

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, a large, cylindrical concrete water tower with a metal lattice structure on top is visible against a clear blue sky. To the right, there are green trees and a modern building with a glass facade. The overall scene is bright and sunny.

Waterstof als energiedrager

16-3-2021

Prof. Dr. Ad van Wijk

Zonne- en Wind-stroom is goedkoop

Abu Dhabi 2.000 MW Zonne-park

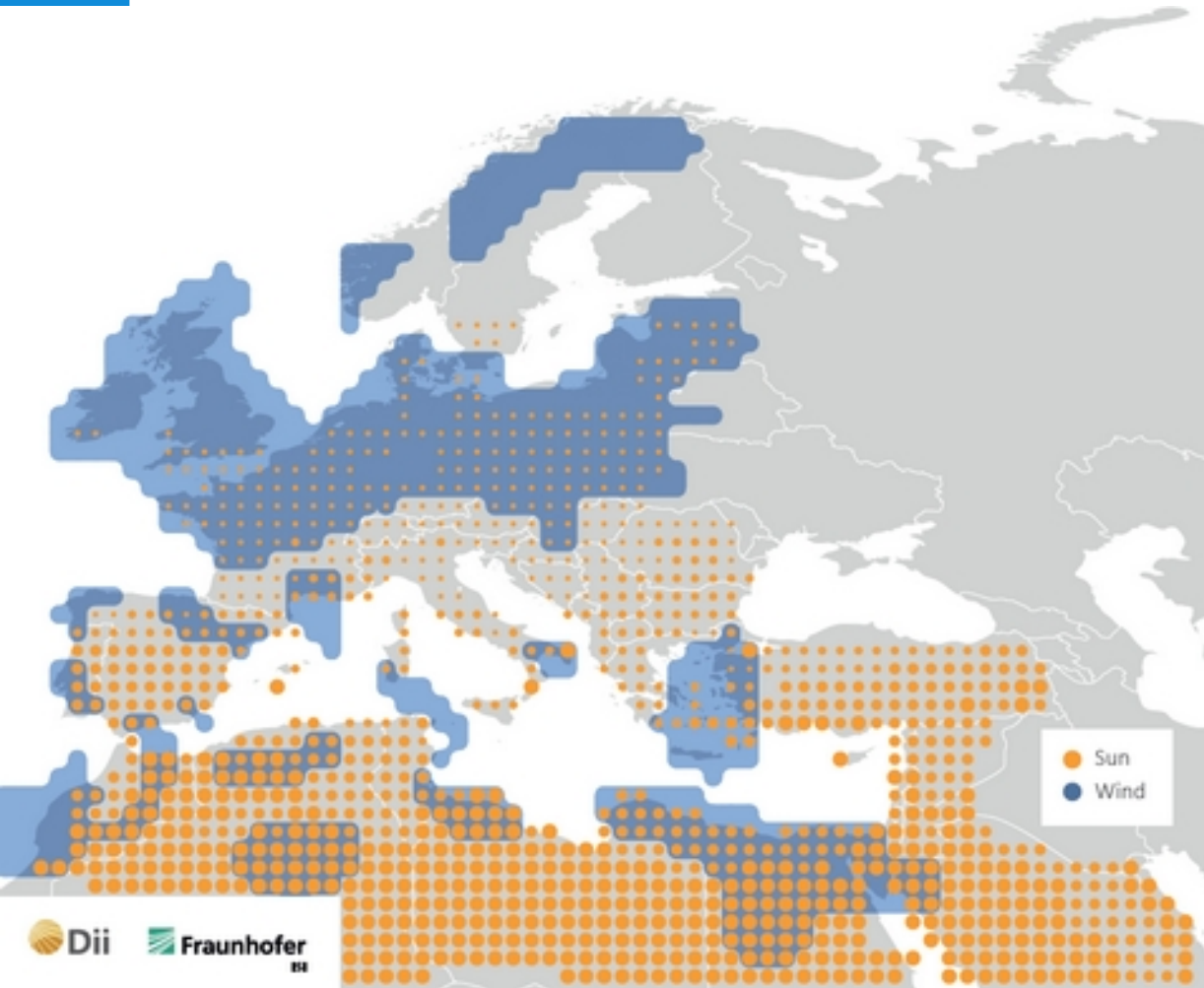
Euro 1.25 ct/kWh Juli 2020

Portugal 700 MW Zonne-park

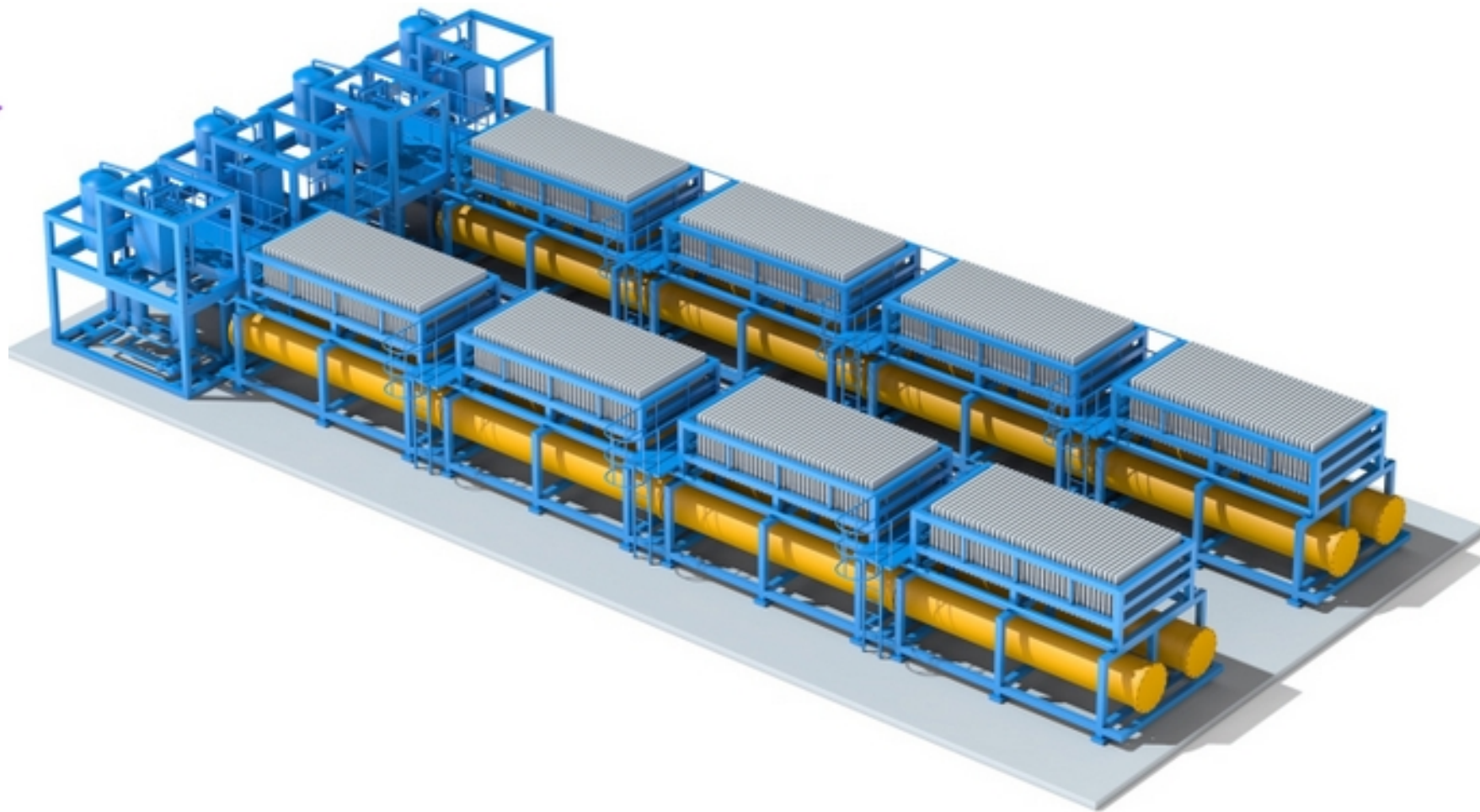
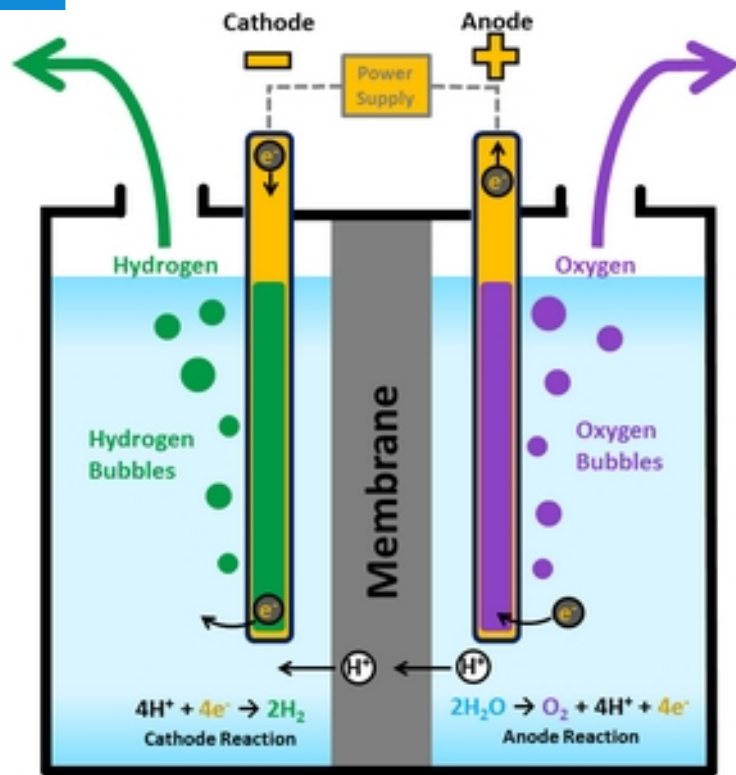
Euro 1.12 ct/kWh Augustus 2020

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

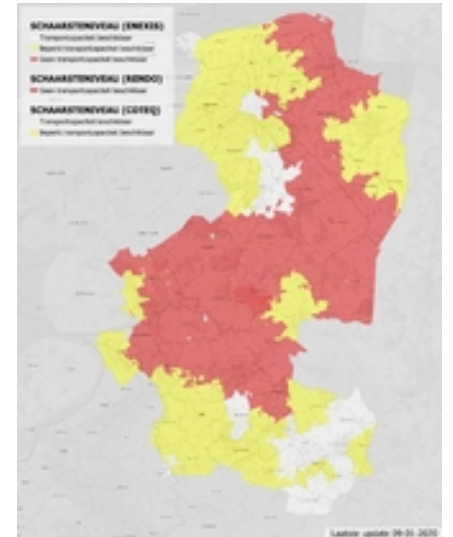
Elektriciteits net is/wordt het knelpunt!

