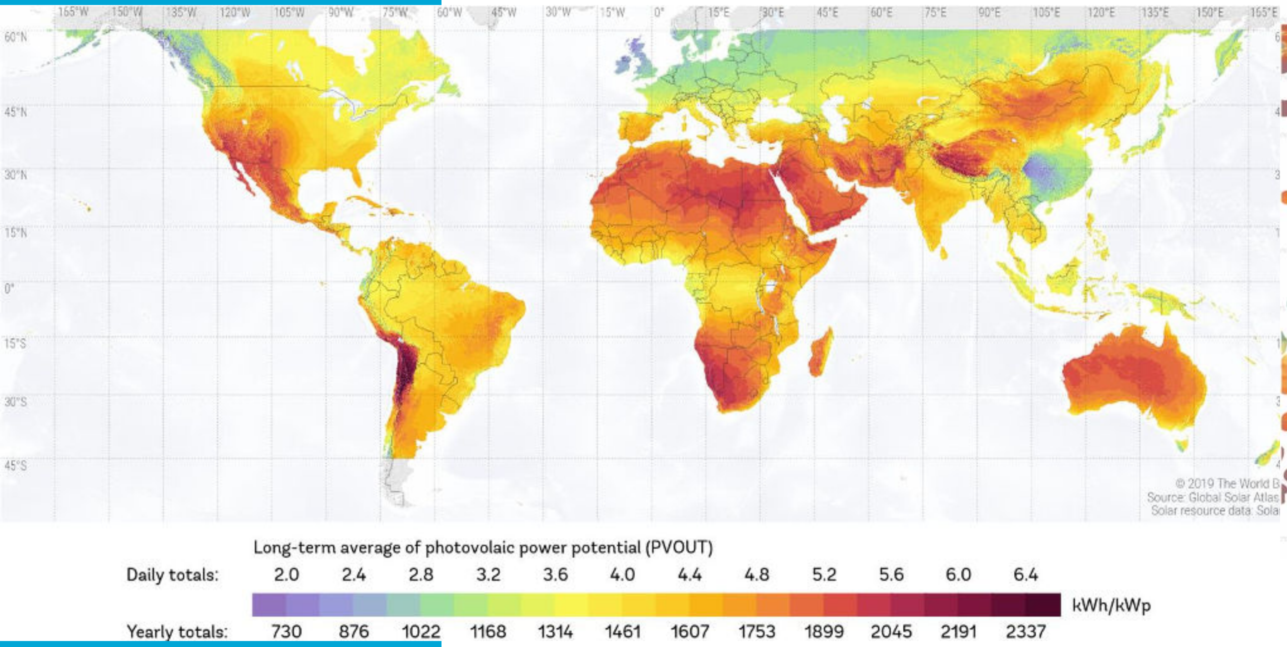
# Waterstof tot nadenken

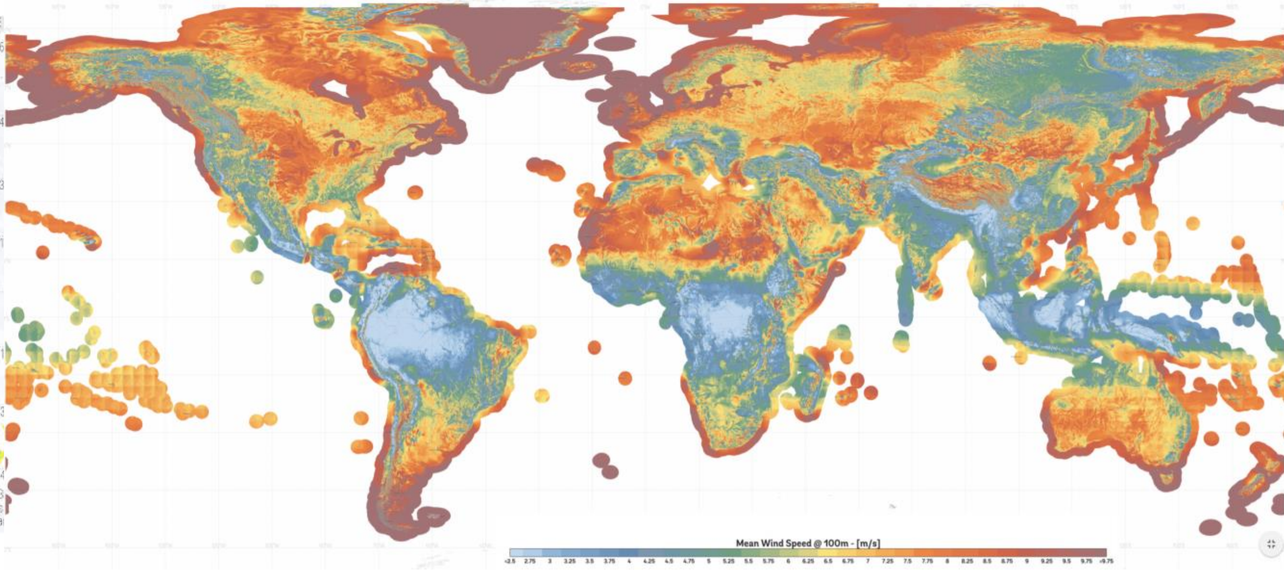
2-11-2023

Em. Prof. Dr. Ad van Wijk

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

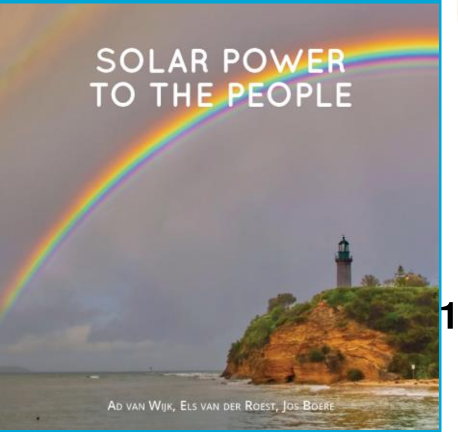



Solar Resources Map

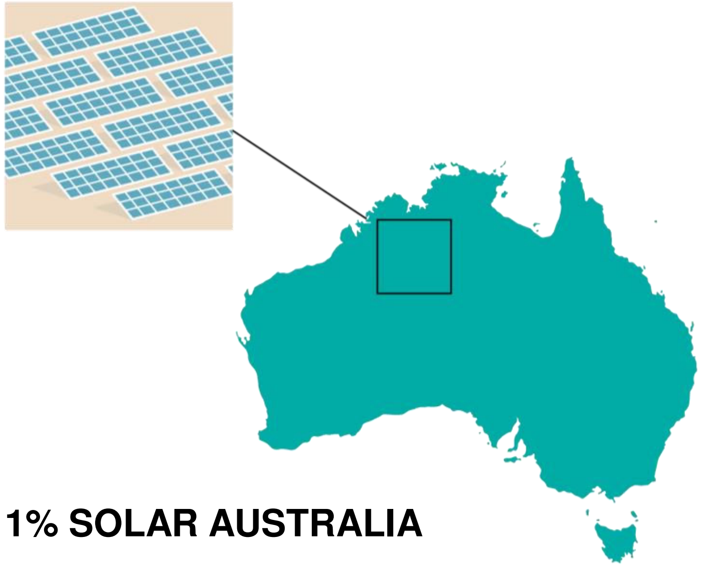


Wind Speed at 100-meter height Map

# Surface needed to produce all the world's energy




**World energy use 2019: 606 EJ = 168.000 TWh**



**11% SOLAR AUSTRALIA**

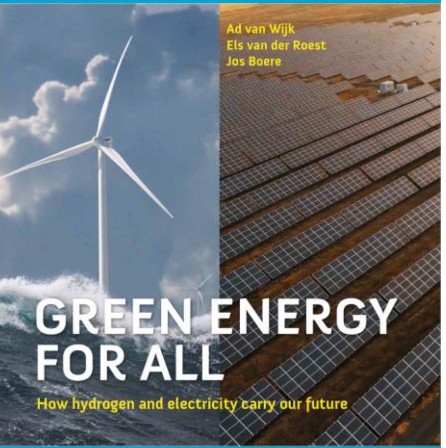
**1.5% WIND PACIFIC OCEAN**

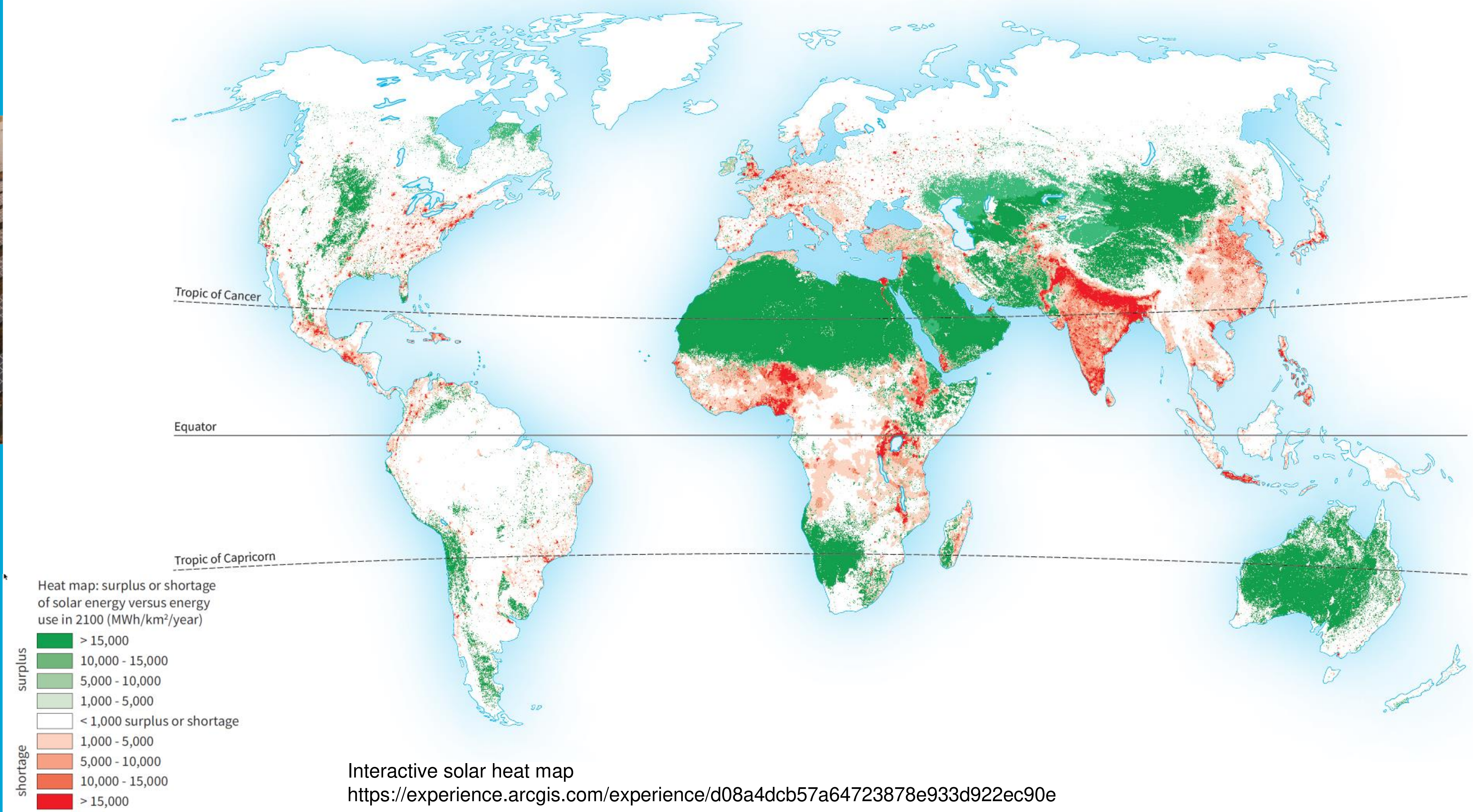
Mohammed Bin Rashid Al Maktoum Solar Farm Dubai;
3.000 MW ready, expansion to 5.000 MW

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

# Heat map Solar Energy 2100;

## Surplus (green) or shortage (red) solar energy - energy use per km$^2$



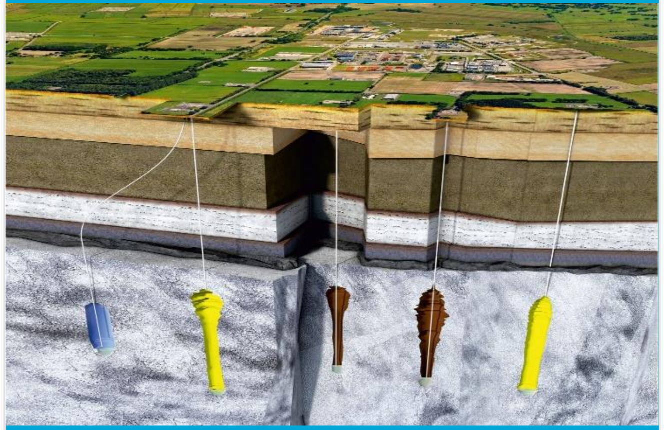




Interactive solar heat map
https://experience.arcgis.com/experience/d08a4dcb57a64723878e933d922ec90e

