

The background image shows a large, modern amphitheater with a wide, sloping concrete staircase. Many people are sitting on the steps, some in groups, some alone. In the background, a large, cylindrical concrete tower with a metal lattice structure on top stands against a clear blue sky. To the right, there are green trees and a modern building. The overall scene is bright and sunny.

Groene Waterstof uit de Woestijn en de Oceaan

Prof. Dr. Ad van Wijk

28-5-2018

Solar and Wind 2016

ONSHORE WIND



SOLAR PV



Location

Price

Morocco

3,0 \$ct/kWh

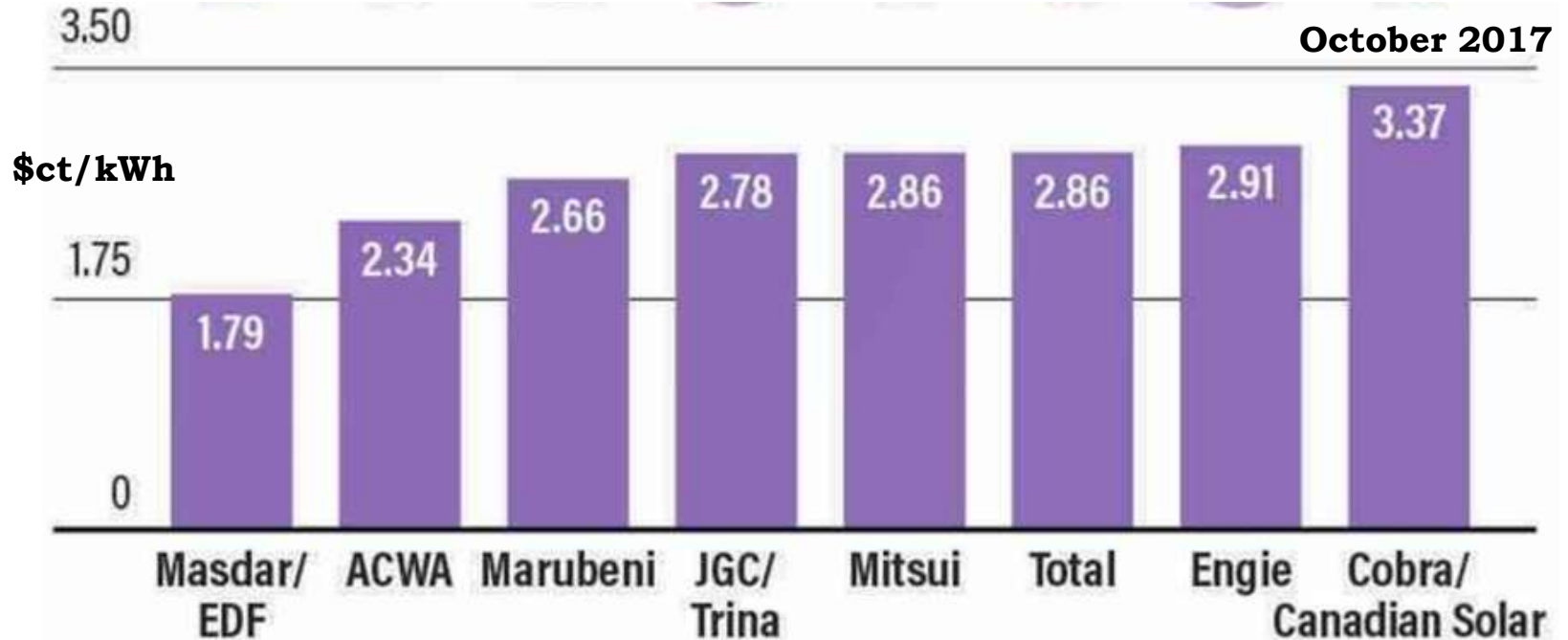
Location

Price

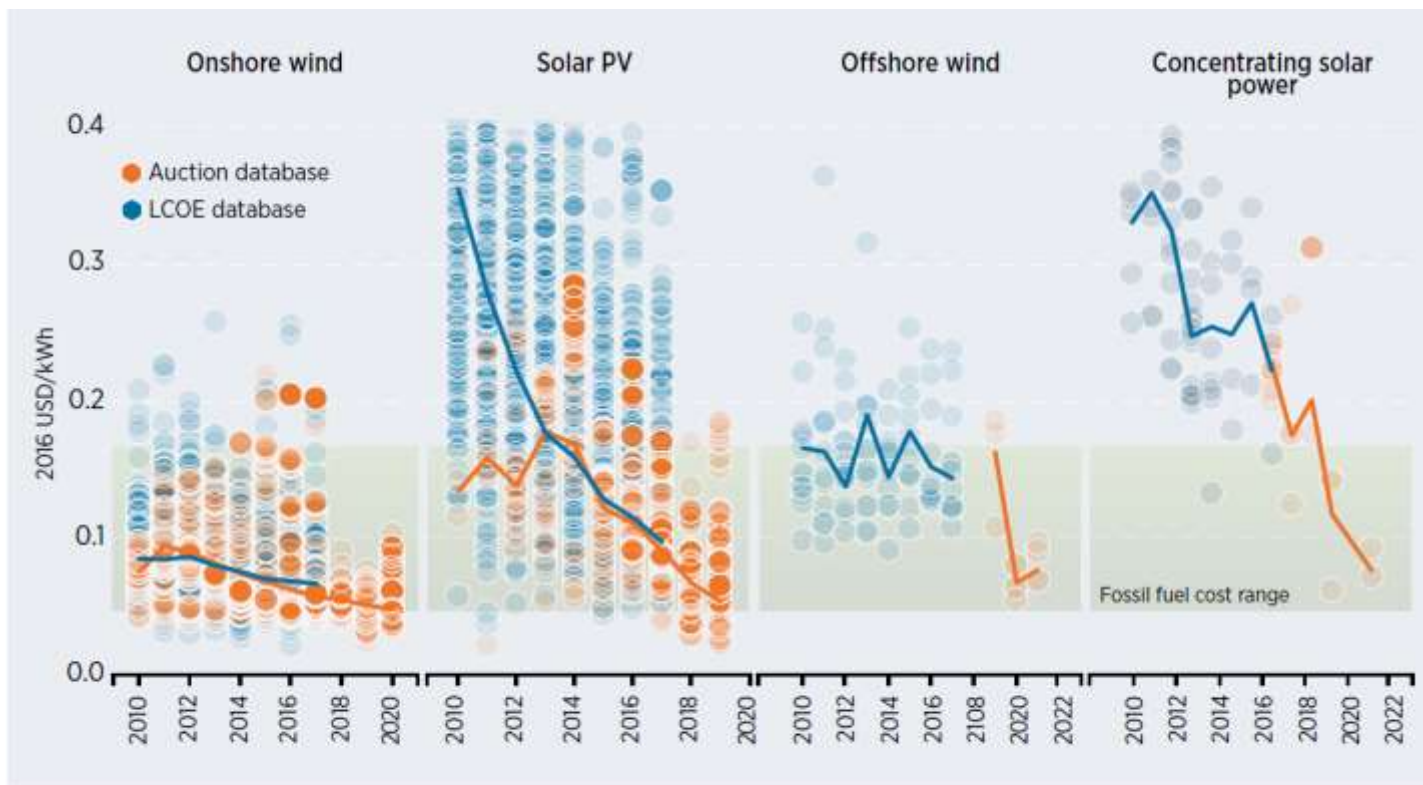
Dubai

2,99 \$ct/kWh

Bids for Saudi Arabia's 300 MW Solar Plant

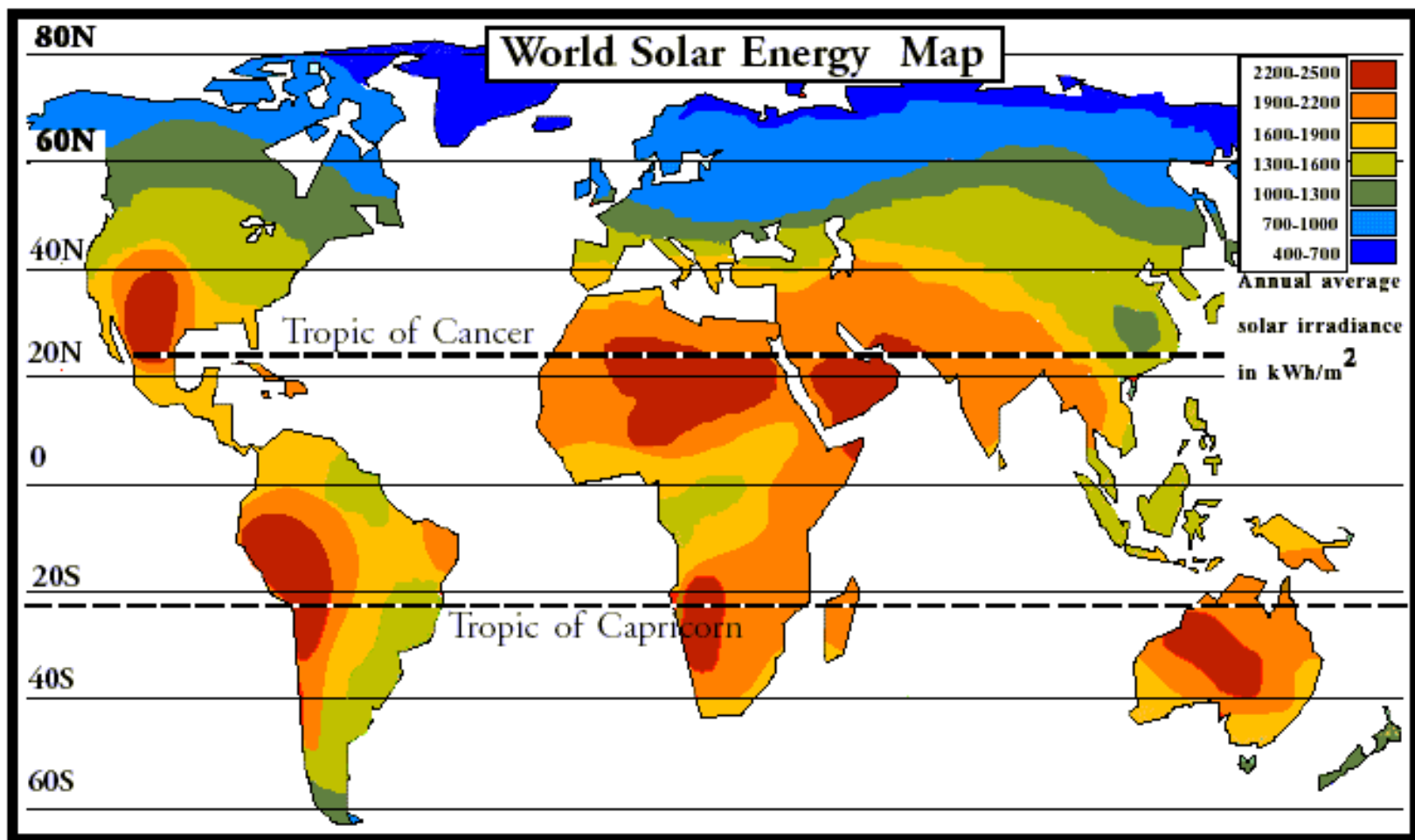


Levelized Cost of Electricity



Source: IRENA Renewable Cost Database and Auctions Database.