Voor het aansluiten van zonnepanelen en windvermogen op het elektriciteitsnet

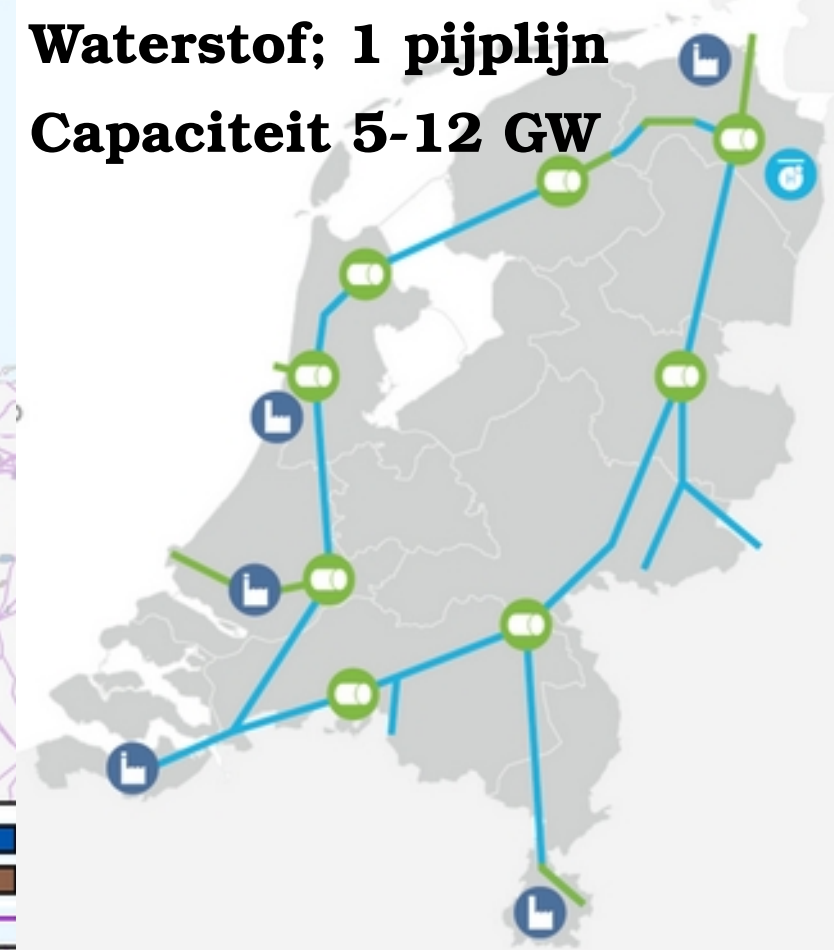
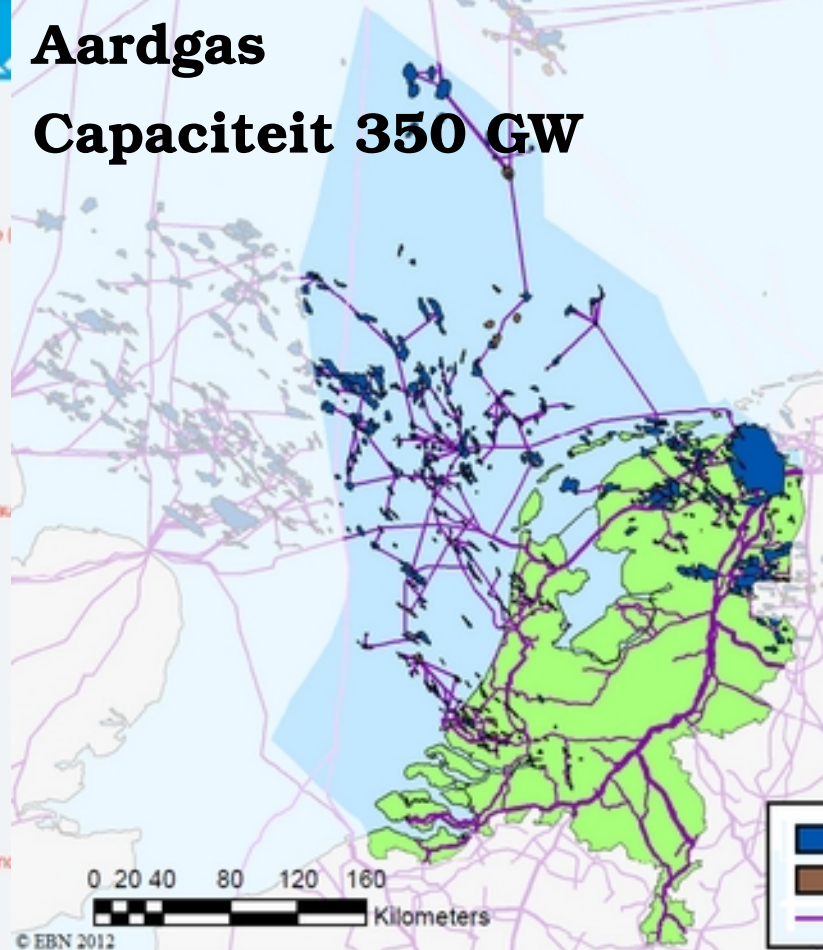
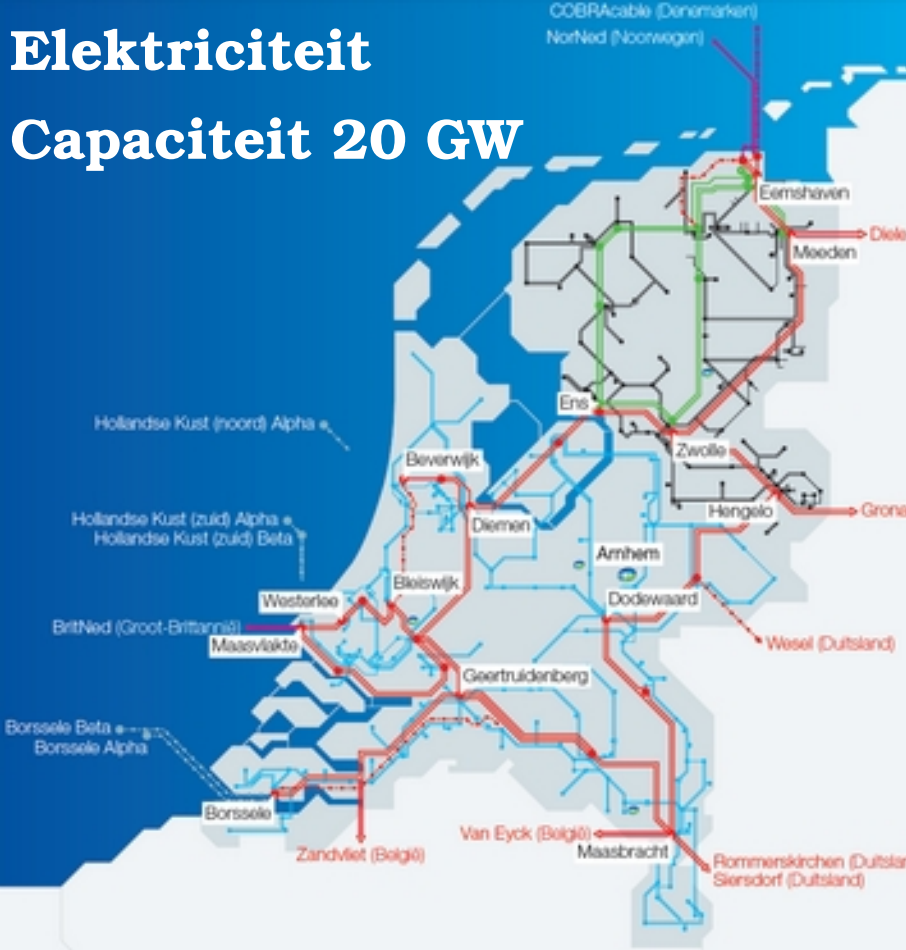
Gas transportnet 15 keer zo groot als elektriciteitstransport net

