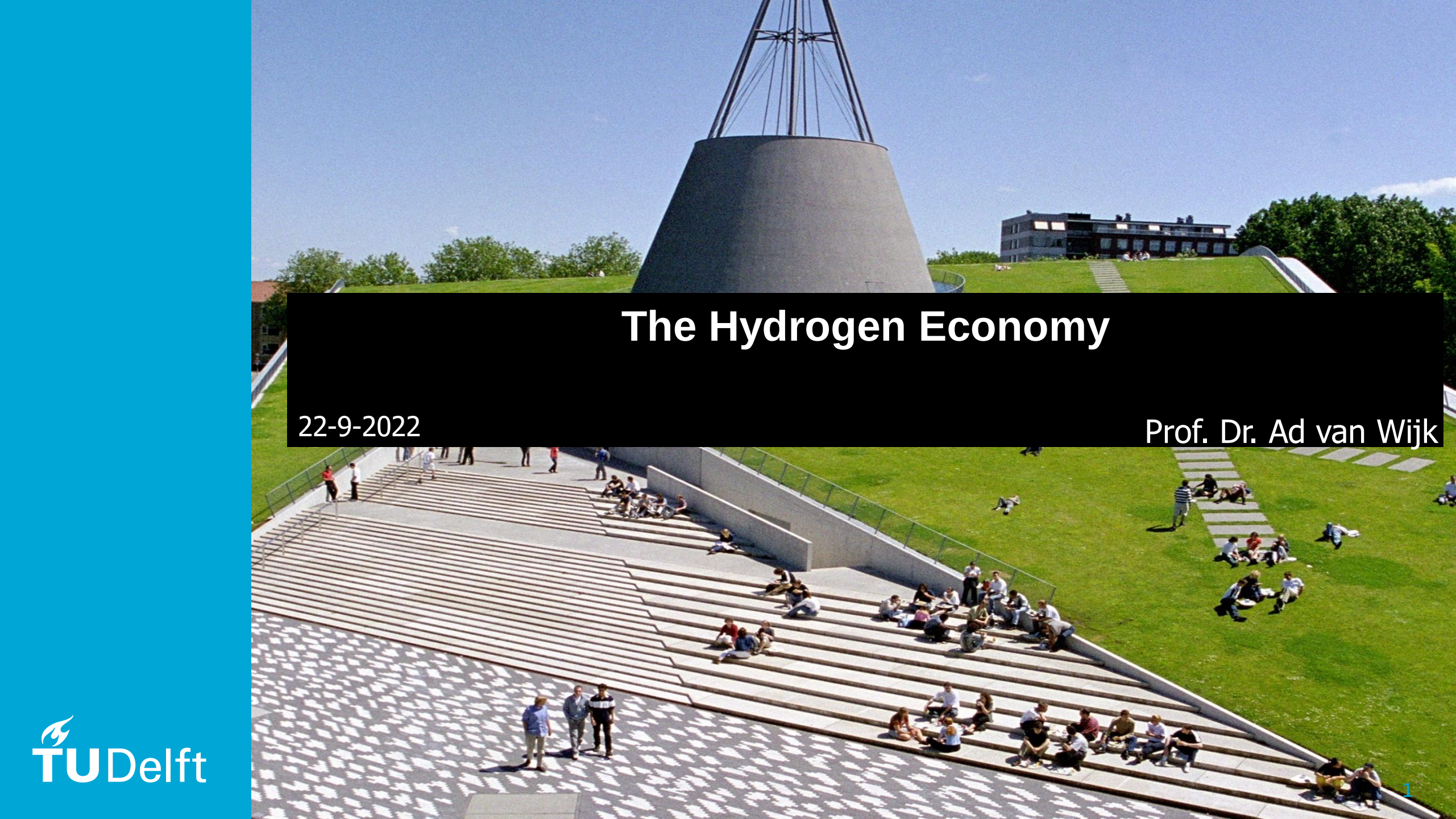


A wide-angle photograph of a TU Delft campus. In the foreground, a large, modern concrete structure with a conical top and a lattice of thin poles stands on a grassy hill. To the right, a multi-story building is visible in the background. The middle ground features a wide, tiered concrete staircase where many people are sitting and walking. The ground in the immediate foreground has a repeating diamond-shaped pattern. The sky is clear and blue.

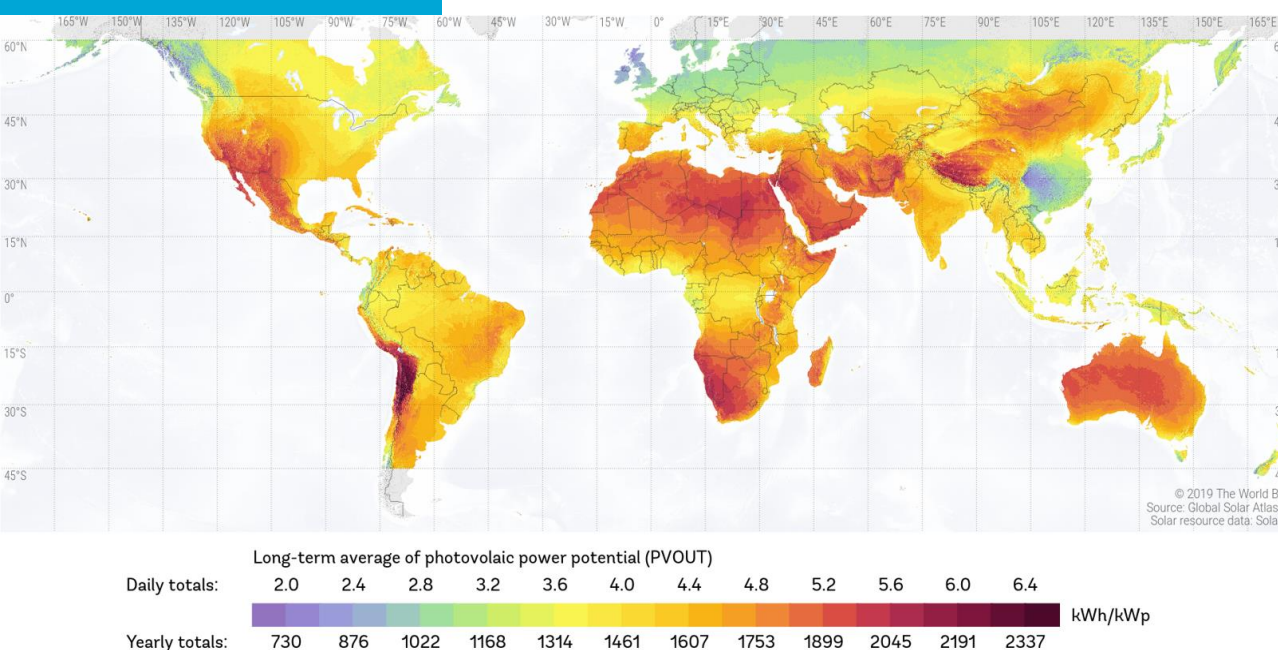
The Hydrogen Economy

22-9-2022

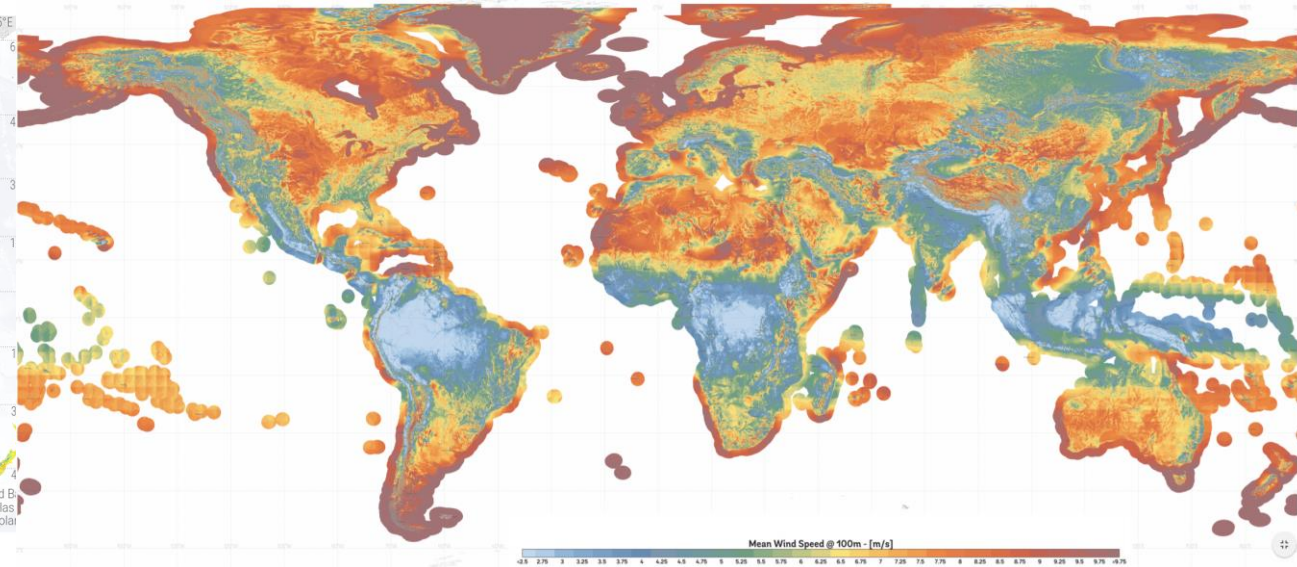
Prof. Dr. Ad van Wijk

Low cost solar and wind electricity 1-2 ct/kWh
Only at places with high irradiation and/or high wind speed
and with lots of available space