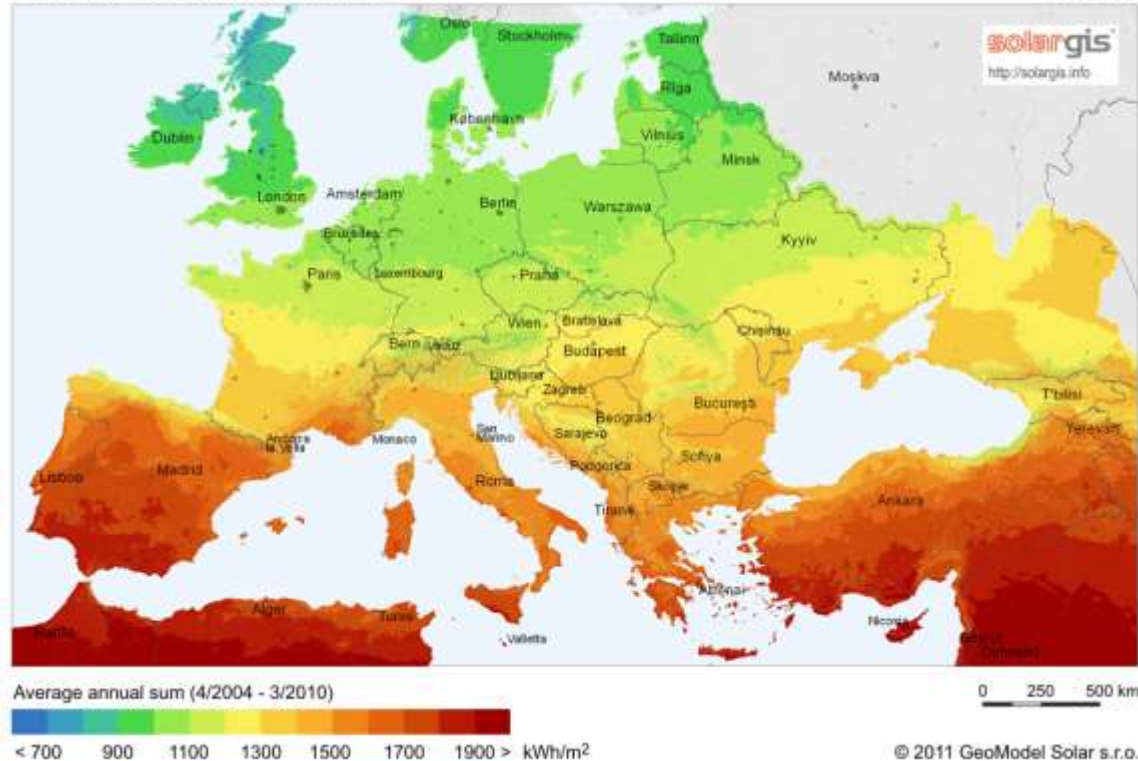
IRENA, January 2018, Renewable Power Generation Costs 2017



European Solar Energy Atlas

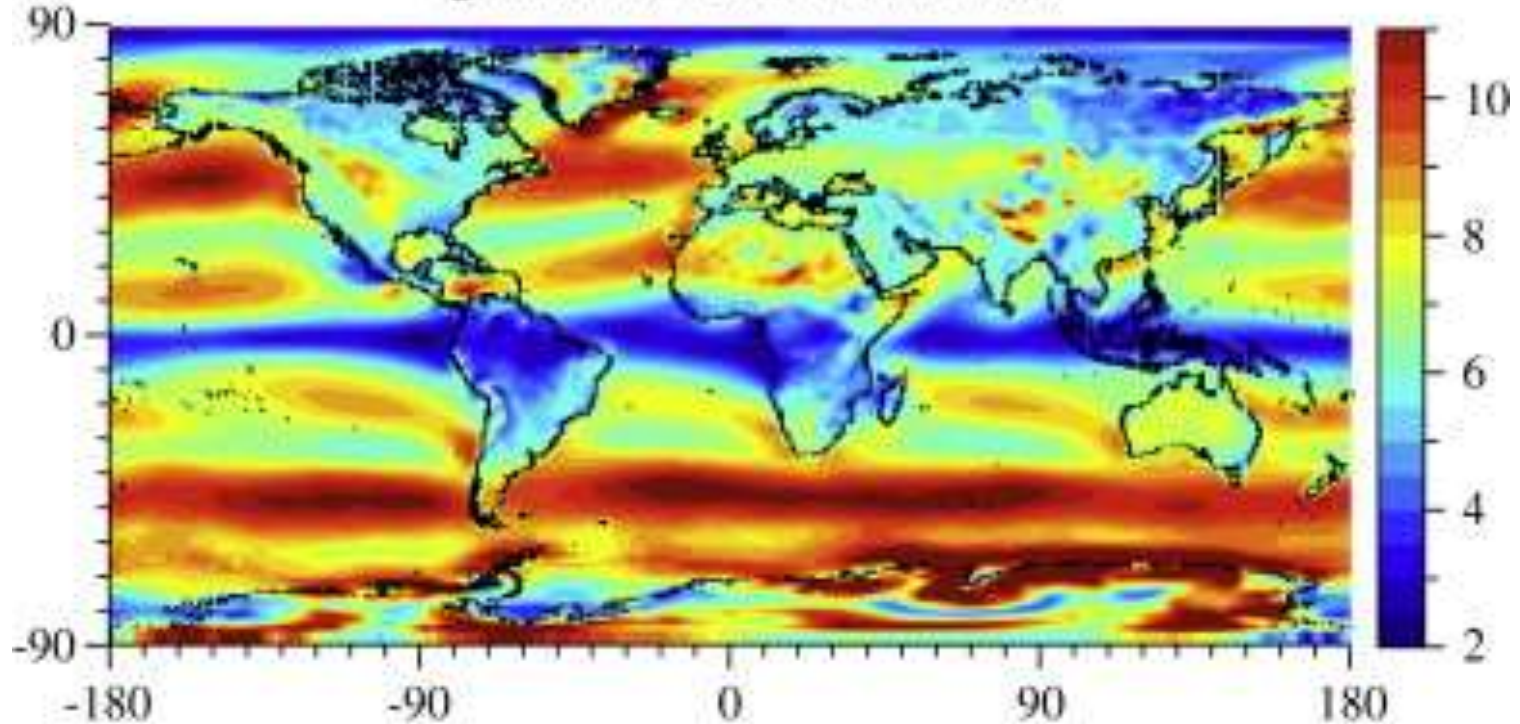
Global horizontal irradiation

Europe

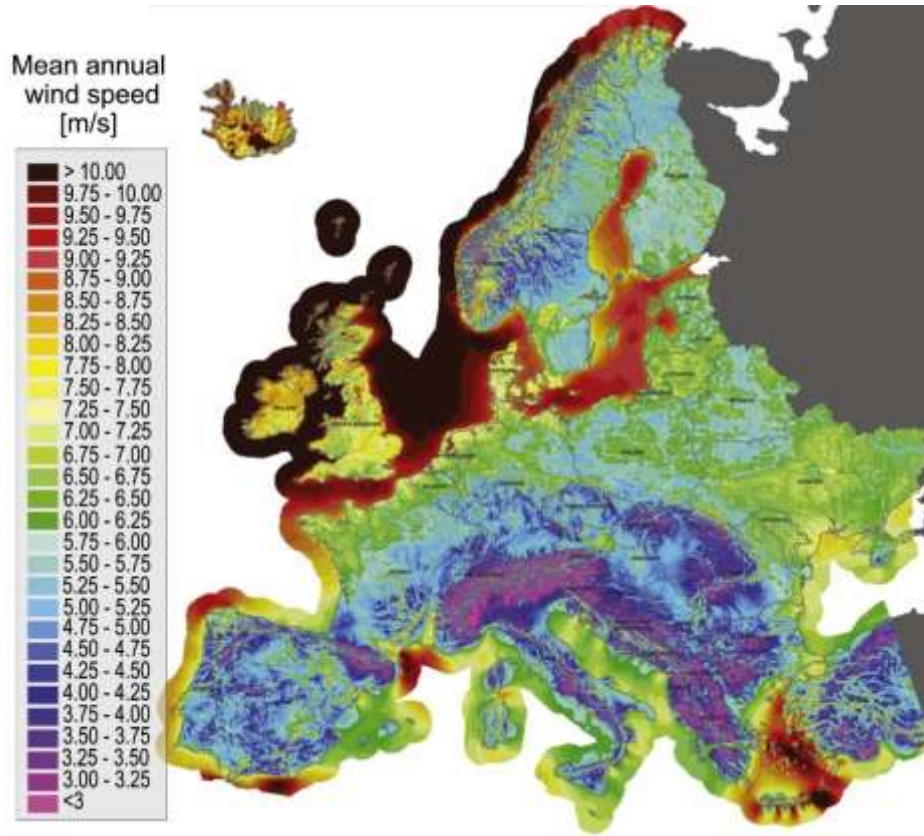


Wind Energy

Annual wind speed 100m above topo (m/s)
(global: 7.0; land: 6.1; sea: 7.3)



