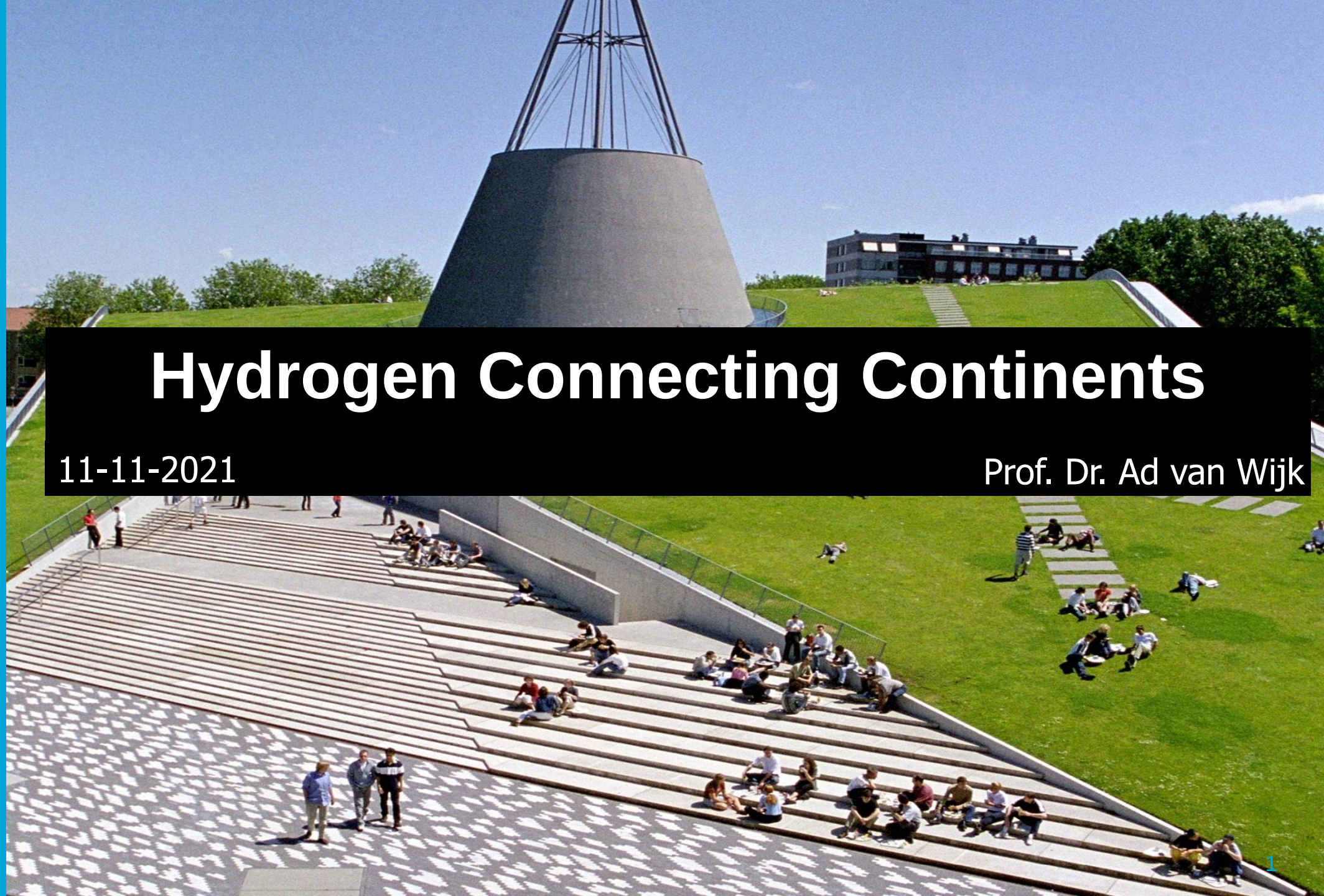


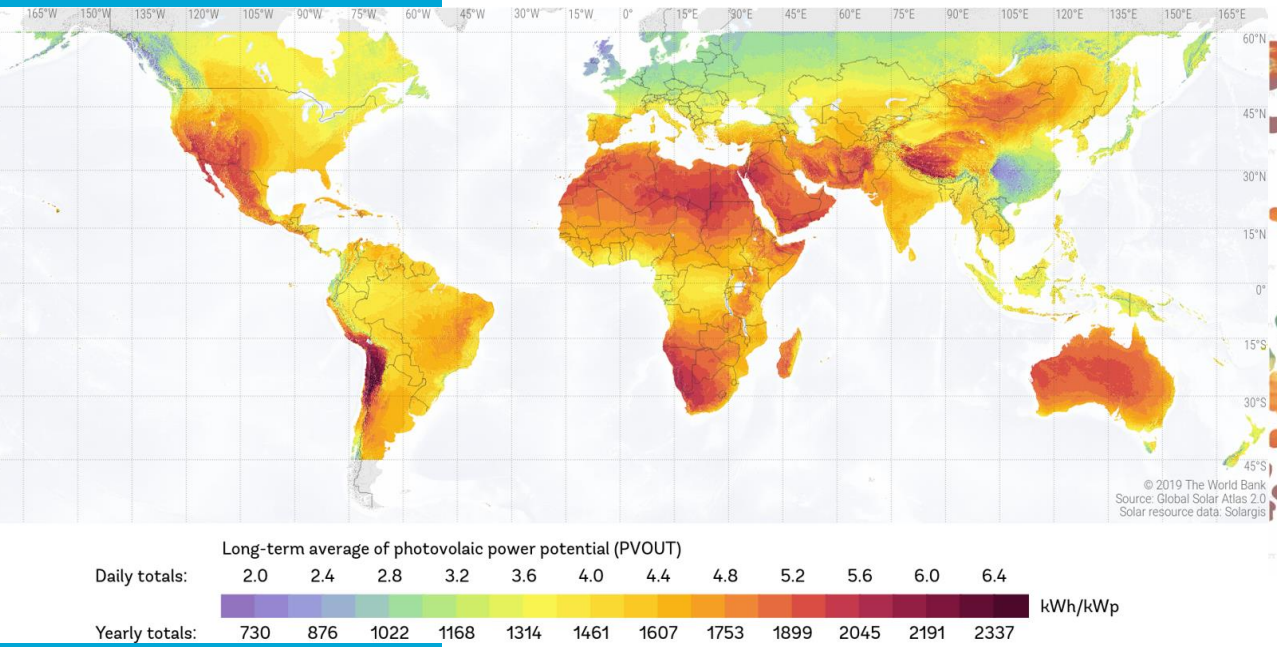
Hydrogen Connecting Continents

11-11-2021

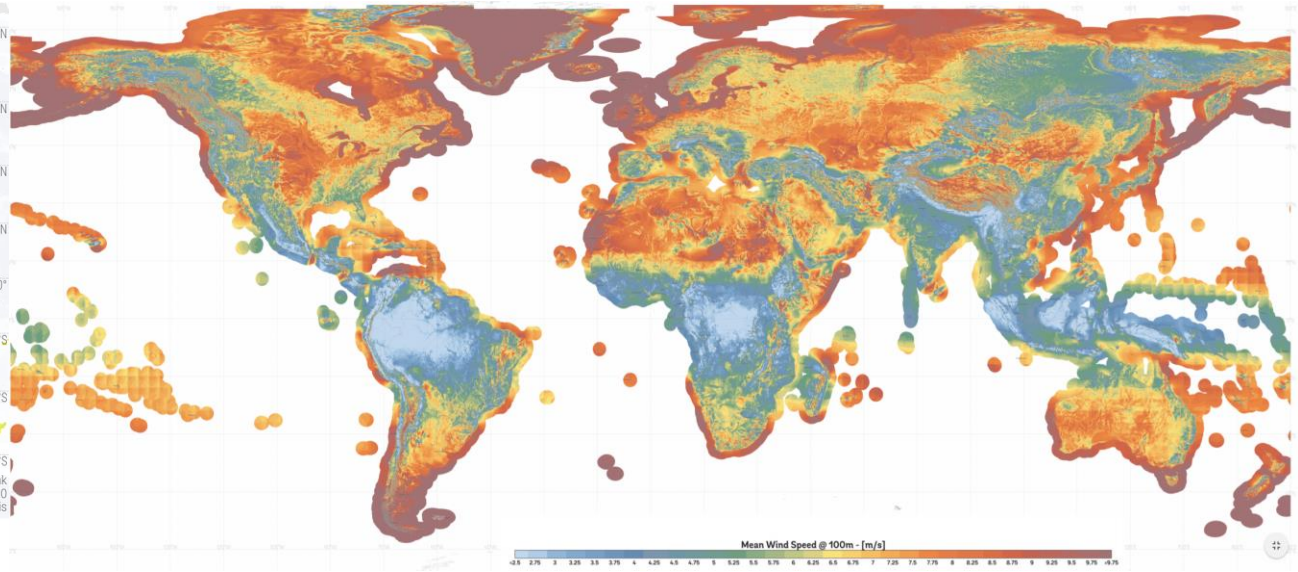
Prof. Dr. Ad van Wijk

TU Delft

Low cost solar and wind electricity at good solar and wind resources sites, often far from energy demand



Solar Resources Map



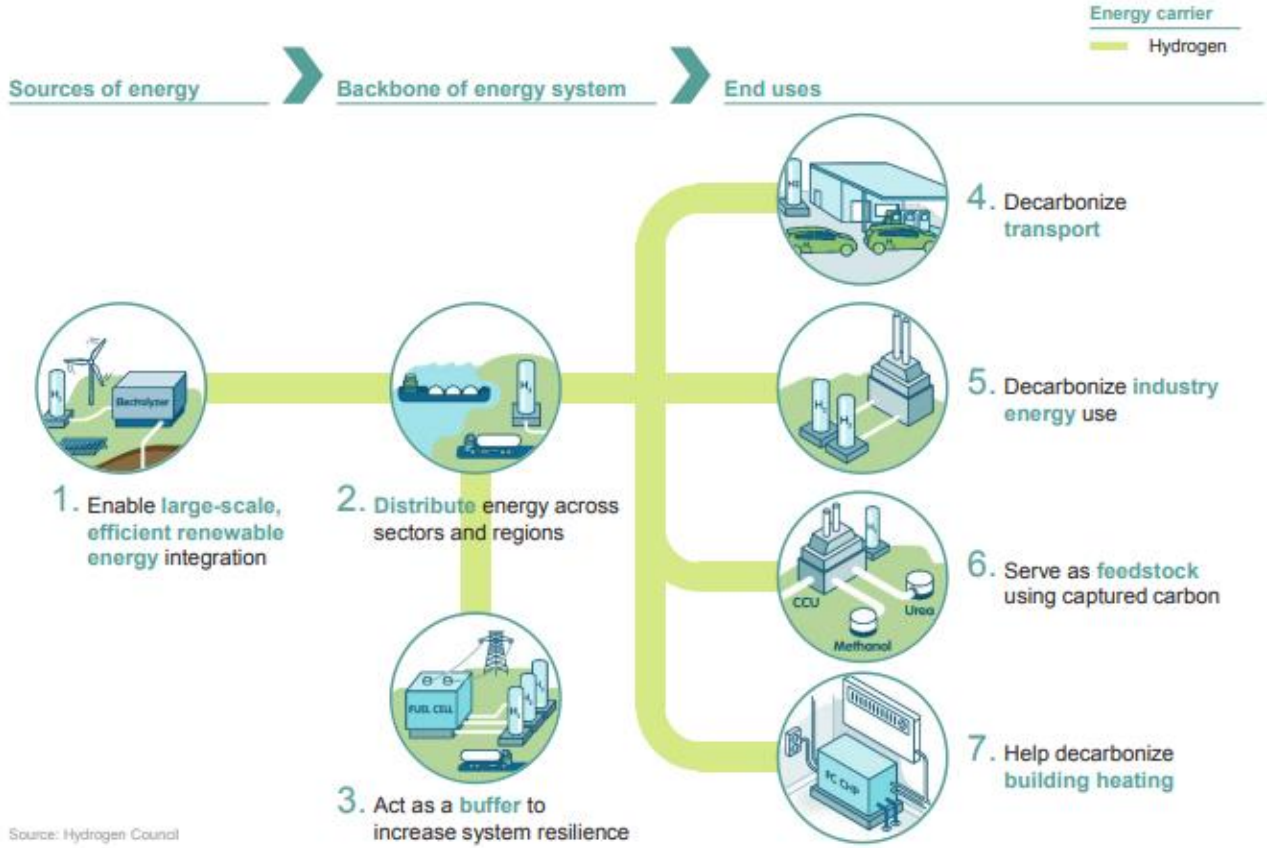
Wind Speed at 100 meter height Map

Hydrogen in a carbon-free energy system

1. To deliver cheap solar and wind energy cost-effectively at the right time and place (transport and storage)

2. To decarbonize hard to abate energy use (industry, feedstock, mobility, heating and balancing electricity system)

Finally cost competition between imported hydrogen with regionally produced hydrogen and electricity



https://hydrogencouncil.com/wp-content/uploads/2017/06/Hydrogen-Council-Vision-Document.pdf

