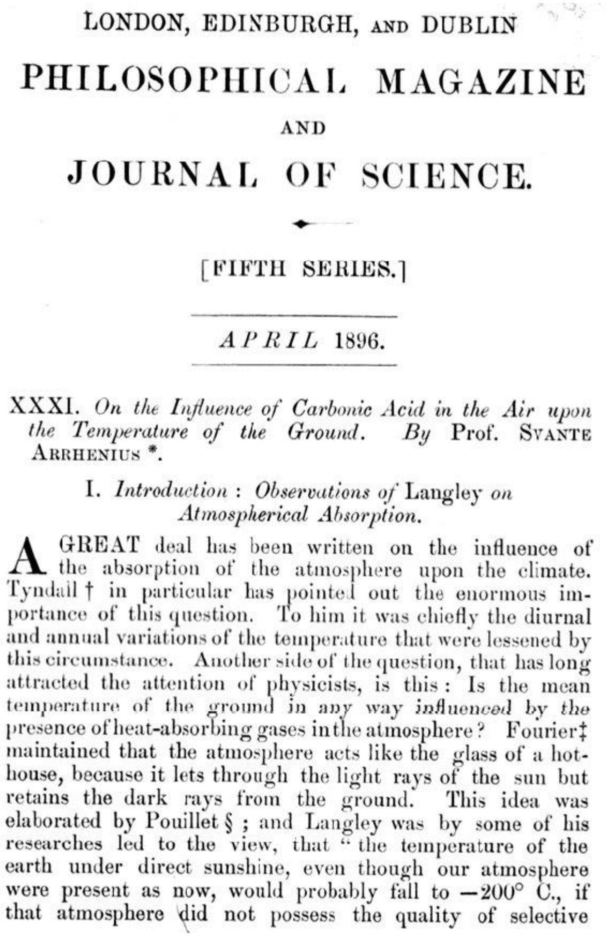
Pathways to Renewable Hydrogen

WANG Lei
ChBE @ NUS
wanglei8@nus.edu.sg

The earliest concern on carbon emission



LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

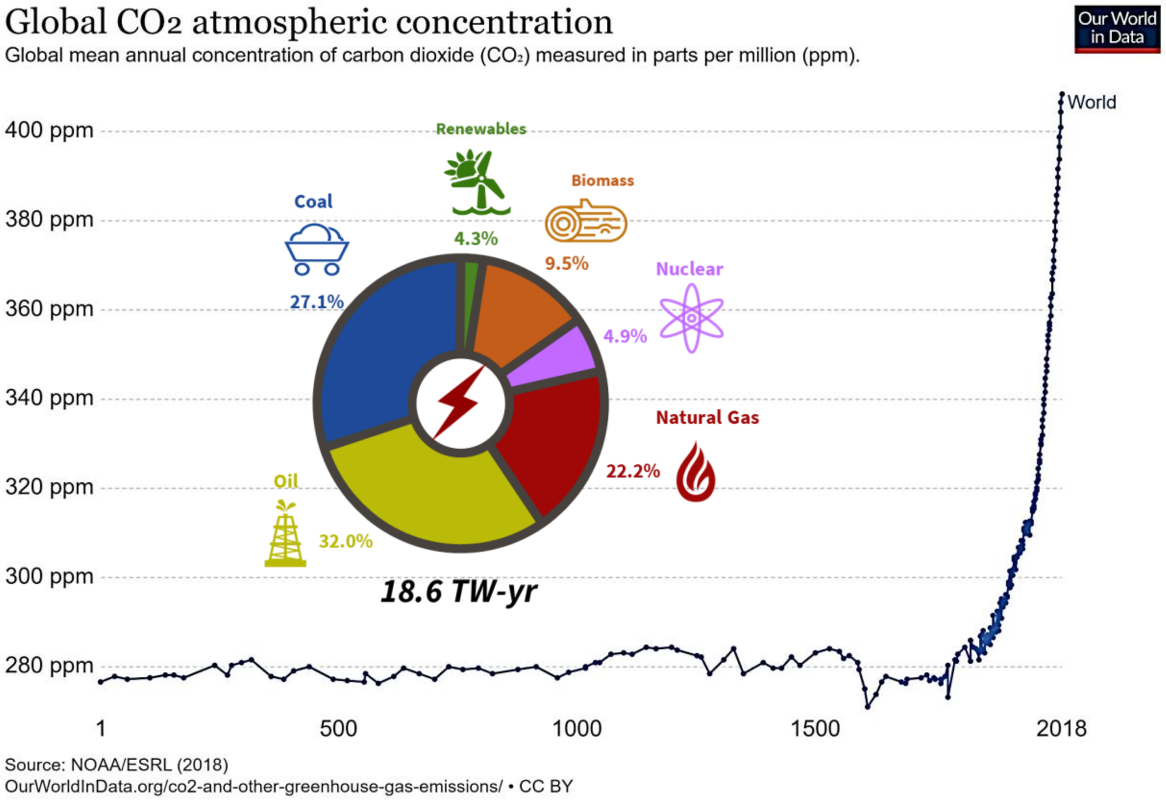
[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