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

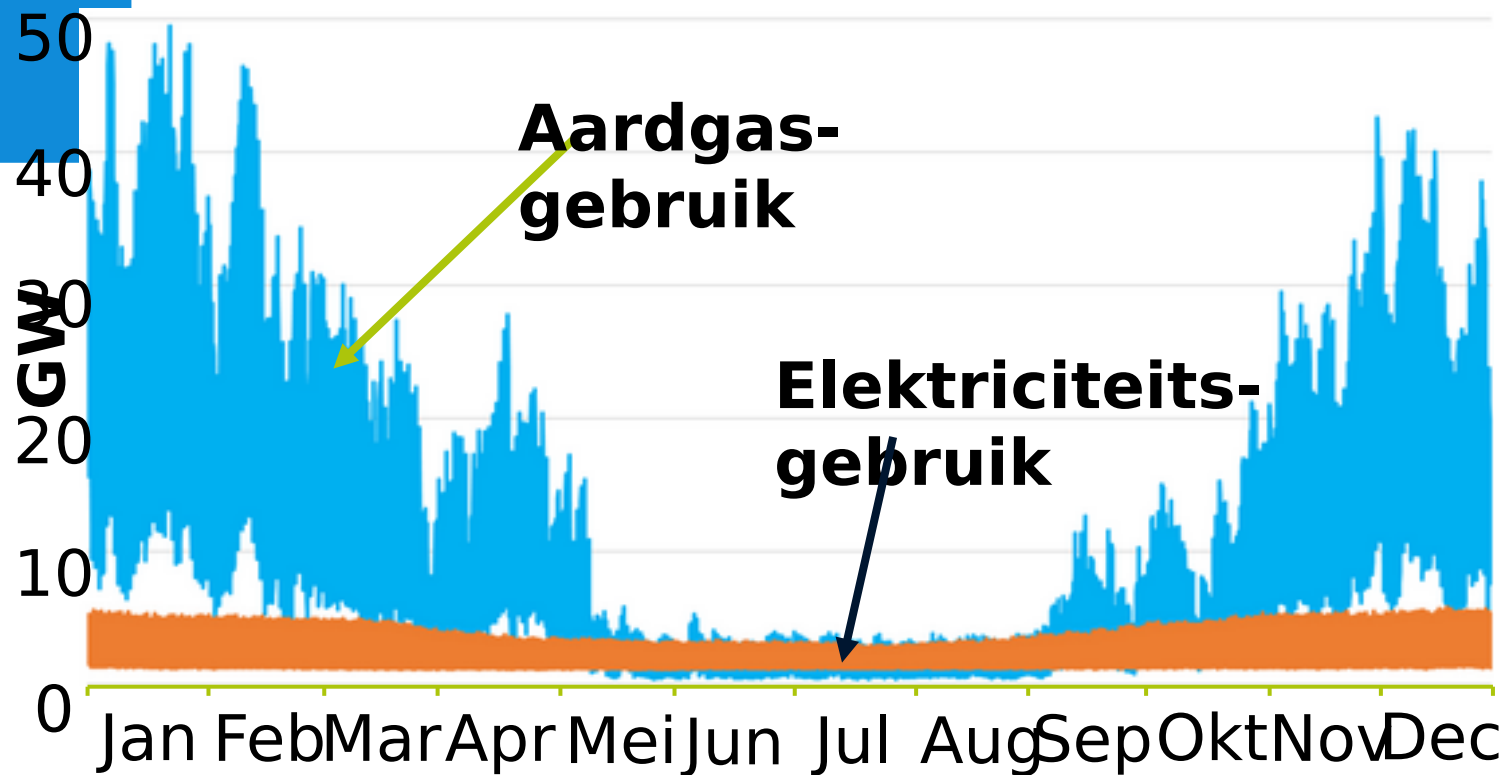
Gasaansluiting huis 10 keer zo groot (30 kW) als elektriciteitsaansluiting (3 kW)



Elektriciteit transport tot 10 X duurder dan Gastransport



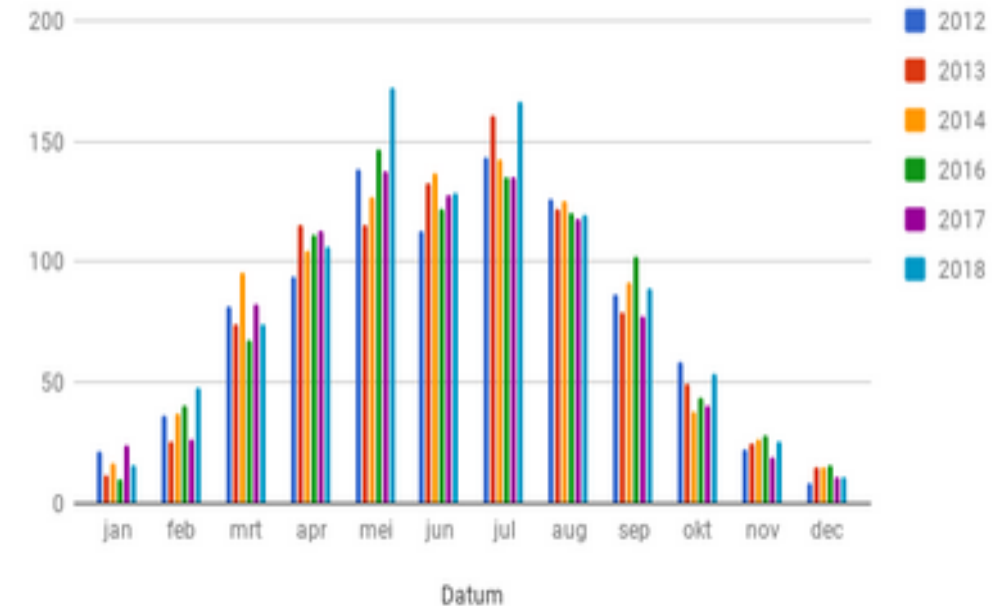
Veel meer opslag is nodig om vraag en aanbod van energie op elkaar af te stemmen