These locations are often far from energy demand



Solar Resources Map



Wind Speed at 100 meter height Map

Mohammed Bin Rashid Al Maktoum Solar Farm in Dubai; 3.000 MW ready, expansion to 5.000 MW

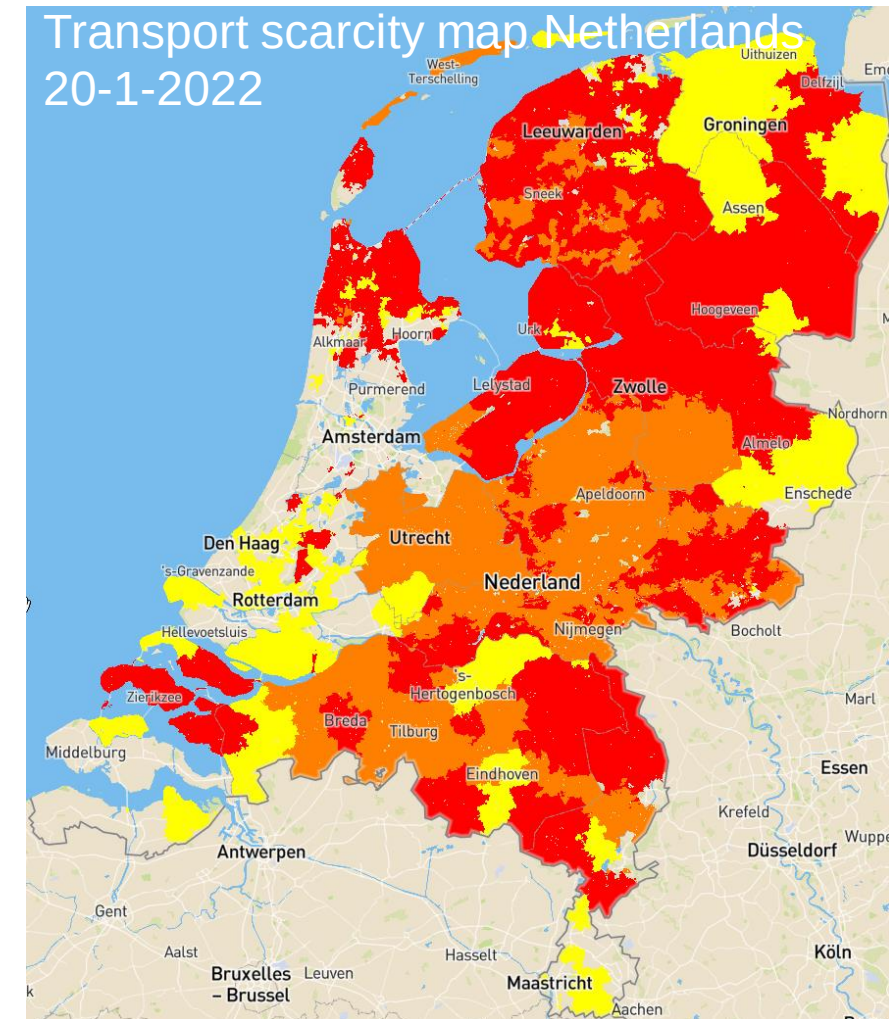


Electricity infrastructure capacity is or becomes a big problem in realising a sustainable energy system

To connect solar or wind to the electricity grid
Gas transport network capacity 10-15 times bigger than electricity network capacity

To connect heat pumps, electric cars and solar roofs to the electricity grid.

In the Netherlands gas network capacity at home 10 times bigger (30 kW) than electricity grid capacity at home (3 kW)



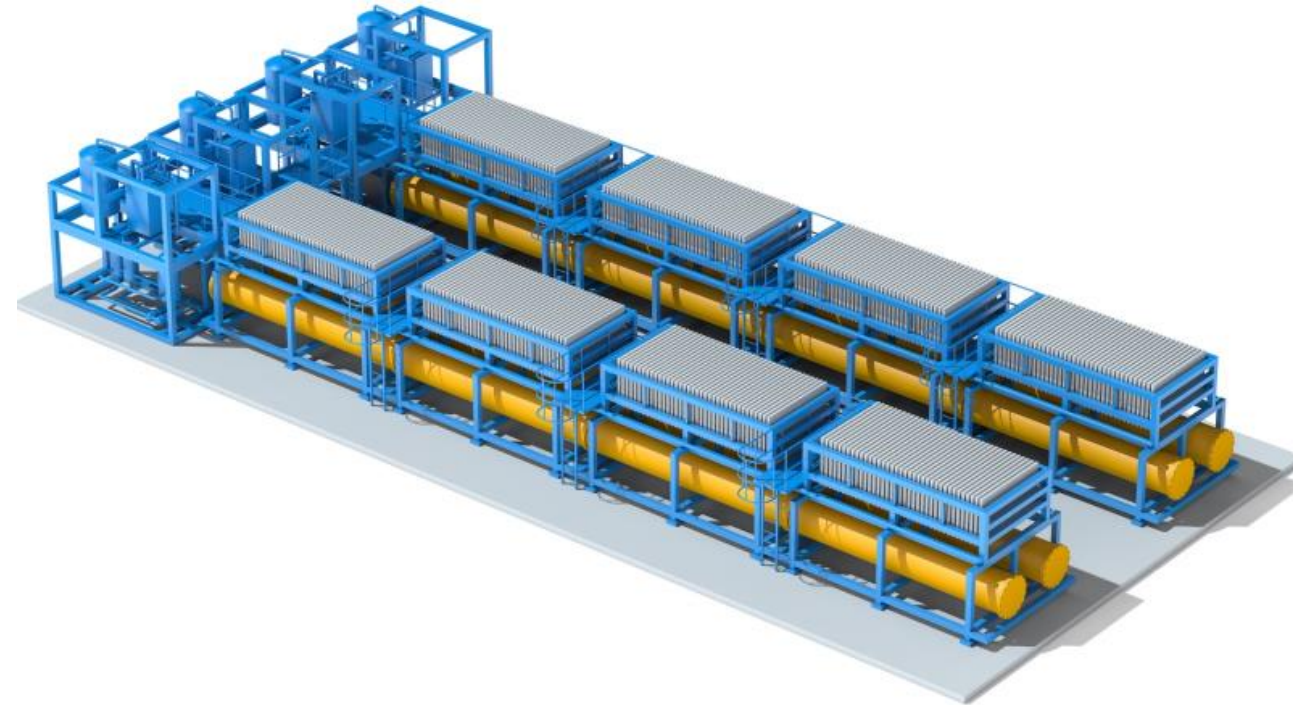
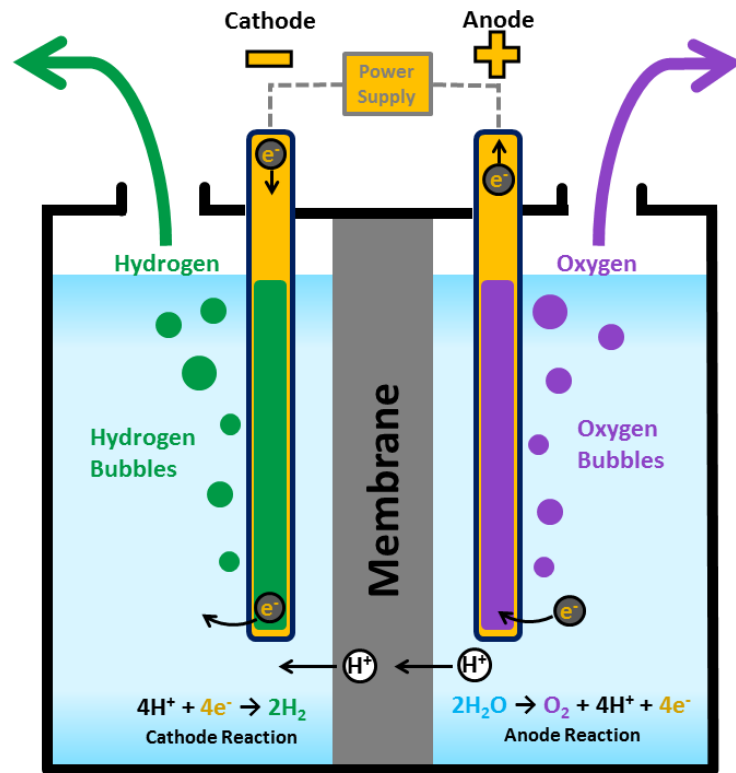
Betekenis van de kleurcodes