# 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

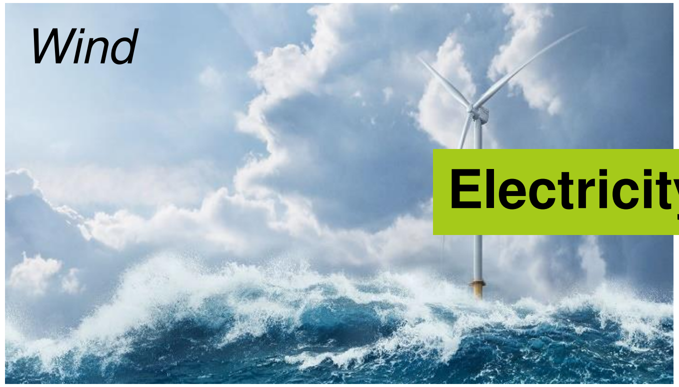

Photolysis Module
Solhyd startup Belgium


**Hydrogen**

Kite H2 ship
Oceanergy startup SouthAfrica


Nuclear Power Plant
Borssele Netherlands

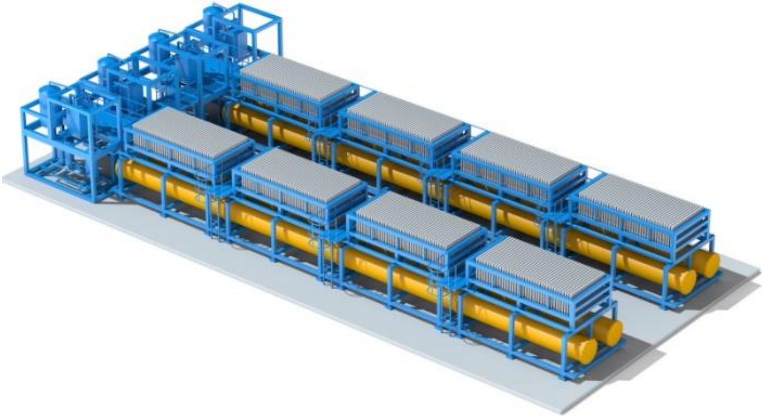

Photovoltaic Modules
Canadian Solar




**Electricity**

Offshore wind turbine
Siemens Gamesa

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

**Electricity** →  → **Hydrogen**

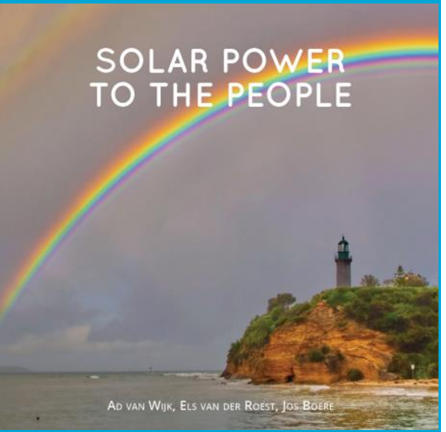
Alkaline electrolyser Thyssen Krupp Germany

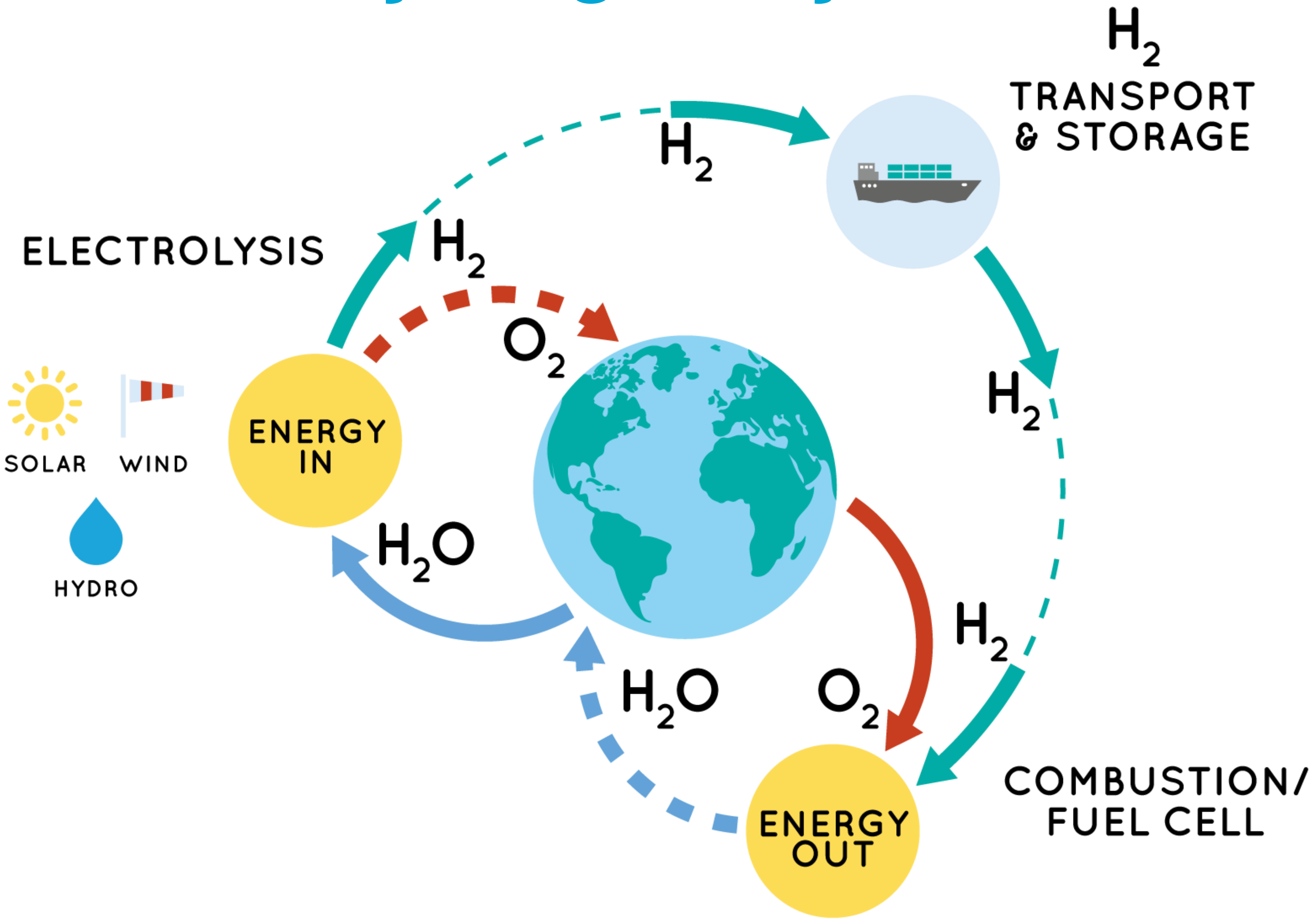
**Hydrogen** → 

→ **Electricity**

PEM fuel cell, Toyota Japan

# The Hydrogen Cycle

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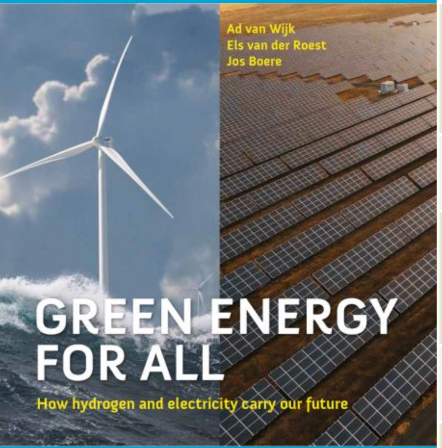
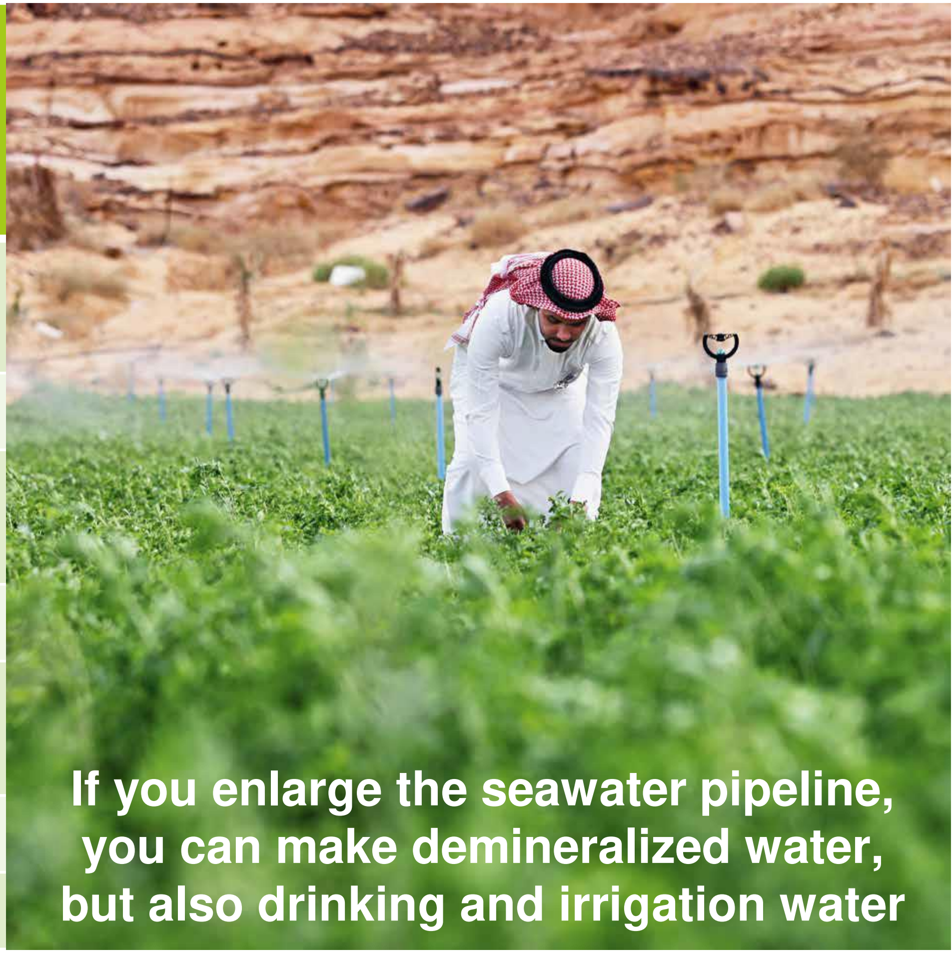
# Seawater as resource for water in the desert




