

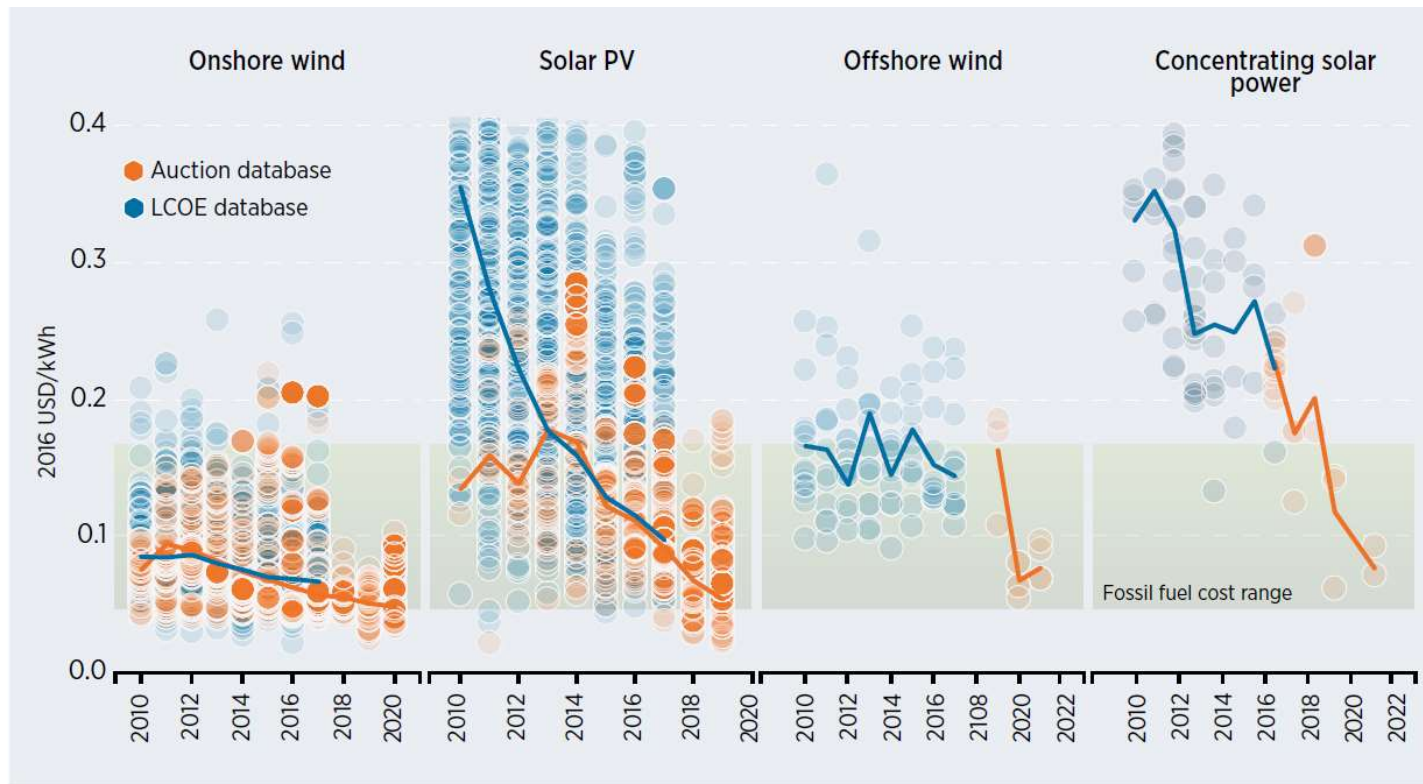


# Waterstof, de energiedrager van de toekomst

Prof. Dr. Ad van Wijk

1-10-2019

# Levelized Cost of Electricity



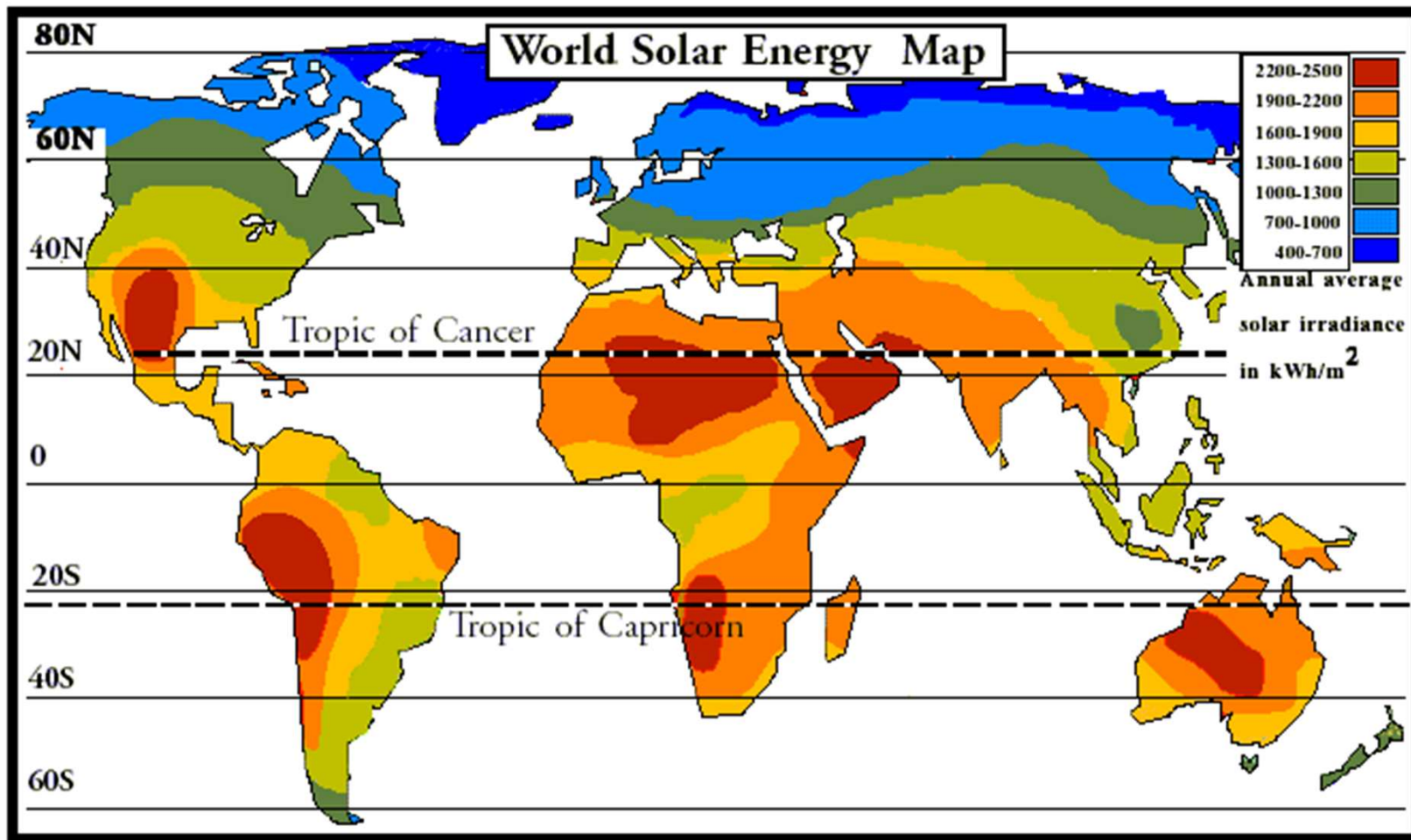
Source: IRENA Renewable Cost Database and Auctions Database.