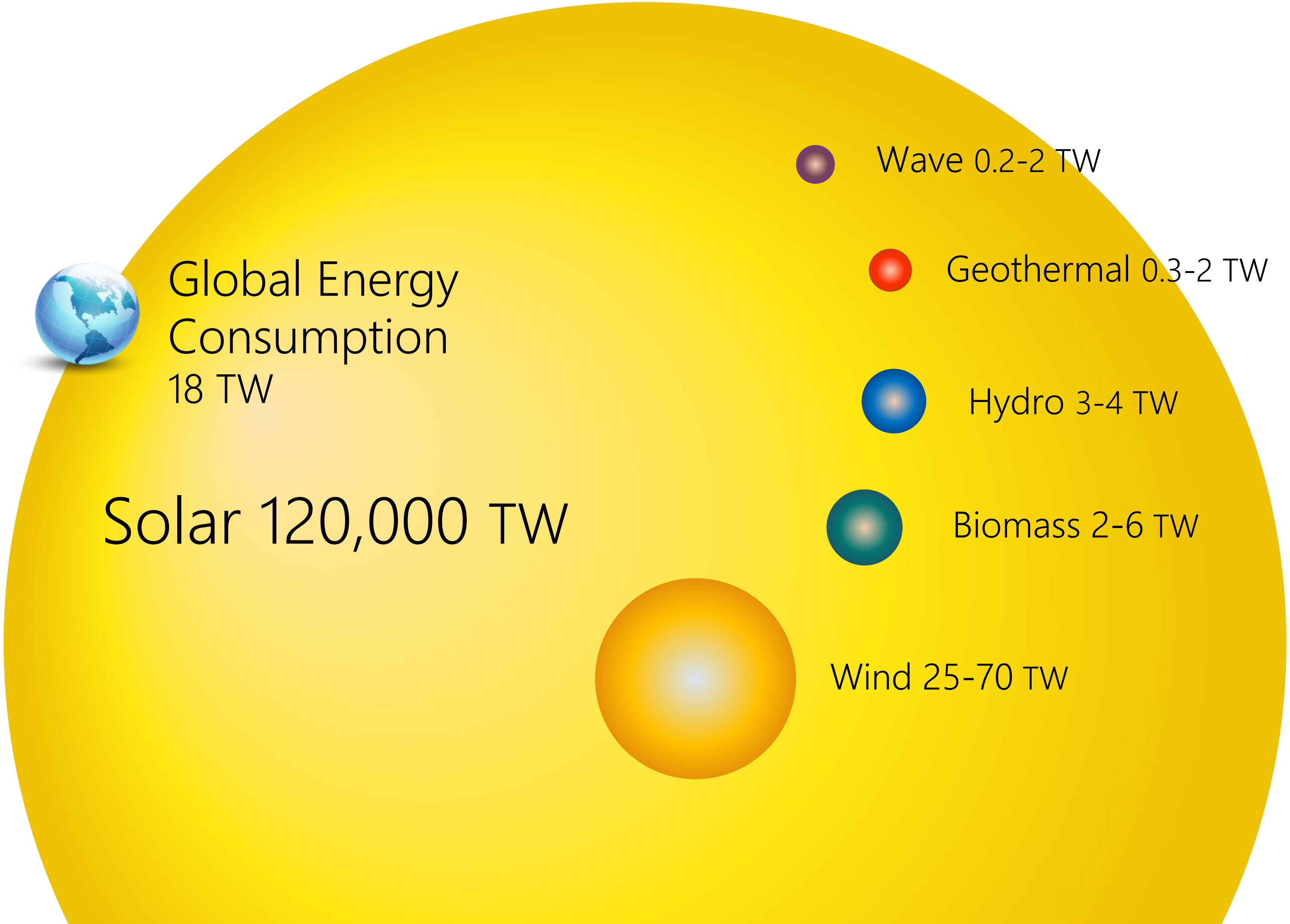
A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective



CO_2 emission > 40 Gton/year

The temperature rise 5-6 ℃ if CO_2 doubled: *~3000 years*

Solution for reducing CO_2 emission: renewable energy

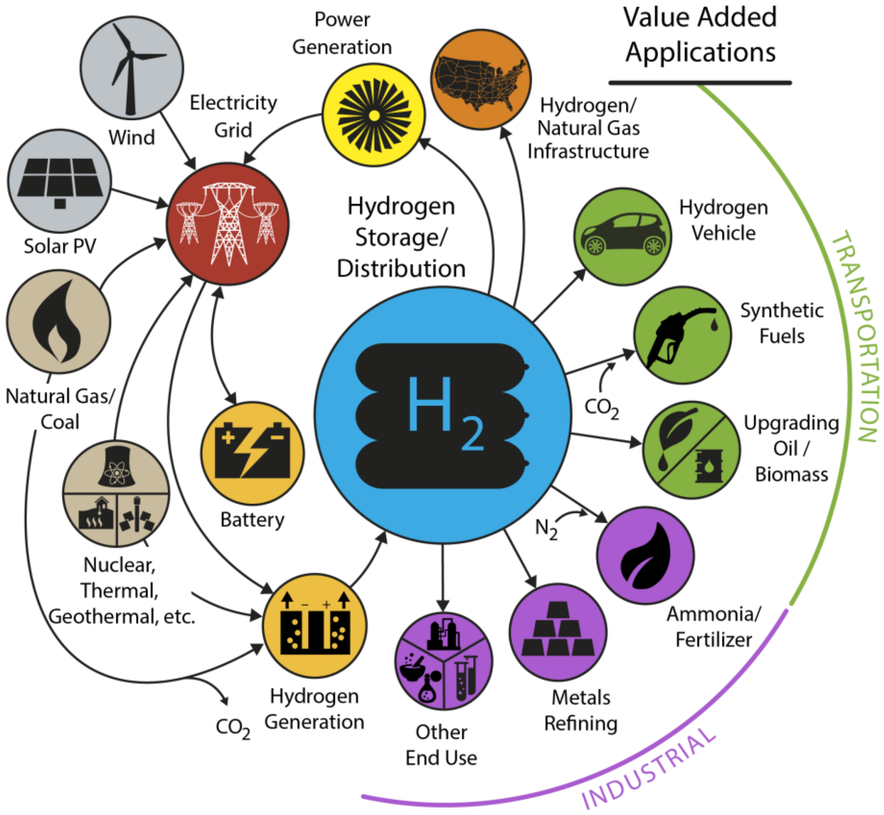


We have more than enough renewable energy resources, the key is to upgrade them into the **quality** that can meet our needs!

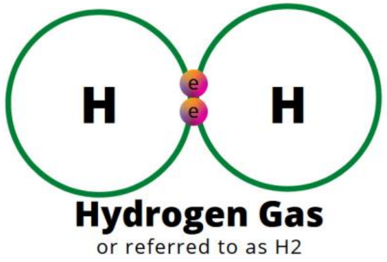
Hydrogen as clean energy carrier

The most abundant element in the universe!

Already a crucial chemicals and fuels today!

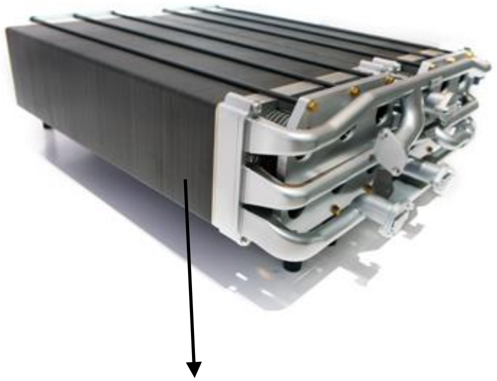


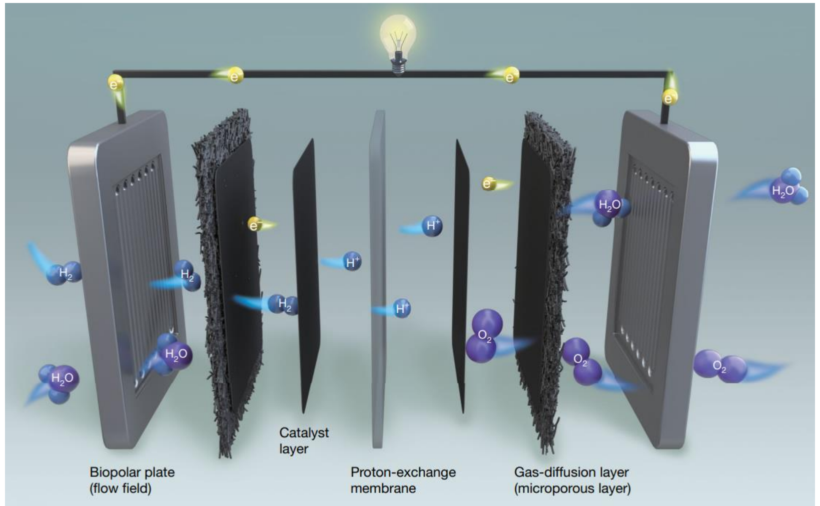
https://eta.lbl.gov/news/article/hydrogen-energy-carrier-future



