Hydrogen in the Netherlands' energy transition

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First Hydrogen Conference, Centro Argentino de Ingenieros, 25 November 2021

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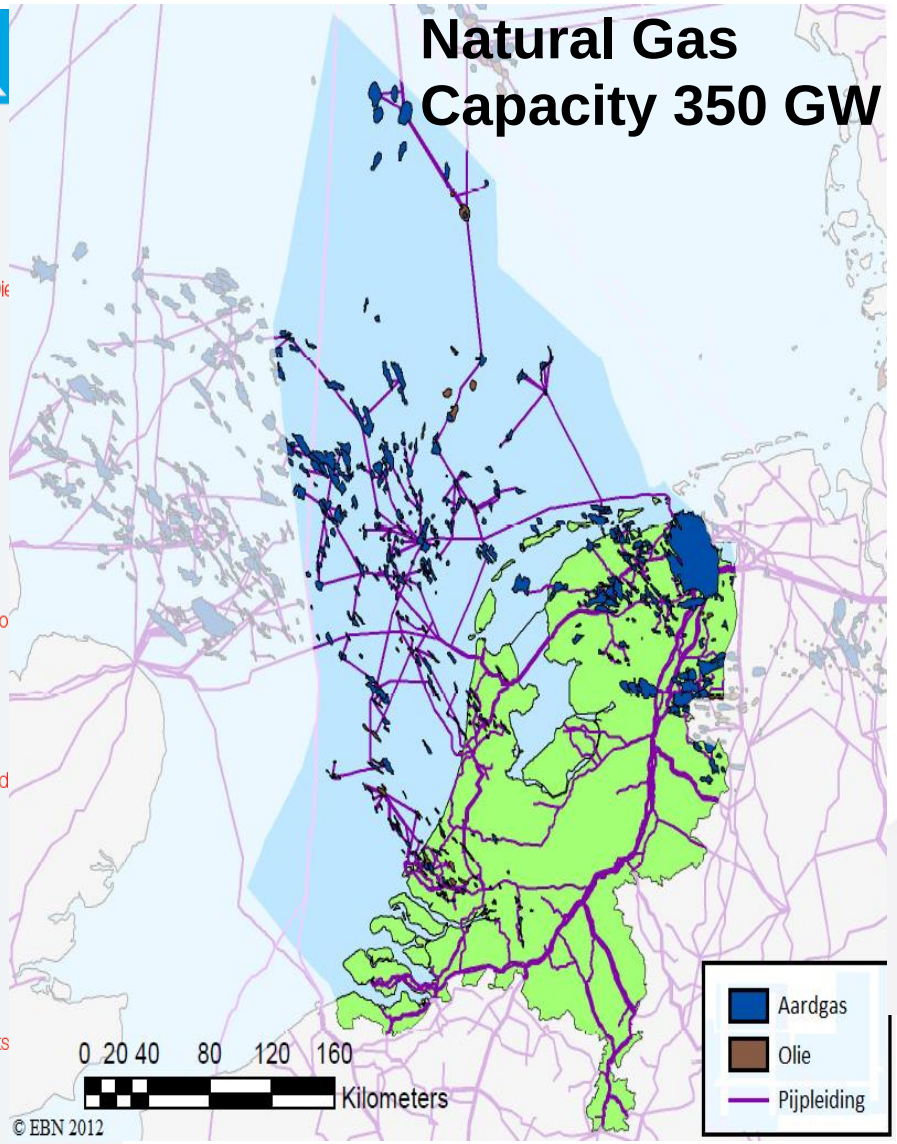
Electricity, Gas and Hydrogen Transport Grid

Electricity
Capacity 20 GW HV

Natural Gas
Capacity 350 GW



Hydrogen
Capacity 5-15 GW
Ready 2026

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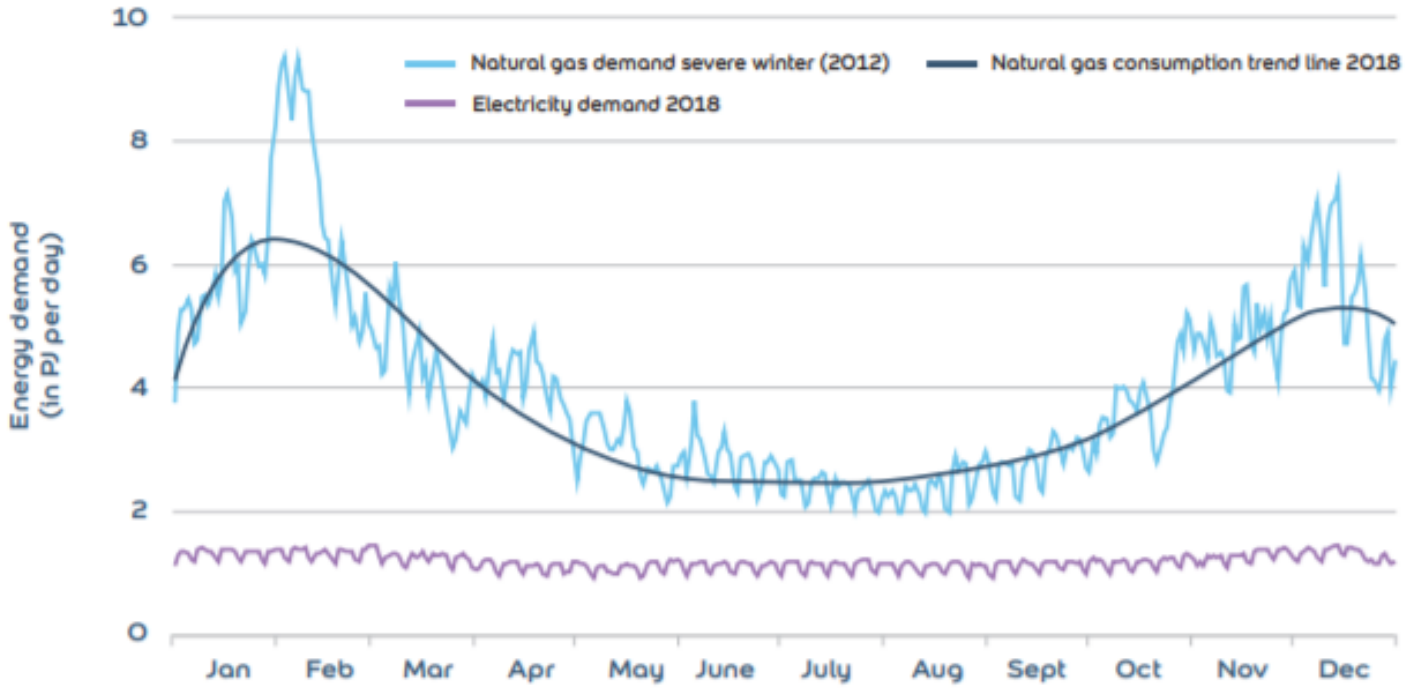
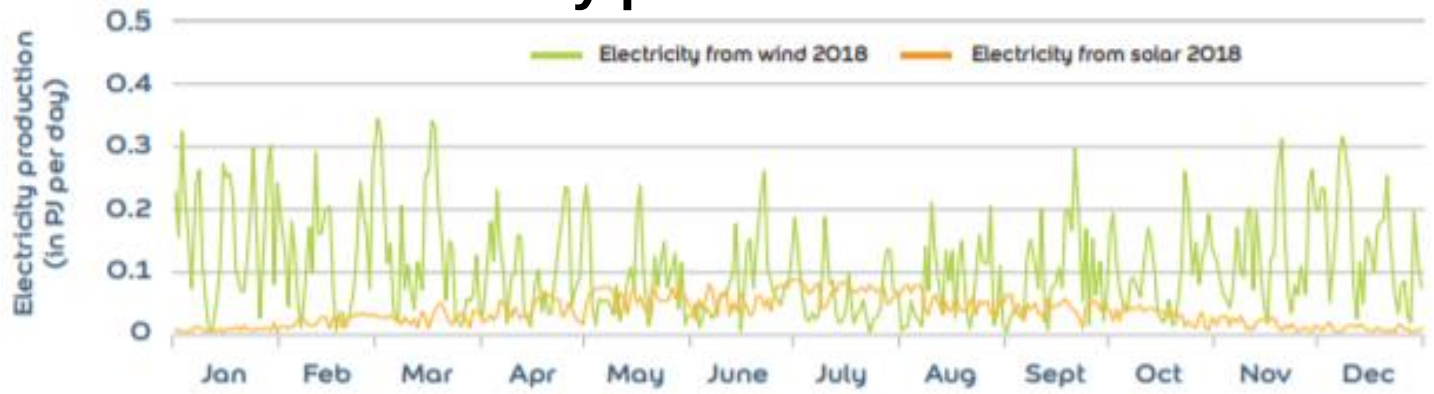
Gas and Electricity consumption in the Netherlands 2018



