NEEST

NEW ENERGY & ENVIRONMENTAL SOLUTIONS AND TECHNOLOGIES

TETHYS WEBINAR – GREEN HYDROGEN PRODUCTION

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INTRODUCTION

Why hydrogen? Climate change

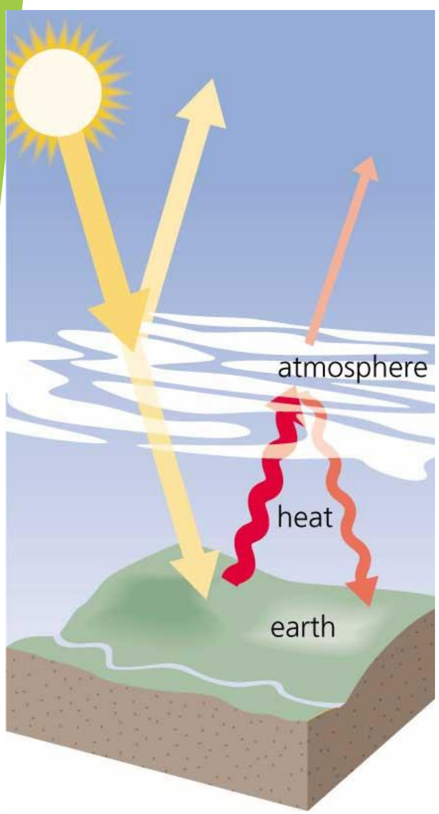
Hydrogen (H_2) as energy carrier

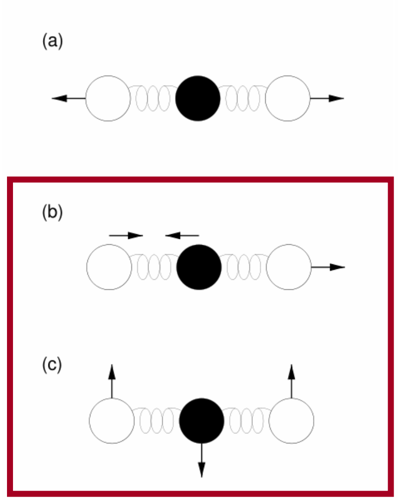
Alternative fuels - European policies

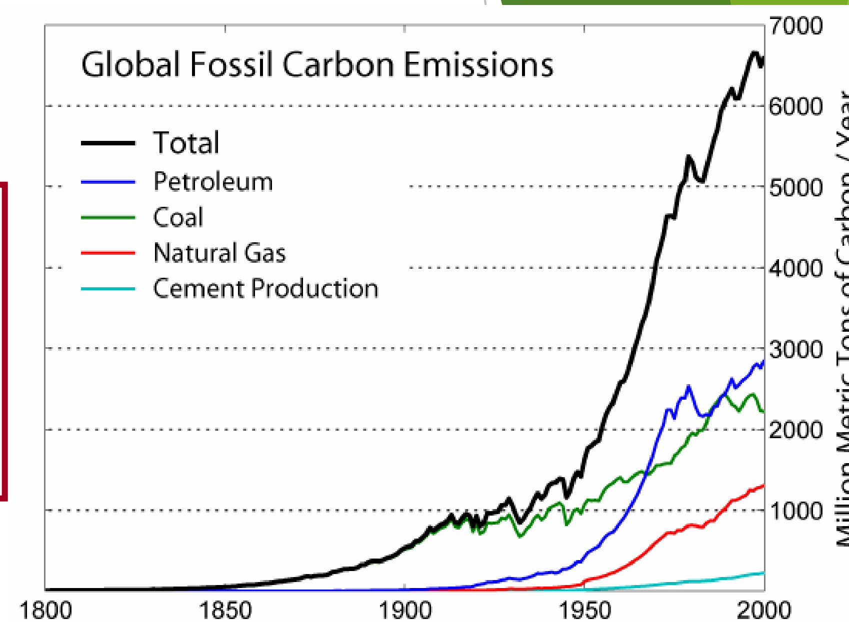
Environmental Crisis ….. before!

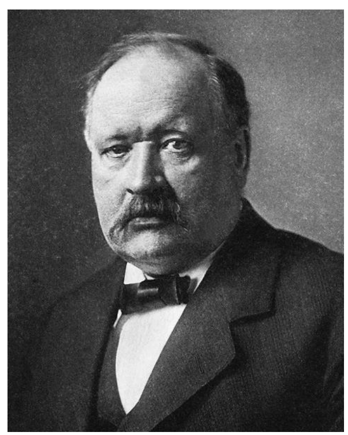
$C+O_2 \rightarrow CO_2$

Greenhouse Gas









Svante Arrhenius
(1859-1927)

If the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.

"On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground", *Philosophical Magazine* **41** (1896) 237-276

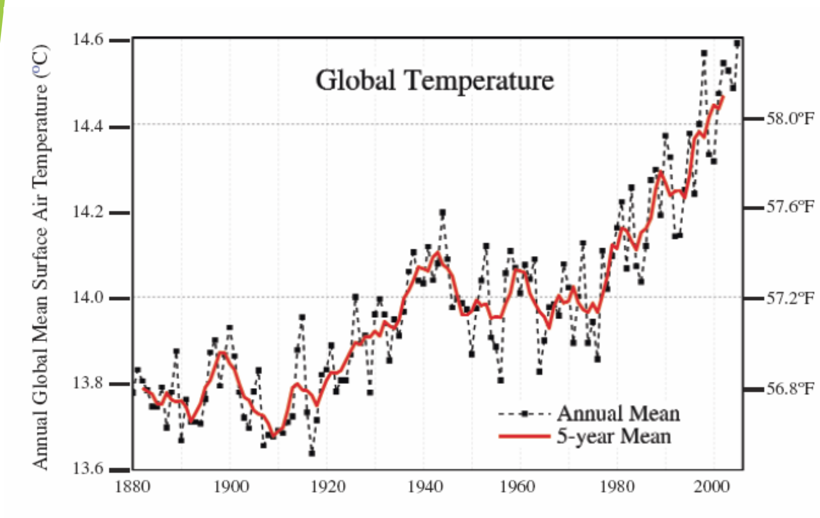
still valid in the simplified expression by Myhre et al. (1998).

Environmental Crisis

The debate on global warming is over.

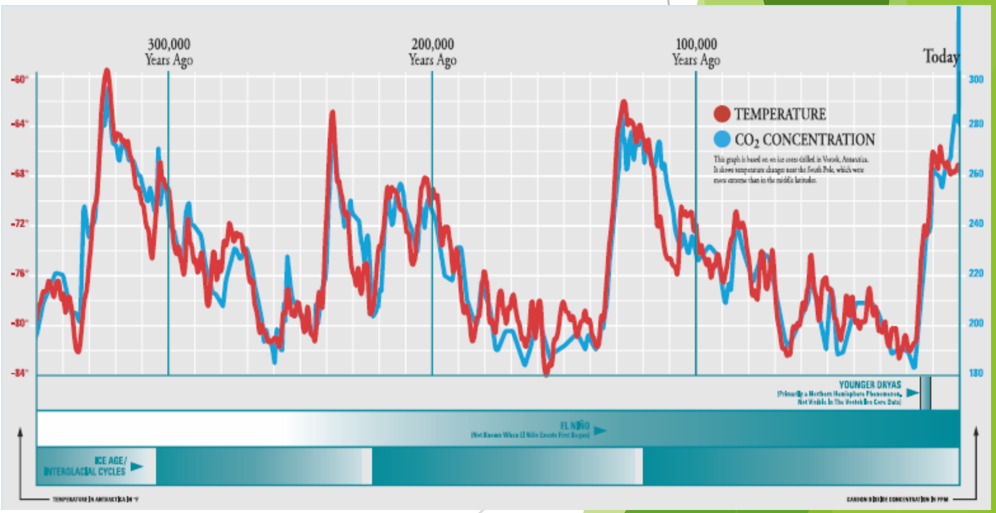
Intergovernmental Panel on Climate Change, 4th Assessment Report (IPCC - AR4), Paris, Feb. 2007

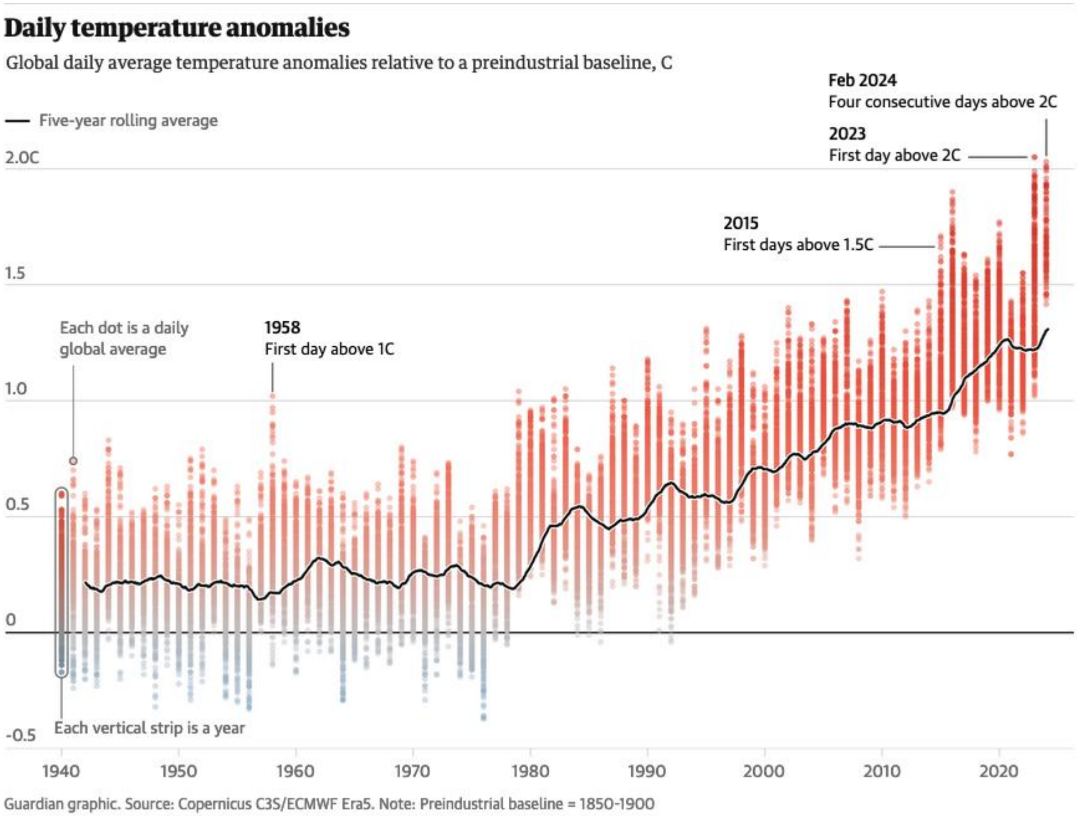
Present levels of carbon dioxide-nearing 400 ppm in the earth's atmosphere-are higher than they have been at any time in the past 650,000 years and could easily surpass 500 ppm by the year 2050 without radical intervention.



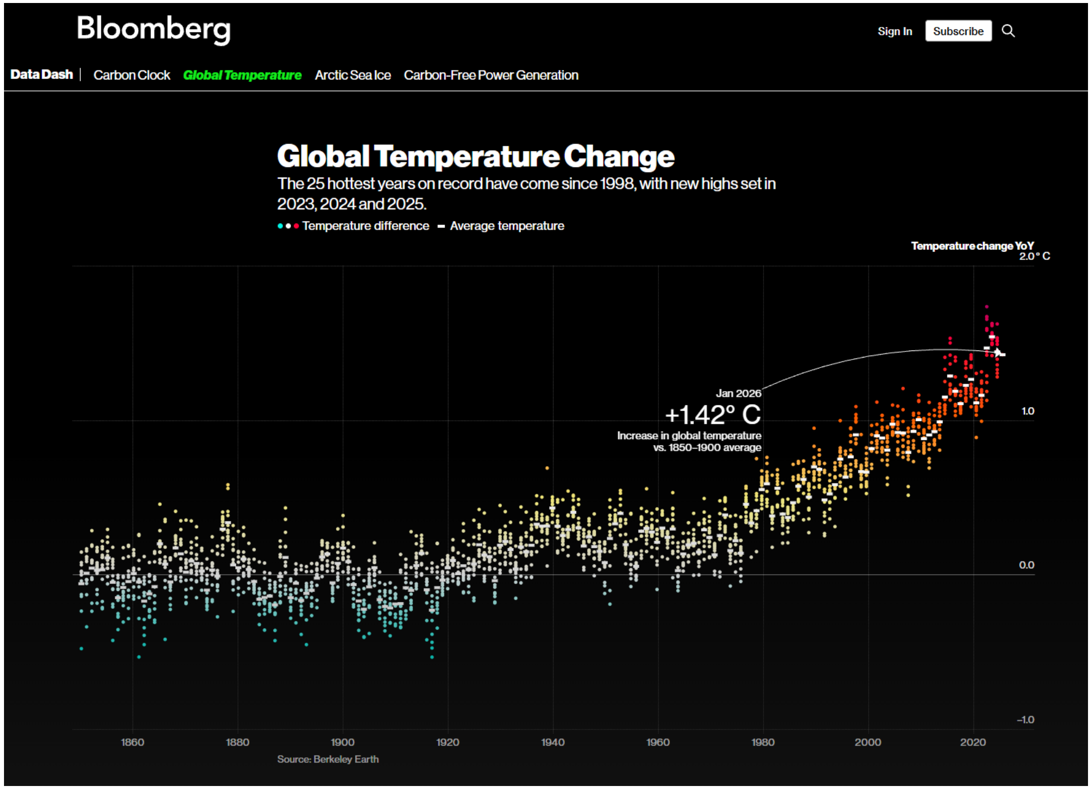
Measurements at meteorological stations
Goddard Institute for Space Studies
Understanding and responding to climate change
MARCH 2006 NATIONAL ACADEMY OF SCIENCES