Driving range: > 600 km
Tank capacity: < 6 kg
Electric motor: > 180 HP

Fuel cell stack

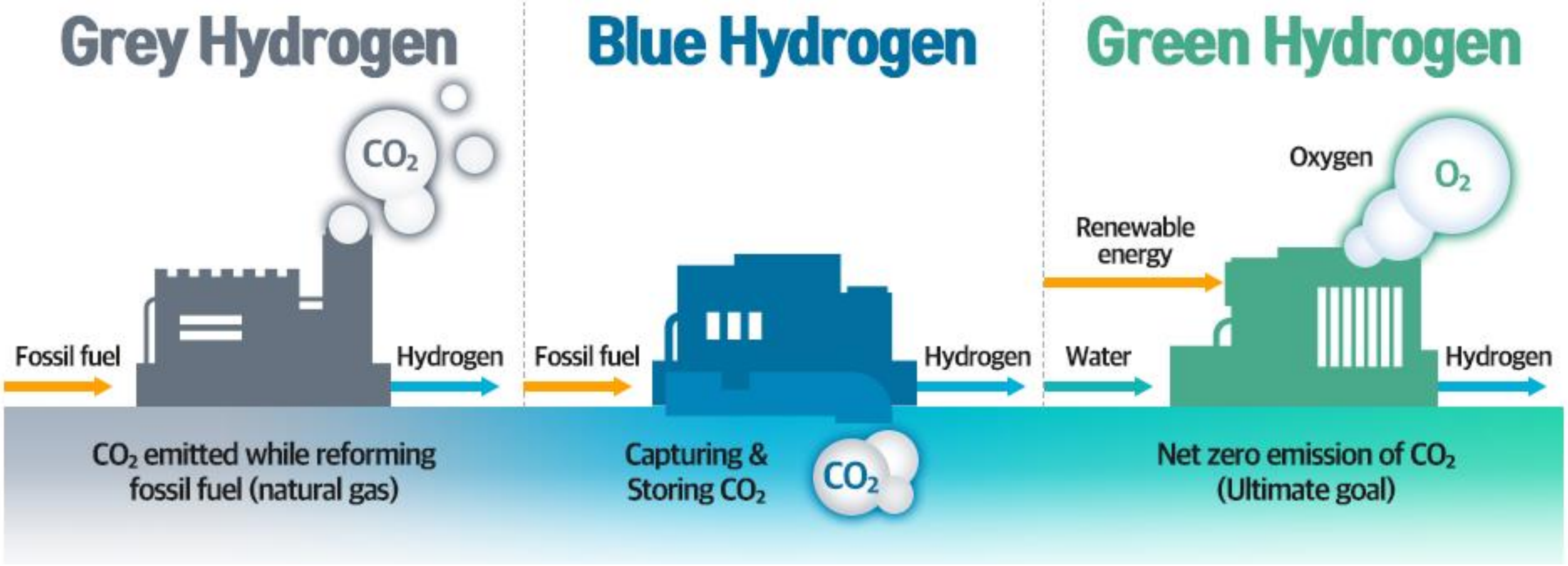




Nature, 595, 361–369 (2021)

