POWER-TO-GAS – P2G

An introductory guide to technologies and applications

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PRESENTATION OVERVIEW AND GOAL

1. Overview of the hydrogen production technologies – not only P2G application
2. Overview of the hydrogen production costs
3. P2G's role in the energy systems of the future

To goal is to introduce and start the discussion within the Contracting Parties about hydrogen technologies and P2G

1) Overview of the H_2 production technologies

Current Large Scale – Hydrocarbon based

1) Steam methane reforming – SMR
$CH_4 + H_2O(+heat) \rightleftharpoons CO + 3\ H_2$
natural gas or other + pressurized steam → synthesis gas
Subsequently water-shift gas reaction
$CO + H2O \rightarrow CO2 + H2$ (+ small amount of heat)

- Majority of H_2 produced today
- Carried out in refineries, very CO_2 intensive (ca 1t H_2 : 9t of CO_2

2) Autothermal reforming - ATR
$2CH_4+O_2+CO_2 \rightarrow 3H_2+3CO+H_2O$(+heat) or
$4CH_4+O_2+2H_2O \rightarrow 10H_2+4CO$

3) Coal Gasification
3C (i.e., coal) + O2 + H2O → H2 + 3CO
Subsequently water-shift gas reaction

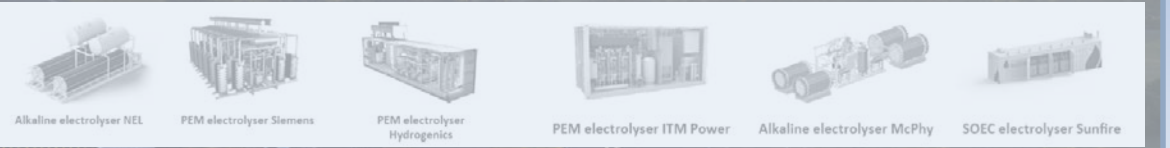
- 4 times more CO_2 than ATR

CCS is needed to make them less GHG intensive; electrolysis can be used to produce O_2

Electrolysis ADD pyrolisys somewhere

1) Alkaline Electrolysis – AEL
"uses a saline solution to separate hydrogen from water molecules by applying electricity"
(Hydrogen Council)

2) Proton-exchange Membrane – PEM
"PEM is slightly less mature and uses a solid membrane to separate the hydrogen



3) Solid Oxide Electrolysis – SOEC
hydrogen production by high temperature electrolysis of steam

GHG intensity mix of the used electricity defines the GHG intensity of the hydrogen: green hydrogen, blue hydrogen, grey hydrogen.

***Nota bene*, H_2 generated by electrolysis can also be *grey*!**

Sources: https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming; https://www.epa.gov/sites/production/files/2015-02/documents/subpartp-tsd_hydrogenproduction.pdf; Path to hydrogen Competitiveness – Hydrogen Council; Gasification of Unconventional Feedstocks – Speight; https://hydrogeneurope.eu/sites/default/files/Hydrogen%20Europe_2x40%20GW%20Green%20H2%20Initative%20Paper.pdf

1) Overview of the H_2 production technologies II

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Pyrolysis – H_2 production from CH_4

“Pyrolysis is a process of chemically decomposing organic materials at elevated temperatures in the absence of oxygen” (Azocleantech)

Produces hydrogen and coal

e.g.:

1) **Kværner process**

Endothermic reaction. In a plasma burner at 1.600C without the presence of oxygen separates C and H from C_nH_n

2) ***continuous catalytic Chemical Vapor Deposition – ccCVD – experimental***

Produces carbon nanotubes

Carbon can be used as by-product in high-tech industry

Methanation of Hydrogen – CH_4 production from H_2

1) Thermocatalytic Methanation

2) Biological Methanation

Possible continuation of electrolysis

Expensive but current natural gas infrastructure, appliances and power generation infrastructure and can be used without modification

Don’t use CH_4 produced from H_2 to produce CH_4 !! !-O

Sources: https://www.azocleantech.com/article.aspx?ArticleID=336; Carbotopia presentation FSR online WS on very-low/decarbonized hydrogen from natural gas 15 April 2020