Recorded in ice cores from Vostok, Antarctica
Understanding and responding to climate change
MARCH 2006 NATIONAL ACADEMY OF SCIENCES



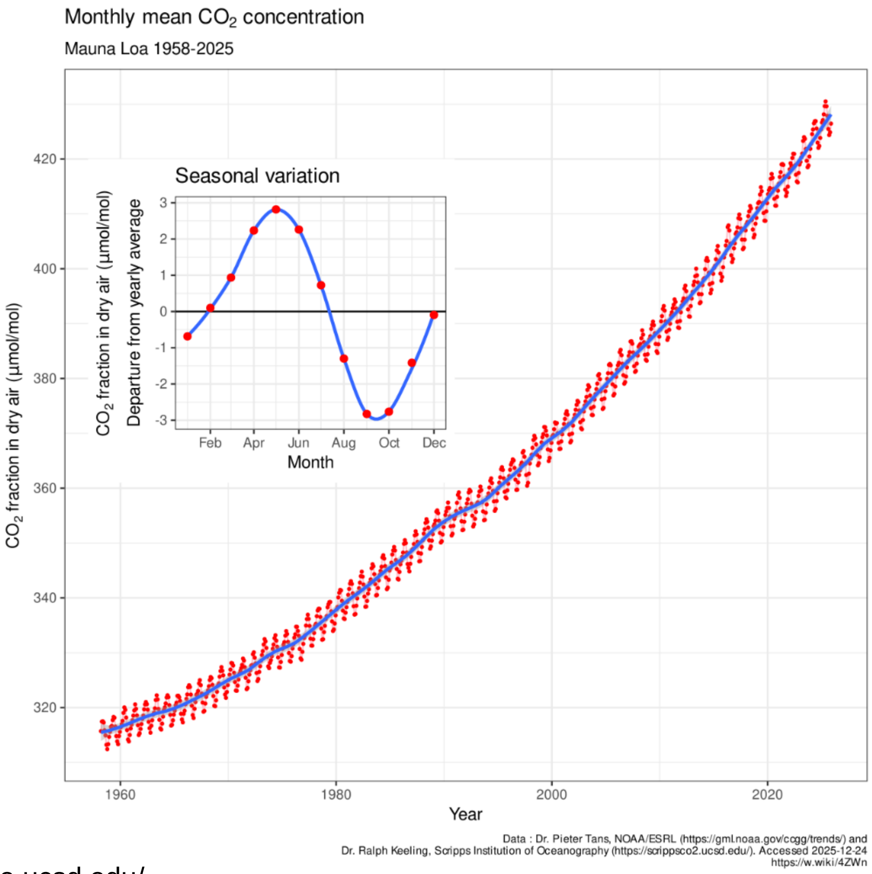

Daily temperature anomalies
Global daily average temperature anomalies relative to a preindustrial baseline, C
Five-year rolling average
Feb 2024
Four consecutive days above 2C
2023
First day above 2C
2015
First days above 1.5C
Each dot is a daily
global average
1958
First day above 1C
Each vertical strip is a year
2.0C
1.5
1.0
0.5
0
-0.5
1940
1950
1960
1970
1980
1990
2000
2010
2020
Guardian graphic. Source: Copernicus C3S/ECMWF Era5. Note: Preindustrial baseline = 1850-1900

Carbon Clock…



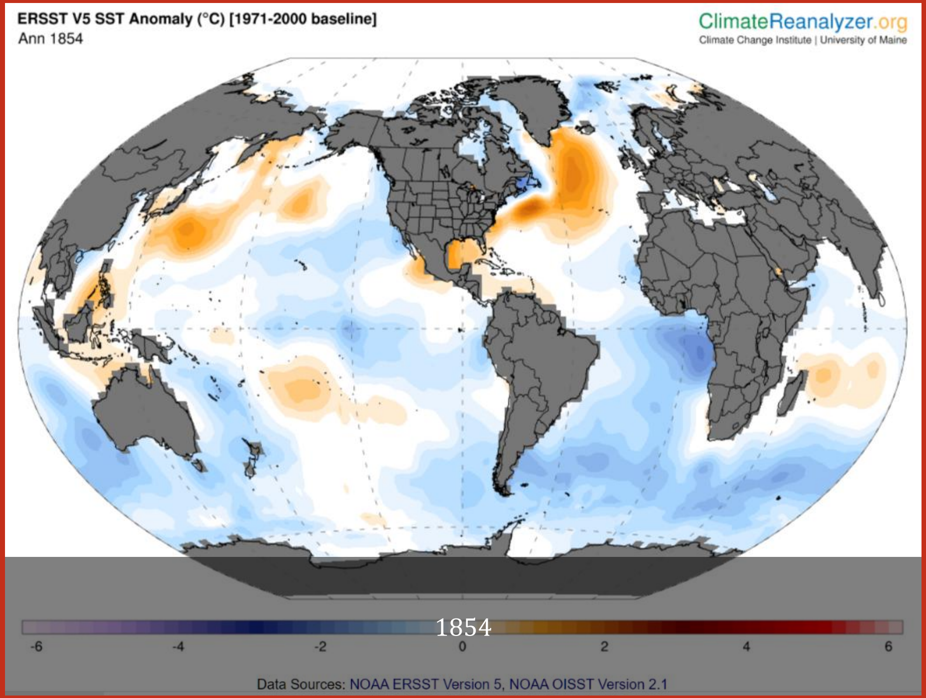
https://www.bloomberg.com/graphics/climate-change-data-green/temperature.html?embedded-checkout=true

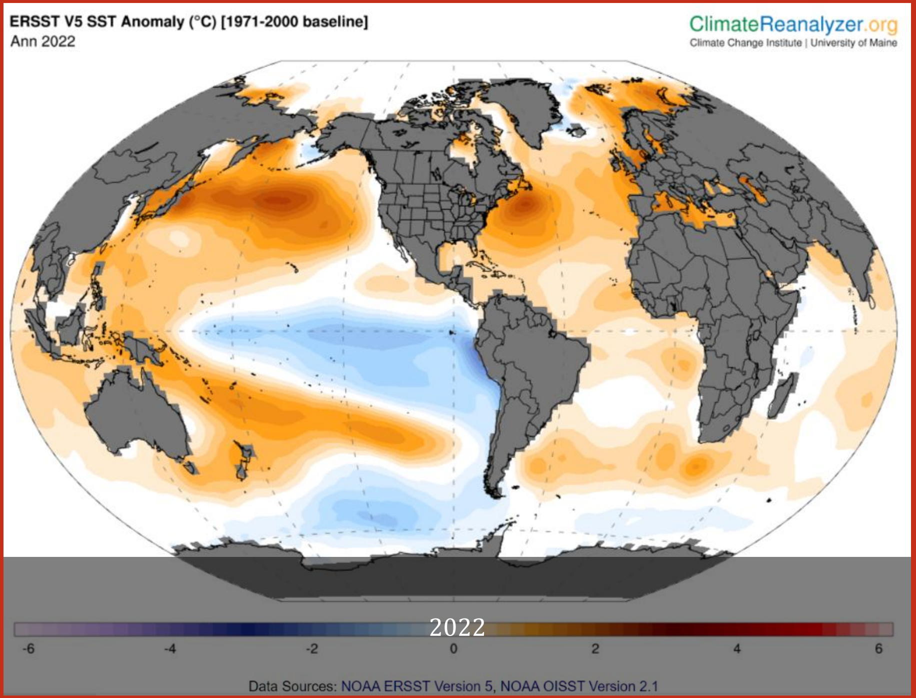
The Keeling Curve



https://keelingcurve.ucsd.edu/

Sea Surface Temperature

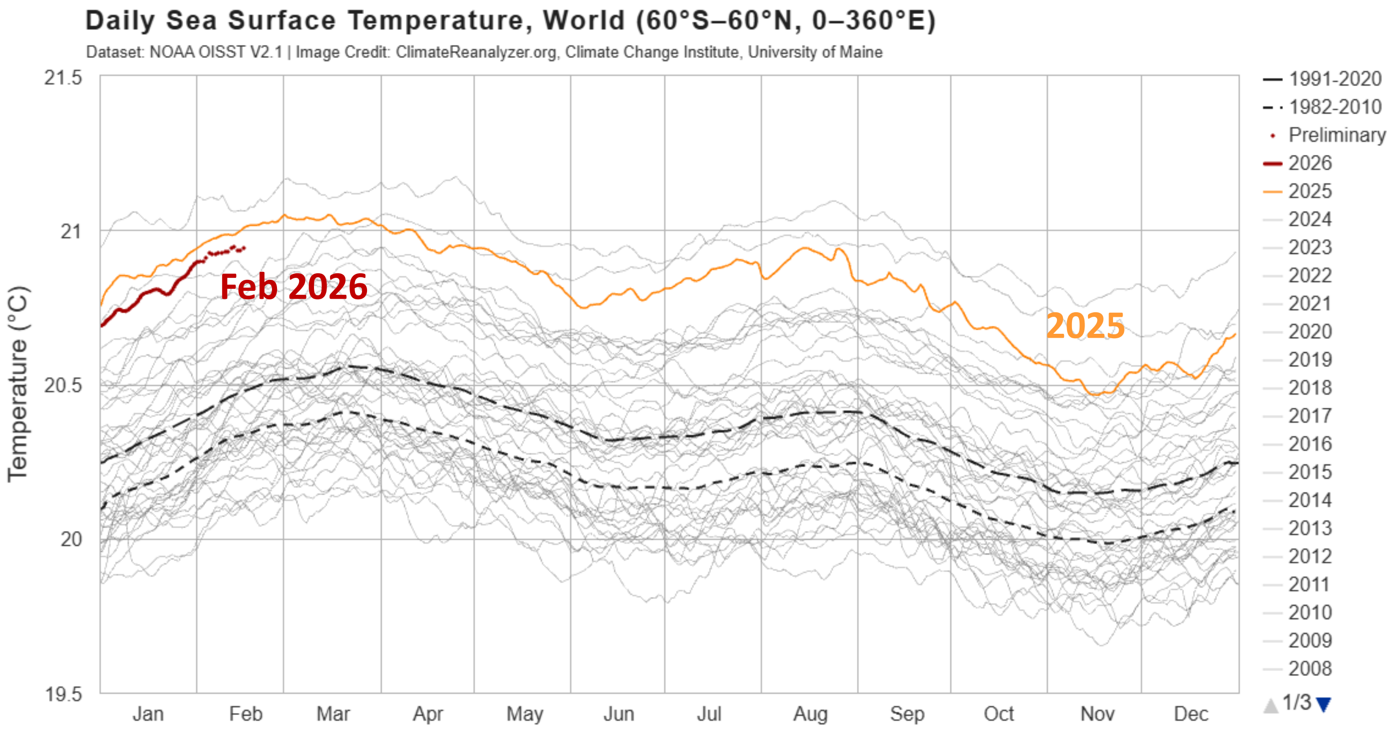




https://climatereanalyzer.org/clim/sst_monthly/

Daily / annual sea surface temperature variation

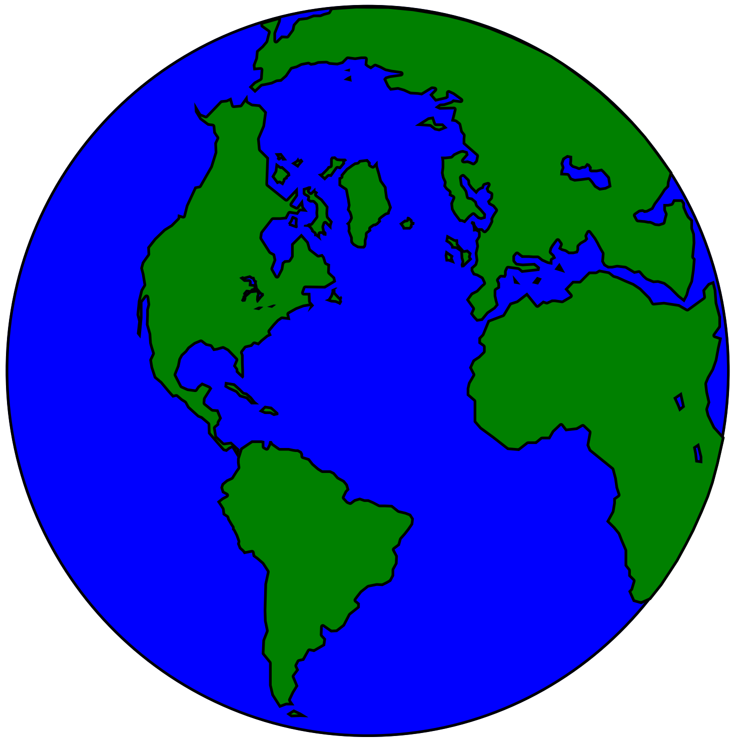
https://climatereanalyzer.org/clim/sst_daily/



Earth's Energy Balance

Sunlight (this is what we call "visible radiation")

