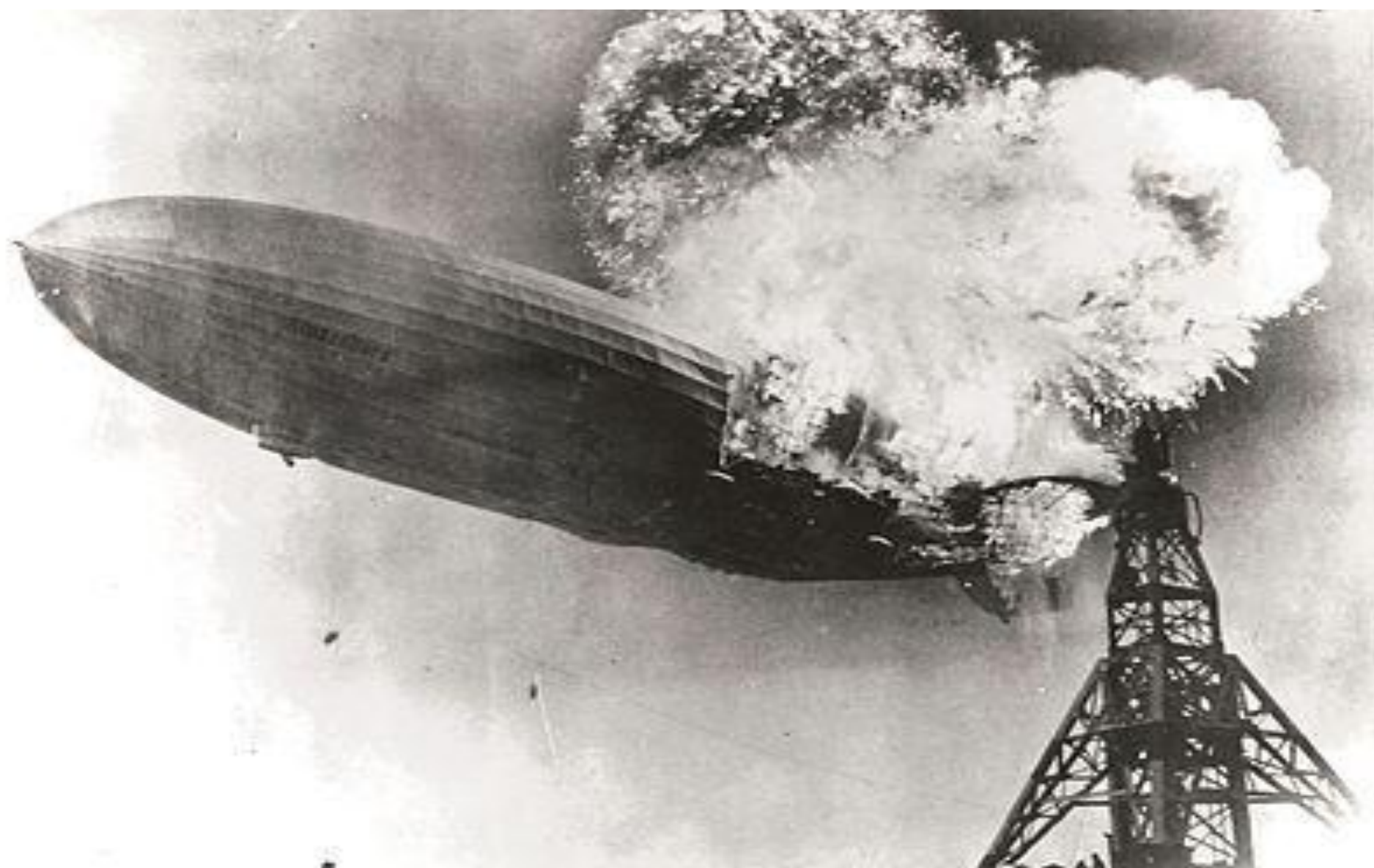


Green Hydrogen

Author: Susana Fernández-García





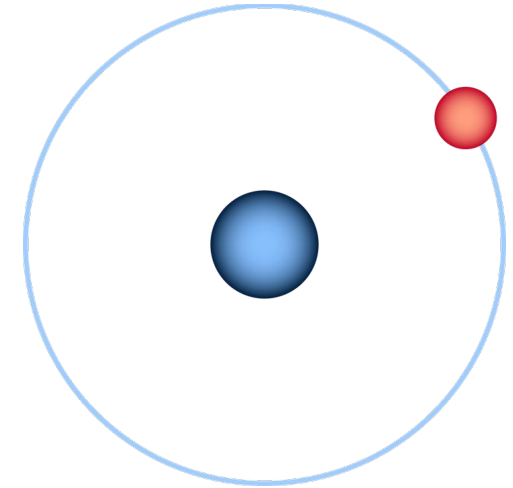




← Elemental Hydrogen

3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium



“hydros” = water

“gene” = generator

Antoine Lavoisier



Molecular
mass:
2 g/mol

Fourteen
times lighter
than air

Diffuse

Low density

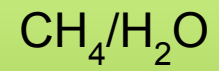
Gas:
Colourless
Odourless
Non-toxic

T_{boiling}:
-253 °C
T_{melting}:
-259 °C



Abundant in
the Universe
(75% of
matter)

Easy reaction
with other
elements:
C, O, N, F, Cl



Highly
flammable

High energy
density

High calorific
value

	Hydrogen	Natural gas	Diesel	Gasoline
Chemical formula	H ₂	CH ₄	C ₉₋₂₅ H ₂₀₋₅₂	C ₄₋₁₂ H ₁₀₋₂₄
Molecular mass (g/mol)	2	16	-	-
Carbon content (%)	0	75	86	84
Density (volumen a 1 atm, 0 °C, kg/m ³)	0.089	0.72	830	730-780
Energy density (volume 1 atm, 0 °C, , MJ/m ³)	10.7	33.0	35·103	33·103
Calorific value (Inferior-Superior) (KJ/mol)	119.9-141-6	50.0-55.5	42.5-44-8	42.5-44.8
T _{autoignition} (°C)	580	540	250	350
Minimum ignition energy (MJ)	0.017	0.30	-	0.29
Flammability scale in air (%vol)	4-75	5.3-15	0.6-5.5	1-7.6
Propagation speed in air (1 atm, 25 °C, m/s)	1.85	0.38	0.37-0.43	0.37-0.43
Diffusion coefficient (1 atm, 0 °C, m ² /s)	8.5·10-6	1.9·10-6	-	-



