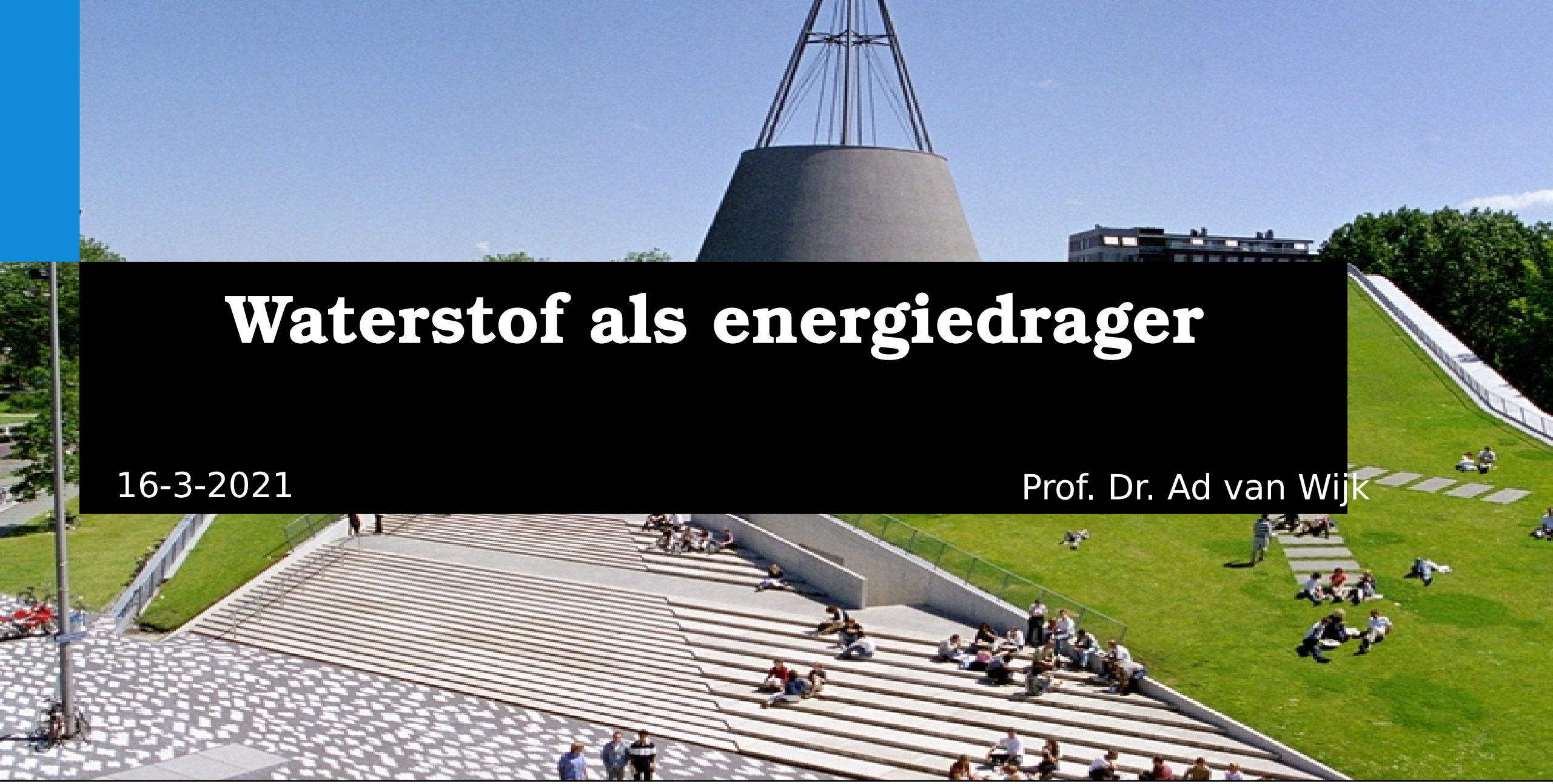
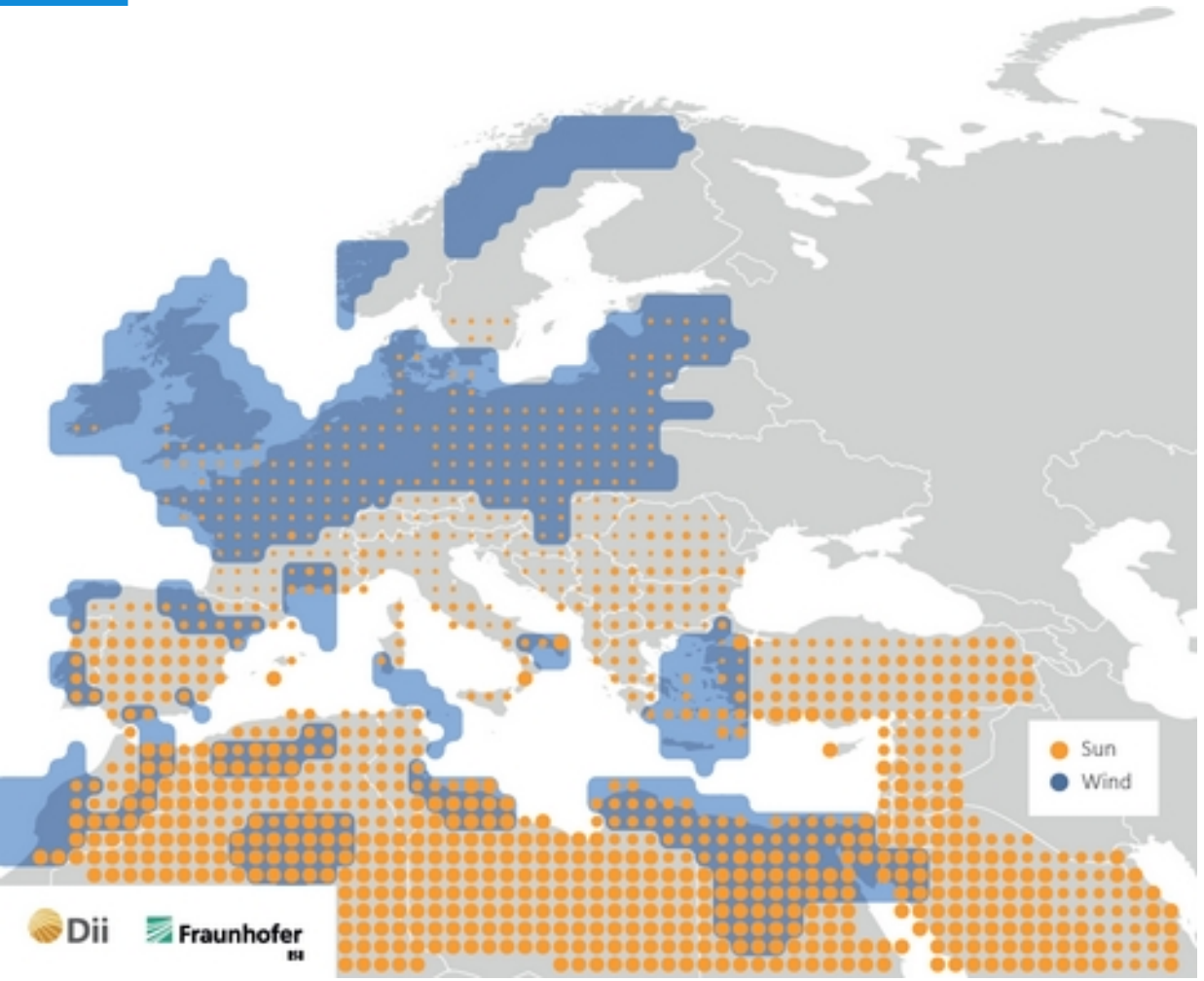