IRENA, January 2018, Renewable Power Generation Costs 2017

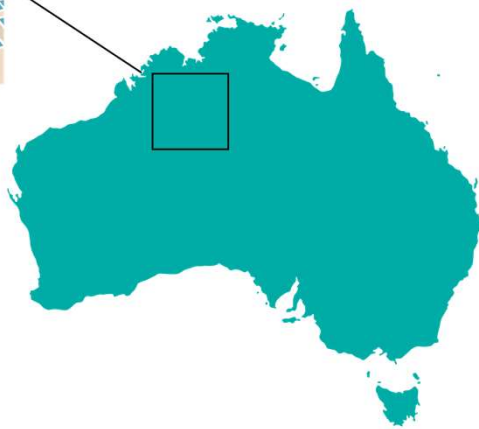
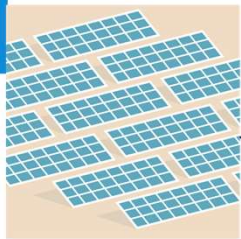


# 5 GW Mohammed Bin Rashid Al Maktoum Solar Park in Dubai

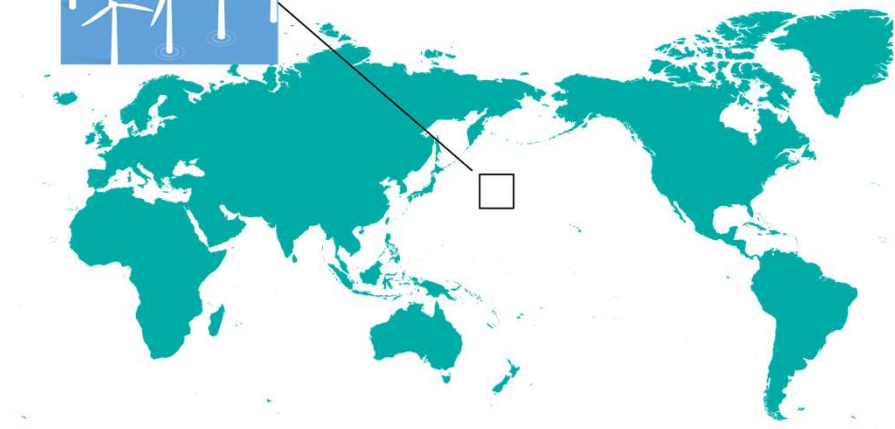
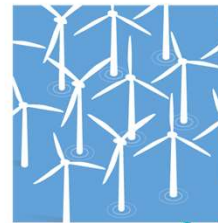




# Surface needed to produce all the world's energy 556 EJ = 155.000 TWh

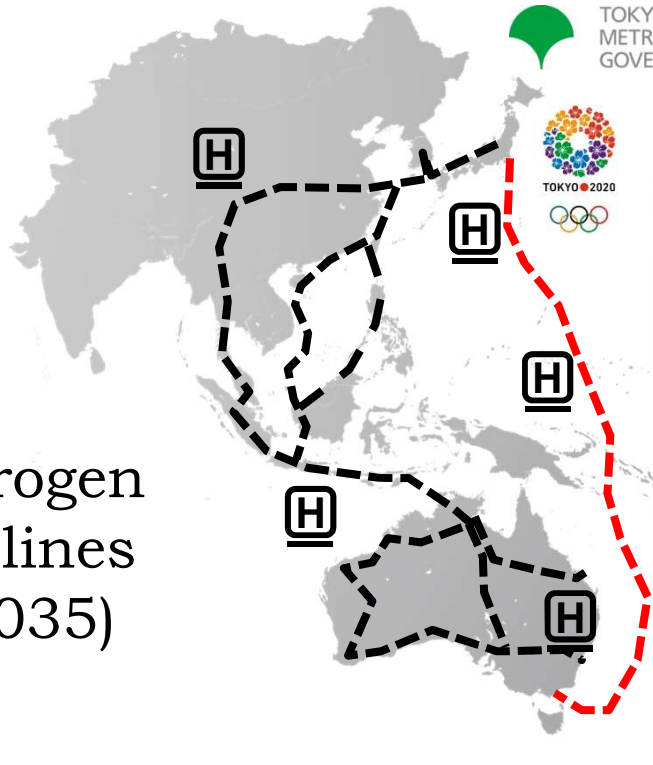


10% SOLAR AUSTRALIA



1.5% WIND PACIFIC OCEAN

# Tokyo Olympic Games 2020



Hydrogen Pipelines (~2035)