Summary

0%
Carbon

High
calorific
value

Fuel/
Electricity

Diffusion

High
flammability

High
density

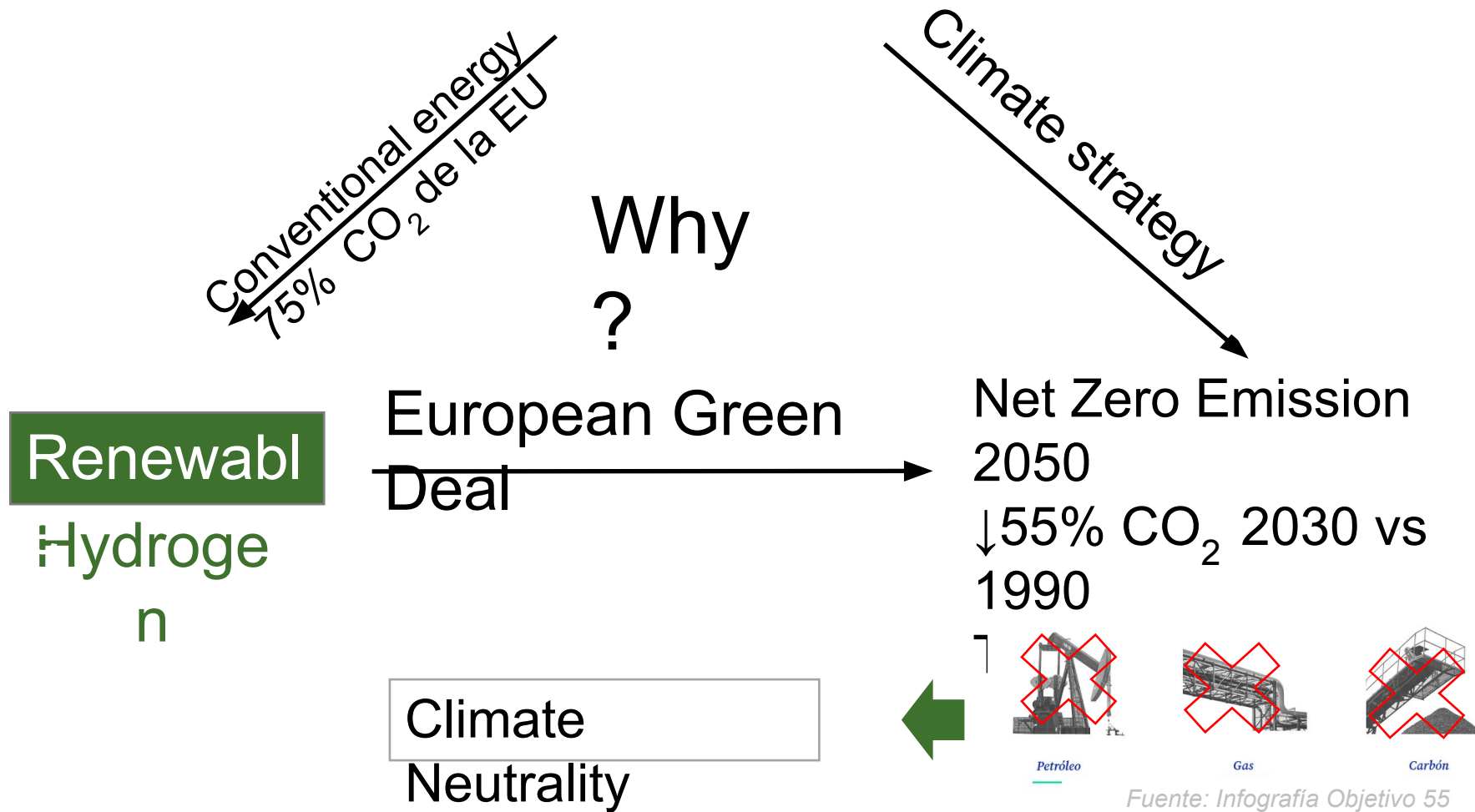




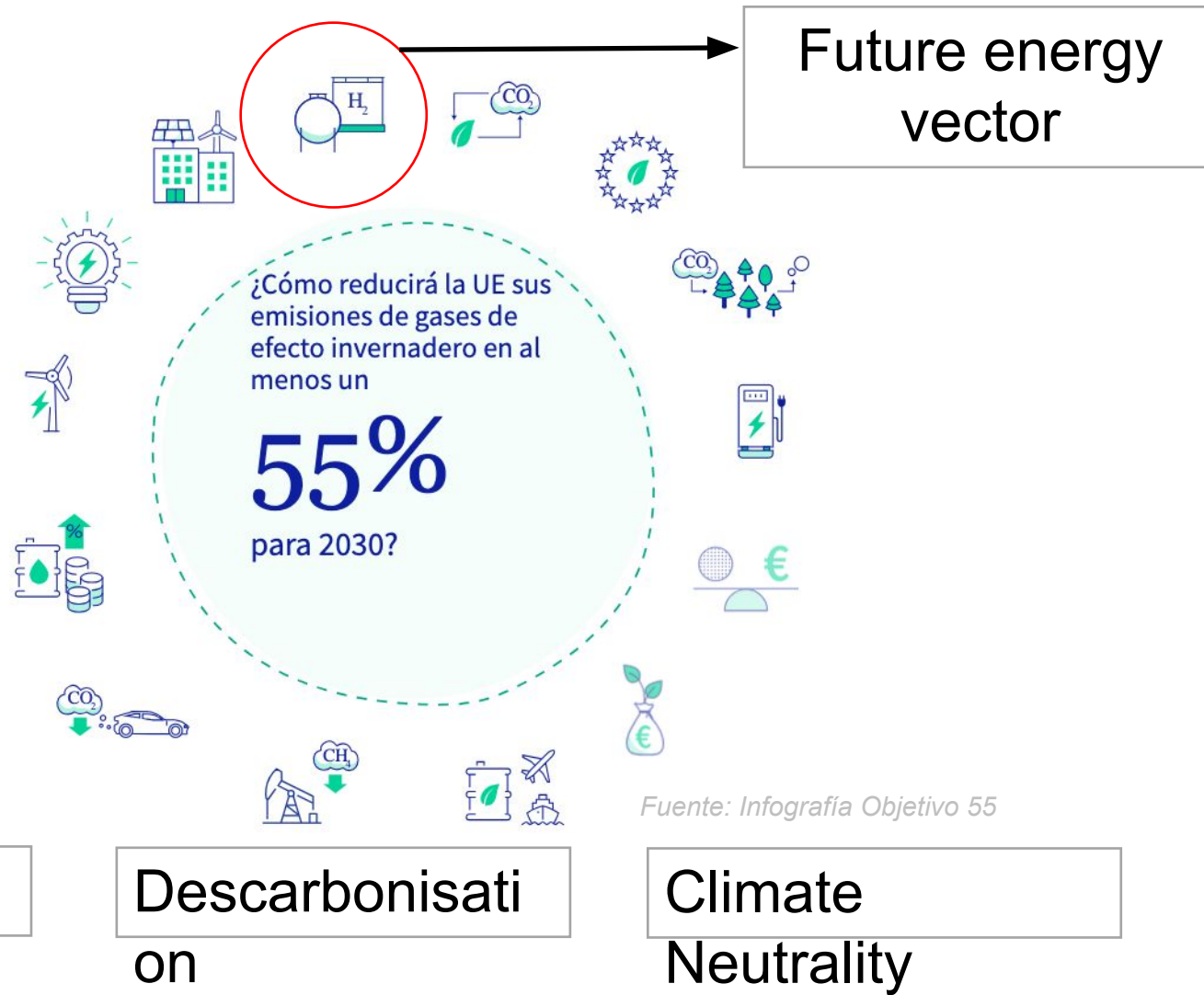
Energy
Vector



Energy
Store
Sustainable
e



Fit for 55 European Green Deal



SDG 7: Affordable and Clean Energy





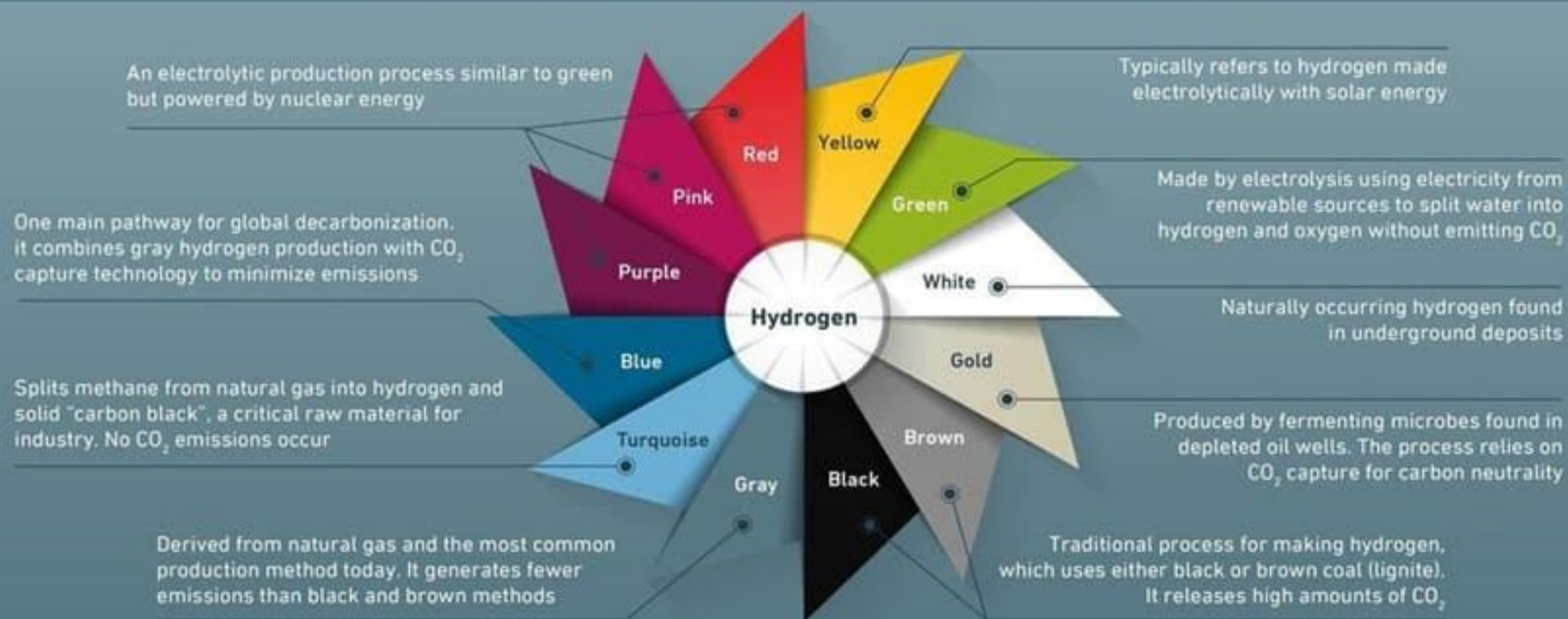
Jules Verne "The Mysterious Island"
Water in its O_2 and H_2 components, an
inexhaustible source of energy.