Waterstof als energiedrager

16-3-2021

Prof. Dr. Ad van Wijk

Zonne- en Wind-stroom is goedkoop



Abu Dhabi 2.000 MW Zonne-park

Euro 1.25 ct/kWh Juli 2020

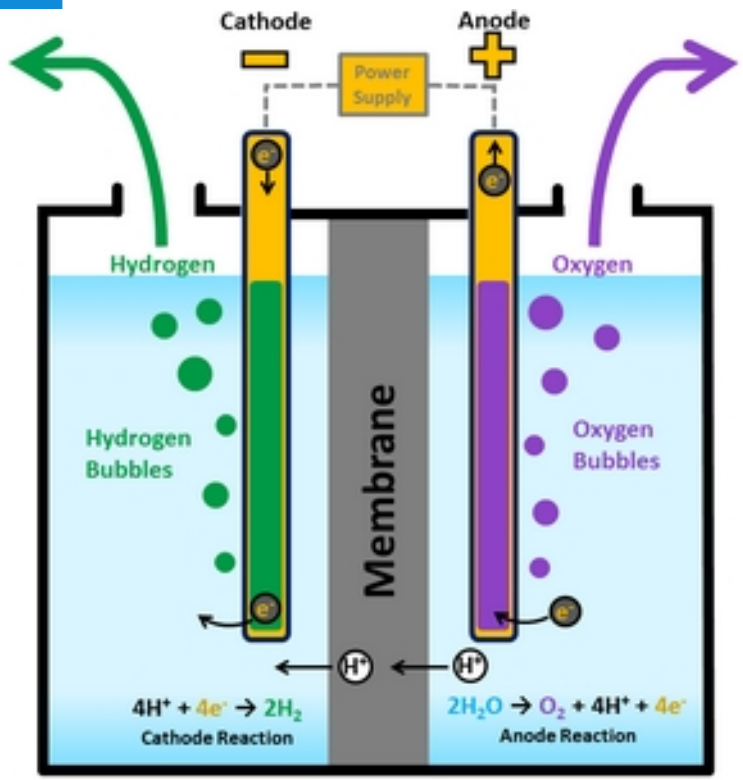
Portugal 700 MW Zonne-park

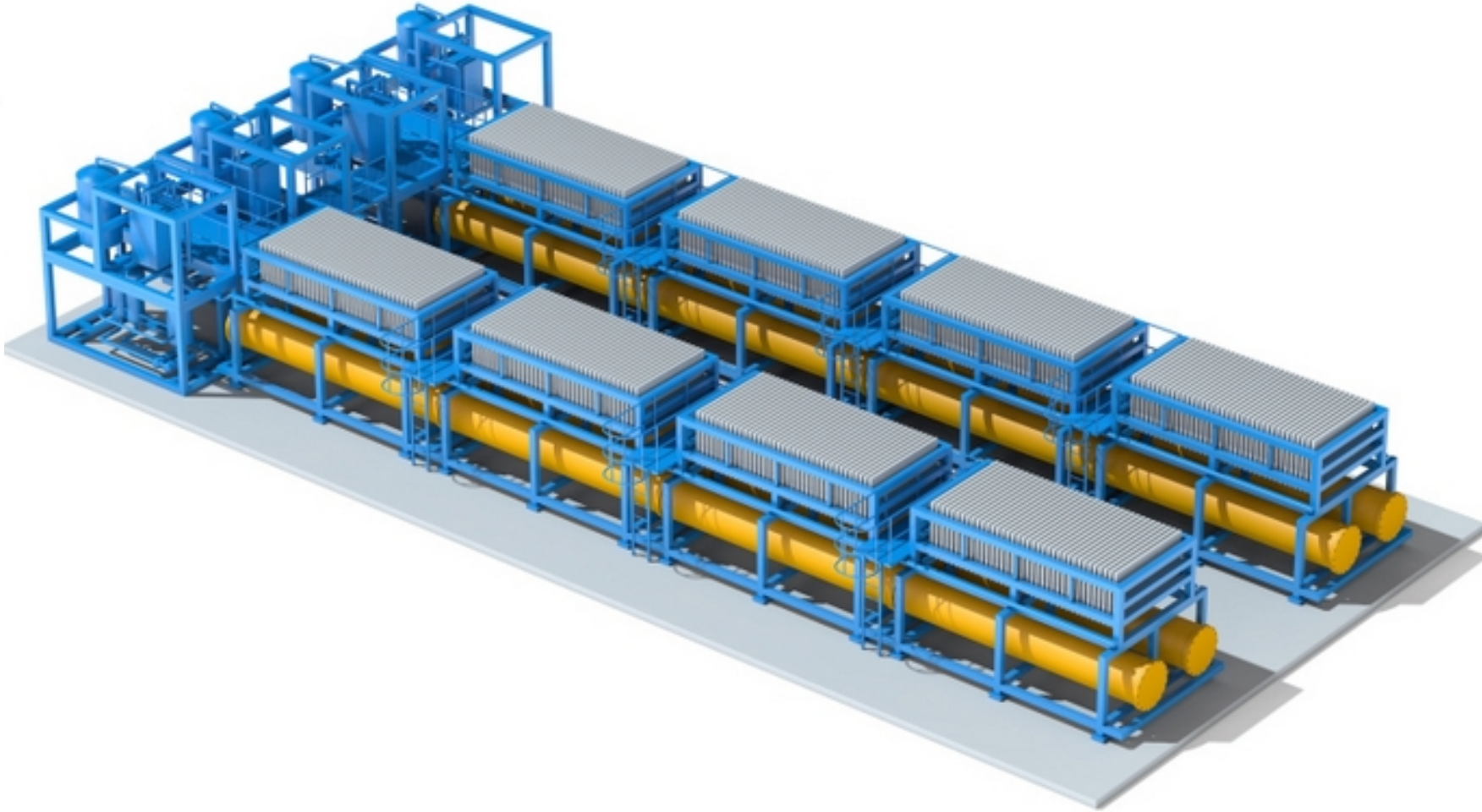
Euro 1.12 ct/kWh Augustus 2020

Spanje 1.000 MW Wind-parken

Range van €2 ct/kWh tot €2,9 ct/kWh
January 2021

Waterstof maak je uit water en elektriciteit, dat proces heet electrolyse





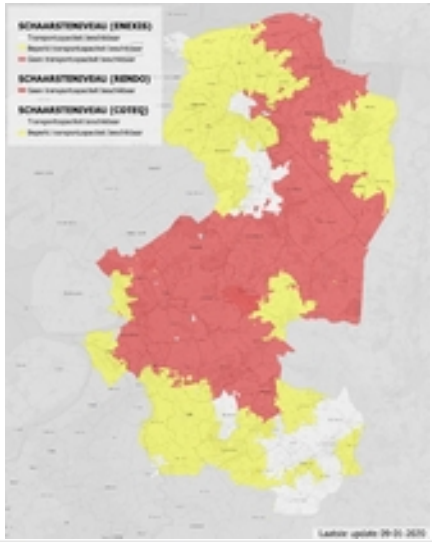
Waterstof is net als electriciteit een energie drager

Source	Process/Technology	Maturity	Output	'Colour' of Hydrogen
Natural gas	Steam methane reforming Auto-thermal reforming Thermal Pyrolysis	Mature Mature First plant 2025	$H_2 + CO_2$ $H_2 + CO_2$ $H_2 + C$	**Grey or blue**, 50-90% of CO_2 can be captured + stored **Turquoise**, CO_2 emissions depend on the source for electricity production
Coal	Gasification Underground coal gasification	Mature Projects exist	$H_2 + CO_2 + C$ $H_2 + CO_2$	**Brown or blue**, 50-90% of CO_2 can be captured + stored
Solid Biomass, Biogenic waste	Gasification Plasma gasification	Near Maturity First Plant 2023	$H_2 + CO_2 + C$ $H_2 + CO_2$	**Green** Negative CO_2 emissions possible
Wet Biomass, Biogenic waste	Super critical water gasification Microbial Electrolysis Cell	First Plant 2023 Laboratory	$H_2 + CH_4 + CO_2$ $H_2 + CH_4$	**Green** Negative CO_2 emissions possible
Electricity + Water	Electrolysis Alkaline PEM SOEC	 Mature Near Maturity Pilot Plants	 $H_2 + O_2$ $H_2 + O_2$ $H_2 + O_2$	**Shades of grey to green and pink** depend on the source for electricity production
Sunlight+Water	Photoelectrochemical	Laboratory	$H_2 + O_2$	**Green**

Elektriciteits net is/wordt het knelpunt!

