

The background image shows a large, modern amphitheater with wide, light-colored concrete steps. Many people are sitting on the steps, some in groups, some alone. In the background, there is a large, cylindrical concrete structure with a tall, thin metal tower on top. The sky is clear and blue. The overall scene is bright and sunny.

Developing the Hydrogen Economy

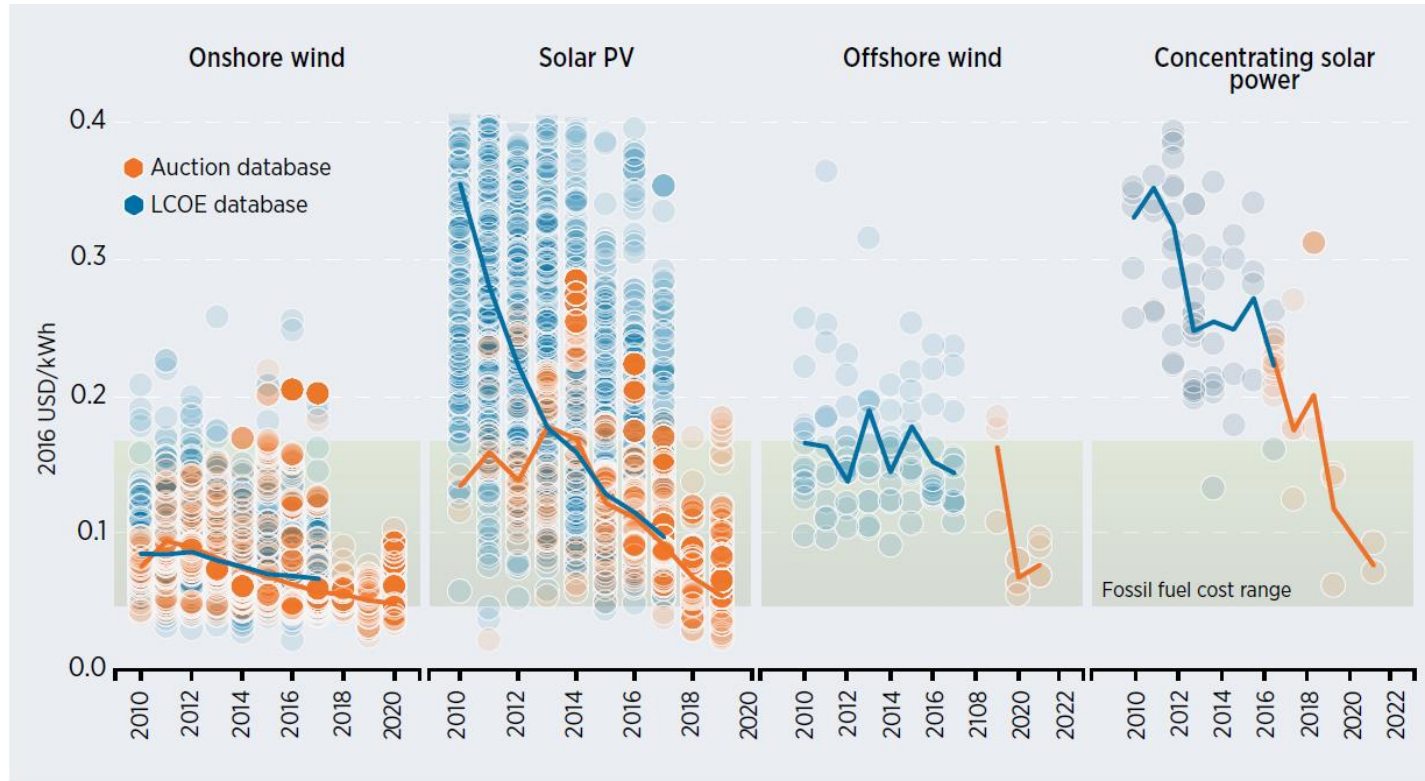