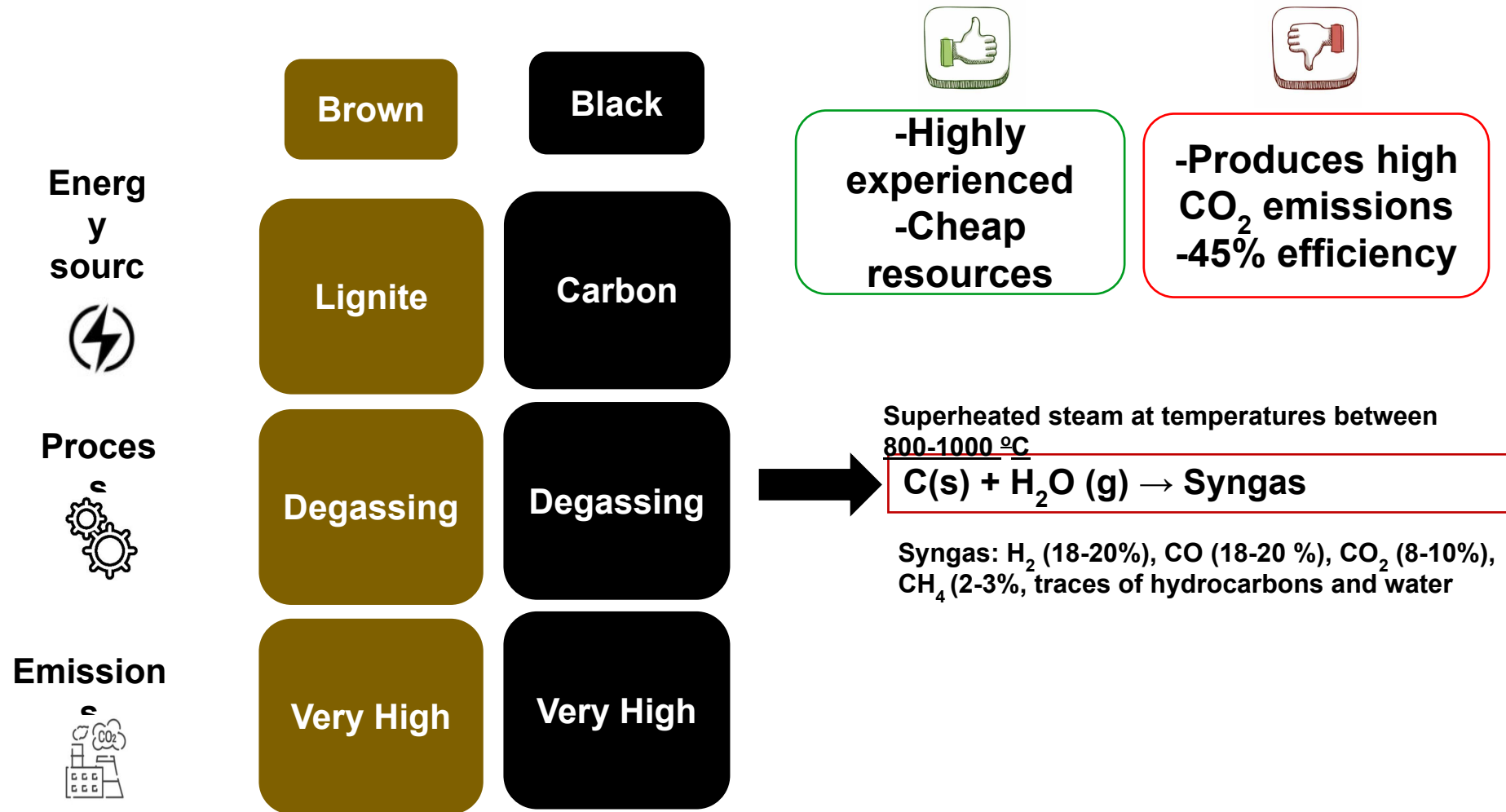


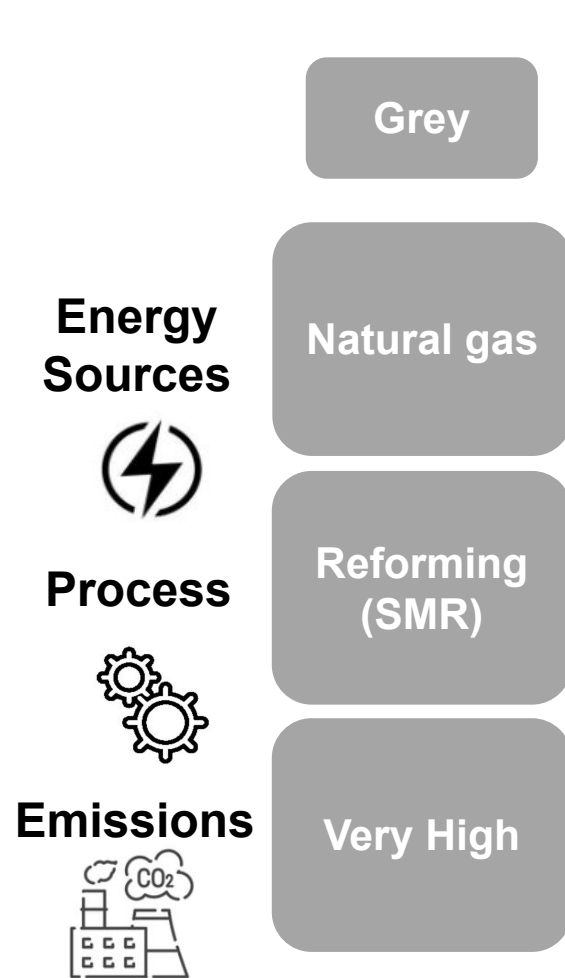
Production

THE HYDROGEN COLOR WHEEL IS EXPANDING

Hydrogen is one of the key replacements for fossil fuels in industry and a critical factor in the race to net zero CO₂ emissions by 2050. But if there's going to be enough hydrogen to meet the expected growth in demand, low-carbon production of the gas will need to be scaled up. There is an expanding range of techniques to achieve this, each referred to by a different color





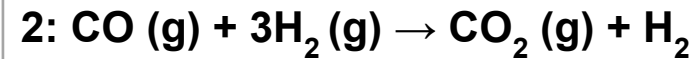
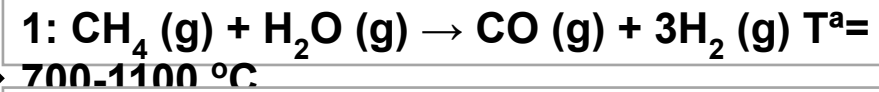


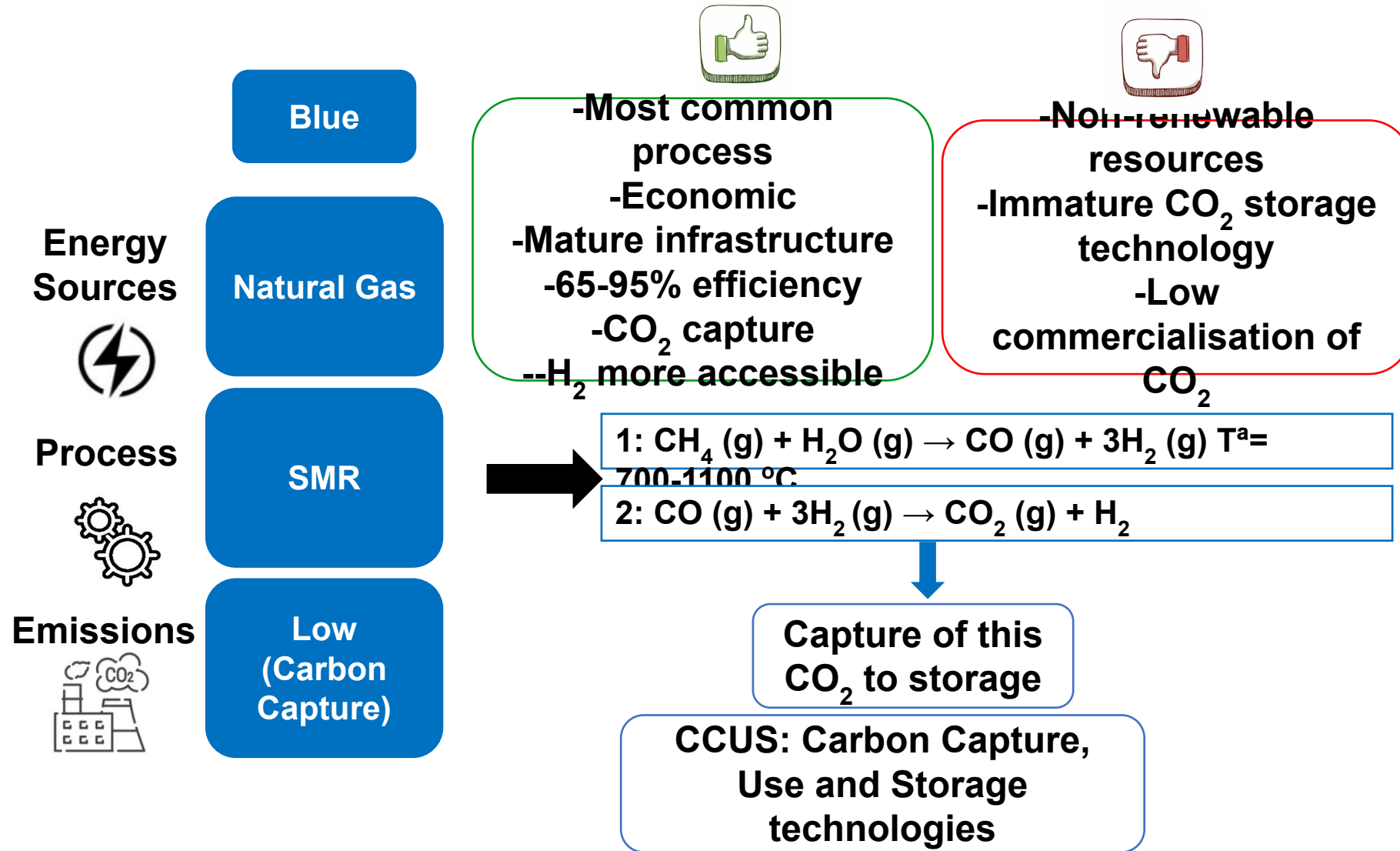
-Most common process
-Economic
-Mature infrastructure
-65-95% efficiency