- Transparant: (nog) geen transportschaarste
- Geel: transportschaarste dreigt, er geldt een aangepast offerteregime
- Oranje: vooraankondiging structurele congestie bij ACM
- Rood: structureel congestie, nieuwe aanvragen voor transport worden niet gehonoreerd

Hydrogen, like electricity is an energy carrier

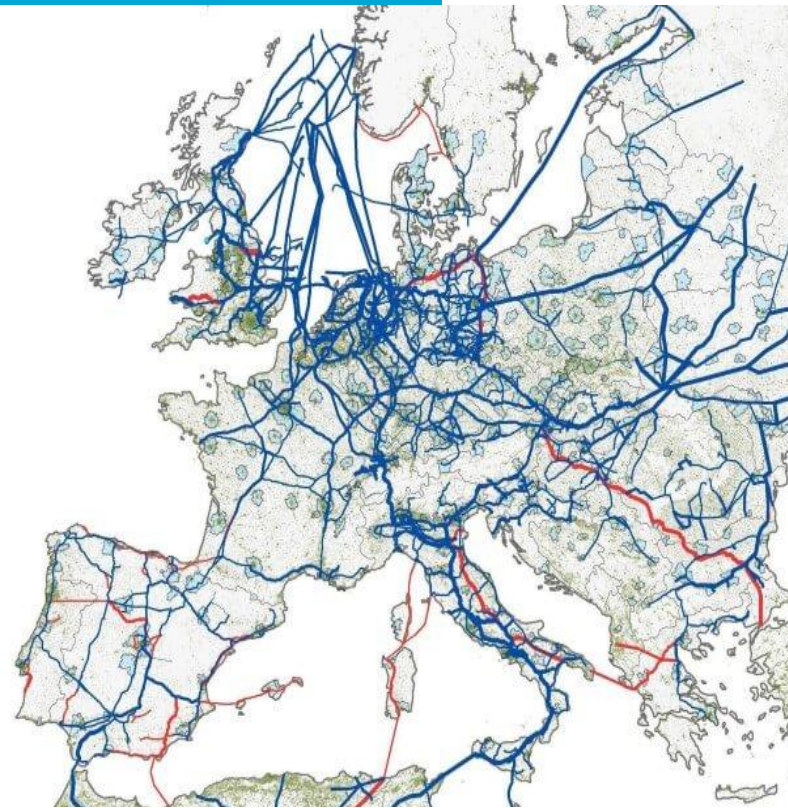
Hydrogen can be produced from fossil energy, biomass residues or from water

Water Electrolysis, using electricity from renewable resources produces green electricity



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



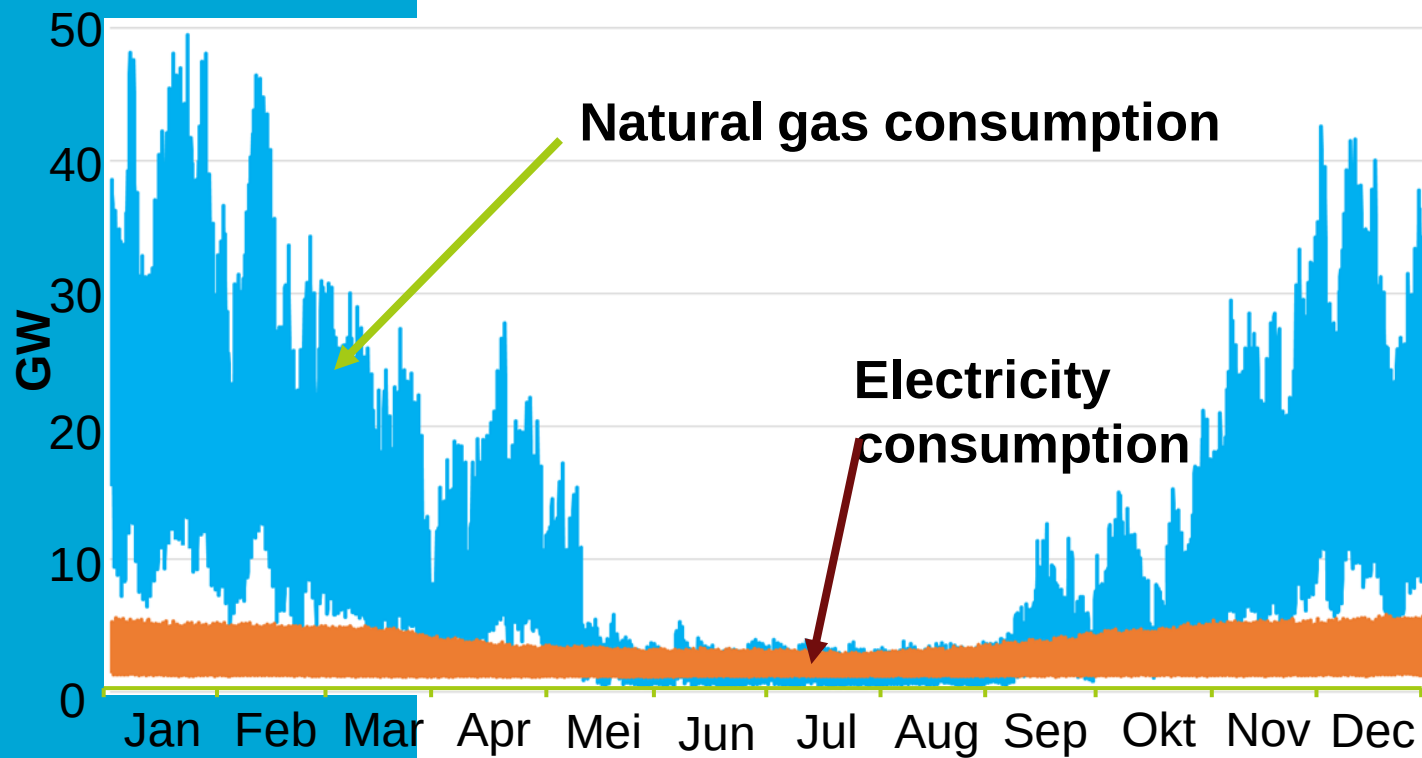
European Hydrogen Backbone

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

Storage will become an even larger challenge then today

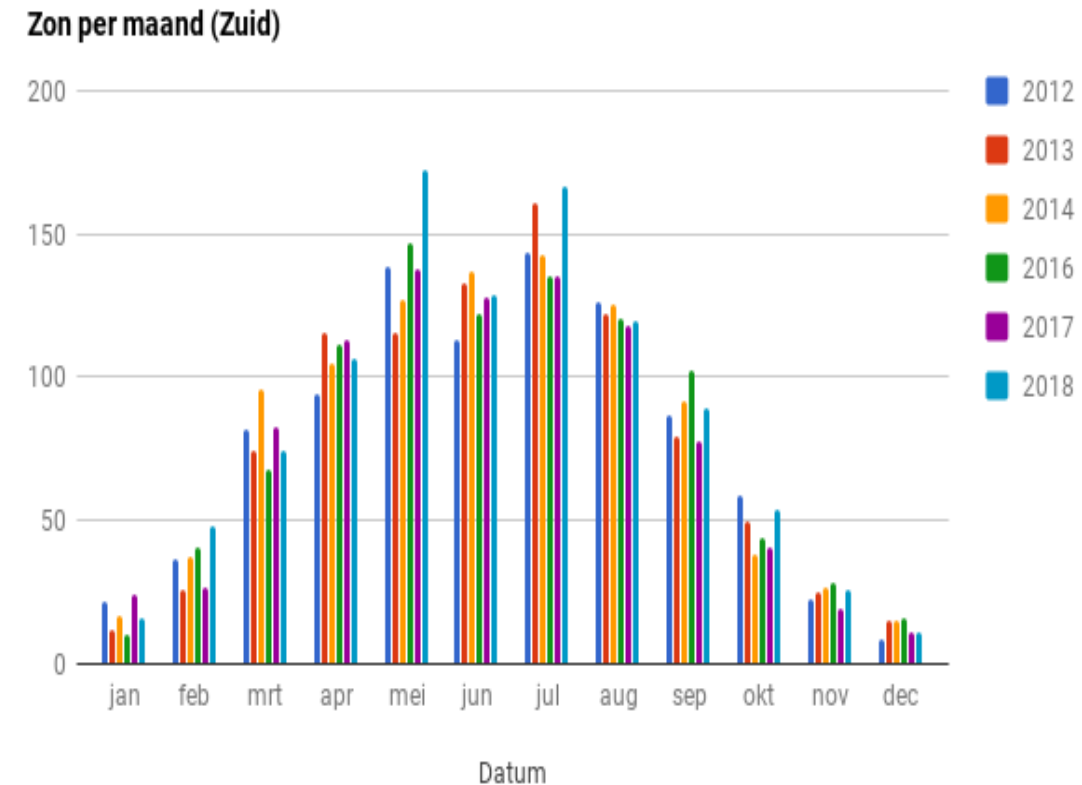
Today large scale seasonal gas storage is already present