Prof. Dr. Ad van Wijk

6-9-2018

Bids for Saudi Arabia's 300 MW Solar Plant

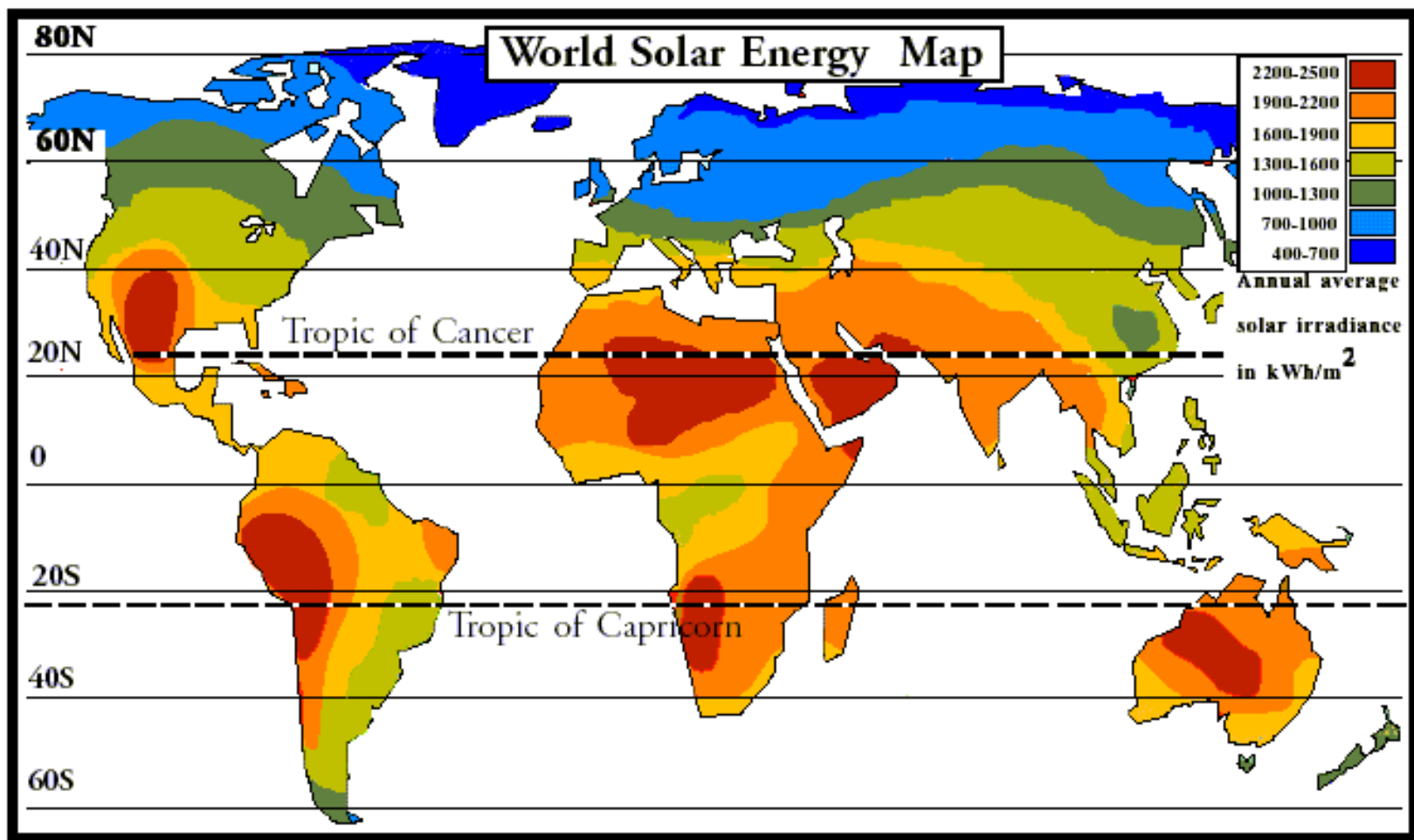


Levelized Cost of Electricity

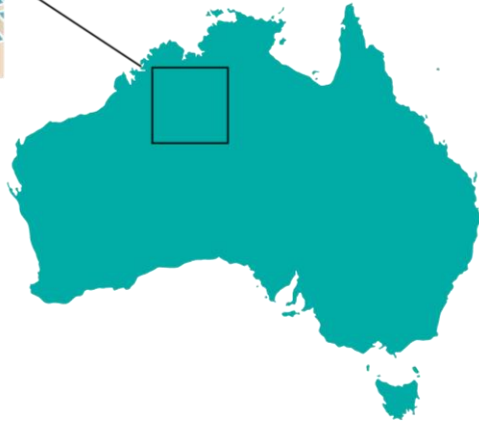
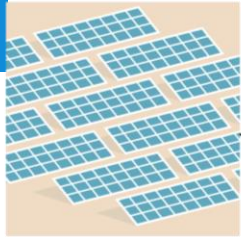


Source: IRENA Renewable Cost Database and Auctions Database.

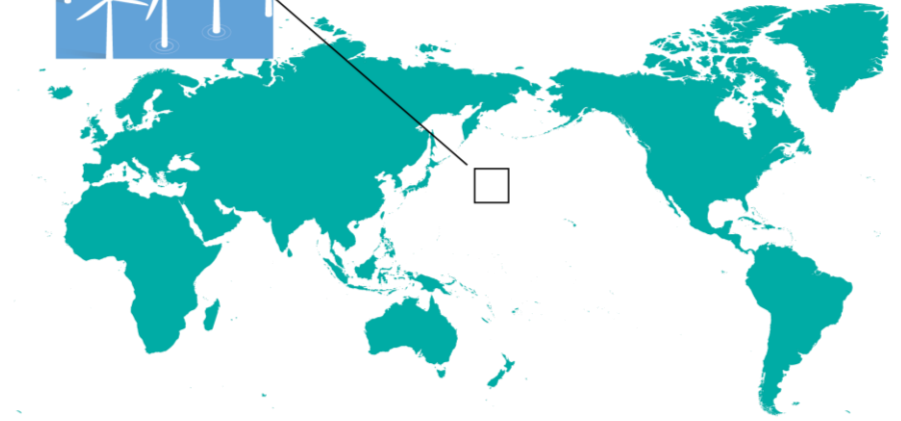
IRENA, January 2018, Renewable Power Generation Costs 2017



