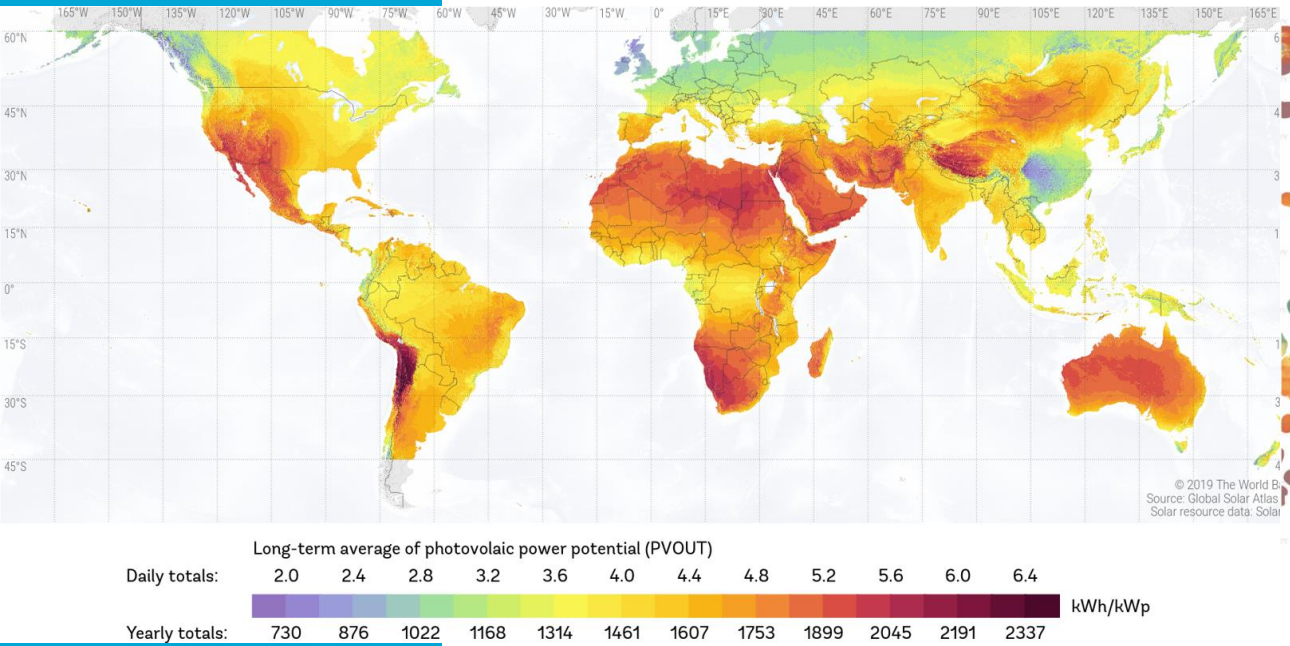
Waterstof tot nadenken

2-11-2023

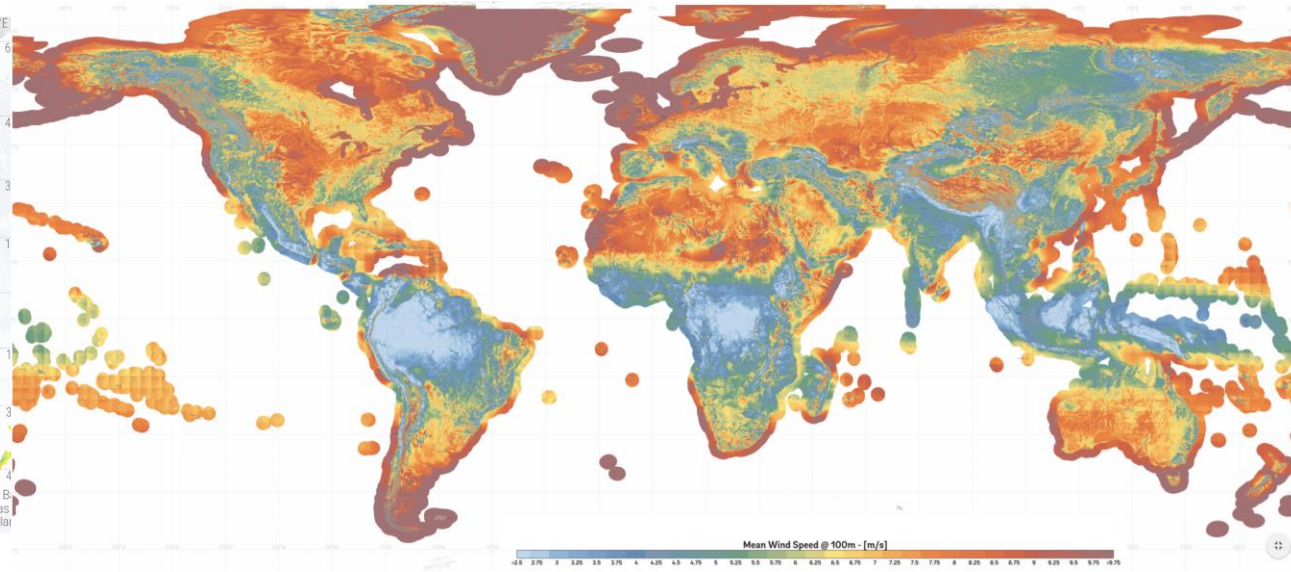
Em. Prof. Dr. Ad van Wijk

TU Delft

Low cost solar and wind electricity only at locations with high solar irradiation or high wind speeds AND lots of available cheap space



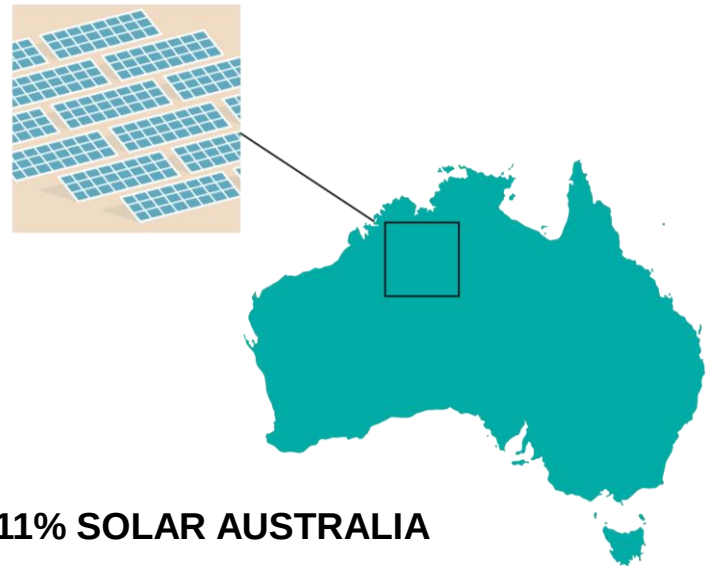
Solar Resources Map



Wind Speed at 100-meter height Map

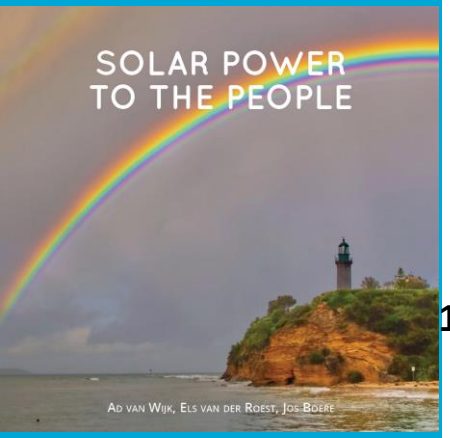
Surface needed to produce all the world's energy

World energy use 2019: 606 EJ = 168.000 TWh



11% SOLAR AUSTRALIA

1.5% WIND PACIFIC OCEAN



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

SiemensGamesa 14-15 MW offshore wind turbine
Rotor diameter 222 meter

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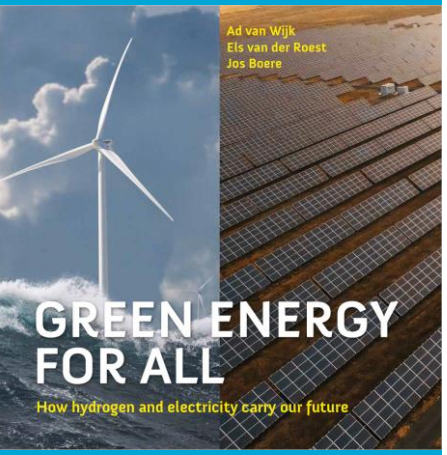
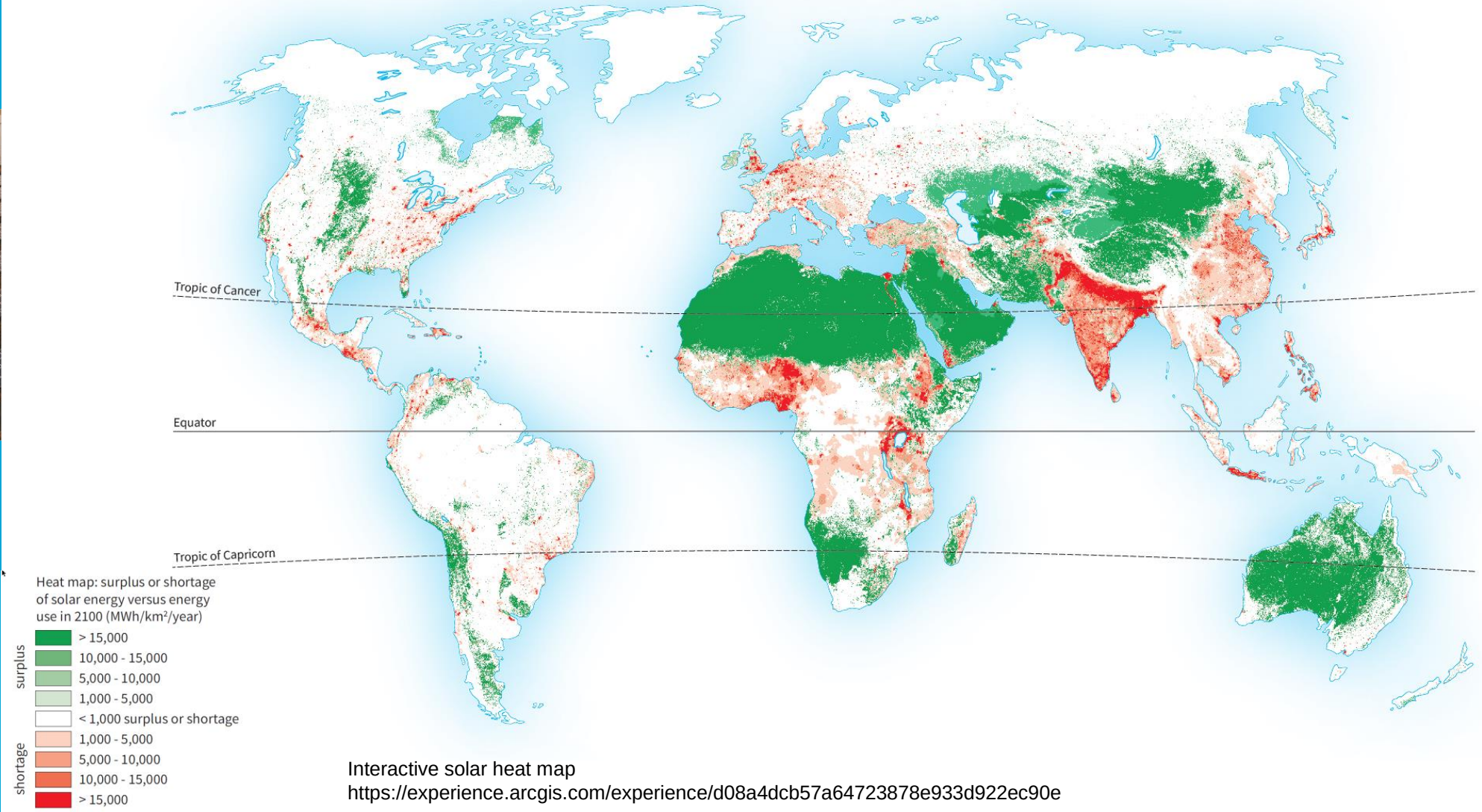
Heat map Solar Energy 2100;

Surplus (green) or shortage (red) solar energy - energy use per km²





Interactive solar heat map
https://experience.arcgis.com/experience/d08a4dcb57a64723878e933d922ec90e

Space and Time important cost factors in a renewable energy system

Space (transport)

Time (Storage)

Hydrogen and electricity production technologies without CO_2 emissions

Methane Pyrolysis Plant
Monolith Nebraska US

Photolysis Module
Solhyd startup Belgium

Kite H2 ship
Oceanergy startup SouthAfrica

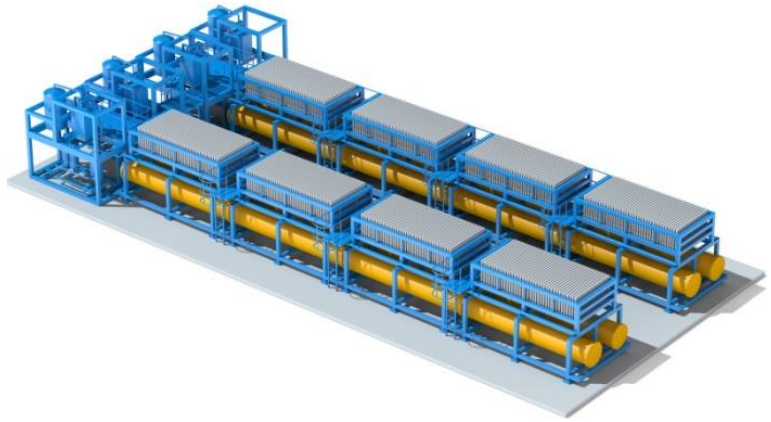
Nuclear Power Plant
Borssele Netherlands