Example the Netherlands



7,8 million Dutch houses (2017)

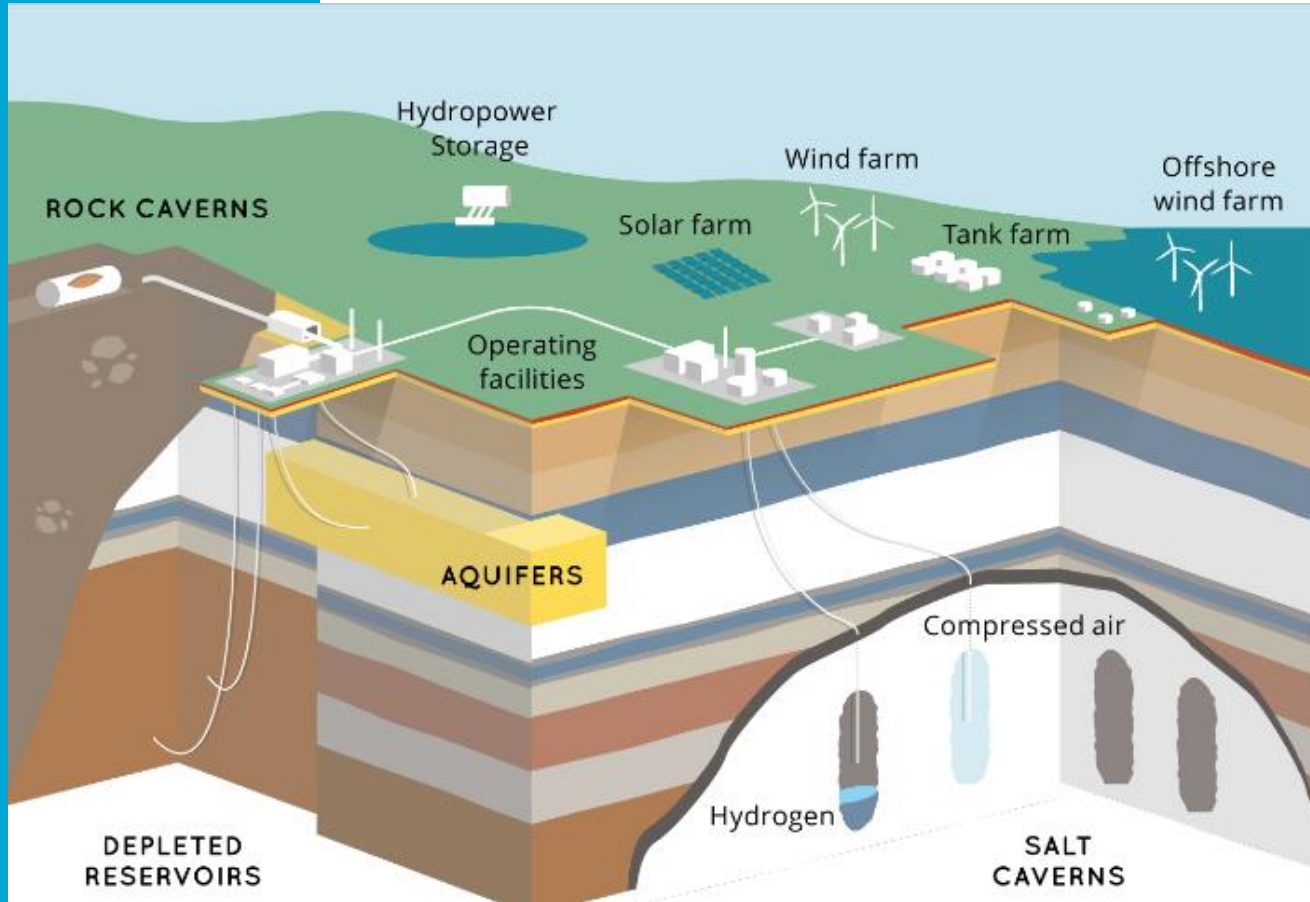
Source: Kellner, 2018



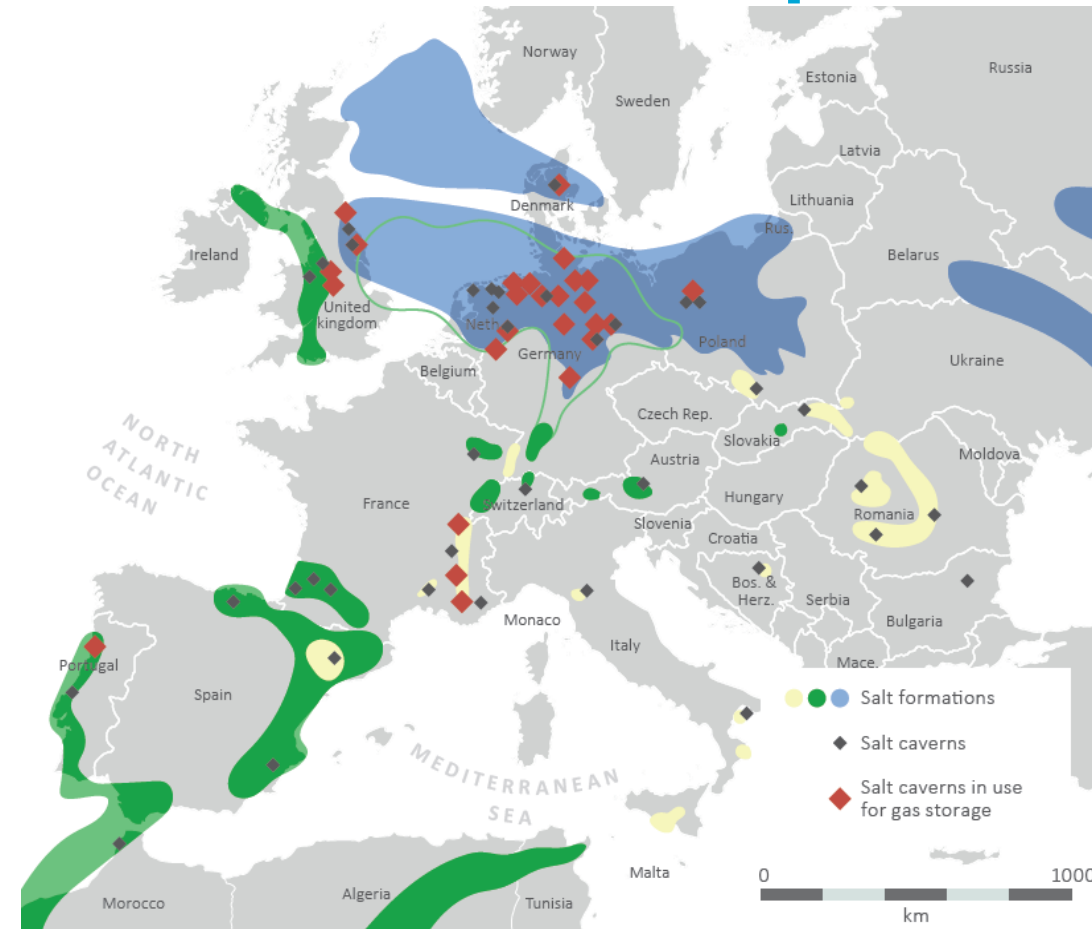
<https://thuiszonnepanelen.nl/opbrengst-van-onze-zonnepanelen/>

**In the Netherlands about 100 TWh seasonal gas storage available
= storage capacity of 1 billion battery electric vehicles with 100 kWh battery.**