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

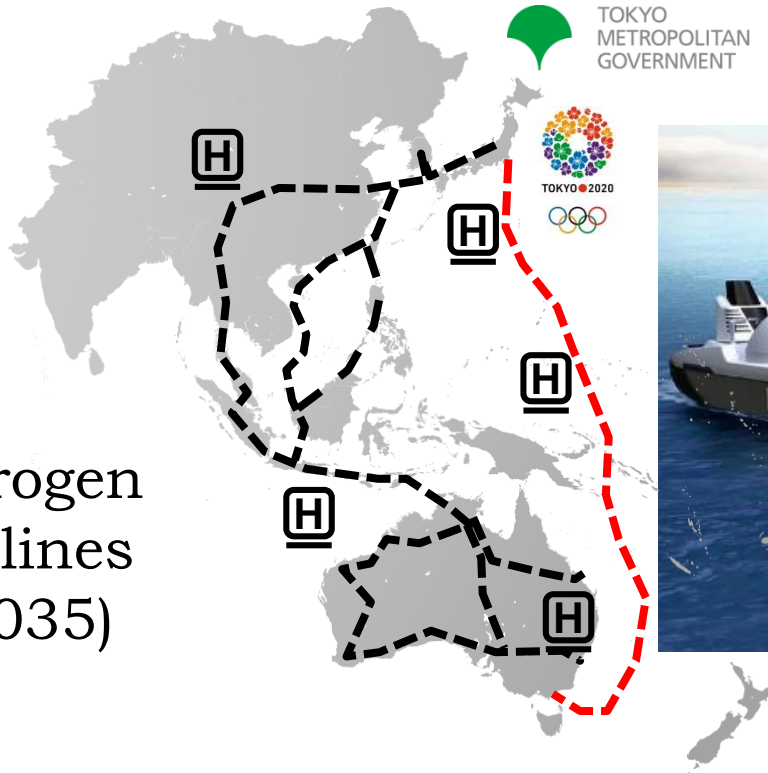


10% SOLAR AUSTRALIA



1.5% WIND PACIFIC OCEAN

Tokyo Olympic Games 2020

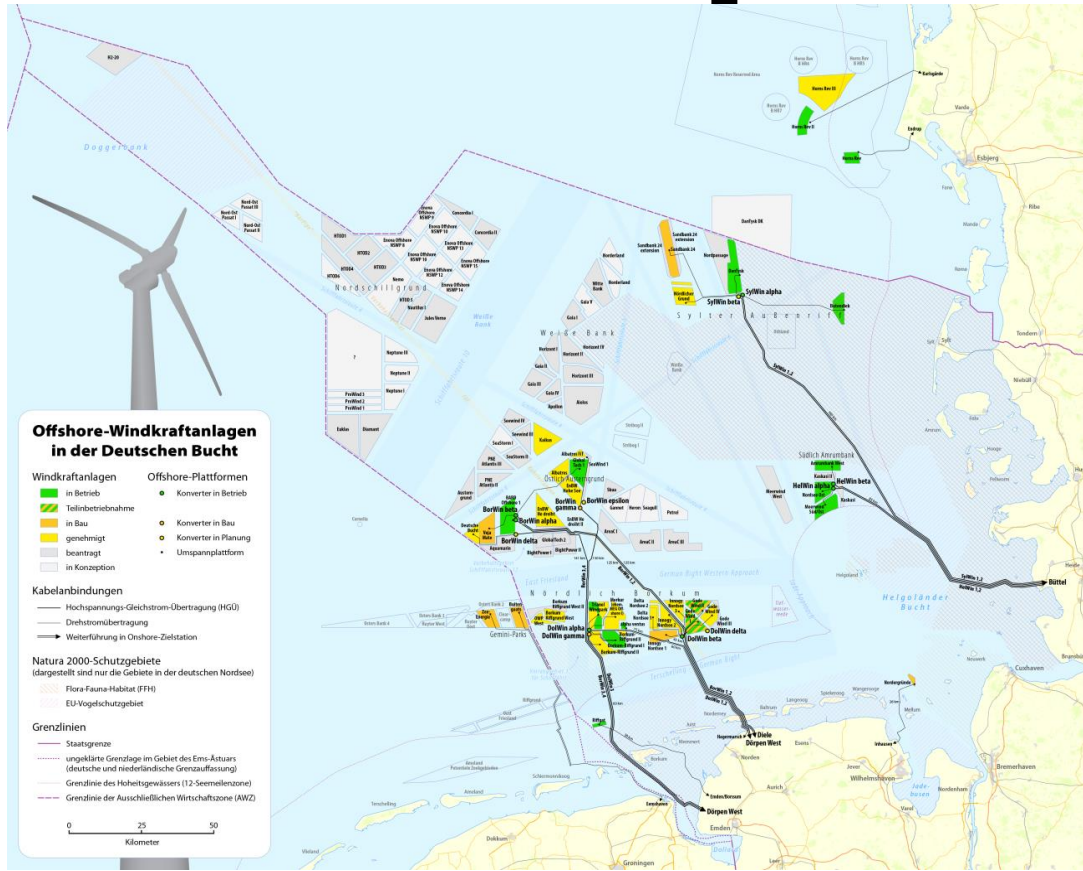


Hydrogen Pipelines (~2035)

Hydrogen Shipping (~2025)