Photovoltaic Modules
Canadian Solar

Offshore wind turbine
Siemens Gamesa

Hydrogen and electricity are zero carbon energy carriers, not energy sources

Electricity →



Alkaline electrolyser Thyssen Krupp Germany

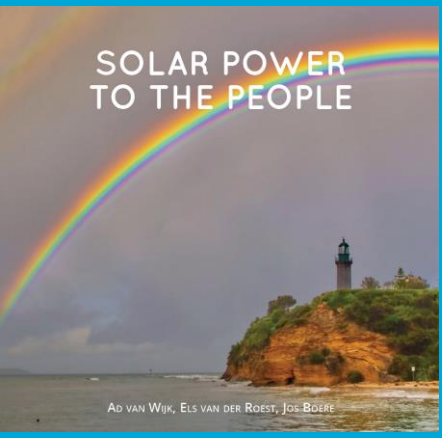
→ **Hydrogen**

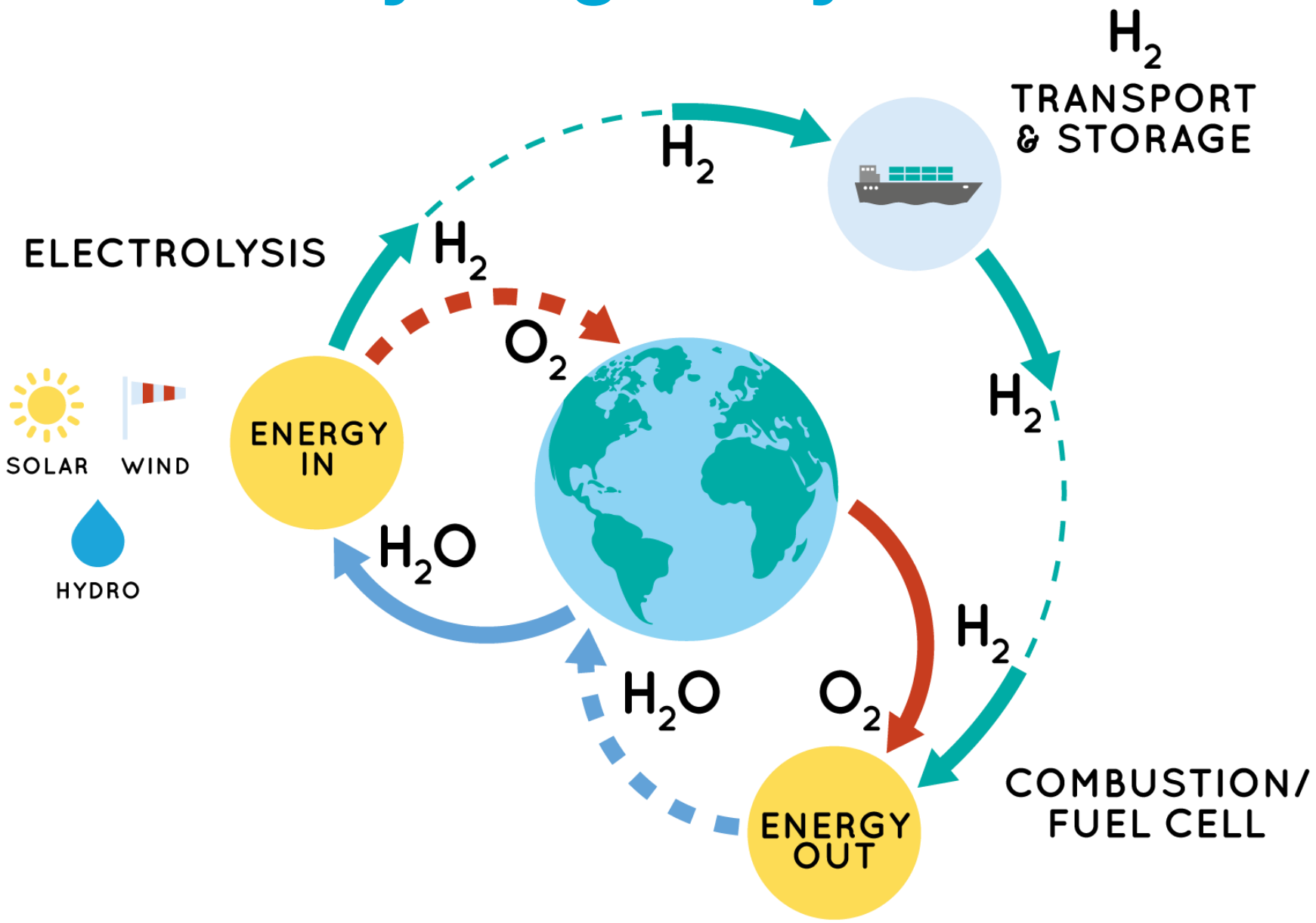
Hydrogen →

PEM fuel cell, Toyota Japan

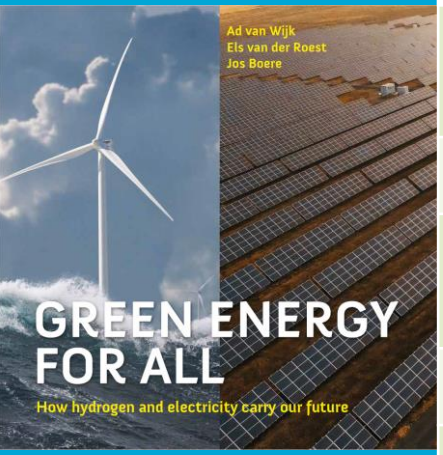
→ **Electricity**

The Hydrogen Cycle

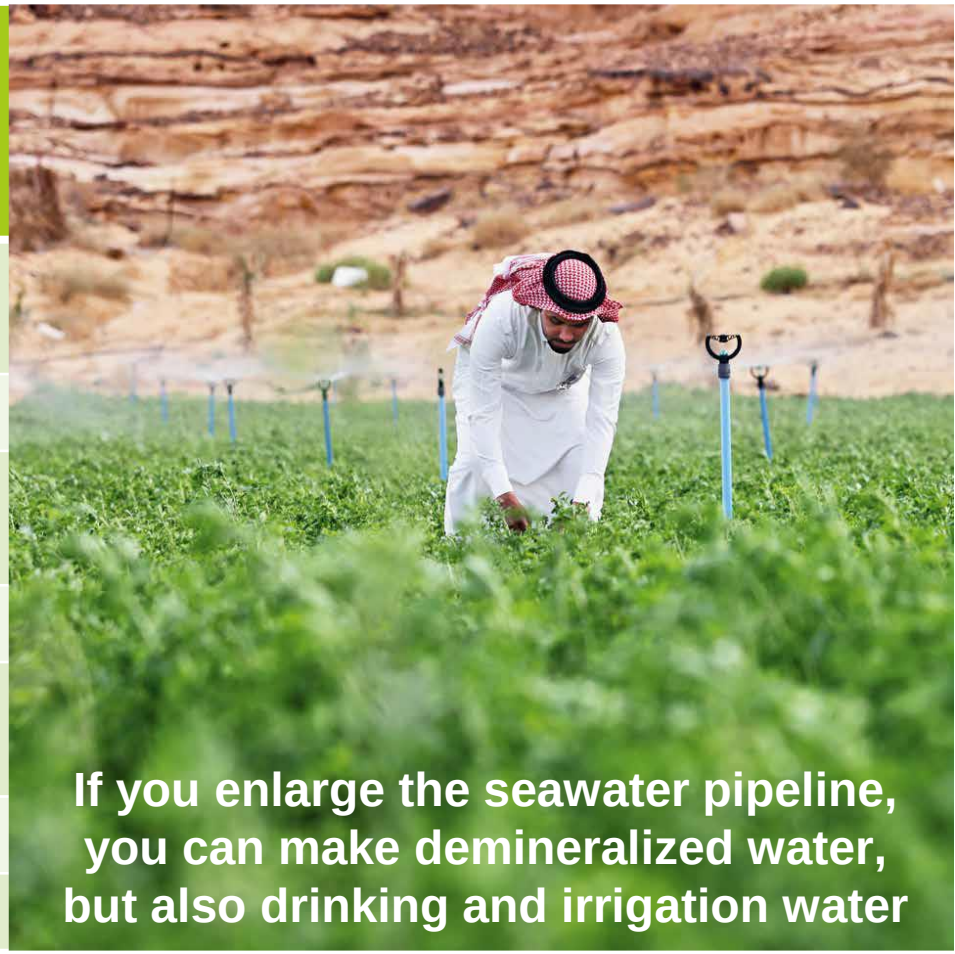




Seawater as resource for water in the desert



Demineralized water for hydrogen production	Costs Demineralized water
1,000 km transport cost seawater and brine	2.0 Euro/m^3
Production costs demineralized water from seawater	2.0 Euro/m^3
TOTAL (Euro/$m^{3)}$	**4.0 Euro/m^3**
TOTAL (Euro/kg H_2)	**0.04 Euro/kg H_2**



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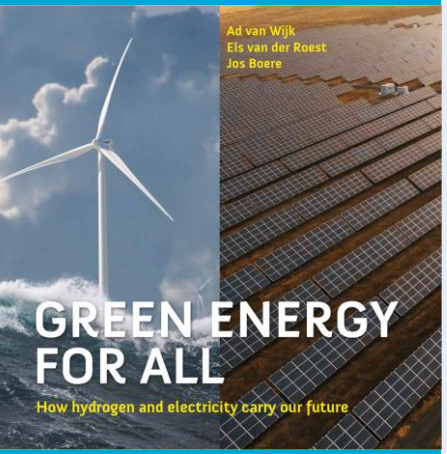
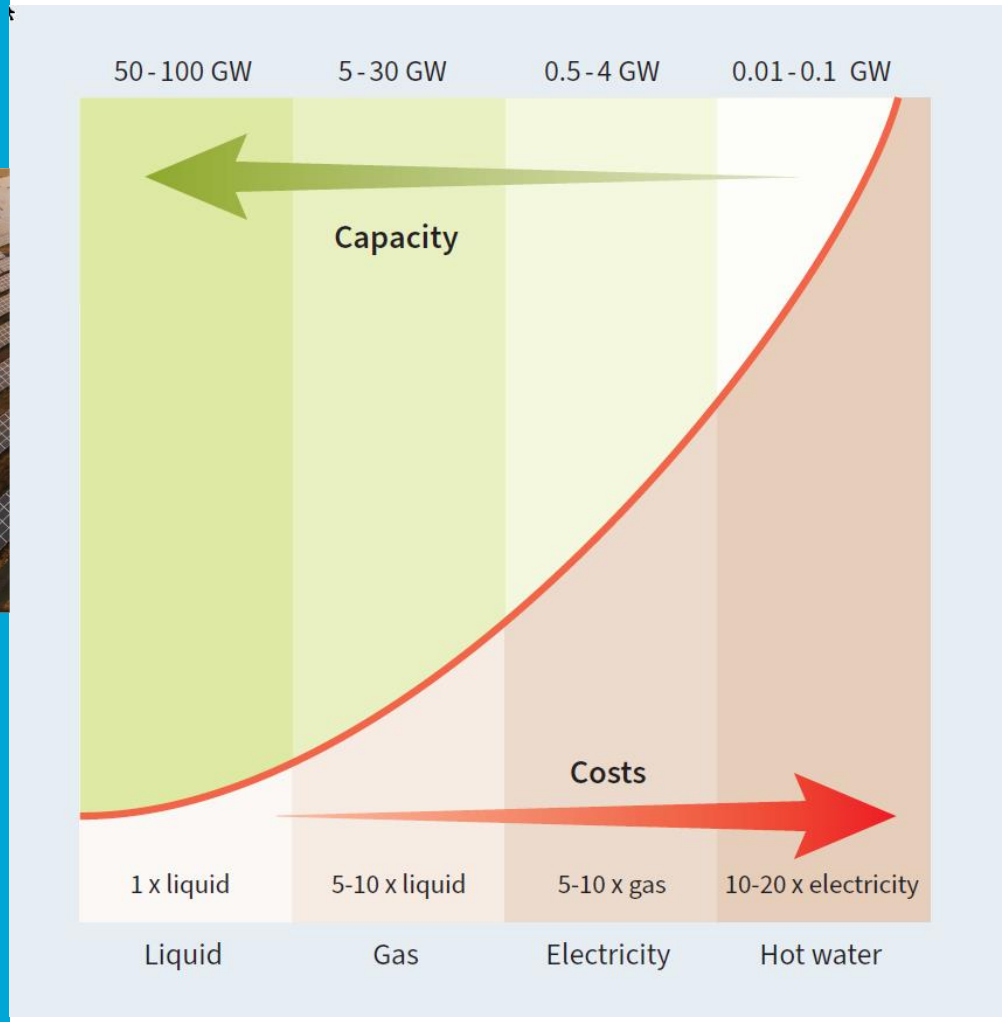
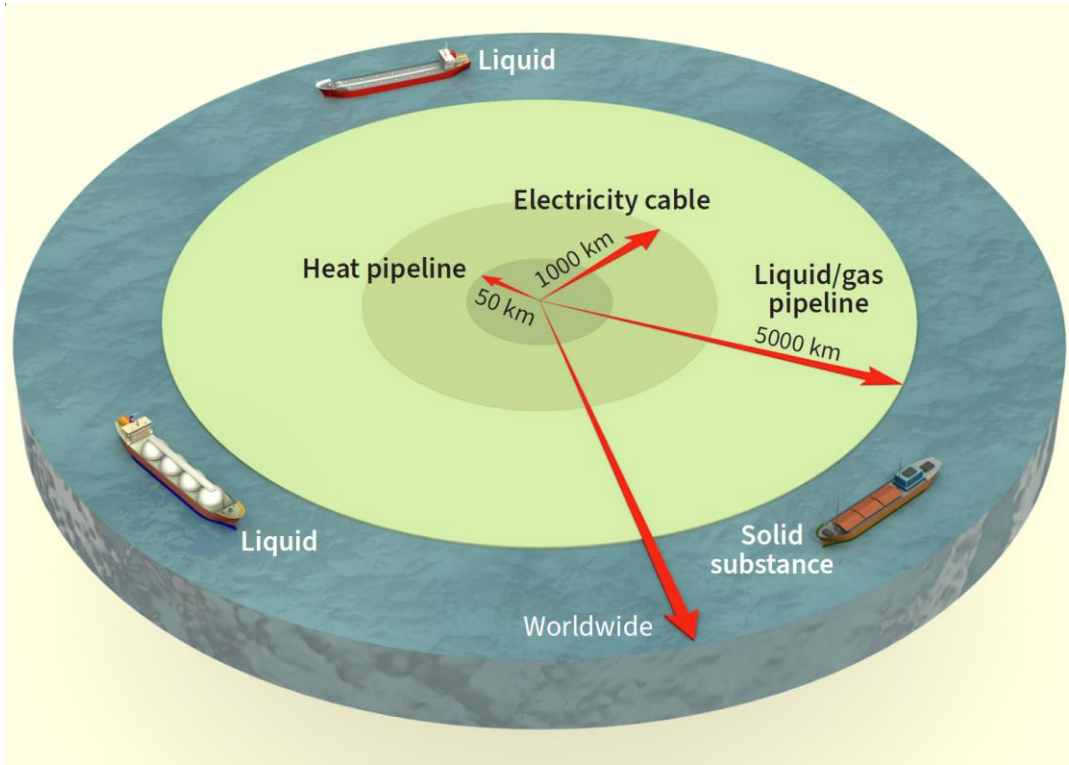
Energy Transport system costs, capacities and configuration