235 Watts per square meter (W/m^2)

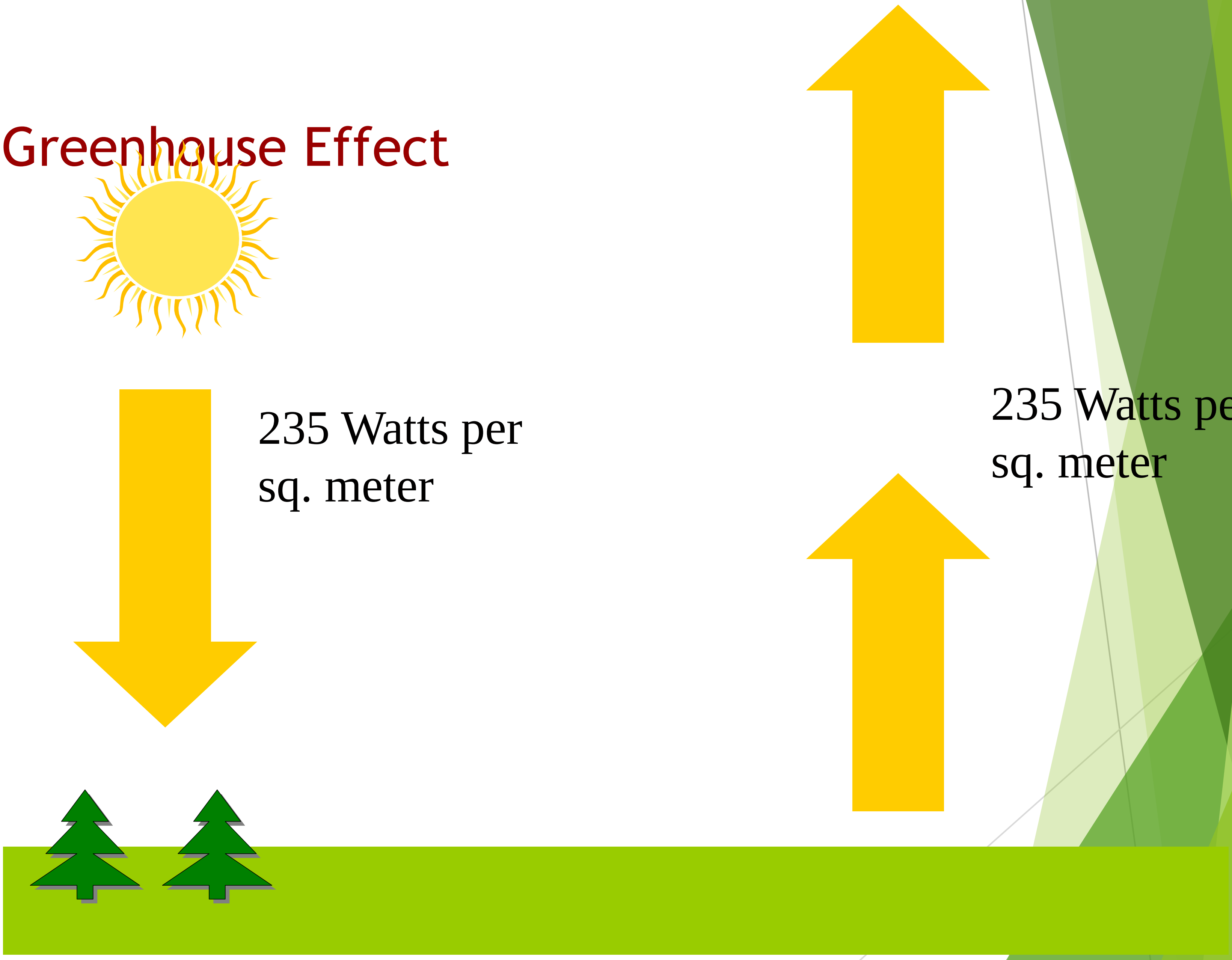


Heat (this is what we call "infrared radiation")

235 Watts per square meter (W/m^2)

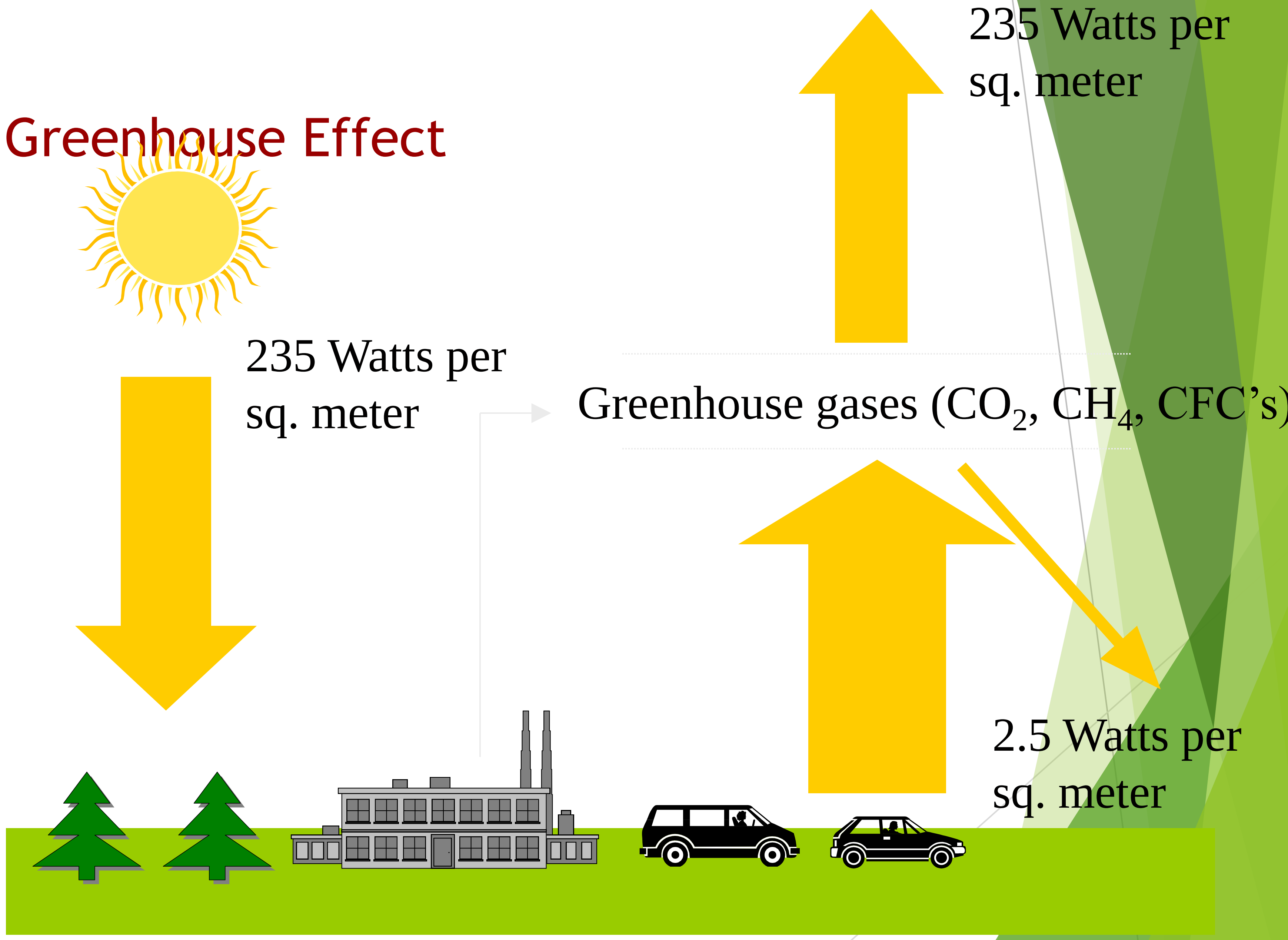
When energy IN = energy OUT, climate does not change much

Greenhouse Effect

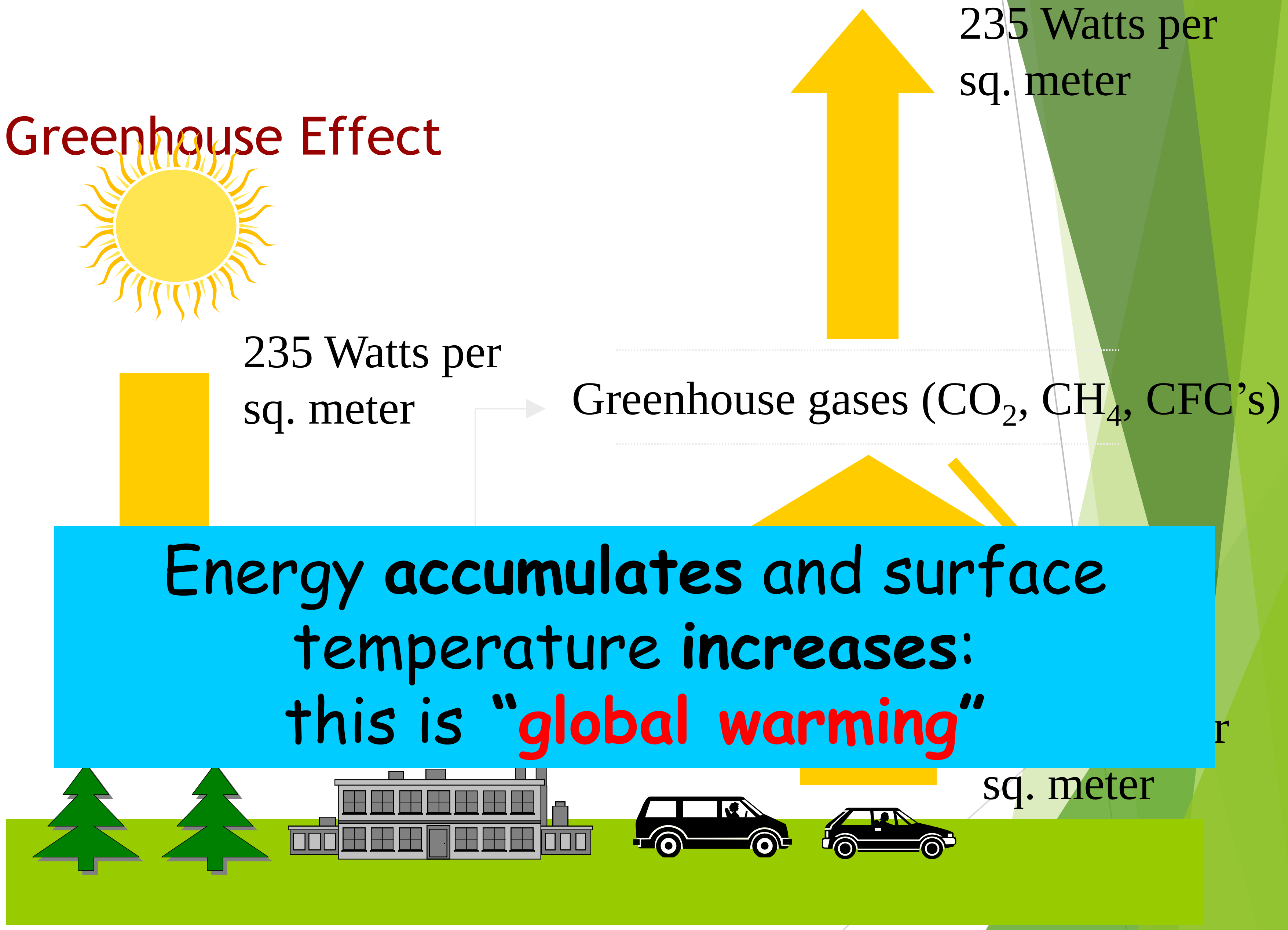


"Natural" state of climate (before late 1700's)

Greenhouse Effect

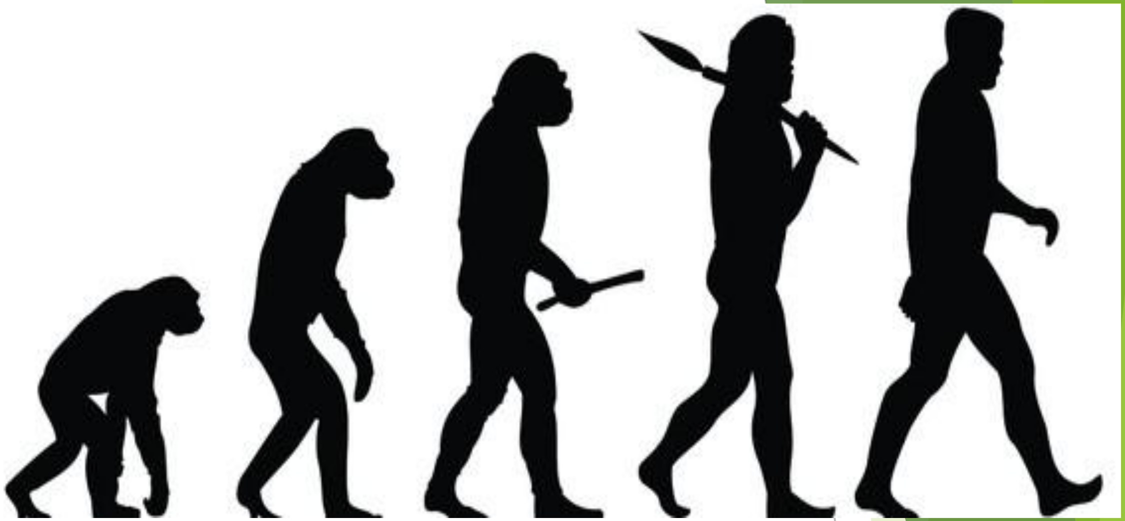


Greenhouse Effect



Hydrogen as Energy Carrier

- Age of coal.
  - CCCCCCC
- Age of oil.
  - CHCHCHCH
- Age of gas.
  - CH_4
- Age of hydrogen ?



AS WE MOVE TO A 100% RENEWABLE ENERGY LANDSCAPE, A KEY CHALLENGE IS TO DECOUPLE SUPPLY FROM DEMAND IN RENEWABLE ENERGY IN ORDER TO ACHIEVE ENERGY BALANCE.

THIS BECOMES IMPOSSIBLE TO MANAGE WITHOUT SIGNIFICANT STORAGE CAPACITY.