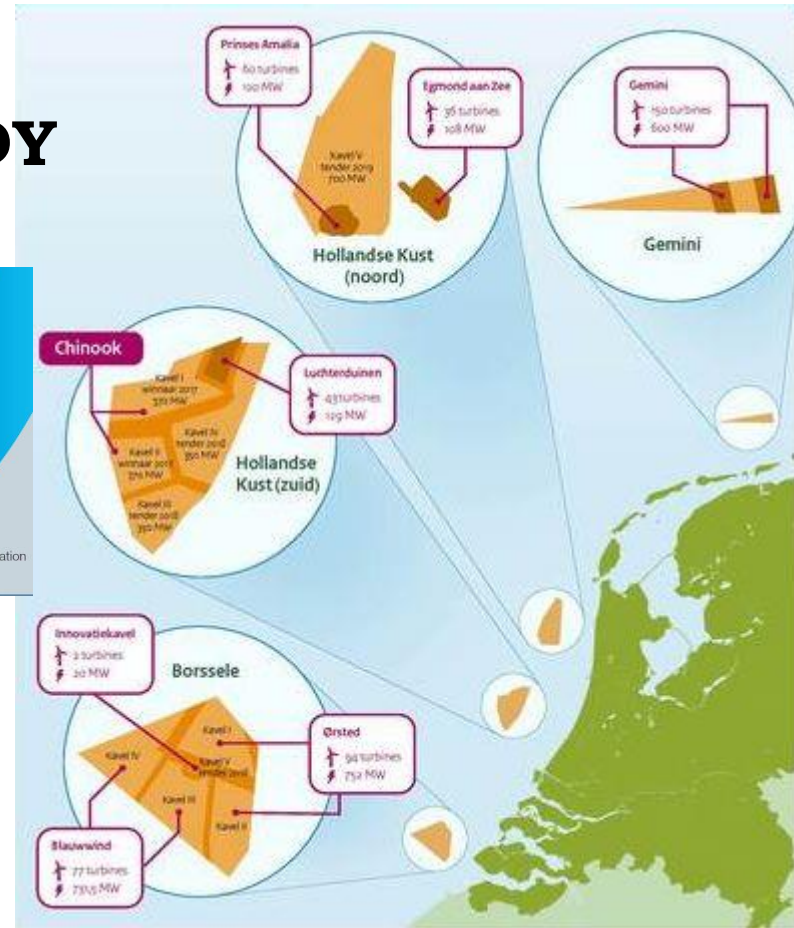
Offshore Wind Development Germany



VATTENFALL BUILDS WIND FARM WITHOUT SUBSIDY

19 March 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

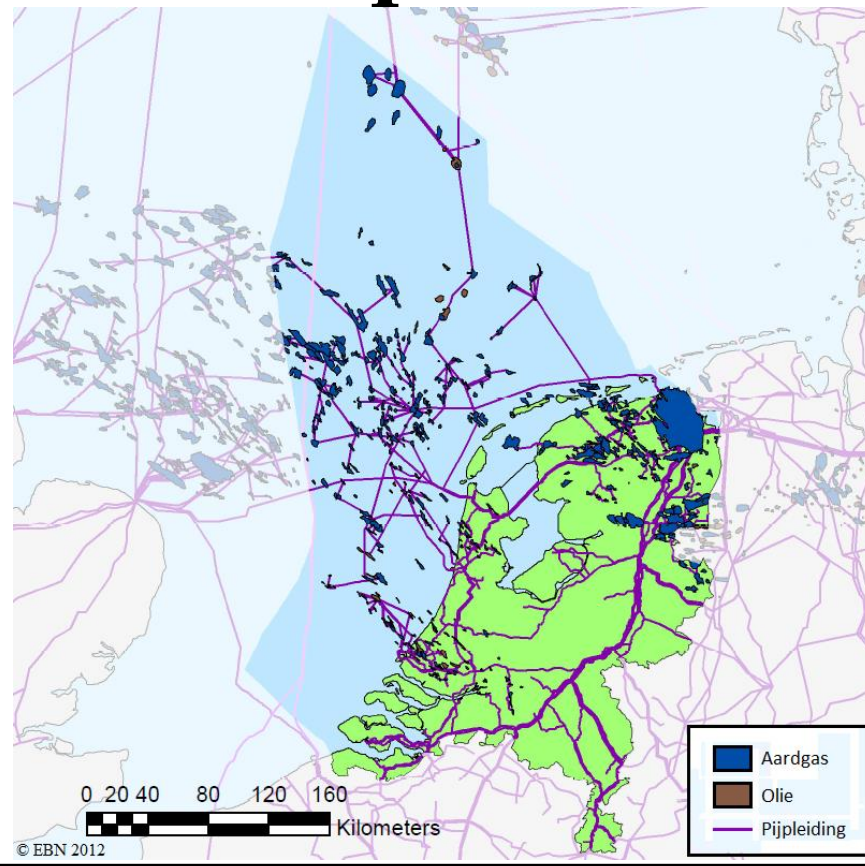
RWE Coal fired power plant 1,560 MW

Engie Gas fired power plant 2,450 MW

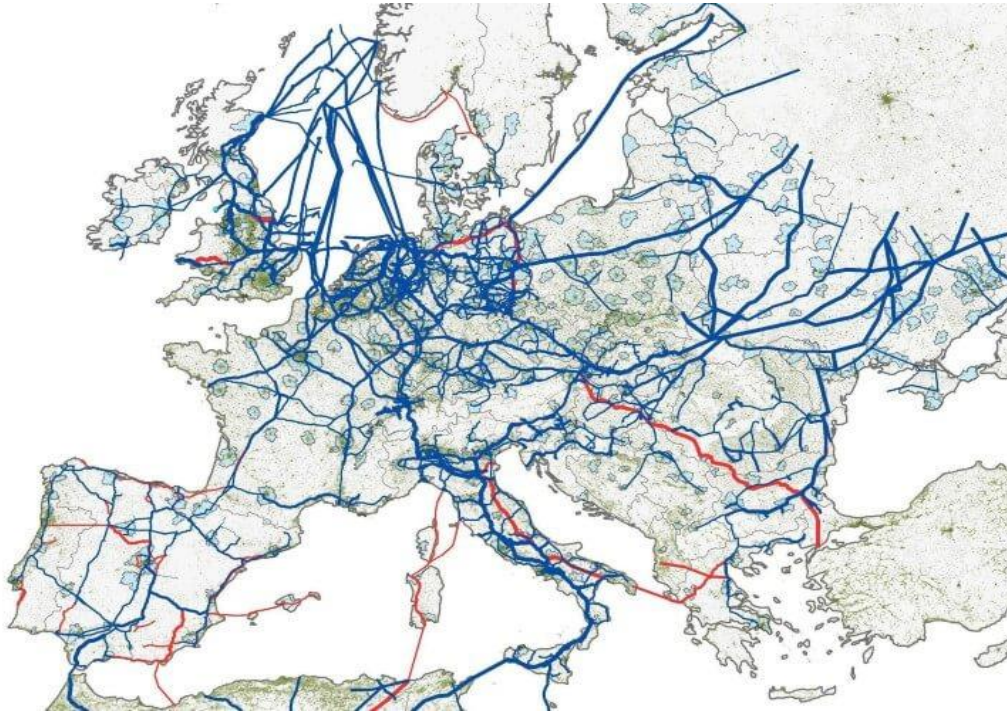
Cable Inland 4,000 MW

Expansion to 5,610 MW

Electricity and Gas Transport Grid



European Gas Infrastructure



5 GW Mohammed Bin Rashid Al Maktoum Solar Park in Dubai



Largest CSP project in the world

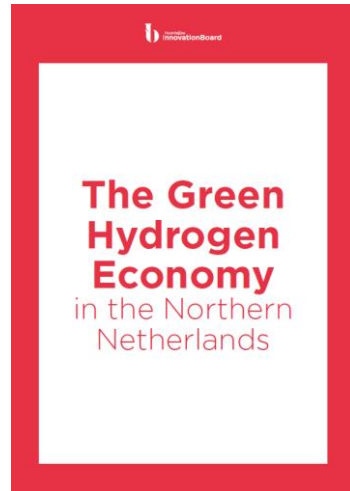
- 700MW CSP, 15 hours storage
- \$3.9 billion investment
- Central Tower 100 MW
- Parabolic Troughs 3x200 MW
- Auxiliary solar PV 4x33 MW
- Tariff 7.3 ct/kWh
- PPA 35 years
- Dispatch: between 4pm and 10am