Hydrogen transport cost 5-10 times cheaper than electricity transport



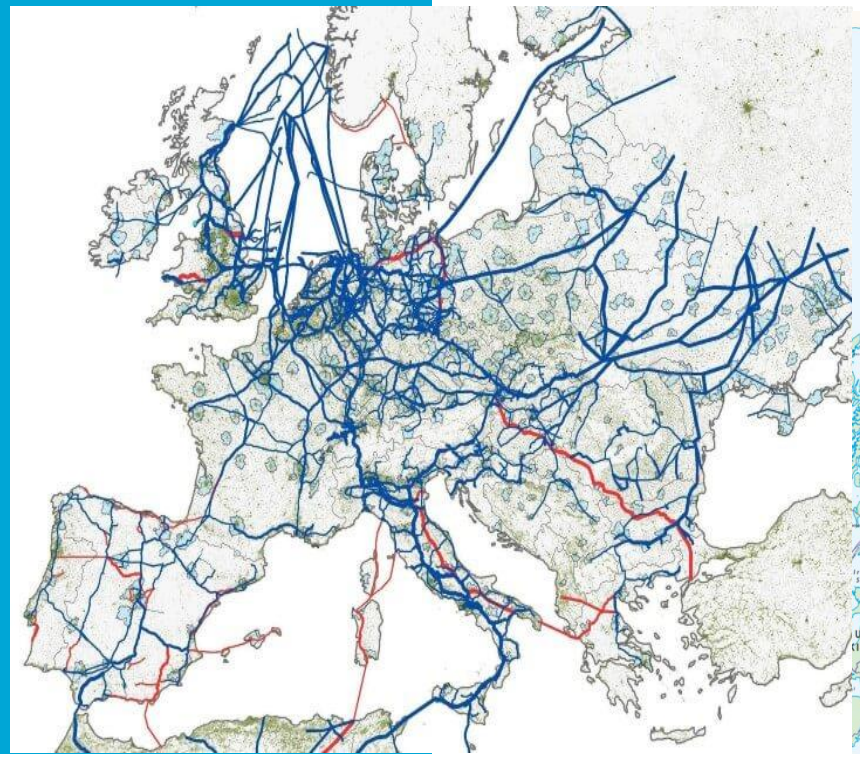


Energy pipeline transport costs and capacities



Worldwide energy transport system

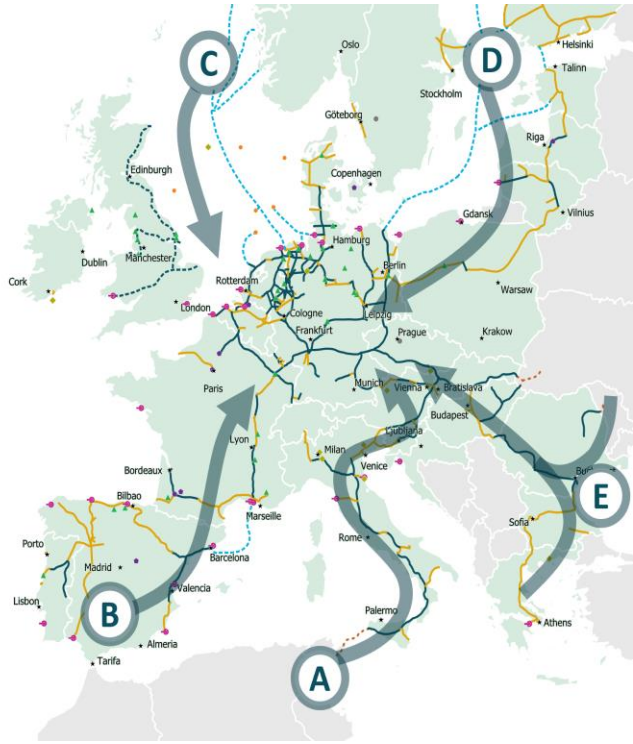
Gas Infrastructure in Europe can be reused for hydrogen



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

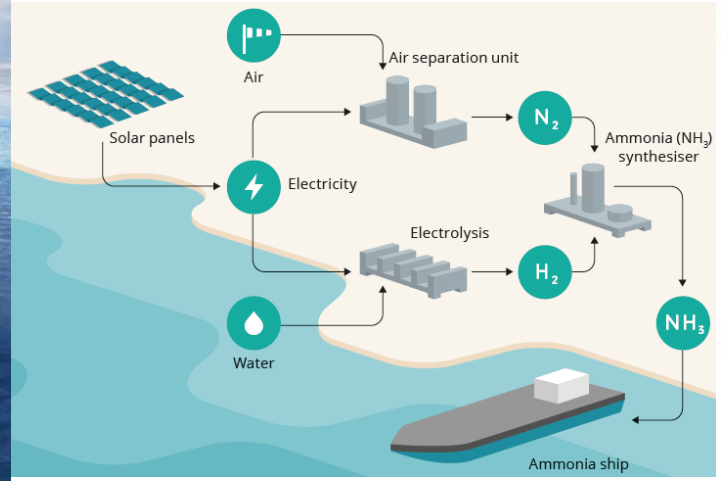
Gas from North-Africa
60 GW Natural Gas Pipeline
2x0.7 GW Electricity Cable



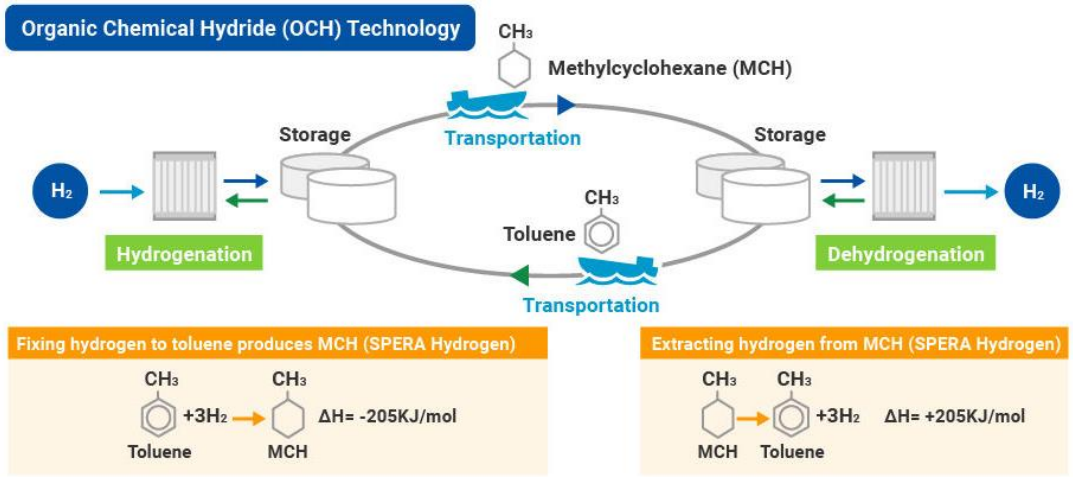
European Hydrogen Backbone 2030
Overall length : 32.616 km
Repurposed gas : 16.864 km