Voor het aansluiten van zon en windvermogen op het electriciteitsnet

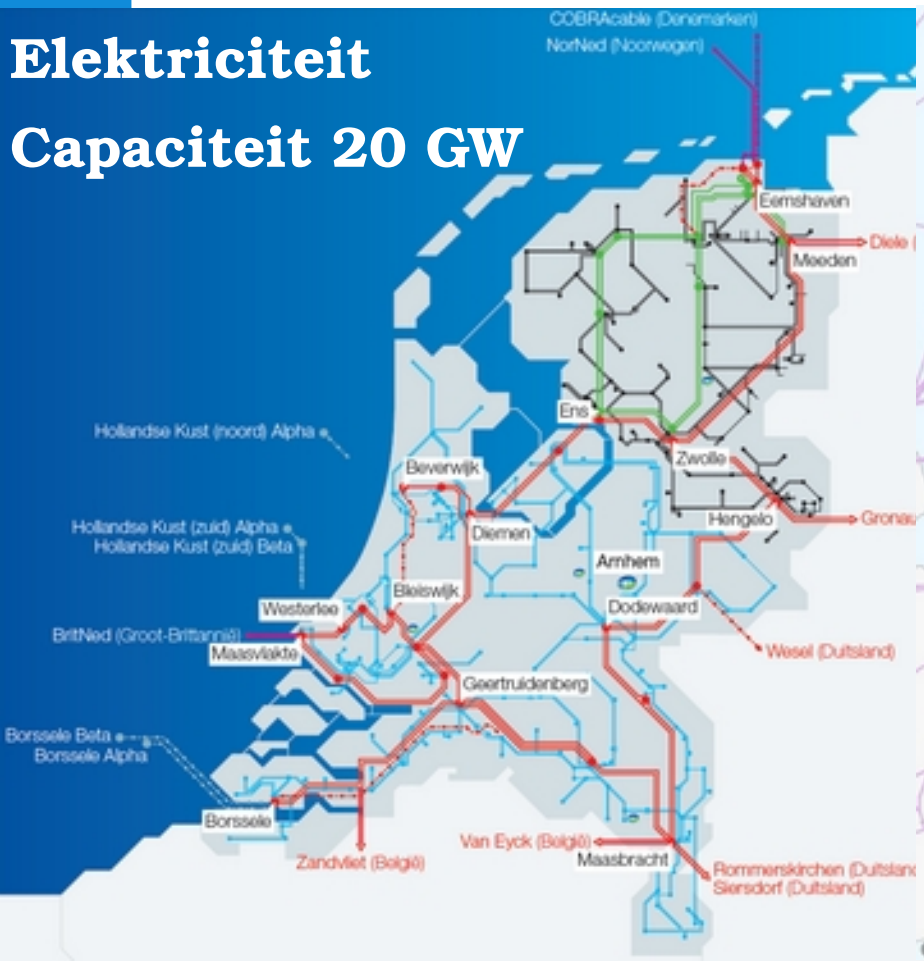
Gas transportnet 15 keer zo groot als elektriciteitstransport net

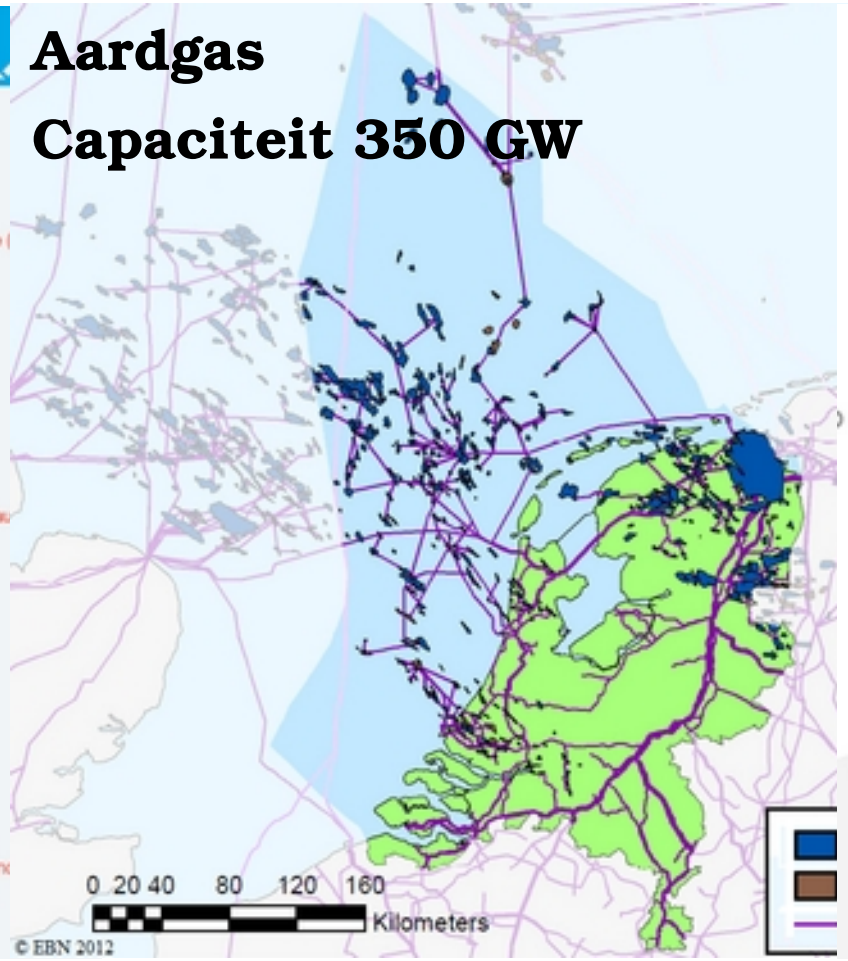


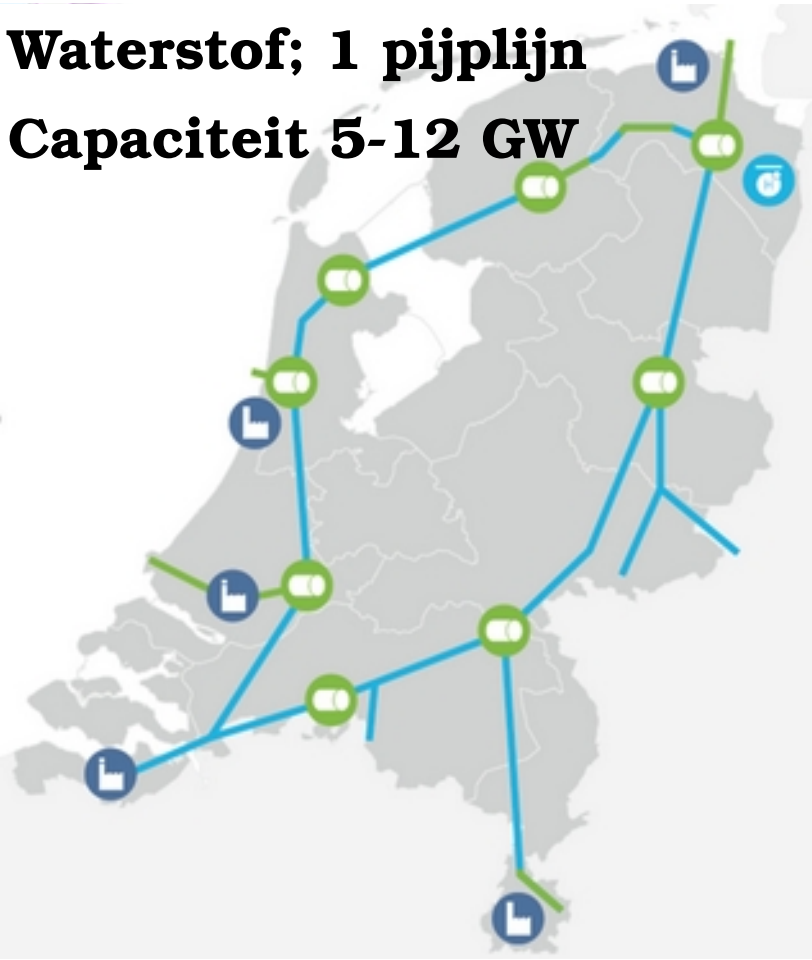
Voor het aansluiten van warmtepompen, Zon op dak en elektrische auto's op elektriciteitsnet

Gasaansluiting huis 10 keer zo groot (30 kW) als elektriciteitsaansluiting (3 kW)