Solar and Wind electricity production in the Netherlands 2018

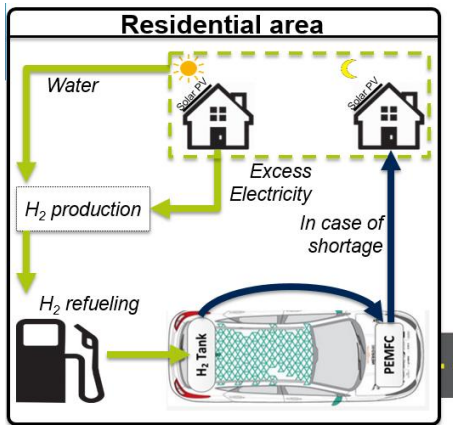


https://www.energieinnederland.nl/wp-content/uploads/2020/02/EBN-INFOGRAPHIC-2020-ENG.pdf

Hydrogen Markets

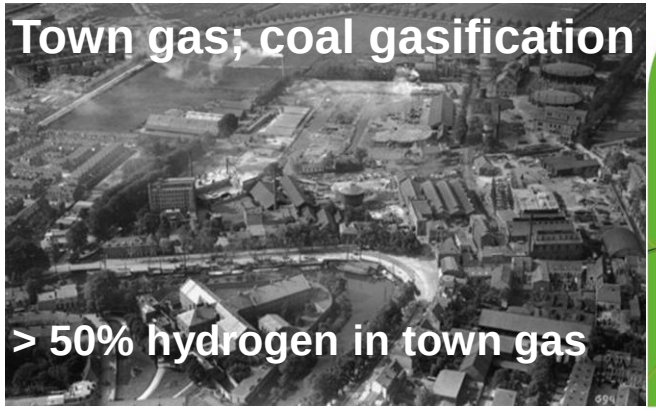
Industry Feedstock/HT Heat

Electricity Balancing



Transport

Heating



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Hydrogen, like electricity, is an energy carrier

Source	Process/Technology	Maturity	Main output	Colour of Hydrogen
Natural gas	Steam methane reforming (SMR)	Mature	$H_2 + CO_2$	**Grey/Blue**, depending on the capture technology and the process input energy 50-90% of CO_2 can be captured and stored.
	Auto-thermal reforming (ATR)	Mature	$H_2 + CO_2$	**Grey/Blue**, with ATR using part of the produced H_2 as energy for process heat, 100% CO_2 emission capture and storage is possible
	Methane Pyrolysis	Small plants operational	$H_2 + C$	**Turquoise**, indirect CO_2 emissions are zero if green electricity or part of the produced hydrogen is used as process energy
Coal	Partial Oxidation/Gasification	Mature	$H_2 + CO_2 + C$	**Brown/Blue**,
	Underground coal gasification	Projects exist	$H_2 + CO_2$	depending on the CCS technology 50-90% of CO_2 can be captured and stored.
Solid Biomass, Biogenic waste	Gasification	Near Maturity	$H_2 + CO_2 + C$	**Green**
	Plasma gasification	First Plant 2023	$H_2 + CO_2$	Negative CO_2 emissions possible
Wet Biomass, Biogenic waste	Super critical water gasification	First Plant 2023	$H_2 + CH_4 + CO_2$	**Green**
	Microbial Electrolysis Cell	Laboratory	$H_2 + CH_4$	Negative CO_2 emissions possible
Electricity + Water	Electrolysis			All shades of **grey to green** and **pink** depending on the source for electricity production.
	Alkaline	Mature	$H_2 + O_2$	
	PEM	Near Maturity	$H_2 + O_2$	With electricity from renewable resources, green H_2 and from nuclear, pink H_2 is produced, both with zero CO_2 emissions
	SOEC	Pilot Plants	$H_2 + O_2$	
Sunlight + Water	Photoelectrochemical	Laboratory	$H_2 + O_2$	**Green**