| 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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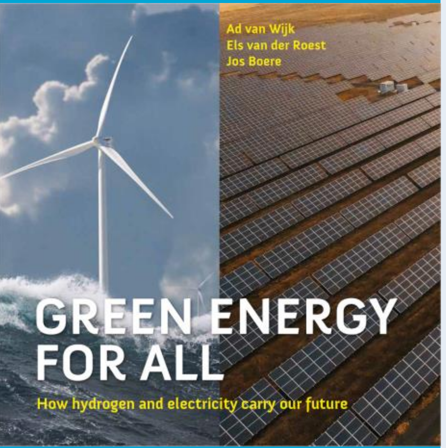
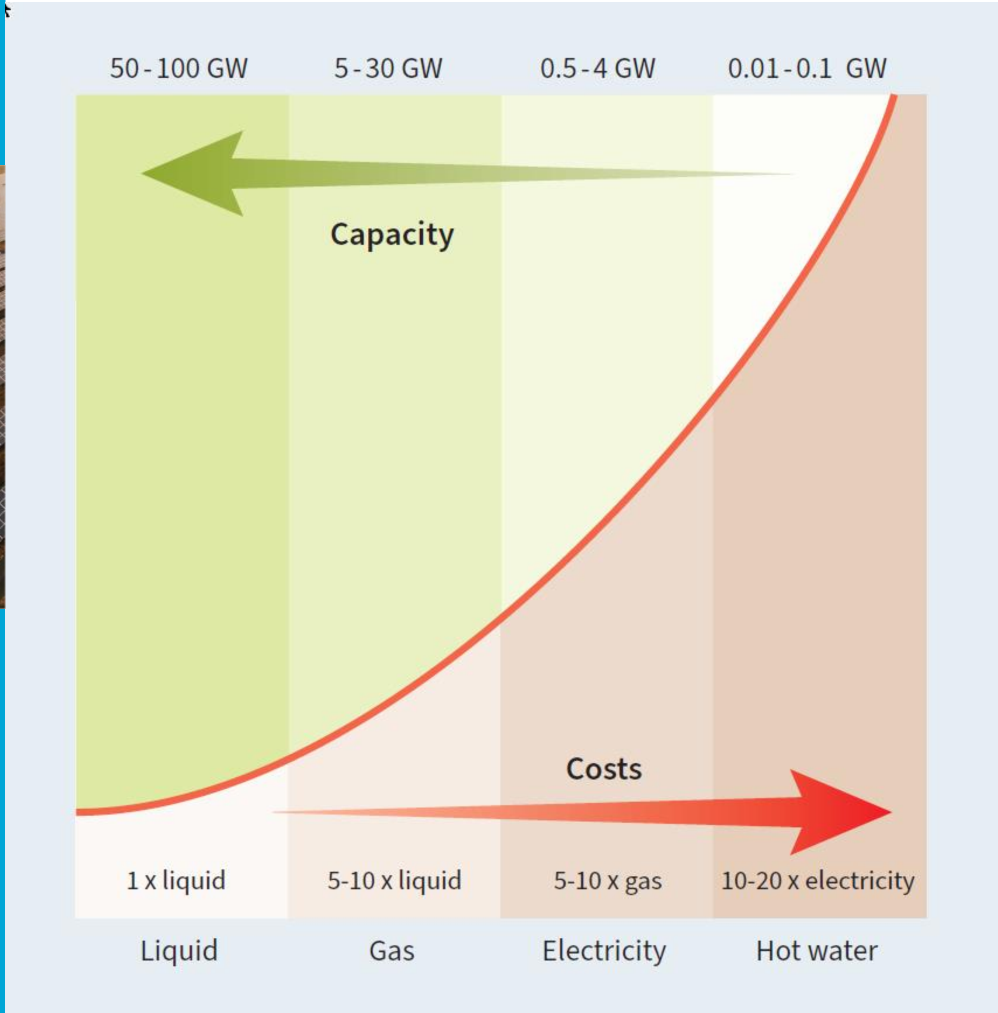
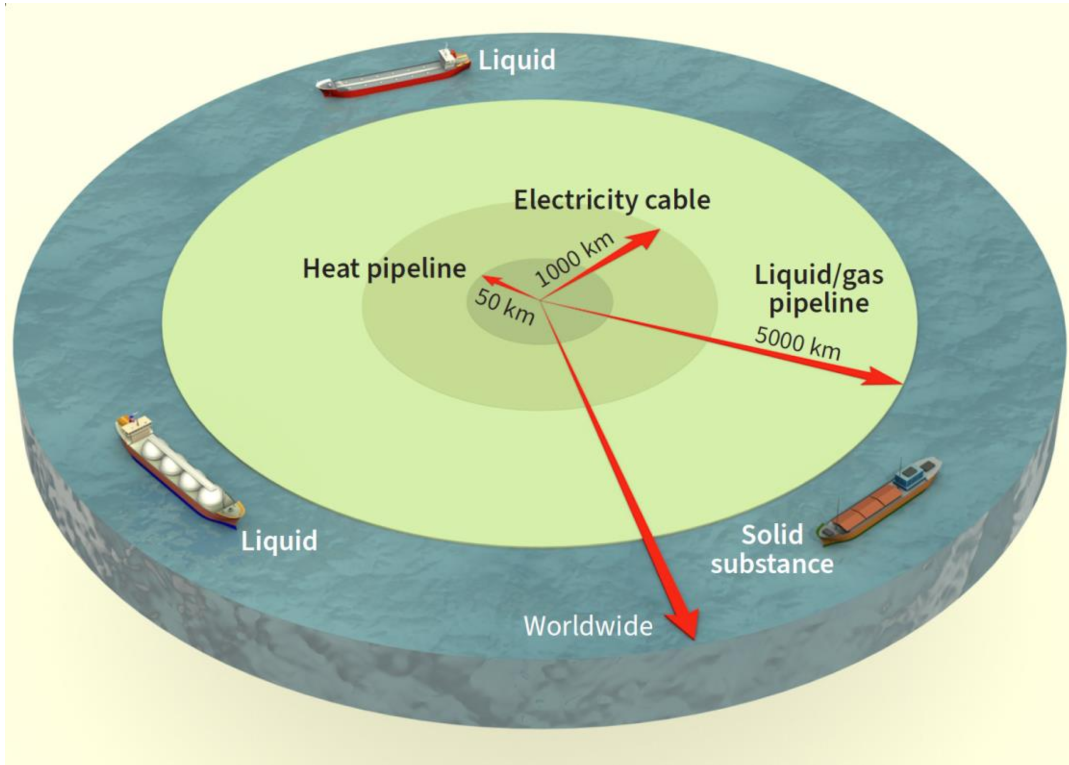
# Energy Transport system
# costs, capacities and configuration

**Hydrogen transport cost 5-10 times cheaper than electricity transport**



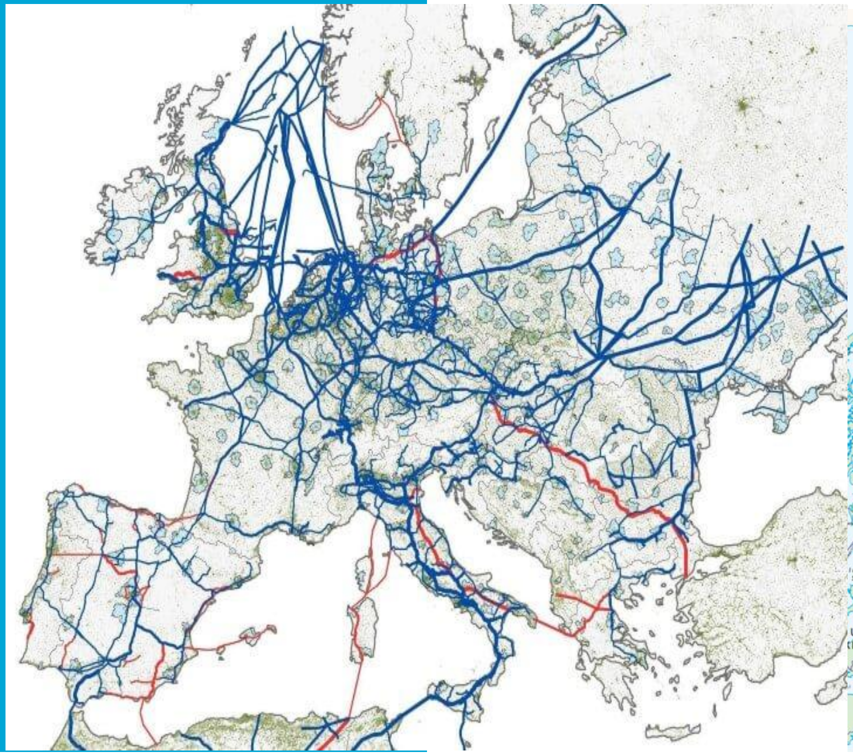




Energy pipeline transport costs and capacities




Worldwide energy transport system

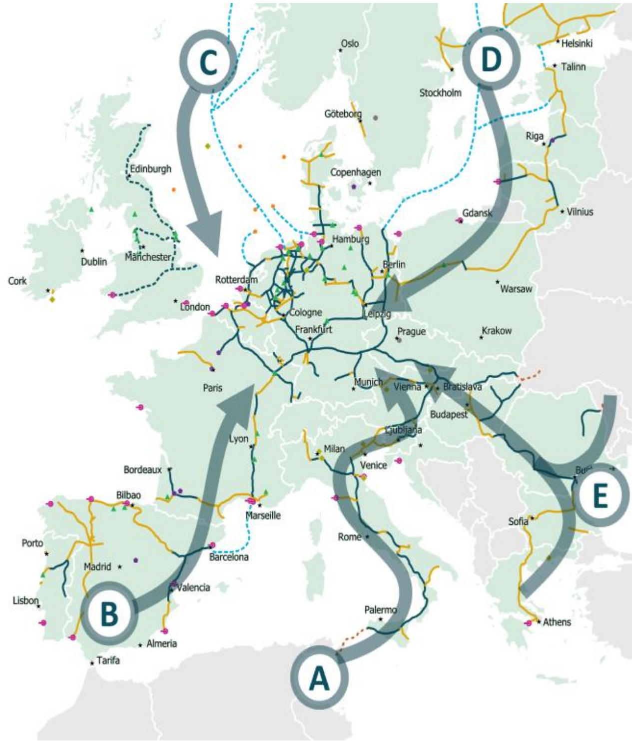
# Gas Infrastructure in Europe can be reused for hydrogen