Hydrogen storage in salt caverns



Salt formations and caverns in Europe



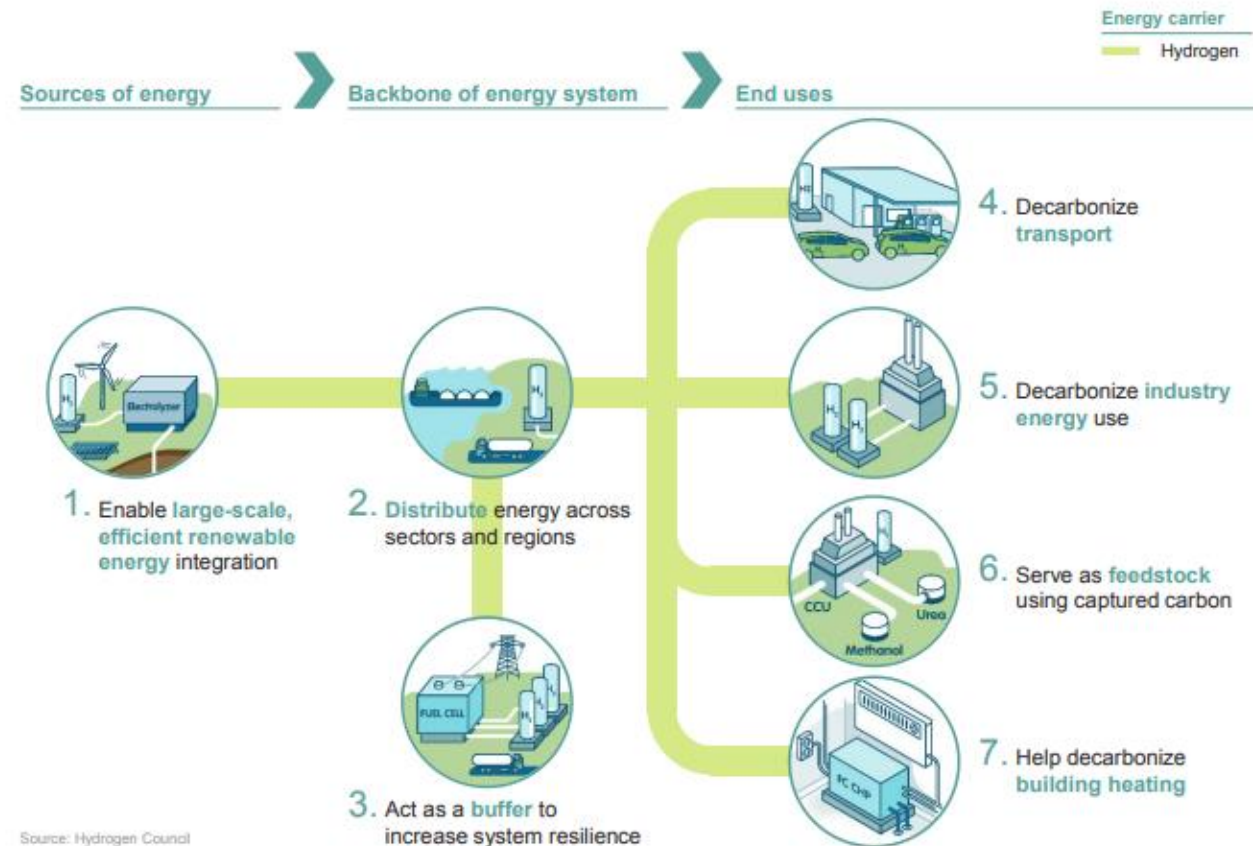
1 salt cavern can contain up to 6,000 ton (= 236.4 GWh HHV) hydrogen,
Salt Cavern CAPEX = 0.5 Euro per kWh, Total Salt cavern CAPEX is 100 million Euro

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

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 in energy markets there will be cost competition between imported hydrogen with regionally produced hydrogen and electricity



Source: Hydrogen Council

REPowerEU; Joint European Action for more affordable and sustainable energy, EC 8-3-2022

REPOWER EU TRACK	FOCUS	FF55 AMBITION BY 2030	REPOWEREU MEASURE	REPLACED BY THE END OF 2022 (BCM equivalent) estimate	ADDITIONAL TO FF55 BY 2030 (BCM equivalent) estimate
GAS DIVERSIFICATION	NON-RU NATURAL GAS	-	LNG diversification	50*	50
		-	Pipeline import diversification	10	10
	MORE RENEWABLE GAS	17 bcm of biomethane production, saving 17 bcm	Boost biomethane production to 35bcm by 2030	3.5	18
ELECTRIFY EUROPE	HYDROGEN ACCELERATOR	5.6 million tonnes of renewable hydrogen, saving 9-18.5 bcm	Boost hydrogen production and imports to 20mt by 2030	-	25-50
	HOMES	Energy efficiency measures, saving 38 bcm	EU-wide energy saving, e.g. by turning down the thermostat for buildings' heating by 1°C, saving 10bcm	14	10
		Counted under overall RES figures below	Solar rooftops front loading – up to 15 TWh within a year	2.5	frontloaded
		30 million newly installed heat pumps installed in 2030, saving 35 bcm in 2030	Heat pump roll out front loading by doubling deployment resulting in a cumulative 10 million units over the next 5 years	1.5	frontloaded
		Deploy 480 GW of wind capacities and 420 GW of solar capacities, saving 170bcm (and producing 5.6 Mt of Green Hydrogen)	Wind and solar front loading, increasing average deployment rate by 20%, saving 3bcm of gas, and additional capacities of 80GW by 2030 to accommodate for higher production of renewable hydrogen.	20	Gas savings from higher ambition counted under green hydrogen, the rest is frontloaded
TRANSFORM INDUSTRY	ENERGY-INTENSIVE INDUSTRIES	Front load electrification and renewable hydrogen uptake	Front load Innovation Fund and extend the scope to carbon contracts for difference	Gas savings counted under the renewable hydrogen and renewables targets	



Ursula von der Leyen, State of the Union 14-9-2022

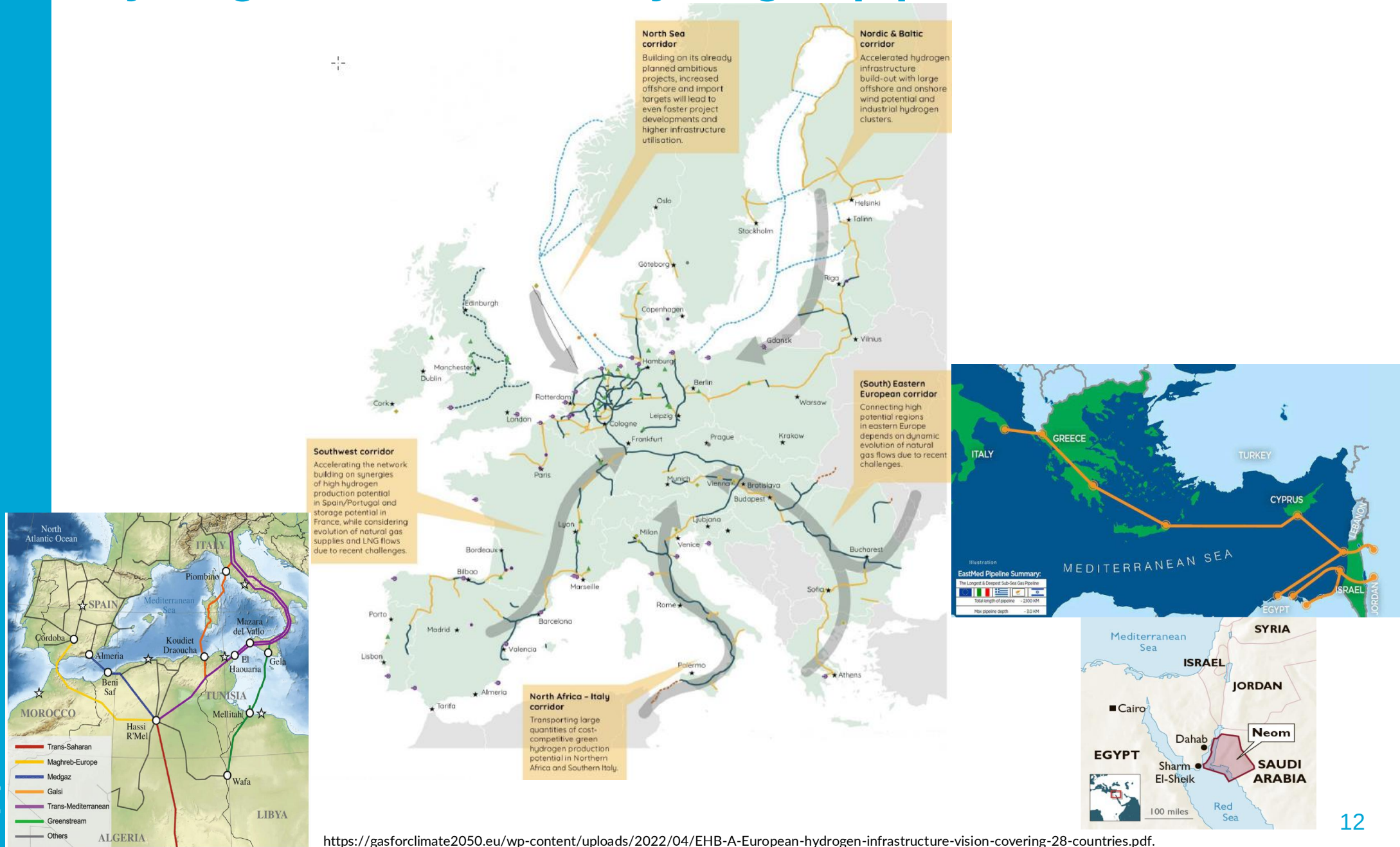
A UNION THAT STANDS STRONG TOGETHER

Hydrogen can be a game-changer for Europe.