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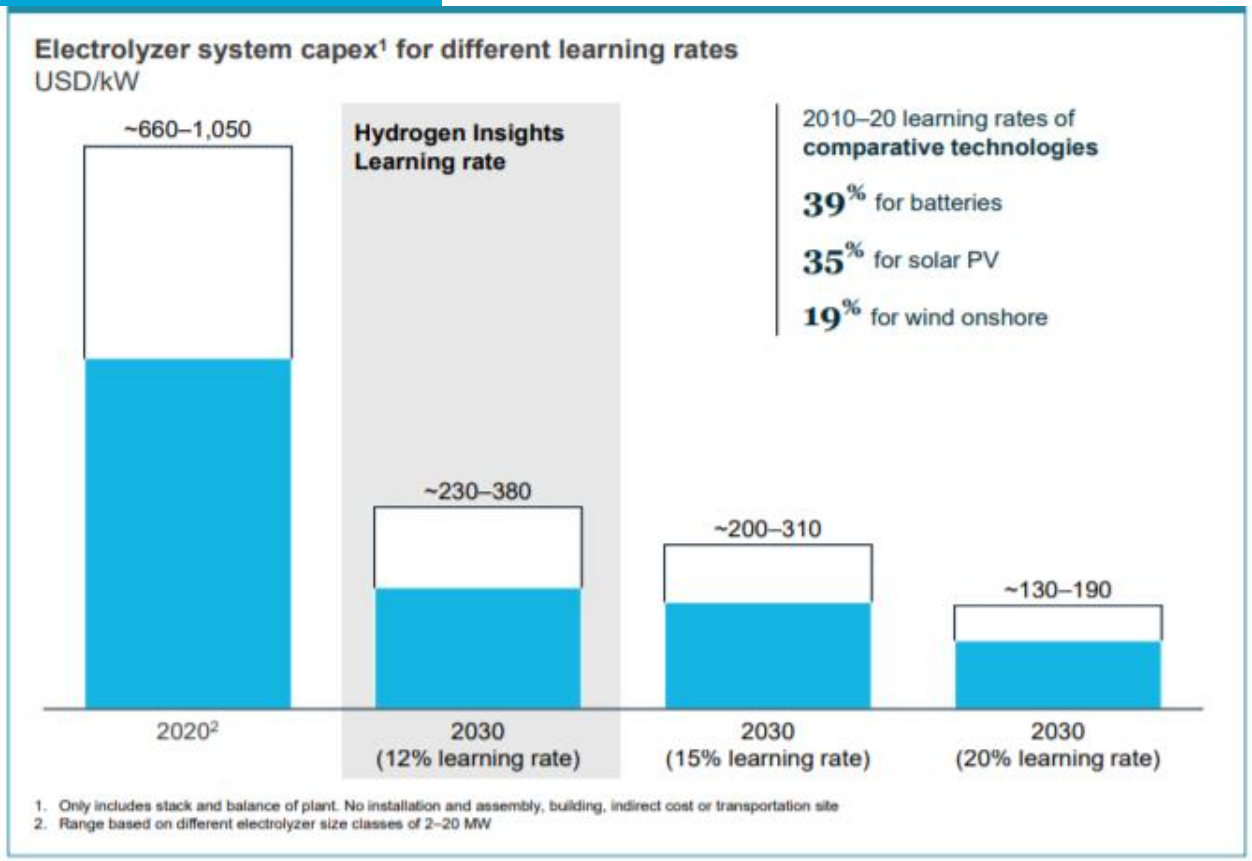
Technology structure electrolysers similar to solar PV, batteries, fuel cells



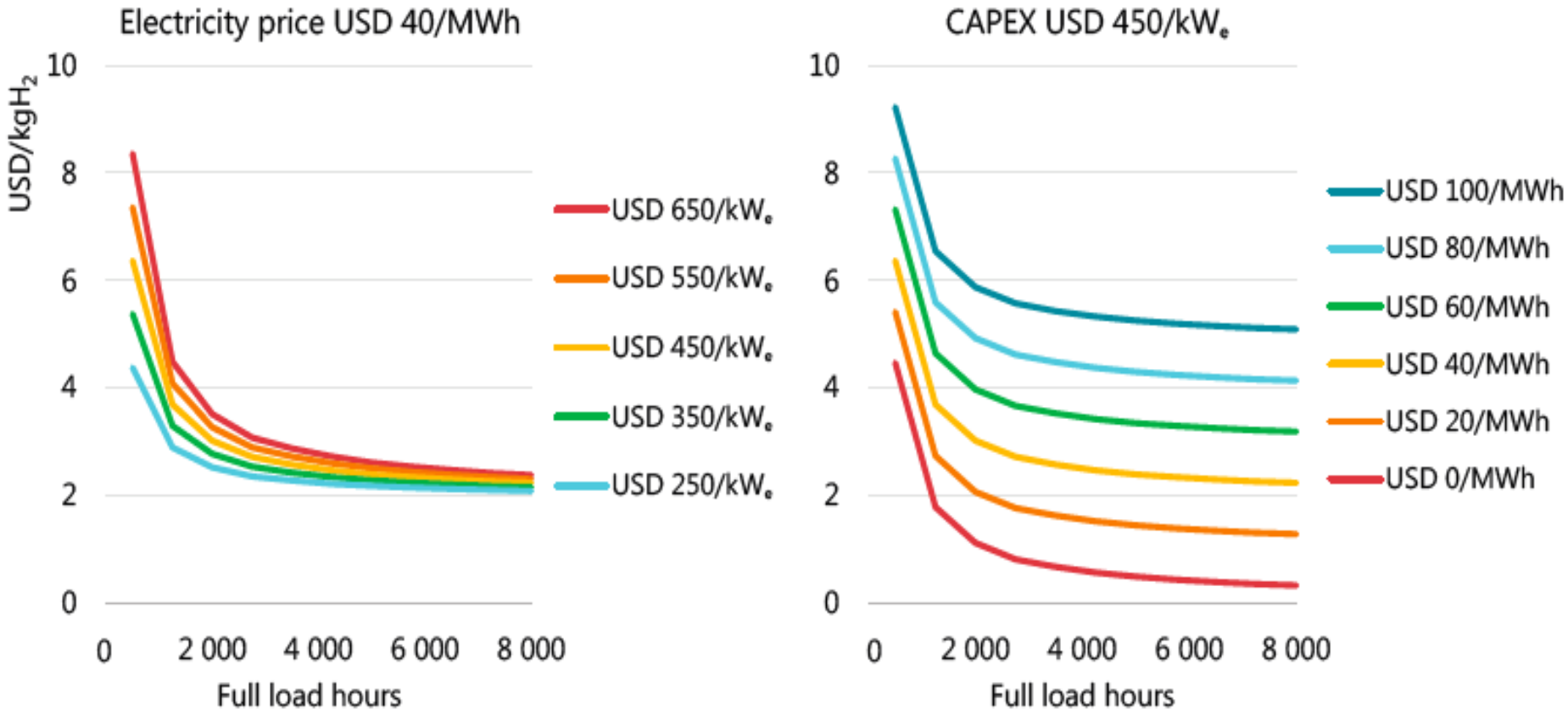
https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021.pdf

Technology structure:

- Cells as the fundamental production unit
- Cells are grouped or stacked together in modules or stacks as a physical production unit.
- A number of modules/stacks together with balance of plant equipment is the system production unit.
- These technologies do not have mechanical components and operates at low temperatures.
- Only balance of plant cost scale with system size, but module/stack or cell cost do not scale with system size.