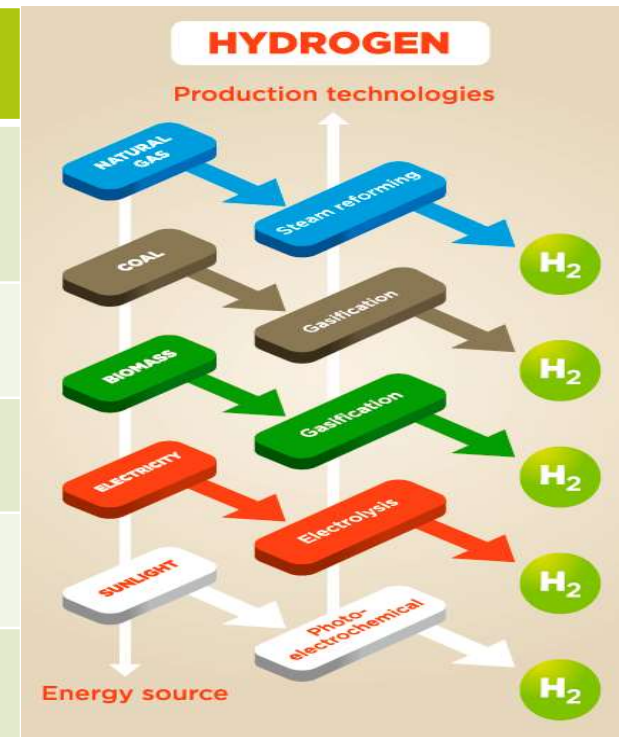
Hydrogen Shipping (~2025)



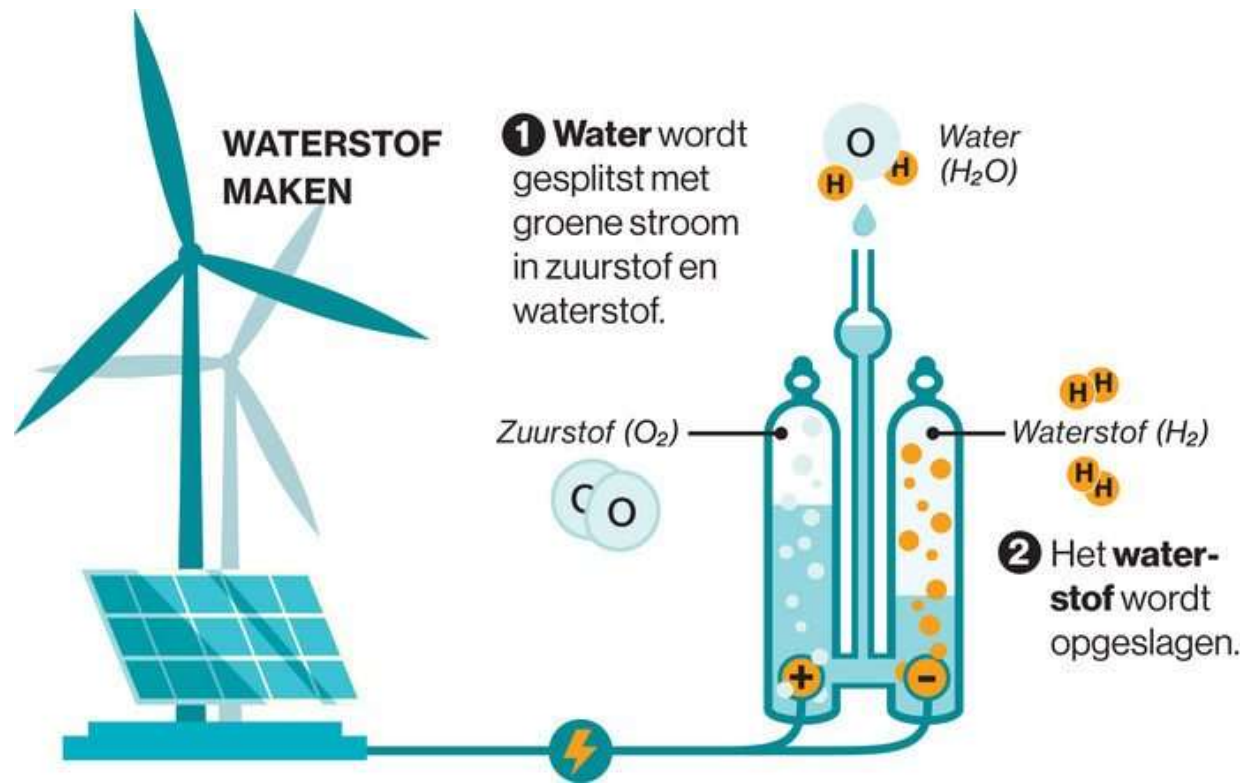


# Hydrogen production

Source	Process	Efficiency Today
Natural gas Bio Gas	Steam reforming Auto-thermal reforming Solid Oxide Fuel Cell	70-75% >75% 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)