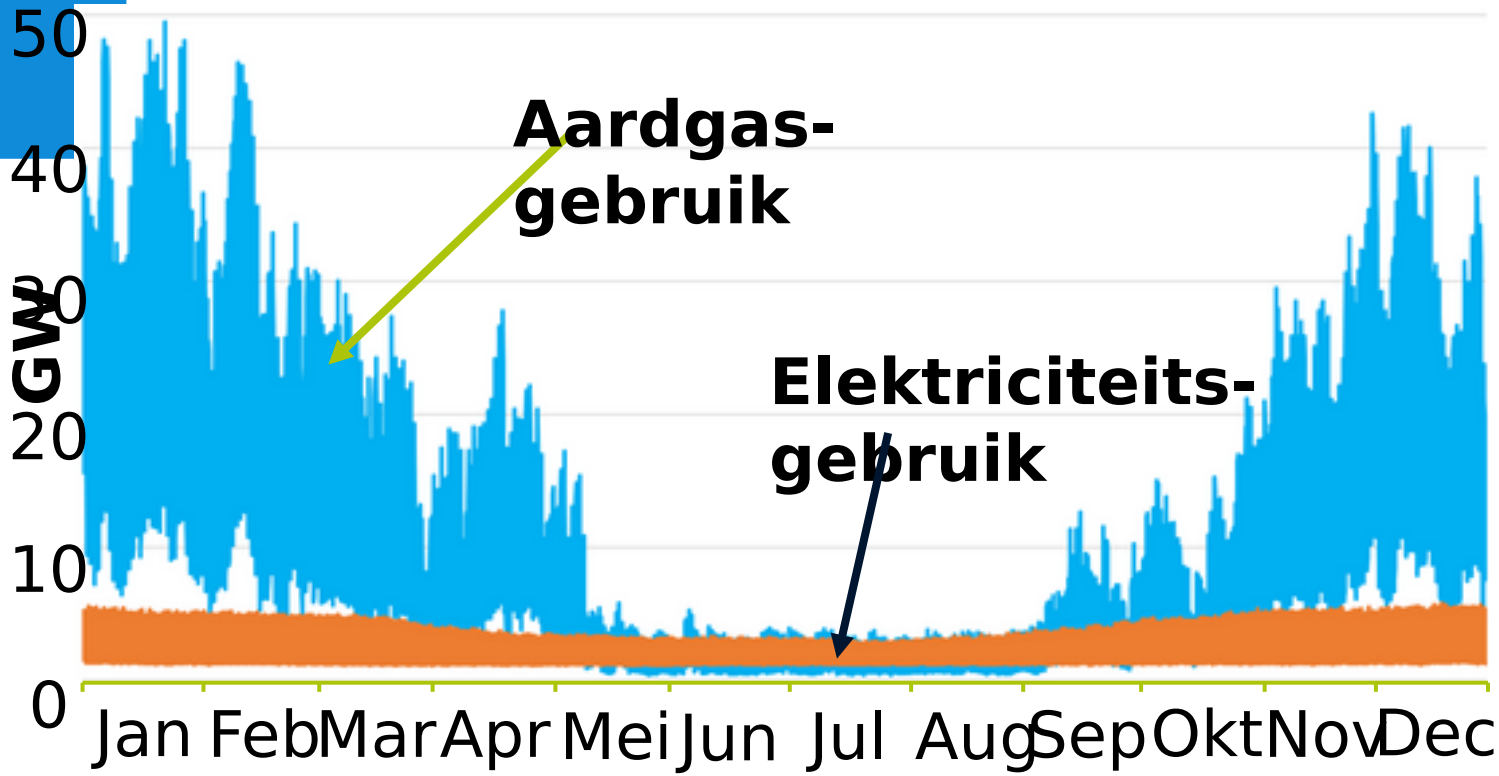
Elektriciteit transport tot 10 X duurder dan Gastransport





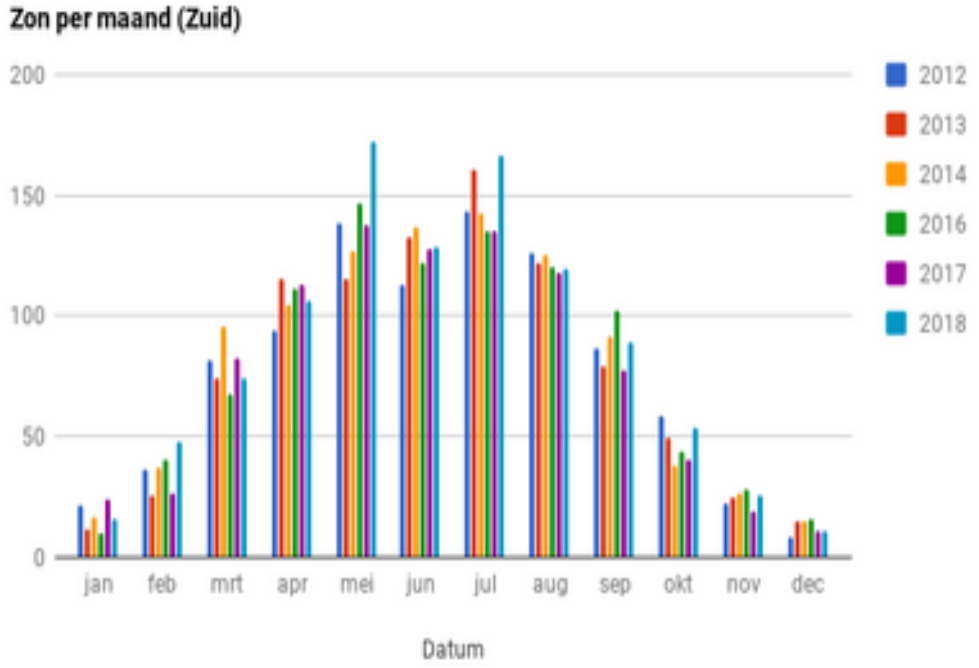


Veel meer opslag is nodig om vraag en aanbod van energie op elkaar af te stemmen



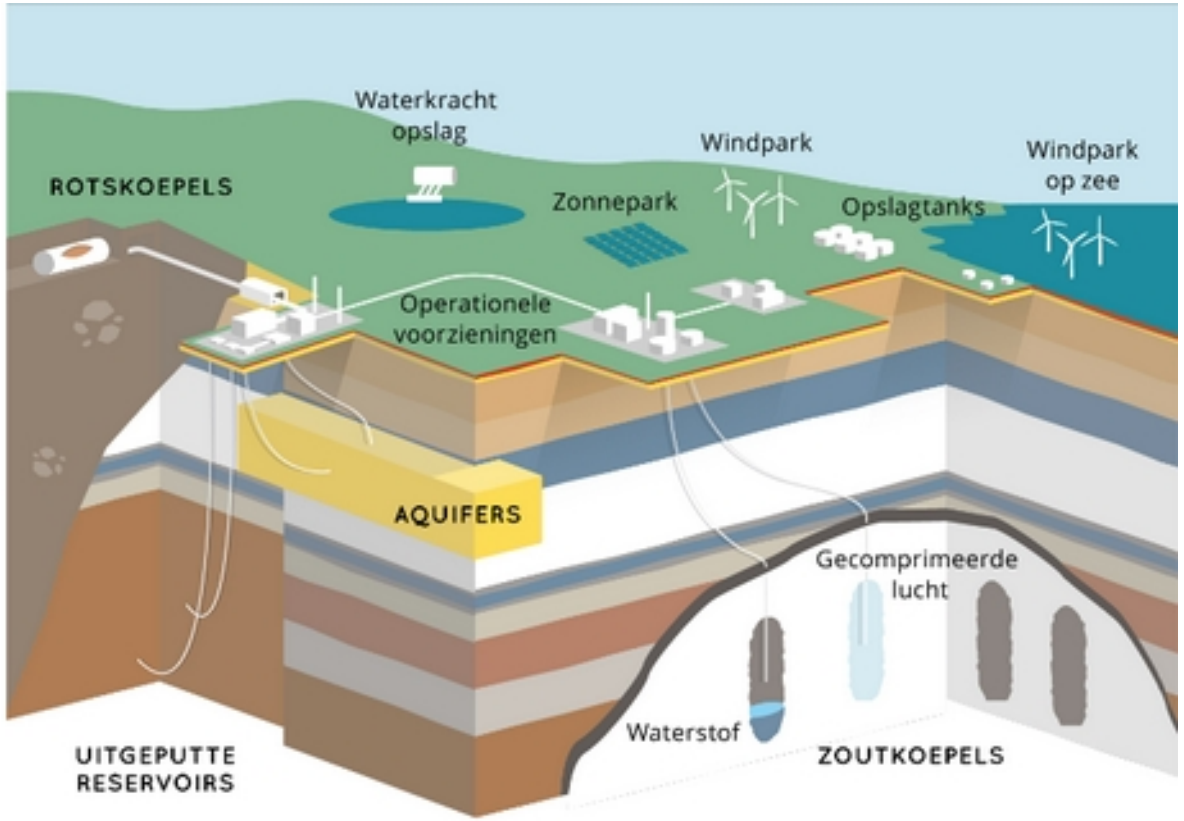
Bron: Kellner, 2018

7,8 miljoen woningen (2017)