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**
	Auto-thermal reforming (ATR)	Mature	$H_2 + CO_2$	**Blue**, ATR 90%-100% CO_2 emission capture and storage is possible
	Methane Pyrolysis	Small plants operational	$H_2 + C$	**Turquoise**, no CO_2 emissions
Coal	Partial Oxidation/Gasification	Mature	$H_2 + CO_2 + C$	**Brown/Blue**,
	Underground coal gasification	Projects exist	$H_2 + CO_2$	50-90% 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			**Grey to green** and **pink** depending on the source for electricity production.
	Alkaline	Mature	$H_2 + O_2$	
	PEM	Near Maturity	$H_2 + O_2$	
	SOEC	Pilot Plants	$H_2 + O_2$	
Sunlight + Water	Photoelectrochemical	Laboratory	$H_2 + O_2$	**Green**

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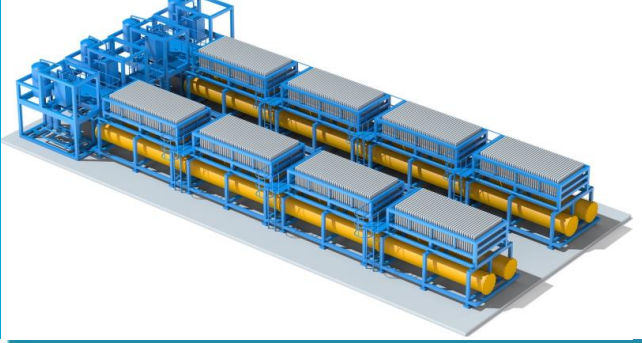
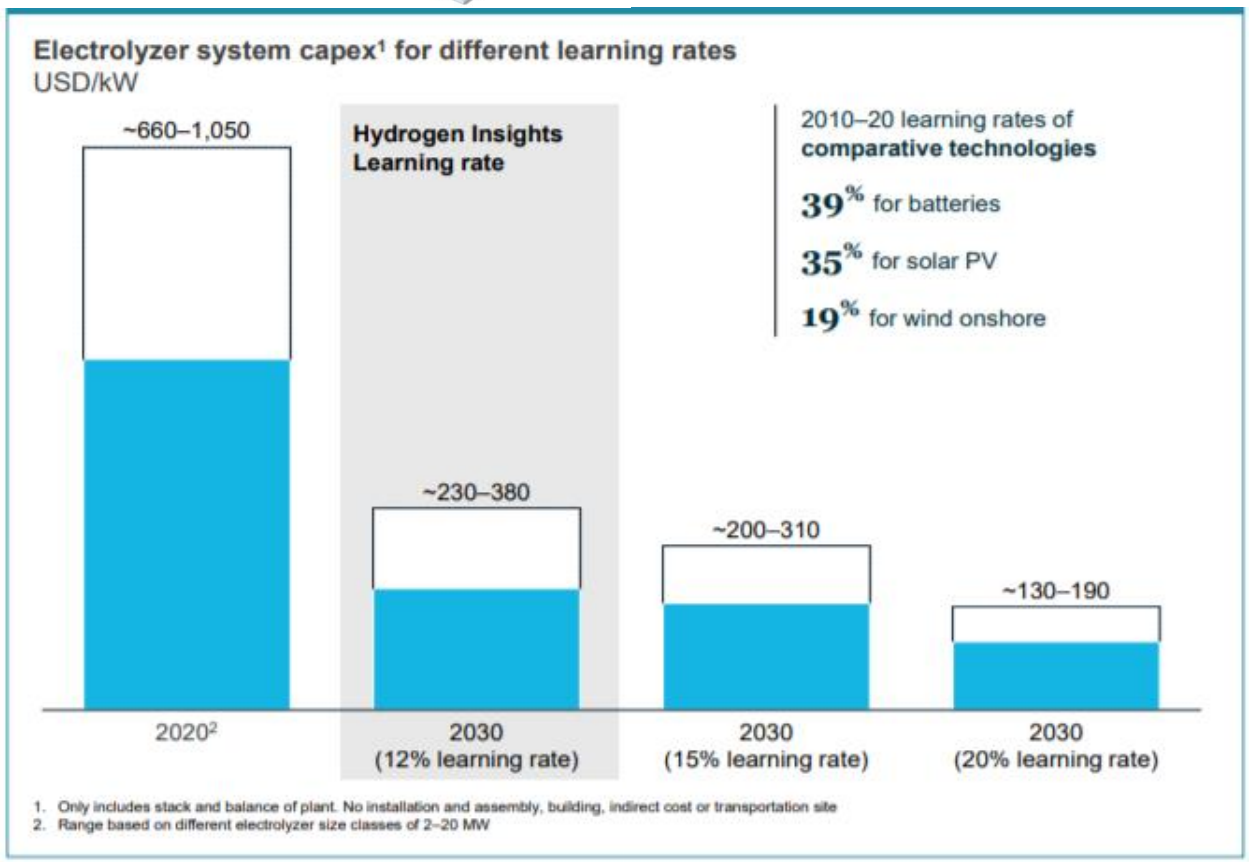