European Wind Speed Atlas (80 m)



Surface needed to produce all the world's energy 556 EJ = 155.000 TWh



10% SOLAR AUSTRALIA

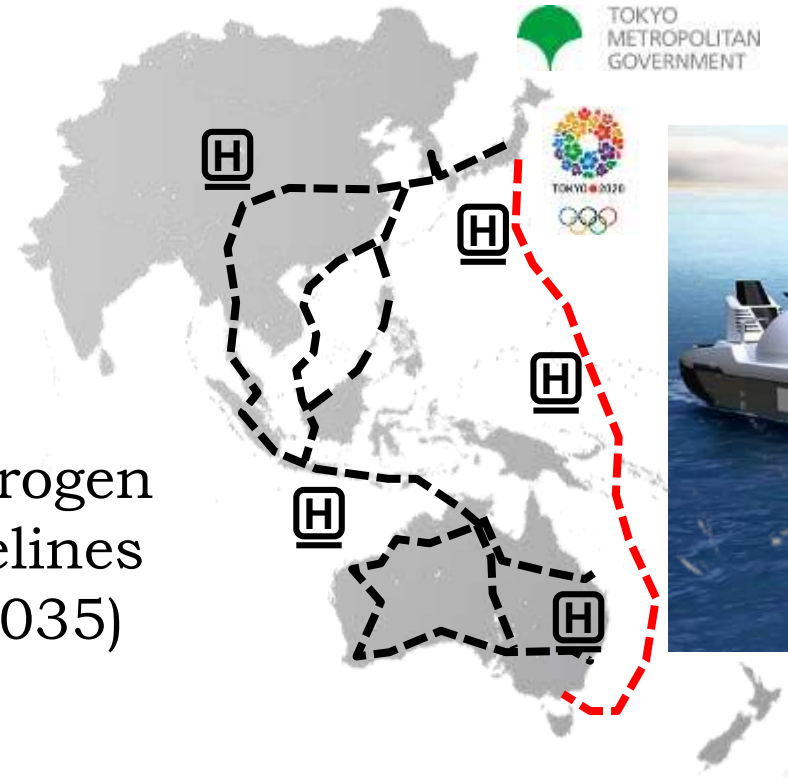


1.5% WIND PACIFIC OCEAN

Tokyo Olympic Games 2020



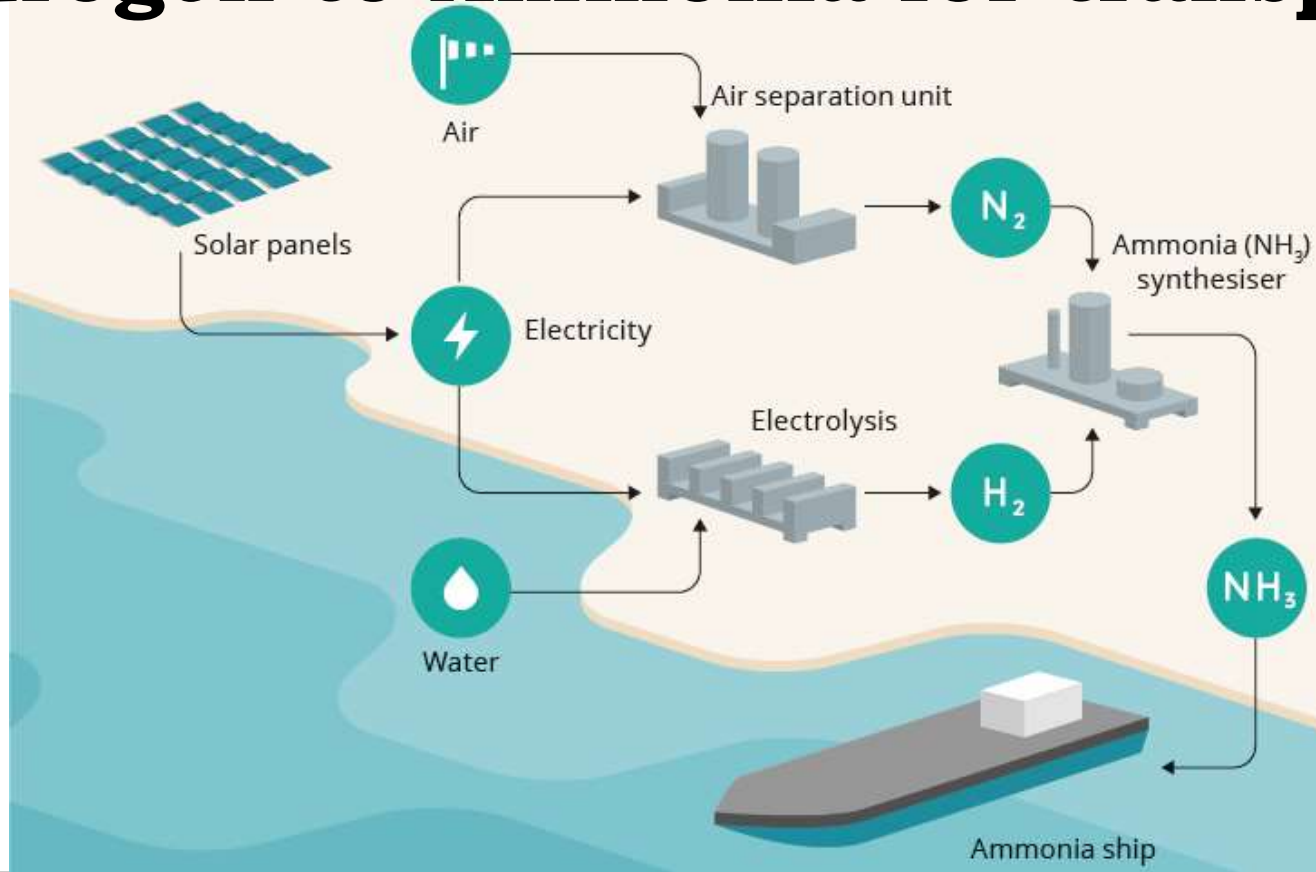
Hydrogen
Pipelines
(~2035)



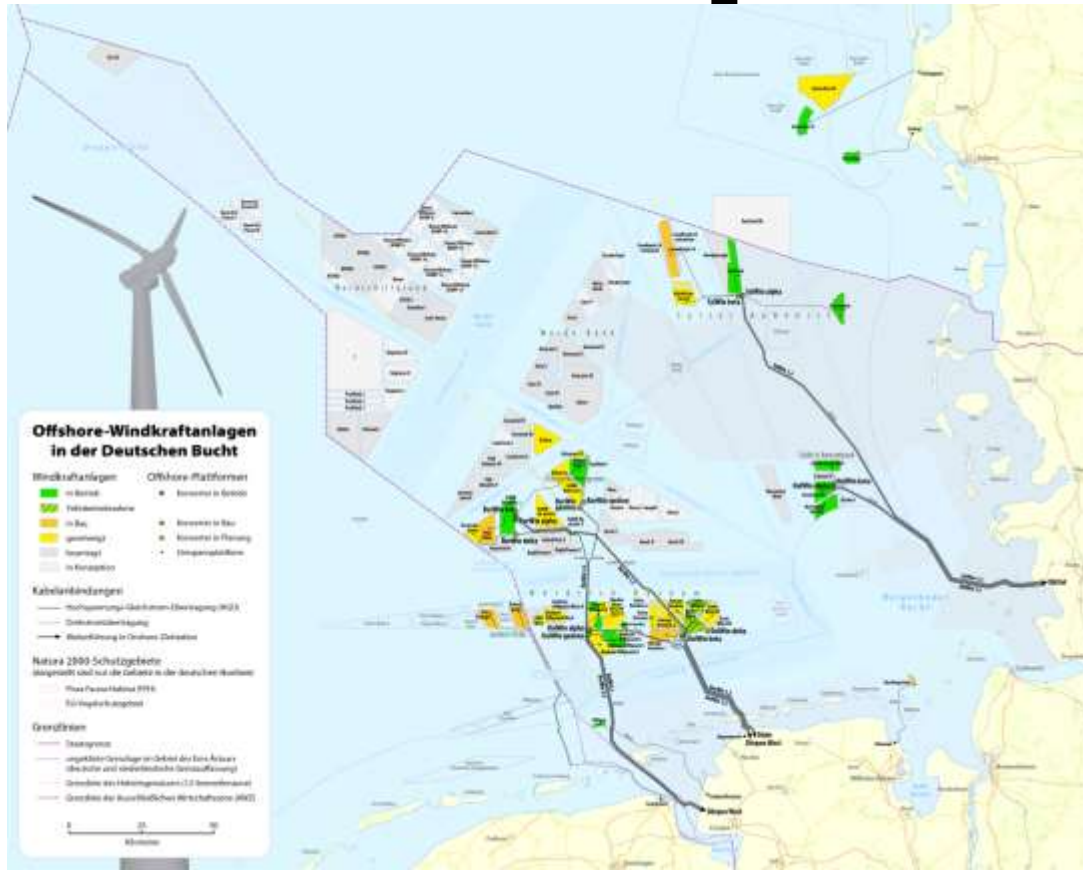
Hydrogen
Shipping
(~2025)



Hydrogen to Ammonia for transport



Offshore Wind Development Germany



VATTENFALL BOUWT WINDPARK ZONDER SUBSIDIE

19 MAART 2018

- Chinook, daughter Vattenfall
- 700 MW wind farm
- Operational 2022
- Location Hollandse Kust (Zuid)
- 22 km from the coast