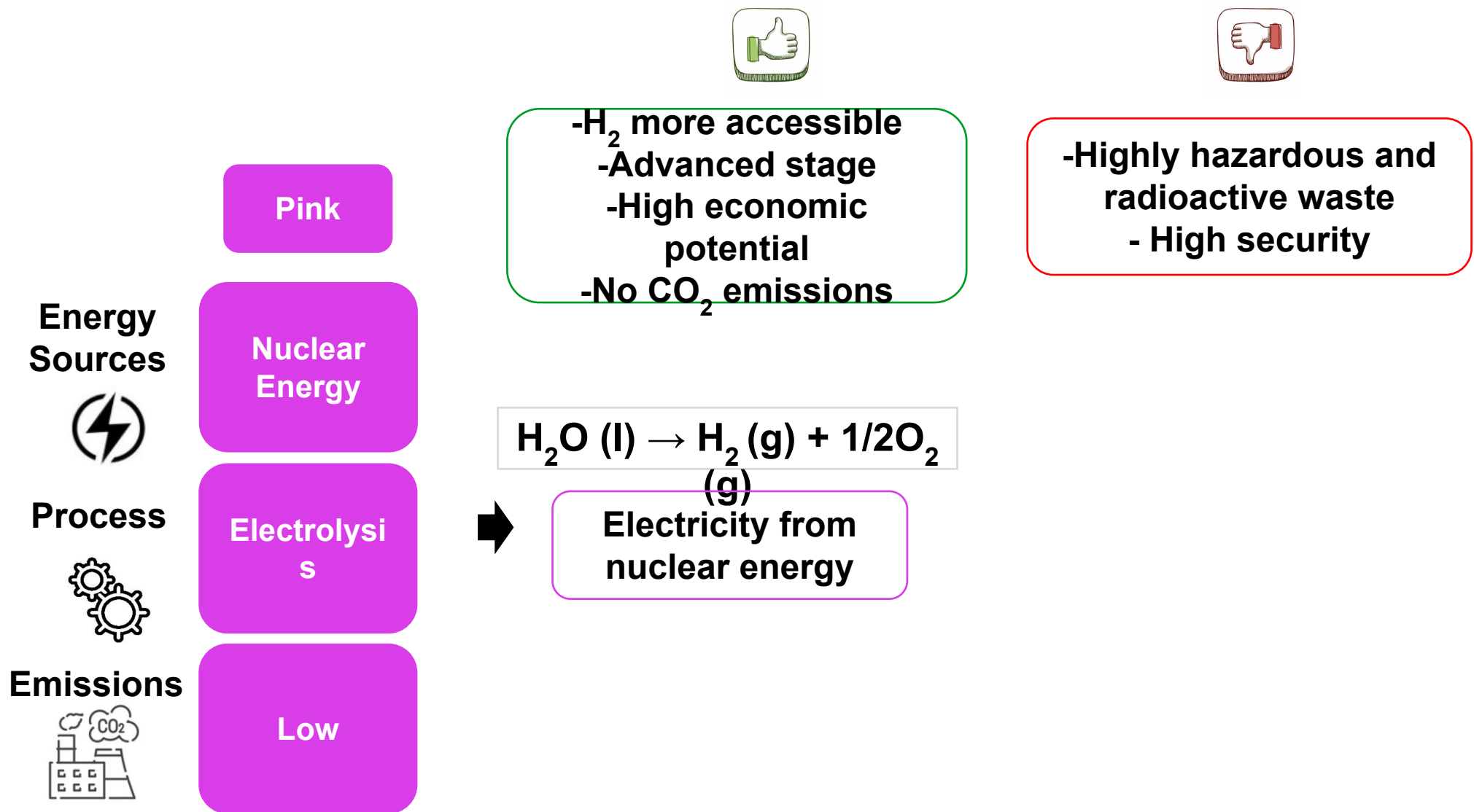


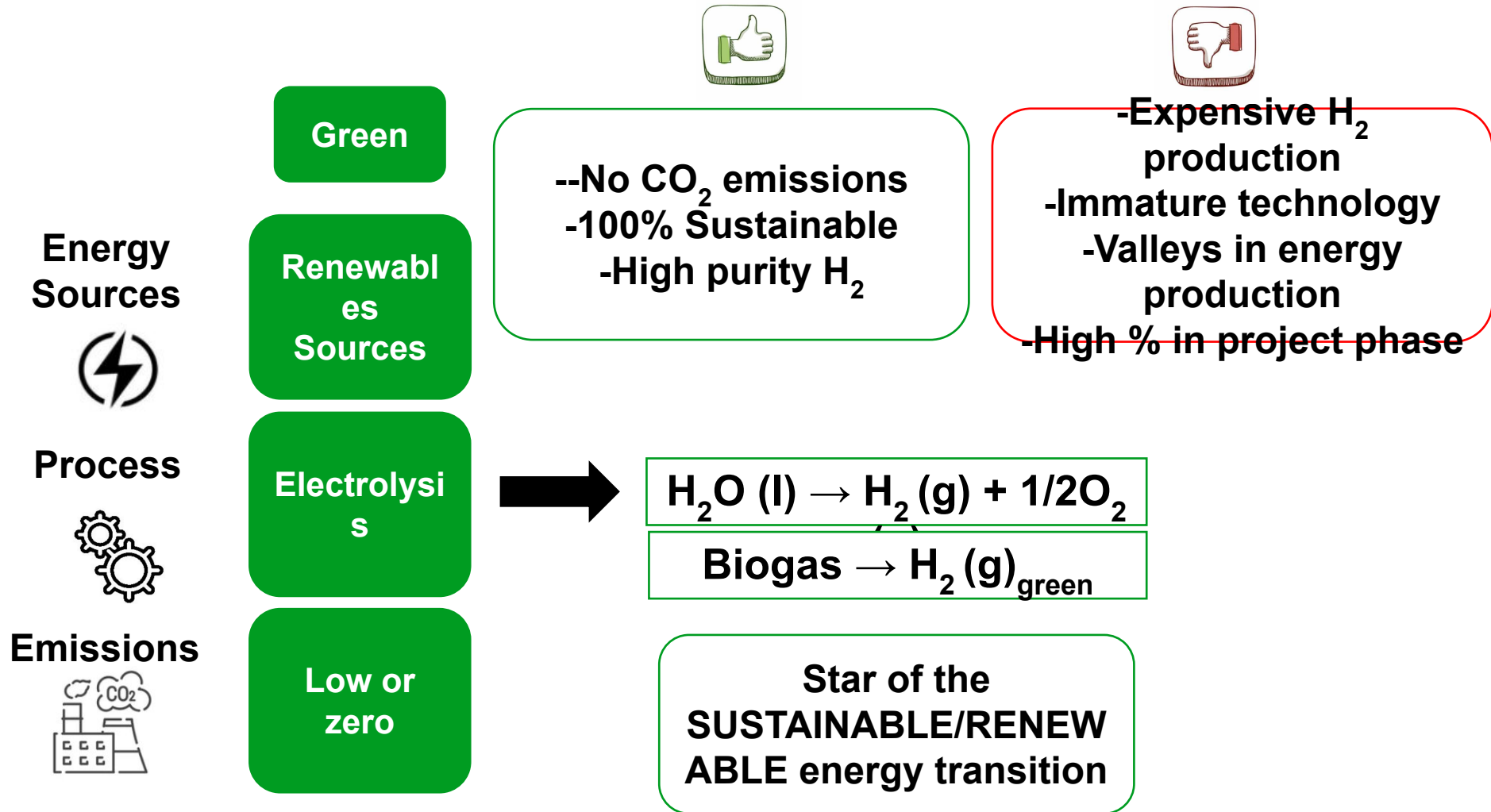
-Produces high CO₂ emissions
-Non-renewable resources

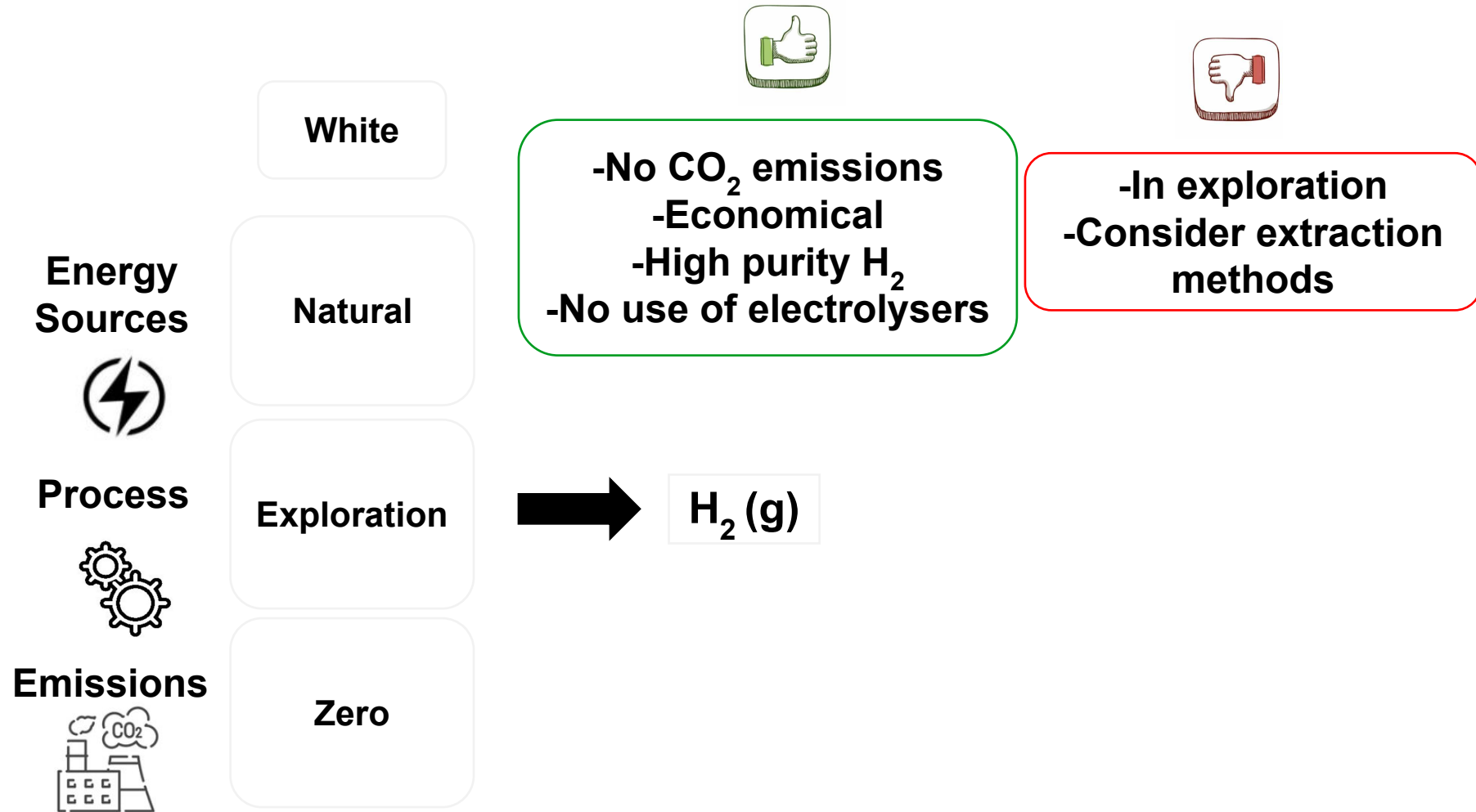
Catalyst; Nickel (Ni)