Electrolyser technology learning rates expected in same range as solar PV and batteries
Mass production of cells and stacks will bring down Capex cost rapidly

Hydrogen production cost; LCoH



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Future levelized cost of hydrogen production by operating hour for different electrolyser investment costs (left) and different electricity costs (right) , from *The Future of Hydrogen (IEA 2019)* (LHV efficiency 69% is HHV efficiency 81%)

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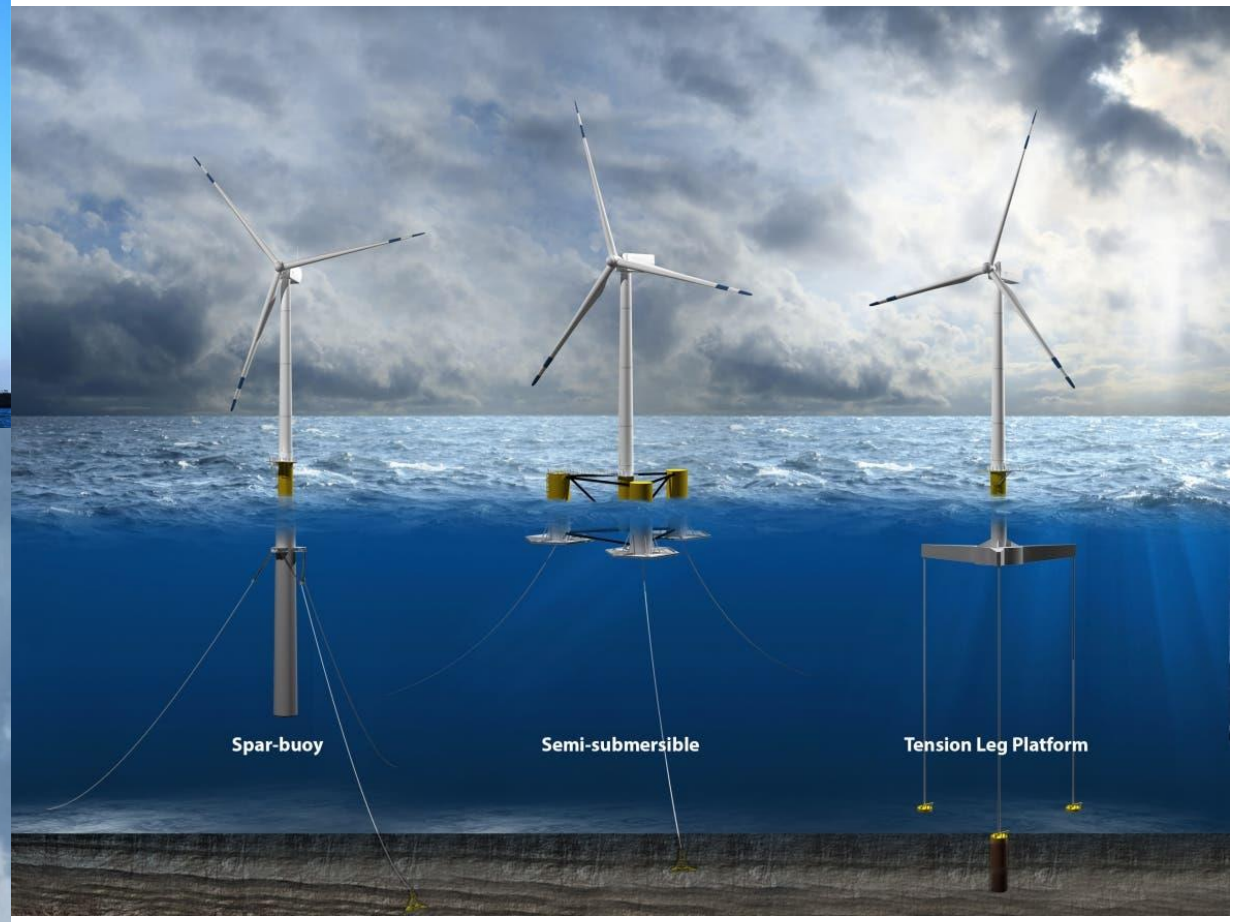
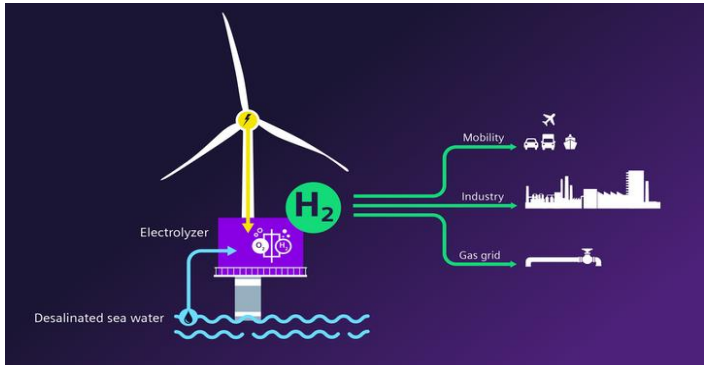
Offshore (Floating) integrated Wind-Hydrogen Turbines

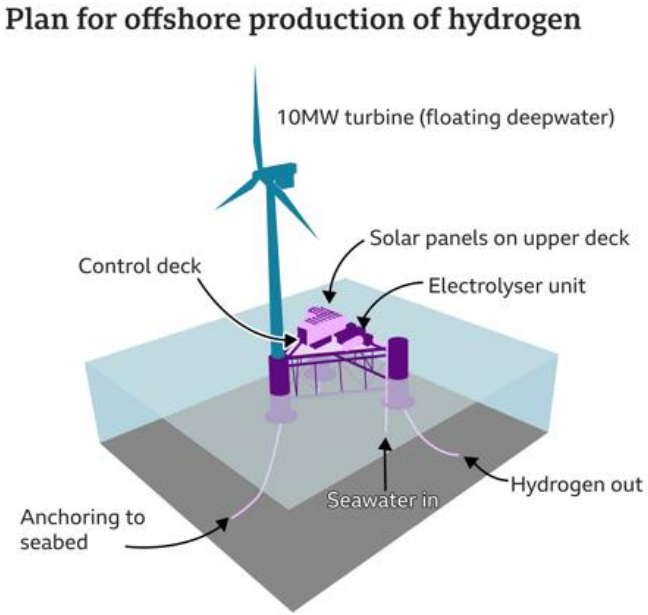
GE Haliade X 12-14 MW

SG 14-222 DD 14-15 MW





SiemensGamesa [SG 14-222 DD offshore wind turbine](#) 15 MW with electrolyser in turbine



ERM UK, 10 MW floating offshore wind turbine with electrolyser at turbine platform

Offshore wind-hydrogen turbine equal investment cost as Offshore wind-electricity turbine

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Offshore wind hydrogen projects in development

Aquaventus and Aquaductus (Germany)

- 10 GW offshore wind Hydrogen
- 1 million ton hydrogen (= 5.000 full load hours)
- Fully Operational 2035
- RWE, Equinor, Orsted, Boskalis + others
- Pipeline: Gascade, Gasunie, RWE, Shell
- Pipeline: connect to hydrogen backbone + salt cavern storage