Eemshaven; The Energy Harbor



Norned Cable 700 MW

Cobra Cable 700 MW (2019)

Gemini Offshore Wind Farm 600 MW

Onshore Wind Farms > 275 MW

Nuon Magnum power plant 1,320 MW

RWE Coal fired power plant 1,560 MW

Engie Gas fired power plant 2,450 MW

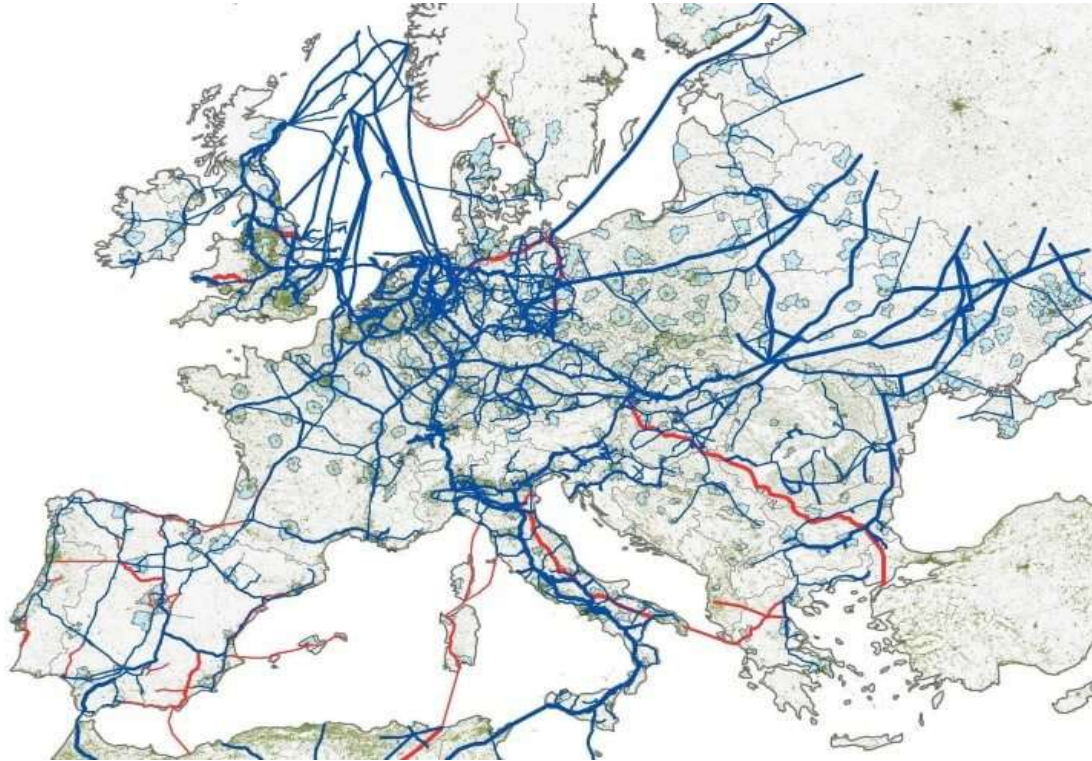
Cable Inland 4,000 MW

Expansion to 5,610 MW

Electricity and Gas Transport Grid



European Gas Infrastructure



Doggersbank Energy Island



5 GW Mohammed Bin Rashid Al Maktoum Solar Park in Dubai



Largest CSP project in the world

- 700MW CSP, 15 hours storage
- \$3.9 billion investment
- Central Tower 100 MW
- Parabolic Troughs 3x200 MW
- Auxiliary solar PV 4x33 MW
- Tariff 7.3 ct/kWh
- PPA 35 years
- Dispatch: between 4pm and 10am

Gas Pipelines

North Africa – South Europe

Solar Electricity-Hydrogen production in Morocco, Algeria, Spain and Italy can be transported throughout Europe via existing gas pipelines converted to hydrogen

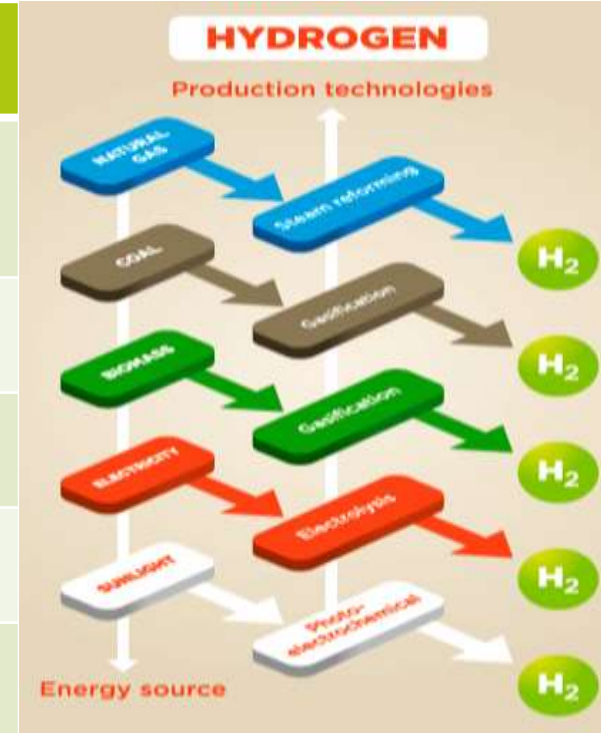


Cable versus pipeline cost

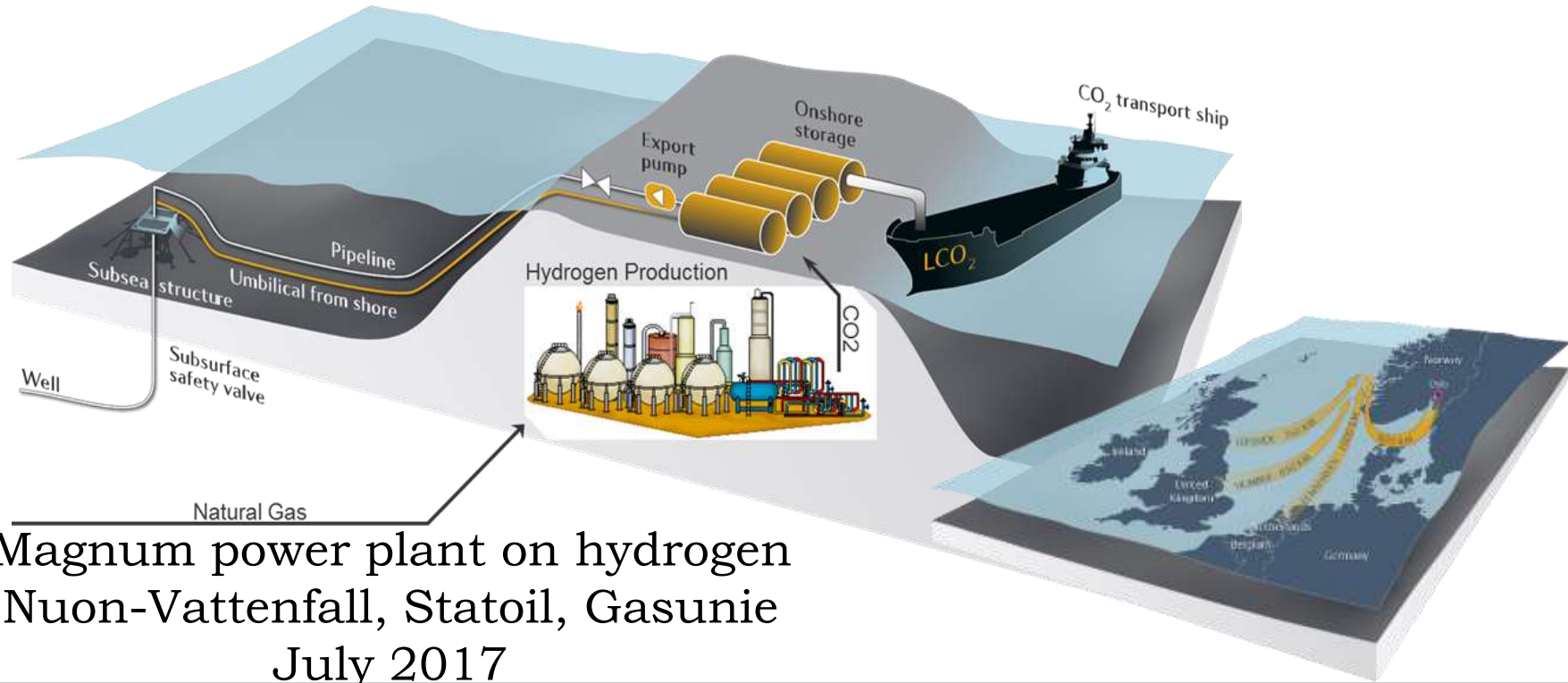
	Cable (BritNed)	Pipeline (BBL)
Capacity	1 GW	15 GW
Construction Cost	€ 500 mln	€ 500 mln
Volume (year)	8 TWh	120 TWh

Hydrogen production

Source	Process	Efficiency Today
Natural gas Bio Gas	Steam reforming Solid Oxide Fuel Cell	72% 80% (40-40)
Coal/Oil	Gasification	56%+ (=syngas)
Biomass	Gasification	44%+ (=syngas)
Electricity + Water	Electrolysis Alkaline and PEM	75-80% (90% exp.)
Sunlight + Water	Photoelectrochemical	14% (lab)