H₂

Technologies

Economic
security



Climate
neutrality

Hydrogen production

Natural gas/Fossil
hydrocarbons/**Biogas**

H₂O decomposition

With CO₂
emission

Without CO₂
emission

Nuclear
energy

Renewable
energy

Natural gas/Fossil
hydrocarbons/**Biogas**

**Steam methane reforming
(SMR)**

Efficiency:
70-85%

Partial oxidation (POX)

Efficiency:
60-75%

**Autothermal reforming
(ATR)= SMR + POX**

Efficiency:
60-75%

Green H₂

Biogas

**Biogas (CH₄ (g)) □ Purify and enrich
(upgrading process) biogas □ Biomethane
substitutes natural gas**

SMR

POX

ATR

Desgassing

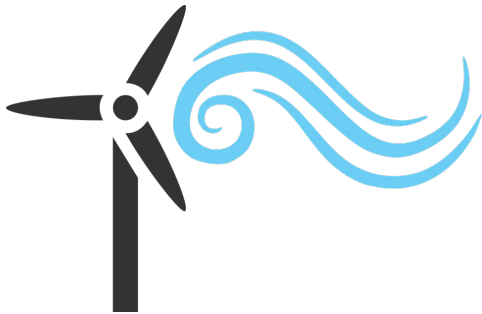
Biometha

Green H₂

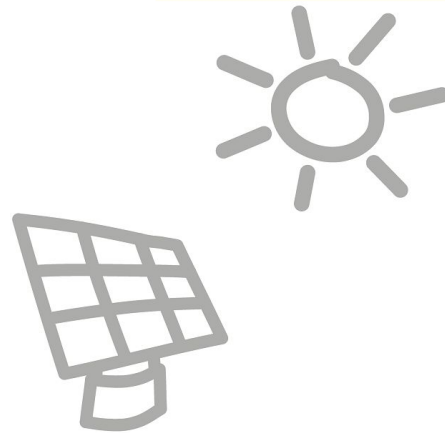


Green H₂

Wind



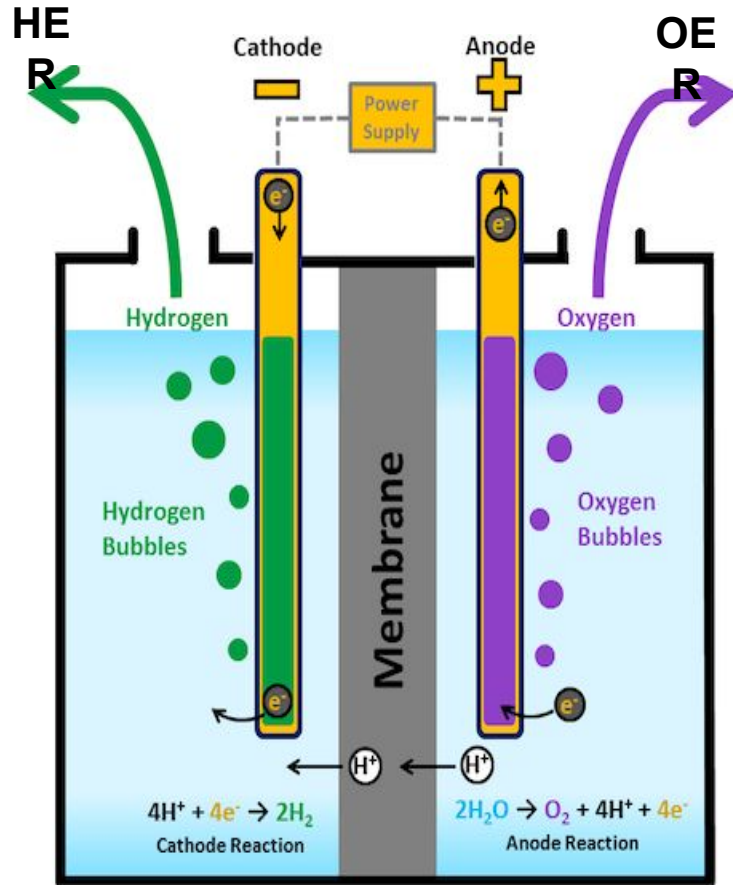
Solar



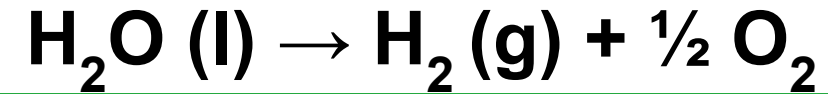
H₂O Decomposition

Electrolysis

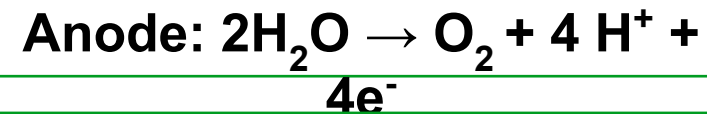
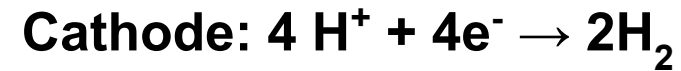
Green H₂



Electrolysis

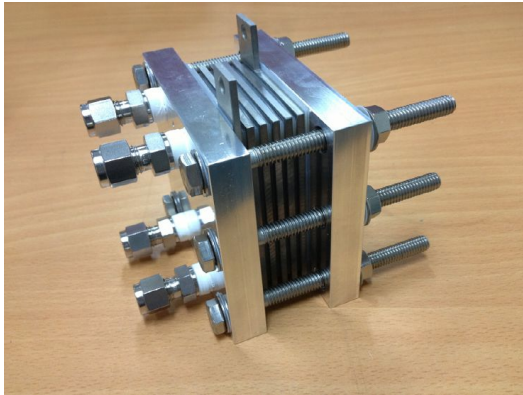


Electrolite: Water (l)