Technology structure electrolysers similar to solar PV, batteries, fuel cells



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

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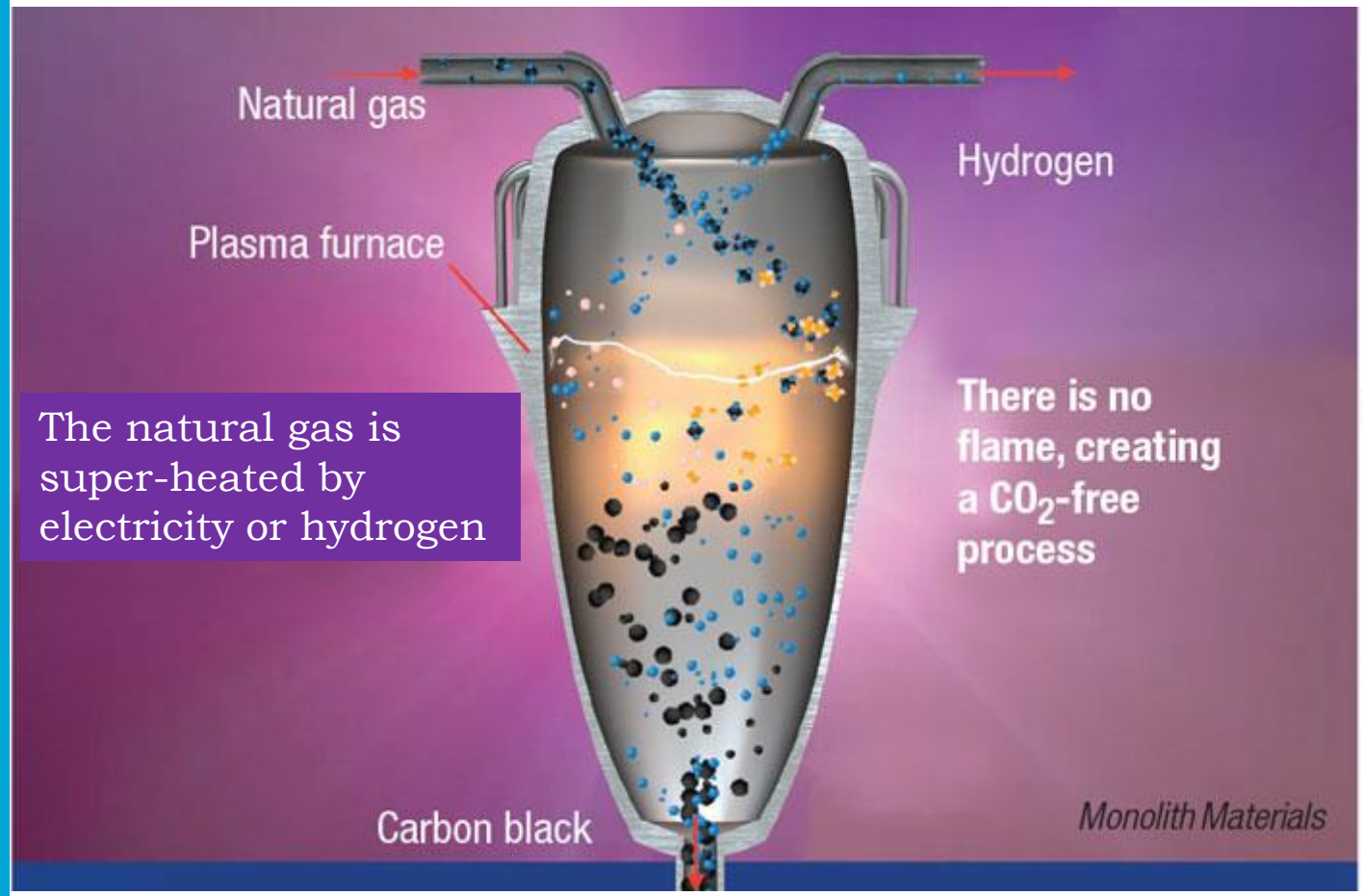
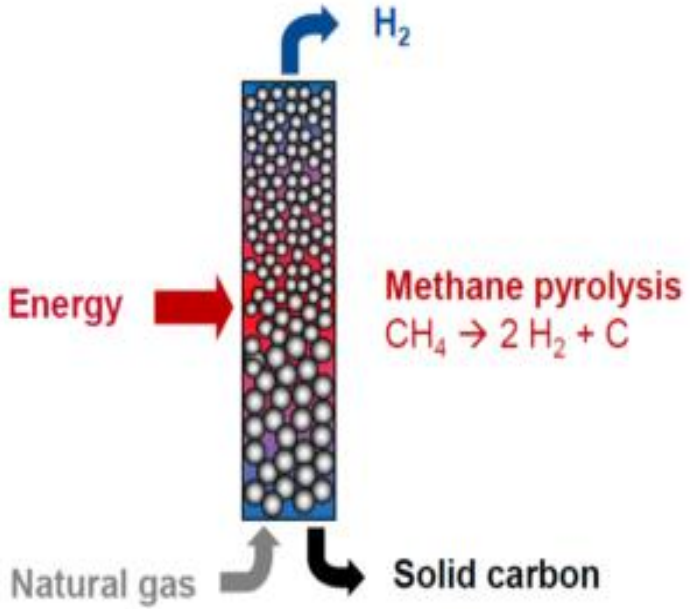
Methane/Natural gas Pyrolysis
No-carbon fossil hydrogen production