**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

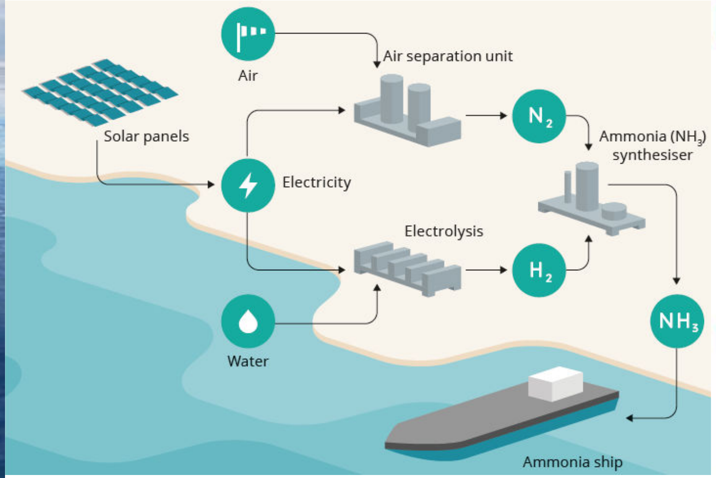

**Gas from North-Africa**
60 GW Natural Gas Pipeline
2x0.7 GW Electricity Cable



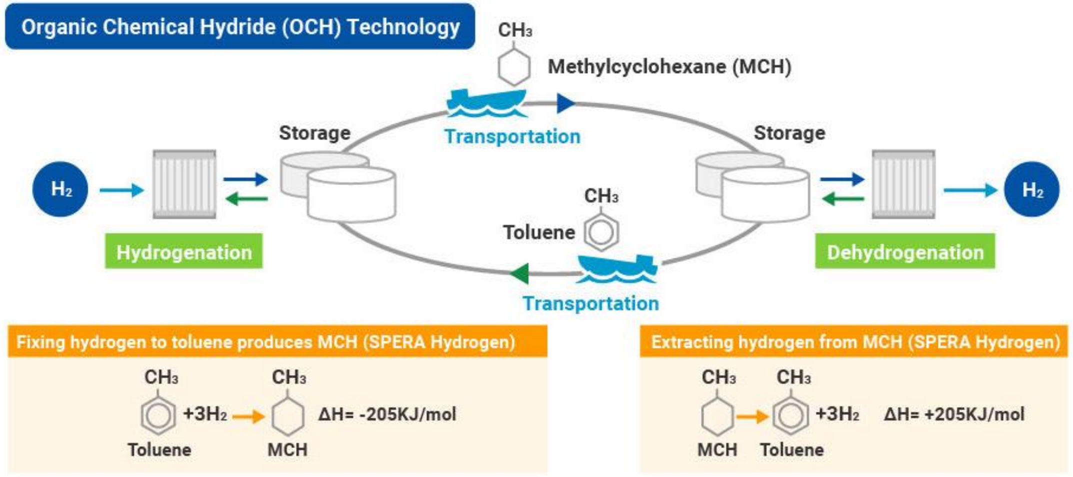

**European Hydrogen Backbone 2030**
Overall length : 32.616 km
Repurposed gas : 16.864 km

# Hydrogen Transport by Ship


Liquid Hydrogen

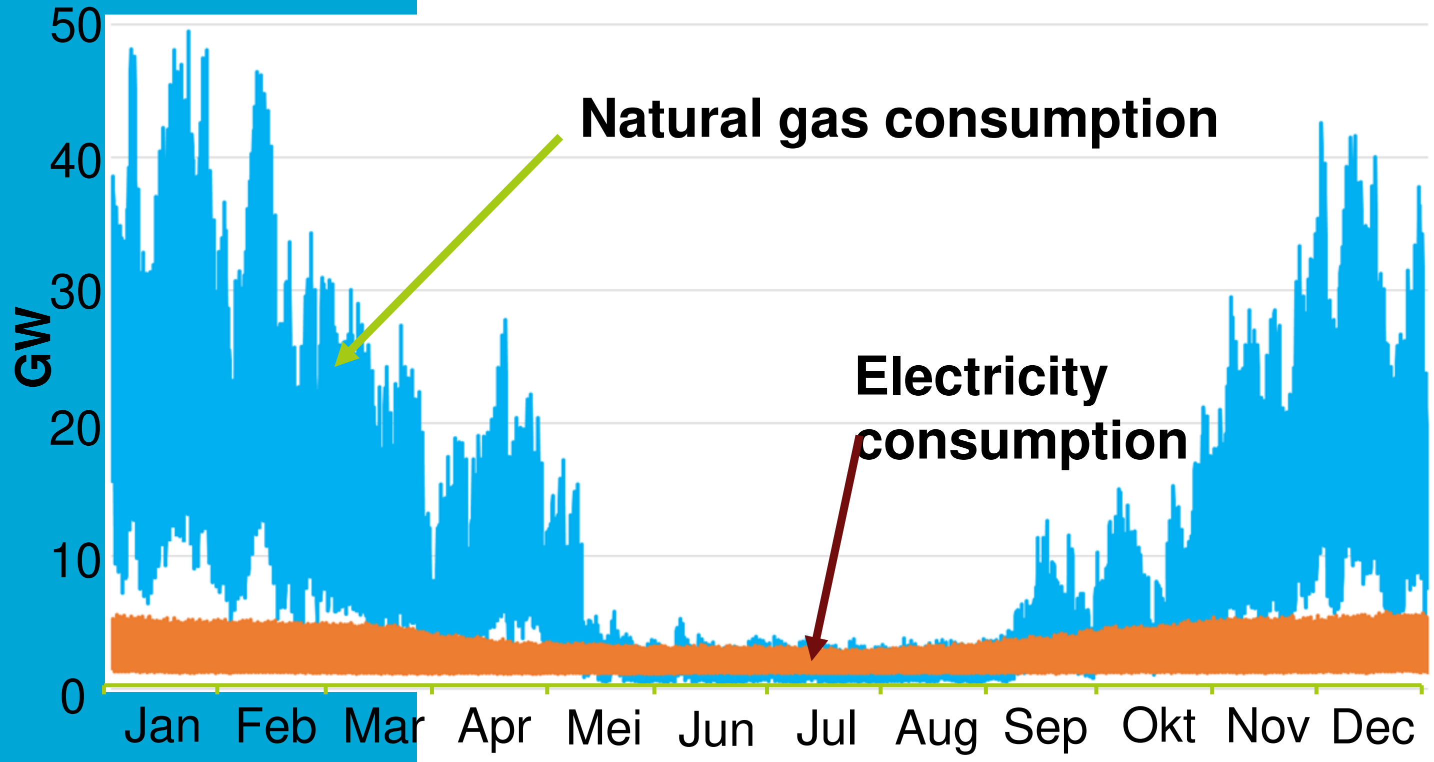



Ammonia



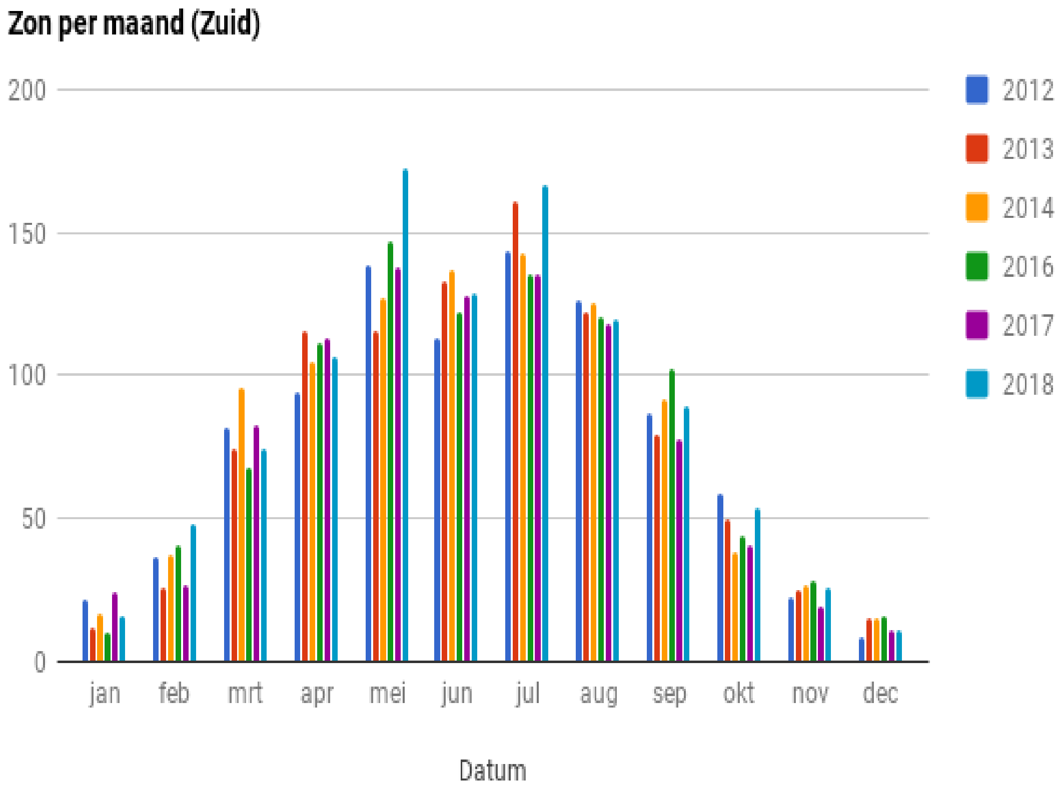

LOHC
Liquid Organic Hydrogen Carrier

# 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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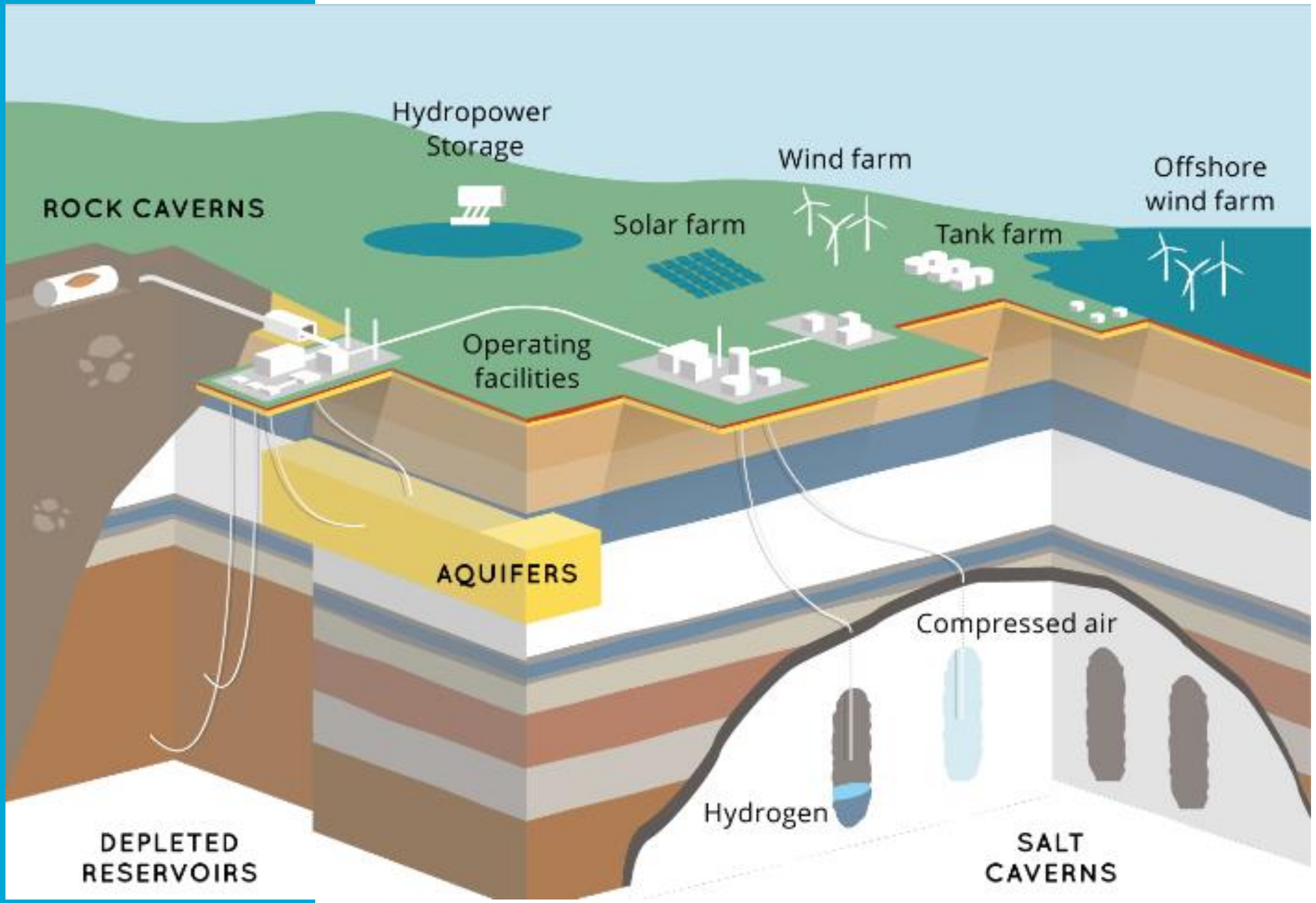
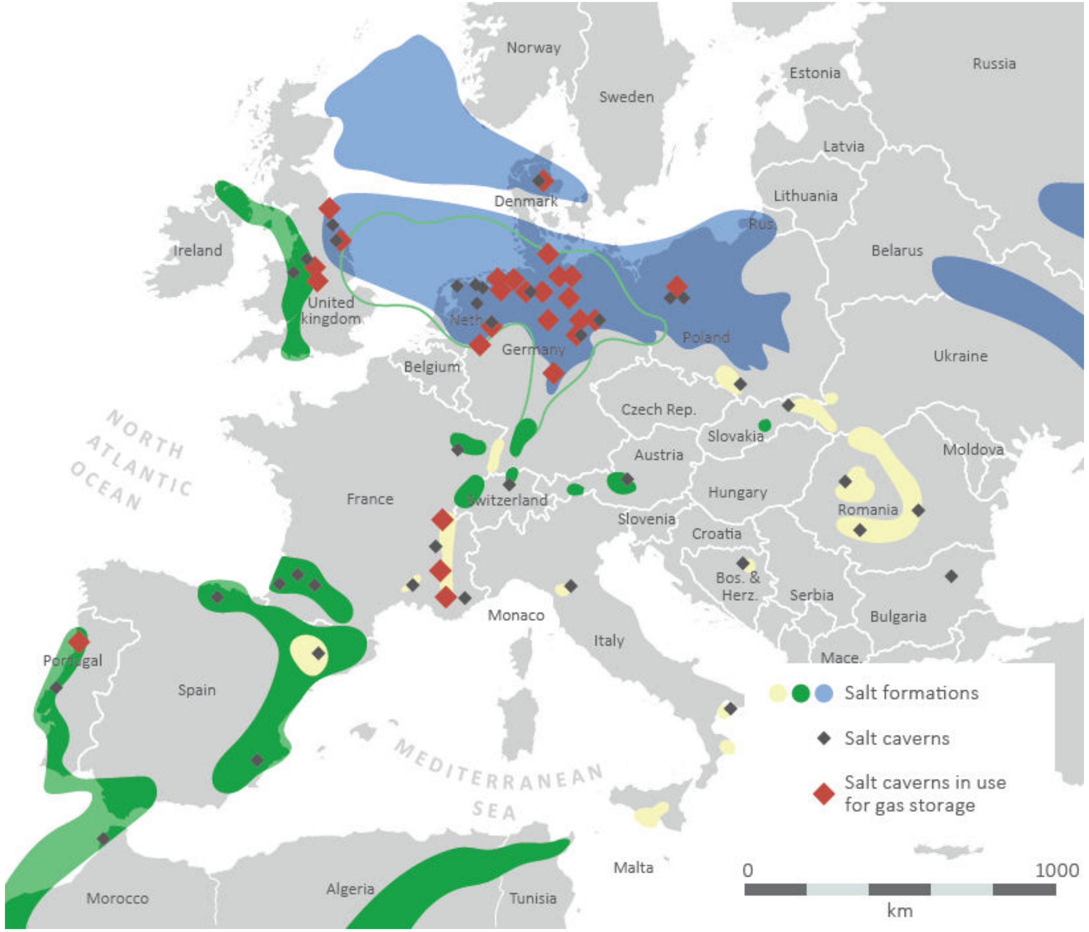
# Hydrogen storage in salt caverns