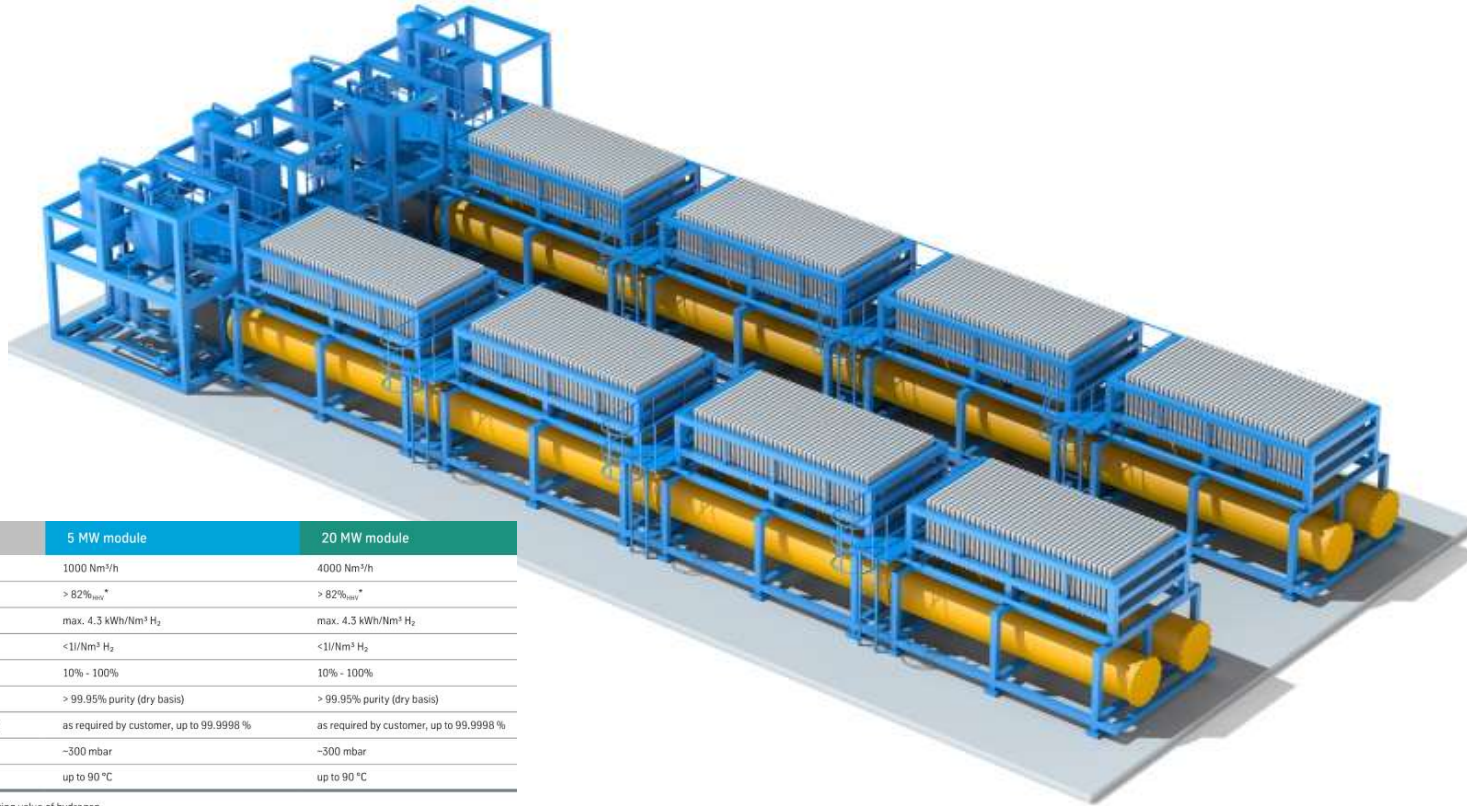


# Elektrolyse van Water



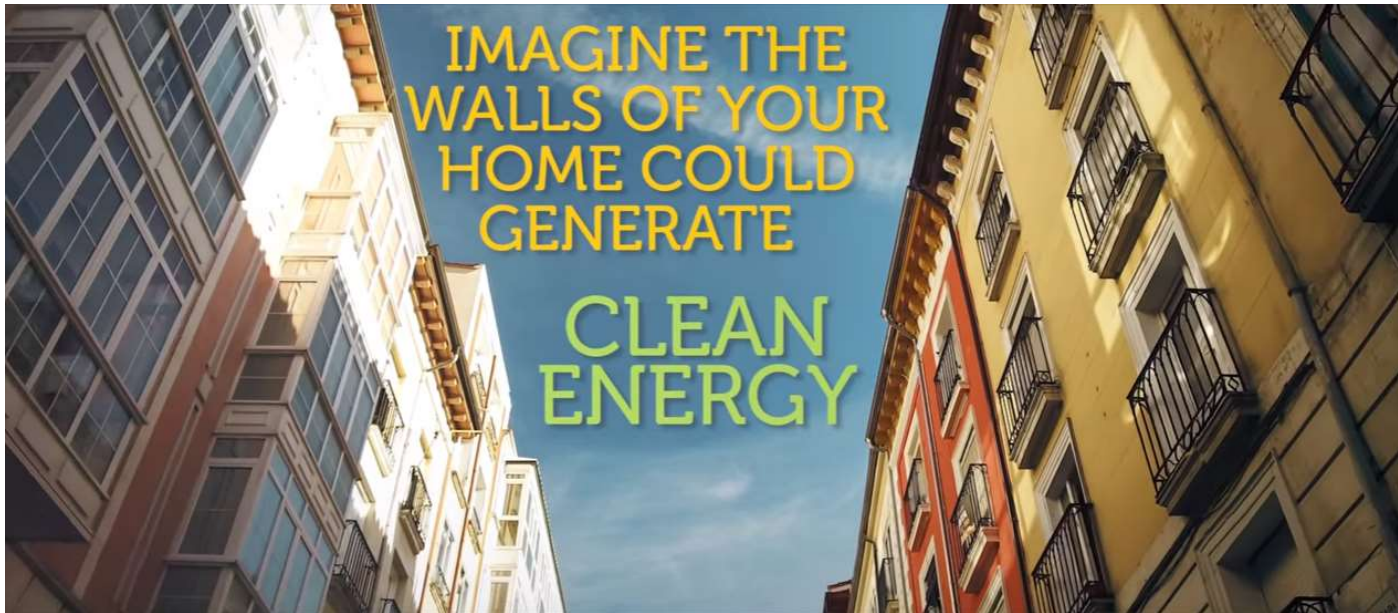


# 20 MW Alkaline Electrolyser

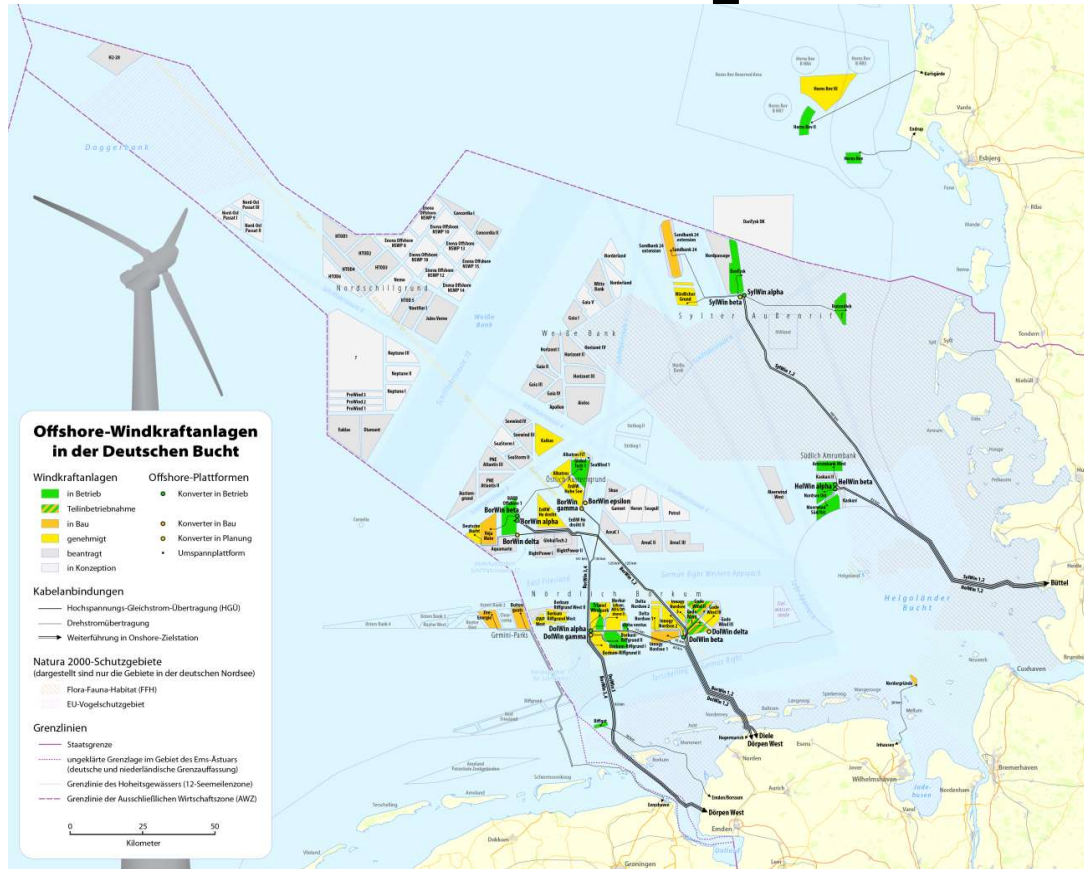


	5 MW module	20 MW module
Design capacity H <sub>2</sub>	1000 Nm <sup>3</sup> /h	4000 Nm <sup>3</sup> /h
Efficiency electrolyzer (DC)	> 82% <sub>HHV</sub> *	> 82% <sub>HHV</sub> *
Power consumption (DC)	max. 4.3 kWh/Nm <sup>3</sup> H <sub>2</sub>	max. 4.3 kWh/Nm <sup>3</sup> H <sub>2</sub>
Water consumption	<1l/Nm <sup>3</sup> H <sub>2</sub>	<1l/Nm <sup>3</sup> H <sub>2</sub>
Standard operation window	10% - 100%	10% - 100%
H <sub>2</sub> product quality at electrolyzer outlet	> 99.95% purity (dry basis)	> 99.95% purity (dry basis)
H <sub>2</sub> product quality after treatment (optional)	as required by customer, up to 99.9998 %	as required by customer, up to 99.9998 %
H <sub>2</sub> product pressure at module outlet	~300 mbar	~300 mbar
Operating temperature	up to 90 °C	up to 90 °C

\* HHV = calculated with reference to higher heating value of hydrogen.  
All values may vary depending on operating conditions.