Universal Energy Vector

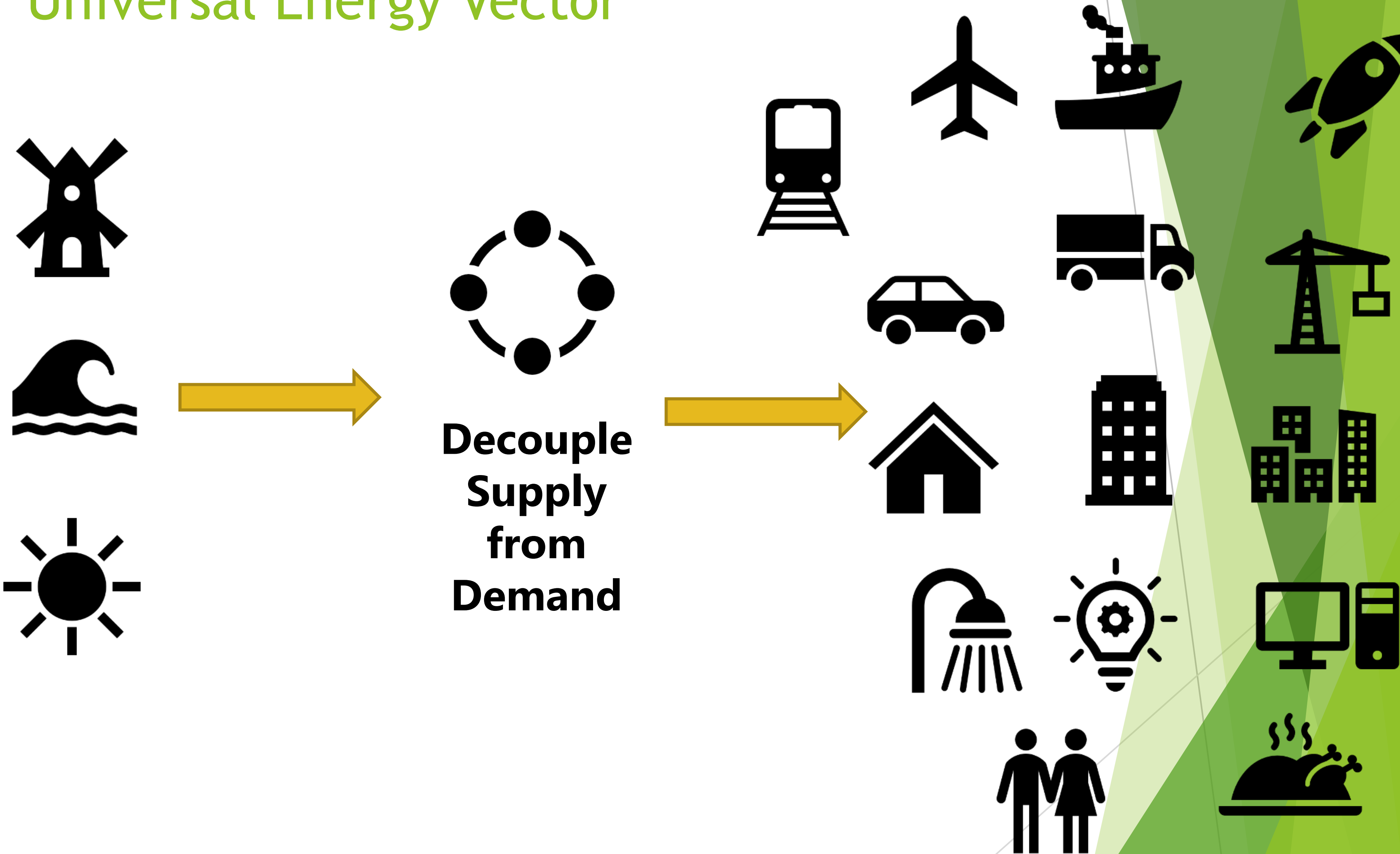
Energy supply does not correlate with energy demand

≠

Need to store the energy for "On Demand" use.

Decouple Supply from Demand

Universal Energy Vector



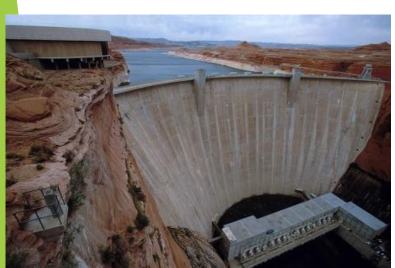
Hydrogen

$$H_2 + 1/2O_2 \rightarrow H_2O + \text{energy}$$

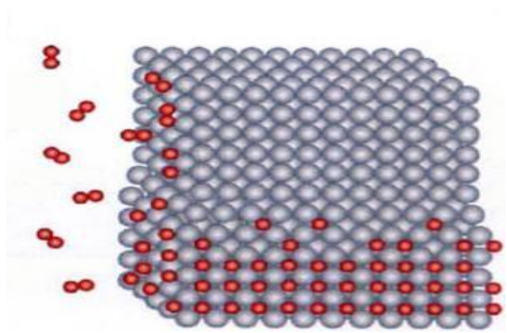
- ✓By far the most abundant element in the universe (75%). However, on earth, it is not found practically free (but in compounds like water, hydrocarbons, etc.)
- ✓The highest energy content per unit mass compared to any other known fuel (120.7 kJ/g, almost three times larger than gasoline).
- ✓Clean combustion, produces water and electricity / heat.
- ✓Safety compared to gasoline, diesel or natural gas.
- ✓Decentralized energy production systems (can be produced in many ways anywhere).

The Hydrogen Economy

- PRODUCTION

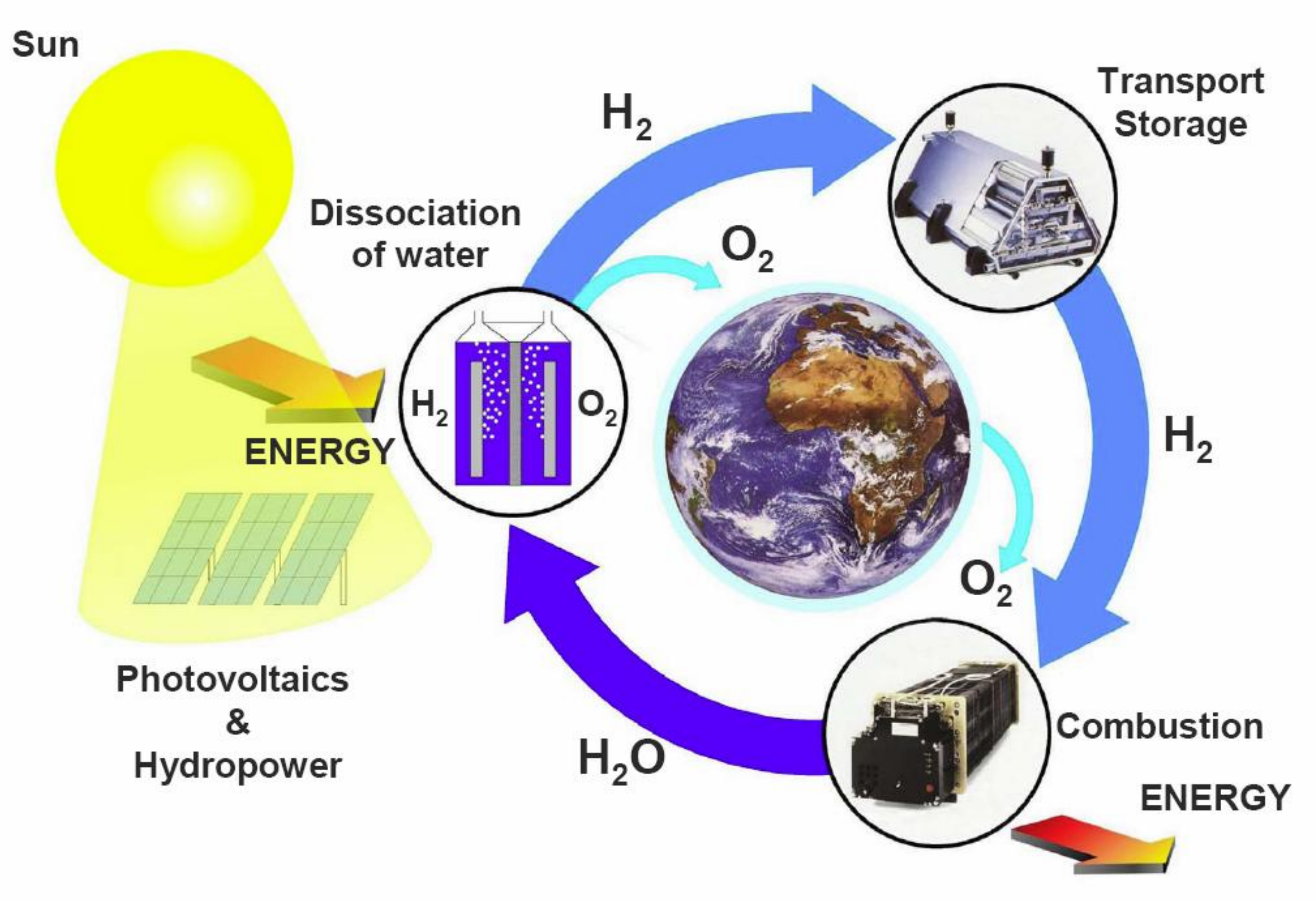


- STORAGE



- USE

The Hydrogen Cycle



P. Mauron, A. Züttel, “The Challenge of Hydrogen Storage”, STORHY – Train In, 25th – 29th September 2006, Ingolstadt, Germany

EU Policies

EU Regulatory Framework: Fit for 55

European climate law sets the reduction targets for net greenhouse gase emissions

- Ultimate goal: climate-neutrality by 2050
- Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

Fit for 55

- Proposals to revise and update EU legislation
- Framework for achieving the climate targets

–New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors

–Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

"Water will be the coal of the future" - Cyrus Harding, 1874 - *hero of Jules Verne's novel «The Mysterious Island»*

150 years later, hydrogen economy is about to become a reality…

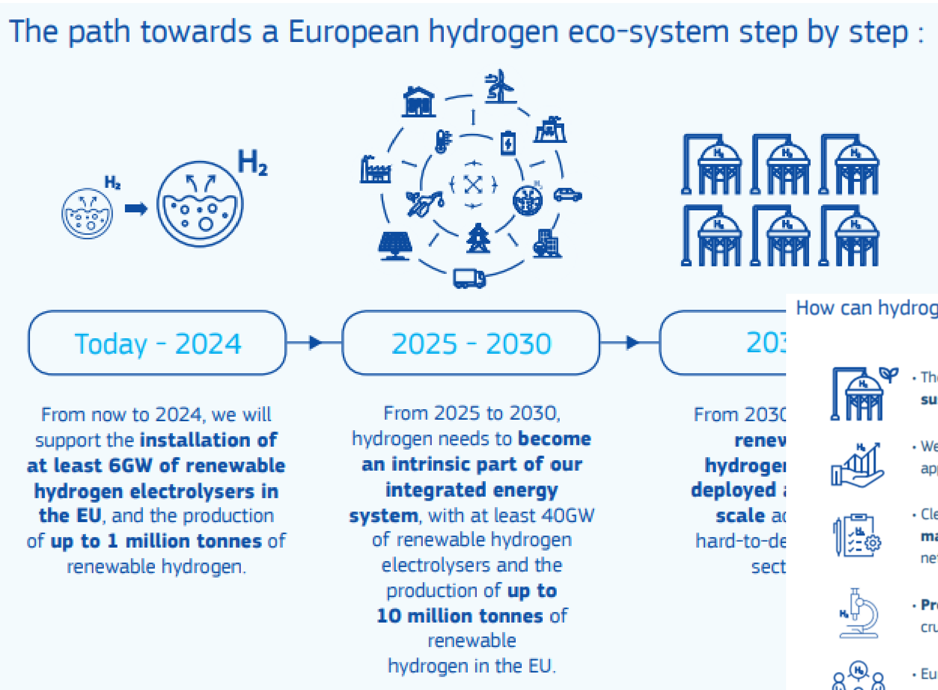
"… In developing and deploying a clean hydrogen value chain, Europe will become a global frontrunner and retain its leadership in clean tech."

Executive Vice-President for the Green Deal, Frans Timmermans
8 July 2020

"I want Next Generation EU to create new European hydrogen valleys, to modernise our industries, to power our vehicles, and to bring new life to our rural areas"
EC President Ursula von der Leyen, 16 September 2020

The President further announced that 30% of the €750 billion #NextGenerationEU budget will be raised through green bonds. And 37% funding will be invested in European Green Deal objectives, including 'lighthouse' European projects – hydrogen, green building and 1 million electric charging points.

EU Position on Hydrogen



European Commission "A Hydrogen Strategy for a Climate-Neutral Europe", 2020. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

Clean Hydrogen Joint Undertaking

EU Institutional Public-Private Partnership (IPPP)

Hydrogen Europe

Industry
More than 350 members

European Commission

Hydrogen Europe Research

Research community
over 103 members

To facilitate the transition to a greener EU society through the development of hydrogen technologies

Joint Undertaking on Hydrogen & Fuel Cells – Industry & Research

Hydrogen Europe
Industry

European Union represented by the European Commission

Hydrogen Europe
Research

A portfolio of clean, efficient and competitive solutions based on fuel cells and hydrogen technologies **in energy and transport**

Clean Hydrogen JU Objectives

Support a sustainable hydrogen economy, contributing to EU's climate goals

Support the implementation of the Commission's Hydrogen Strategy

Stimulate research and innovation on clean hydrogen production, distribution, storage and end use applications

Strengthen the competitiveness of the EU clean hydrogen value chain

Contribute to the EU ambitious 2030 and 2050 climate ambition

EU Hydrogen Strategy launched on 8th July 2020

Objectives in 3 phases with the Hydrogen Alliance to support the investment agenda

Phase 1: 2020-2024

- **6GW** of renewable H_2 electrolysers
- 1 million tonnes renewable H_2
- Replace **existing** H_2 **production**
- Regulation for liquid H_2 markets
- Planning H_2 infrastructure

Phase 2: 2025-2030

- **40GW** renewable H_2 electrolyser
- 10 million tonnes renewable H_2
- New applications in steel & transport
- H2 for electricity balancing purposes
- Creation of "Hydrogen Valleys"
- Cross-border logistical infrastructure

Phase 3: 2030-2050

- H_2 technologies matured and deployed at large scale in hard to abate sectors.
- Expansion of hydrogen-derived synthetic fuels
- EU-wide infrastructure network
- An open international market

Clean Hydrogen Alliance to support the EU investment agenda

Research and Innovation priorities in Clean Hydrogen JU

PILLAR H2 PRODUCTION

SO1 Low carbon H2 production

1. Electrolysis
2. Other modes of production

SO2 Integration of renewables

3. Role of electrolysis in the energy system

PILLAR H2 DISTRIBUTION

SO3 Storage & delivery of H2

4. Large scale storage
5. Pipeline transport (grid)
6. Liquid carriers
7. Non-pipeline transport
8. Key technos for distribution