Hydrogen Transport by Ship

Liquid Hydrogen

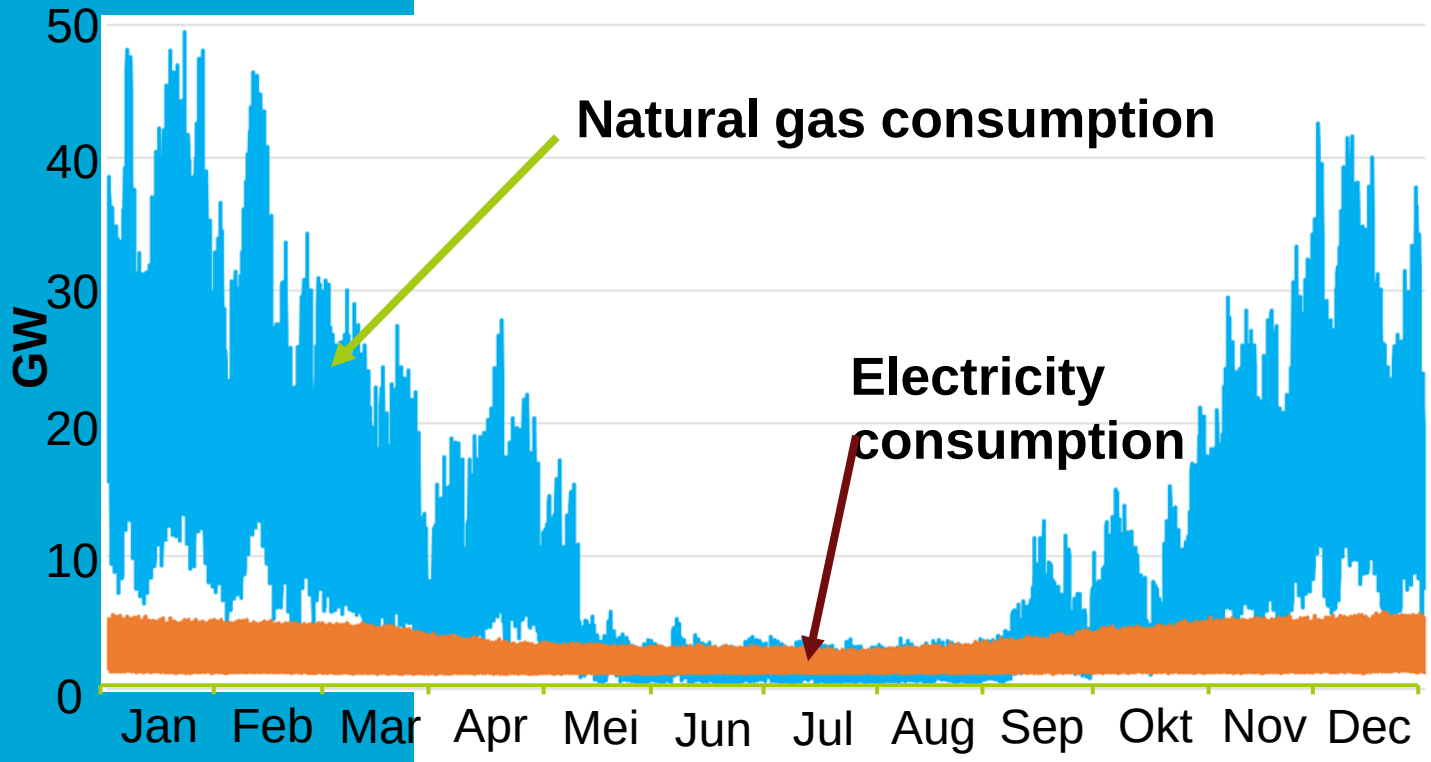


Ammonia



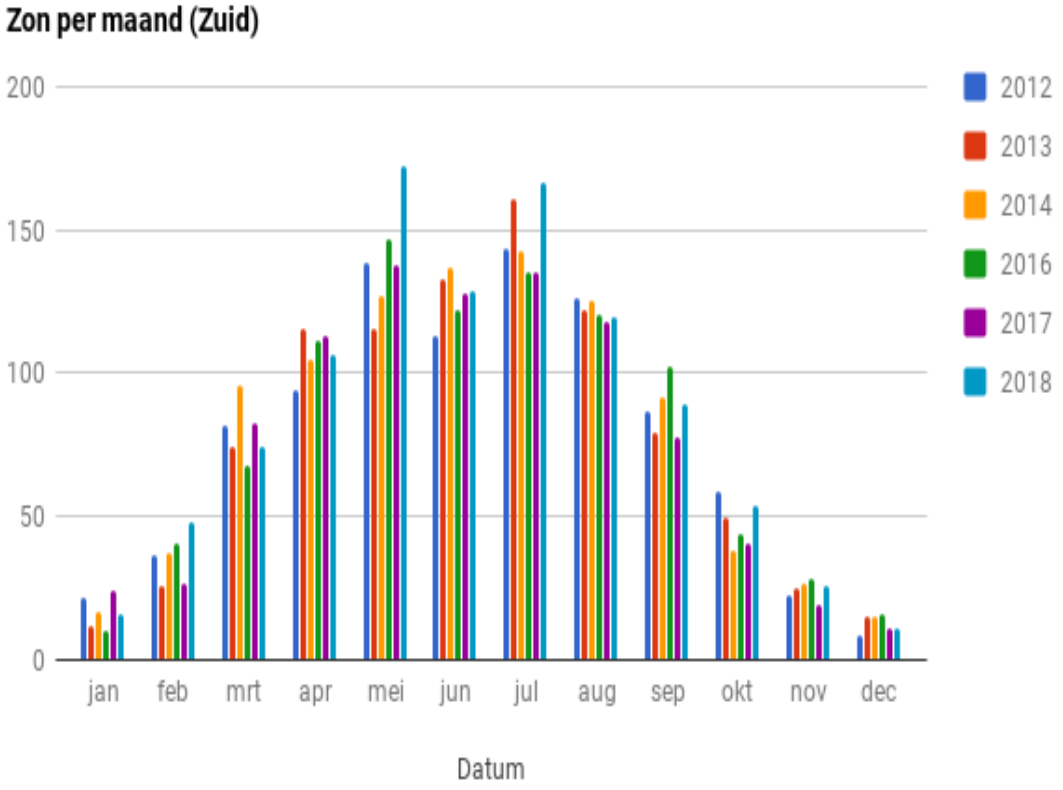
LOHC
Liquid Organic Hydrogen Carrier

Energy storage is needed to deal with renewable resource fluctuations in time AND with energy demand fluctuations in time



7,8 million Dutch houses (2017)

Source: Kellner, 2018



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

Gas seasonal storage capacity in the Netherlands 100 TWh (billion kWh) = storage capacity of 1 billion battery electric cars with 100 kWh battery.

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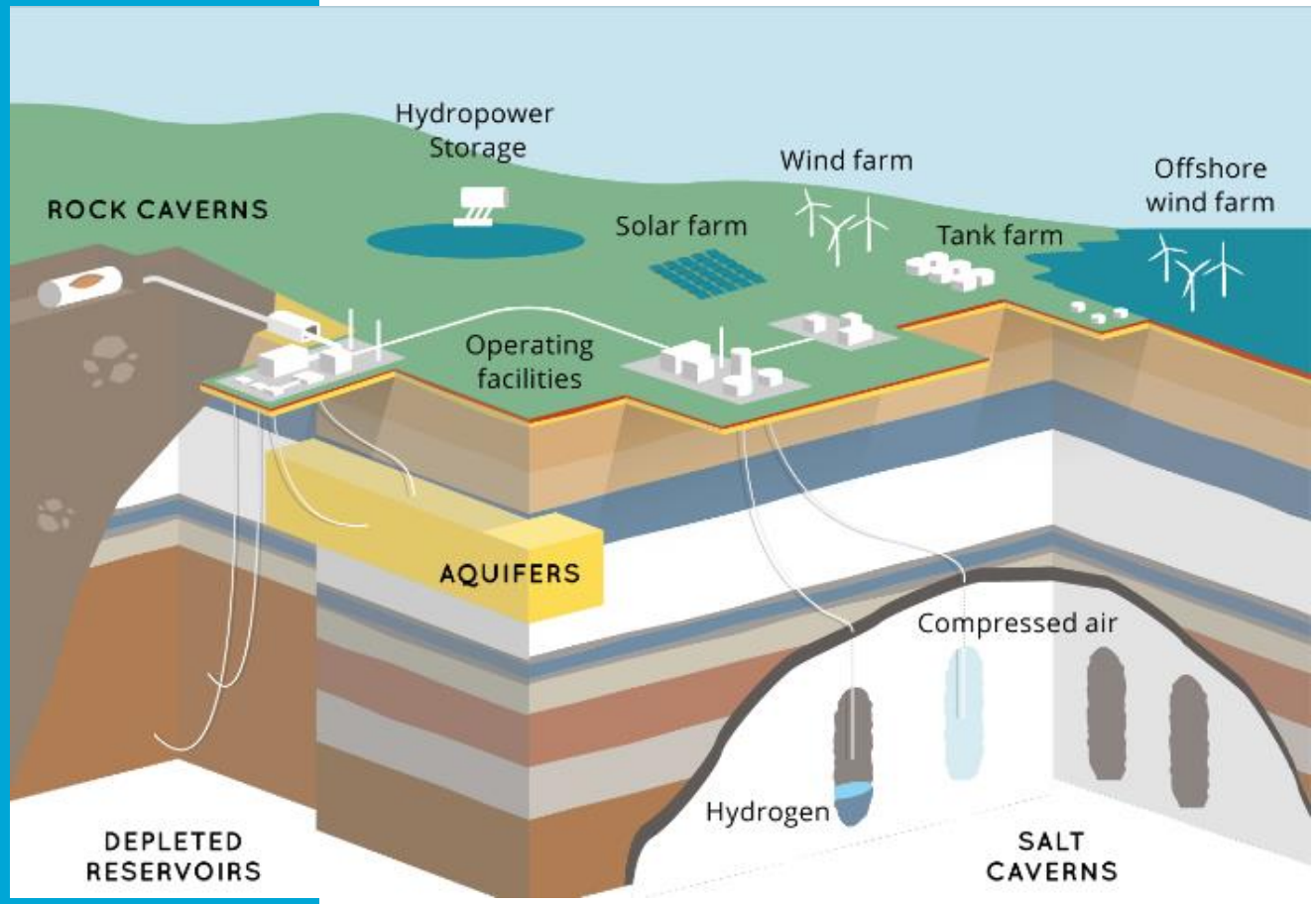
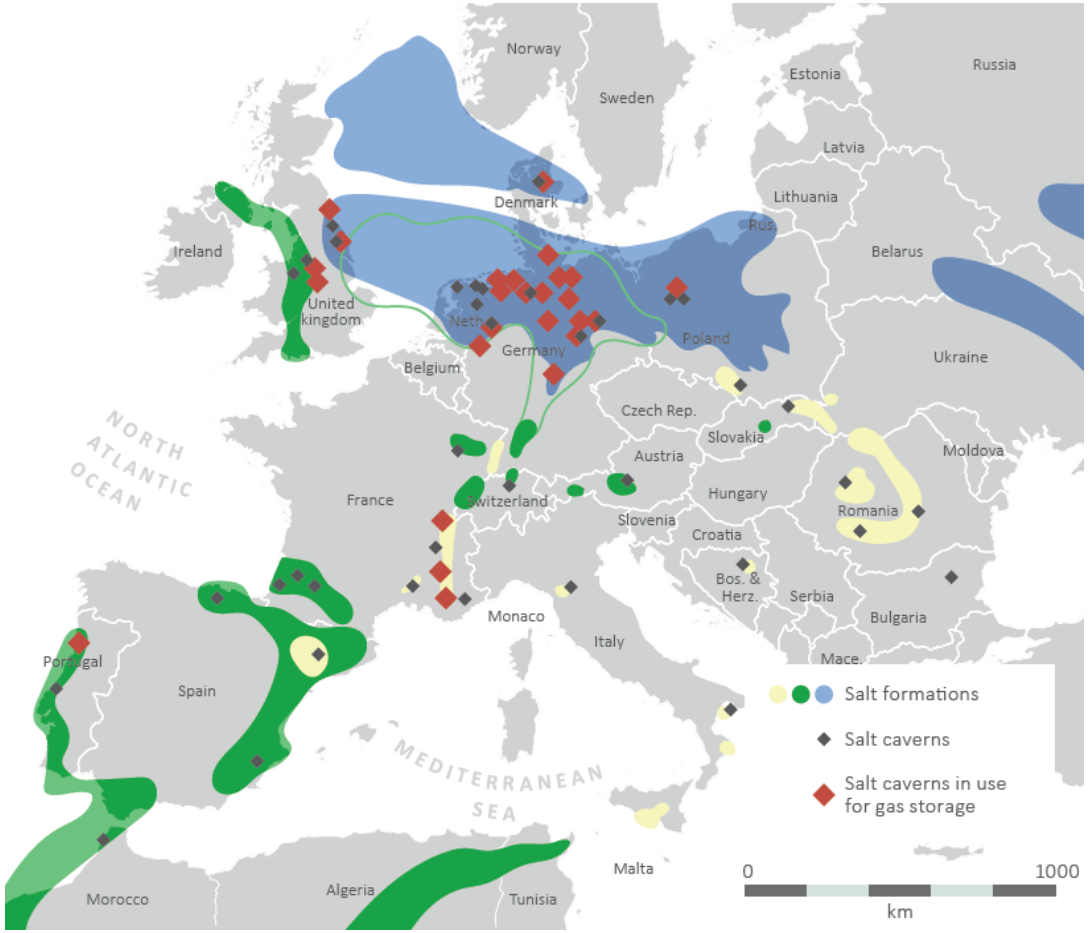
Hydrogen storage in salt caverns



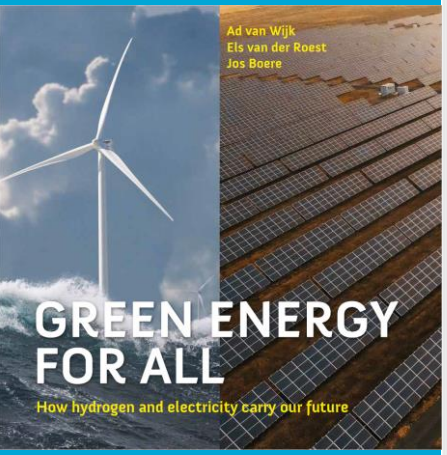
Salt formations and caverns in Europa

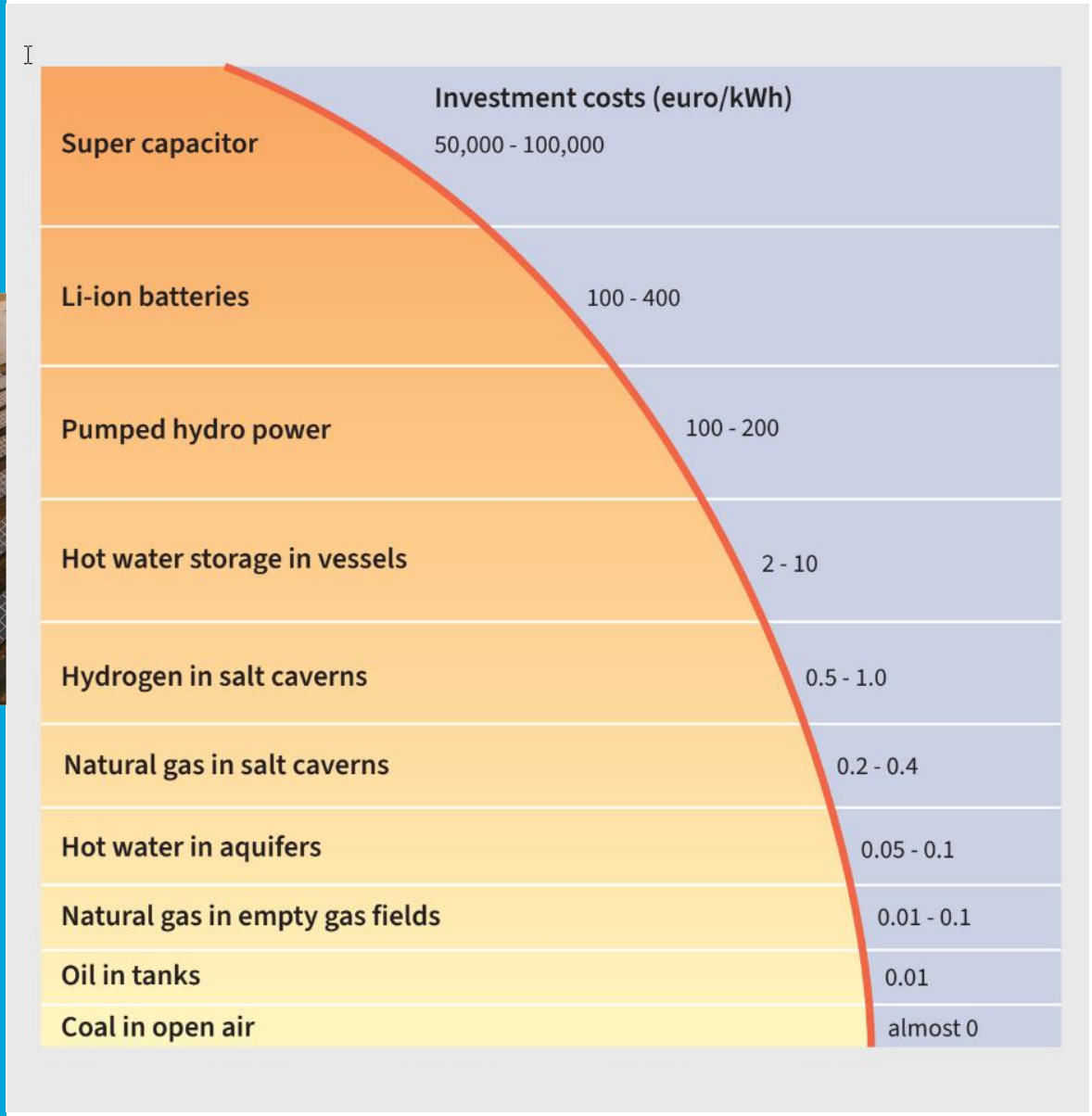


1 salt cavern can contain up to 6,000 ton (= 236.4 GWh HHV) hydrogen,
Salt Cavern CAPEX = 0.5 Euro per kWh, Total Salt cavern CAPEX is 100 million Euro