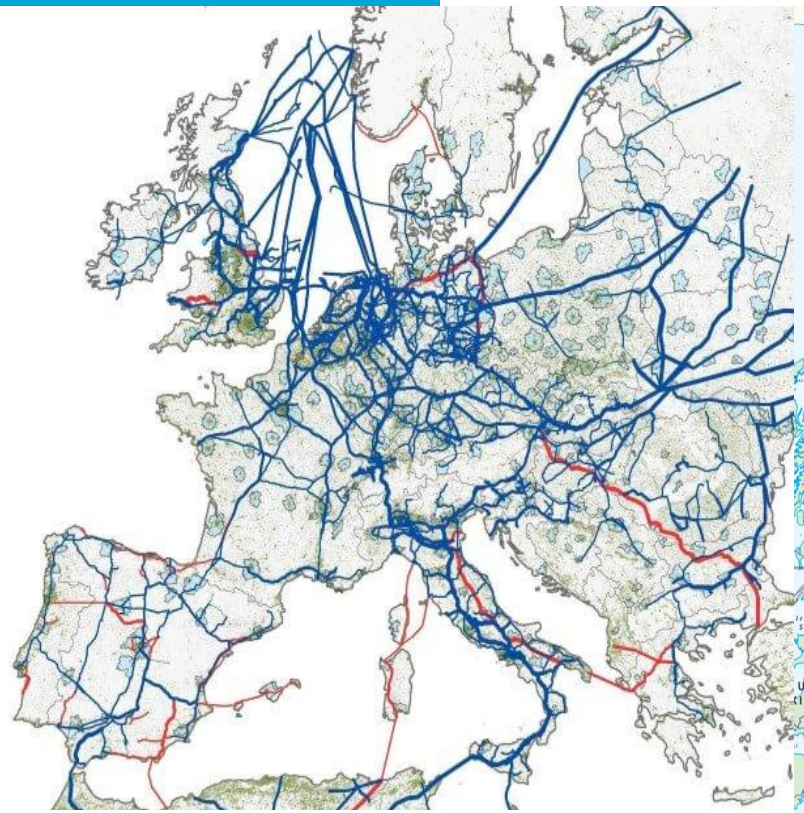
NortH2 (Netherlands)

- 10 GW offshore wind Hydrogen
- 1 million ton hydrogen (= 5.000 full load hours)
- 3-4 GW onshore electrolyser 2030 in Eemshaven
- 6-7 GW offshore electrolyser <2040
- Shell, Gasunie, Groningen Seaports, Equinor, RWE+ others
- Pipeline: Connect to Hydrogen backbone + salt cavern storage

Gas Infrastructure in Europe can be reused for hydrogen

Gas Pipeline Capacity 10-20 GW, Electricity cable capacity 1-2 GW

Gas transport cost roughly a factor 10 cheaper than electricity transport



Gas Pipelines Europe
Transporting gas from gas fields at North Sea, Norway, Russia, Algeria, Libya to Europe

Gas from North-Sea
2017 production
190 bcm = 1.900 TWh

Gas from North-Africa
60 GW Natural Gas Pipeline
2x0.7 GW Electricity Cable

European Hydrogen Backbone
75% re-used gas pipelines
25% new hydrogen pipelines
40.000 km pipelines

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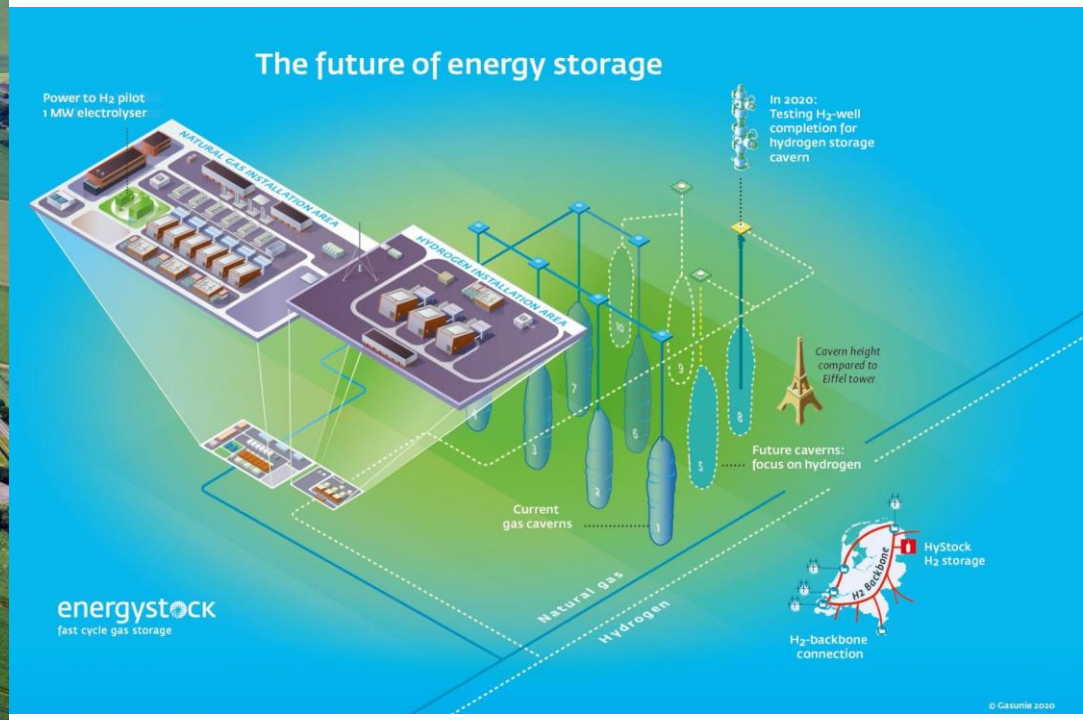
Hystock/Gasunie