SO4 Refuelling infrastructure

9. HRS for multiple applications

PILLAR H2 END USES

SO5 Transport vehicles

10. Building blocks
11. Trucks & large vans
12. Maritime (inc. ports)
13. Aviation
14. Rail
15. Coaches

SO6 Heat & Power

16. Stationery H2 fuel cells
17. H2 burners and turbines

SO7 Industry

18. H2 in industry

SO9 Supply Chain
Manufacturing & scale-up

Comms

Knowledge

Safety

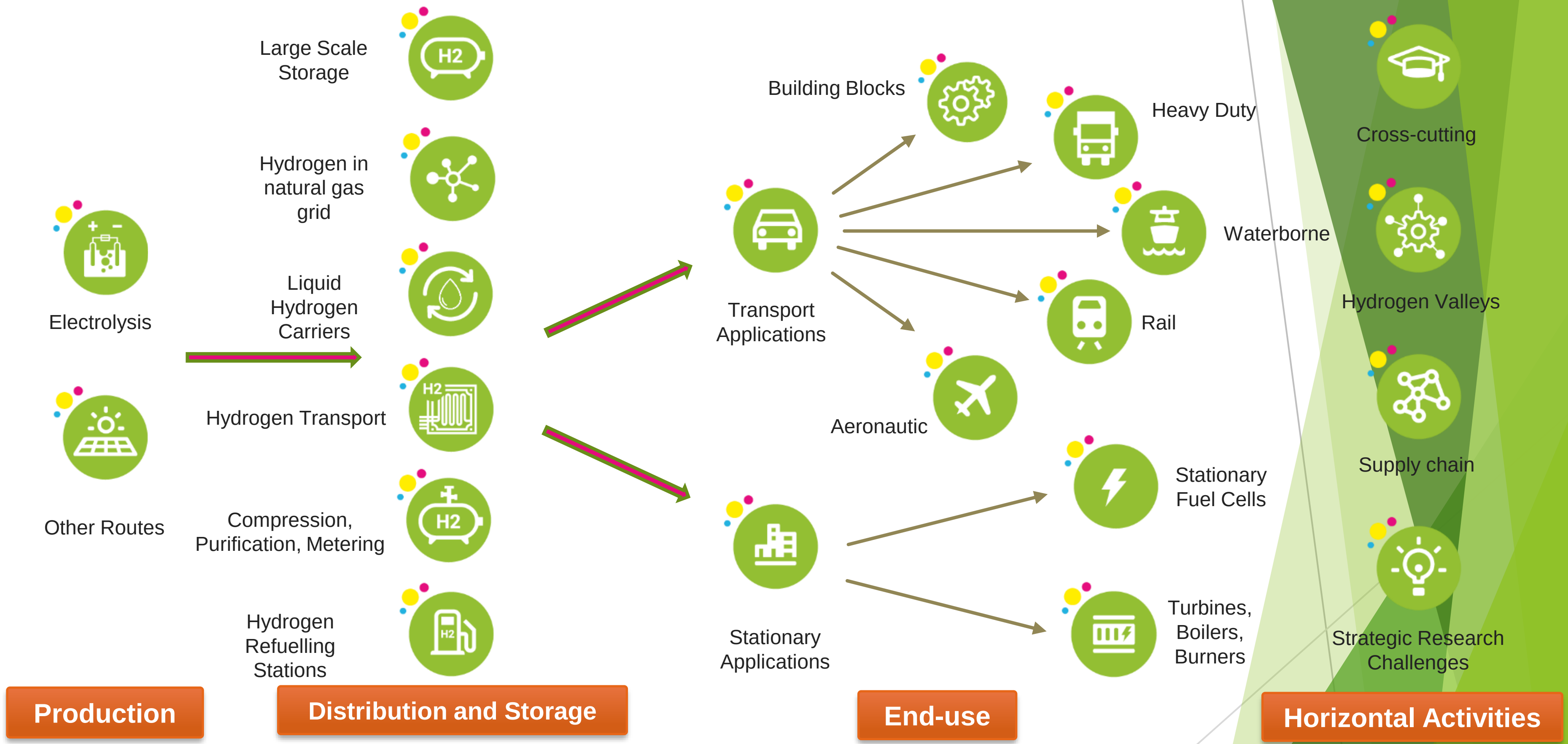
Int'l coop.

SO8 Hydrogen Valleys
Integrated H2 ecosystems combining multiple applications (ports, industrial hubs, cities, etc.)

S10 Cross-Cutting
Regulations, Codes, Standards, Training, Safety, social, etc.

Co-funded by the European Union

Research & Innovation Activities



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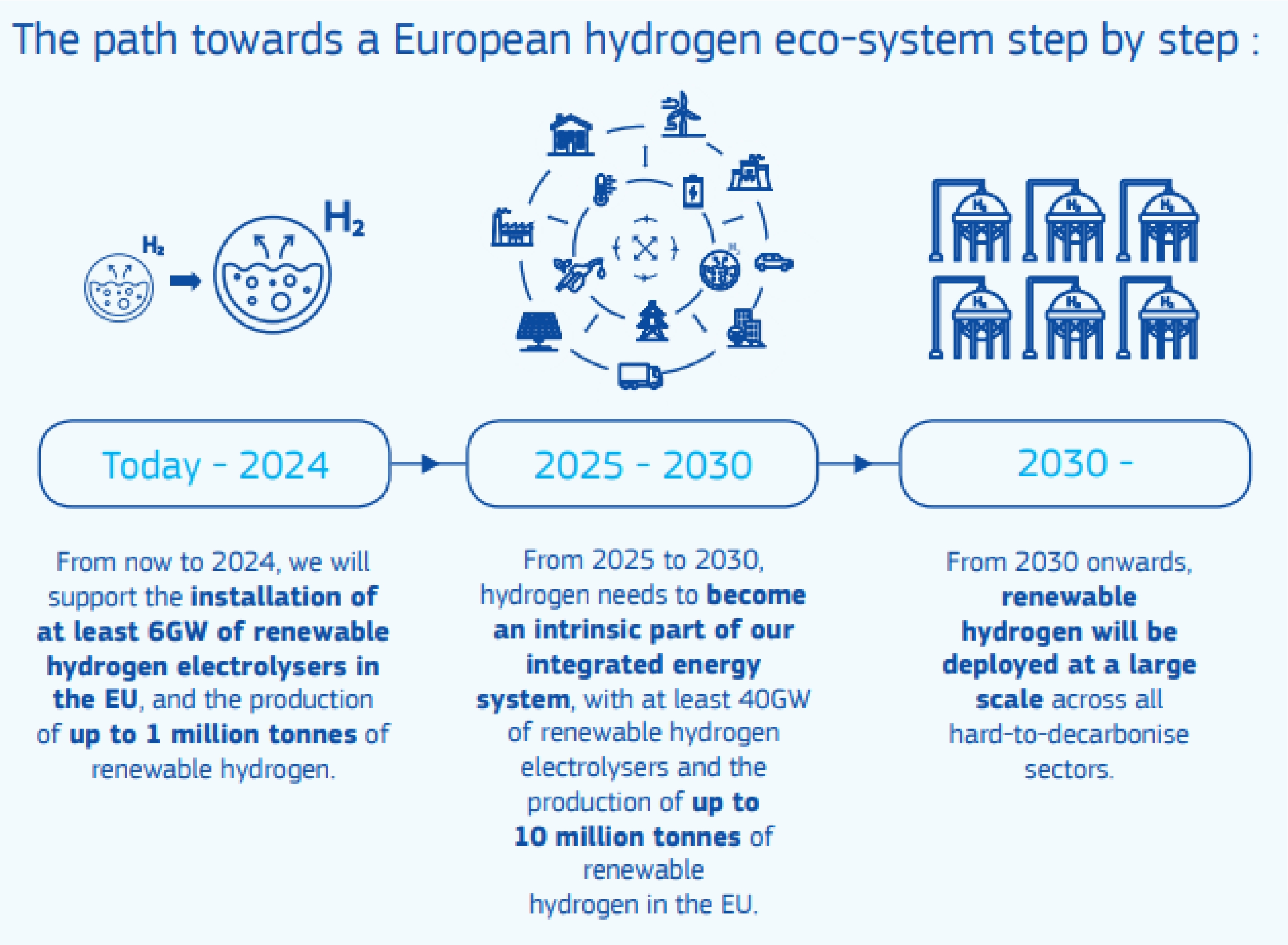
HYDROGEN PRODUCTION

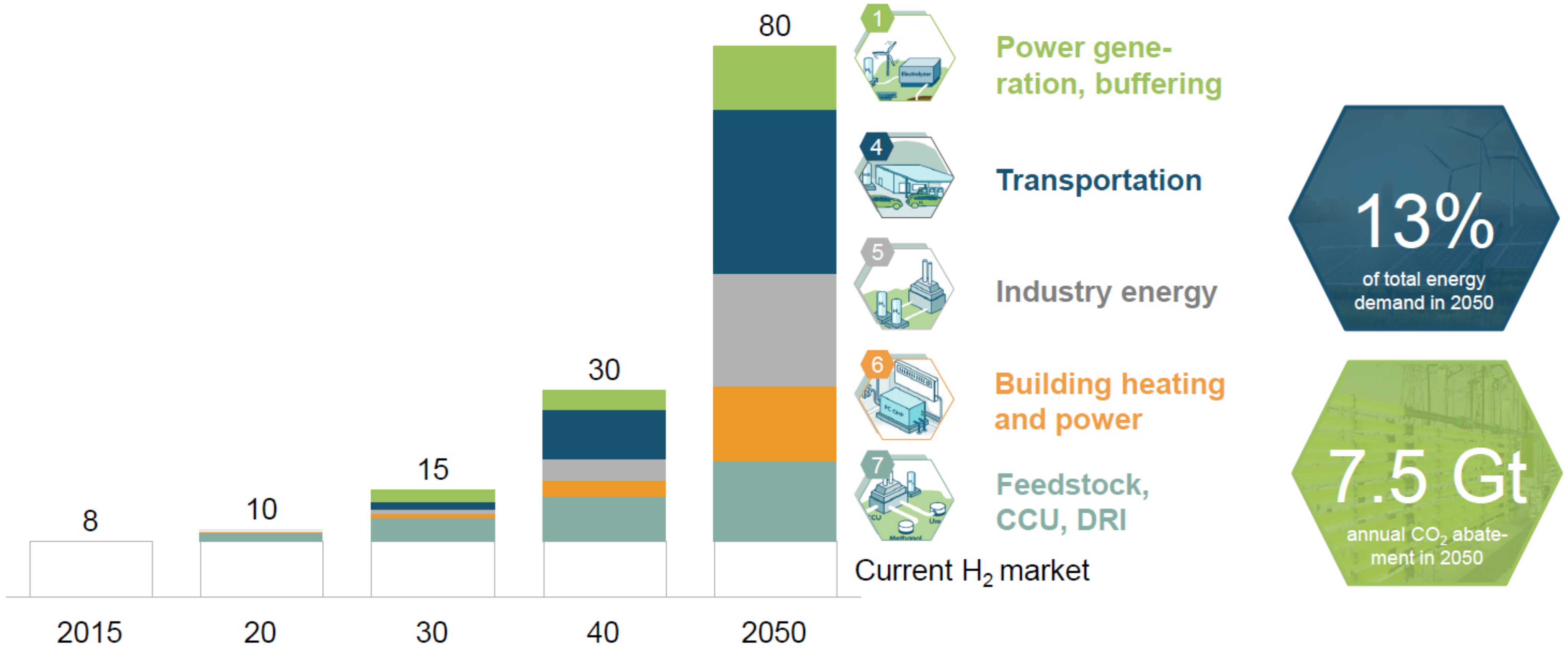
EU Position on Hydrogen



European Commission “A Hydrogen Strategy for a Climate-Neutral Europe”, 2020. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

By 2050, hydrogen can enable major CO_2 emission reductions

Global Energy demand supplied with hydrogen, Exajoule (EJ)