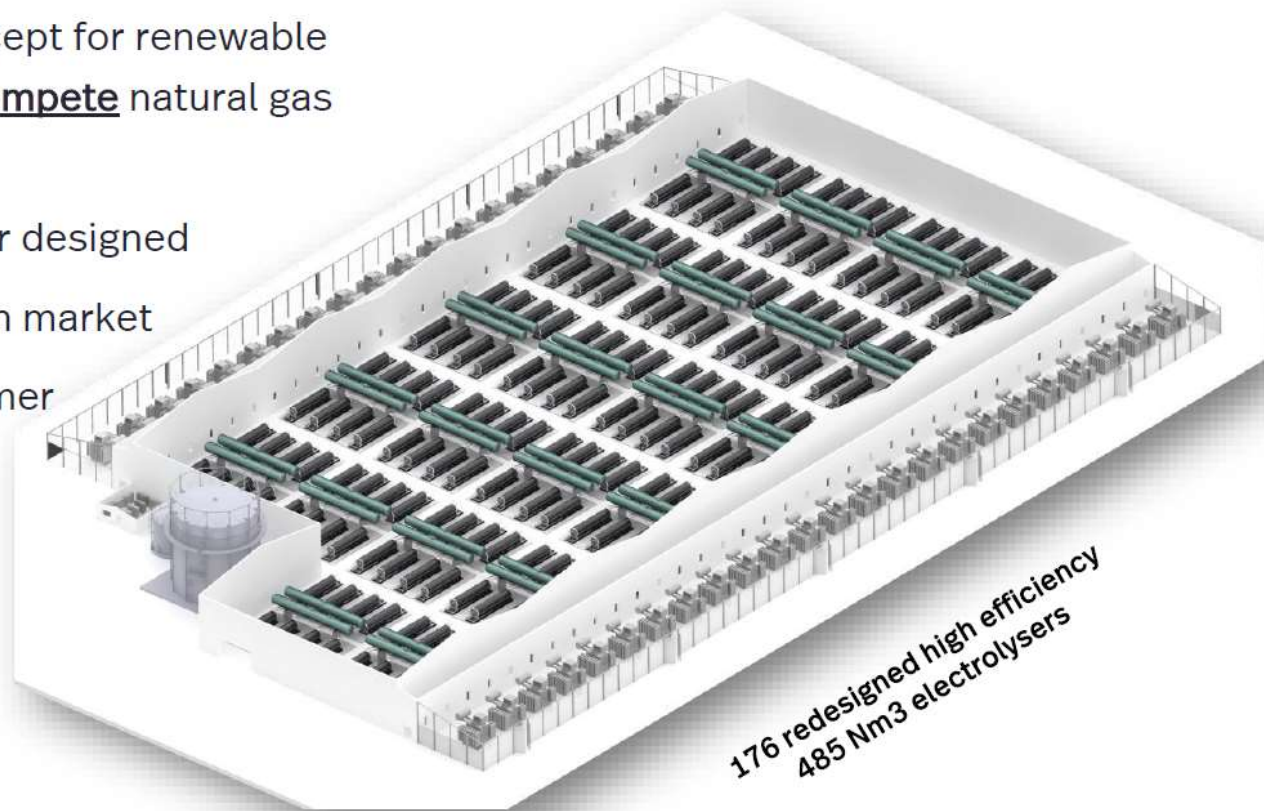
Gas-Hydrogen production with CO₂ storage in Smeaheia field



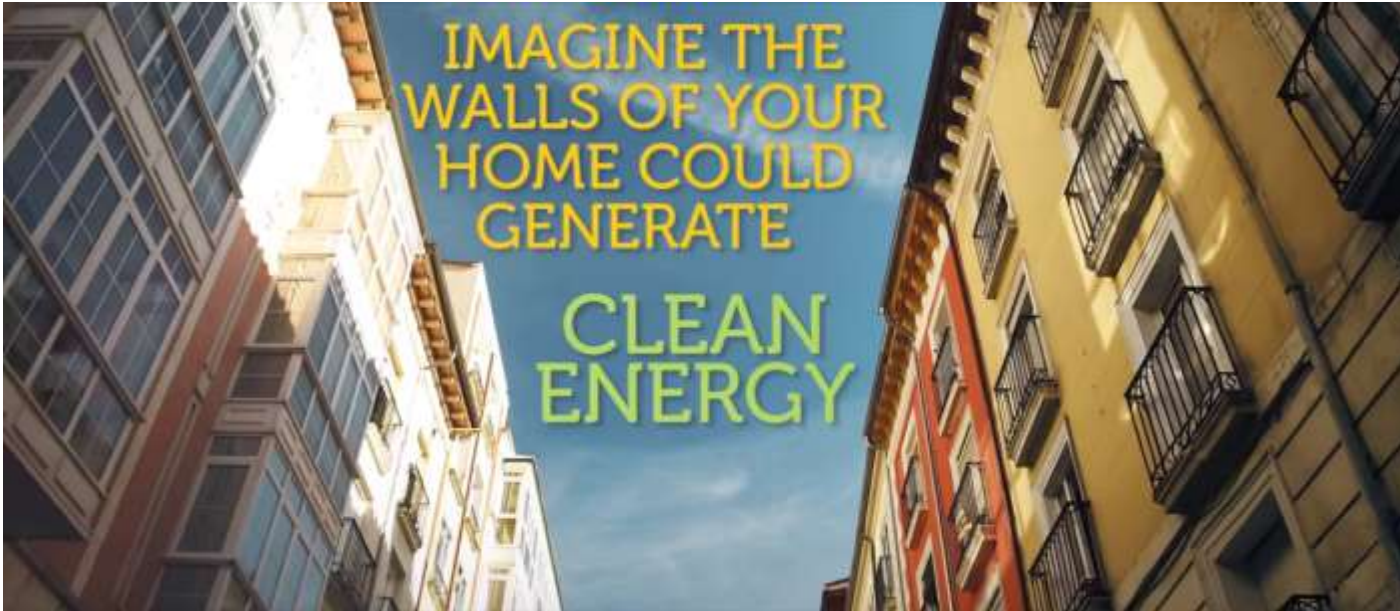
Magnum power plant on hydrogen
Nuon-Vattenfall, Statoil, Gasunie
July 2017

NEL 400 MW Alkaline Electrolyzer

- Working on GIGA factory concept for renewable hydrogen production to **outcompete** natural gas reforming
- Largest electrolyser plant ever designed
- Addressing a USD ~ 150 billion market
- International industrial customer
- Tied to solar power
- CapEx of USD ~175 million
- Benchmark CapEx ratio:
 - 0.45 MUSD/MW



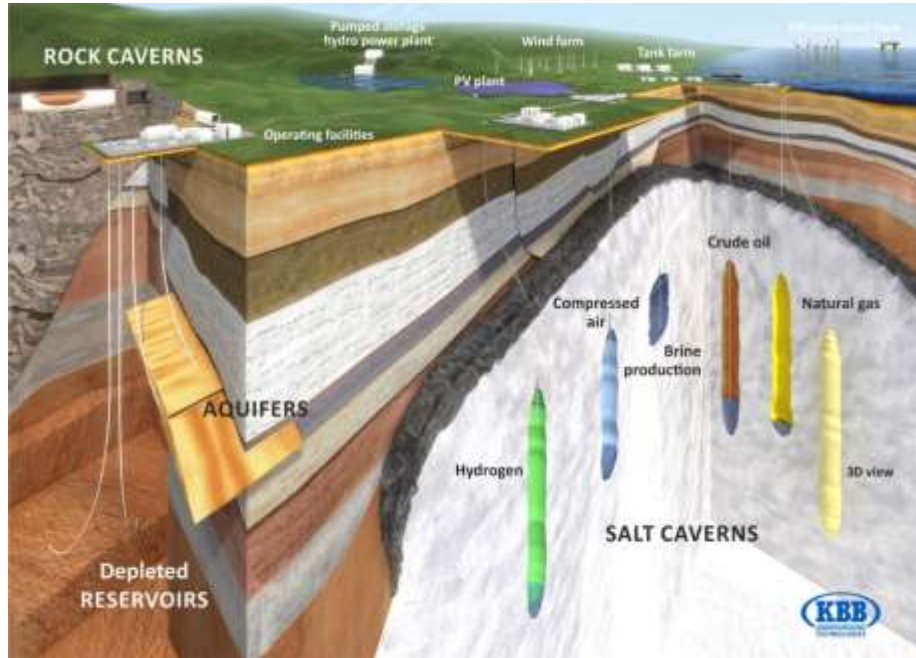
176 redesigned high efficiency
485 Nm³ electrolysers