Hydrogen productions

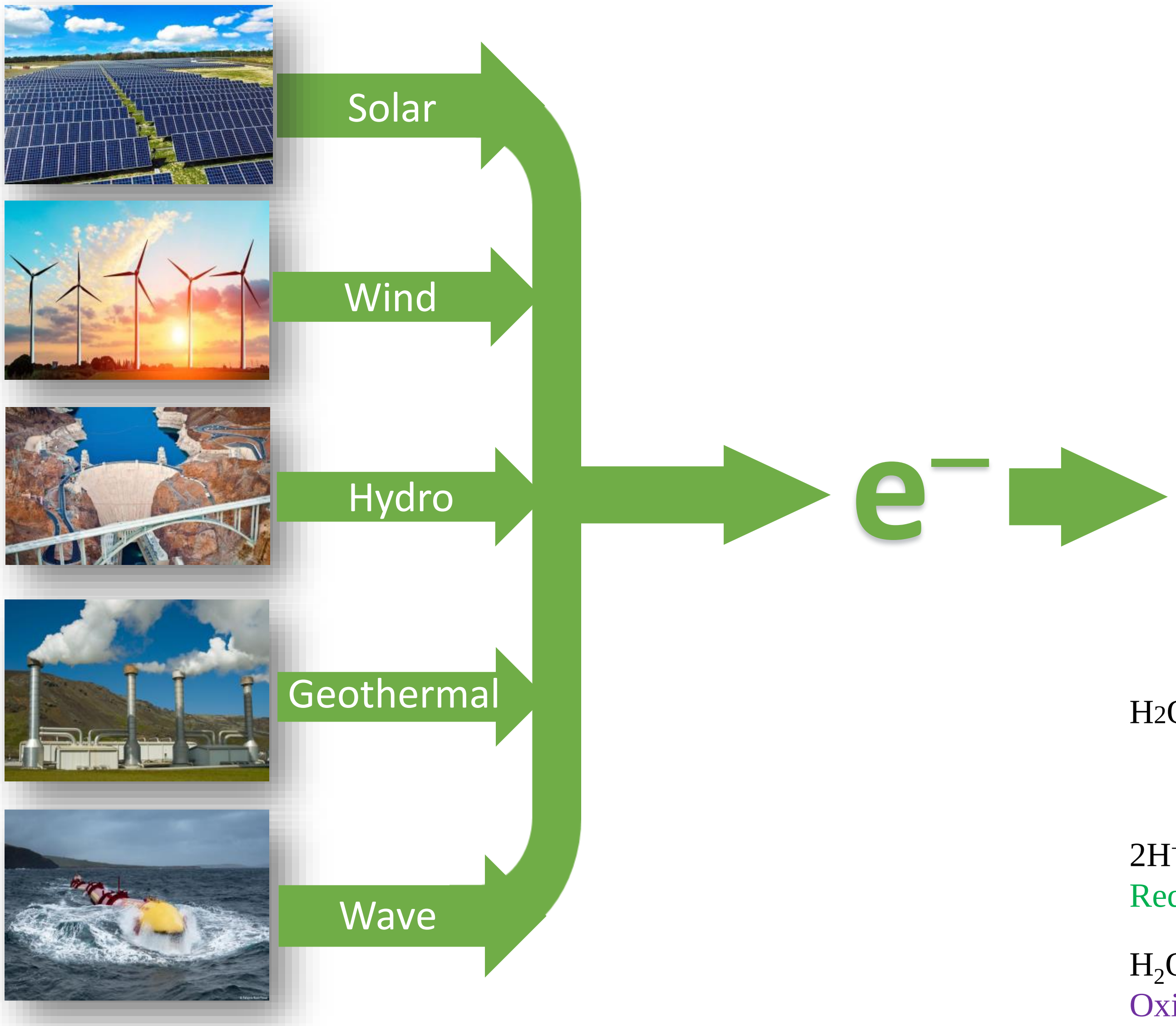
~70 million tonnes/yr



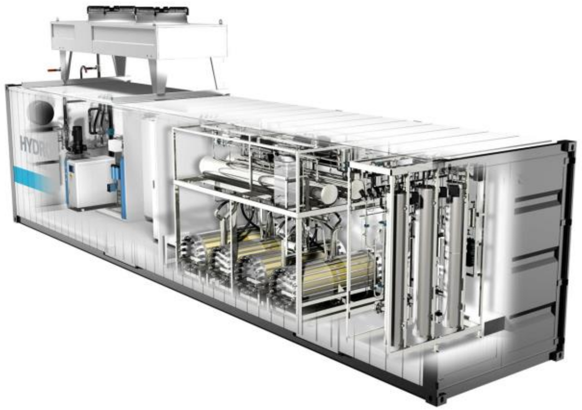
>96% of H_2 production produced from fossil fuels today

https://newsroom.posco.com/en/

Green hydrogen productions



Water Electrolysis



$H_2O\ (l) \rightleftharpoons H_2\ (g) + \frac{1}{2}\ O_2(g)$ $\Delta G = +\ 237.1$ kJ/mol $(\Delta G^0 = -nFE^0)$

$E^0_{rev} = 1.229$ V

$2H^+ + 2e^- \rightleftharpoons H_2$ $E^0 = 0$ V *vs.* SHE

Reduction reaction

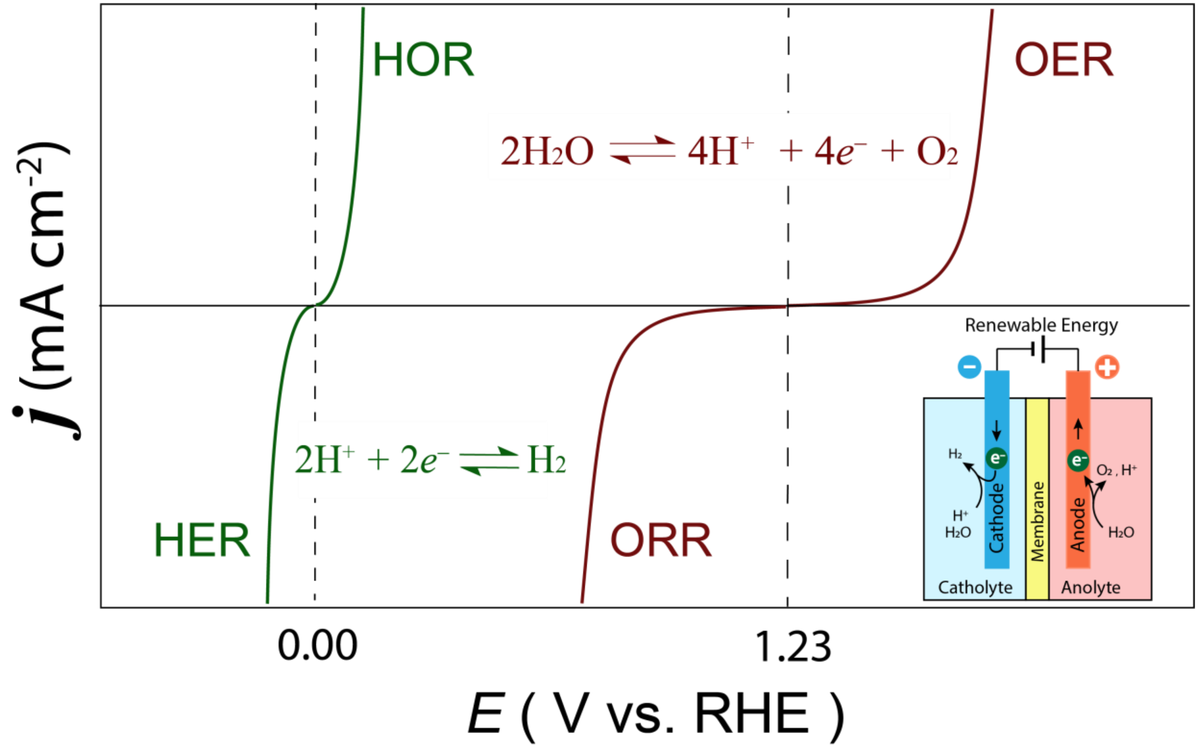
$H_2O \rightleftharpoons 2H^+ + 2e^- + \frac{1}{2}\ O_2$ $E^0 = 1.229$ V *vs.* SHE