1) Overview of the H_2 production costs

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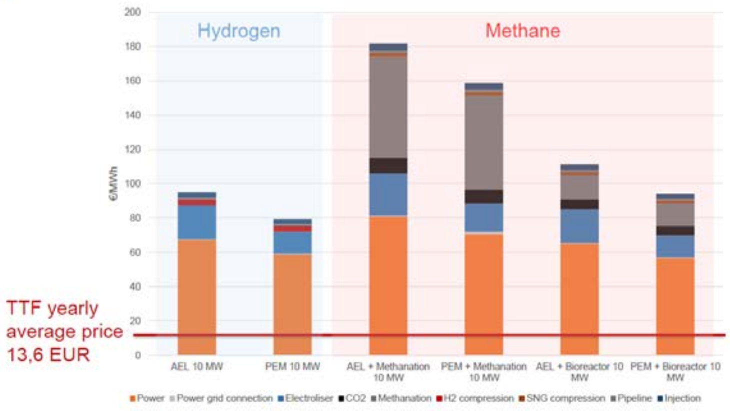
COSTS

REKK calculation on the LCOE values of the P2M process – German wholesale market 2019

REKK



- **Electricity price and load factor based on 2019 German market characteristics**
- Optimal load factor: 7354 hours
- Average power price: 31 EUR/MW
- CO_2 price: 50 EUR/ton
- The LCOE value is lower by around 10 EUR for all technologies.

Source: REKK

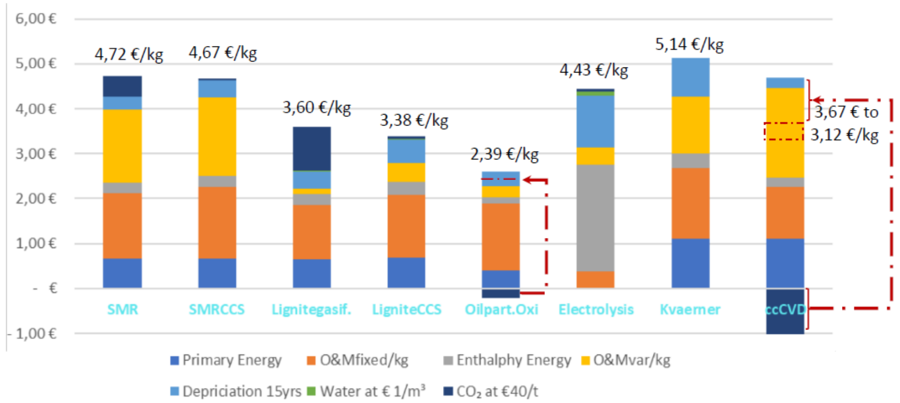
Note: 96 EUR/MWh = 3,2 EUR/kg 1kg H_2 contains 33,33 kWh

Source: THE ROLE OF POWER TO GAS IN THE ENERGY VALUE CHAIN AND THE LCOE VALUES OF DIFFERENT P2G SOLUTIONS – Á. Törőcsik – REKK – Power To Gas Forum, Budapest 18 February 2020

Hydrogen production by electrolysers*	Capex (€/kW)	OPEX %/yr Capex	System Efficiency (HHV**)	Electricity (4.000-5.000hr) (€/MWh)	Hydrogen (€/kg)
2020-2025	300-600	1.5%	75-80%	25-50	1.5-3.0
2025-2030	250-500	1%	80-82%	15-30	**1.0-2.0**
Up to 2050	<200	<1%	>82%	10-30	0.7-1.5

*Hydrogen production cost for hydrogen delivered at 30 bar pressure and 99,99% purity
**HHV = Higher Heating Value

Source: Green Hydrogen for a European Green Deal A 2x40 GW Initiative – (Wijk, Chatzimarkakis) Hydrogen Europe



Source: Carbotopia presentation FSR online WS on very-low/decarbonized hydrogen from natural gas 15 April 2020

1) Overview of the H_2 production technologies

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COSTS Continued

Exhibit 14 | Renewable hydrogen from electrolysis production cost scenarios[5], USD/kg hydrogen

Cost of renewable hydrogen with varying LCOE and load factors
USD/kg H_2

■ < USD 2/kg ■ USD 2-3/kg ■ USD 3-4/kg ■ > USD 4/kg ⬚ Viable medium-term (<2030)