Green Hydrogen Cost development

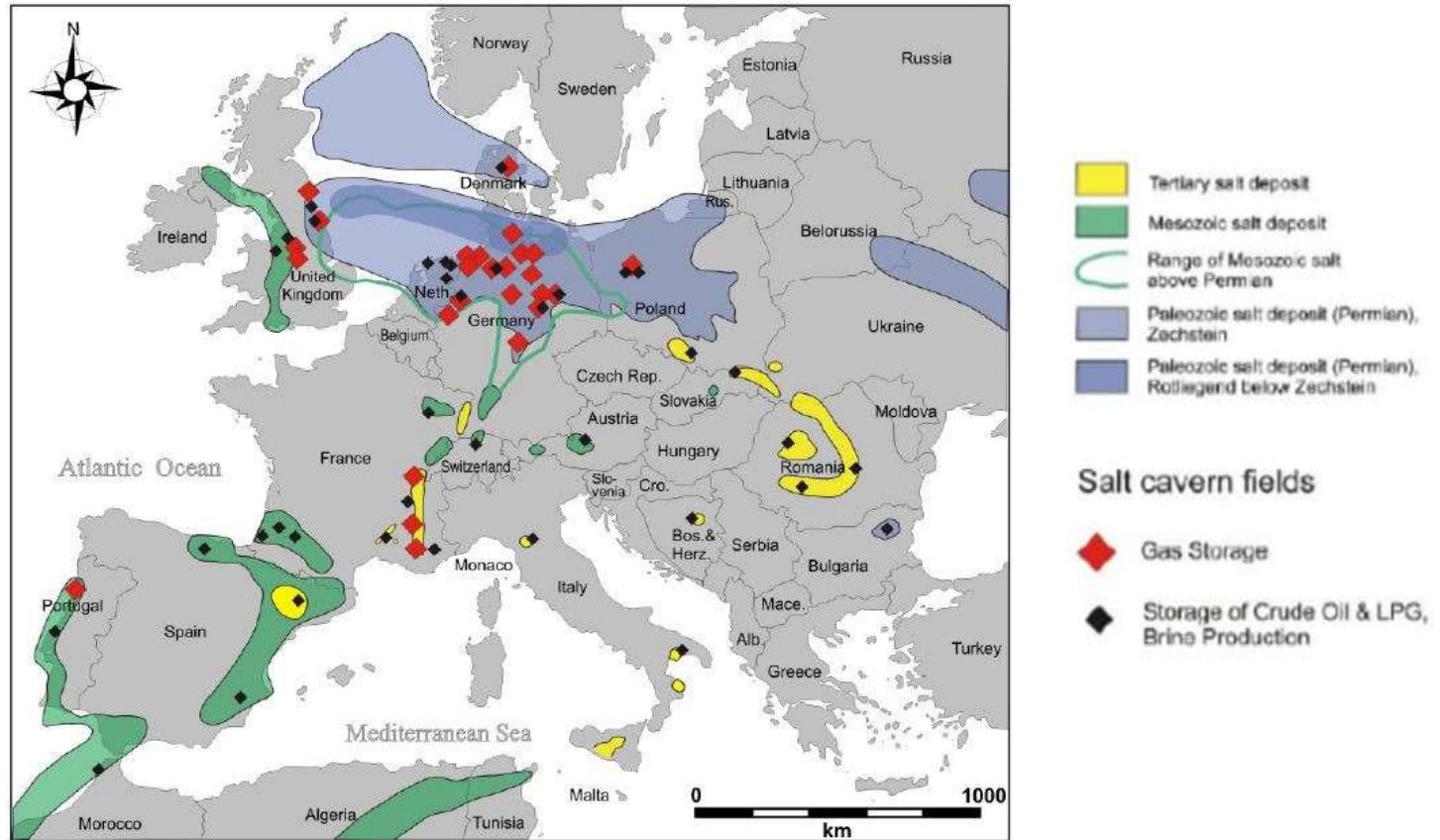
	Investment cost	Efficiency	Electricity Price Offshore Wind	Hydrogen Price
Till 2020	600-900 Euro/kW	72-75%	40-50 Euro/MWh	3-4 Euro/kg
2020-2025	300-600 Euro/kW	75-78%	30-40 Euro/MWh	2-3 Euro/kg
2025-2030	250-400 Euro/kW	78-80%	25-35 Euro/MWh	1.5-2.5 Euro/kg
After 2030	<250 Euro/kW	>80%	20-30 Euro/MWh	1-1.5 Euro/kg

Hydrogen storage in Salt Caverns

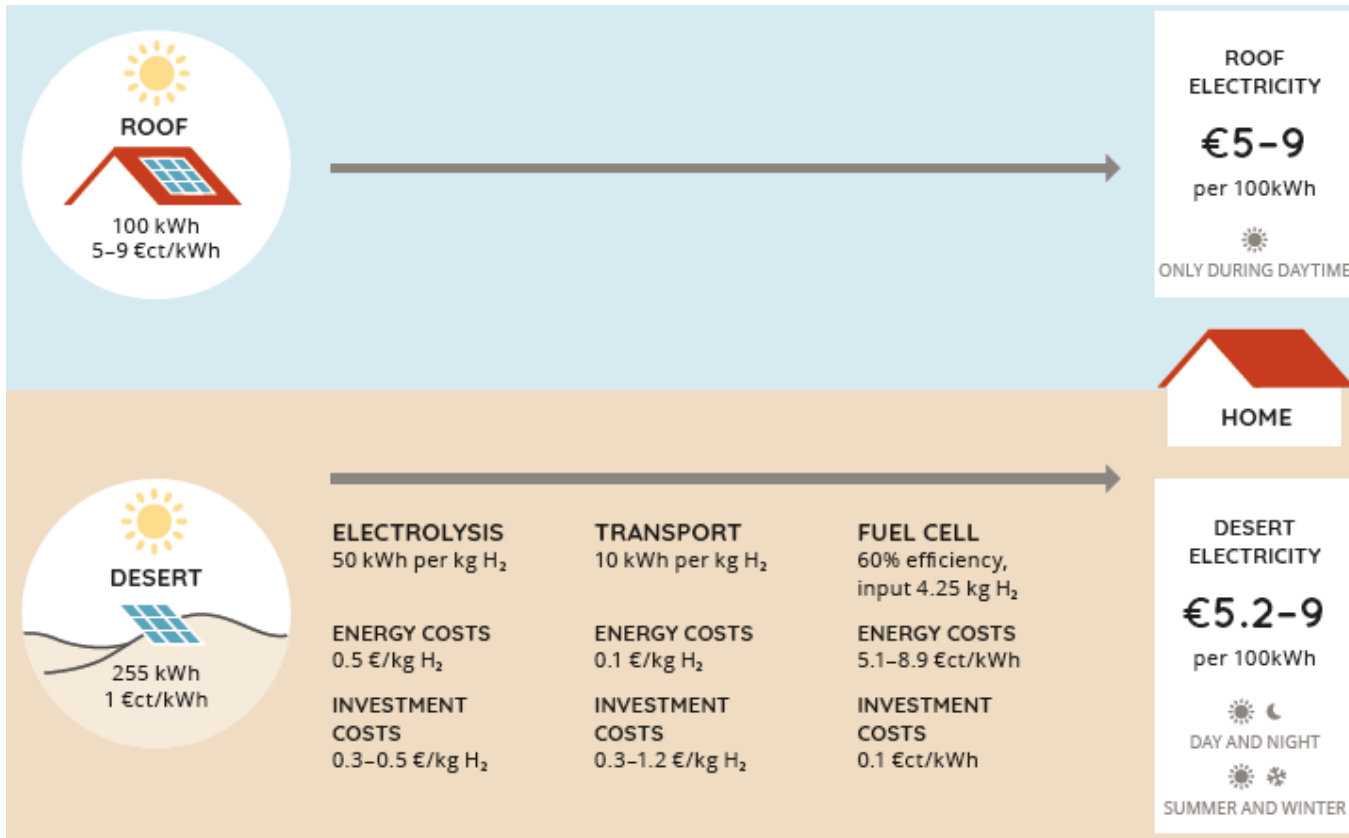


1 salt cavern can contain 6,000 ton hydrogen
Equivalent of 17 million Tesla Power walls

Salt formations and caverns in Europa



Roof versus Desert Solar

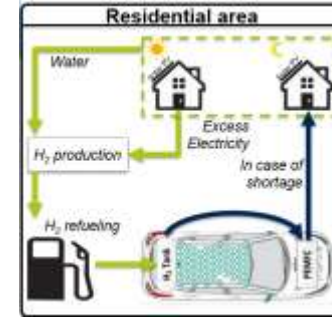


Green Hydrogen Markets

Chemical Feedstock



Electricity Balancing



Transport



Heating



The Future is Electric!

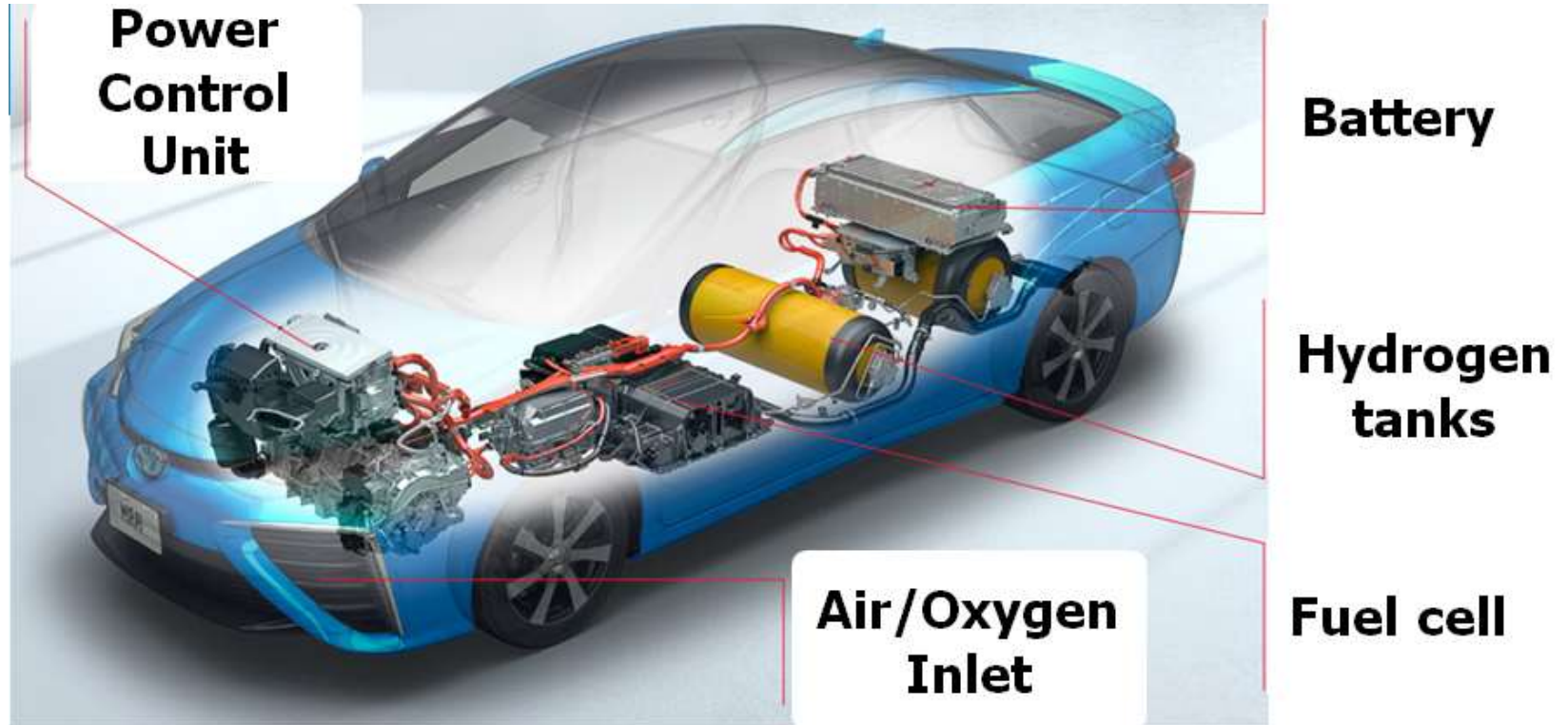


Tesla Model S



Toyota Mirai

Toyota Mirai; Fuel cell car



Fuel cell car characteristics

Fuel cell type	Proton Exchange Membrane
Capacity	80-120 kW
Electrical efficiency	60% at full load
Hydrogen tank capacity	4-6 kg
Hydrogen energy content (HHV)	39 kWh per kg
Water production	9 Liter per kg Hydrogen
Driving distance	100 km per kg Hydrogen