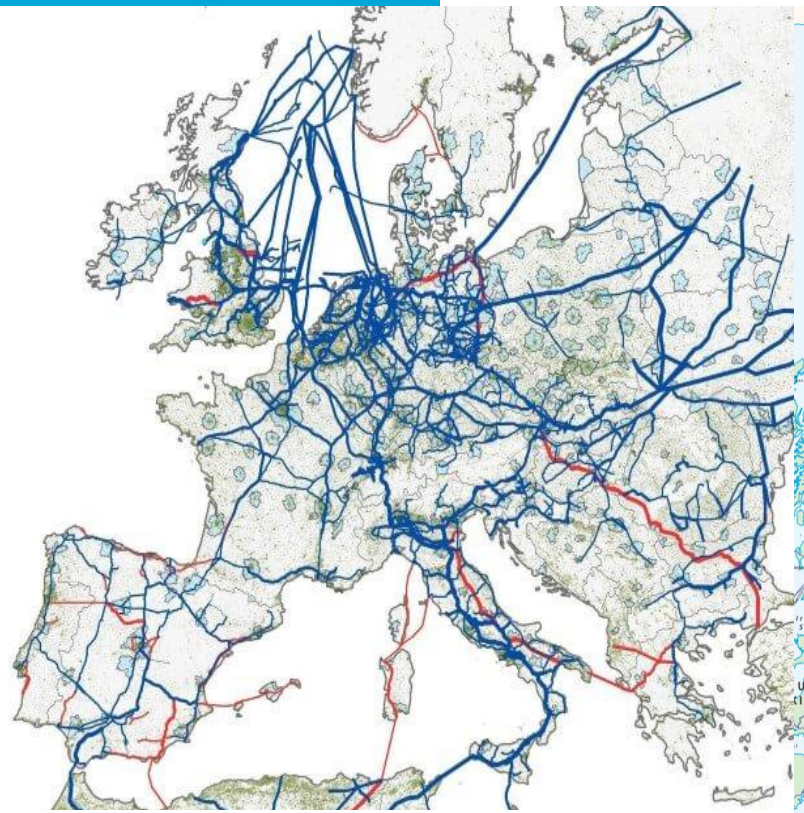




Gas Infrastructure in Europe can be reused for hydrogen

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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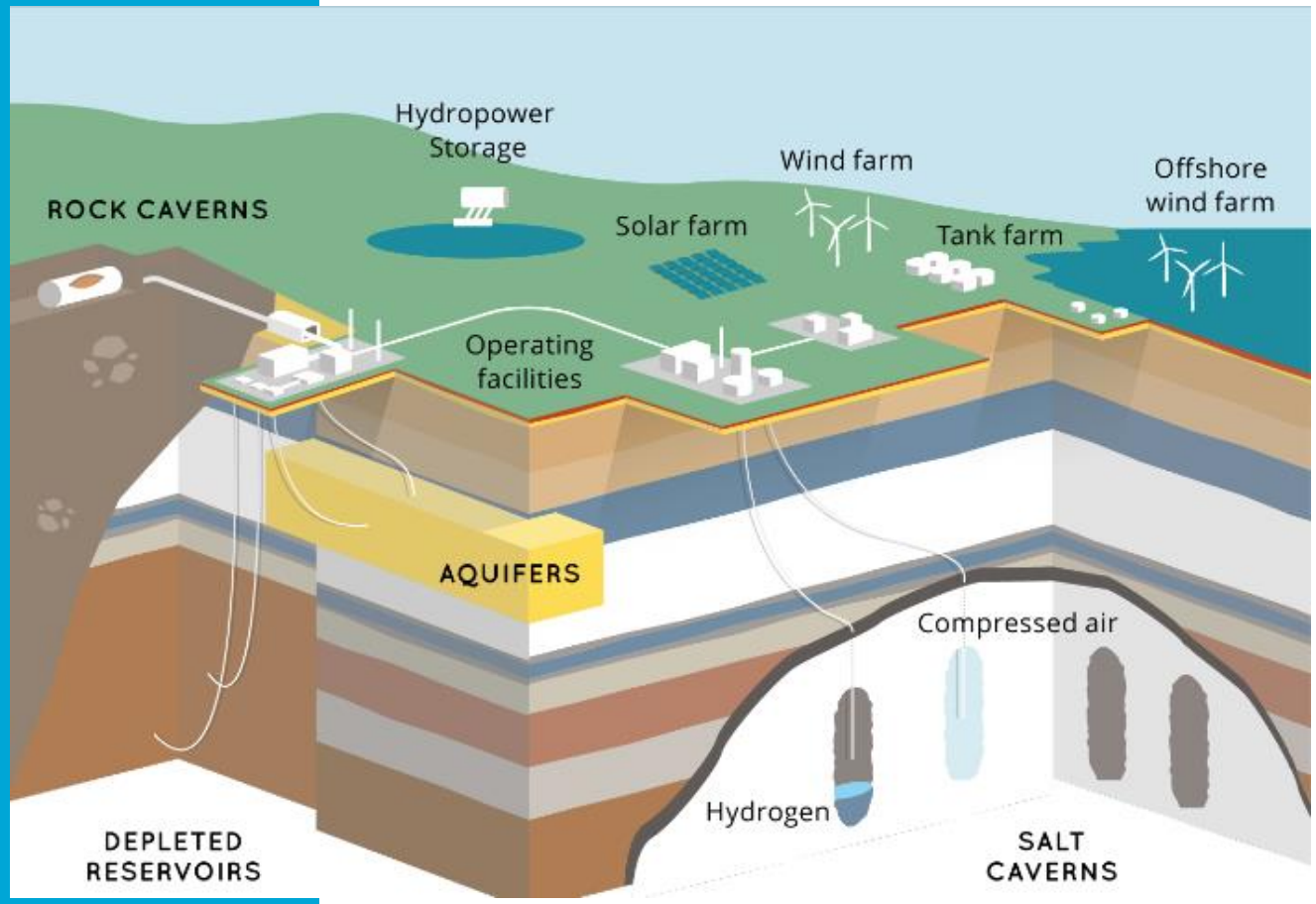
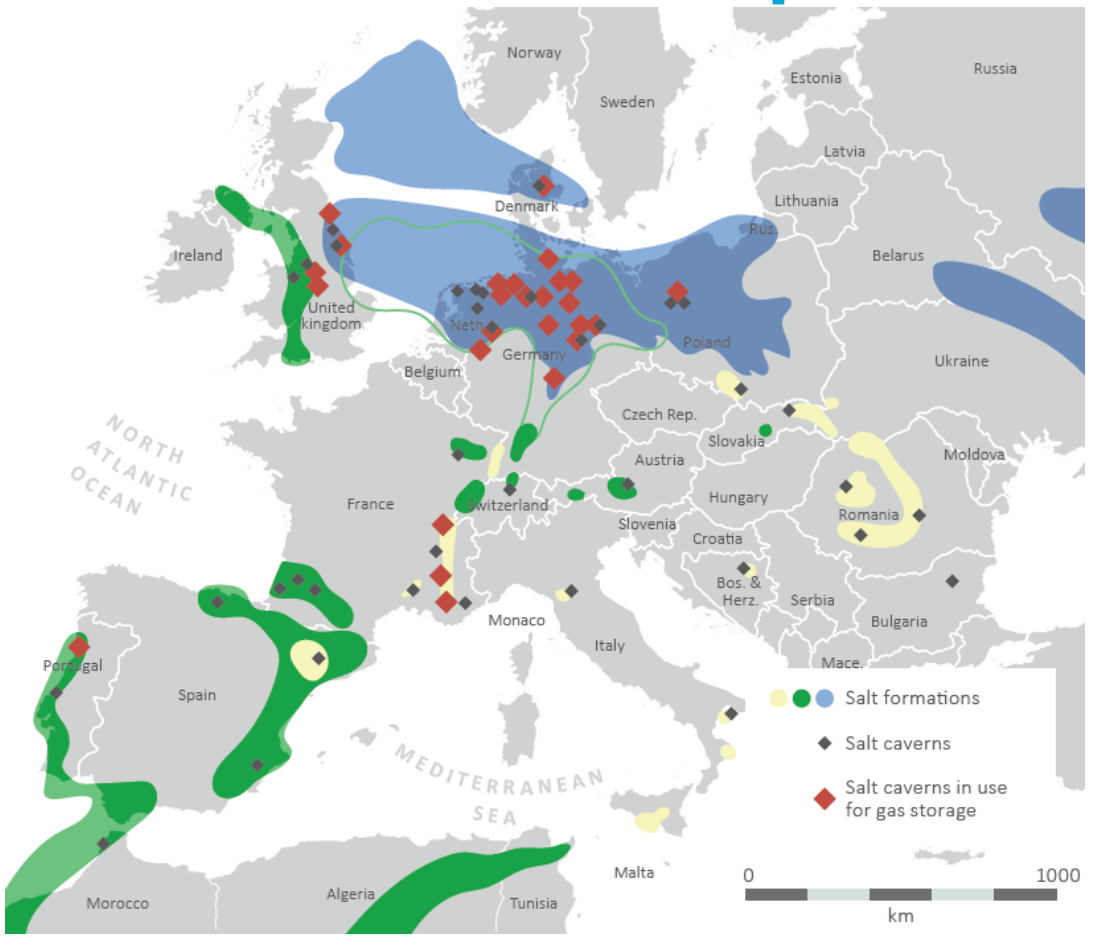
Hydrogen storage in salt caverns