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

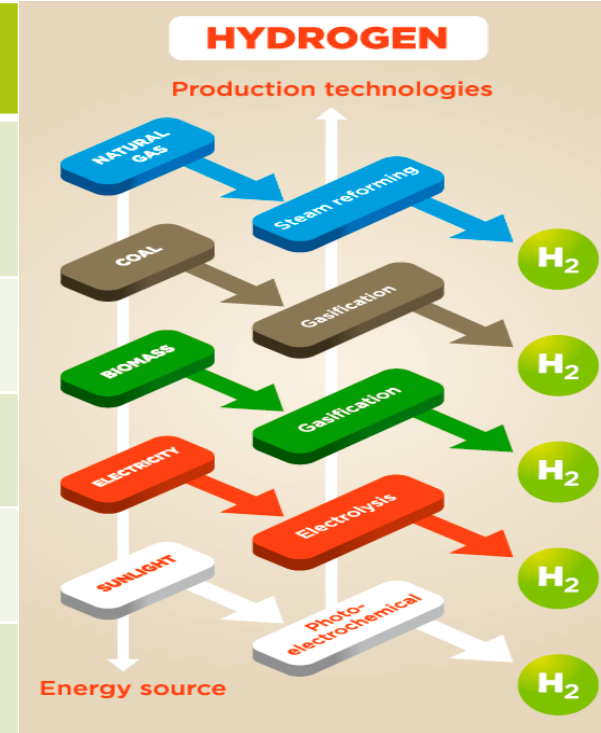
Transport and Distribution gas grids can be easily converted to hydrogen

- No technical issues, compressor needs to be adjusted
- System design development necessary; hydrogen quality, flow velocity, pressure, odorization, hydrogen measurement equipment, sensors, etc.
- Conversion cost are 5-10% of investment cost new pipeline

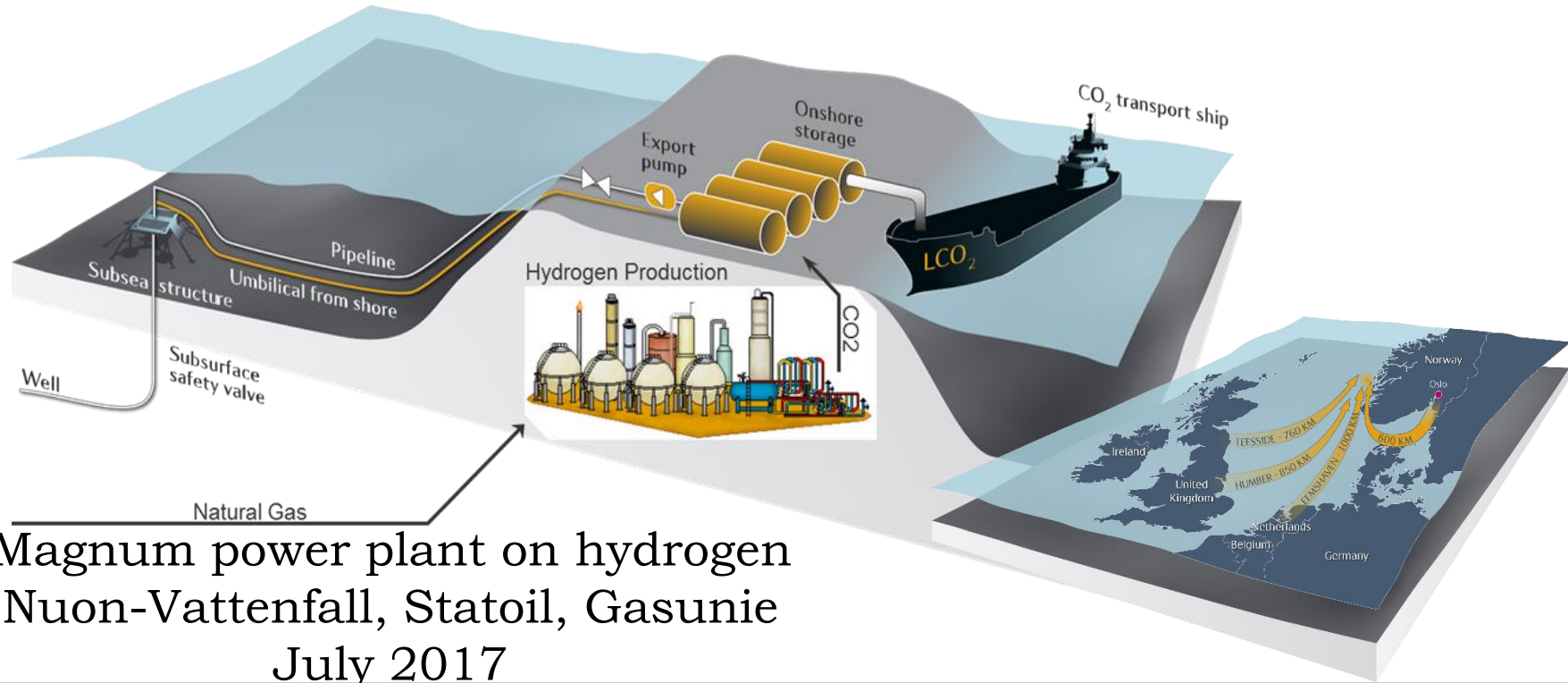


Hydrogen production

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)