Bron: Kellner, 2018

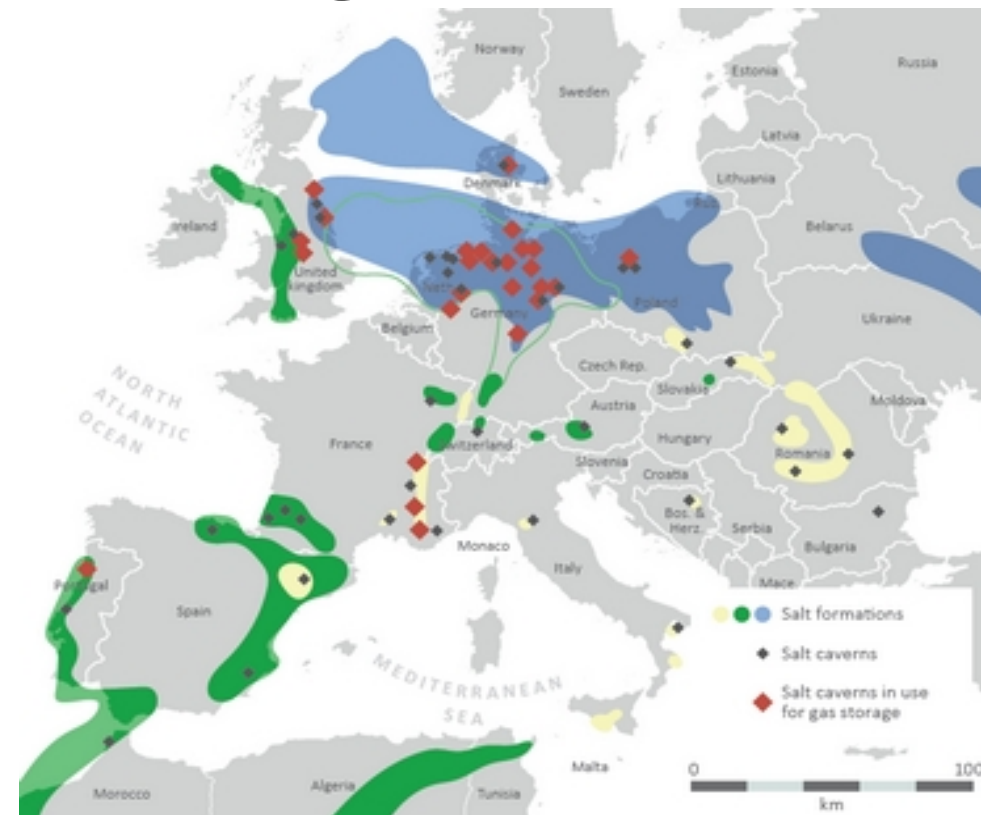
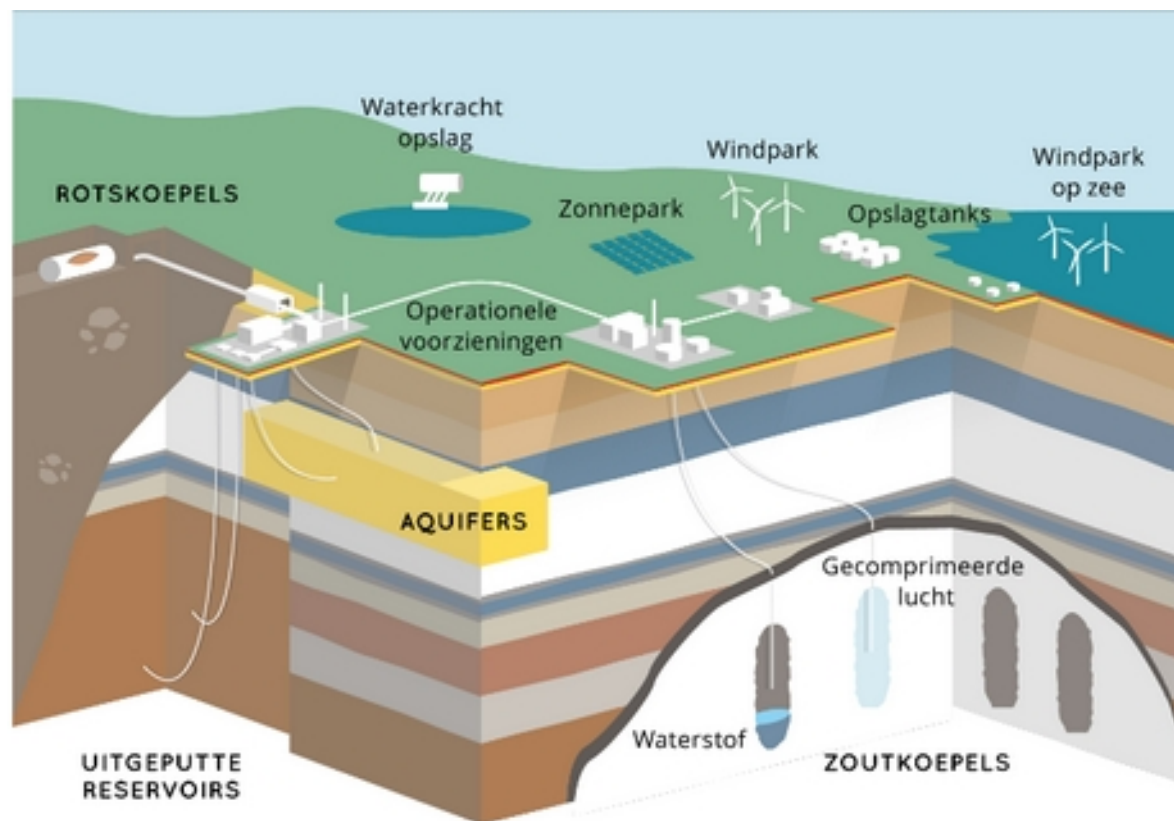
7,8 miljoen woningen (2017)

Zon per maand (Zuid)