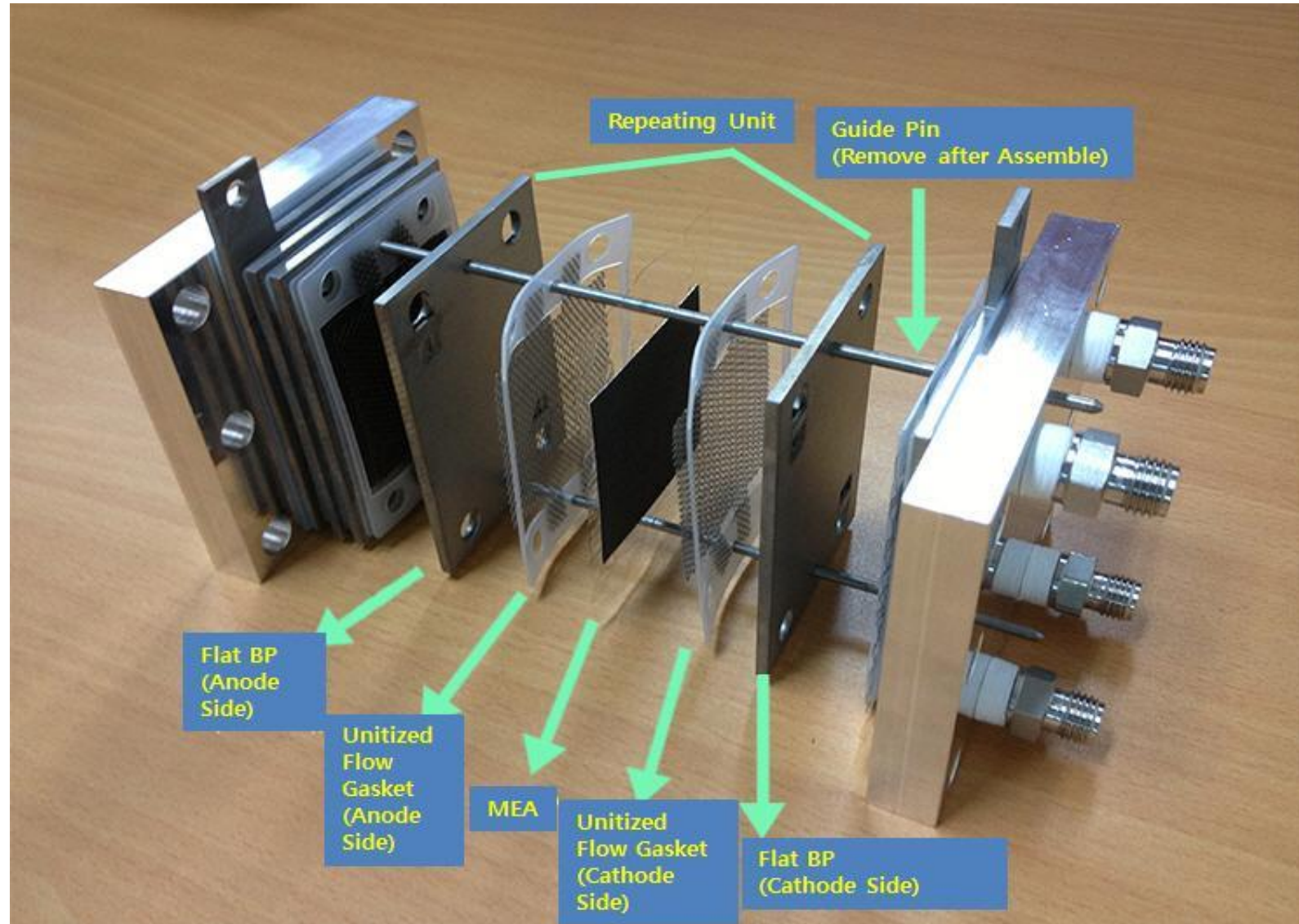


Efficiency of electrolyzers (low temperature): 50-70%

Electrolysers



Stack



Electrolysers

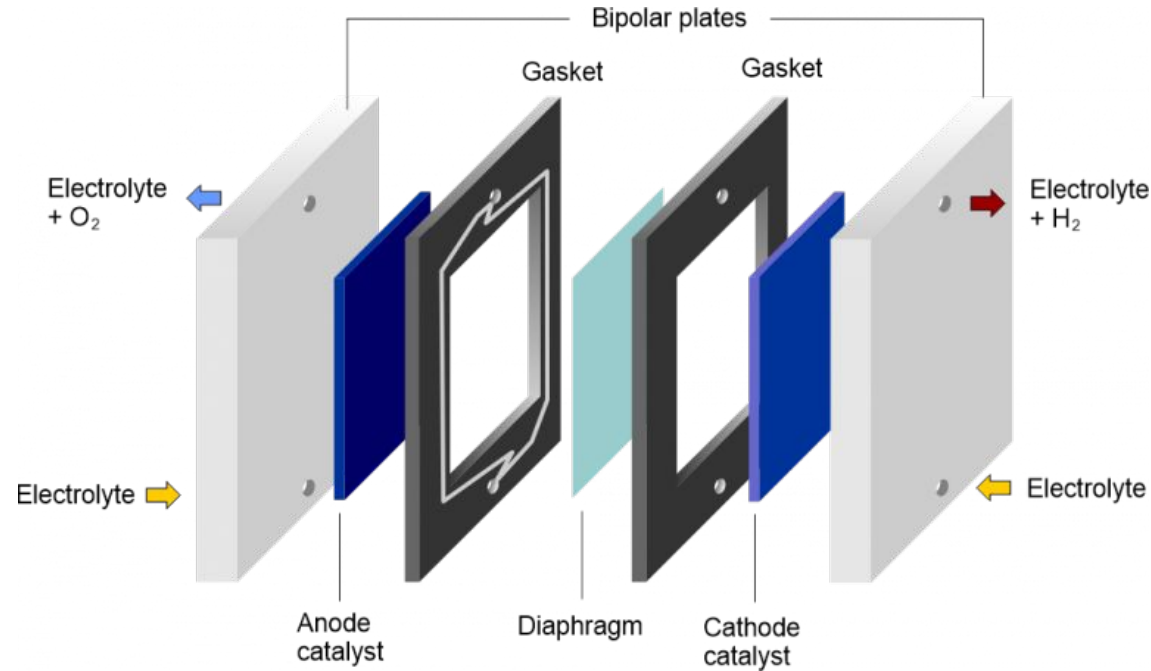
Alkaline

Proton Exchange Membrane (PEM)

Anion Exchange Membrane (AEM)

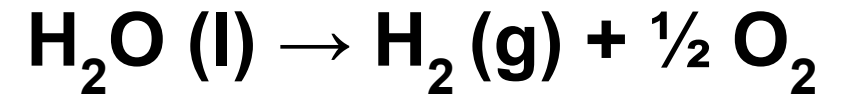
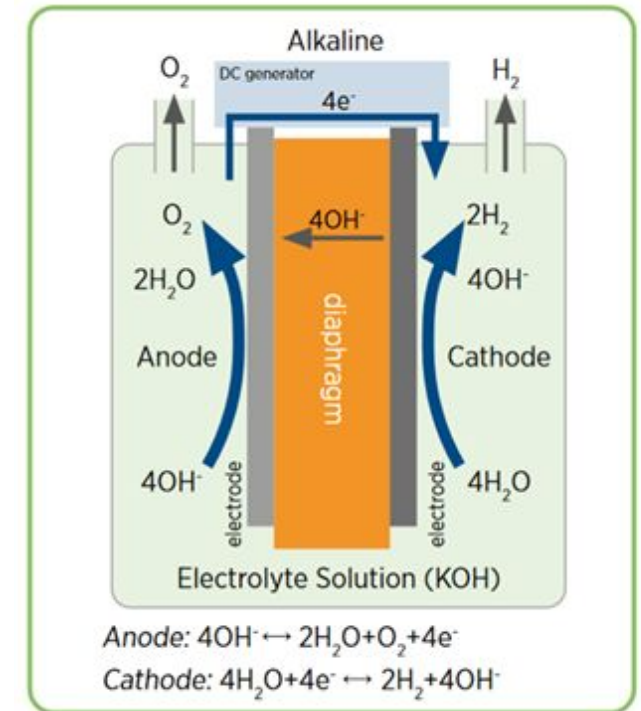
Solid Oxide Electrolysis Cell (SOEC)

Alkaline



Temperature:
70-100 °C

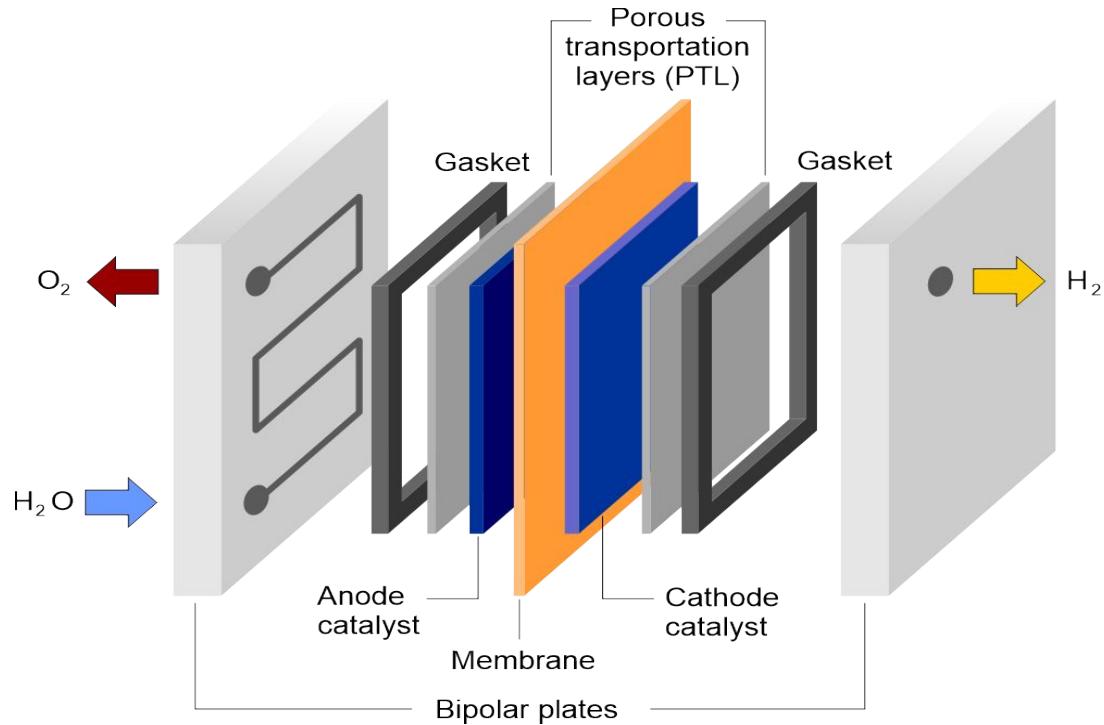
Efficiency:
60-70%



Anode/Cathode: Nickel

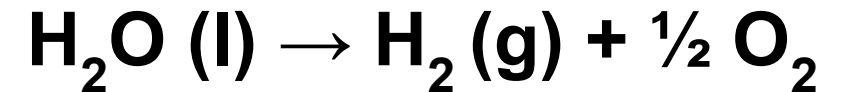
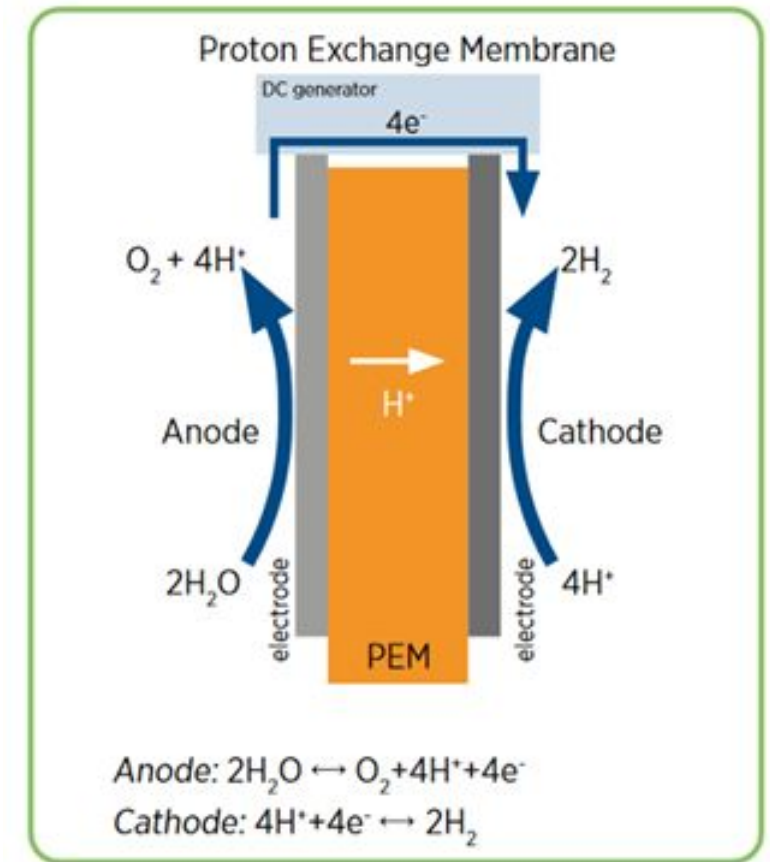
**Electrolyte: KOH ó NaOH
25-30% wt**