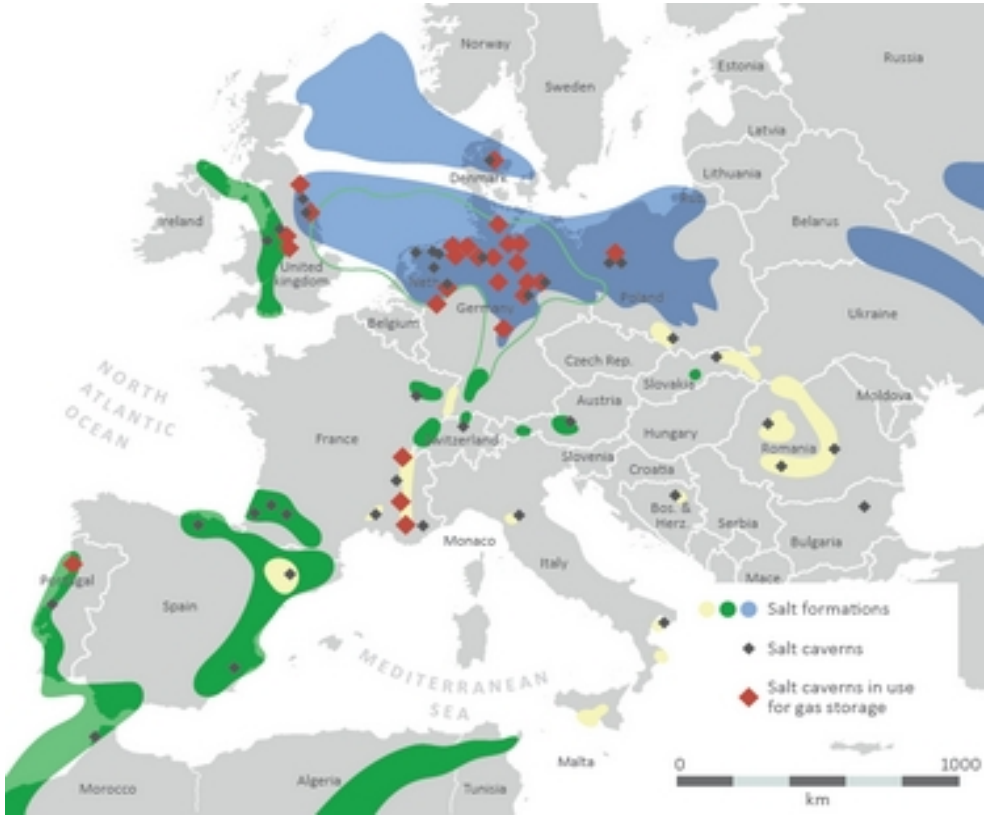
https://thuiszonnepanelen.nl/opbrengst-van-onze-zonnepanelen/

Waterstof opslag in zoutkoepels ruim 200 keer goedkoper dan elektriciteit opslag in batterijen



1 zoutkoepel kan 6,000 ton=236 miljoen kWh waterstof bevatten
Investeringen 100 miljoen Euro

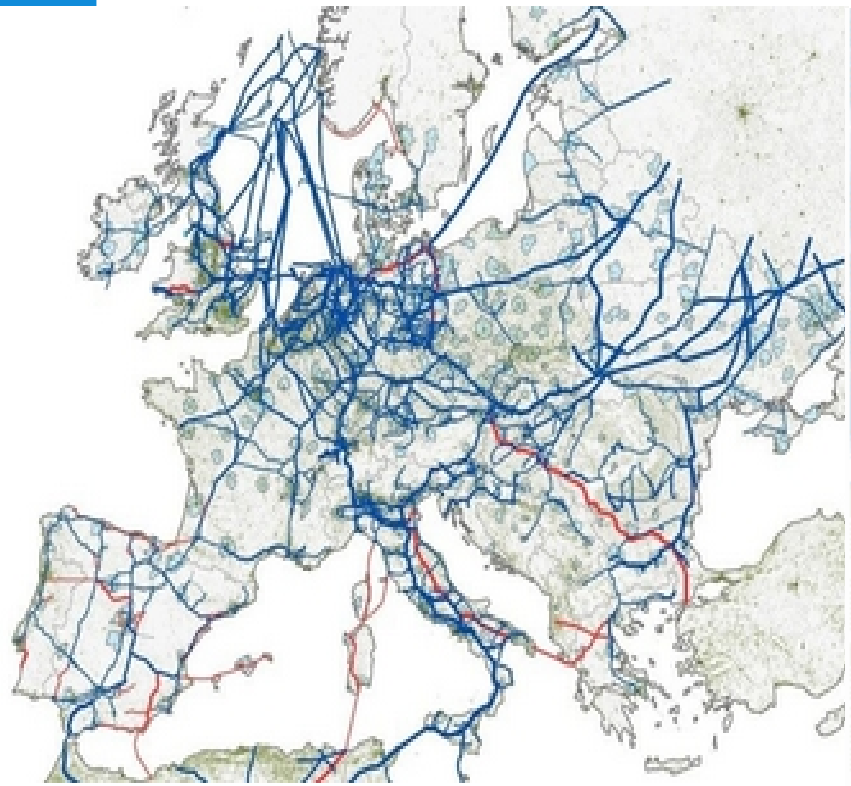
Dat zijn 24 miljoen batterijen van 10 kWh
Investeringen (100 Euro/kWh) 23,6 miljard Euro



Rood zijn zoutkoepels in gebruik voor gasopslag
Zoutkoepels ook al decennia in gebruik voor waterstofopslag

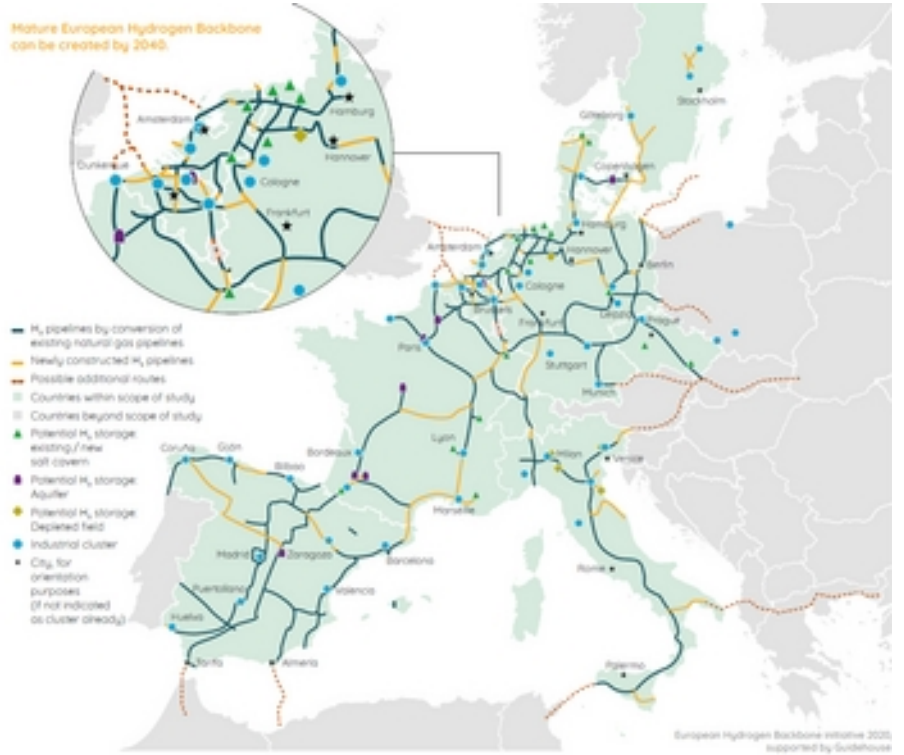
Gas Infrastructure in Europe and from North-Africa