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

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



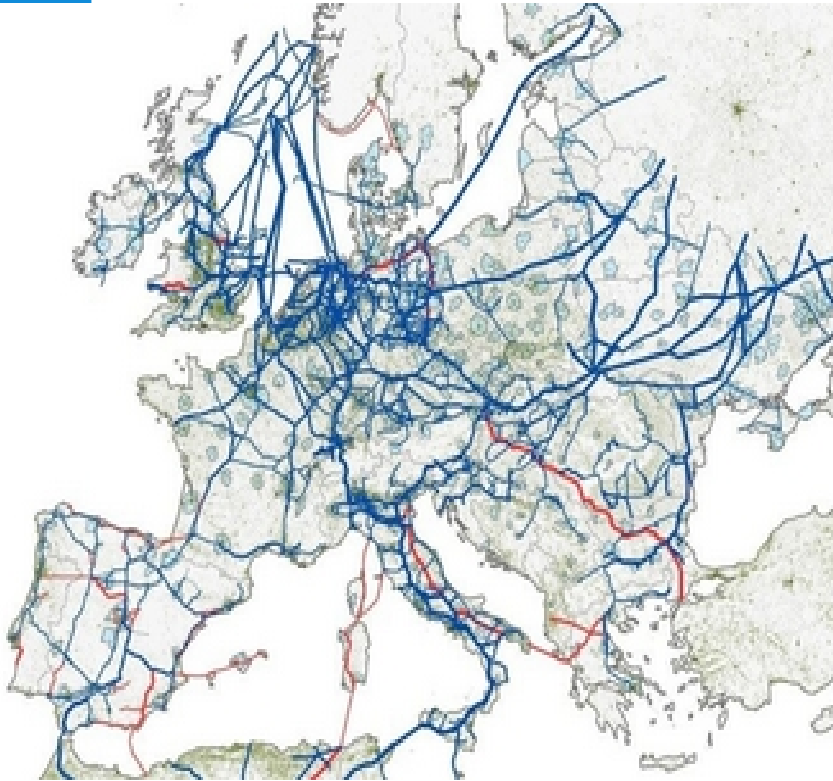
1 zoutkoepel kan 6,000 ton=236 miljoen kWh waterstof bevatten
Investerings 100 miljoen Euro

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

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

Gas Infrastructure in Europe and from North-Africa

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



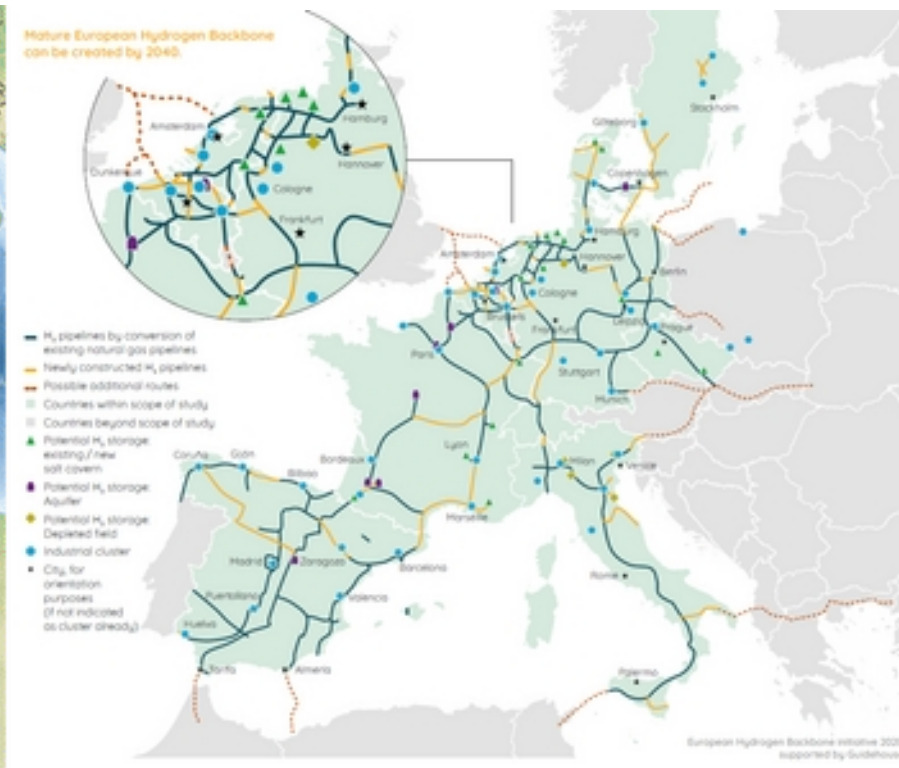
Gas Pipeline Infrastructure Europe

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 H₂ =0.04 €/kWhH _{2(HHV)}

Port of Rotterdam Hydrogen Strategy

HYDROGEN ECONOMY IN ROTTERDAM STARTS WITH BACKBONE

PROJECTS

Backbone

The backbone connects production and import (barge) with clients in the port area. Public infrastructure.

Conversion park

2GW conversion park (industrial estate) for the production of green hydrogen with electrolysis.

Upscaling of electrolyzers

Shell is planning a 150-250 MW electrolyzer for the conversion park. Nouryon, BP and the Port of Rotterdam Authority have teamed up in H2-Fifty on the development of a 250 MW electrolyzer.

Offshore wind

2 GW Offshore wind energy is linked to the production of green hydrogen.

Import terminals

Large-scale imports of hydrogen compounds are needed to provide Northwest Europe with adequate supplies of sustainable energy. This requires import terminals and pipelines.

Blue hydrogen

Nelion for blue hydrogen production. Natural gas and refinery gas are converted into hydrogen. The released CO₂ is stored in depleted gas fields under the North Sea (Porthos).

Transport

A consortium is being developed with the aim of operating 500 trucks on hydrogen. Under the name H2PNE, 17 parties are collaborating on a climate-neutral transport corridor between Rotterdam and Genoa based on hydrogen.

Eventually, hydrogen can also be used to heat greenhouses and buildings, particularly where heat networks or heat pumps are not a solution.

In addition to the large projects shown here, many smaller ones are in preparation.

TIMETABLE

Backbone and Maxxcelite conversion park operational (Investment decision 2022)
2023

Shell goes operational with 150-250 MW electrolyzer on conversion park (Investment decision 2022)
2023

H2-Fifty's 250 MW electrolyzer goes operational (Investment decision 2023)
2025

Road transport: 500 hydrogen-powered trucks
2025

Installation of Nelion operational (Investment decision 2023)
2026

Import terminal, pipelines to Chemelot and North Rhine-Westphalia operational
2030

Import mainly from South Europe, North Africa and the Middle East.



Connection to national H₂ grid, Chemelot and North Rhine-Westphalia (NRW).



3x

DUTCH ENERGY CONSUMPTION FLOWS THROUGH THE PORT OF ROTTERDAM

20 Mt

TOTAL HYDROGEN FLOW IN ROTTERDAM IN 2050

200 GW

WIND POWER NEEDED TO PRODUCE 20MT OF GREEN HYDROGEN

5,000%

INCREASE IN HYDROGEN FLOW THROUGH ROTTERDAM

Strong growth in hydrogen flow through Rotterdam due to imports

The coming decades will see the rise of blue and green hydrogen. In order to meet national and international demand, the lion's share will come from import in 2050.