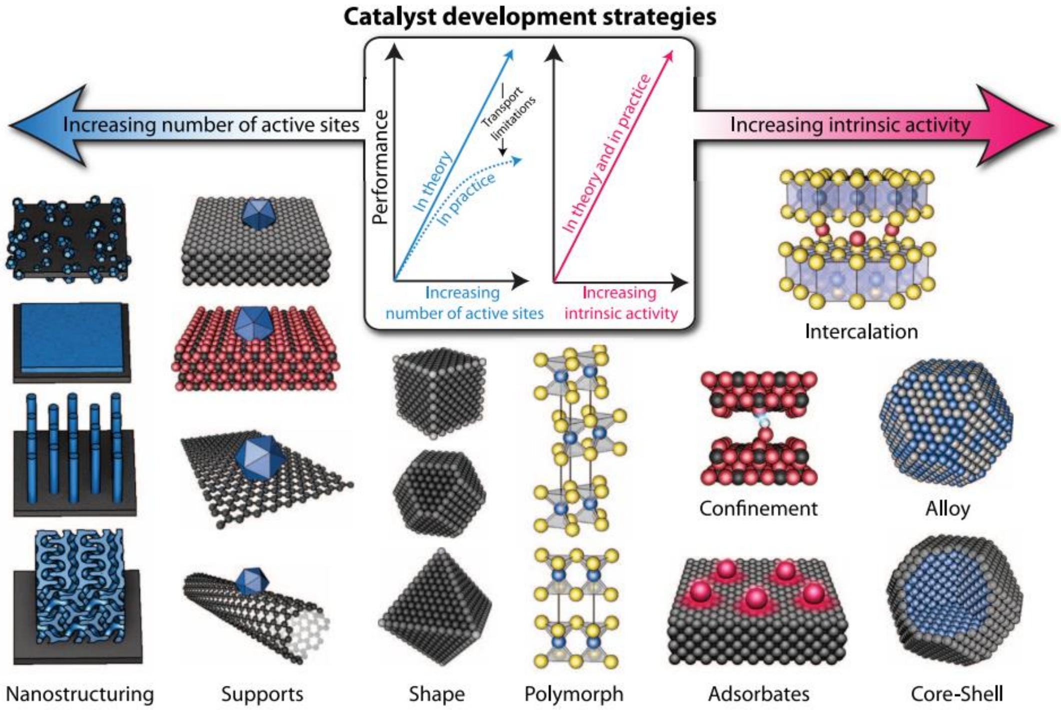
Oxidation reaction

Water Electrolysis

$2H^+ + 2e^- \rightleftharpoons H_2$ $E^0 = 0$ V *vs.* SHE
Hydrogen Evolution Reaction (**HER**)

$H_2O \rightleftharpoons 2H^+ + 2e^- + ½ O_2$ $E^0 = 1.229$ V *vs.* SHE
Oxygen Evolution reaction (**OER**)

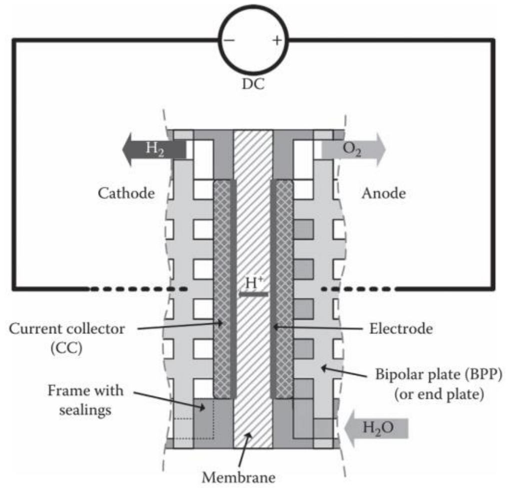


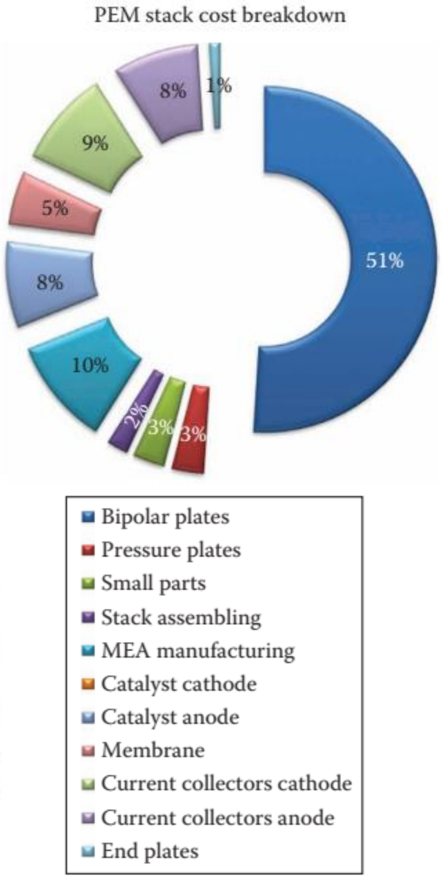


Science **355**, eaad4998 (2017)

Water Electrolysis : Alkaline, PEM, Solid oxide…

PEM water electrolyzer

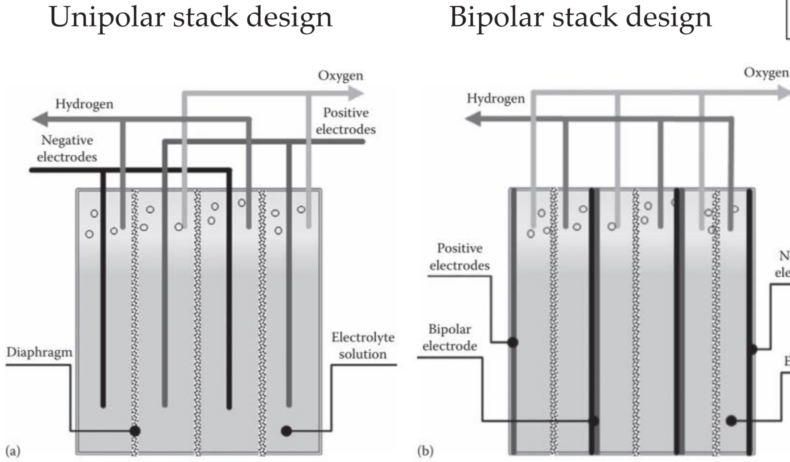


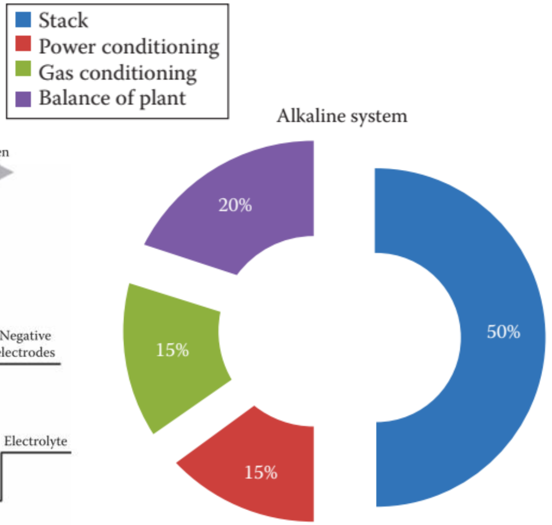


Electrode materials:
Cathode: Pt/substrates;
Anode: IrO2/TiO2.
PEM: Nafion from DuPont

Typical performance:
Current density: > 2 A/cm^2;
Efficiency [%] (HHV) 48.5–65.5;
Hydrogen purity [vol.%]: >99.999;
System lifetime: 10–20 years.