Gas pipeline capacity 10-20 GW, Electricity cable 1-2 GW



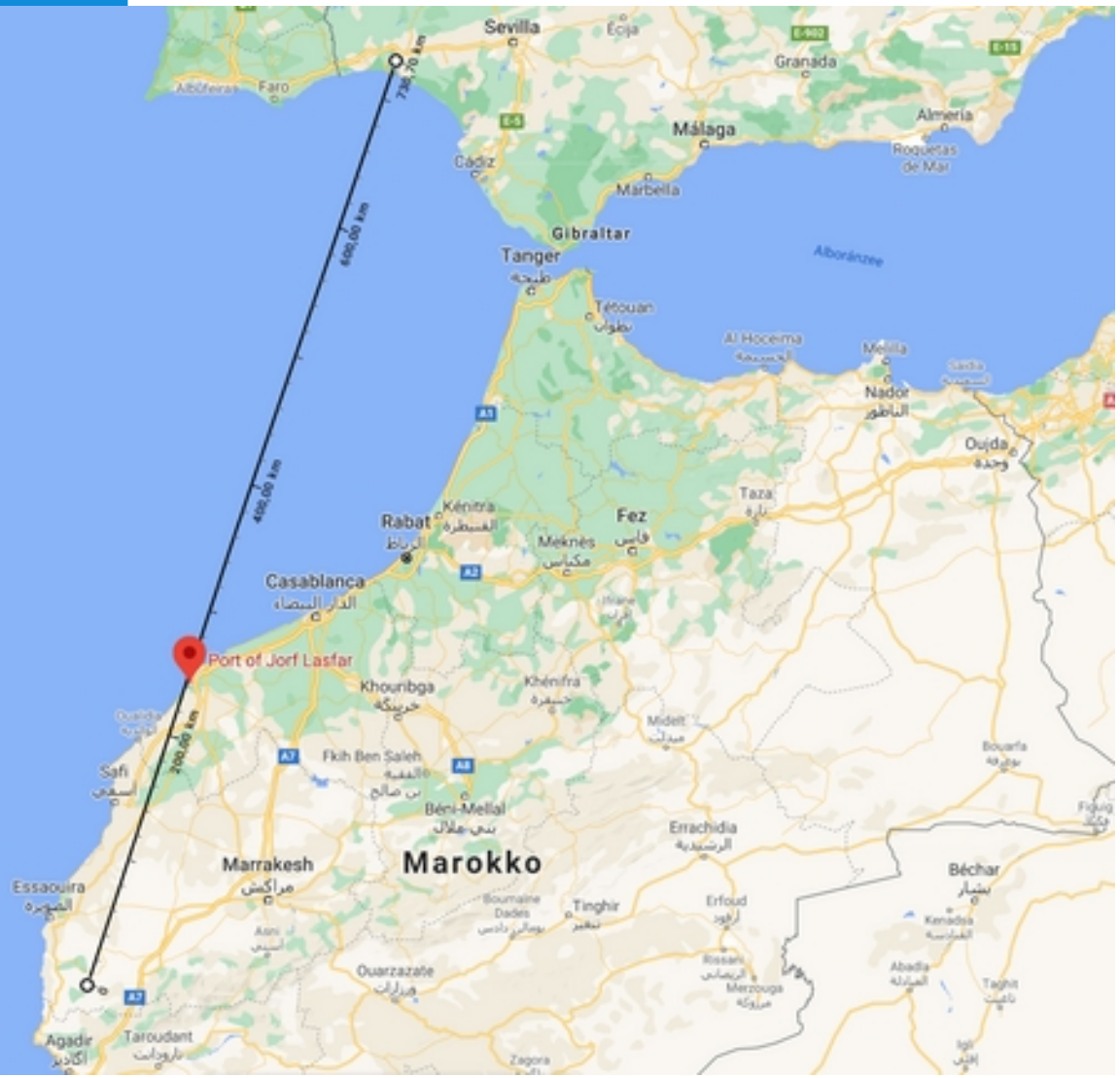
Gas Pipeline Infrastructure Europe
Transporting gas from gas fields at North Sea, Norway, Russia, Algeria, Libya to European demand

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



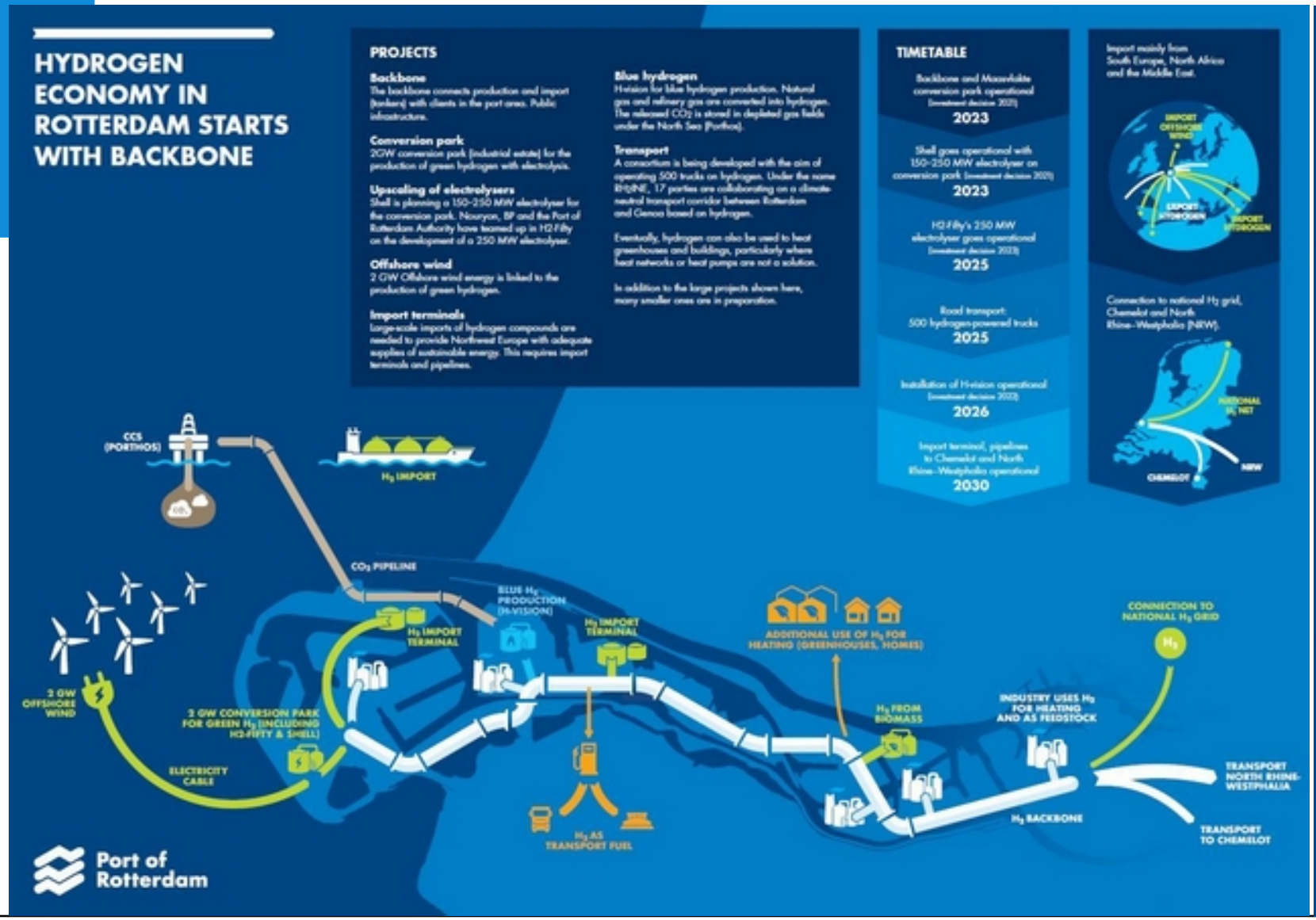
European Hydrogen Backbone
75% re-used gas pipelines
25% new hydrogen pipelines

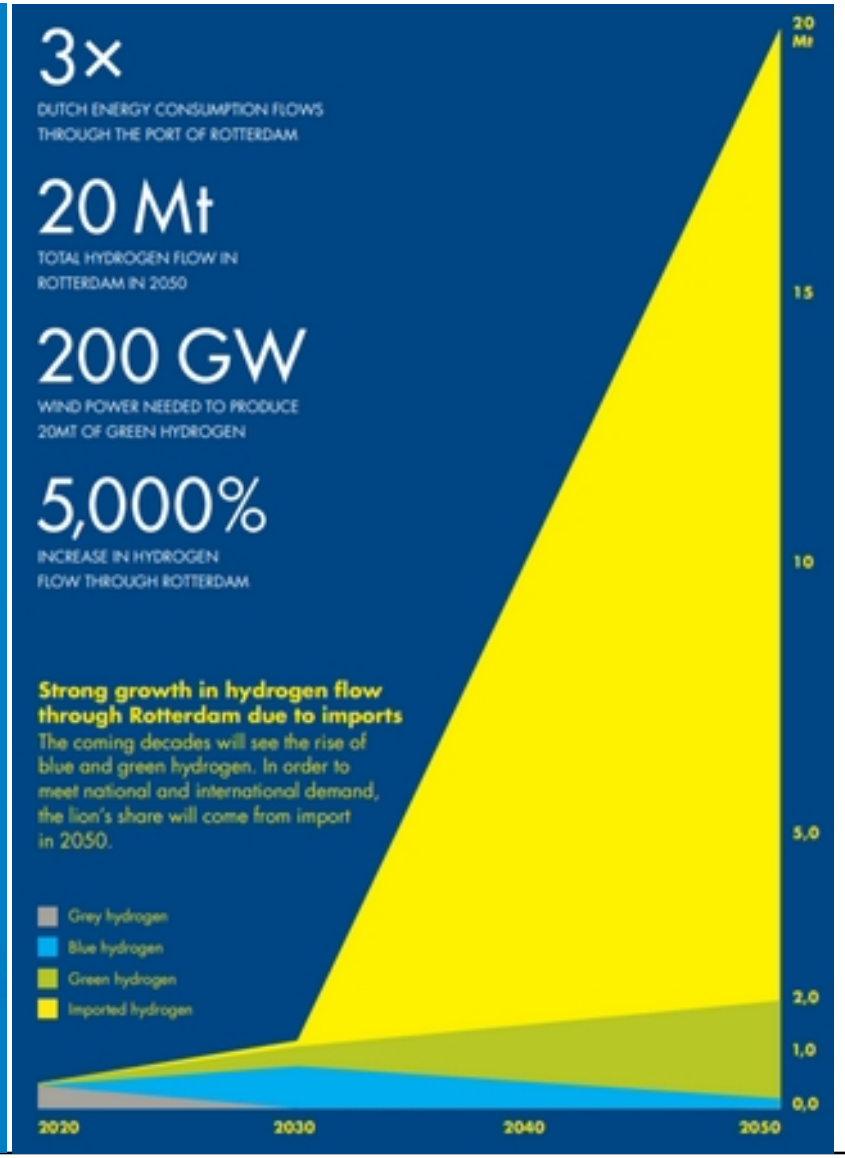
Base load solar hydrogen Morocco to Germany