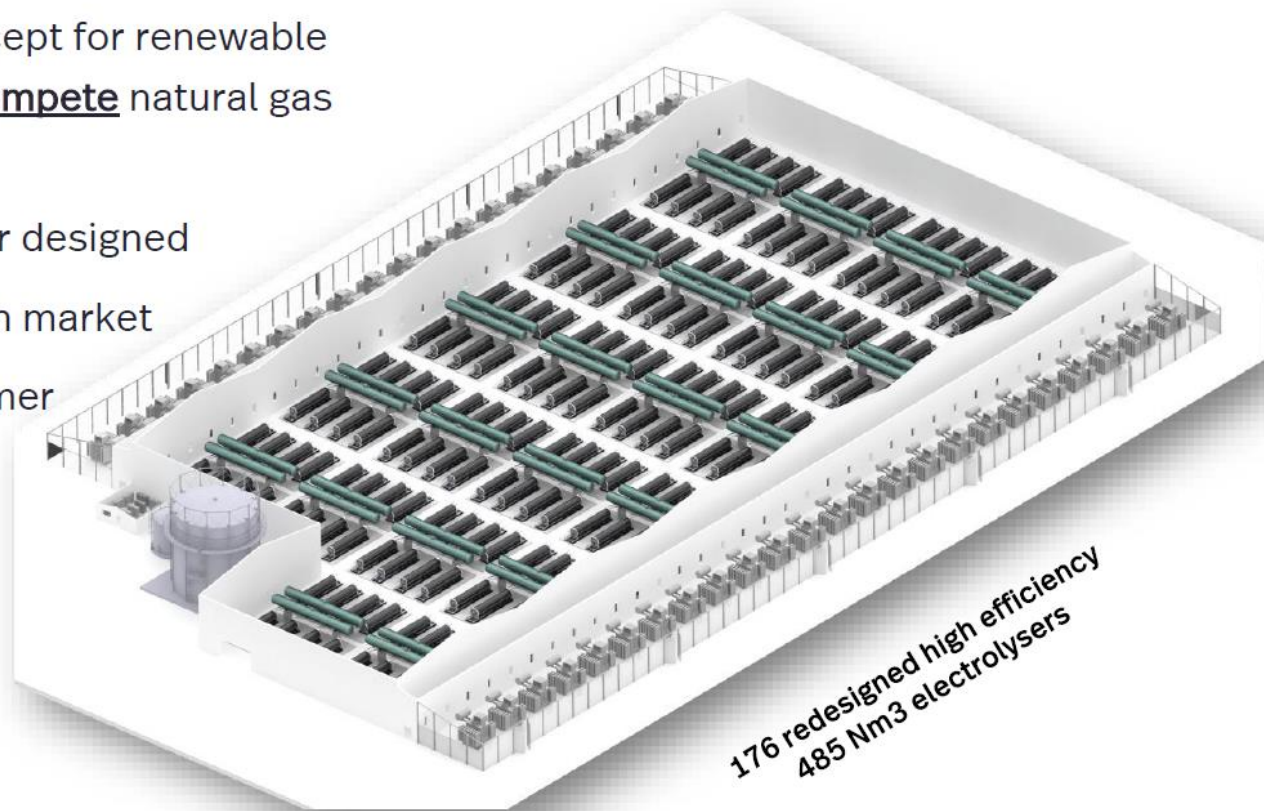


Gas-Hydrogen production with CO₂ storage in Smeaheia field



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



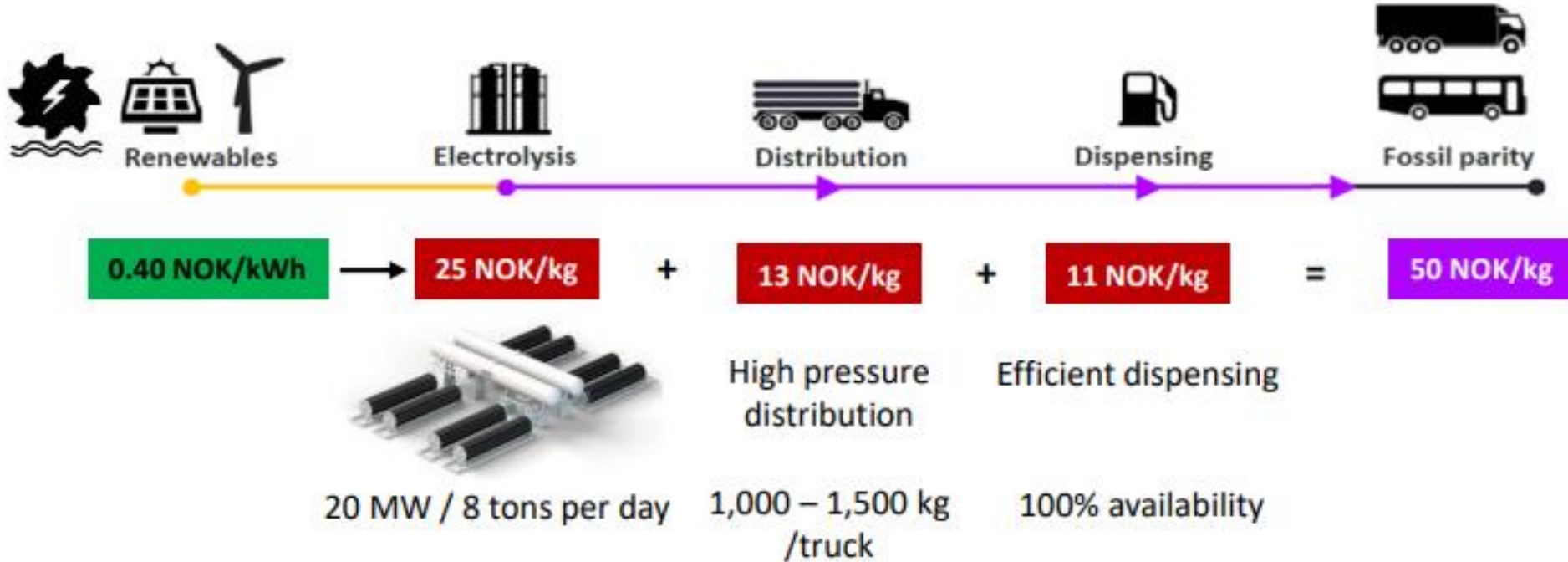
176 redesigned high efficiency
485 Nm³ electrolysers