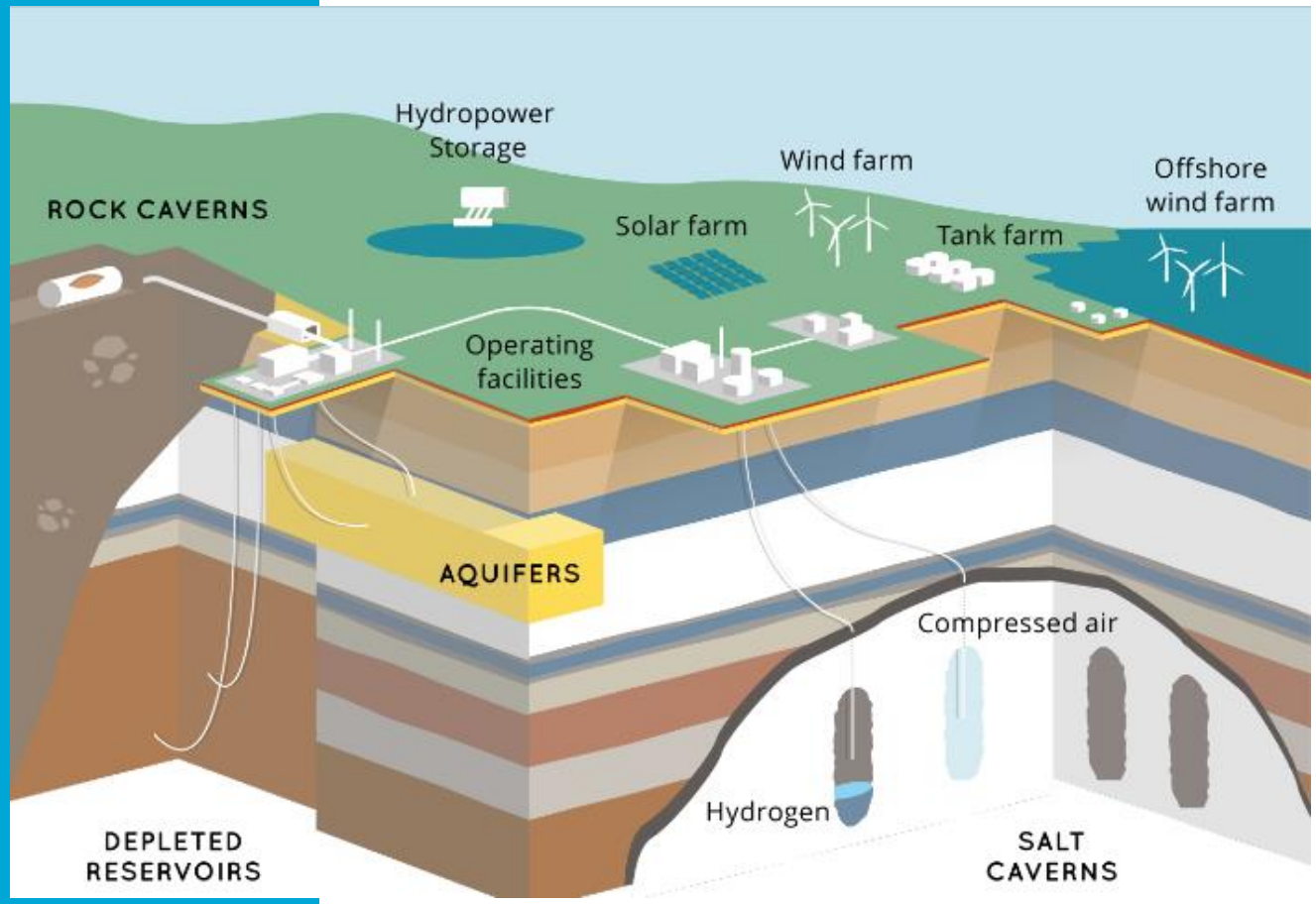
Salt Cavern Hydrogen storage



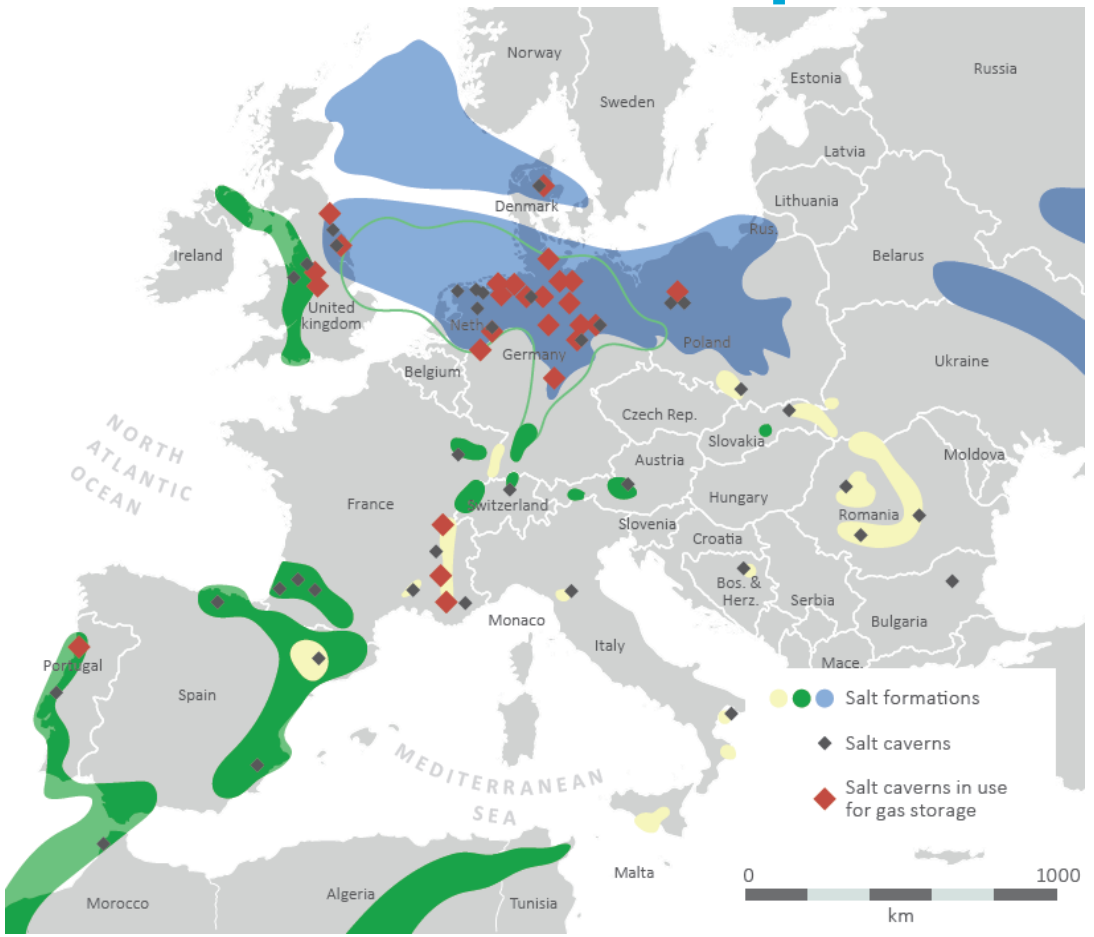
Zuidwending-Veendam 10 salt caverns, 5 in use for gas storage

Zuidwending-Veendam 10 salt caverns, 2 in preparation for hydrogen storage, ready 2026