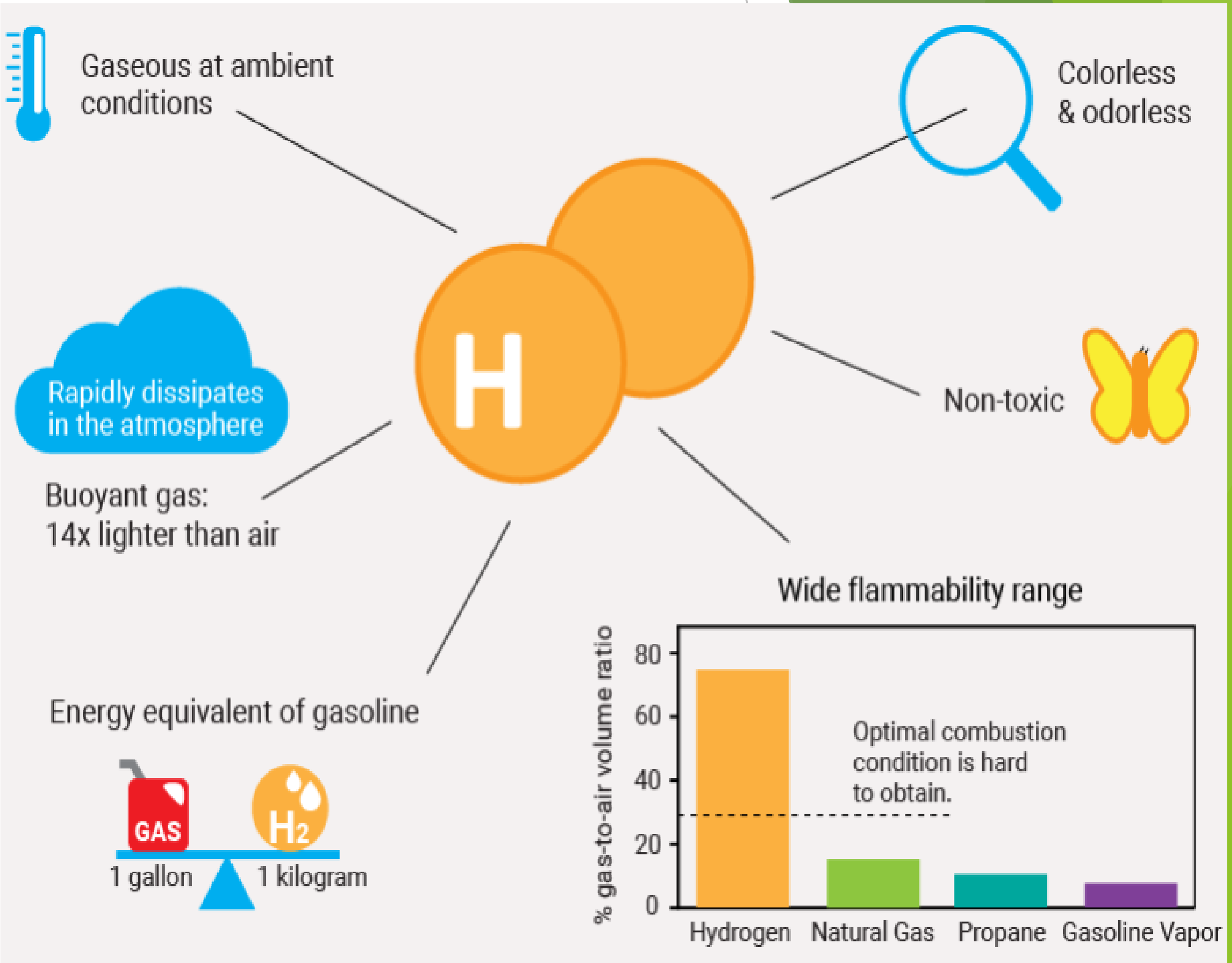
1 Excluding feedstock

SOURCE: Hydrogen Council, IEA ETP Hydrogen and Fuel Cells CBS, National Energy Outlook 2016"

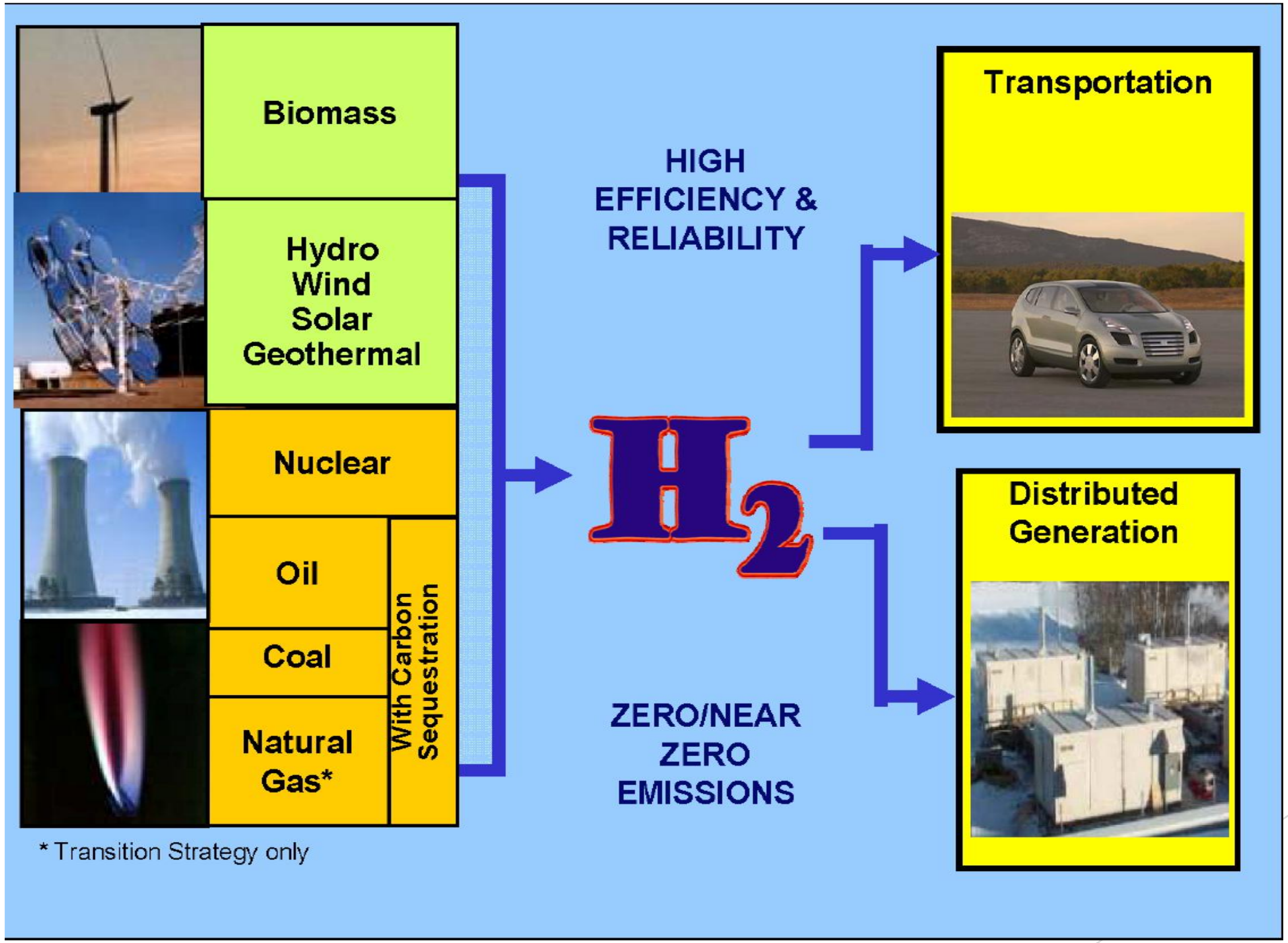
Basic properties and Initial Safety Concerns

Hydrogen (H_2) is :

- the simplest, lightest and most abundant element in the universe.
- the first element in the periodic table and is a fundamental building block for many of the chemicals, materials and processes we use every day.
- a very small, diffusive molecule that is 14 times lighter than air.
- a non-toxic element that has been safely used in manufacturing for more than 90 years.
- is flammable (like all fuels) and safety systems at the H_2 stations (HRS) and in the H_2 vehicles (FCEV) are designed specifically for hydrogen's properties.
- an energy carrier as it can be used to store and transport energy, offering the possibility of greater diversification and sustainability in energy supply



DIFFERENT ROUTES TO HYDROGEN



Production Methods

Hydrogen production methods can be categorized based on their energy sources and environmental impact. So, here are the most common methods from :

MATURE TECHNOLOGIES

1. Steam Methane Reforming (SMR) – Grey or Blue

Process: SMR is the most common method for producing hydrogen. It involves reacting natural gas (mostly methane) with steam at high temperatures to produce hydrogen and carbon monoxide. POX is a similar method but even less efficient than SMR.

2. Electrolysis – Green (if powered with RES)

Process: Electrolysis uses electricity to split water into hydrogen and oxygen.

3. Biomass Gasification – Brown

Process: Biomass (organic matter) is heated in the presence of a controlled amount of oxygen, producing a mixture of hydrogen, carbon monoxide, and CO_2.

4. Methane Pyrolysis - Turquoise (if powered with RES)

Process: Methane is split into hydrogen and solid carbon through high-temperature pyrolysis, without producing CO_2.

EXPERIMENTAL PHASE

1. Photolysis (Photo-electrochemical Water Splitting) - Green Hydrogen

Process: Uses sunlight to split water into hydrogen and oxygen using special photo-sensitive materials.
Efficiency is lower compared to electrolysis (PEM, AEL, SOEL, AEM).

2. Thermochemical Water Splitting – Green or Pink

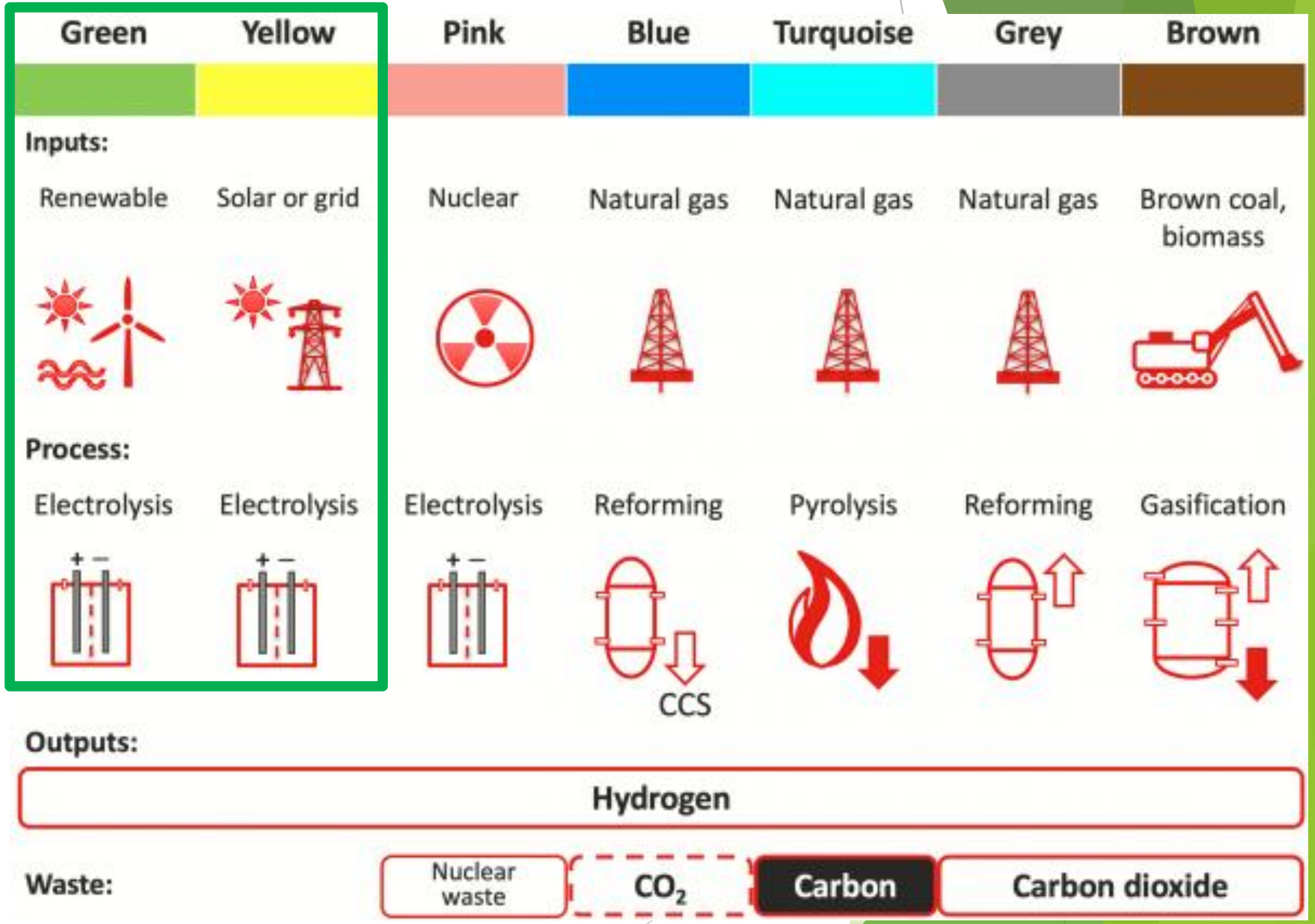
Process: Uses high-temperature heat, often from nuclear reactors or solar concentrators, to drive chemical reactions that split water into hydrogen and oxygen.
Efficiency expected to be high if coupled with high-efficiency heat sources.

3. Microbial Electrolysis Cells (MEC) - Green

Process: Uses microbes and electricity to split water or wastewater into hydrogen.
Efficiency is low, but improving with research

Types (colors) of Hydrogen

- Each method offers different trade-offs in terms of :
  - ✓ Efficiency
  - ✓ Scalability
  - ✓ Environmental impact



- **Green hydrogen,** though currently more expensive, is viewed as the future energy carrier, offering at the same time **zero-emission energy**.