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

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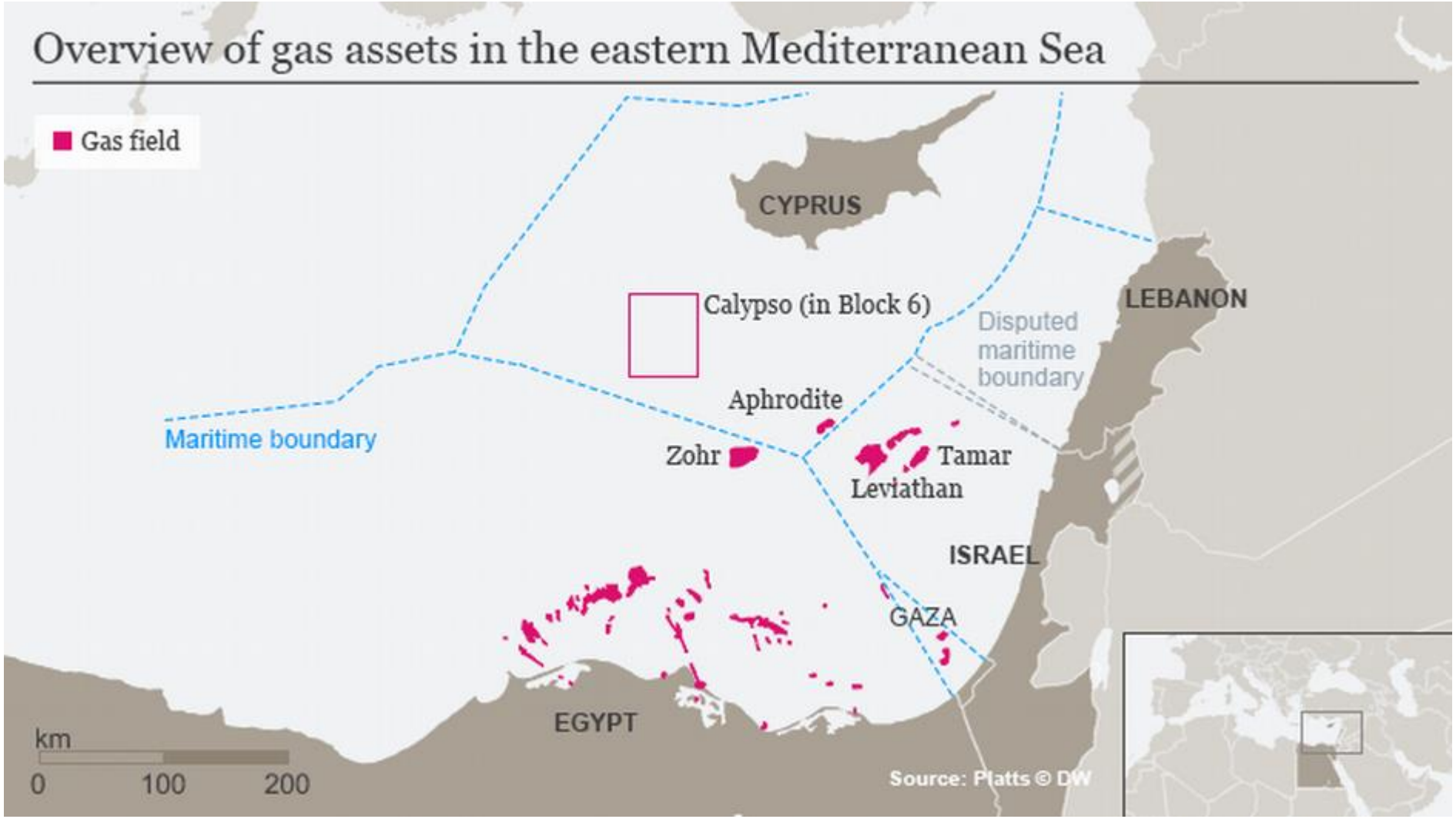
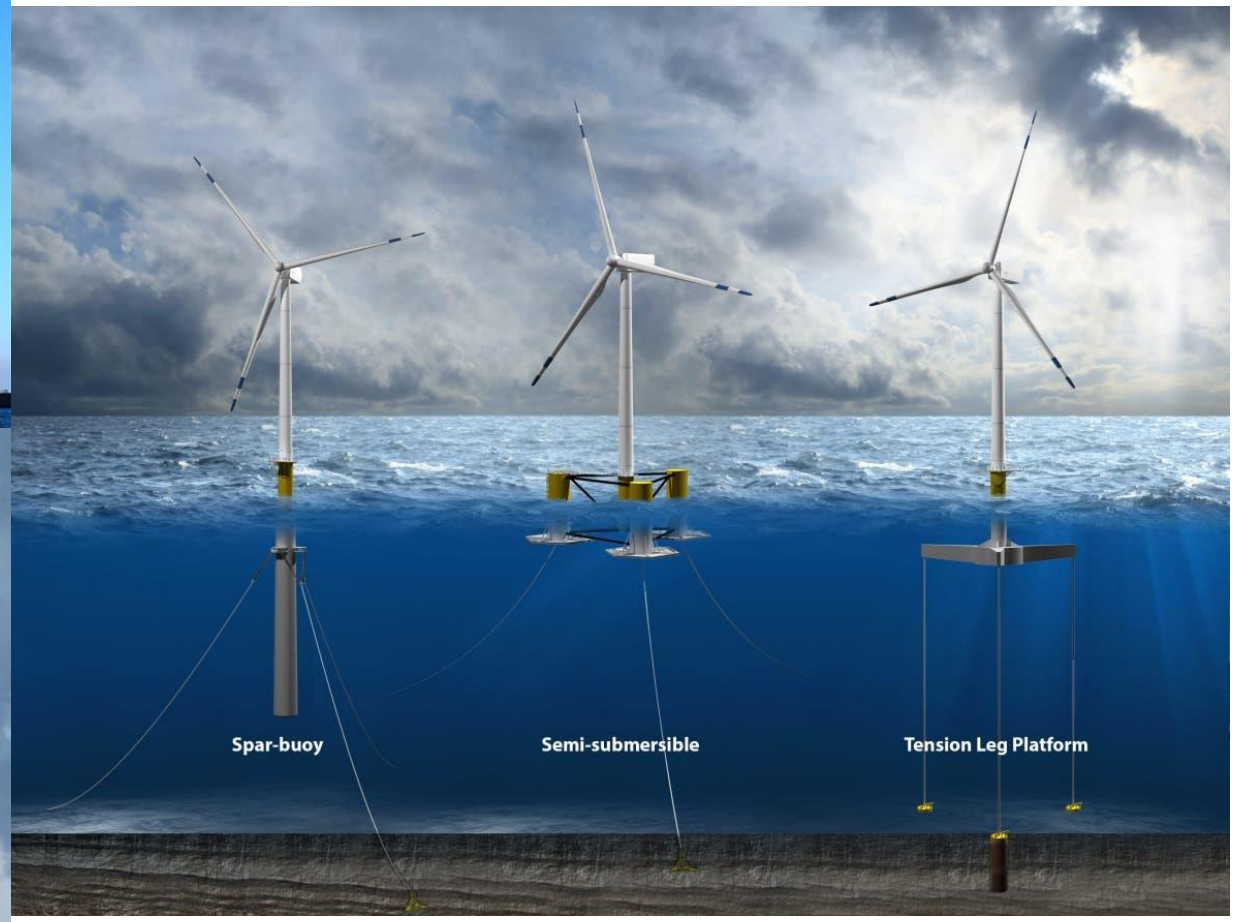
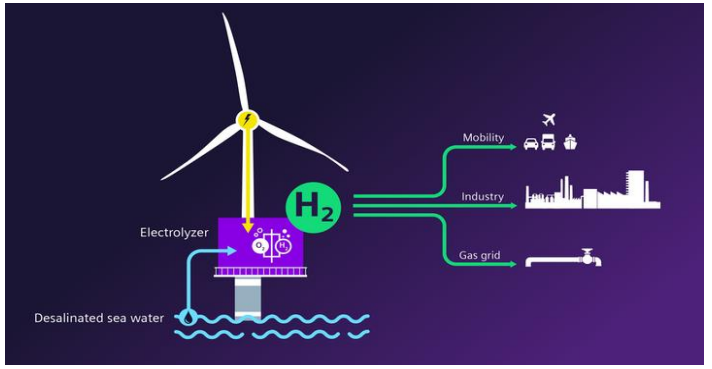
Offshore Gas to No-Carbon Hydrogen