Hydrogen Cost development

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

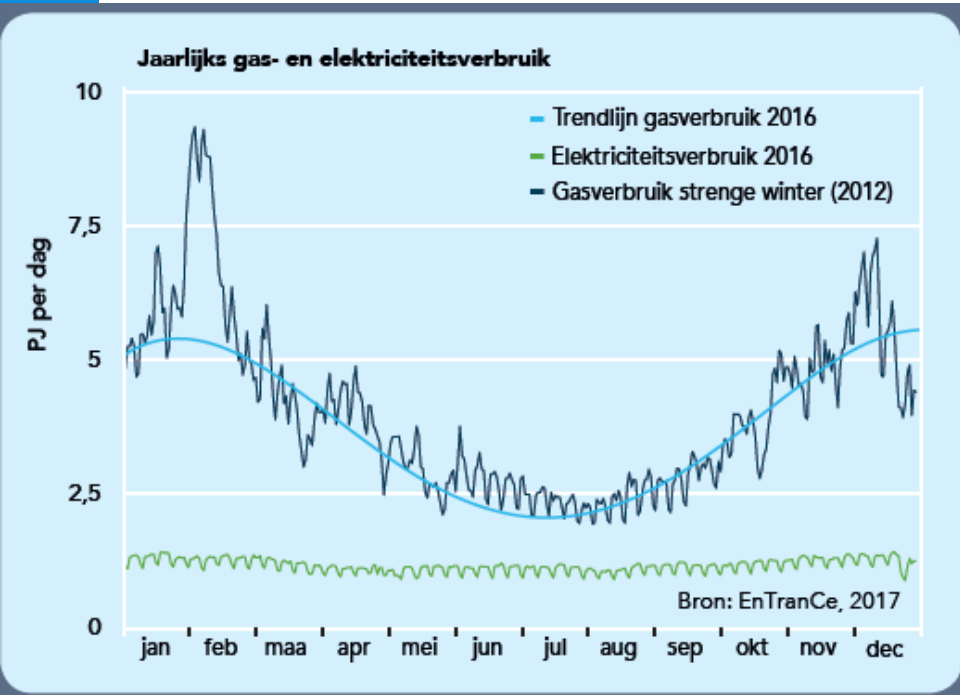
Hydrogen cost at fueling station

10 NOK = 1 Euro

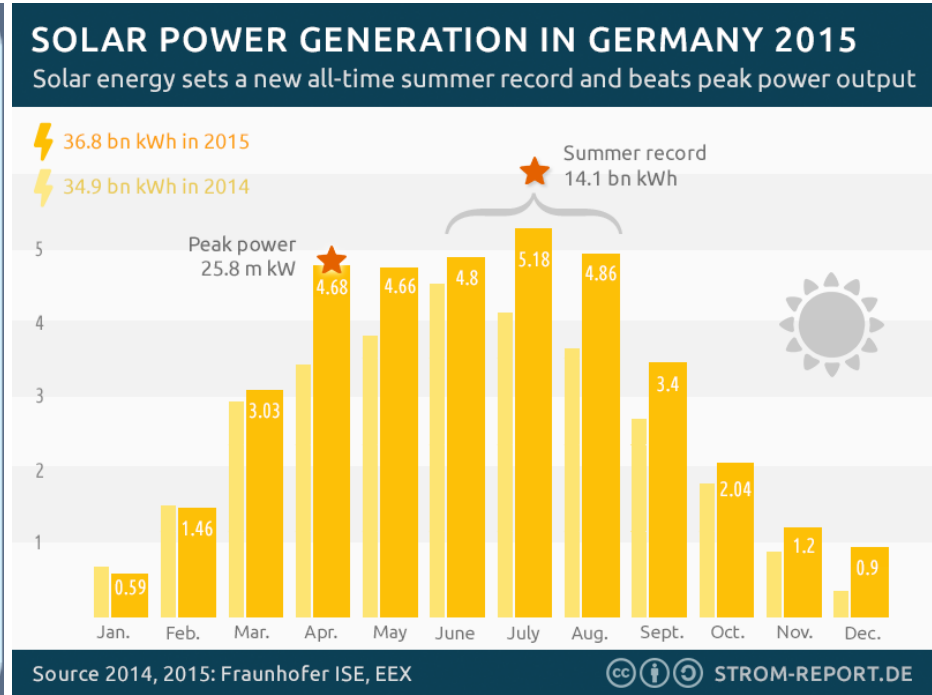


<http://nelhydrogen.com/assets/uploads/2018/07/nel-q1-2018-presentation.pdf>

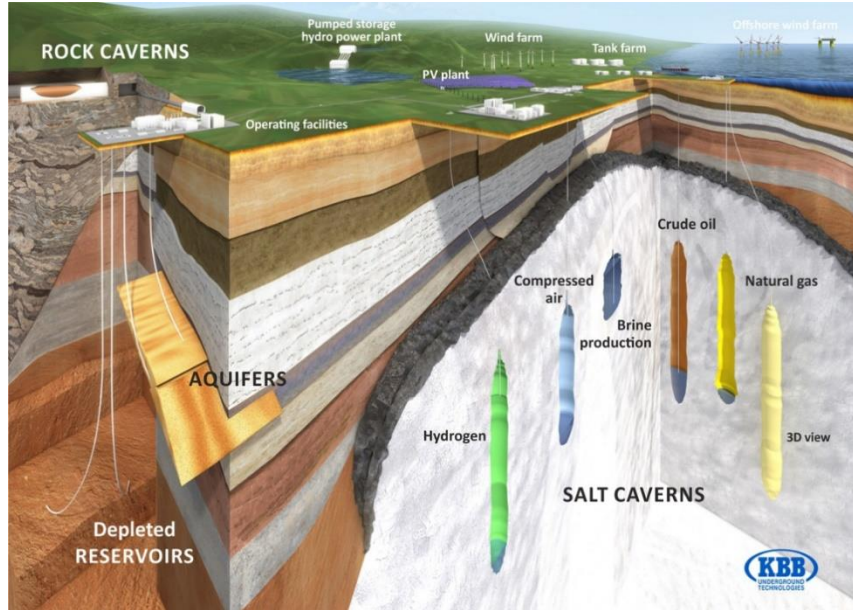
Gas and electricity consumption in the Netherlands