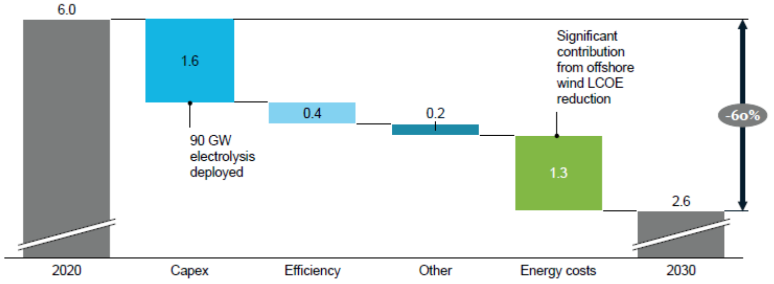
LCOE \ Capex electrolyser	USD 750/kW					USD 500/kW					USD 250/kW				
UDD 0/MWh	5.7	2.8	1.9	1.4	1.1	4.2	2.1	1.4	1.1	0.9	2.8	1.4	0.9	0.7	0.6
USD 10/MWh	6.1	3.3	2.4	1.9	1.6	4.7	2.6	1.9	1.5	1.3	3.2	1.9	1.4	1.2	1.0
USD 20/MWh	6.6	3.8	2.8	2.4	2.1	5.2	3.0	2.3	2.0	1.8	3.7	2.3	1.9	1.6	1.5
USD 30/MWh	7.1	4.2	3.3	2.8	2.5	5.6	3.5	2.8	2.5	2.2	4.2	2.8	2.3	2.1	2.0
USD 40/MWh	7.5	4.7	3.8	3.3	3.0	6.1	4.0	3.3	2.9	2.7	4.6	3.2	2.8	2.6	2.4
USD 50/MWh	8.0	5.2	4.2	3.7	3.5	6.5	4.4	3.7	3.4	3.2	5.1	3.7	3.2	3.0	2.9
USD 100/MWh	10.3	7.5	6.5	6.1	5.8	8.9	6.7	6.0	5.7	5.5	7.4	6.0	5.6	5.3	5.2
Load factor	10%	20%	30%	40%	50%	10%	20%	30%	40%	50%	10%	20%	30%	40%	50%

SOURCE: McKinsey

Source: Path to hydrogen Competitiveness – Hydrogen Council

Exhibit 13 | Renewable hydrogen from electrolysis cost trajectory

Cost reduction lever for hydrogen for electrolysis[1] connected to dedicated offshore wind in Europe (average case)
USD/kg hydrogen



1. Assume 4,000 Nm3/h (~20 MW) PEM electrolysers connected to offshore wind, excludes compression and storage
2. Germany assumed

SOURCE: H21; McKinsey; Expert interview

Capex decreases ~60% for the full system driven by scale in production, learning rate, and technological improvements.

Increasing system size from ~2 MW to ~90MW.

Efficiency improves from ~65% to ~70% in 2030.

Other O&M costs go down following reduction in parts cost and learning to operate systems.

Additionally, storage may become cheaper (not included).

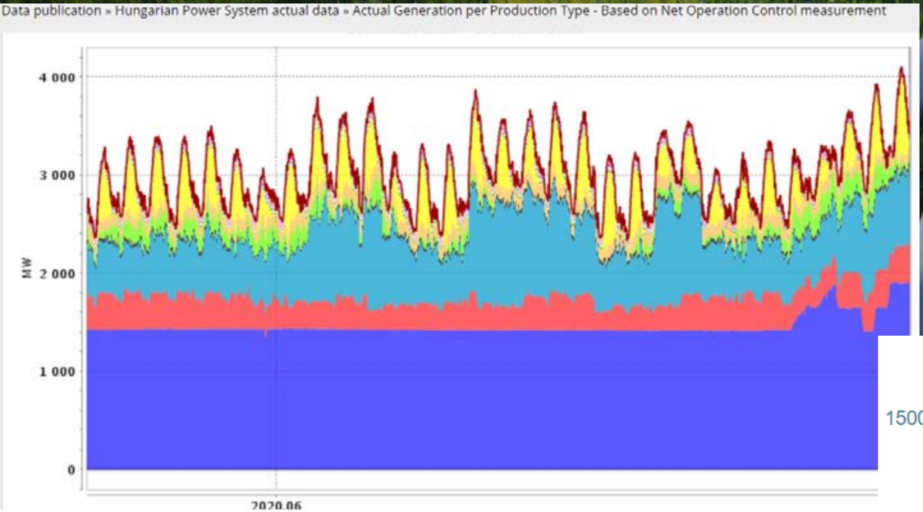
Energy costs[2] offshore wind LCOE decreases from 57 to 33 USD/MWh, and is assumed to be dedicated to hydrogen production.

Grid fees decrease from ~15 to 10 USD/MWh.