Alkaline water electrolyzer

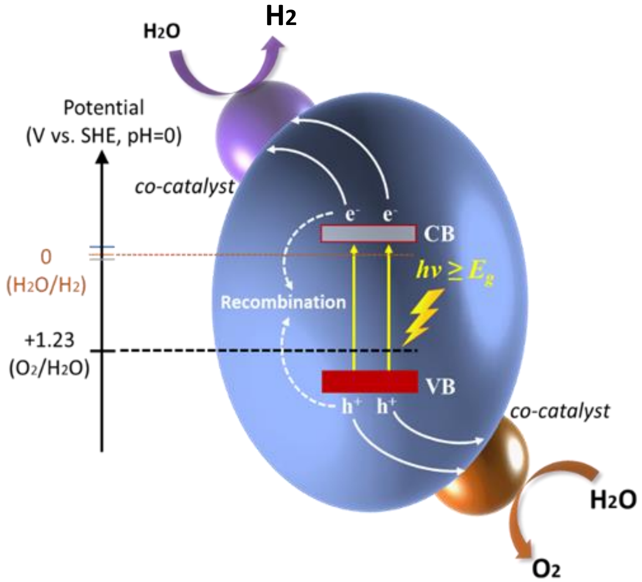


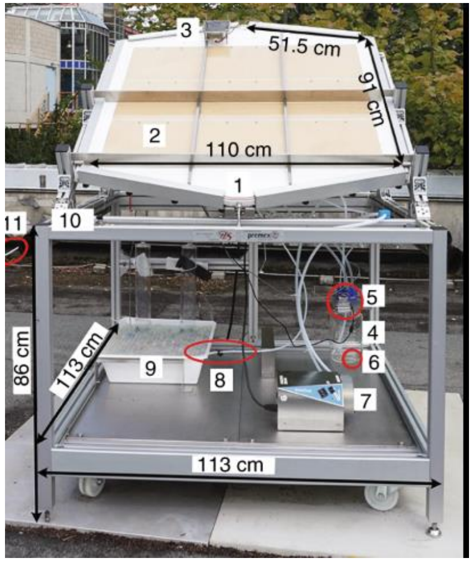


Electrode materials:
Ni treated stainless steel (corrosion resistant in alkaline media); Cobalt is usually added to the anode, while Iron and Vanadium are used at the cathode.

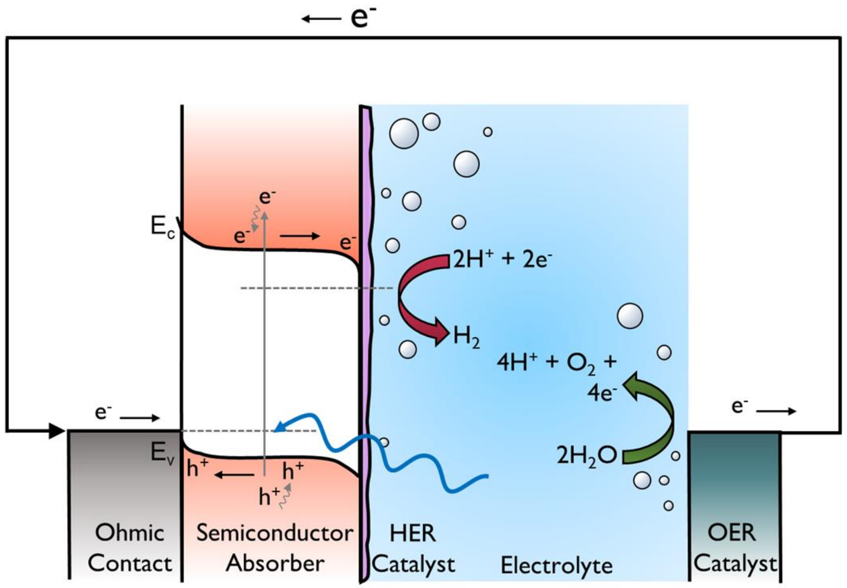
Typical performance:
Current density: ~ 500 mA/cm^2;
Efficiency [%] (HHV) 50–70.8;
Hydrogen purity [vol.%]: 99.3–99.999;
System lifetime: 20–30 years.

Photocatalytic water electrolysis





Photoelectrochemical water electrolysis



Suitable for non-centralized facilities

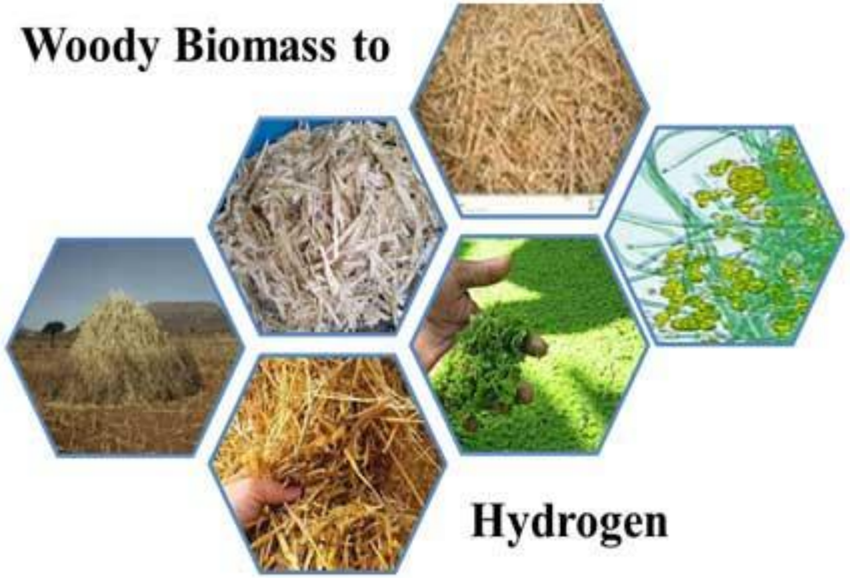
Photobiological hydrogen production

Can extend to other bio-fuel, e.g., bio-diesel

Solar Thermochemical Hydrogen production

A solar concentrator uses mirrors to capture and focus sunlight to produce temperatures up to 2,000°C, to thermal decompose water.