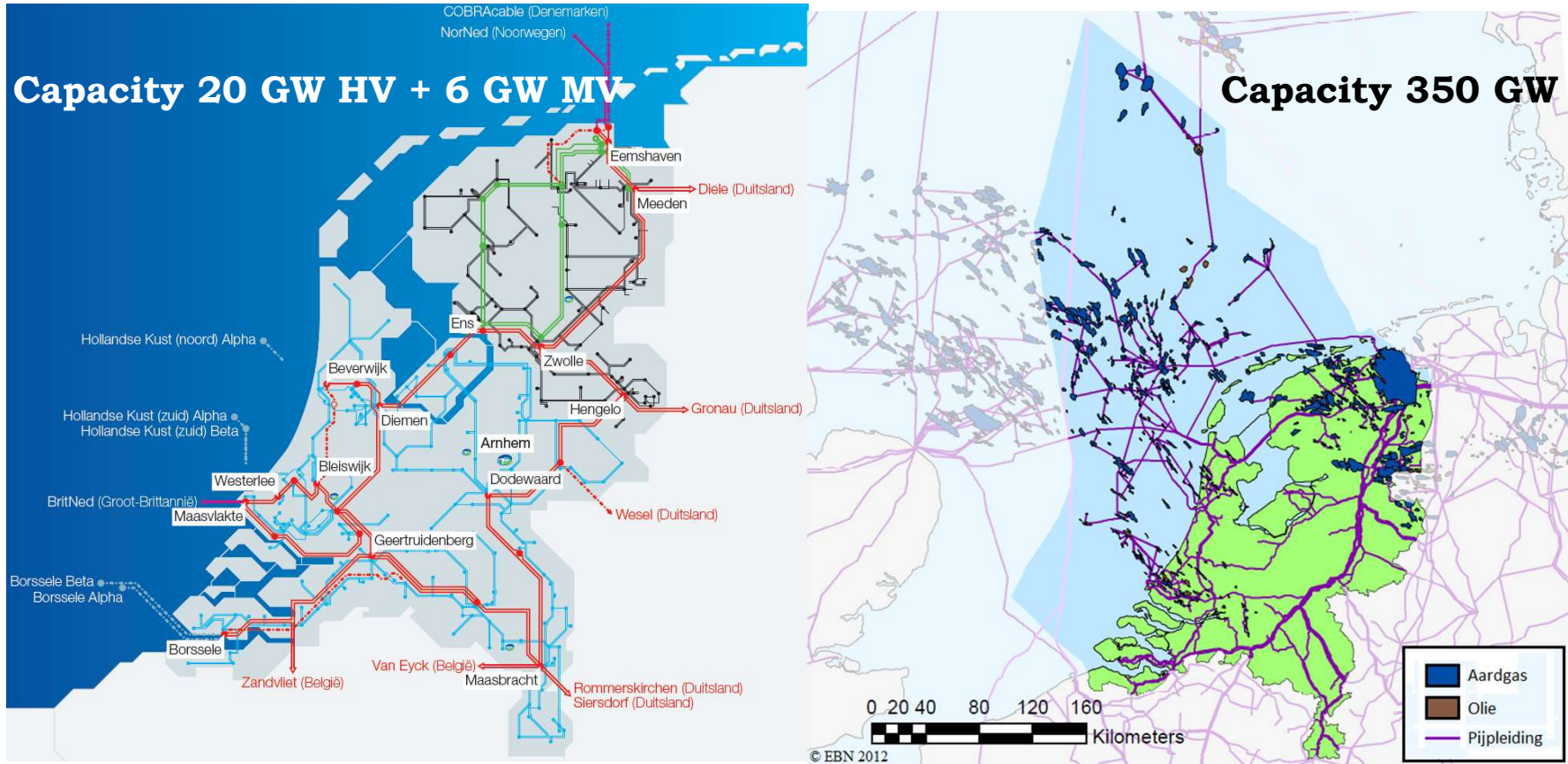


# Offshore Wind Development Germany





# Electricity and Gas Transport Grid





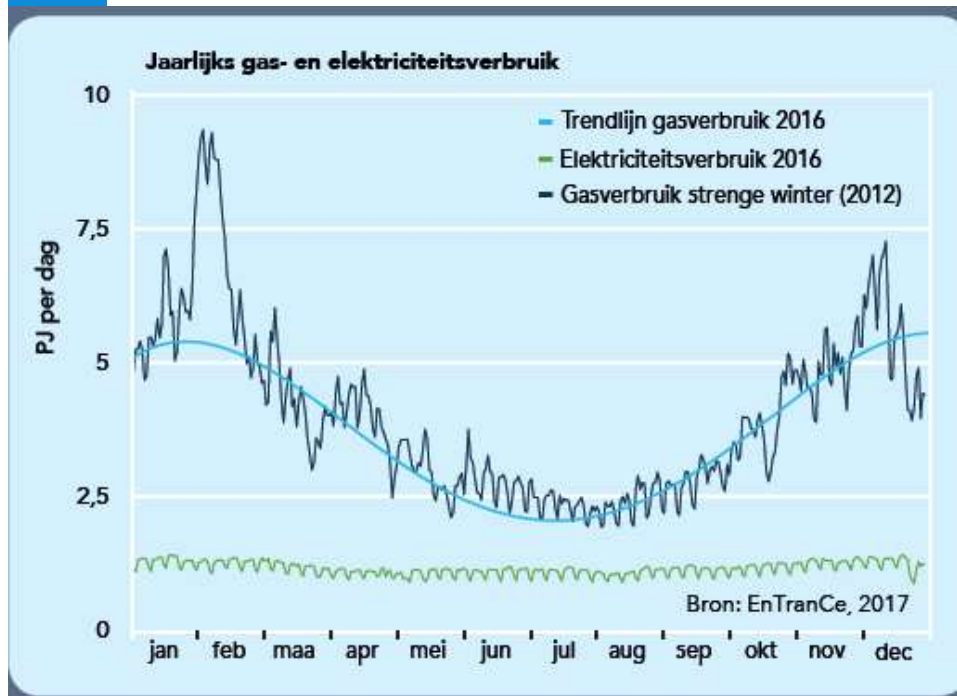
# Hydrogen backbone the Netherlands 2030



- Low caloric gas pipelines will become available, because the Groningen gas field has to reduce production to 0 in 2030
- 1 Transport pipeline capacity about 10-15 GW
- New hydrogen pipeline connections to offshore wind farms
- Connections to Germany (Ruhr-area, Bremen-Hamburg and Belgium (Antwerp, Zeebrugge)
- European connections to France, Austria, Italy, etc.

- Existing gas pipeline
- Retrofitted compressors
- New hydrogen pipeline
- ⚙ Industrial cluster
- ⚙ Hydrogen storage in salt cavern

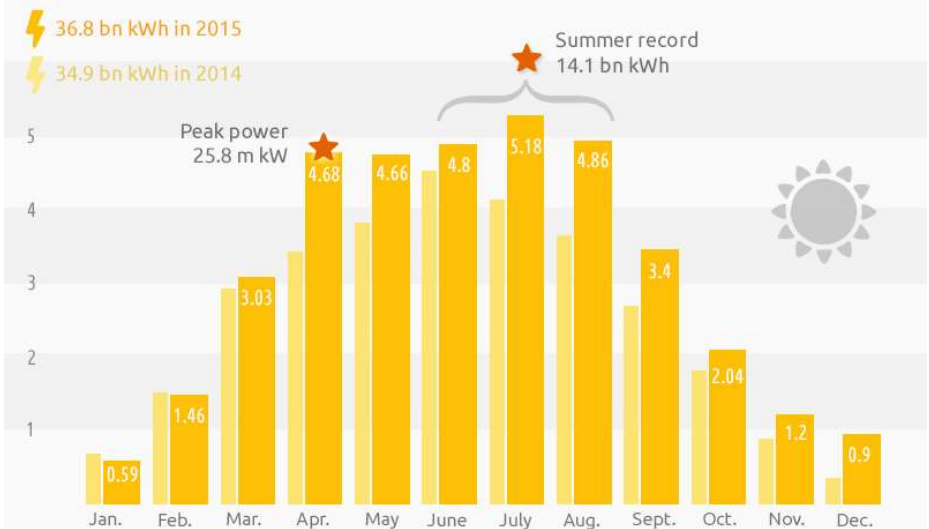
## Gas and electricity consumption in the Netherlands