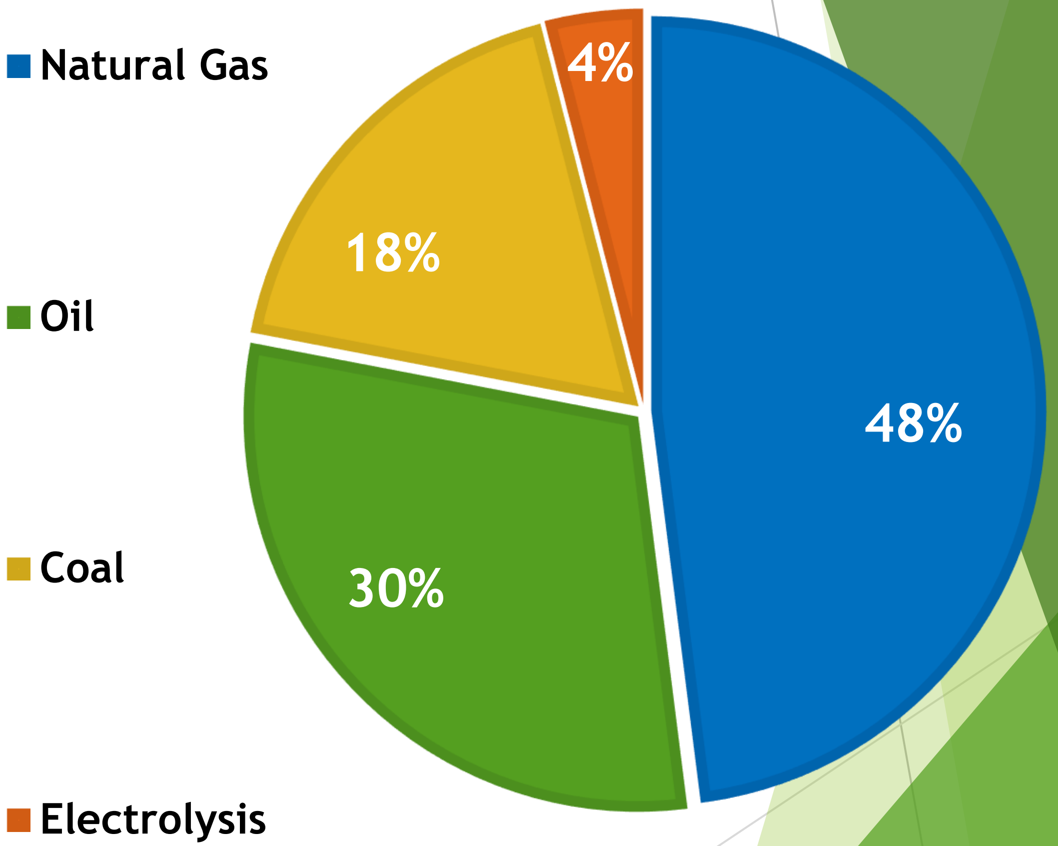
Main routes for H2 production

- Hydrocarbon based production
- Water Electrolysis
- Biogas, CCS & novel routes

Current situation

- 70 million metric tons of H2 produced in 2019, emitting in the process 830 million tons CO2
- About 95% of which is produced by fossil fuel based methods

H2 PRODUCING SOURCE

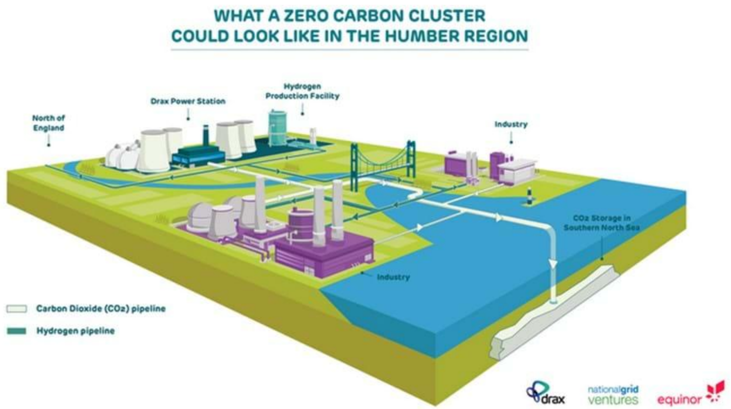


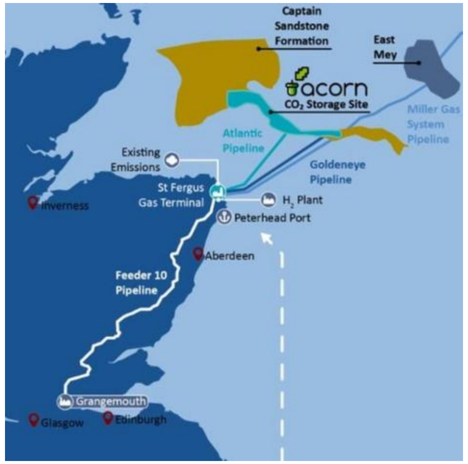
Steam Methane Reforming (SMR)

- SMR technology splits natural gas (NG) into mixture of hydrogen, CO and CO_2
- Industries use SMR technology to deliver large quantities of H_2 and CO with remaining CO_2 being released to atmosphere
- The process is mature with systems capable of producing up to 100s of metric tonnes per day of H_2/CO
- Currently over half the world's hydrogen is derived from NG feedstocks

SMR and Carbon Capture Utilisation and Storage (CCUS)

- Capturing the CO_2 produced by SMR can decarbonise the process
- Captured CO_2 can be stored in underground geological features or used
- **If CO_2 is captured/used, <u>HYDROGEN IS BLUE</u>**
- Many large scale CCUS projects are being developed internationally.





The <u>Acorn Project</u> will capture about 200,000 tonnes of CO_2 from the St Fergus Gas Terminal

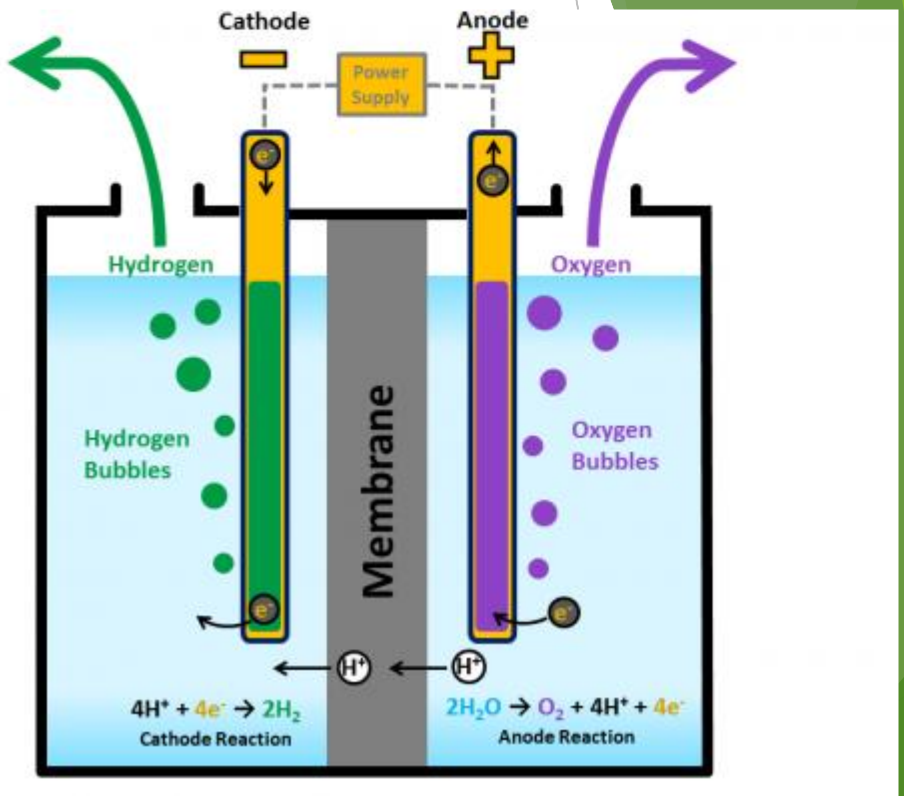
Water ELECTROLYSIS

- One of the most promising methods for hydrogen production

Reaction taking place:

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$$

- Requires a minimum energy of 39.4 kWh /kg of H2
- Has the potential to be carbon free, if powered by renewable sources

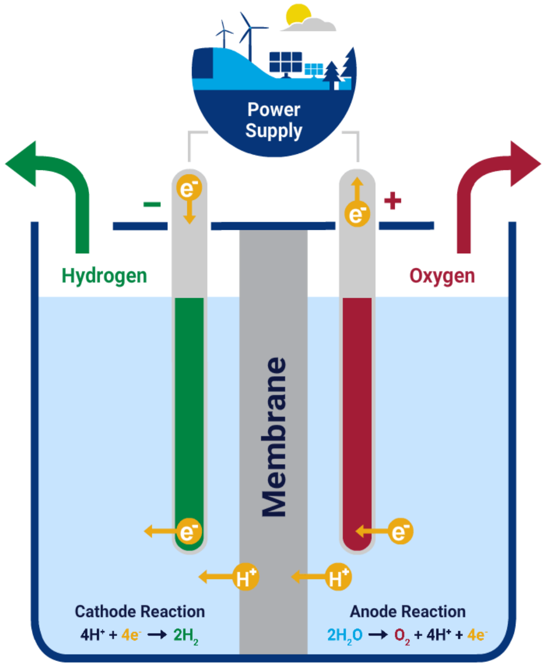


H2 Production by water electrolysis

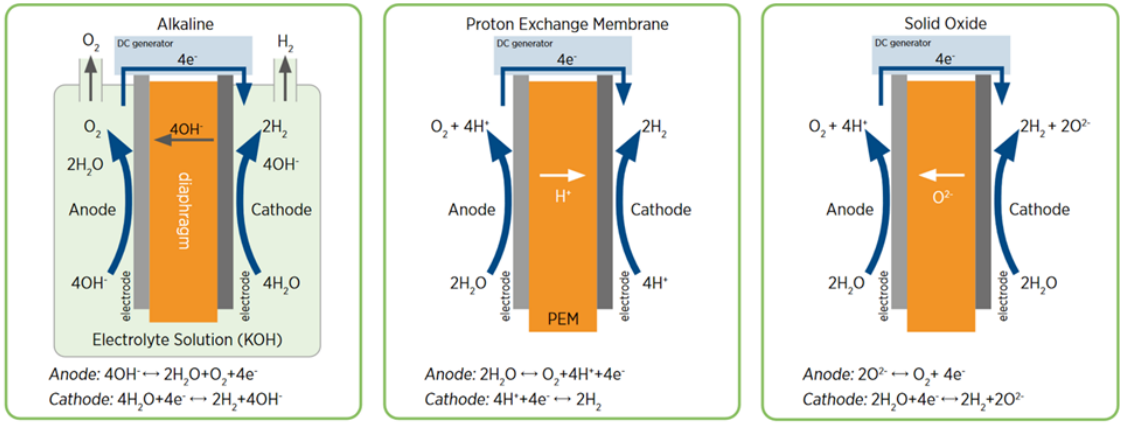
Electrolysis – Production of Green Hydrogen

- First mentioned by Faraday, so not exactly modern technology.

- Green hydrogen produced.
- Electric current is passed through water to separate it in hydrogen and oxygen.
- Membranes to separate the gases.
- Alkaline
- PEM (and HT-PEM at about 180 C)
- Solid Oxide (High temperature > 600 C)



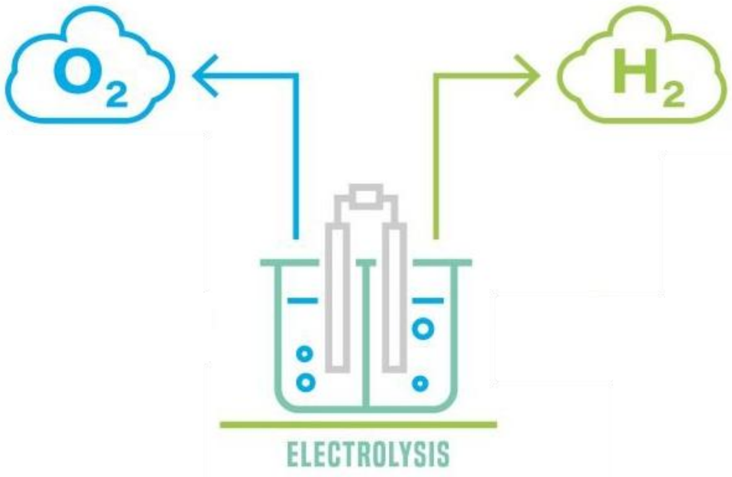
Electrolyzer technologies



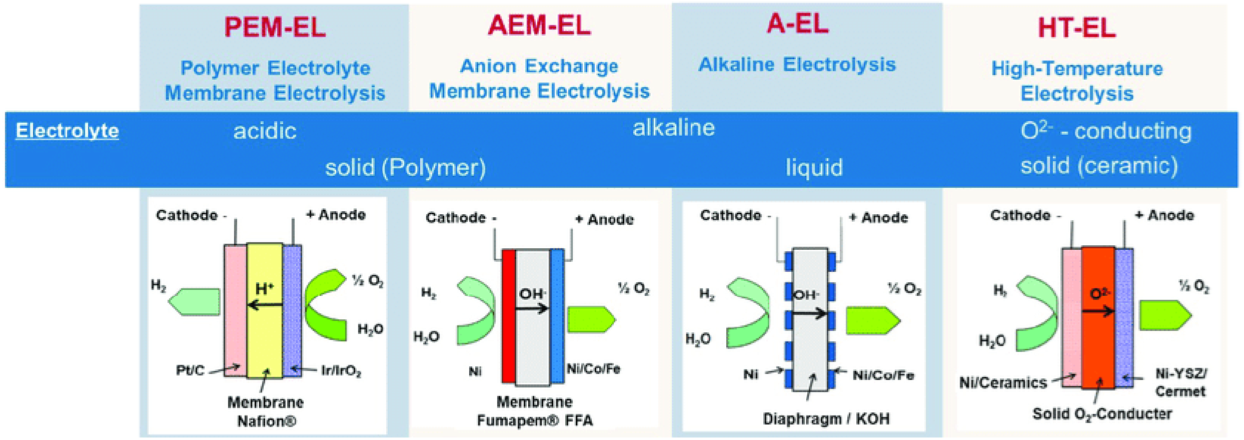
Alkaline
- ✔ Cheap
- ✘ Large equipment

PEM
- ✔ Pure hydrogen
- ✘ Expensive catalysts

Solid oxide
- ✔ Reversible
- ✘ High temperature



	PEM	AEM	Alkaline	SOE
Electrolyte	PFSA membranes (e.g., Nafion)	Anion exchange ionomer	Aqueous potassium hydroxide	Yttria Stabilises Zirconia (YSZ)
Cathode	Platinum, Platinum - Palladium alloy	Nickel and Nickel alloys	Nickel, Nickel - Molybdenum alloy	Nickel/YSZ
Anode	Ruthenium oxide, Iridium oxide	Nickel, Ferrous, Cobalt oxides	Nickel, Nickel - Cobalt alloys	YSZ
Operating Temperature (℃)	50-80	50-60	60-80	500-850
Operating Pressure (Bar)	70	1-30	30	1-25
Stack Lifetime (h)	20-60k	-	60-100k	<10k
Technology Readiness	Commercialised	Large prototype	Matured	Demonstration
Cost	USD 1100-1800/kW		USD 500-1400/kW	USD 2800-5600/kW



E- FUELS as a short term solution

- E fuels are synthesized from hydrogen and CO_2 from unavoidable emissions, producing e-methane , e-methanol or e- gasoline
- A short to mid-term plan is required, so we can make use of the existing infrastructure and a suitable solution could be energy rich e-fuels
- Gradual infiltration of hydrogen and green energy to carbon based fuels

Examples of E-fuel production:

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$ (e-Methane Production)

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$ (e-Methanol Production)

Fischer- Tropsch process for producing e- fuels:

$(2n + 1)\ H_2 + n\ CO \rightarrow C_nH_{2n+2} + n\ H_2O$

Overall balance of these processes is largely carbon neutral

Thanks for your interest!