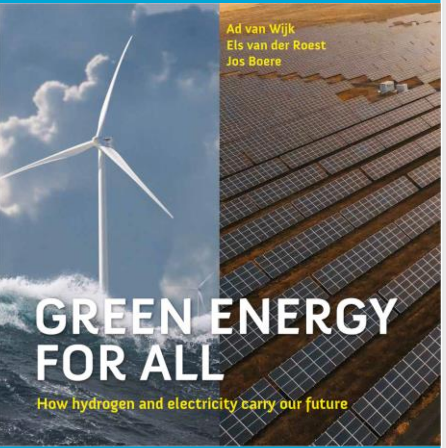

# Salt formations and caverns in Europa

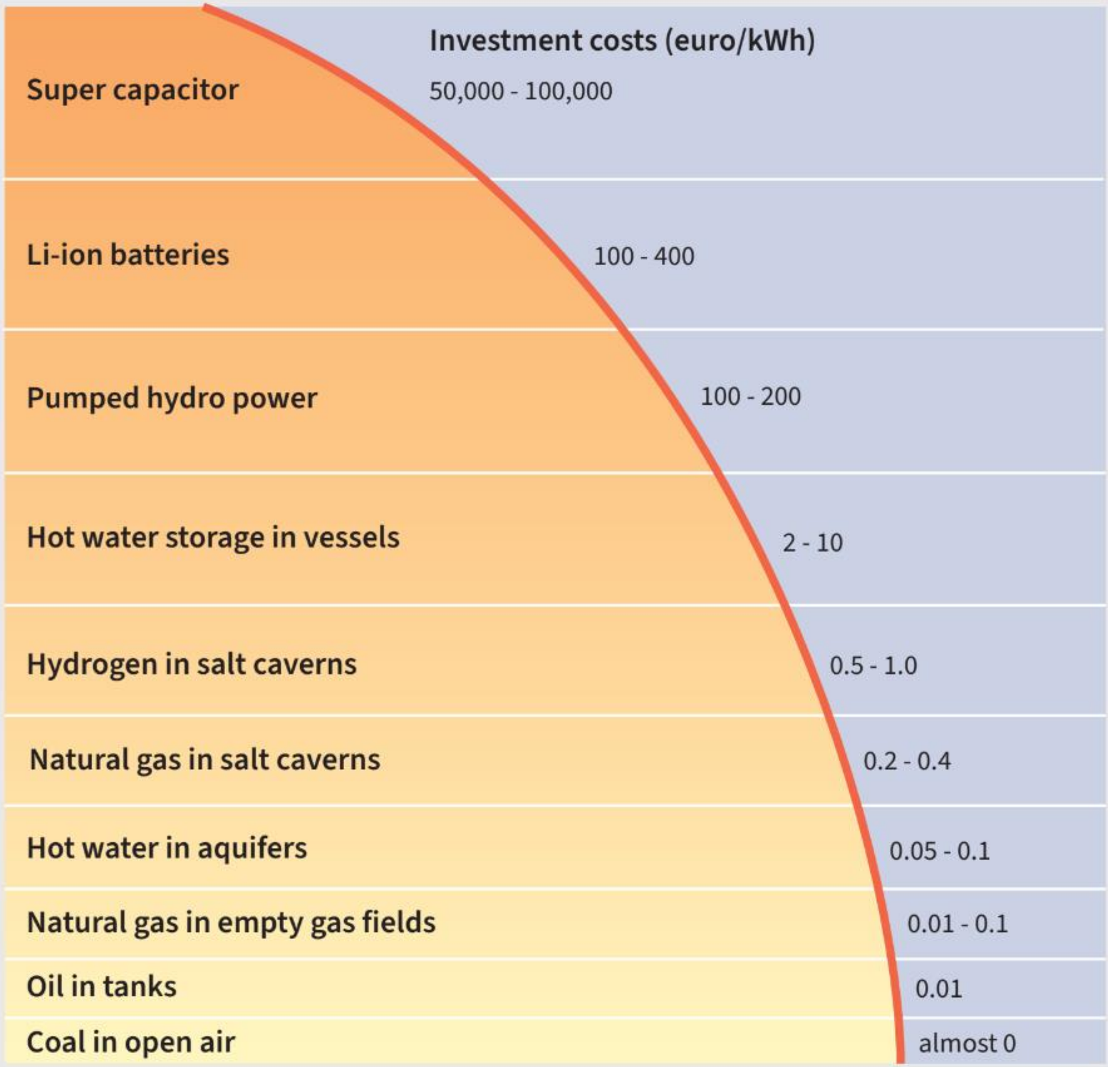



**1 salt cavern can contain up to 6,000 ton (= 236.4 GWh HHV) hydrogen,**
**Salt Cavern CAPEX = 0.5 Euro per kWh, Total Salt cavern CAPEX is 100 million Euro**

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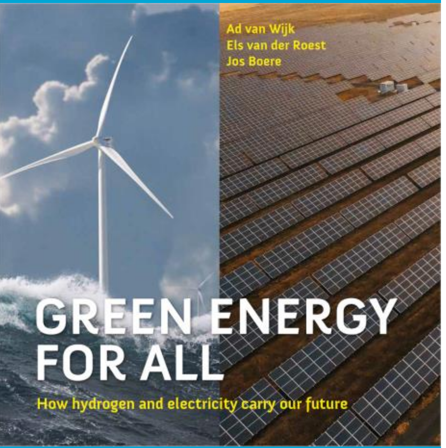
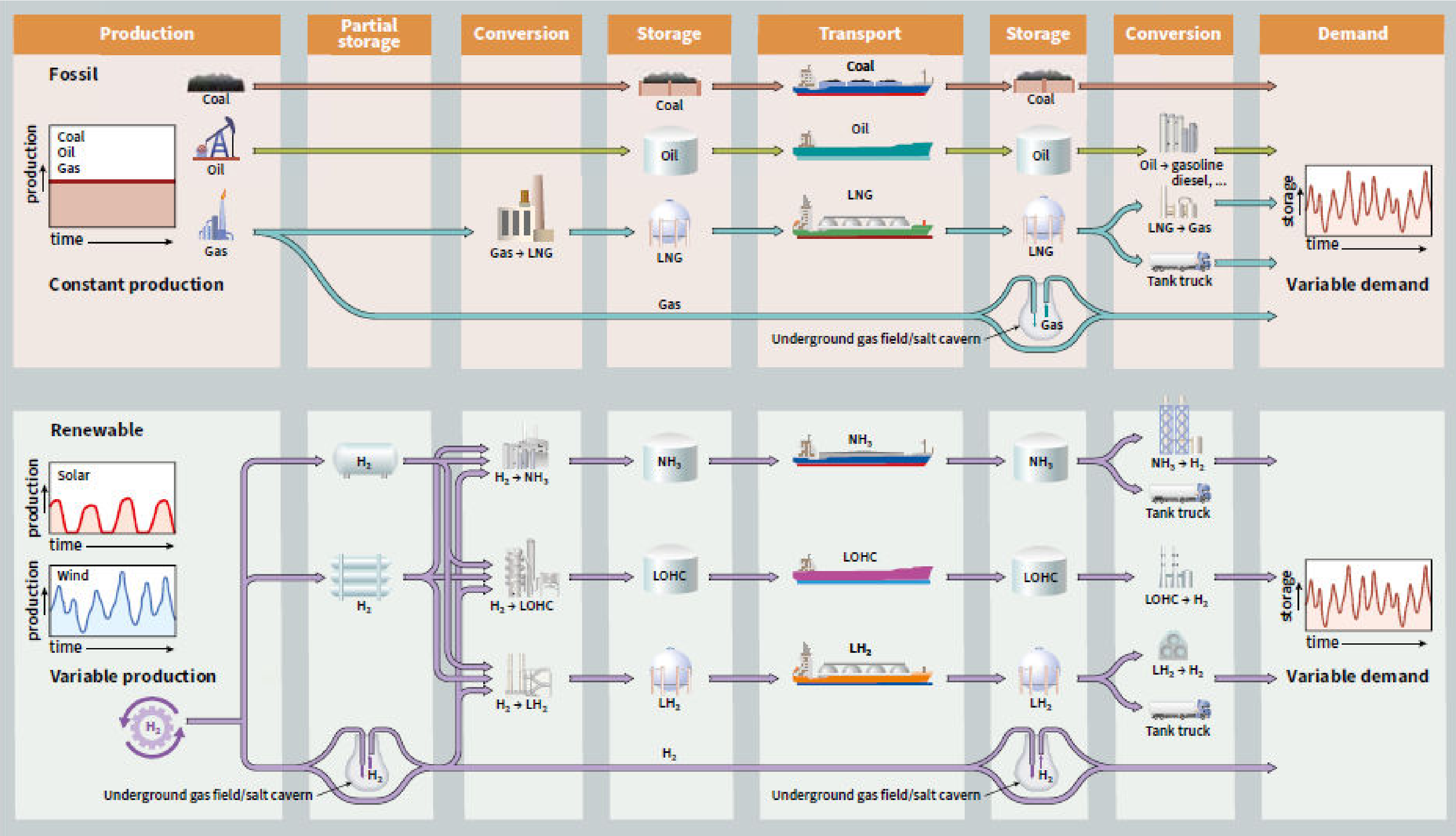
# Energy storage costs in a renewable energy system higher than in a fossil energy system

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# Wastewater treatment plant Echten, the Netherlands

