H_2[1)]
- Gas price for large consumers in Europe 4.8 -9.9 Euro/GJ
- Electricity price for large consumers in Europe 45 -118 Euro/MWh
- Variable cost per kg H_2 : 0.7 – 1.4 €/kg
- CO_2 emission is 9.06 kg CO_2/kg H_2



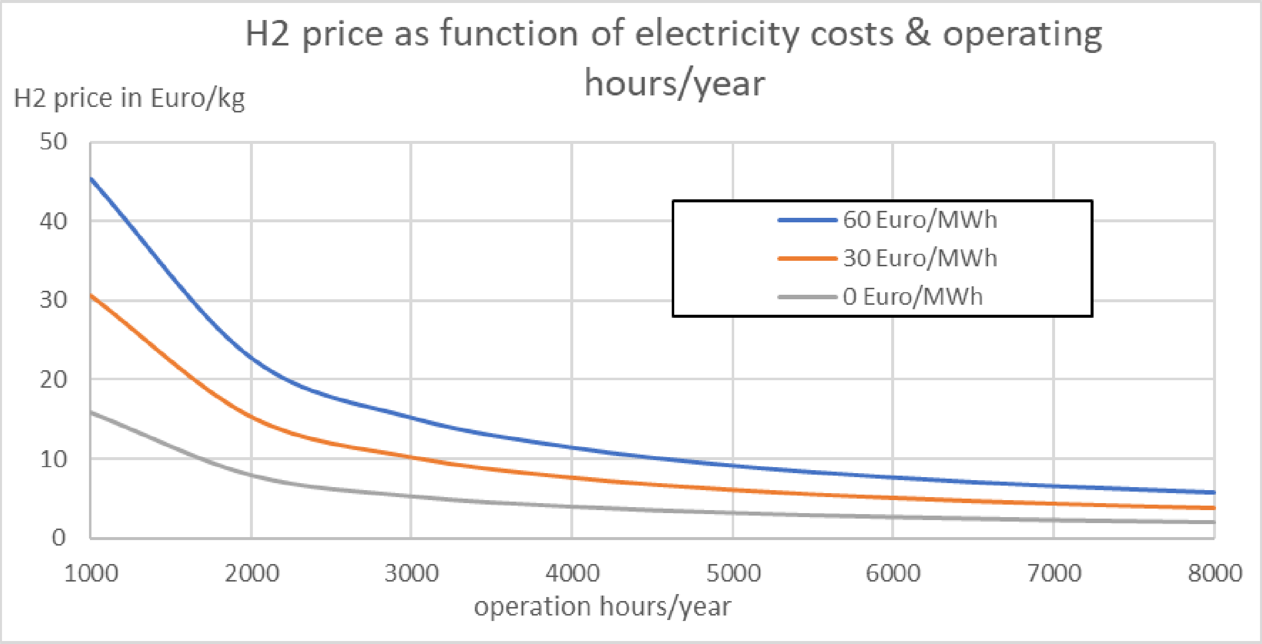
[1)] See: http://documents.ieaghg.org/index.php/s/HKtMncwfw2vaBxl/download)

Some economics: comparison

- Variable costs via electrolysis: 3 – 8 €/kg H_2
- Variable costs via methane steam reforming: 0.7 – 1.4 €/kg H_2
- Delta: 2.3 – 6.6 €/kg H_2
- CO_2 emission: 9.06 kg CO_2/kg H_2
- CO_2- costs: 253 -728 Euro per ton CO_2
- Actual CO_2 price around 16 -29 Euro/ton

Some economics, partial operation of electrolysis

- Some see that the electrolysis will only operate when there is excess sun/wind electricity
  - Logic at those times this electricity is for "free"
- But there is a huge conflict due to the cost of capital



Hydrogen from Electrolysis

- Hydrogen from electrolysis is from an efficiency point of view not the best solution
- It requires huge amounts of carbon-neutral electricity (65-68 kWh/kg for hydrogen at 350-700 bar)
- Hydrogen from electrolysis is only attractive when electricity prices are in the range of 10 Euro/MWh
- Do we have enough carbon-neutral electricity at this low price?

Environmental aspects o: ‘green’ electrolysis hydrogen

Water consumption:

Hydrogen generation entails a considerable water consumption. Chemically, in the conversion of methane to hydrogen some 4.5 litres of water are used per kilogram of hydrogen produced, but, due to excess steam, in the overall process the quantity is likely to be very much higher.
The IEA reports that SMR without carbon capture requires 7 litres of water per kilogram of hydrogen, and Lampert et al. of the Argonne National Laboratory in the United States report 11.7 litres per kilogram of hydrogen produced at centralised, larger-scale SMR, and 22 litres per kilogram at smaller, distributed plants.

The addition of carbon capture would increase water consumption, (CCS would require an additional 1.9 litres per kilogram of hydrogen giving a figure of about 13.6 litres per kilogram of hydrogen overall.

Environmental aspects o: ‘green’ electrolysis hydrogen

Water consumption:

For electrolysis, the IEA reports that 9 litres of water are required per kilogram of hydrogen.
Information provided by a manufacturer of electrolysers estimated the water cost on the basis of a consumption of 28 litres per kilogram of hydrogen…

Safety

General thoughts: ‘green’ versus ‘climate-neutral’

In the long term, all climate-friendly, sustainable (or climate-neutral) technologies providing hydrogen will be needed and should be considered: The enormous hydrogen demand expected in the future prohibits the exclusion of suitable technologies.

- Hydrogen from chlor-alkali electrolysis - provided the power supply is green - has the same regenerative quality as hydrogen from green electricity-powered water electrolysis.
- Same is valid for hydrogen from biomethane by steam reforming or from other processes where hydrogen is generated as a co-product.
- Also, hydrogen produced during processing of biogenic or recycled raw materials in ethylene crackers meets these requirements.
- Correspondingly produced cracker methane can also be processed into sustainable hydrogen through reforming.
- Methane pyrolysis enables climate-friendly H2 production even when fossil natural gas is used as the carbon introduced through natural gas is transformed into solid from.

General thoughts: ‘green’ versus ‘climate-neutral’

- In the case of the use of biomethane instead of natural gas as a starting product, methane pyrolysis can even be used as a greenhouse gas sink.

A restricted focus on water electrolysis should therefore be avoided. Alternative hydrogen sources, such as chlor-alkali electrolysis, methane pyrolysis and steam reforming or other processes using biogas and/or CCS/CCU technology (storage/use of the resulting carbon dioxide) should be considered together with water electrolysis in a balanced, technology-open manner.

The decisive factor should be the carbon footprint of hydrogen production. Furthermore, a technology-open approach to barrier-free connectivity to a future global hydrogen market.

National and European hydrogen strategies should avoid an exclusive focus on "green" hydrogen from water electrolysis only and should not eliminate but enable in the longer term competition with alternative low-greenhouse gas sources for hydrogen.