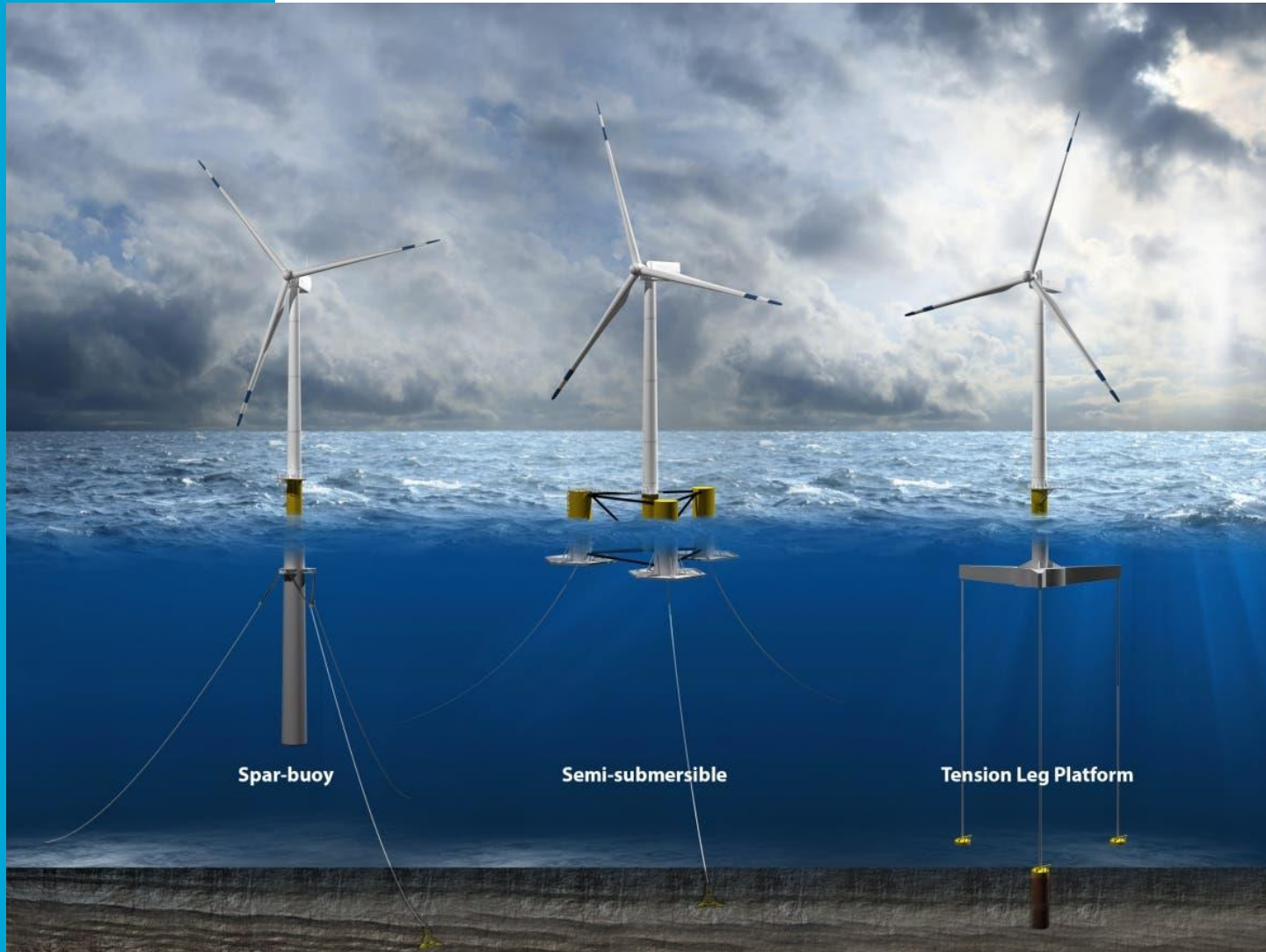
- We need to move from the niche market to the mass market for hydrogen.
- With REPowerEU, we have doubled our target: we want to produce ten million tonnes of renewable hydrogen in the EU each year by 2030.
- To achieve this, we need to create a market maker for hydrogen, to bridge the investment gap and connect future supply and demand.
- This is why I can announce today that we are going to create a new European Hydrogen Bank.
- It will help guarantee the purchase of hydrogen, in particular by using the resources of the Innovation Fund.
- It will be able to invest 3 billion euros to help build the future hydrogen market.

This is how the economy of the future will be built.

Hydrogen Accelerator; hydrogen pipeline infrastructure



Floating wind turbine development

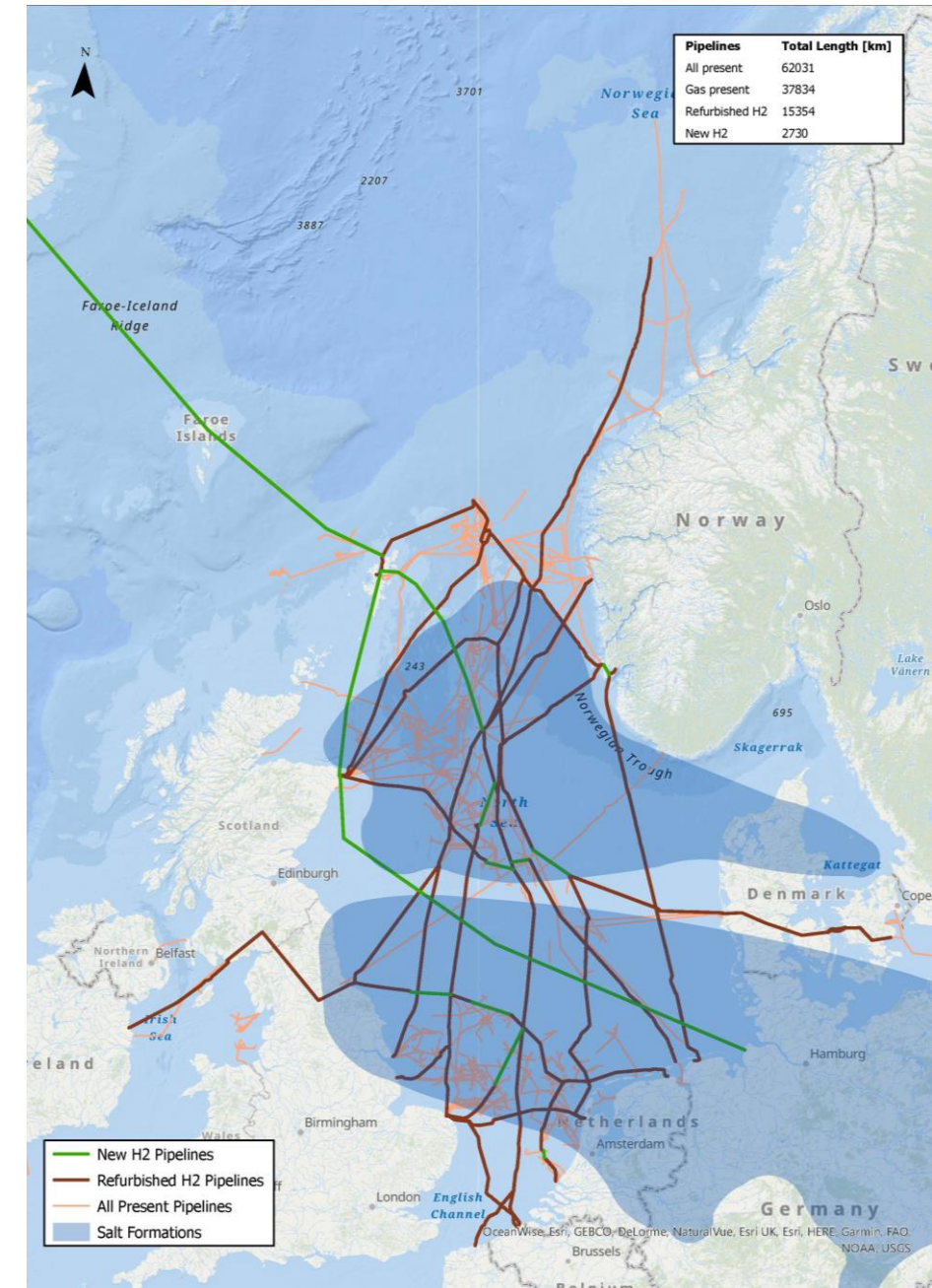


“ScotWind” seabed tender, March 2022 : Auction 8,600 km² of sea space which could host almost 25 GW of offshore wind. 17 projects won. With 15 GW floating offshore wind.