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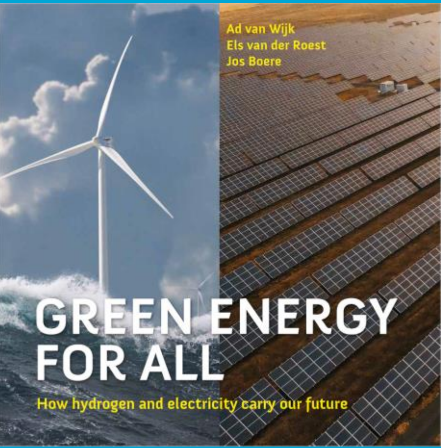
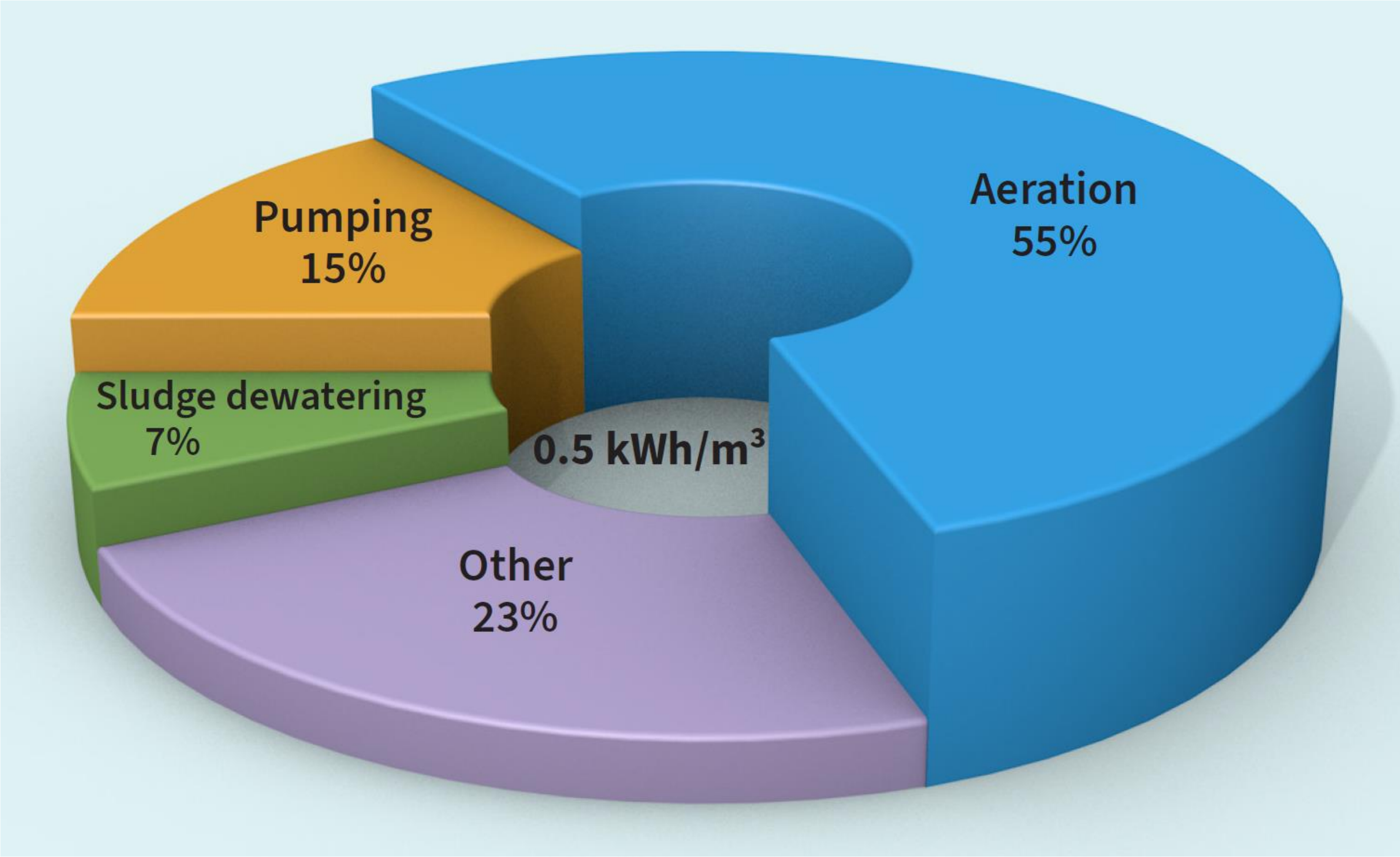
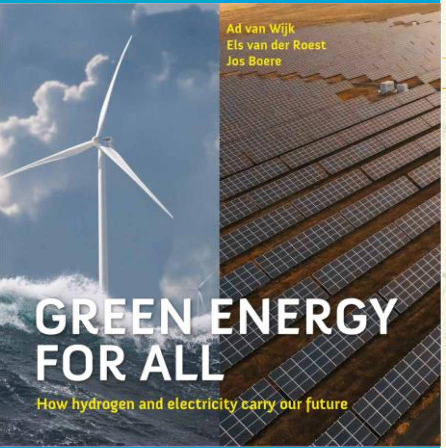
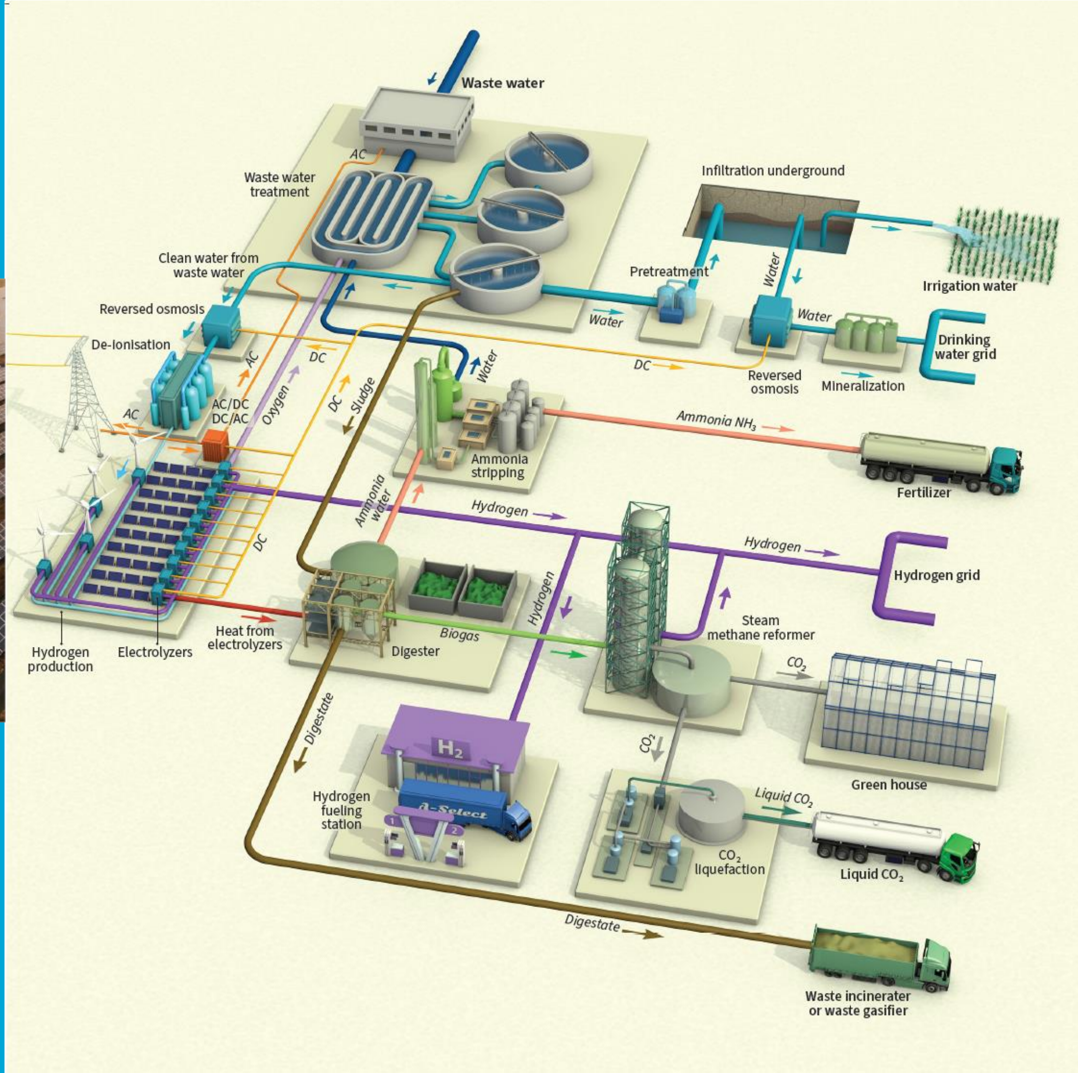
# Electricity Consumption wastewater treatment plant