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

Energy storage Investment Costs





Hydrogen storage in salt caverns is 100 to 200 times cheaper than electricity storage in pumped hydro power

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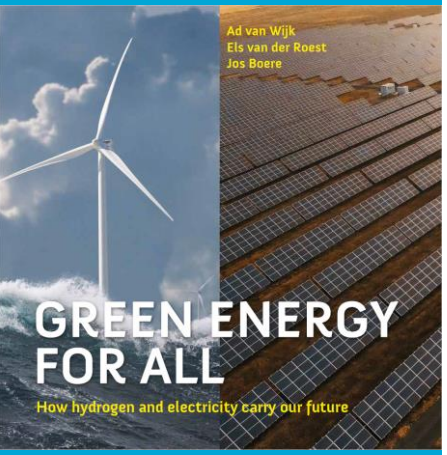
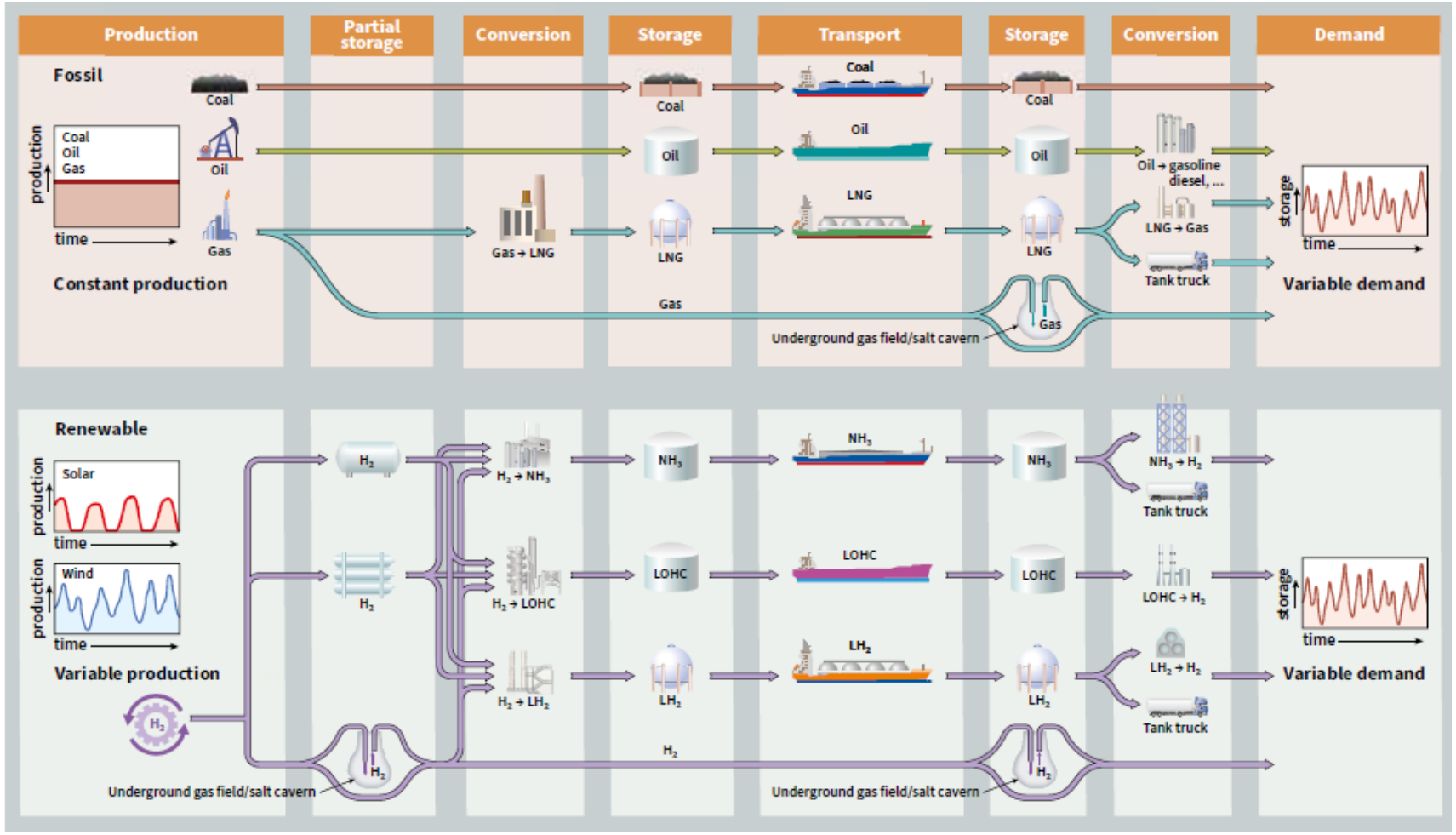
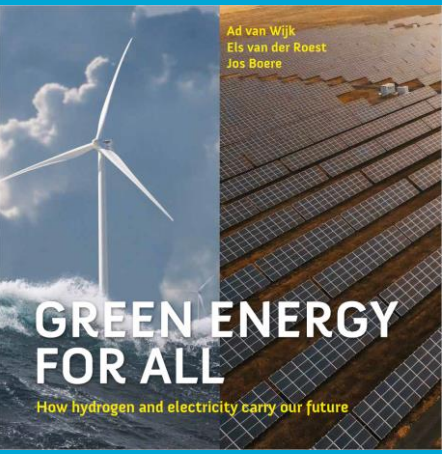
Energy storage costs in a renewable energy system higher than in a fossil energy system

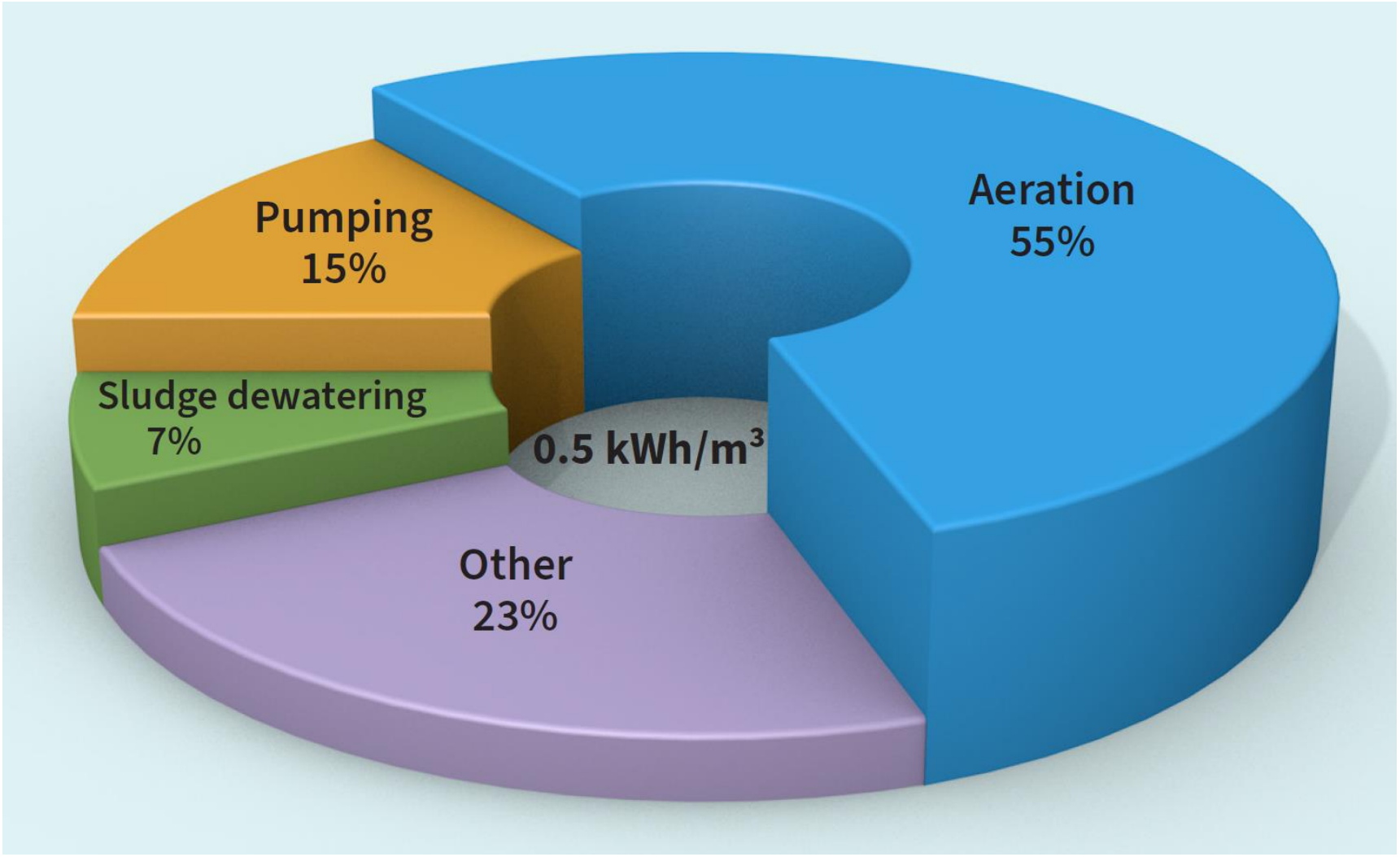




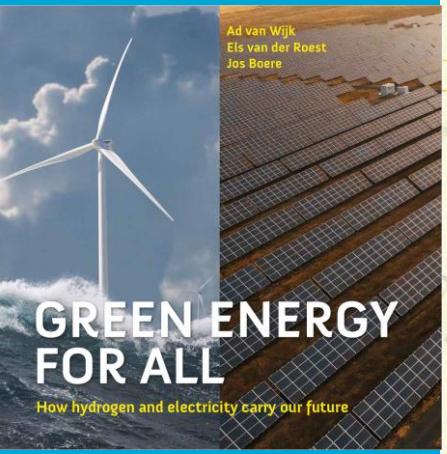
Wastewater treatment plant Echten, the Netherlands

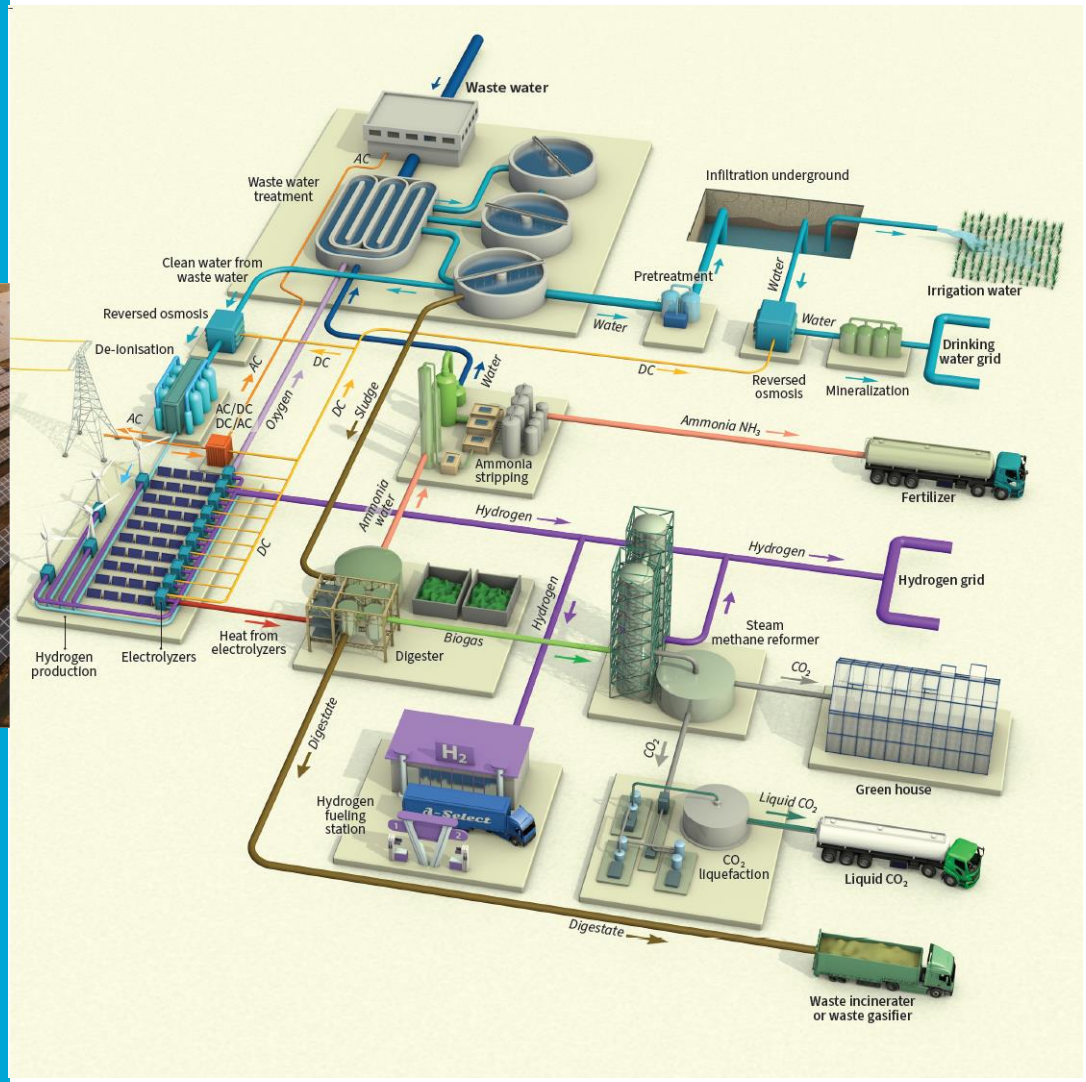
Electricity Consumption wastewater treatment plant