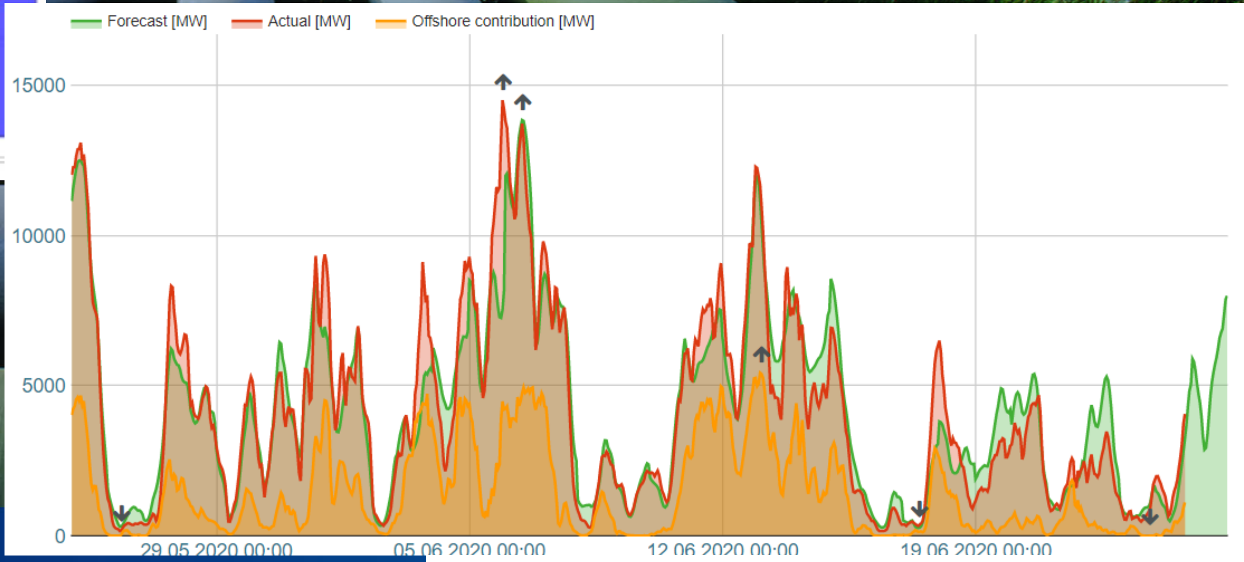
Load factor of 50%, i.e. ~4,400 full load hours equivalent.