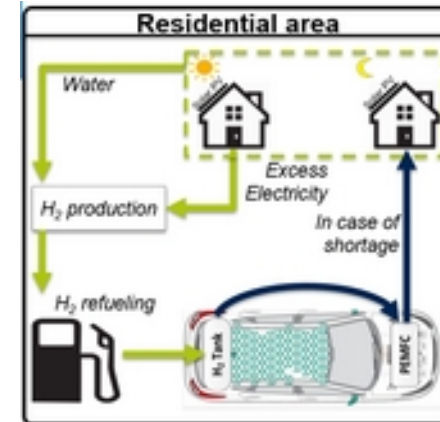


Waterstof markten

Industrie; grondstof, HTwarmte



Electriciteit Balancing



Transport



Verwarming



De toekomst is elektrisch!

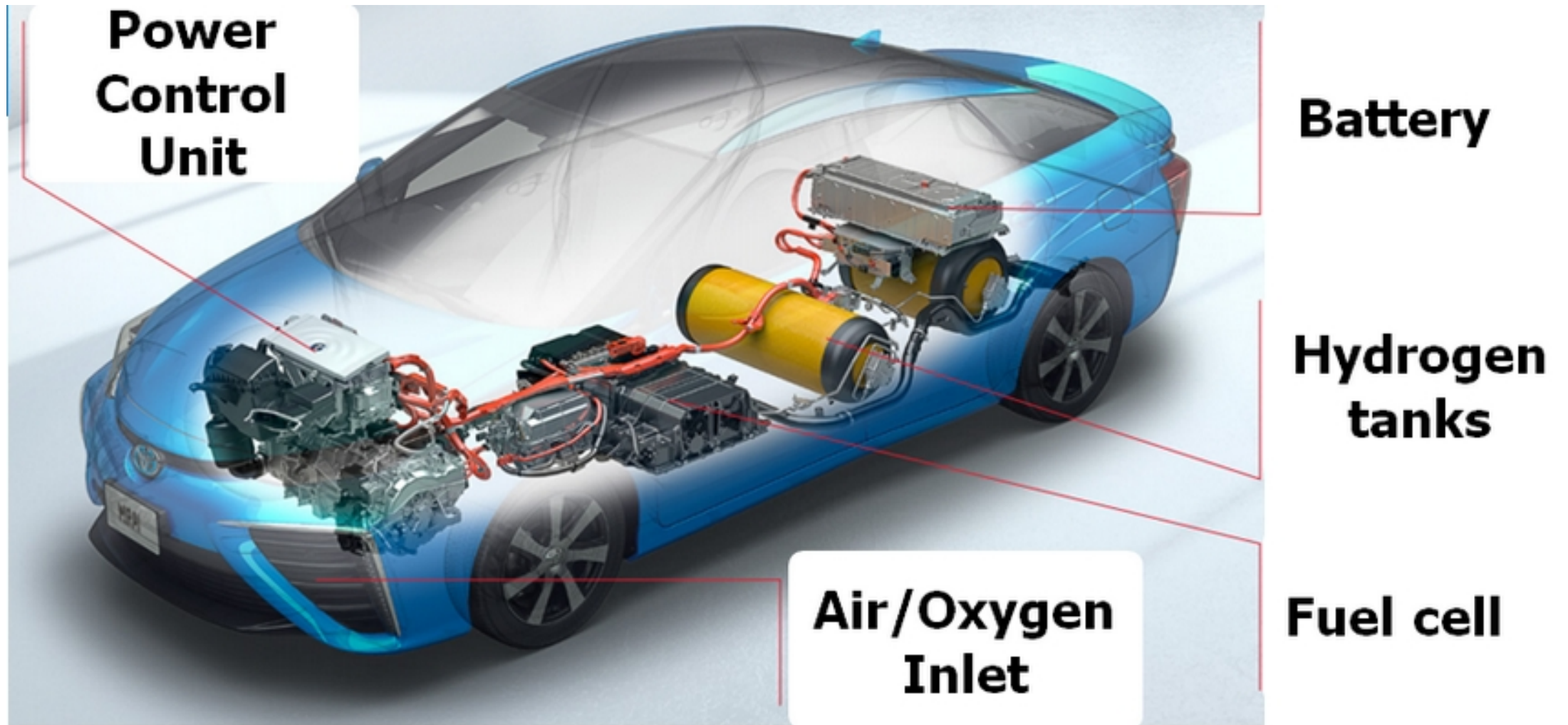


Tesla Model S



Toyota Mirai

Toyota Mirai; Brandstofcel auto



Meer en meer waterstof in mobiliteit



New-Holland: Tractor, diesel+H₂ (2-10-2020)



Airbus: Vliegtuig, LH₂+Gasturbine (21-9-2020)