Solar power production in Germany

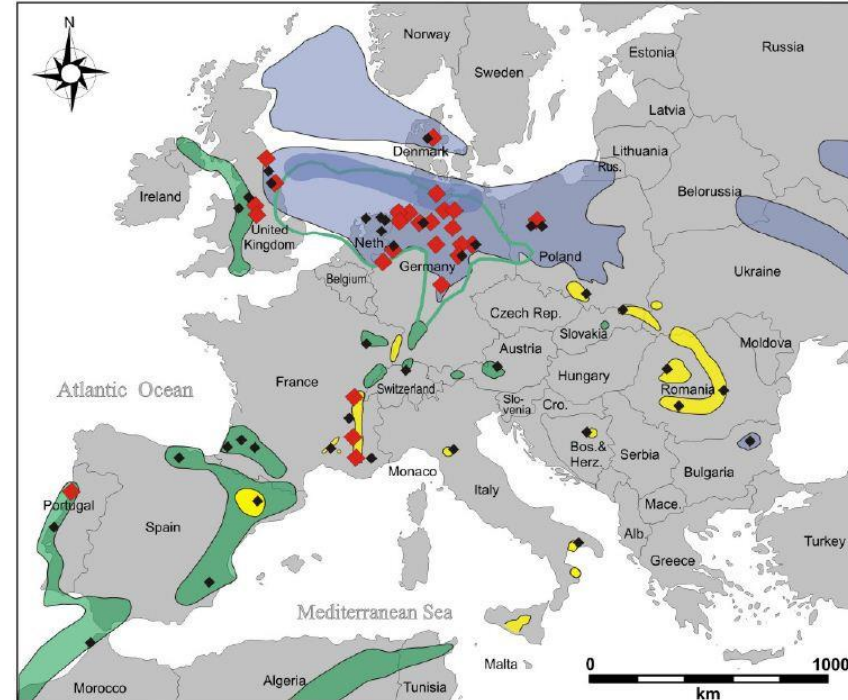


Hydrogen storage in Salt Caverns

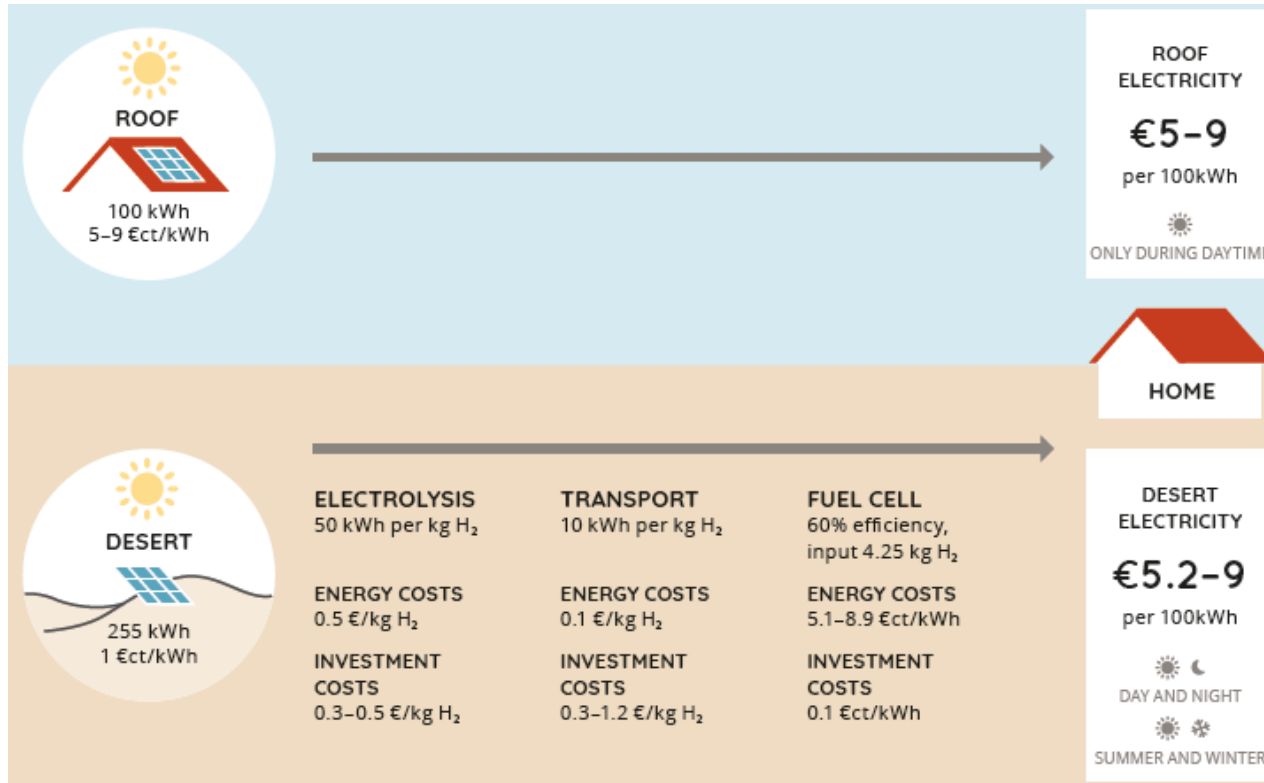


**1 salt cavern can contain 6,000 ton hydrogen
Equivalent of 17 million Tesla Power walls**

Salt formations and caverns in Europa



Roof versus Desert Solar



In a renewable energy system it is all about system cost, not system efficiency

Hydrogen Coalition

3-4 GW electrolyser capacity 2030



Gasunie

Backbone Hydrogen Infrastructure 2030, 15 GW capacity, 1 billion Euro



The Netherlands