Hydrogen storage in salt caverns



Salt formations and caverns in Europa

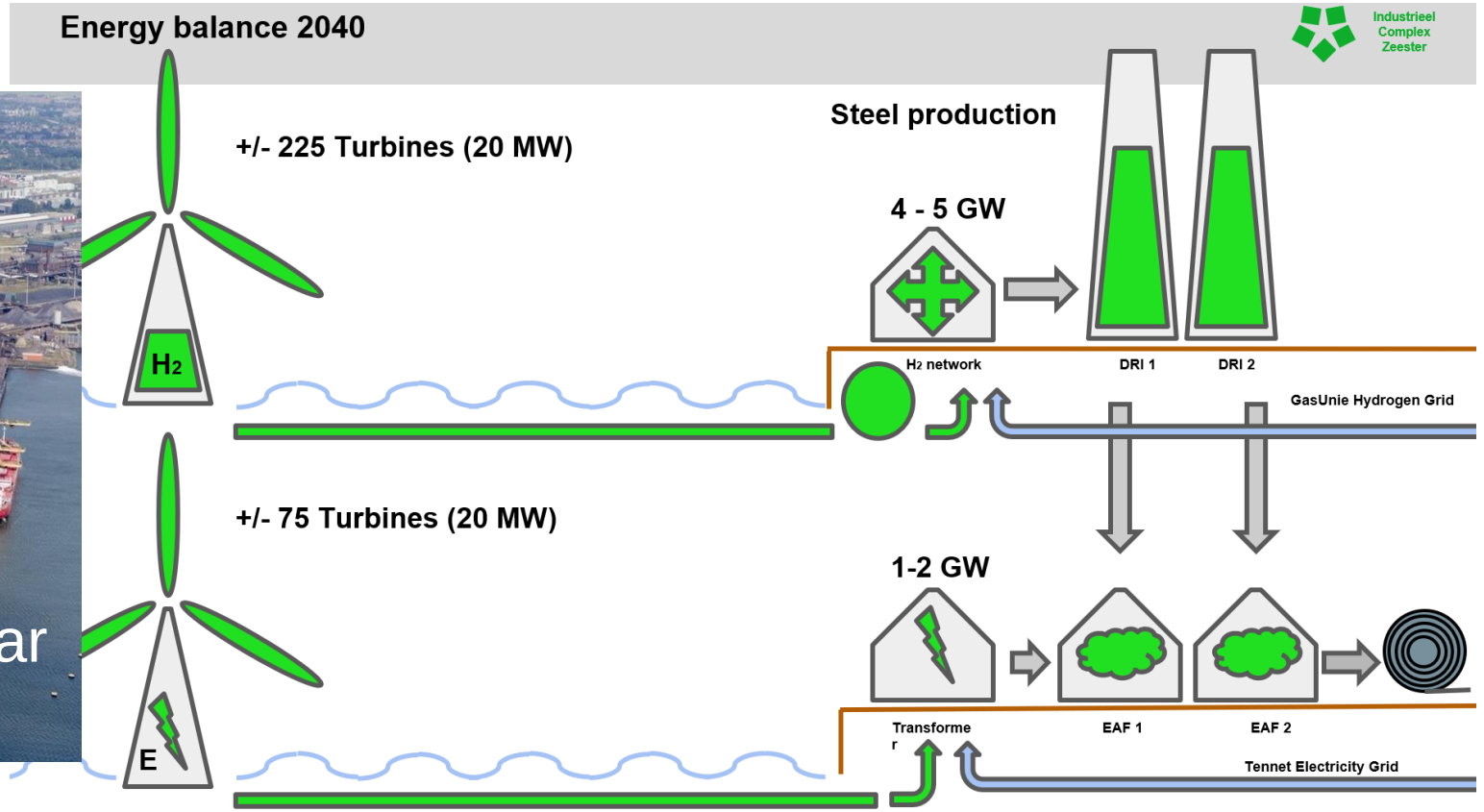


1 salt cavern can contain up to 6,000 ton (= 236.4 GWh HHV) hydrogen,
Salt Cavern CAPEX = 0.5 Euro per kWh, Total Salt cavern CAPEX is 100 million Euro

For comparison, with battery CAPEX 100 Euro per kWh, Total battery CAPEX would be 23.6 billion Euro

Tata Steel on green hydrogen, biogas and electricity

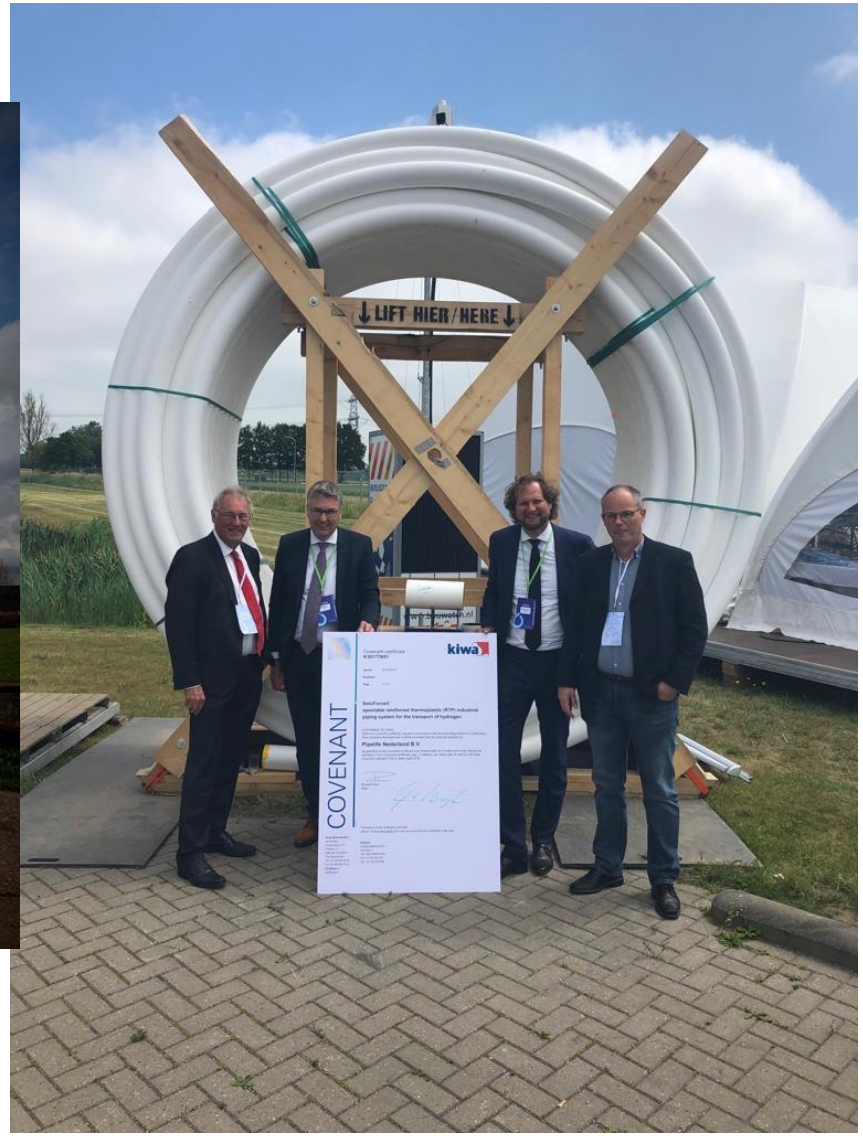
Offshore wind turbine require between 100-200 ton steel per MW