2) P2G's role in the energy systems of the future

Grid Balancing and Frequency Management



Source: MAVIR.hu – Net Actual Generation by Production Type



Source: TENNET.eu - Actual and forecast wind energy feed-in-

This is just the beginning…

2) P2G's role in the energy systems of the future

SECTOR COUPLING

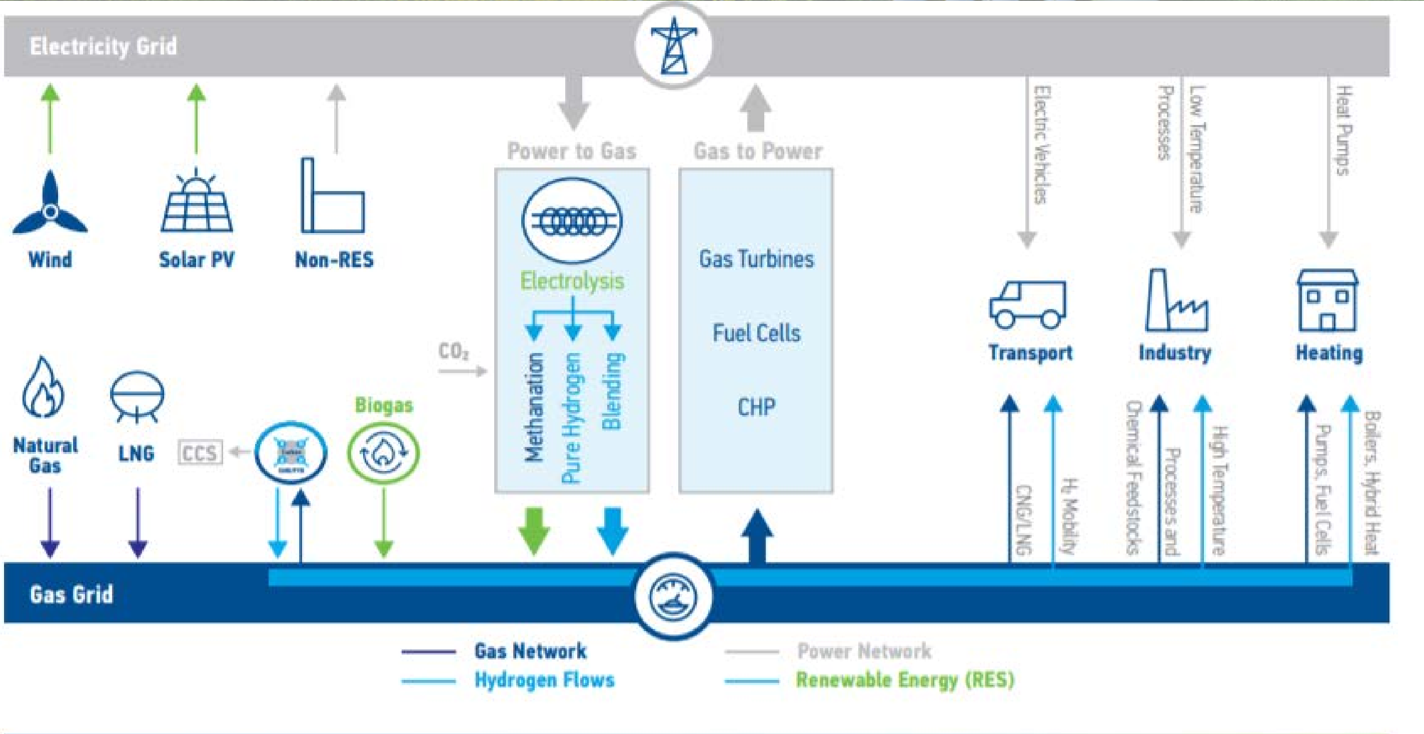


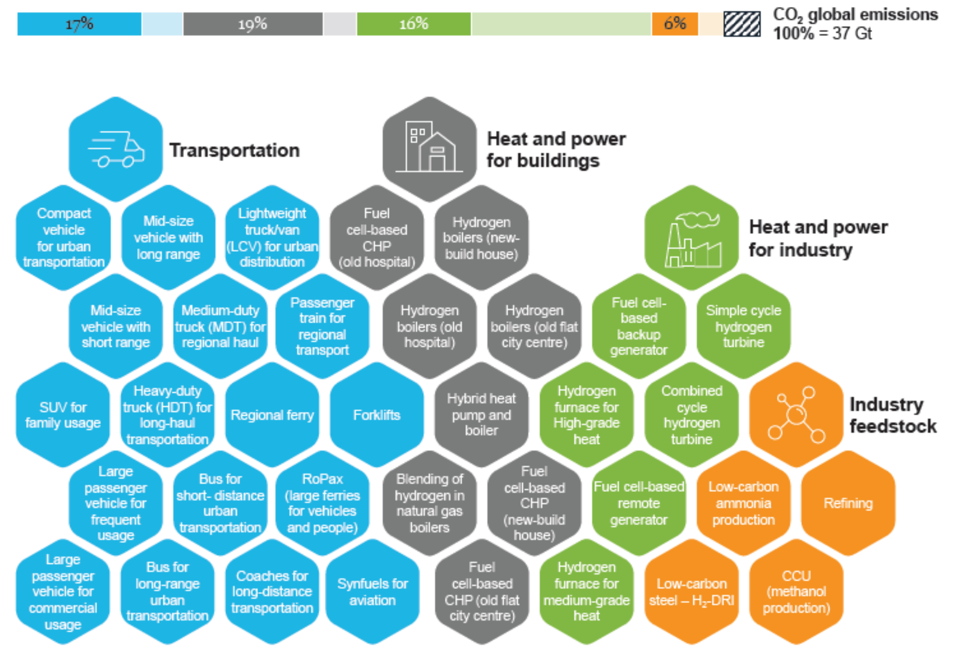
Figure 5: Hybrid Energy System, ENTSOG, 2019.

Source: ENTSOG 2050 Roadmap for Gas Grids

2) P2G's role in the energy systems of the future

OTHER USES

Exhibit 4 | Overview of hydrogen applications



In addition, hydrogen can also be used in, e.g.

Mobility: Container ships, tankers, tractors, container ships, motorbikes, tractors, off-road applications, fuel cell airplanes.

Other: Auxiliary power units, large scale CHP for industry, mining equipment, metals processing (non-DRI steel), etc..

Source: Path to hydrogen Competitiveness – Hydrogen Council

Hydrogen complements electrification and provides large potential for synergies between production, transportation and various utilizations.

Has the potential to contribute to the decarbonisation of power and gas systems, certain industrial processes and transport

Can ensure long-term utilization of the existing (modified?) gas grids

Note the challenges!

THANK YOU
FOR YOUR ATTENTION

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