Base load solar H_2 from Morocco to Germany		LCoH €/kg H_2
	Assumptions	
Solar-Hydrogen production	Solar electricity cost = 0.01 €/kWh Full load hours = 2,000 hours/yr Electrolyser efficiency = 50 kWh/kg H_2 100 GW solar = 4 million ton H_2 Required surface = 1,800 km^2	1.0
Salt cavern storage	Flexible production to base load; daily cycles	0.1-0.2
Pipeline Transport	Pipeline capacity = 20 GW Full load hours = 8,000 hours/yr Pipeline length = 3,000 km	0.3
TOTAL		**1.5 €/kg H_2** =0.04 €/kWh$H_{2(HHV)}$

Port of Rotterdam Hydrogen Strategy

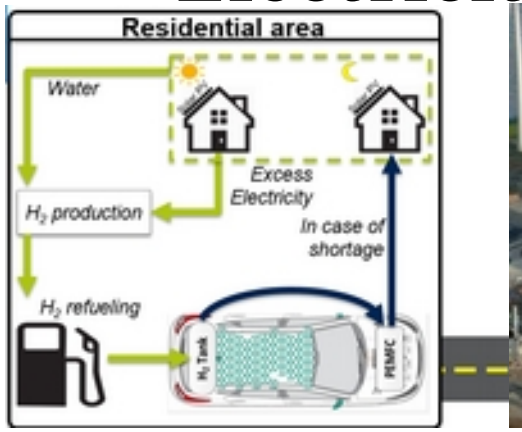




Waterstof markten

Industrie; grondstof, HTwarmte

Electriciteit Balancering



Transport

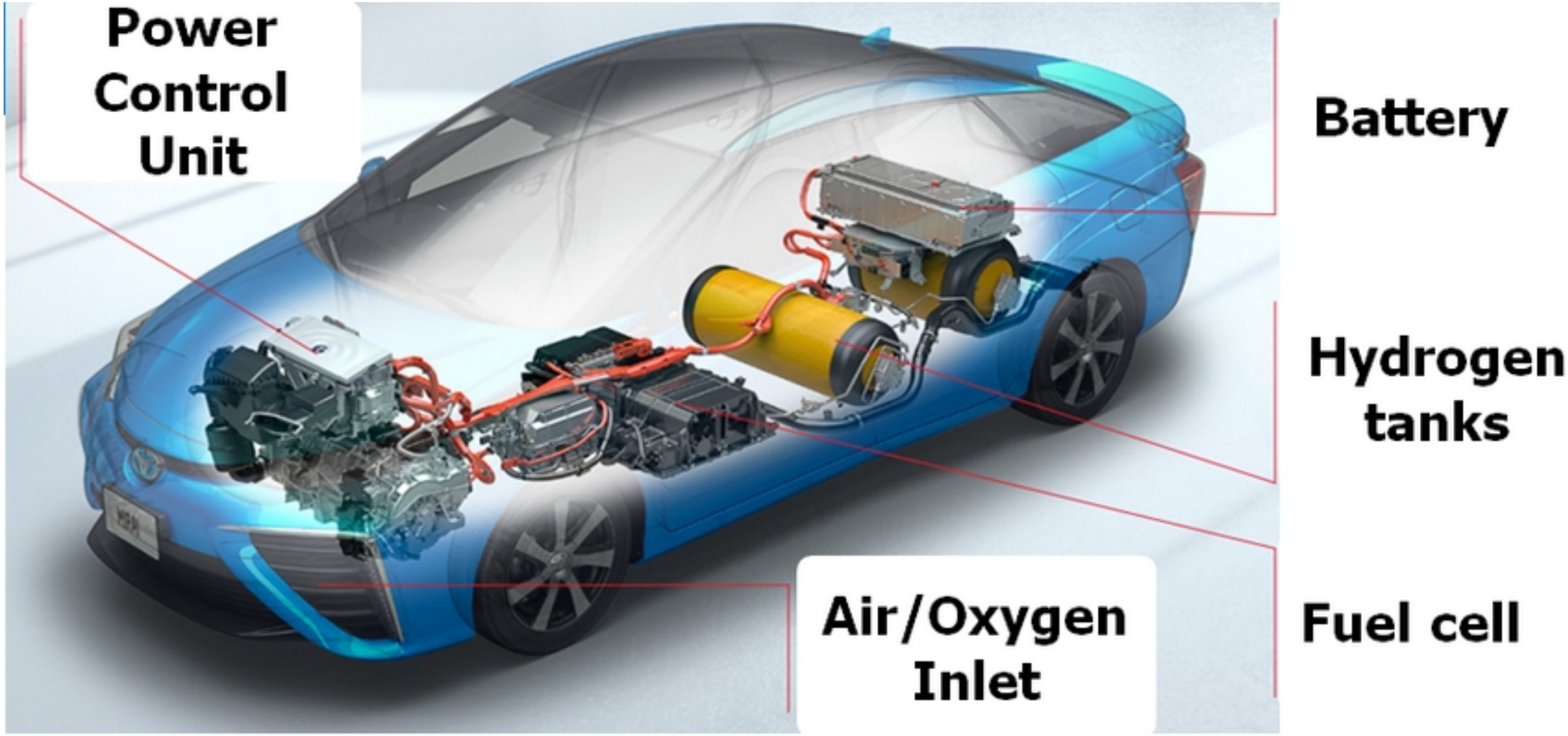
Verwarming

De toekomst is elektrisch!

Tesla Model S

Toyota Mirai

Toyota Mirai; Brandstofcel auto



Meer en meer waterstof in mobiliteit

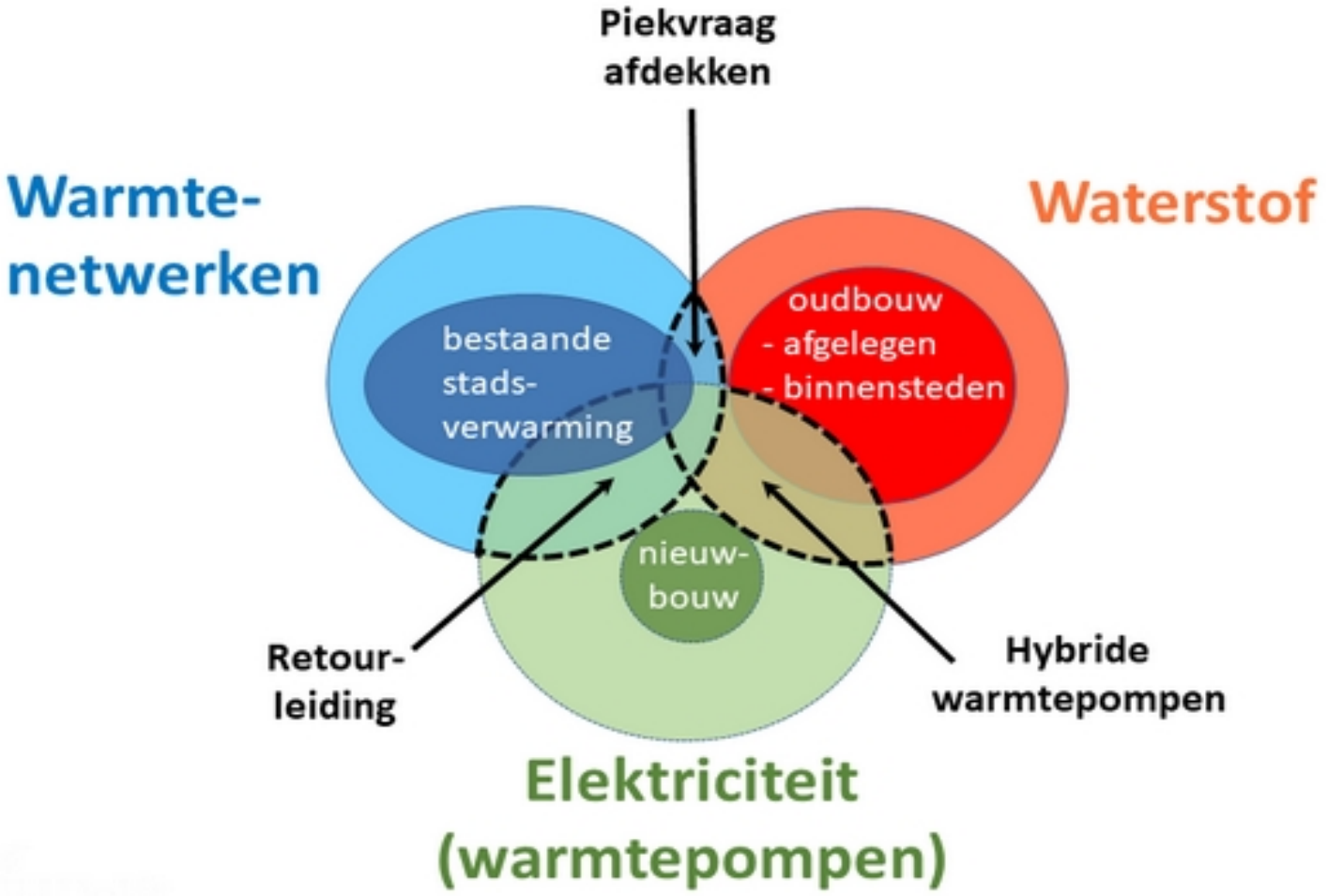
New-Holland: Tractor, diesel+H_2 (2-10-2020)