ATR with CCS and/or Methane Pyrolysis

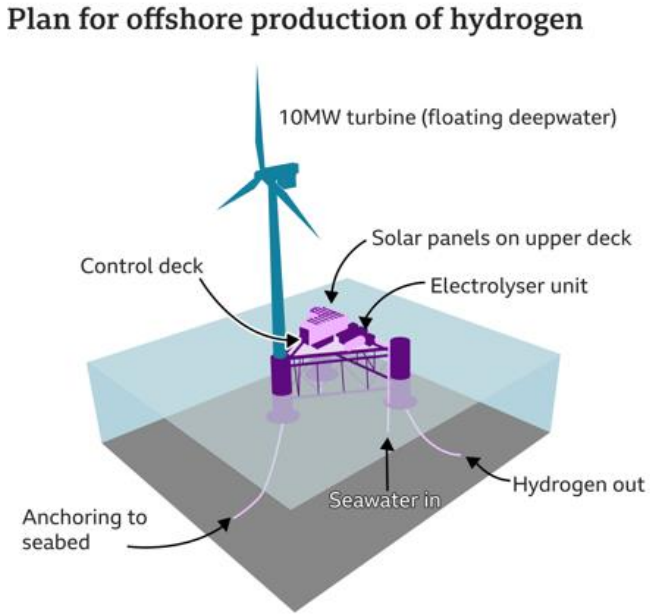


Offshore (Floating) integrated Wind-Hydrogen Turbines





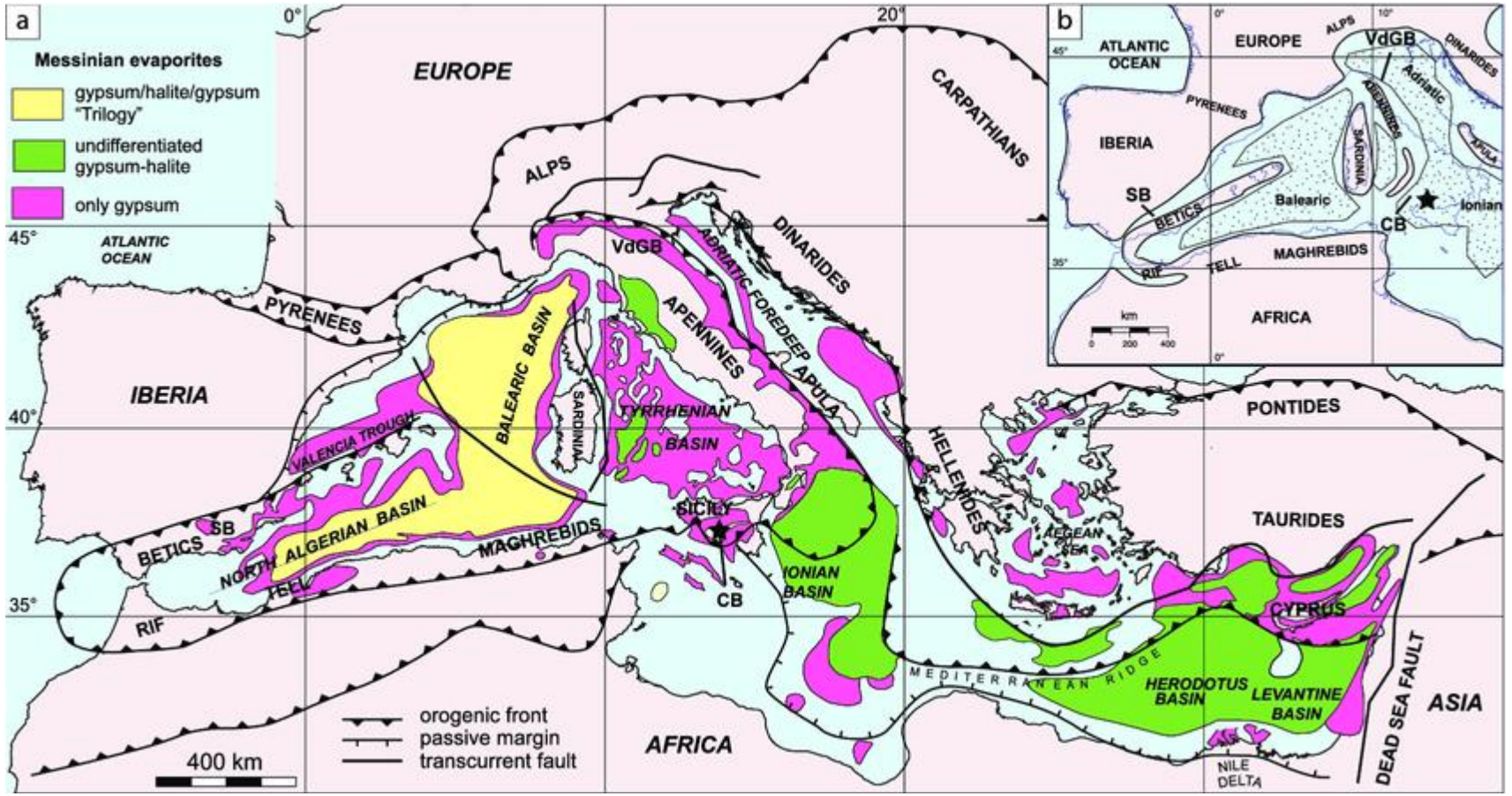
SiemensGamesa [SG 14-222 DD offshore wind turbine](#) 15 MW with electrolyser in turbine