## Solar power production in Germany

### SOLAR POWER GENERATION IN GERMANY 2015

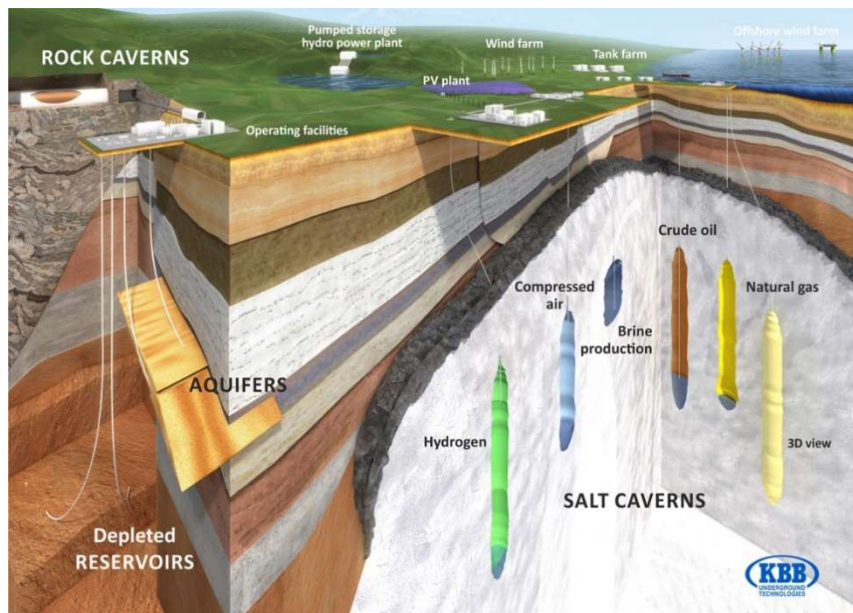
Solar energy sets a new all-time summer record and beats peak power output



Source 2014, 2015: Fraunhofer ISE, EEX

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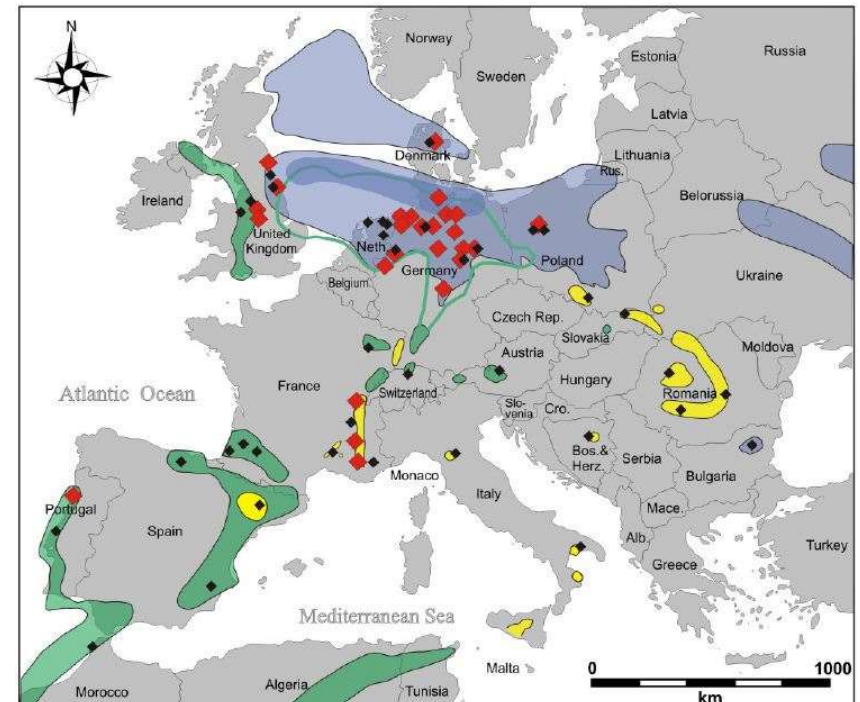
# Waterstof opslag in Zout Koepels



**1 zout koepel bevat 6,000 ton waterstof (kosten 100 miljoen Euro)**

**Dat is 240 miljoen kWh of 17 miljoen thuis batterijen van 14 kWh  
(kosten 240 miljard Euro)**

# Zout formaties en zout koepels in Europa



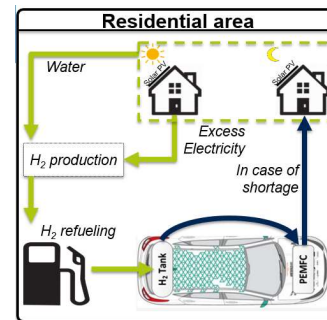
**Rood gekleurde koepels in gebruik voor aardgas opslag**

# Green Hydrogen Markets

## Chemical



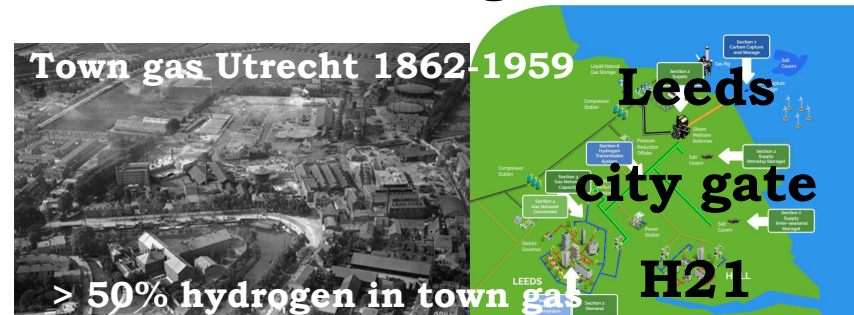
## Electricity Balancing



## Transport



## Heating





# Stadsgas productie Utrecht 1862-1959

> 50% waterstof in stadsgas



# Remeha Hydrogen Boiler



# Hybrid Heat Pump + Boiler

## Natural gas shifting to hydrogen



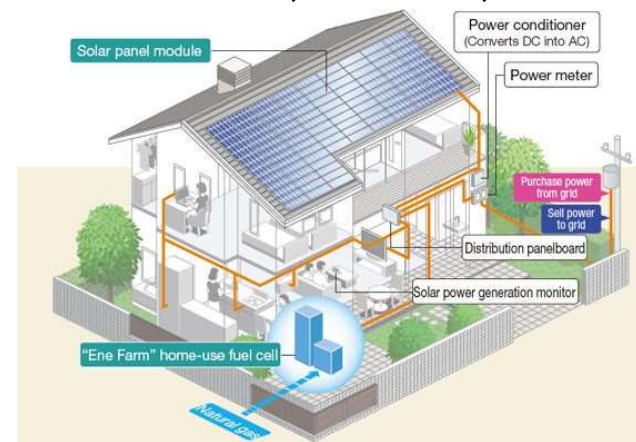
# Ene Farm: Home Fuel cell systems Japan

- Japan 200.000 sold 2017
- Aim 1.4 million end 2020
- Panasonic with Viessmann started sales in UK and Germany in 2017
- Kyocera makes systems for restaurants, hotels, etc.