Airbus: Vliegtuig, LH_2+Gasturbine (21-9-2020)

Still: Waterstof vorkheftruck

Hyzon-Holthausen Waterstof trucks (Juli 2020)

Duurzame verwarmingsopties



Verwarmen met waterstofketels

Remeha

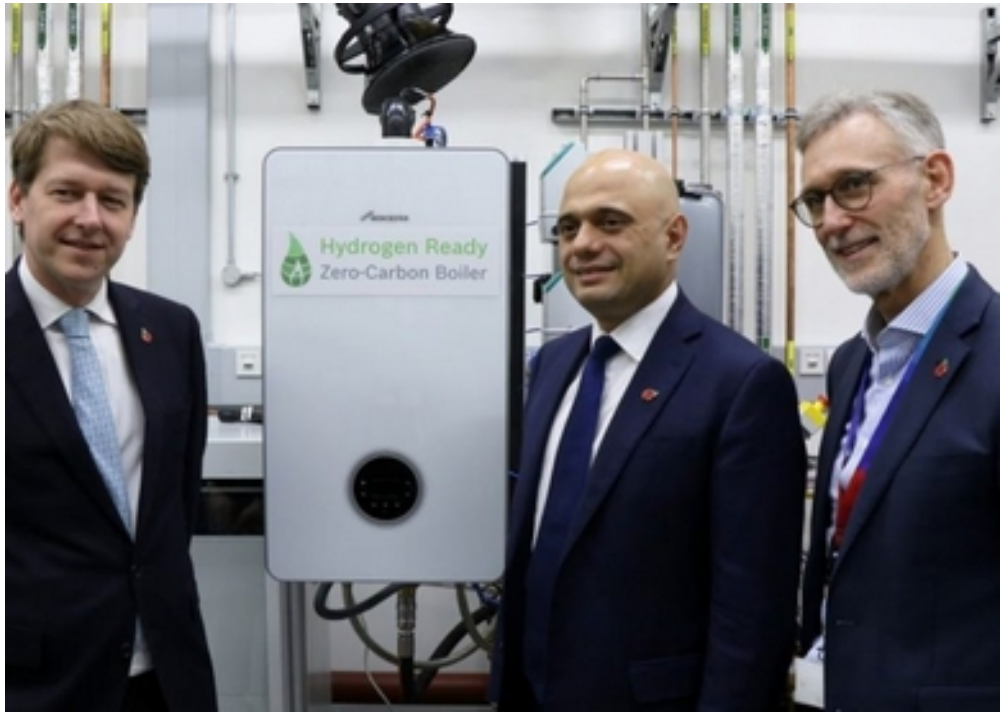
Remeha HYDRA

	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

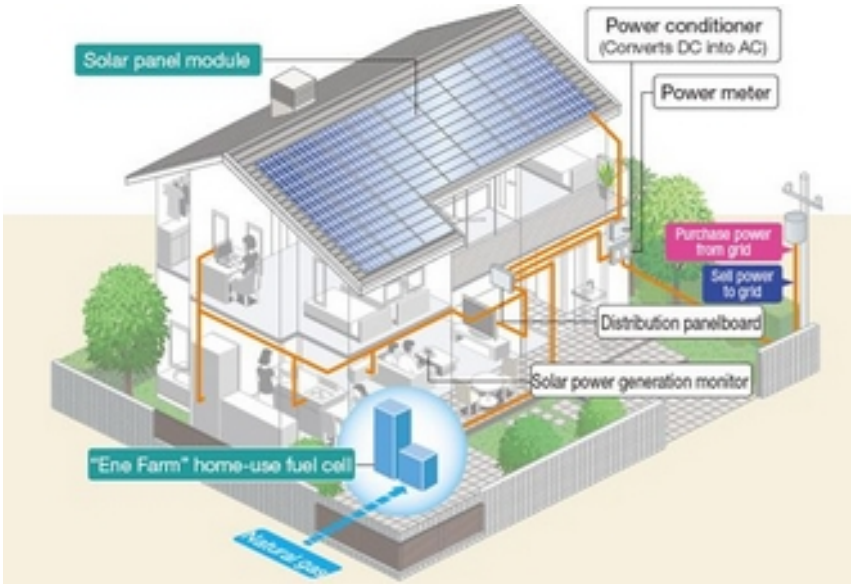
- Waterstofketel voor pieklast in winter

Panasonic: Huis Brandstofcel systemen Japan

- 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

Warm water vat Brandstofcel



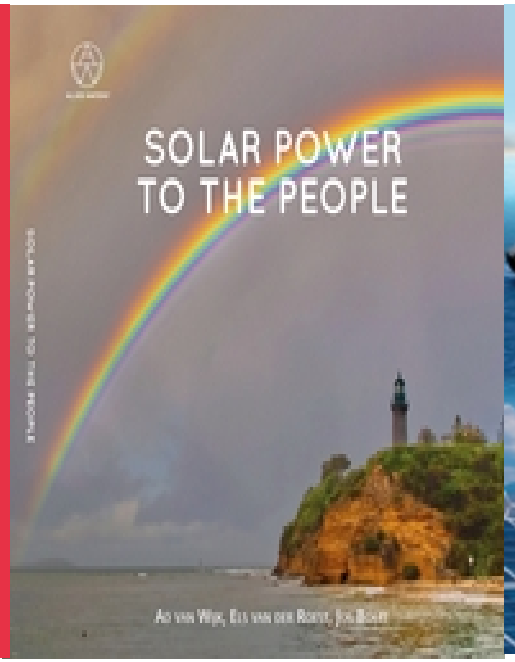
CO_2 emissies voor verwarmen en rijden

CO_2 emissie	Bron g/kWh	Verwarmen g/kWh thermisch	Rijden g/km
CO_2 emissies in 2020			
Gas***	204	210 (ketel 97% efficiency)	154**** CNG verbrandingsmotor
Mix elektriciteit (2020)**	475	140 (Warmtepomp COP=3,4)	95 BEV: 5 km/kWh
CO_2 emissies in 2030			
Blauwe waterstof (90% afvang)	28	29 (ketel 97% efficiency)	11 FCEV: 100 km/kg H_2
Mix elektriciteit (2030)*****	150	44 (Warmtepomp COP=3,4)	30 BEV: 5 km/kWh

*https://www.certifhy.eu/images/media/files/CertifHy_2_deliverables/CertifHy_H2-criteria-definition_V1-1_2019-03-13_clean_endorsed.pdf 10,9 kg CO_2/kg H_2
**https://www.co2emissiefactoren.nl/wp-content/uploads/2020/05/CO2-emissiefactoren-stroom-Milieu-Centraal-25-februari-2020.pdf
***https://www.rvo.nl/sites/default/files/2020/03/Nederlandse-energiedragerlijst-versie-januari-2020.pdf
****https://www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf
*****https://www.pbl.nl/sites/default/files/downloads/pbl-2020-klimaat-en-energieverkenning2020-3995.pdf 18,8 Mton CO_2, 125 TWh Klimaatakkoord

Meer lezen over waterstof www.profadvanwijk.com

April 2017



November 2017

May 2018

September 2019

April 2020