Integrated wastewater treatment plant





Advantages

- Solar and wind electricity production
- Water Electrolysis for H_2 and O_2 production
- O_2 for aeration saves >50% electricity for aeration
- Lower methane and laughing gas emissions
- Heating digester by waste heat electrolyser, resulting in more biogas production
- Biogas reforming for H_2 and CO_2 production
- CO_2 as feedstock in greenhouses and industry
- Recovery ammonia from wastewater
- Increasing size of reverse osmosis plant for irrigation and drinking water production
- Underground storage of treated wastewater for use in dry periods

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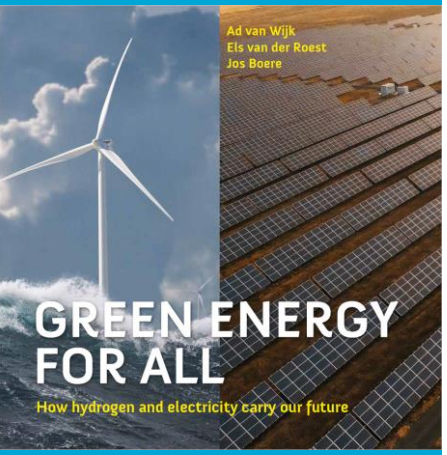
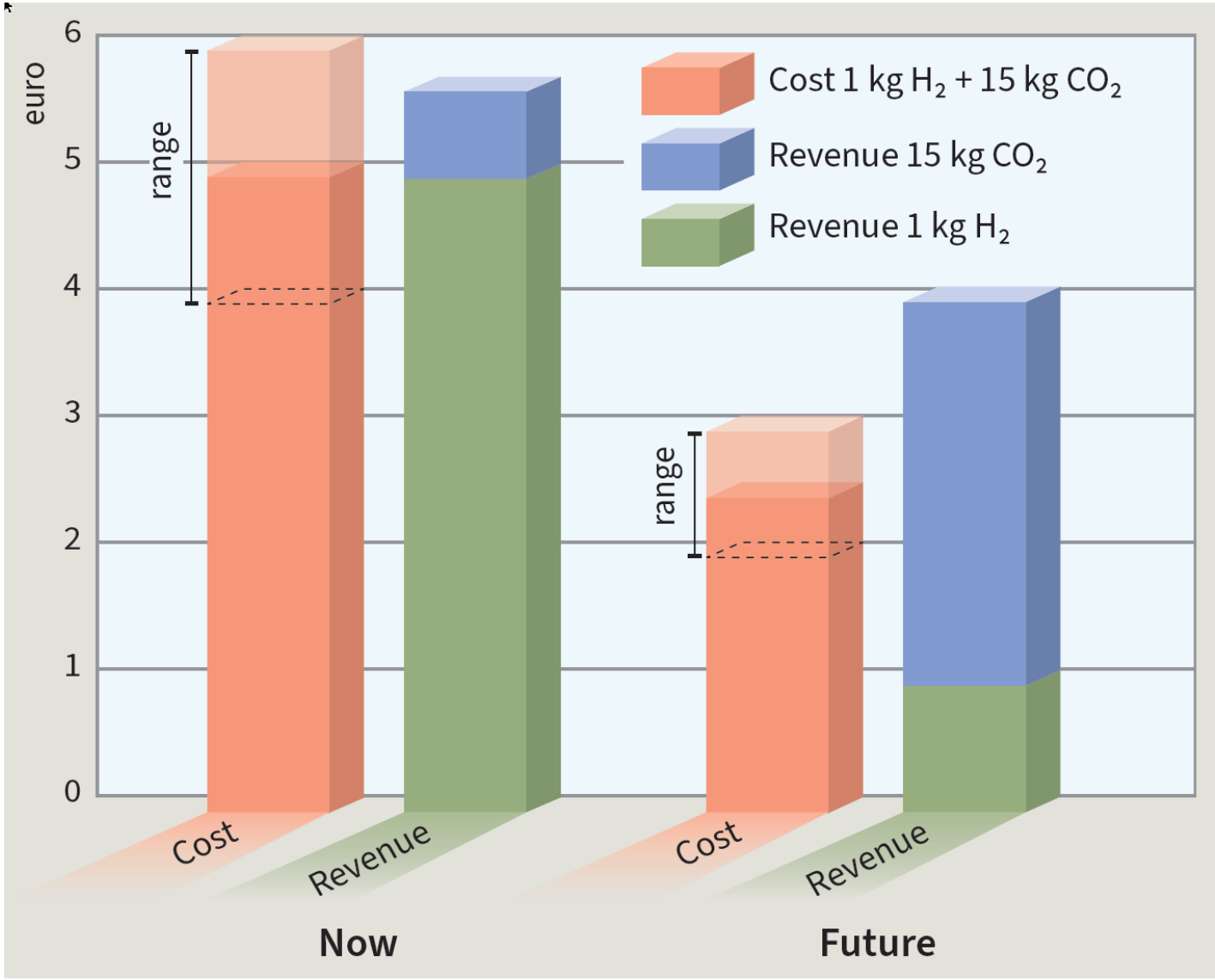
Biogas to H_2 and CO_2 conversion

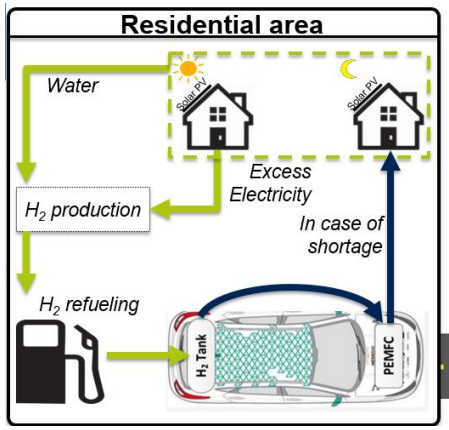




Hydrogen Markets

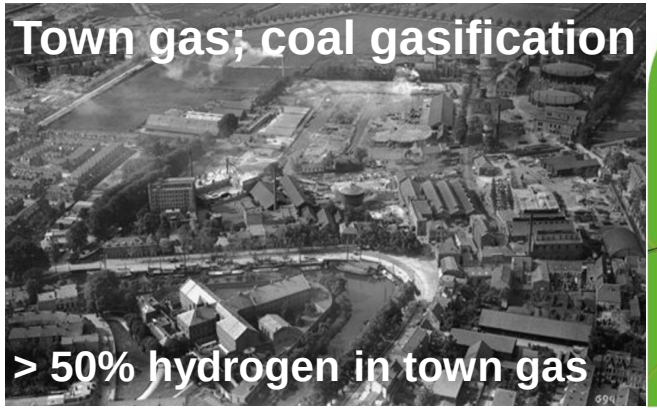
Industry Feedstock/HT Heat

Electricity Balancing



Transport

Heating



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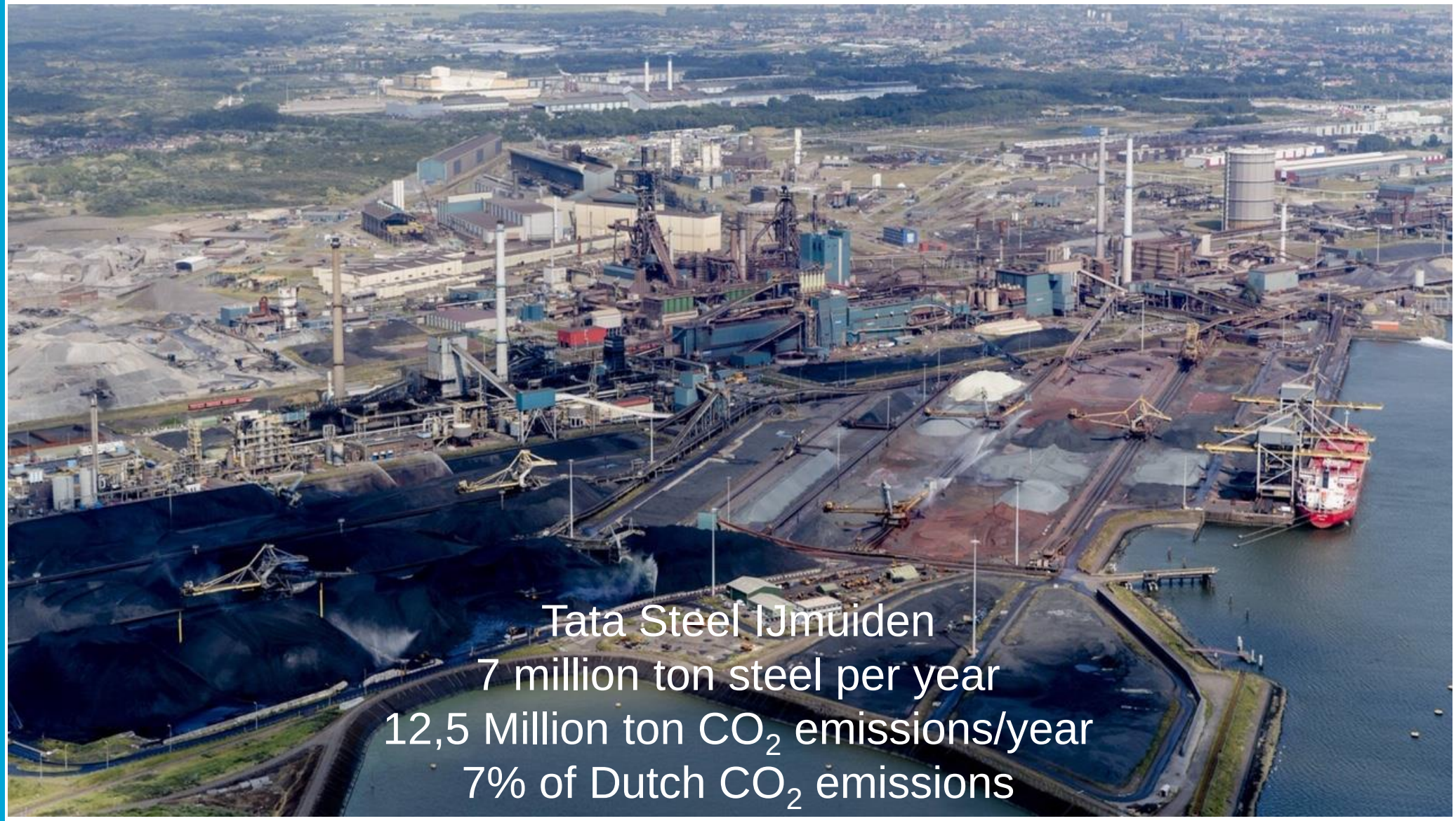
The Future for Steel Plant and site IJmuiden



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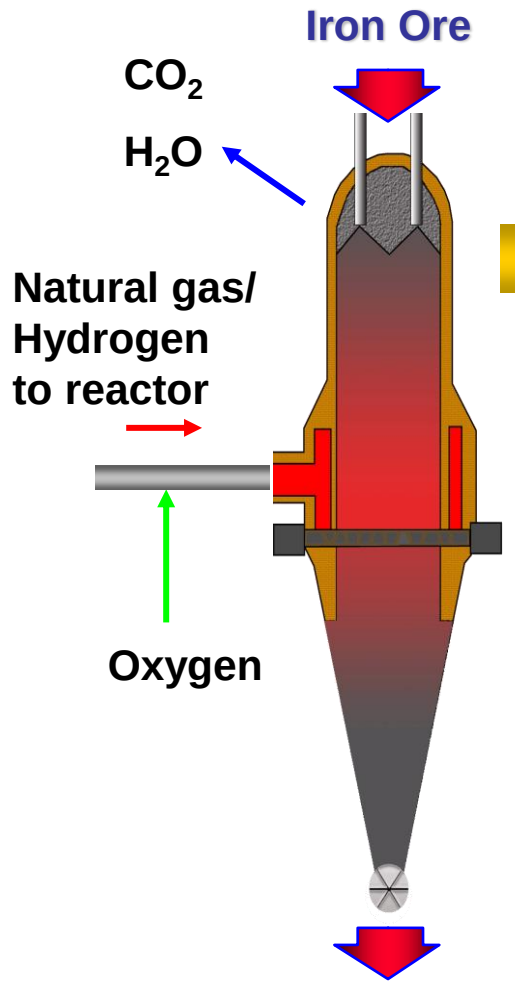
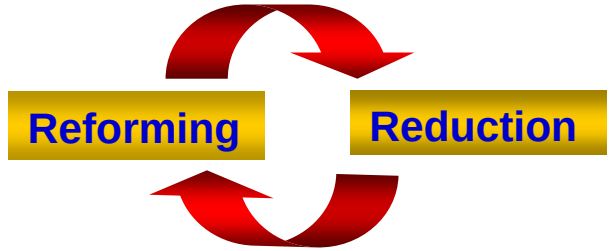
DRI (Directed Reduced Iron) Proces on Natural Gas