Proton Exchange Membrane



Temperature:
50-80 °C

Efficiency: 55-60%
Theoretical
efficiency: 90-95%

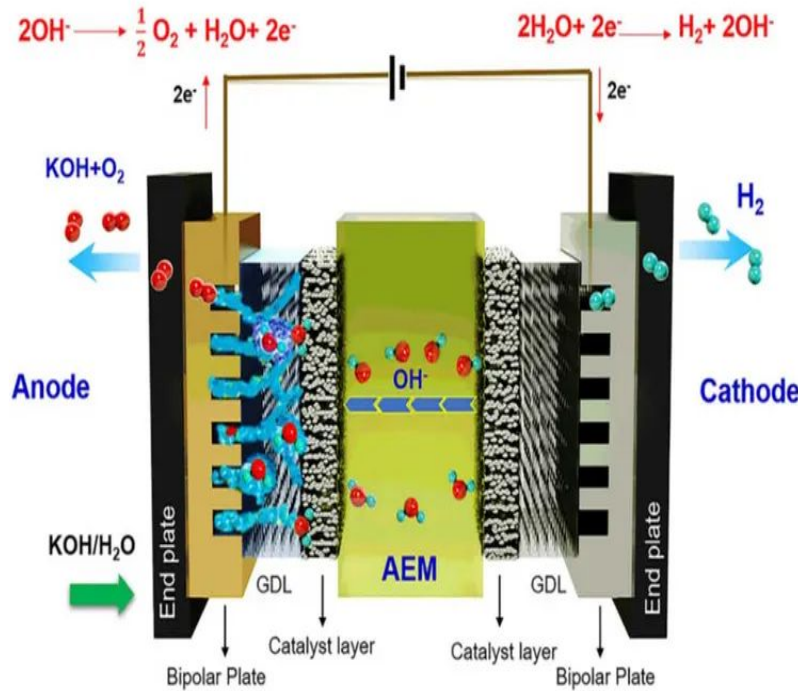


Anode: Iridium oxide

Cathode: Platinum

**Electrolyte: Polymeric
membrane**

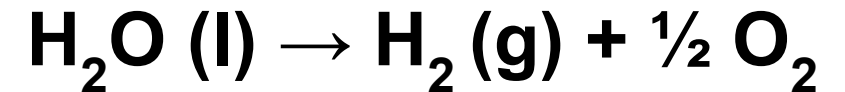
Anion Exchange Membrane



Temperature:
40-60 °C

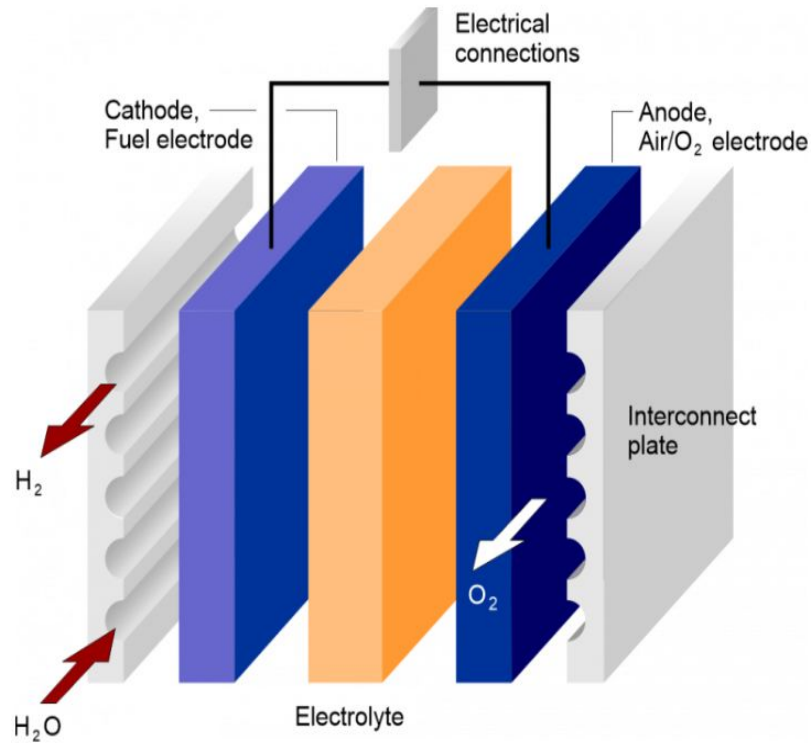
Research Phase

Alkaline + PEM = AEM



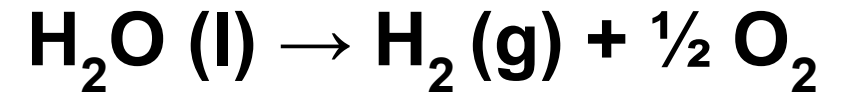
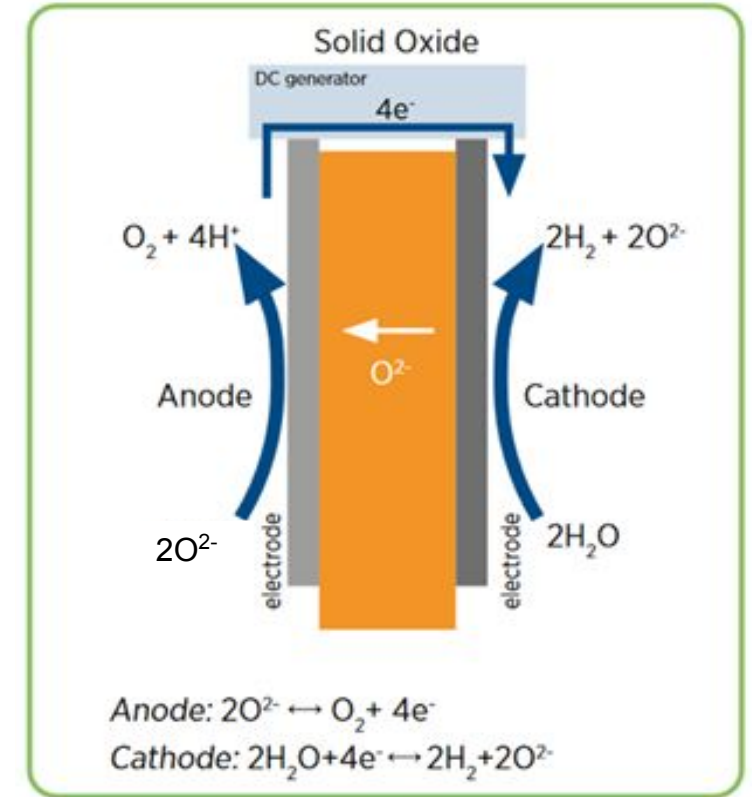
Electrolyte: Polymeric
membrane

Solid Oxide Electrolysis Cell



Temperature >
700 °C

Efficiency: 75-80%



Anode/Cathode: Nickel +

YSZ
Electrolyte: YSZ



Alkaline

- Commercial and mature technology
- Medium to high efficiency
- Inexpensive materials (non-noble metals)
- Low cost



- Large volume
- Corrosion problems
- Low hydrogen purity

PEM

- Mature developing technology
- High efficiency
- High purity hydrogen
- High responsiveness
- Compact cell

- Use of noble metals
- High cost of materials
- Corrosion problems
- Low working power

AEM

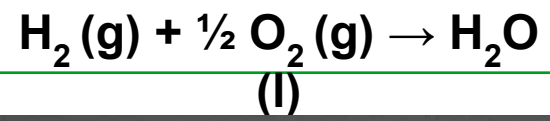
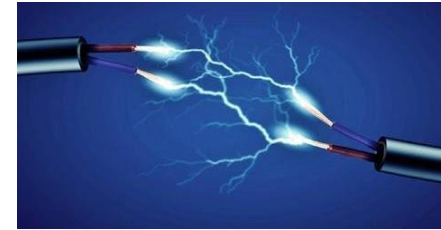
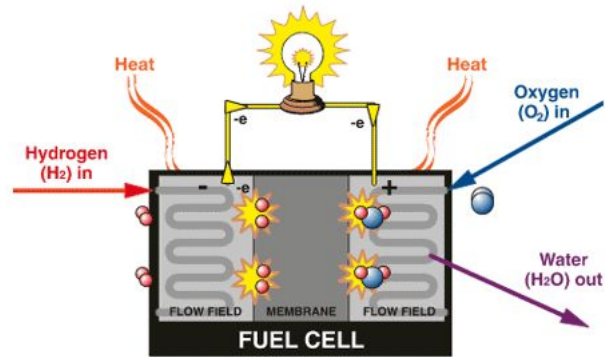
- Cheaper than PEM
- No use of precious metals
- Low cost
- Compact cell

- Research phase
- Low performance at laboratory scale
- Membrane degradation

SOEC

- Use of ceramic metals
- Low cost of materials
- High degree of energy efficiency

- Immature technology
- Little commercialised
- High volume
- Low durability
- High temperatures