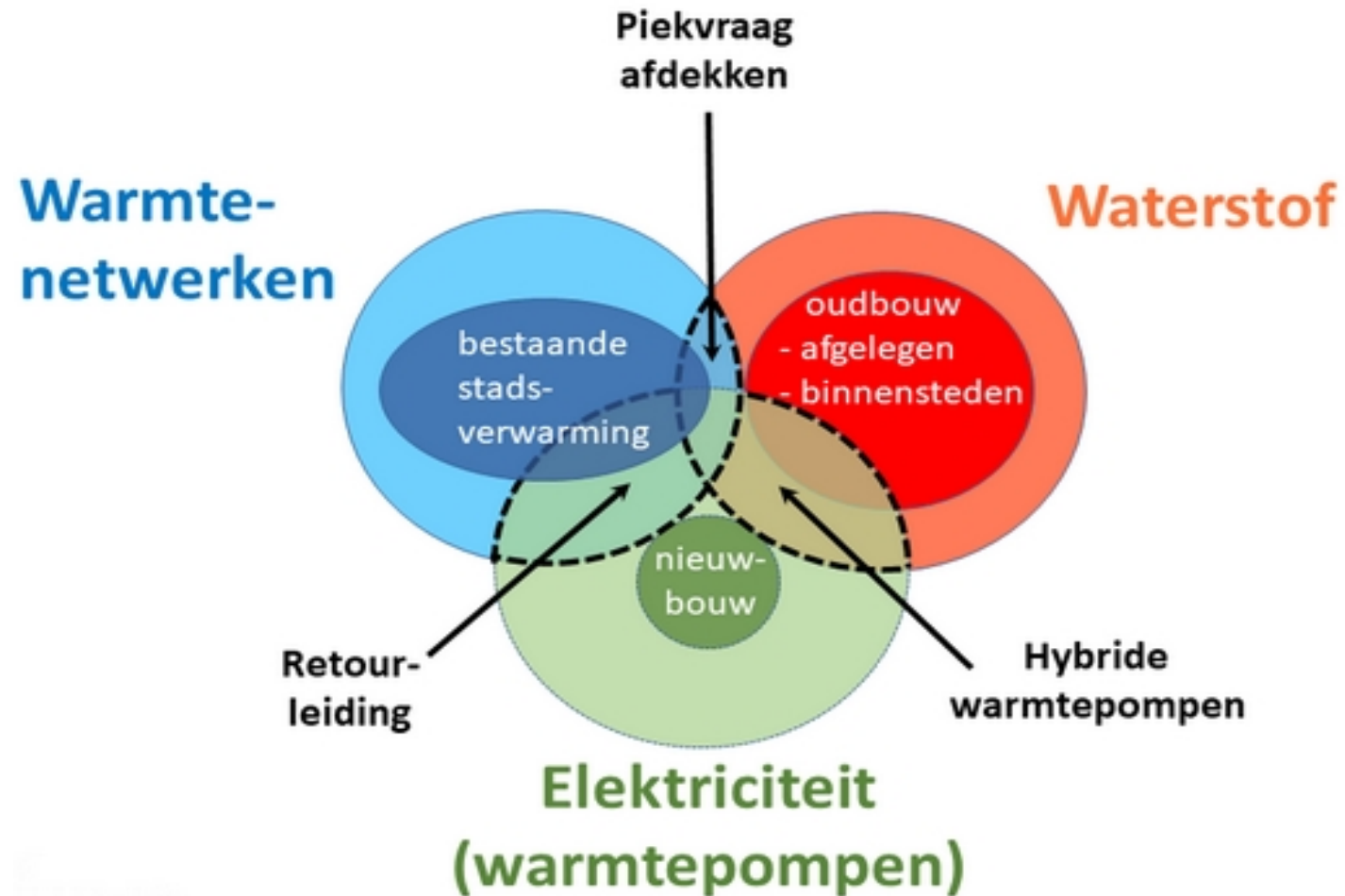


Still: Waterstof vorkheftruck




Hyzon-Holthausen Waterstof trucks (Juli 2020)

Duurzame verwarmingsopties



Verwarmen met waterstofketels

Remeha



CR remeha

Remeha HYDRA

	Hydrogen	Natural gas	
CO ₂	0	9	%
	0	190	g/kWh
	0	2500	kg/jaar*
CO	0	48	ppm
NO _x	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

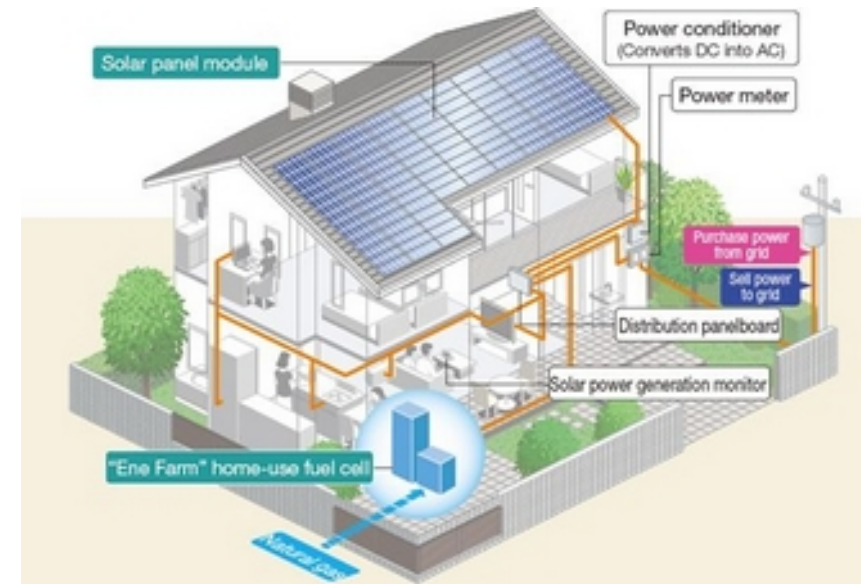
Reforming aardgas naar $H_2 + CO_2 +$ warmte

1 kW brandstofcel zet H_2 om in elektriciteit+warmte



Warm water vat

Brandstofcel



CO₂ emissies voor verwarmen en rijden

CO ₂ emissie	Bron g/kWh	Verwarmen g/kWh thermisch	Rijden g/km
CO₂ 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
CO₂ 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 CO₂/kg H₂

**<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-energie-dragerslijst-versie-januari-2020.pdf>

****<https://www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf>

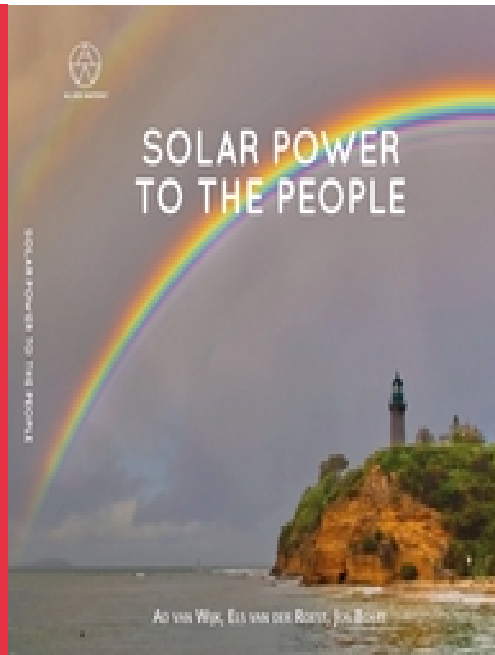
*****<https://www.pbl.nl/sites/default/files/downloads/pbl-2020-klimate-en-energieverkenning2020-3995.pdf> 18,8 Mton CO₂, 125 TWh Klimaatakkoord

Meer lezen over waterstof

www.profadvanwijk.com



April 2017



November 2017



May 2018



September 2019



April 2020