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

Offshore wind-hydrogen turbine equal CAPEX as Offshore wind-electricity turbine

Hydrogen storage in offshore salt caverns Under Mediterranean Sea, green areas



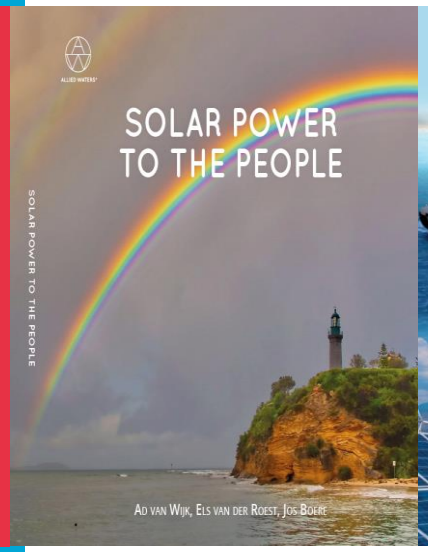
Connecting Continents!
By Hydrogen Pipelines

Middle-East to Europe
Eastmed Hydrogen Pipeline

North-Africa to Europe
Repurposing gas pipelines

Further Reading
www.profadvanwijk.com

April 2017



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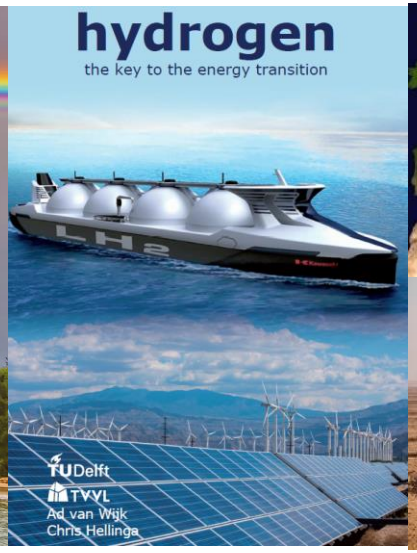

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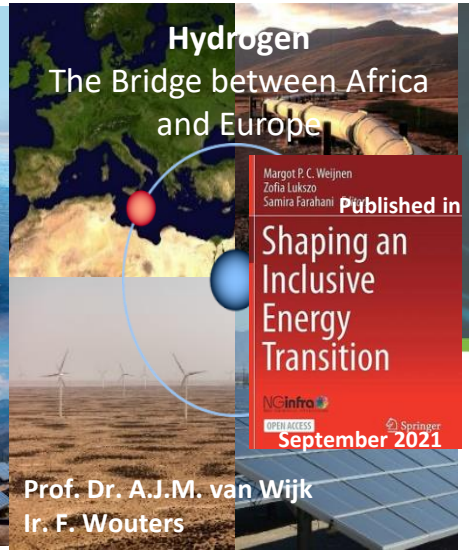

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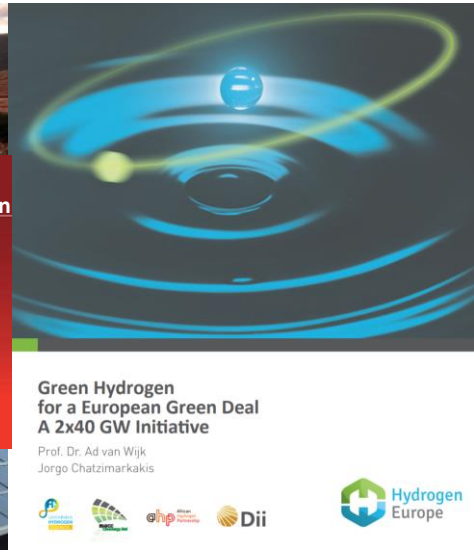

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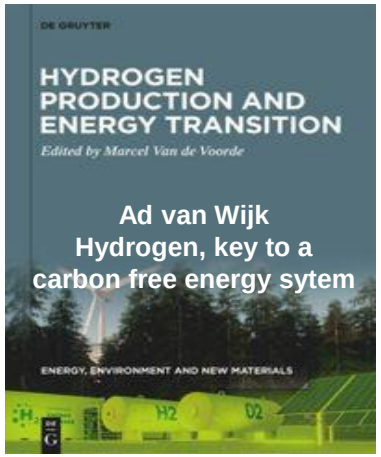

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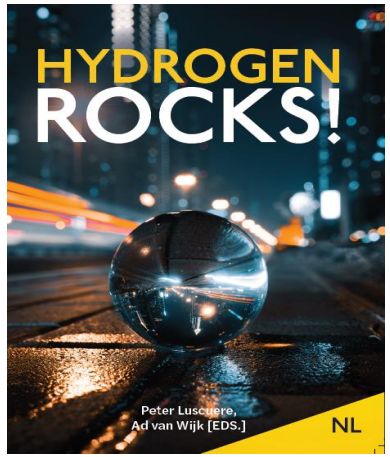

October 2021