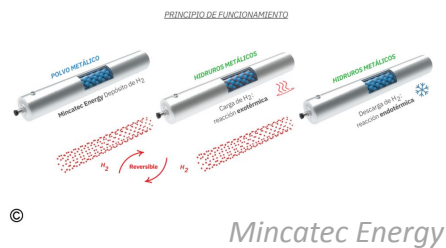
Store

Compressed H₂



Ariema

Metal hydrides: LiH, LiAlH₄



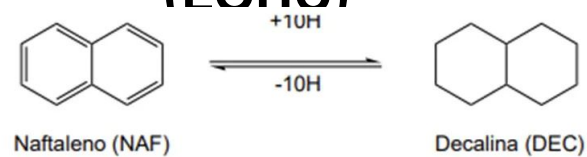
Green Ammonia



Liquefied H₂



Liquid Organic Hydrogen Carriers (LOHC)



Renewable Methanol



AtlantHy



Uses



Industria

H

Industry

Refining

**Use as
feedstock:
To remove
impurities from
crude oil
Upgrading
heavy crudes**

Metallurgic

**Use as an energy
vector:
Energy source for
making alloys
Use as feedstock
material:
Reducing agent in
alloys**

Chemistry

**Use as
feedstock:
To produce
green ammonia
and methanol.**



Integración
sectorial

H

Sectorial Integration

Energy storage

**Use as an
energy
vector:
Fuel cells**

Electric

**Use as an
energy vector:
Absorbing
renewable
electricity
discharges.**



Integración
sectorial

H

Sectorial Integration

Gas sector

**Use as a fuel:
Gradual
incorporation
into the gas
pipeline by
“Blending”
(50% of H₂)**

Circular economy

**Use as
feedstock:
H₂ produced
from renewable
biogas, biomass**



Movilidad

H

Mobility

**Fuel Cell Electric
Vehicles (FCEV)**

**Combined with
electric batteries**



Toyota Mirai Concept 2021

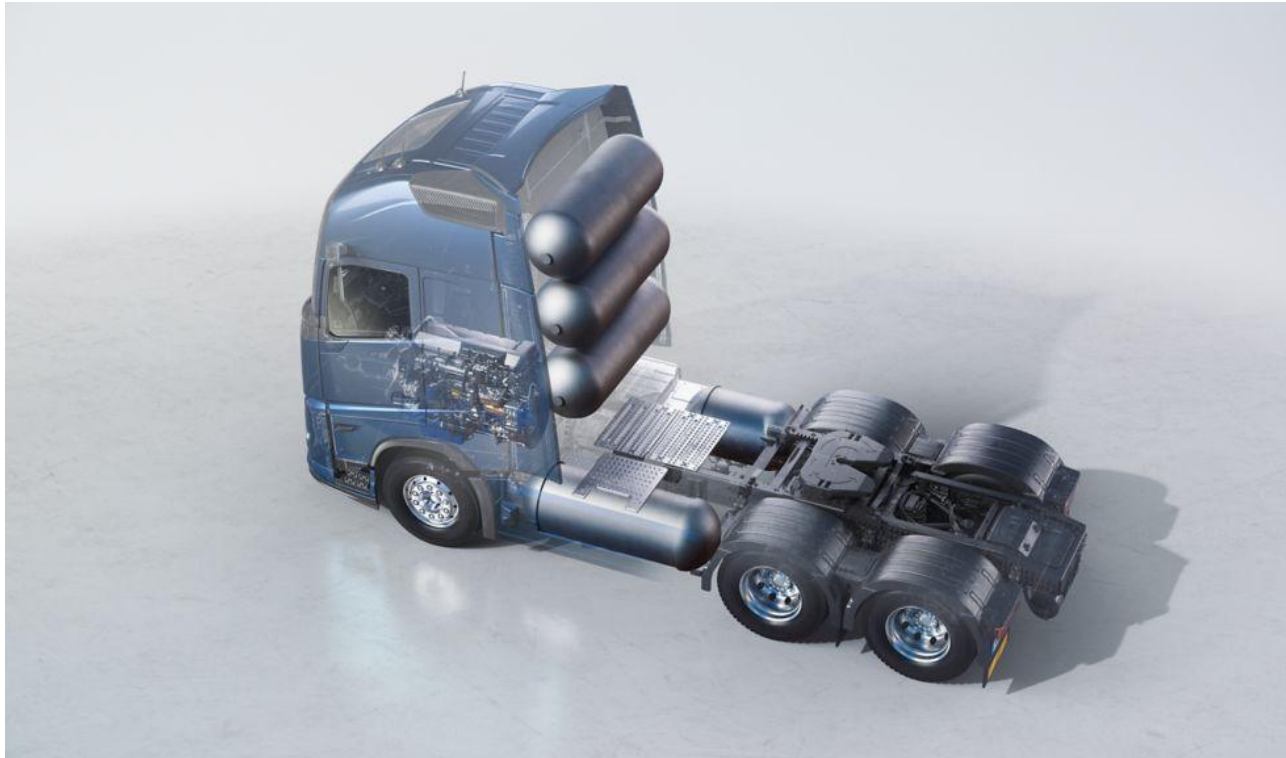


Movilidad

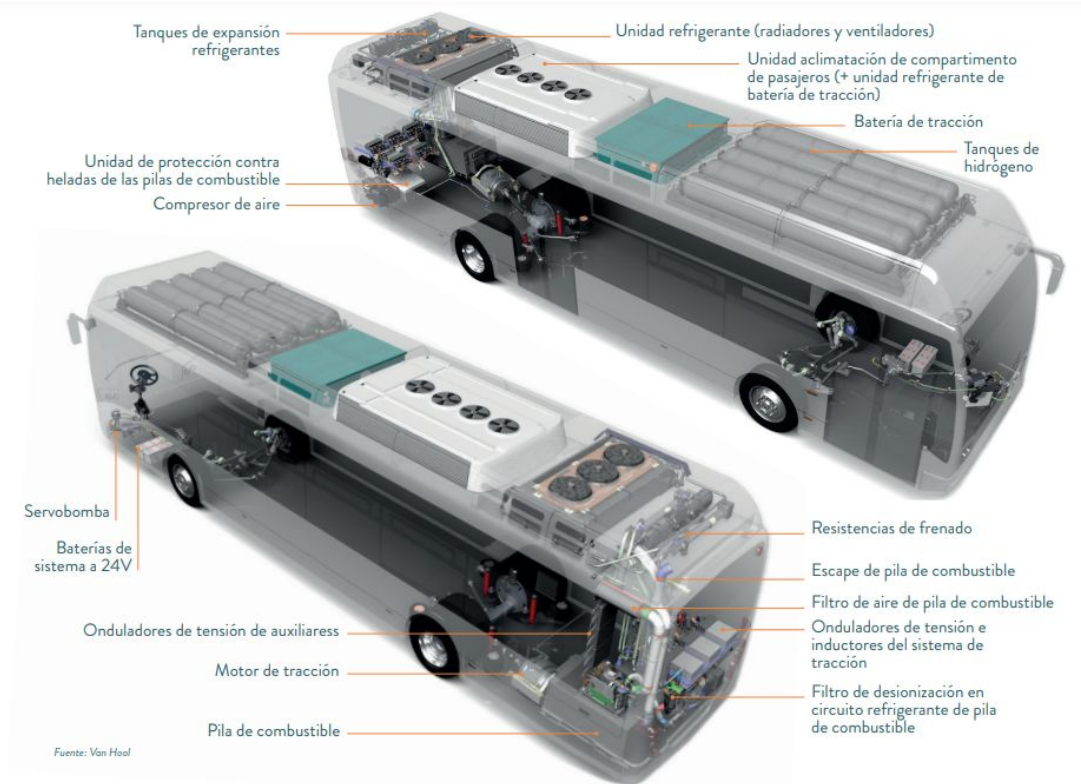
H

Mobility

Road



Volvo: hydrogen-powered combustion engine



Hydrogen Buses



Movilidad

H

Mobility

Railway

El tren de hidrógeno FCH2Rail inicia pruebas entre Torralba y Soria

Es parte del proyecto conjunto que desarrollan Adif, Renfe Operadora y CAF. Estas pruebas buscan evaluar las prestaciones del tren híbrido bimodal de pilas de combustible.

NOVIEMBRE 15, 2023 **LUIS INI**

HIDRÓGENO

TECNOLOGÍA E I+D

ESPAÑA



Imagen: FCH2Rail



Movilidad

H

Mobility

Maritime

**Use as energy
vector (electricity)/
fuel:
Small vessels and
machinery in ports
and cargo
terminals.**

Bramble
Energy



Prototype of
Reachstacker





Movilidad

H

Mobility

Maritime

**Use as energy
vector (electricity)/
fuel:
Small vessels and
machinery in ports
and cargo
terminals.**

Bramble
Energy



Prototype of
Reachstacker





Movilidad

H

Mobility

Aviation

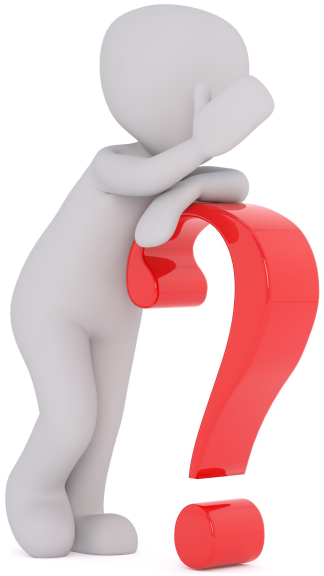
**Sustainable Aviation
Fuel (SAF): Biokerosene**

**Fuel cell propulsion
for aircraft, airport
and terminal
machinery and
cargo terminal
equipment**



FOTO: AIRBUS





Is hydrogen just a fad or is it here to stay?

Thank you for
your attention!

e-mail: susana.fernandezgarcia@gm.uca.es