# Integrated wastewater treatment plant

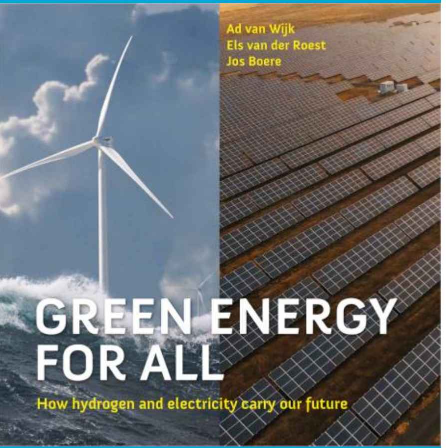


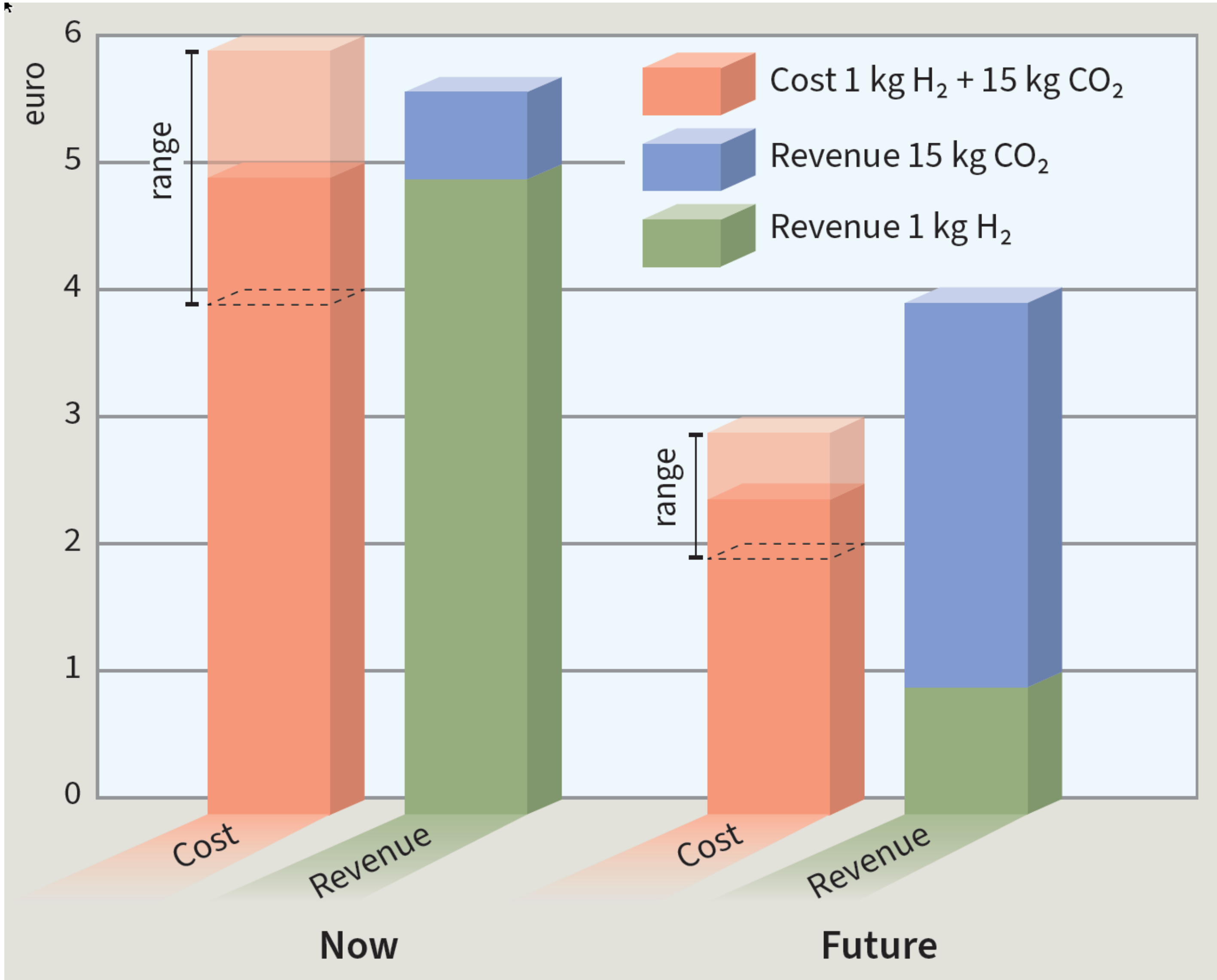




**Advantages**

- 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

# Biogas to $H_2$ and $CO_2$ conversion

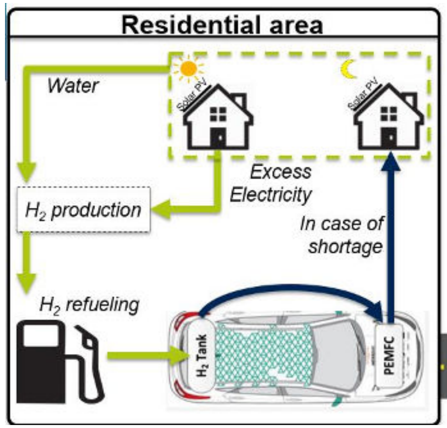


# Hydrogen Markets

## Industry Feedstock/HT Heat

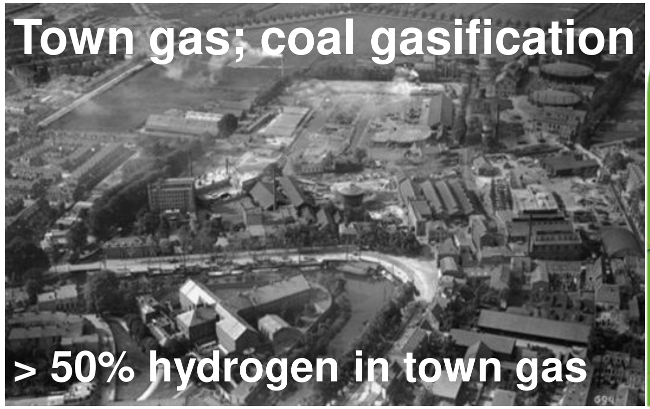
## Electricity Balancing



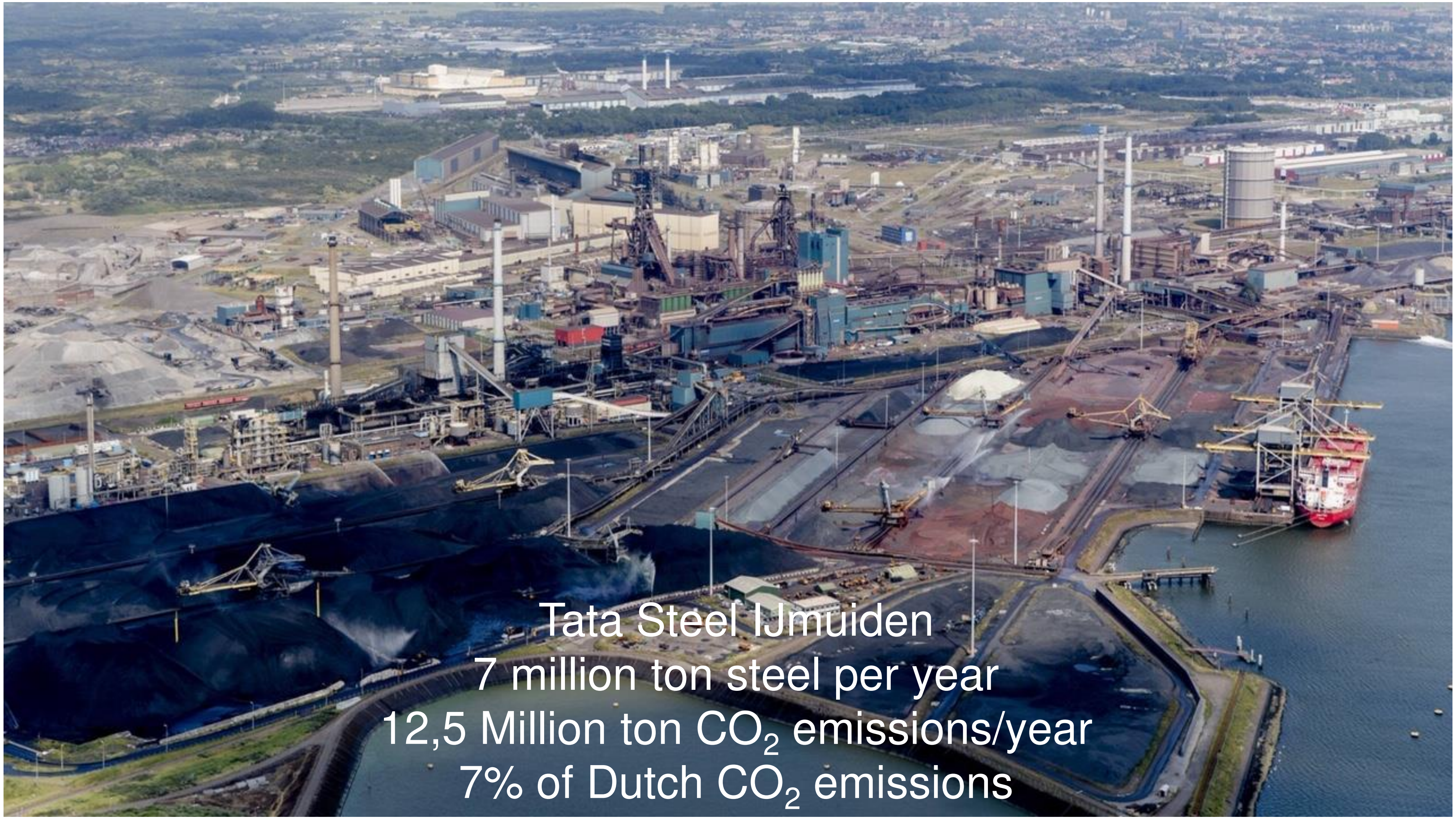


## Transport


## Heating




# The Future for Steel Plant and site IJmuiden

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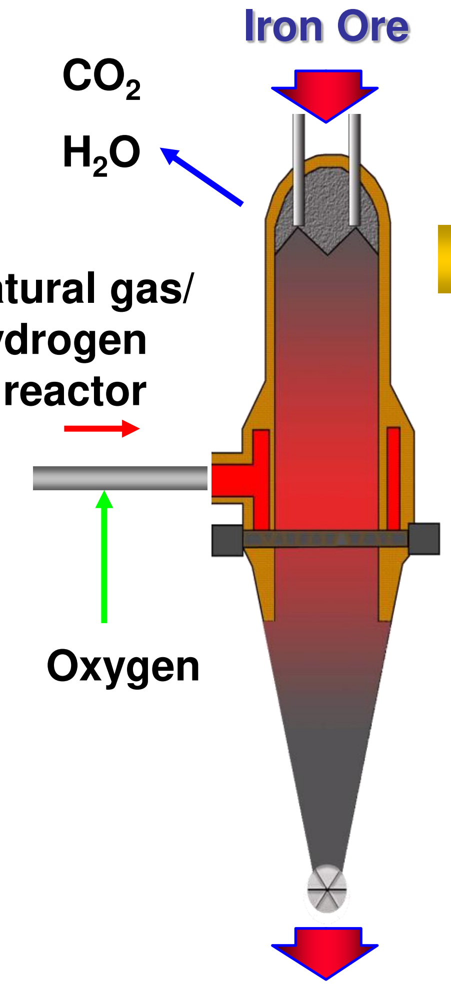
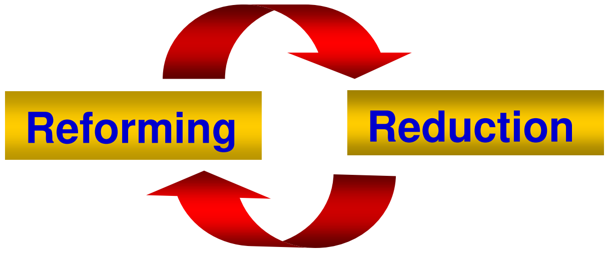
# DRI (Directed Reduced Iron) Proces on Natural Gas


**In-situ Reforming**

$CH_4 + H_2O \rightarrow CO + 3H_2$

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

**Reduction**

$Fe_2O_3 + 3CO \rightarrow 2Fe^\circ + 3CO_2$

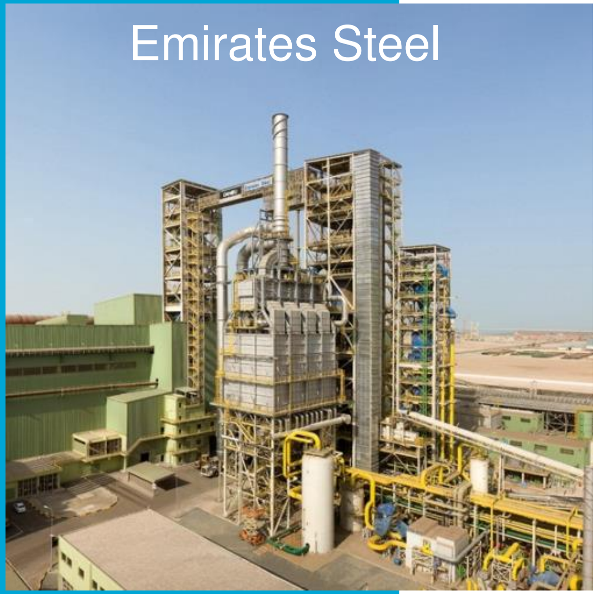
$Fe_2O_3 + 3H_2 \rightarrow 2Fe^\circ + 3H_2O$

**Carburization**

$3Fe^\circ + CH_4 \rightarrow Fe_3C + 2H_2$

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

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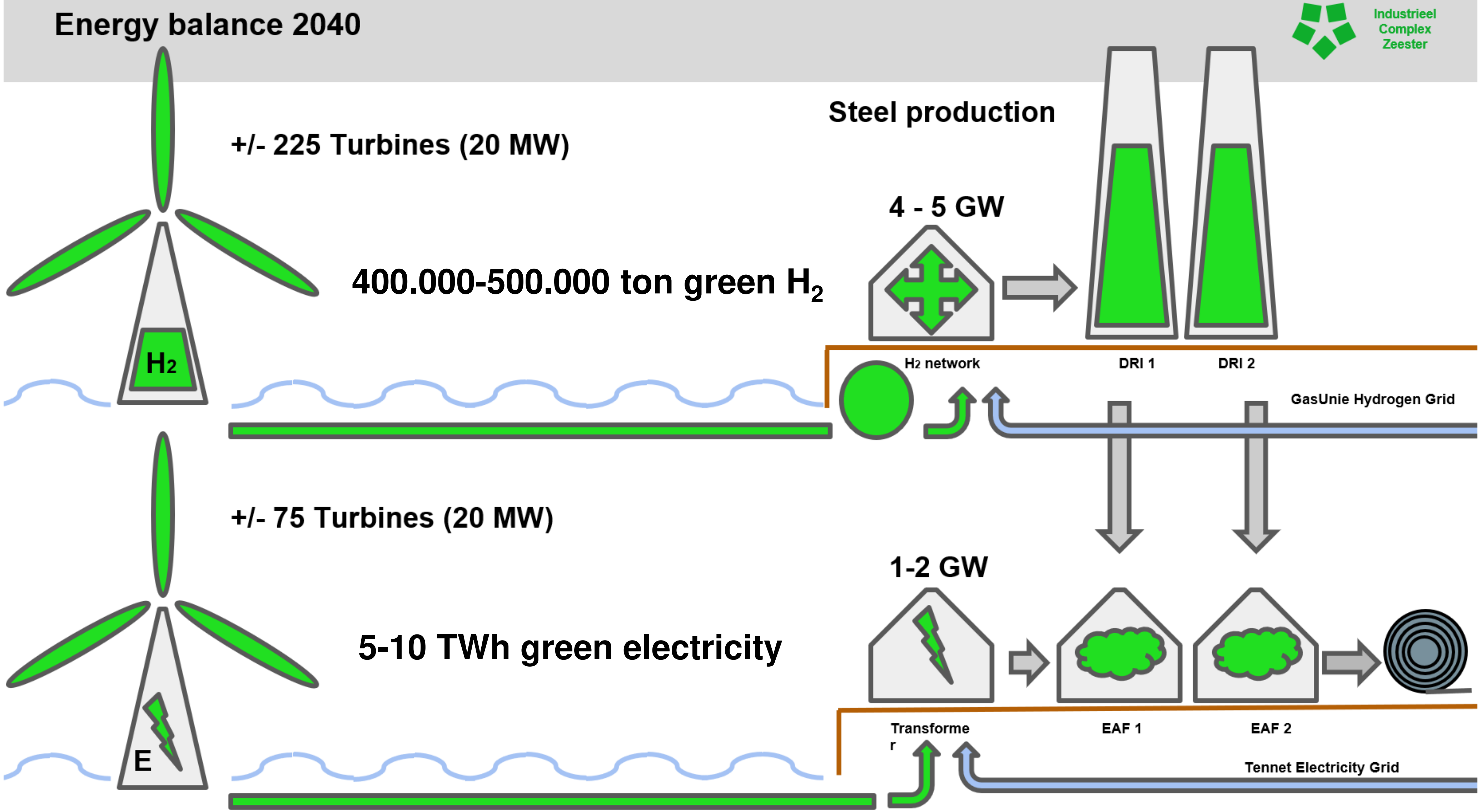
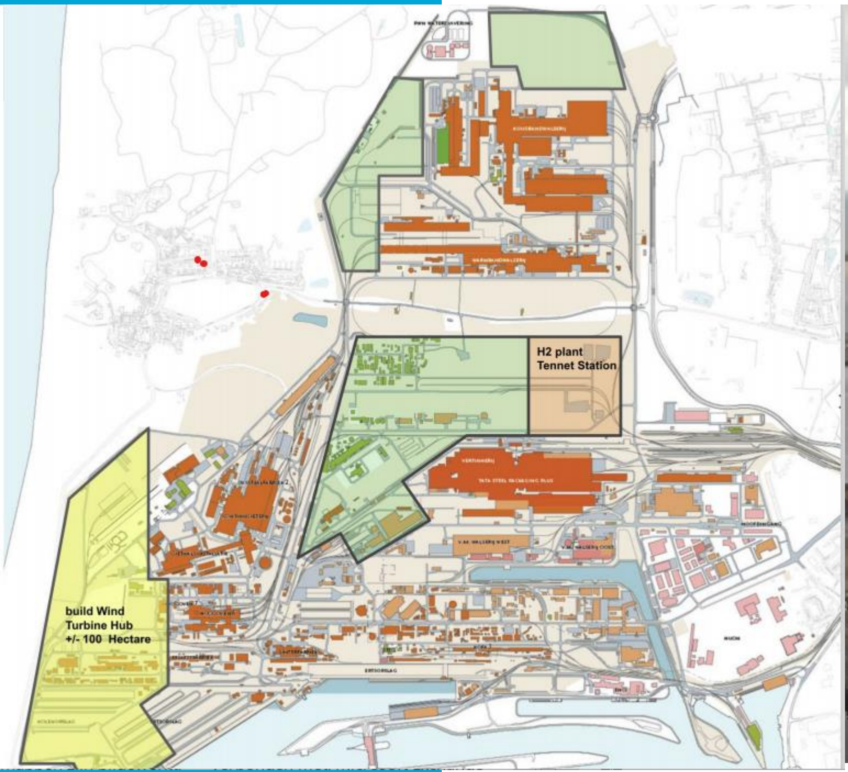
# Tata Steel on green hydrogen and electricity




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

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# De toekomst voor mobiliteit is elektrisch!