Biomass hydrogen production

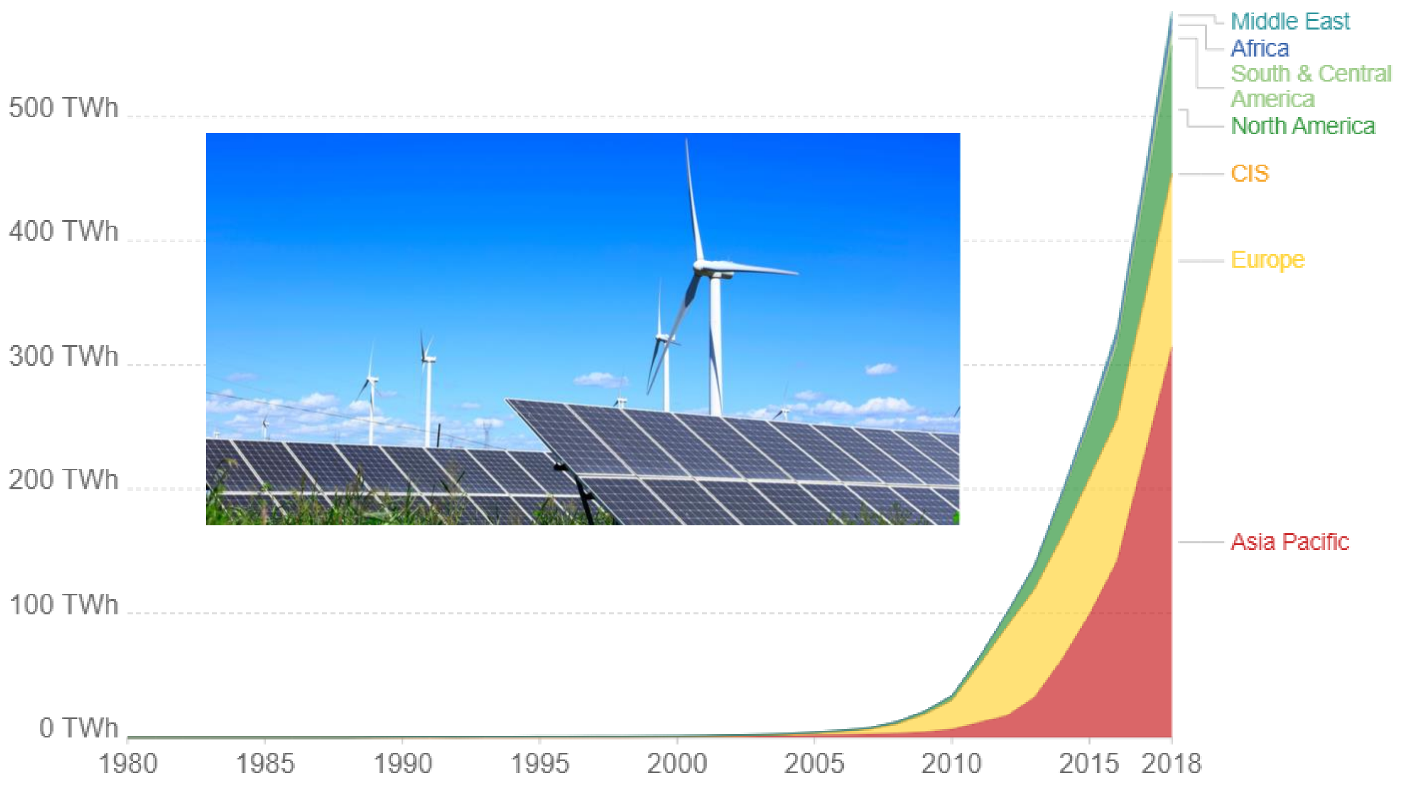


Thermal chemical, biochemical, fermentations…

Opportunities and challenges

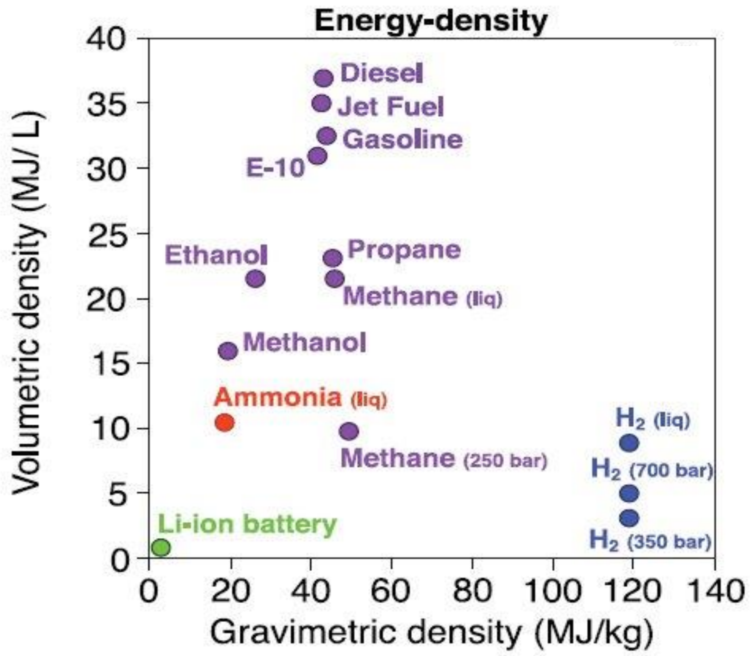
Solar energy generation by region, 1980 to 2018

Solar energy generation is measured in terawatt-hours (TWh) per year.



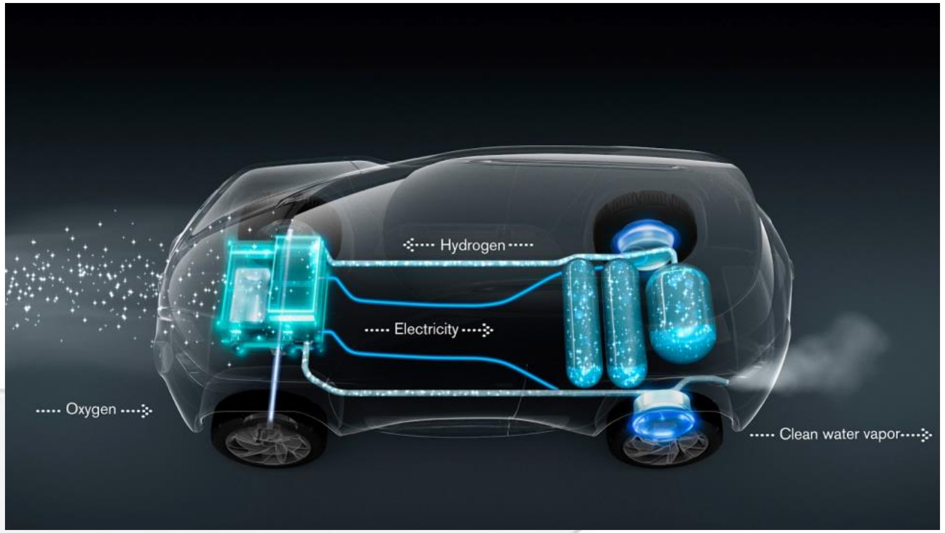
Source: BP Statistical Review of Global Energy (2019)