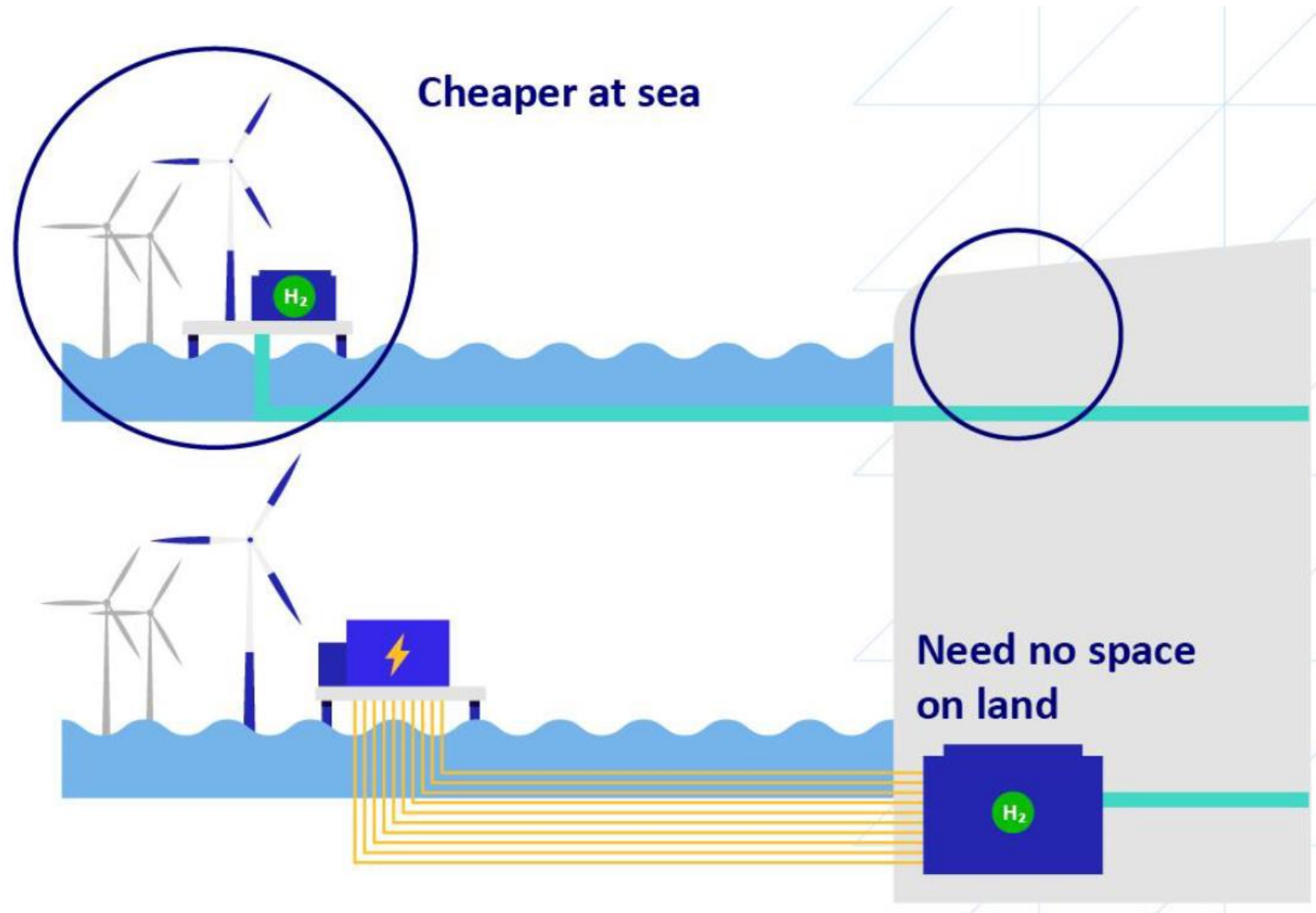
Hydrogen Infrastructure Design at the North Sea

Design assumptions

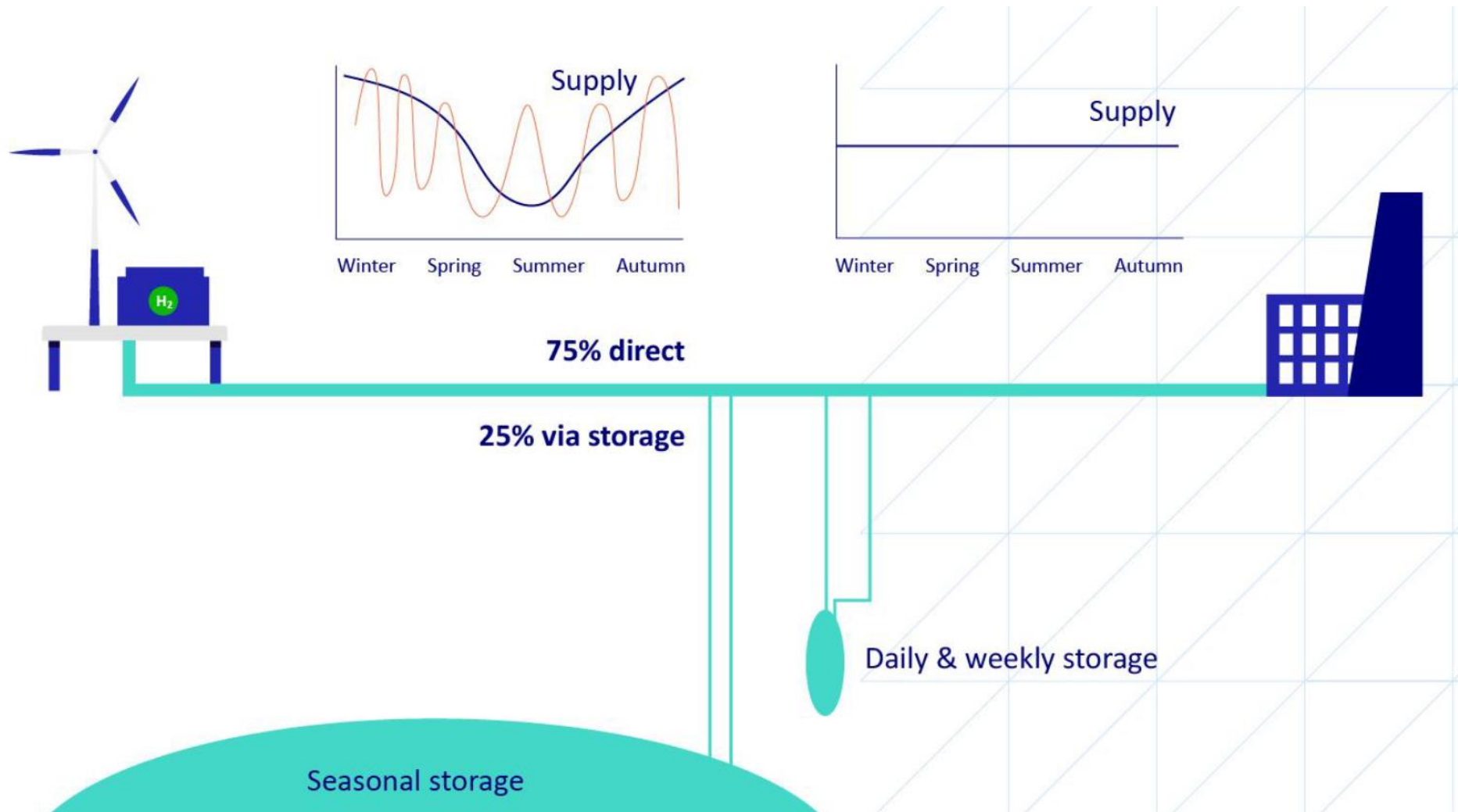
- Able to transport similar energy volumes as today for gas
- Re-using as much as possible existing gas infrastructure
- Using same onshore landing points as for gas.
- Connecting to proposed European Hydrogen Backbone
- Connecting feasible renewable hydrogen production locations