**Tesla Model S**

**Toyota Mirai**

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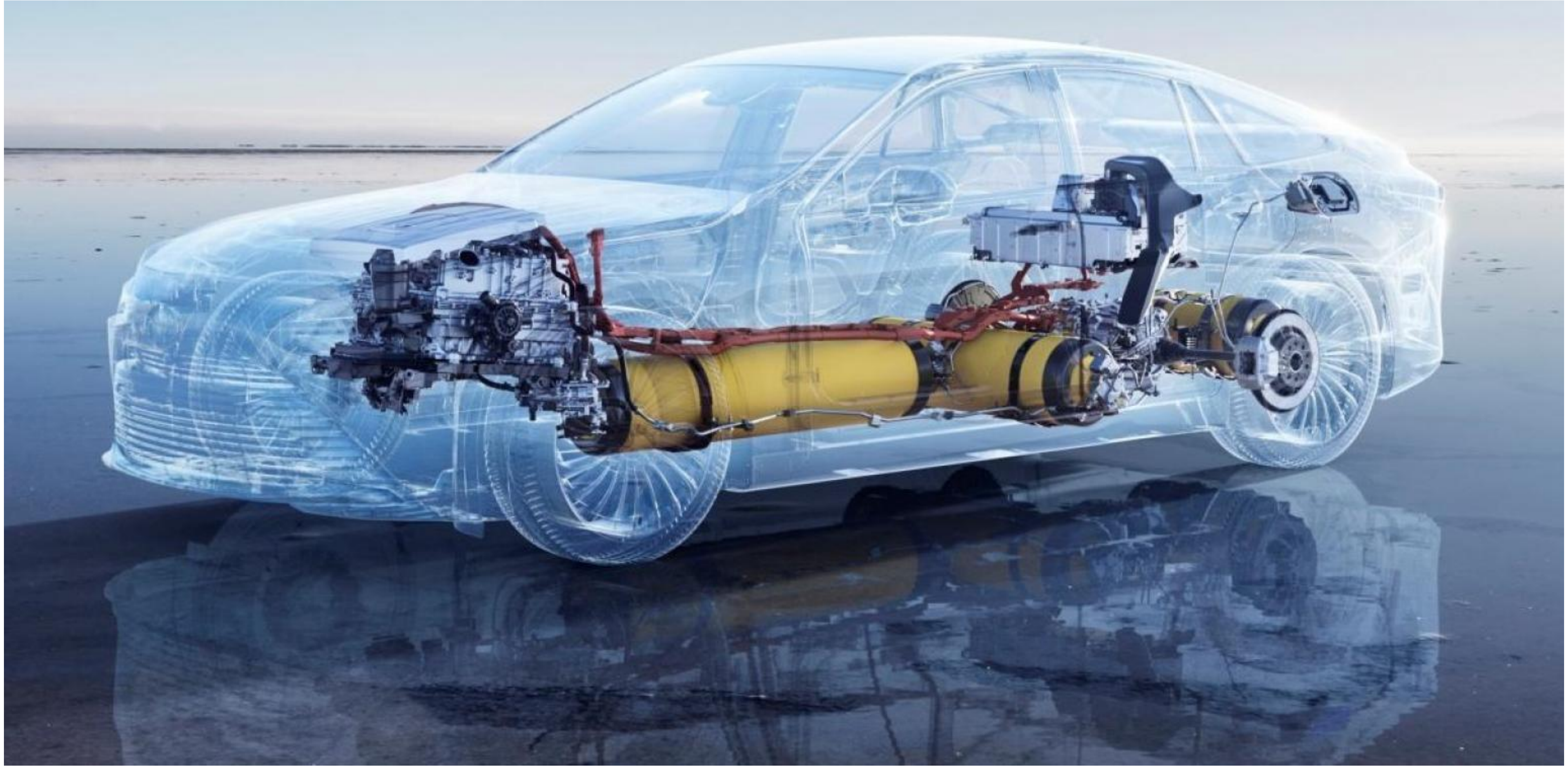
# Toyota Mirai, second version



# Waterstof Brandstofcel Elektrisch Transport


Stellantis/Opel:
Waterstof elektrische Bestelwagen

Doosan:
Waterstof drones

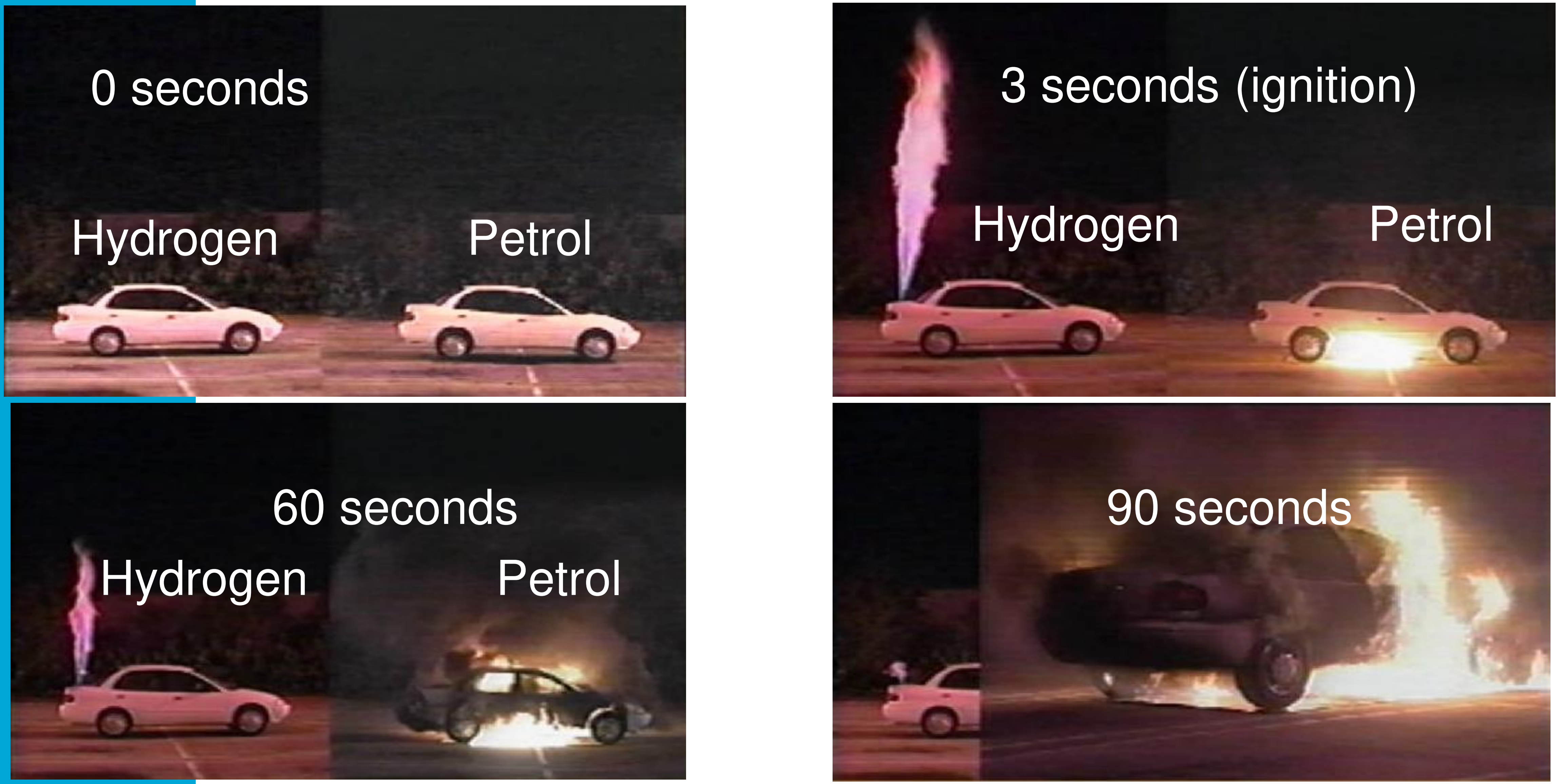
Alstom
Waterstof brandstofcel trein


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)



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# Power to Hydrogen and Heat Nieuwegein


Dual Fuel Tractor, 2021

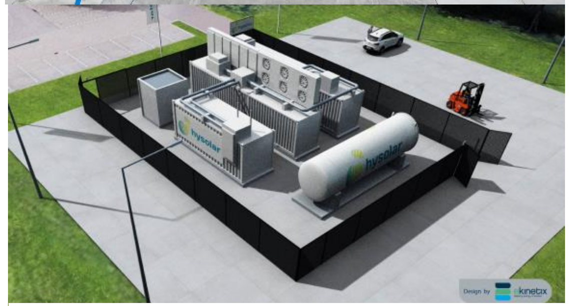

Dual Fuel Holder, 2021


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

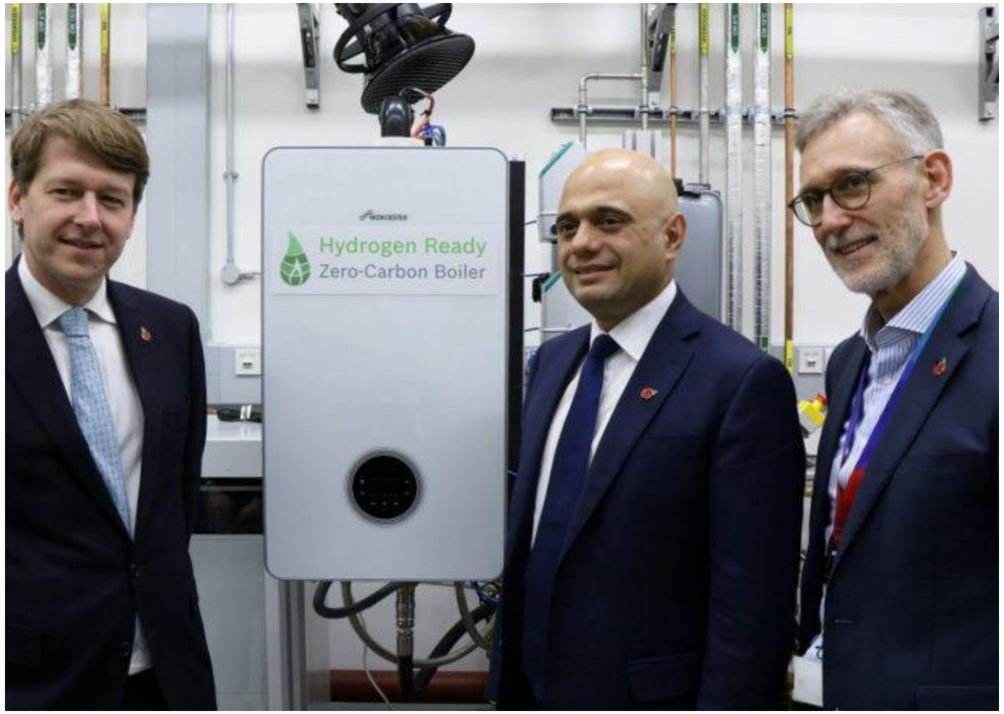

**Remeha HYDRA**

| | 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)

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## 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



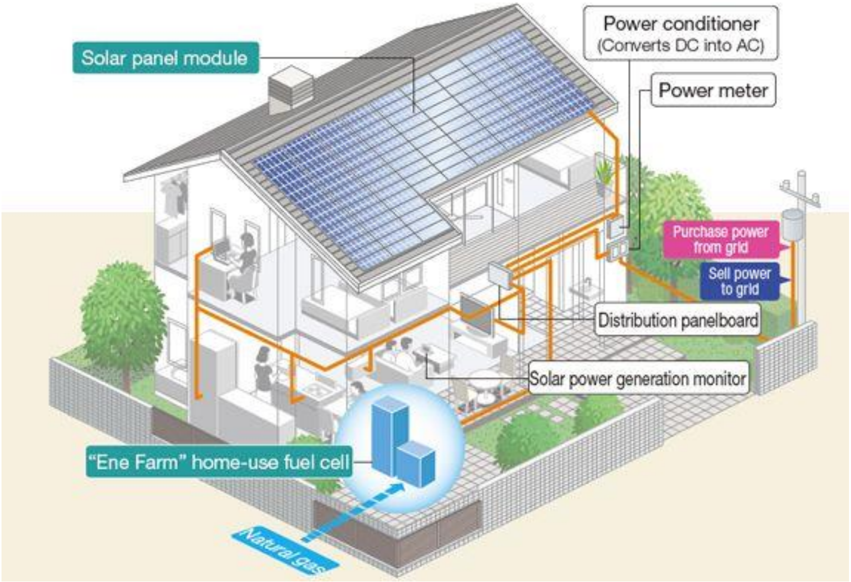
TUDelft

# 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



# Te bestellen op: www.profadvanwijk.com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