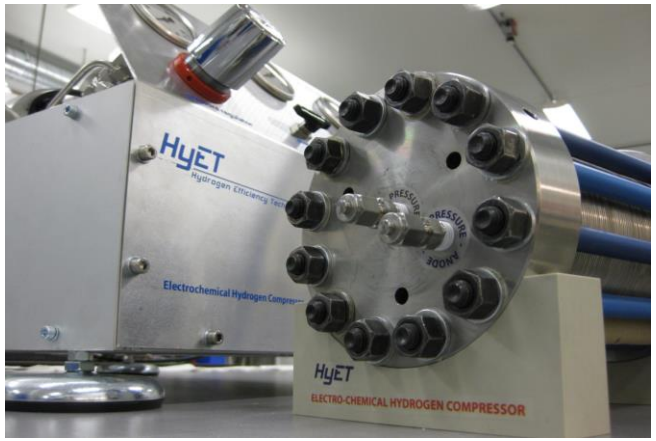
Tata Steel chooses for hydrogen 15-9-2021

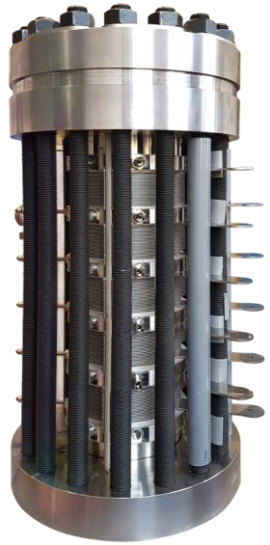
SoluForce

Flexible composite pipe for hydrogen transport



AMF Bakery Systems
Hydrogen Tunnel Oven





Hyet Hydrogen
Electrochemical hydrogen compressor and purification

Domestic heating with hydrogen boilers

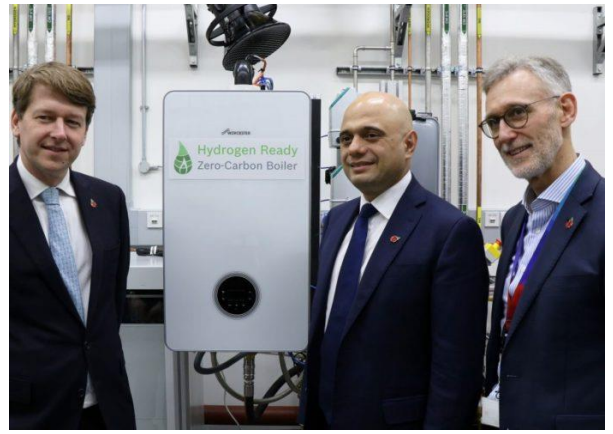
Remeha HYDRA

	Hydrogen	Natural gas	
CO_2	0	9	%
	0	190	g/kWh
	0	2500	kg/jaar*
CO	0	48	ppm
NOx	20	30	mg/kWh Hs
Efficiency**	115	108	% LCV
	97	97	% HCV
Output Heating	24	24	kW
Output DHW	28	28	kW

* At average gas consumption
** Tretour = 30°C, 30% load

Remeha:
Hydrogen boiler
(launched March 2019)
<<<

Worcester Bosch:
hydrogen ready boiler
(launched Nov. 2019)
>>>



Hyzon, JV Holthausen and Horizon, manufacturing Hydrogen Fuel Cell trucks

RESATO Assen
Hydrogen compressor for fuelling stations

Jos Scholman/New Holland, manufacturing diesel/hydrogen dual fuel tractor, with H2 injection in diesel engine

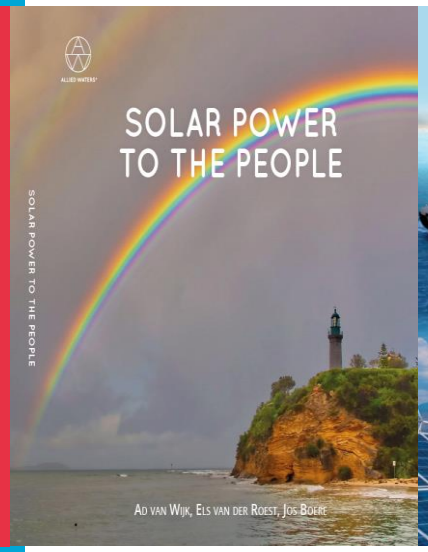
ZEPP Solutions
Building hydrogen fuel cell drive trains

And Our King drives on hydrogen October 2021

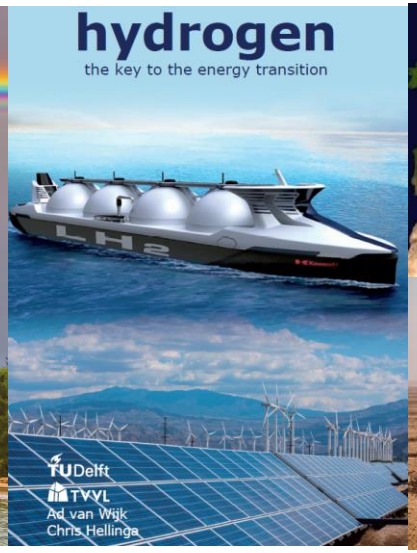
Thank you for your attention!

For further reading, see: www.profadvanwijk.com

April 2017



November 2017



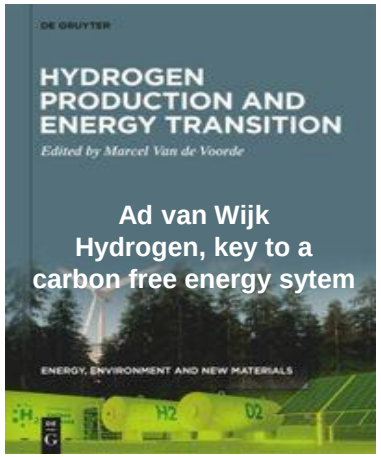
May 2018

September 2019

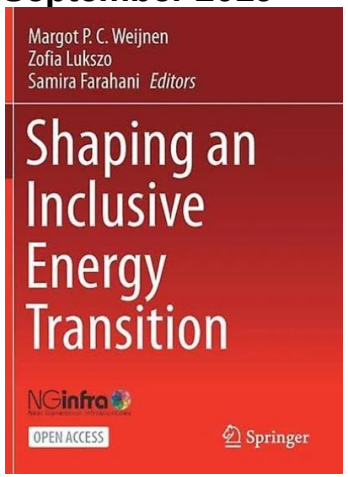
April 2020

April 2021

May 2021



September 2021



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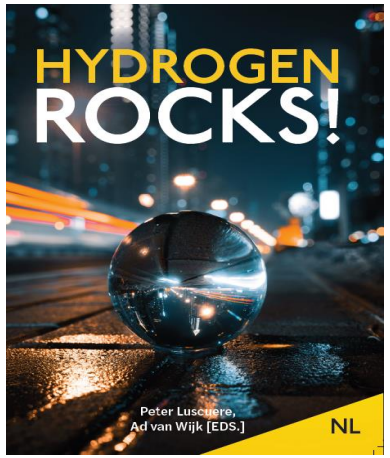

October 2021