Hydrogen versus petrol safety



Fuel Cell Hydrogen Train, Ferry, Drone

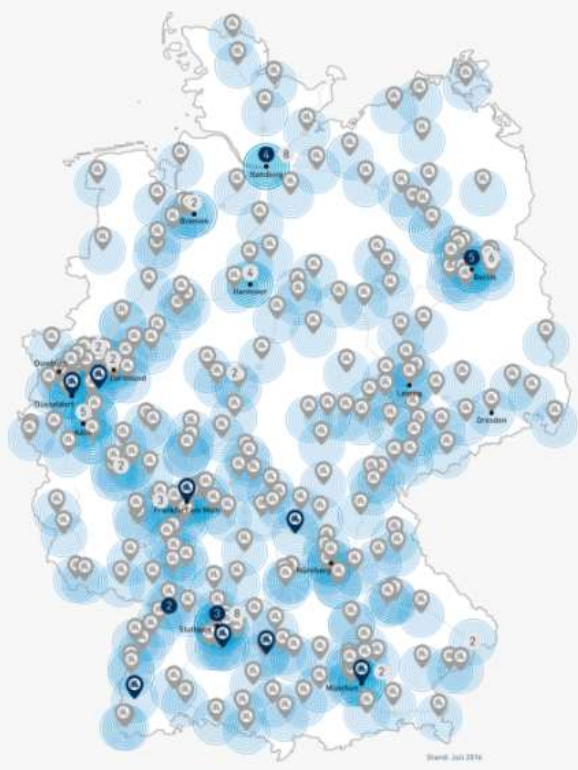


Holthausen converted Tesla in Hesla

Nov 2017



Duitsland 400 waterstof tankstations in 2023

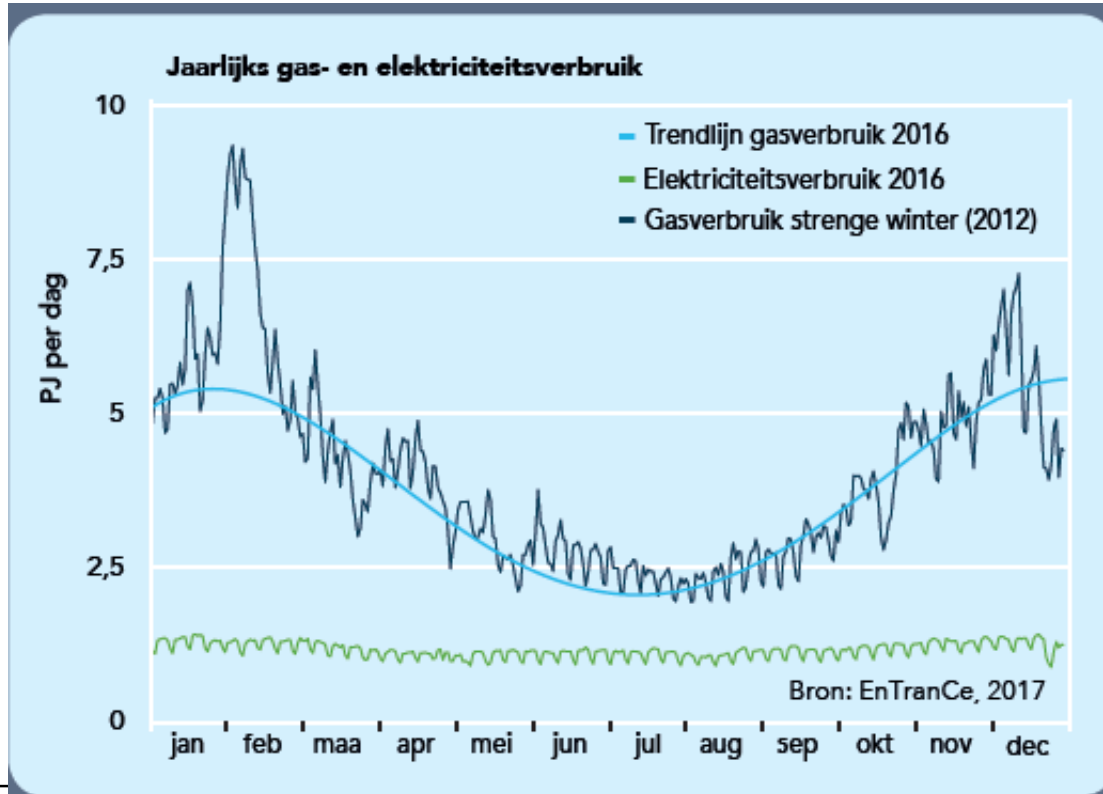


400 waterstof tankstations in 2023, bij bestaande tankstations.

Investerings: 350 miljoen Euro, half overheid, half bedrijven.

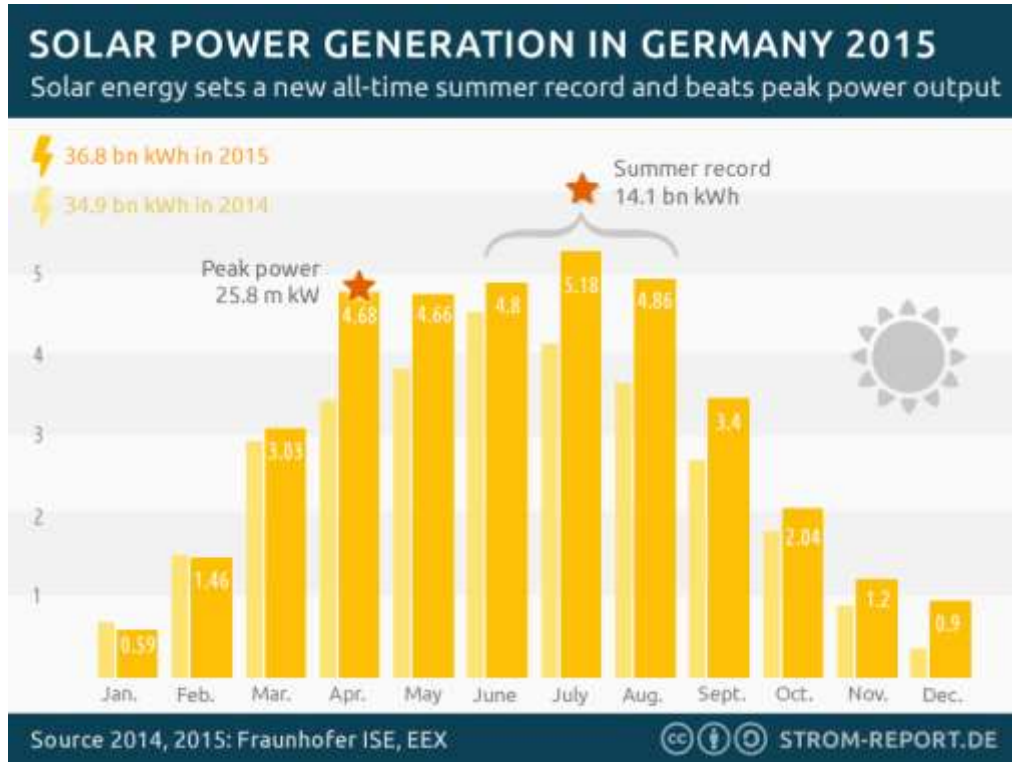
Consortium: Shell, Total, Linde, Air Liquide, OMV, Daimler, BMW, Volkswagen, Toyota, Honda, Hyundai, NOW (Duitse Overheid)