Hot water unit

Fuel cell





# The Future is Electric!

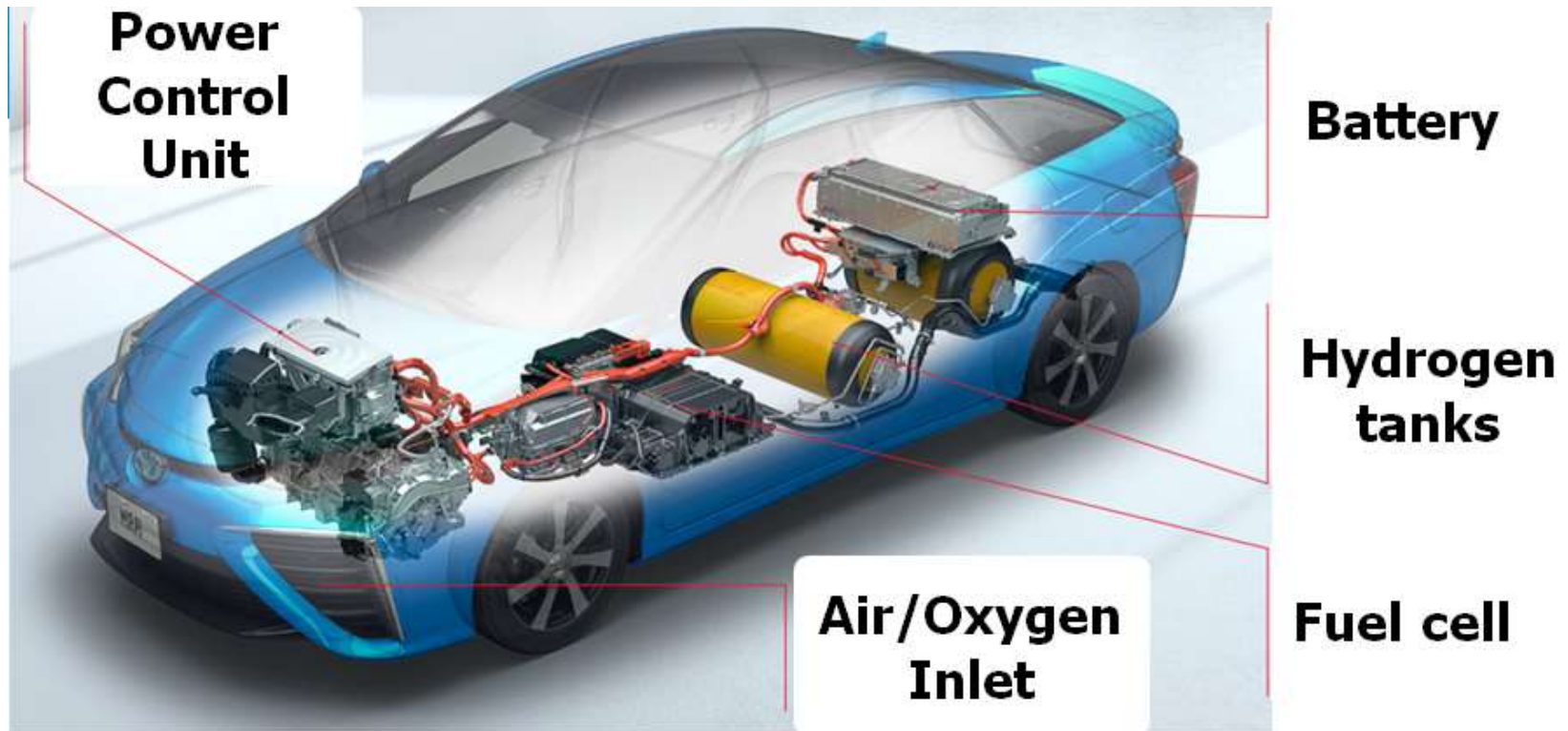


**Tesla Model S**

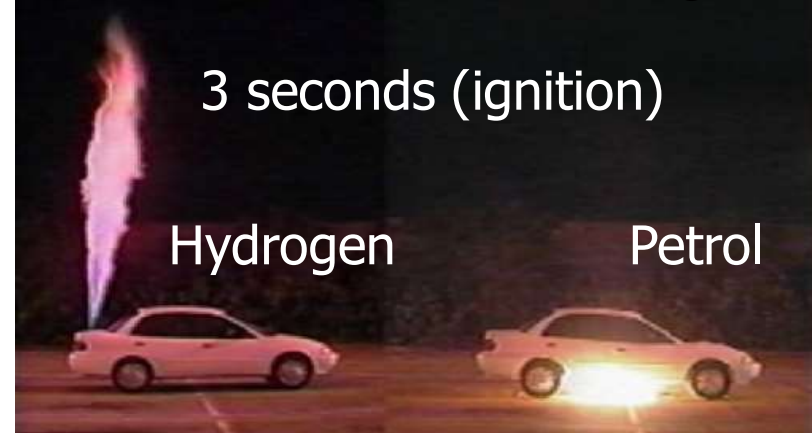


**Toyota Mirai**

# Toyota Mirai; Fuel cell car



# Hydrogen versus petrol safety



# Defying Death Valley





# Further reading about hydrogen

[www.profadvanwijk.com](http://www.profadvanwijk.com)