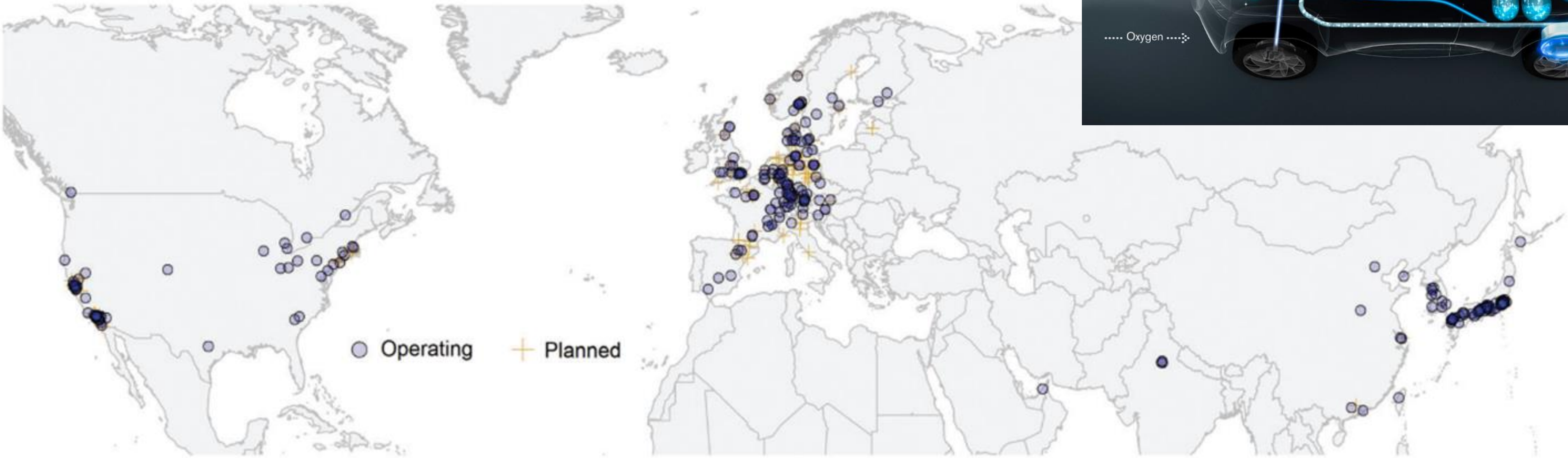
Note: CIS (Commonwealth of Independent States) is an organization of ten post-Soviet republics in Eurasia following break-up of the Soviet Union.



Storage & Transportations

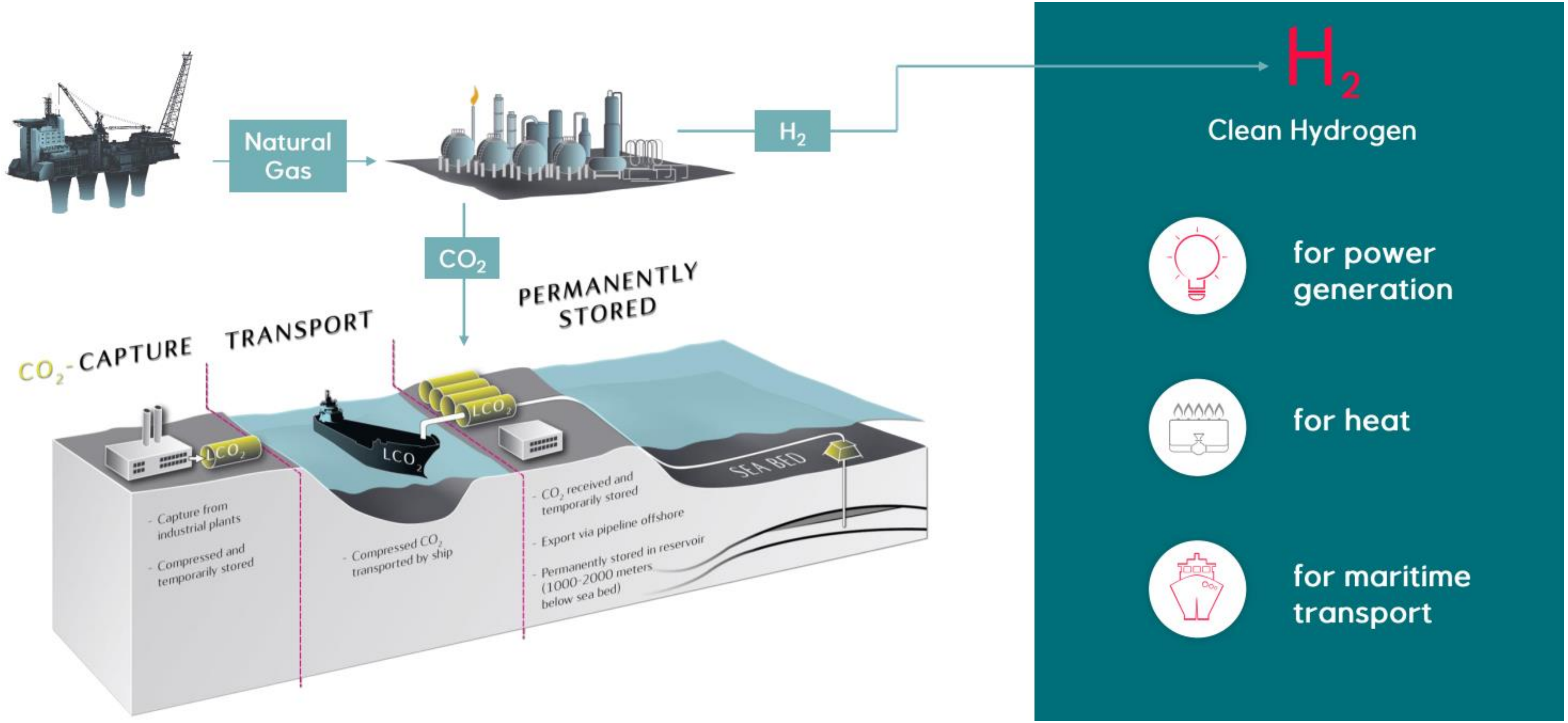
Hydrogen fueling station worldwide





https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee01157e

Thank You!



Natural Gas
H_2
CO_2
PERMANENTLY STORED
CO_2- CAPTURE
TRANSPORT
LCO_2
LCO_2
LCO_2
SEA BED
- Capture from industrial plants
- Compressed and temporarily stored
- Compressed CO_2 transported by ship
- CO_2 received and temporarily stored
- Export via pipeline offshore
- Permanently stored in reservoir (1000-2000 meters below sea bed)
H_2
Clean Hydrogen
for power generation
for heat
for maritime transport