In-situ Reforming

$CH_4 + H_2O \rightarrow CO + 3H_2$

$CH_4 + CO_2 \rightarrow 2CO + 2H_2$

Reduction

$Fe_2O_3 + 3CO \rightarrow 2Fe° + 3CO_2$

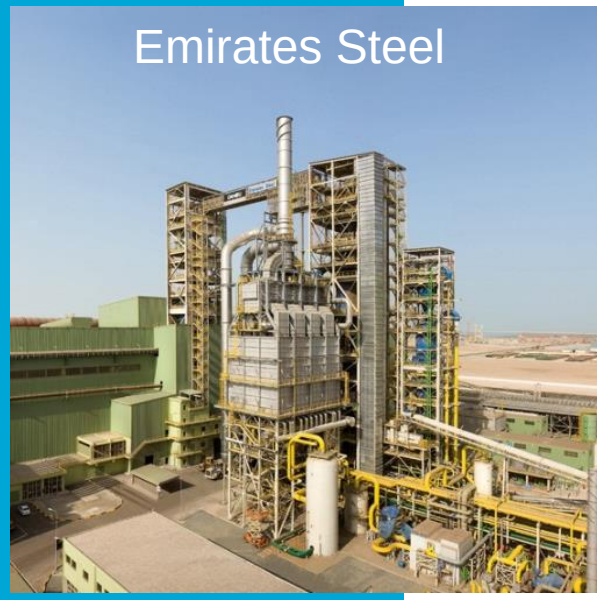
$Fe_2O_3 + 3H_2 \rightarrow 2Fe° + 3H_2O$

Carburization

$3Fe° + CH_4 \rightarrow Fe_3C + 2H_2$

Courtesy of Danieli

DRI (Directed Reduced Iron) Plants on Natural Gas mature technology



Two Modules:

2.0 Mtpy each
Carbon 1.5-2.5%
Met. 94%-96%
Hot DRI feed to EAF

Startup 2009/2011

One Module:

2.0 Mtpy
Carbon 3.0-4.0%
Met. 94%-96%
Hot DRI feed to EAF

Startup 2013

One Module:

2.5 Mtpy
Carbon 3.0-4.5%
Met. 94%-96.5%
Cold DRI

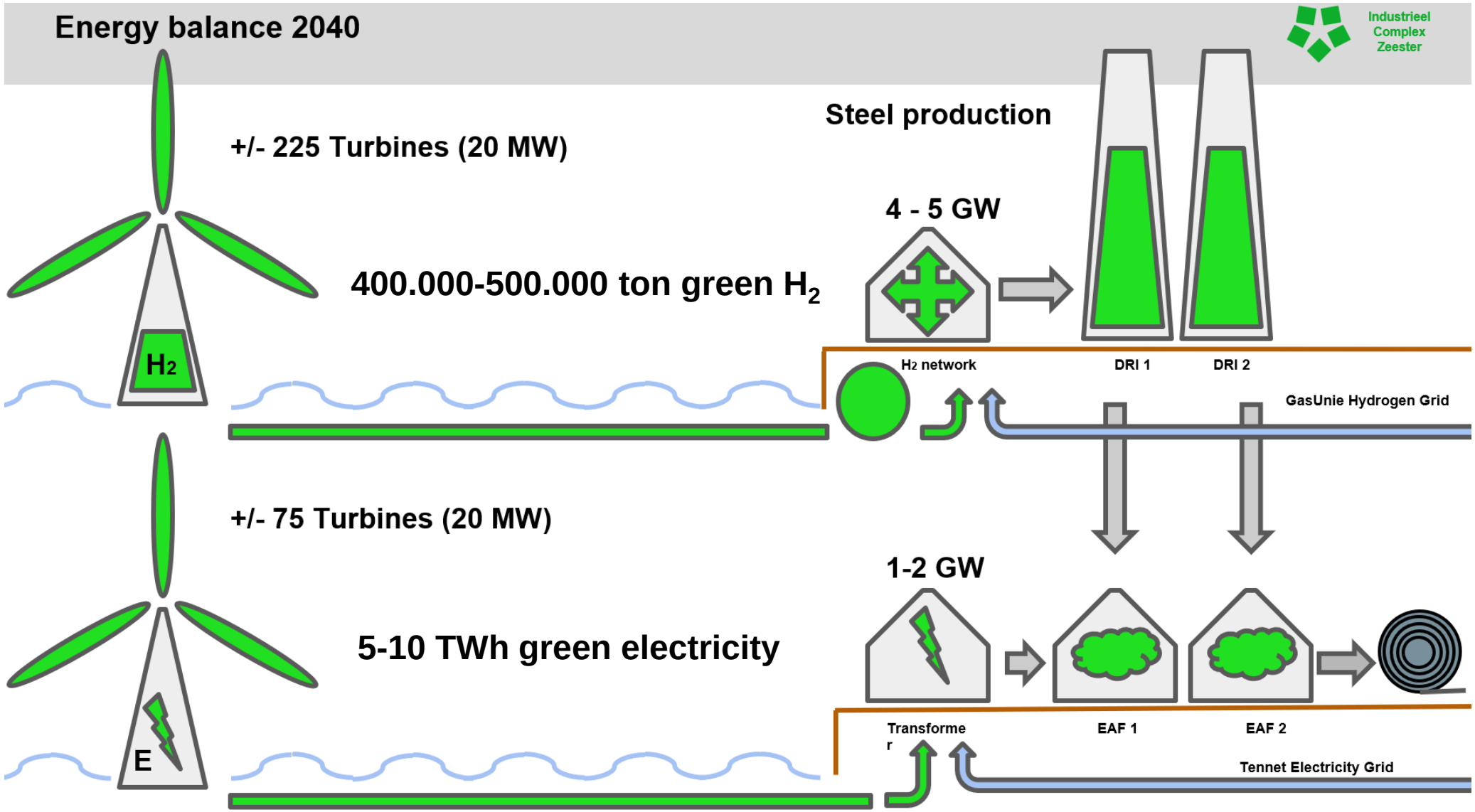
Startup 2013

One Module:

1.95 Mtpy
Carbon 1.5-2.5%
Met. 94%-96%
Cold DRI

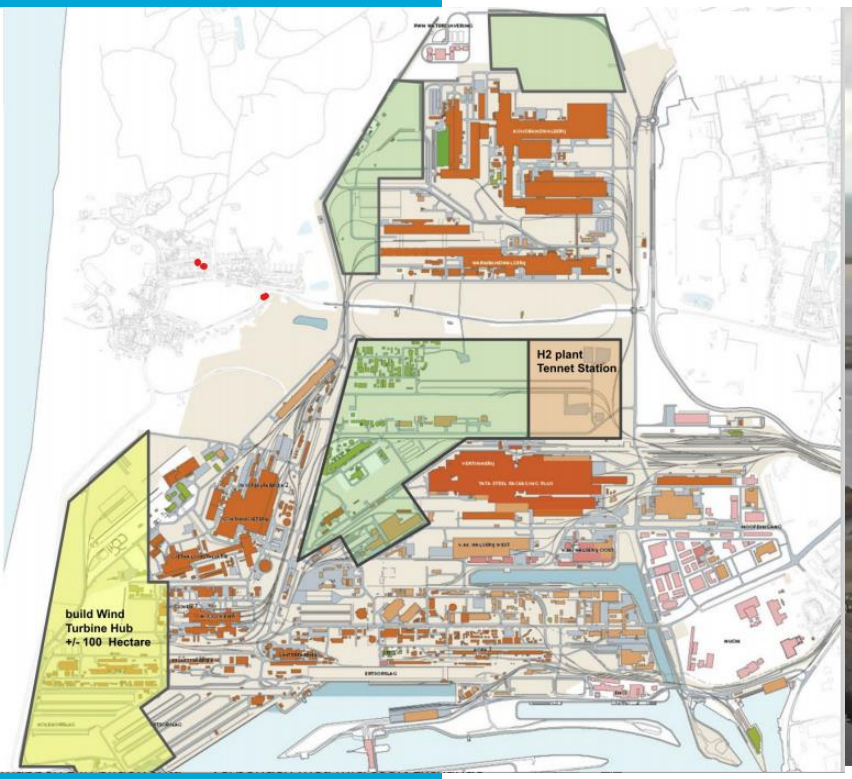
Startup 2015

Tata Steel on green hydrogen and electricity



Tata Steel the Netherlands chooses for hydrogen 15-9-2021

Manufacturing Offshore Wind Turbine components only possible at the coast, because of Size and Weight



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

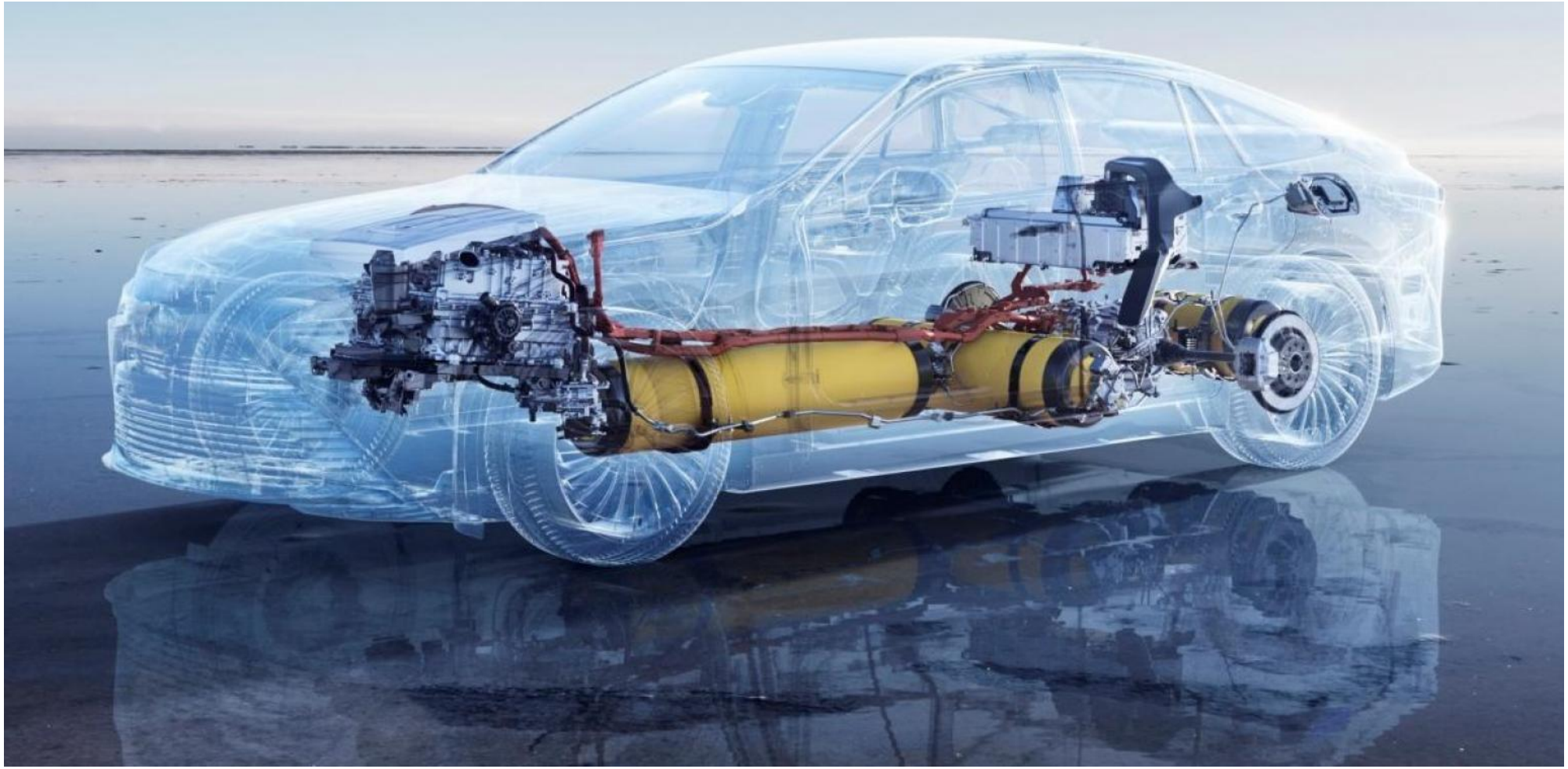
De toekomst voor mobiliteit is elektrisch!