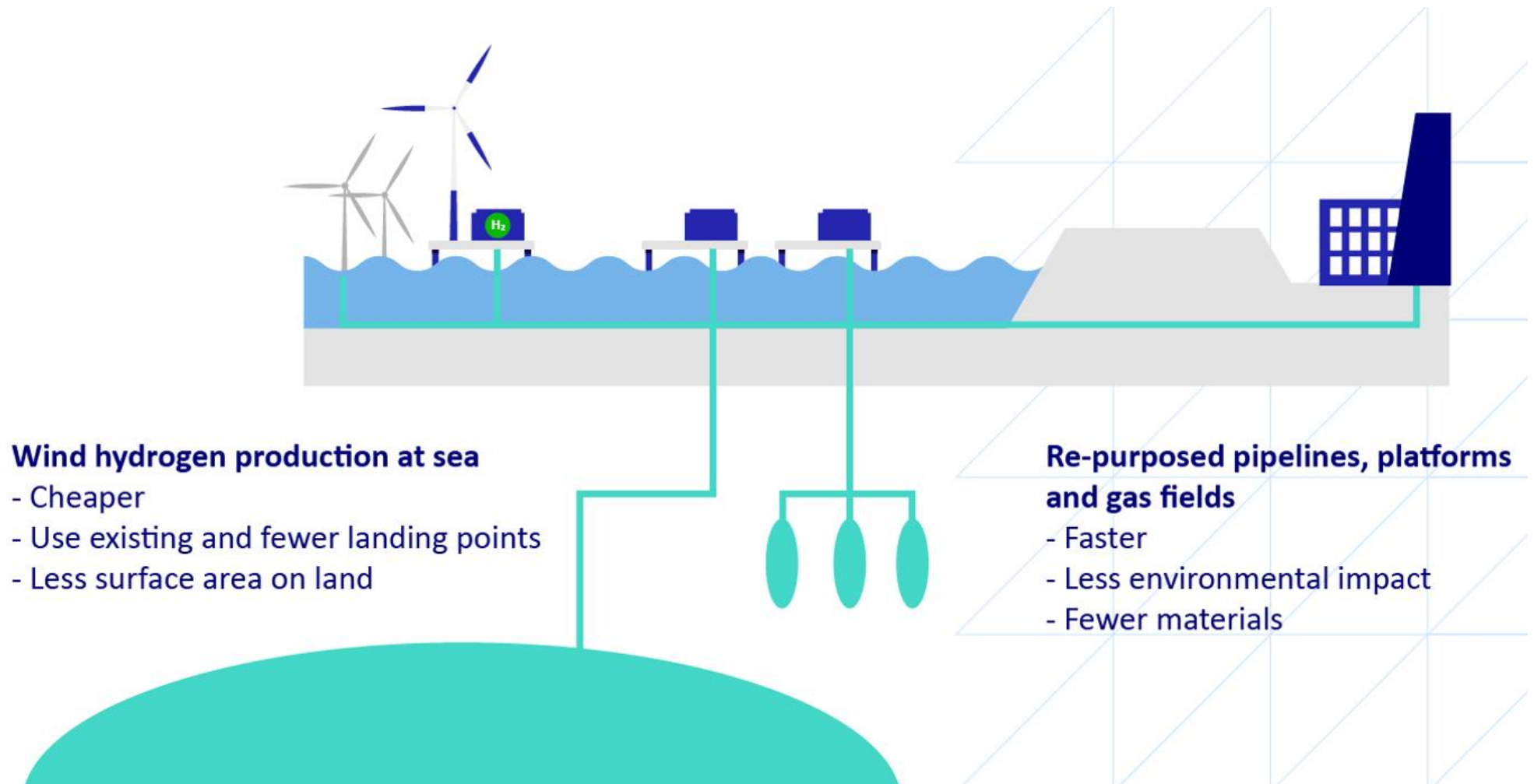
Offshore Wind Hydrogen production is cheaper than Onshore Hydrogen production because Less Electricity conversion cost and cheaper transport cost



**Wind hydrogen production volumes are fluctuating over time.
To deliver base load hydrogen, requires 25% production flow
via storage**



Offshore Wind Hydrogen Production at the North Sea, Cheaper, Faster and Cleaner

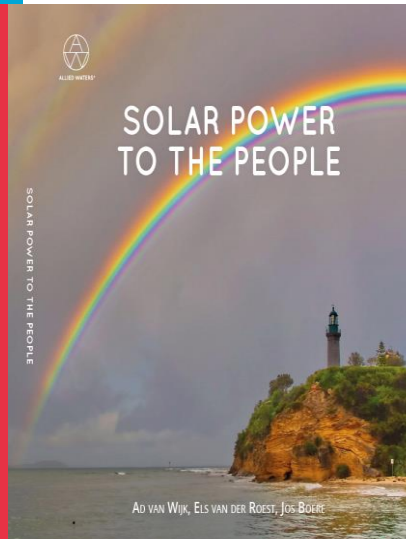


Further Reading

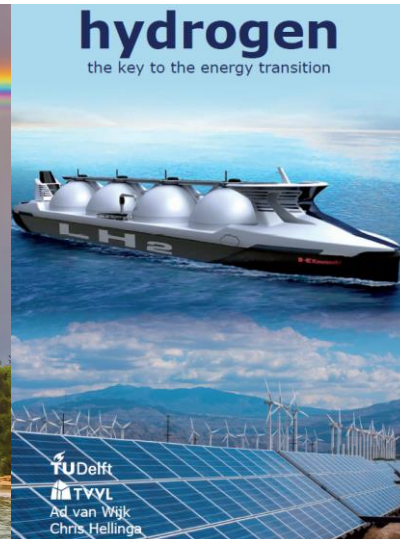
www.profadvanwijk.com



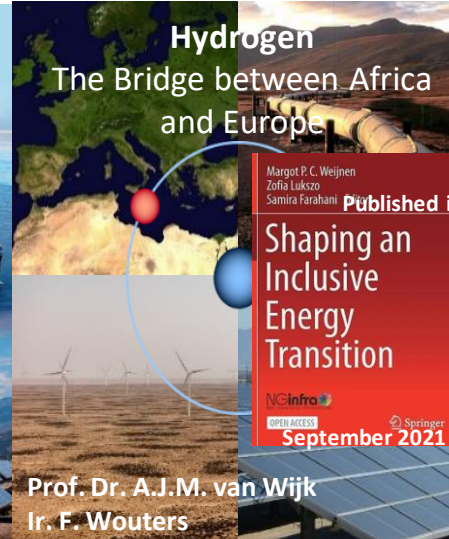
April 2017



November 2017



May 2018



September 2019



November 2019

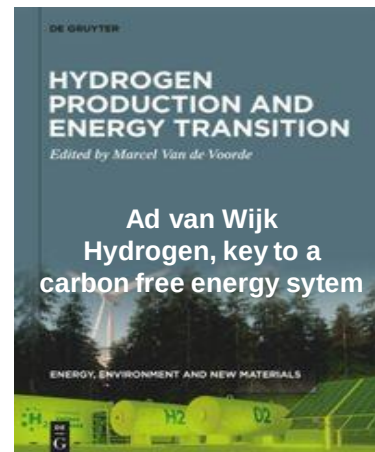


April 2020

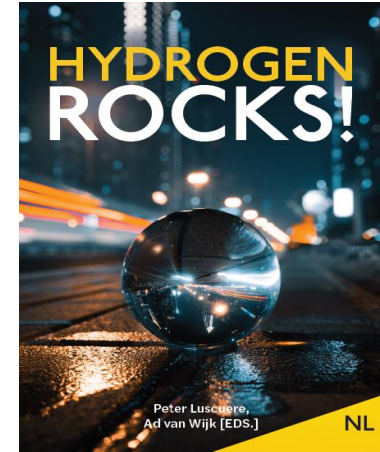


April 2021
Hydrogen Europe

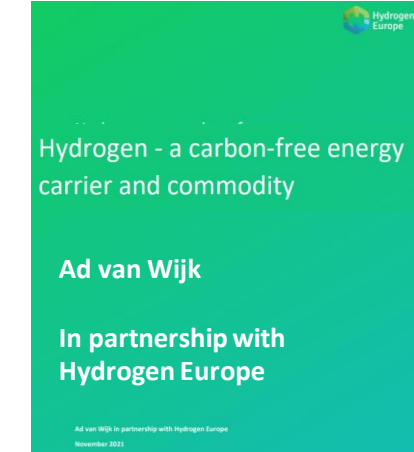
April 2021



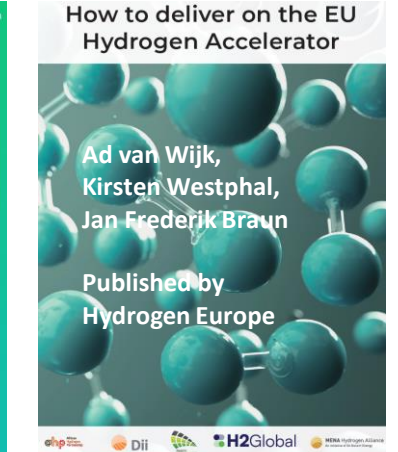
September 2021



October 2021



November 2021



May 2022