Gas and Electricity consumption the Netherlands



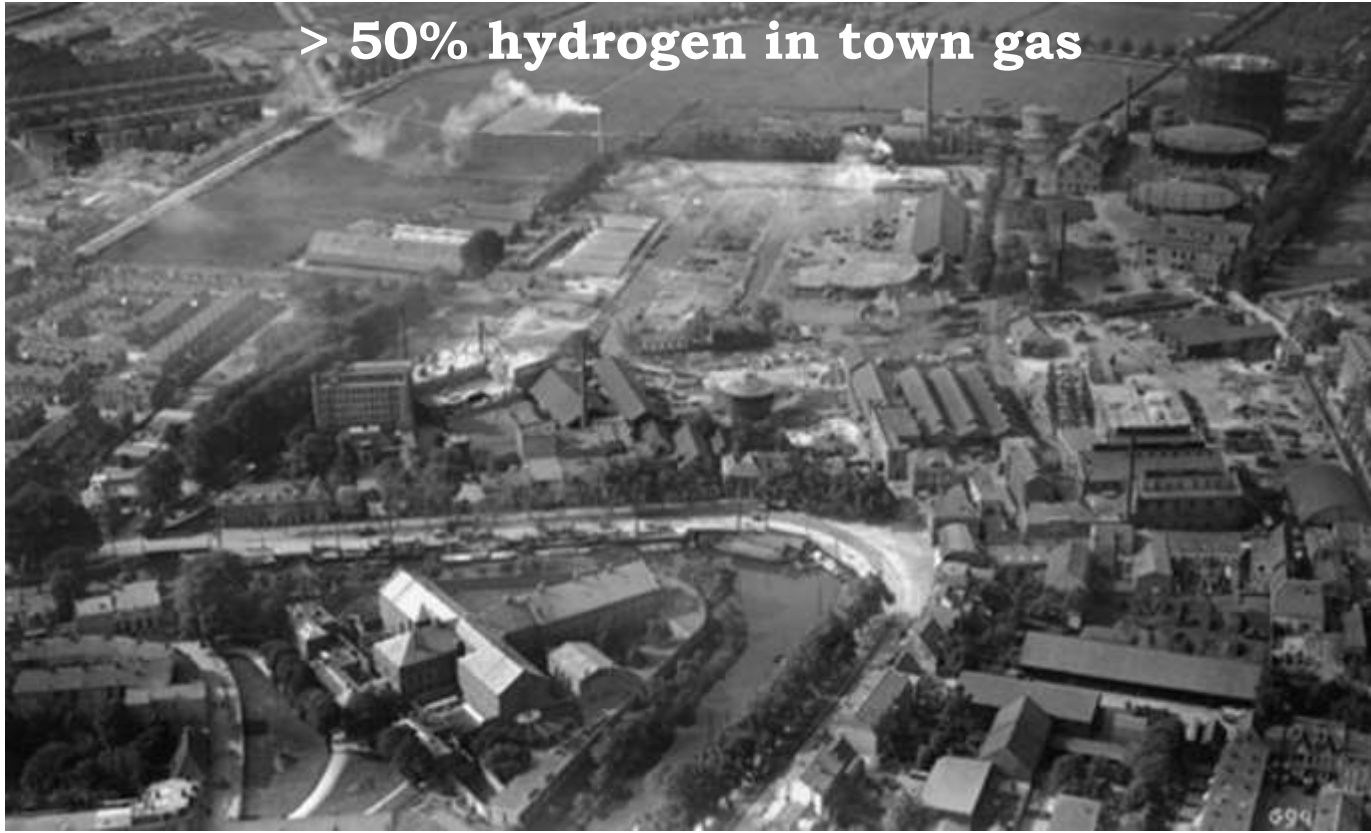
Large seasonal difference in gas consumption due to heating demand. Therefore a huge need for seasonal storage.

Solar power production in Germany

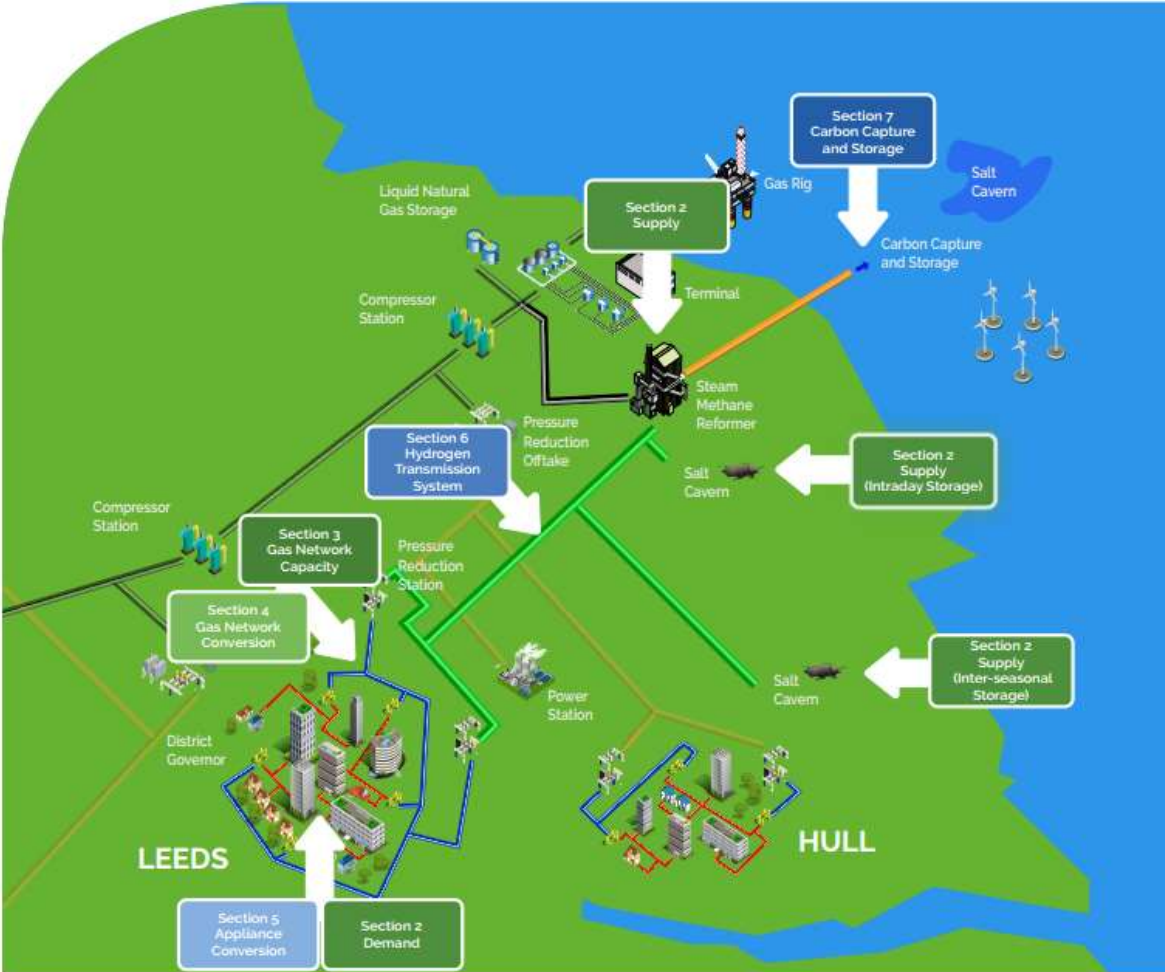


Town Gas production Utrecht 1862-1959

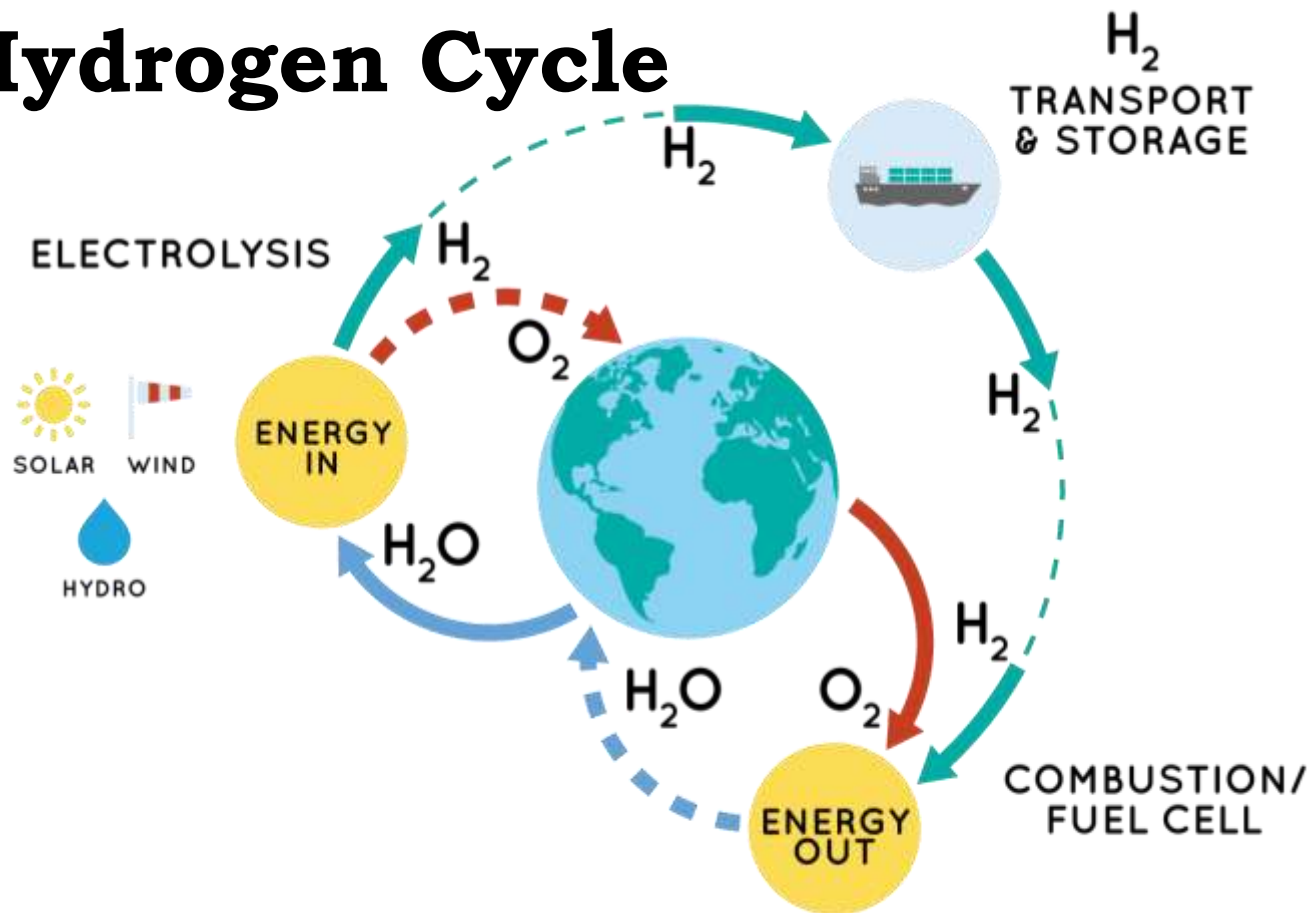
> 50% hydrogen in town gas



Leeds City Gate Project



The Hydrogen Cycle



Defying Death Valley