Tesla Model S

Toyota Mirai

TU Delft

Toyota Mirai, second version



Waterstof Brandstofcel Elektrisch Transport

Stellantis/Opel:
Waterstof elektrische Bestelwagen

Doosan:
Waterstof drones

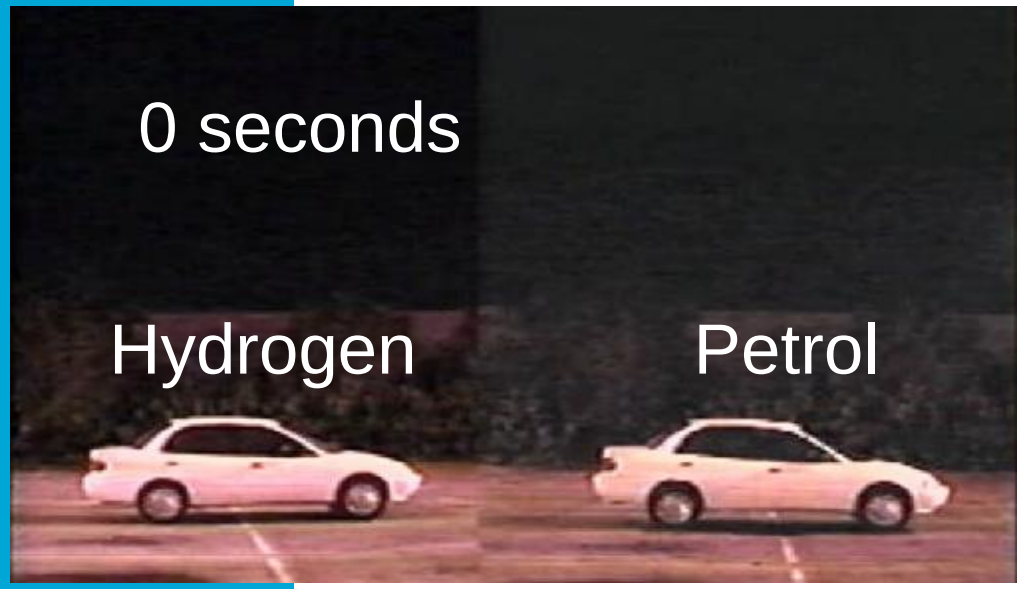
Alstom
Waterstof brandstofcel trein

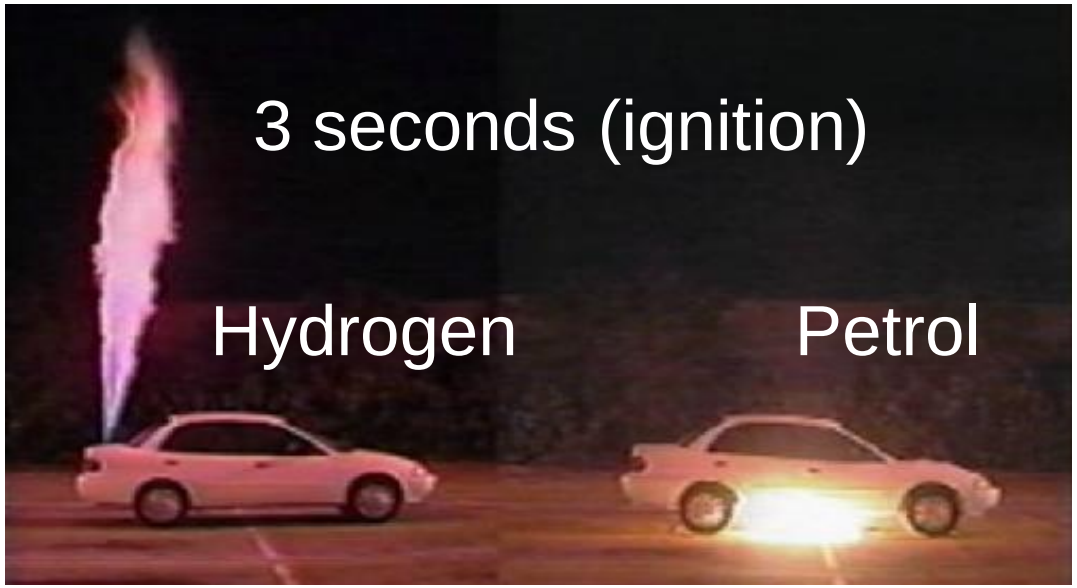
Toyota: Waterstof Heftruck

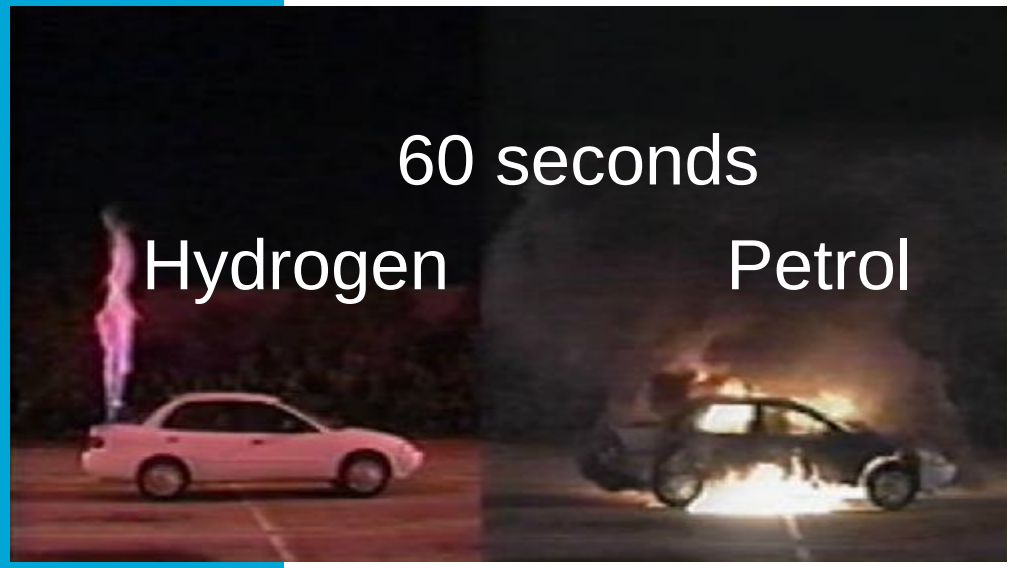
Caetano: Waterstof bus met
Toyota brandstofcel

Hyzon-Holthausen: Productie
waterstof brandstofcel trucks

Veiligheid: Waterstof versus benzine







Dual fuel Tractor, waterstof bijmengen in diesel motor (60%-80% van diesel wordt vervangen door waterstof)

Power to Hydrogen and Heat Nieuwegein

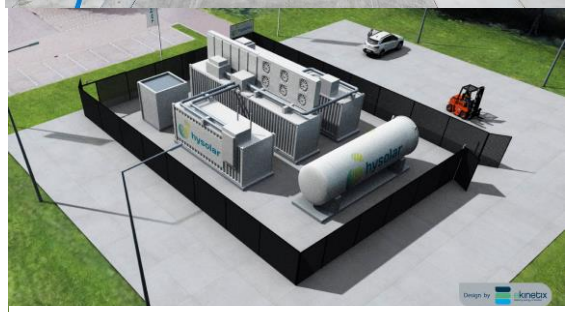
Dual Fuel Tractor, 2021

Dual Fuel Holder, 2021

Fuel Cell Crane, 2023

Solar Farms

Hydrogen Re-Fuelling Station, 2021



Electrolyser Realisation in progress

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Stadsgas productie Utrecht
Gemeentelijke gasfabriek 1862-1959
> 50% waterstof in stadsgas

AD 18-5-2022

TOEN EN NU OVERVECHT

Gasfitters in de wijk Overvecht

Heel Utrecht moet eind 1966 van het stadsgas af zijn. Te beginnen in Overvecht. Dus trekt op 6 juli 1965 een grote ploeg gasfitters de wijk in om huis-aan-huis alle kachels, geisers en fornuizen geschikt te maken voor aardgas. In één dag moet de klus geklaard zijn, want de stadsgasleiding is al afgesloten en vanavond moeten de huisvrouwen natuurlijk wel weer hun potje kunnen koken. Aardgas, wat een wonder was dat. Kant-en-klaar zat het zomaar onder de grond in Groningen. Veel schoner dus dan het uit steenkool gewonnen fabrieksgas, waar Utrechters tot dan toe op kookten en stookten. Een nadeel: álle gastoestellen in álle huizen moesten ervoor worden omgebouwd. Maar dat valt in het niet bij de energietransitie waar we nu voor staan. Heel Utrecht moet in 2050 van het gas af zijn. En weer is Overvecht de proeftuin. Bij de tienhoogflat van Marijke aan de Henriëttedreef zijn ze al zover. Het dak, de gevel en zelfs alle balkonhekjes zijn bekleed met zonnepanelen.
De bewoners stoken en koken alleen nog maar op de elektriciteit die de flat zelf opwekt. Dus geen last van stijgende energieprijzen en kijk, de pannen blijven zo lekker schoon aan de onderkant.
– Paula Swieringa

▲ Vanavond kookt deze huisvrouw op aardgas. FOTO HET UTRECHTS ARCHIEF

▲ Marijke kookt elektrisch, veel schoner voor de pannen. FOTO PAULA SWIERINGA

Verwarmen met waterstofketels

Remeha

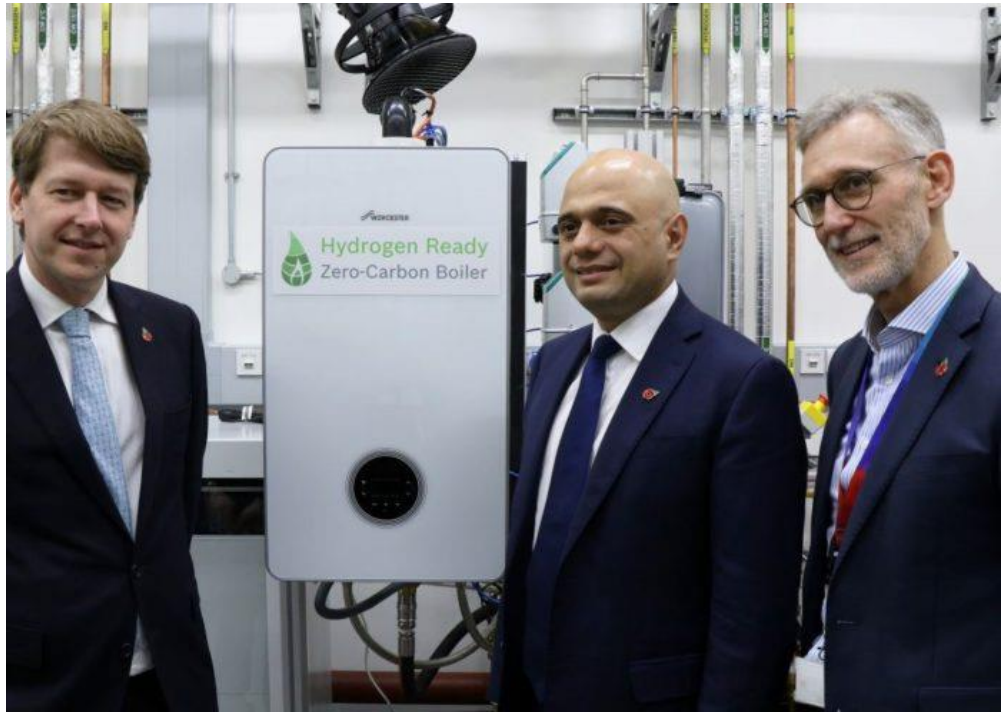
Remeha HYDRA

	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

Waterstofketel
(Maart 2019 gelanceerd)

Worcester Bosch



Gasketel die geschikt is voor waterstof
(15-11-2019 gelanceerd)

Slimme hybride oplossing, kosten efficient en weinig overlast:

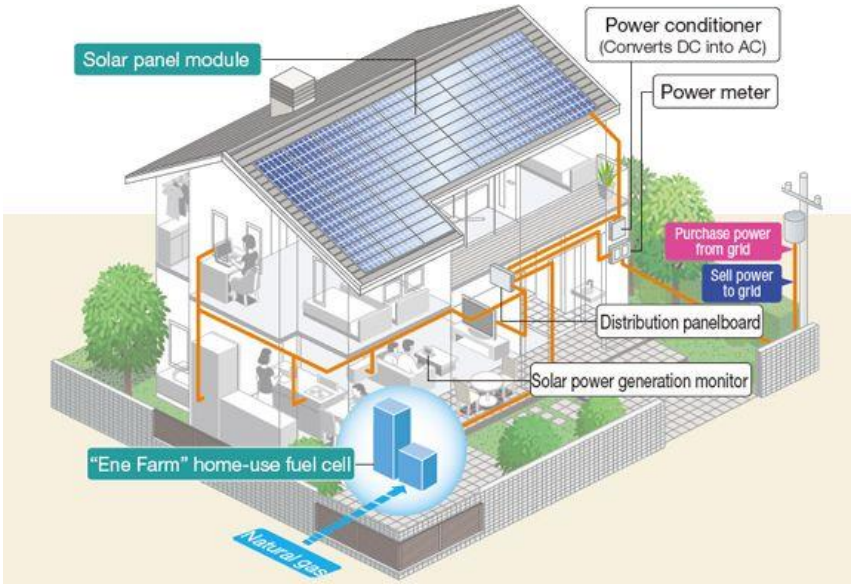
- Isoleren wat eenvoudig en goedkoop kan
- Warmtepomp voor basislast; COP 5,2 ipv COP 3,4
- Aardgas/Waterstofketel voor pieklast in winter

Panasonic: Huis Brandstofcel systemen Japan

Warm water vat Brandstofcel

Japan 270.000 verkocht 2018
Doel 5.3 miljoen verkocht eind 2025

Reforming aardgas naar H_2 + CO_2 + warmte
1 kW brandstofcel zet H_2 om in elektriciteit+warmte



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