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Dr. Athanasios Stubos

Dr. Emmanuel Stamatakis

STORAGE / DISTRIBUTION OF HYDROGEN

Compressed Gas

Liquefaction - Cryocompression

Solid Materials

Underground Storage

Hydrogen - Storage issues

- ✓Gas under normal conditions
- ✓Density (0 °C) 0.0899 kg/m^3 (12 times less than air)
- ✓Low Boiling Point (20K)
- ✓Safety (under specific conditions)

Hydrogen Storage

Under normal temperature and pressure conditions, 1 kg of hydrogen will occupy a volume of 12.15 m^3 and an energy content of 33.5 kWh. Hydrogen presents HIGH energy per unit mass 140MJ/kg but LOW energy density per volume: 12.7MJ/m^3

For hydrogen to become a competitive energy carrier, its volume density must be increased → **reducing the volume that hydrogen occupies under normal conditions**

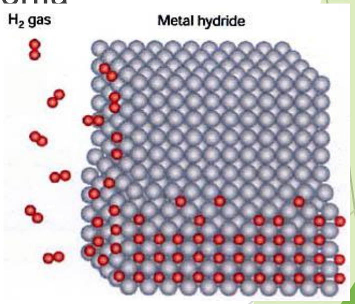
- Compressing the gas (increasing the temperature) → *Compressed Hydrogen Storage*
- Decreasing the temperature below the critical point → *Cryogenic Hydrogen Storage*
- Decreasing the repulsion interaction between the hydrogen molecules by creating bonds with another material. → *Solid-State Hydrogen Storage*

HYDROGEN STORAGE

- One of the major issues regarding hydrogen is its storage
- High energy density per weight / Low energy density per volume

3 main ways to store hydrogen:

- Storage as a compressed gas: By compressing H2, the volume it occupies is reduced thus resulting in higher energy density per volume
- Storage as a liquid: Liquid hydrogen is cryogenic and boils around -252.882 °C.
- Chemical Storage: H2 can be chemically stored in substances like ammonia or various hydrides



gen in
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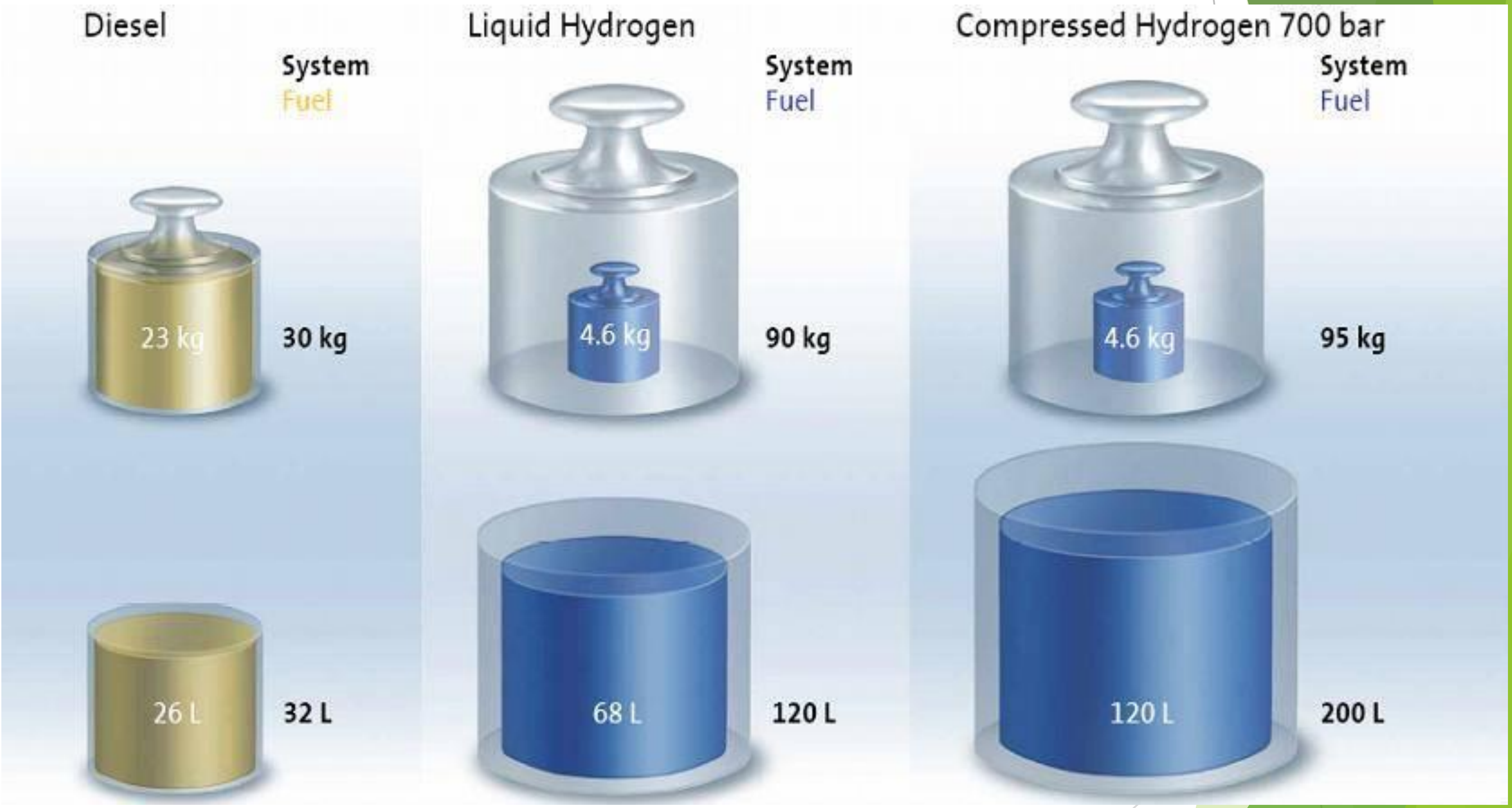
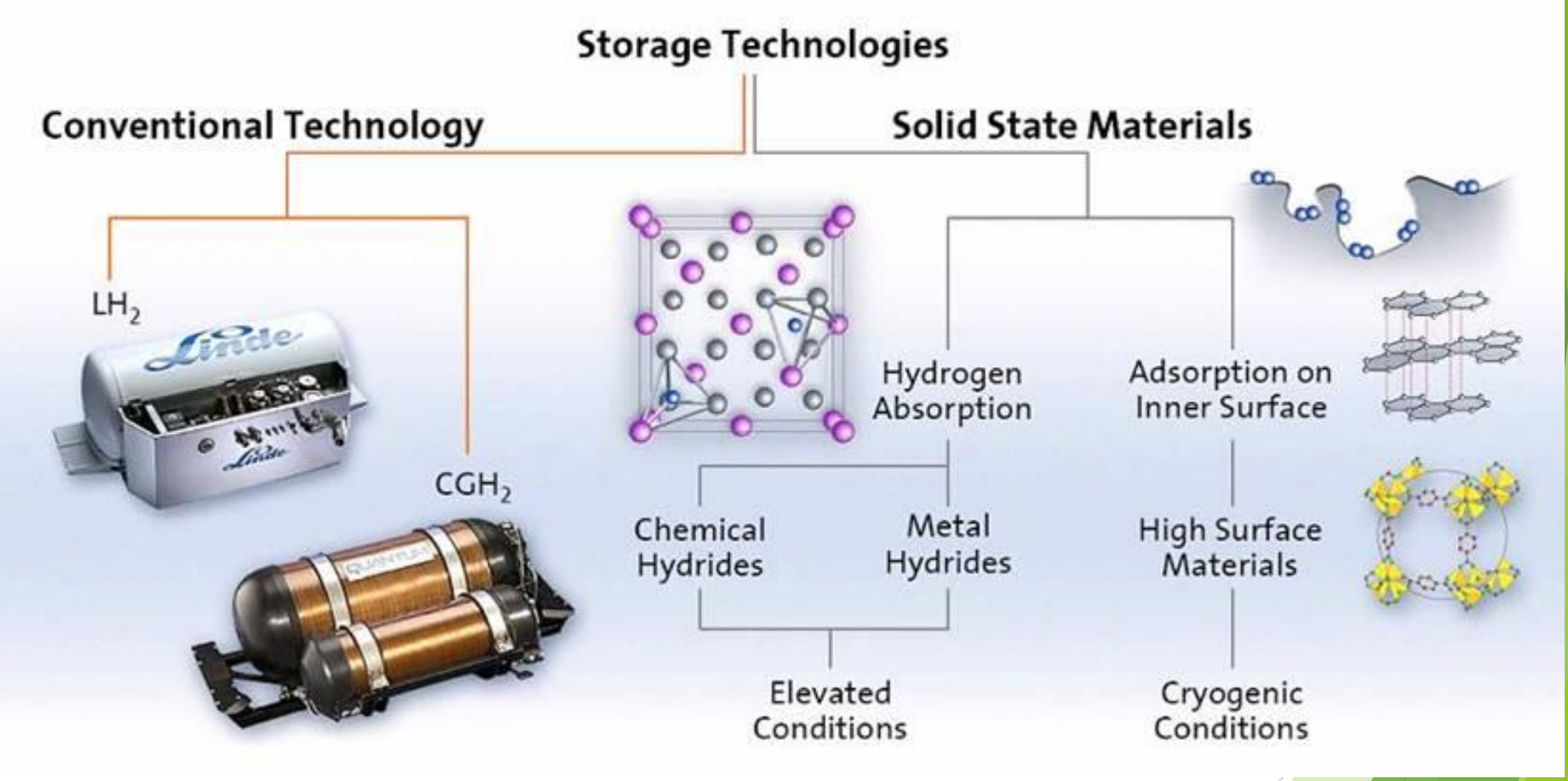
H2 Tank Mass & Volume (autonomy ~600 km)



H2 Storage Technologies



“Conventional” Technologies

Minimize Heat Inflow (300 K → 20 K)

↓

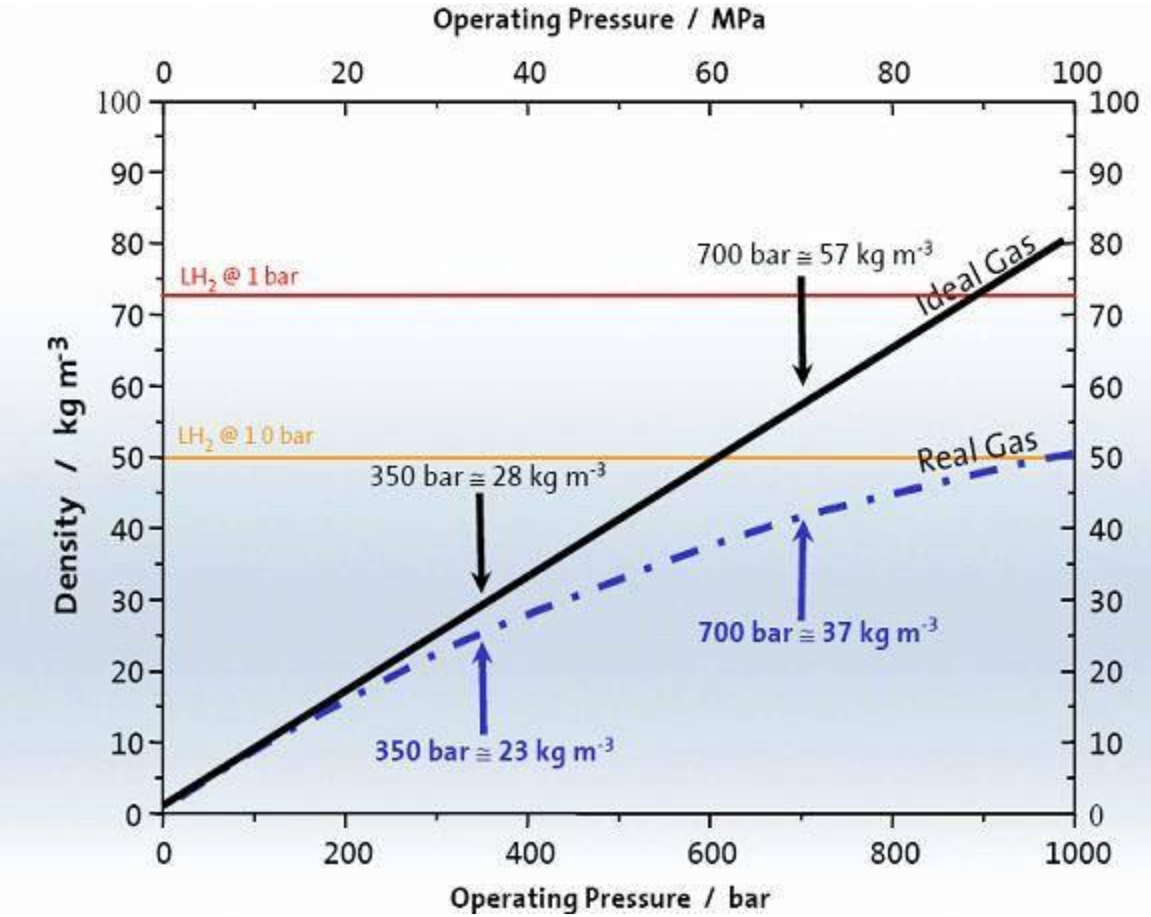
Optimize Volume / Surface Ratio

Pressure Vessel Equation (700 bar)

↓

Optimize Geometry

H2 density



General Challenge

Low Volumetric Density

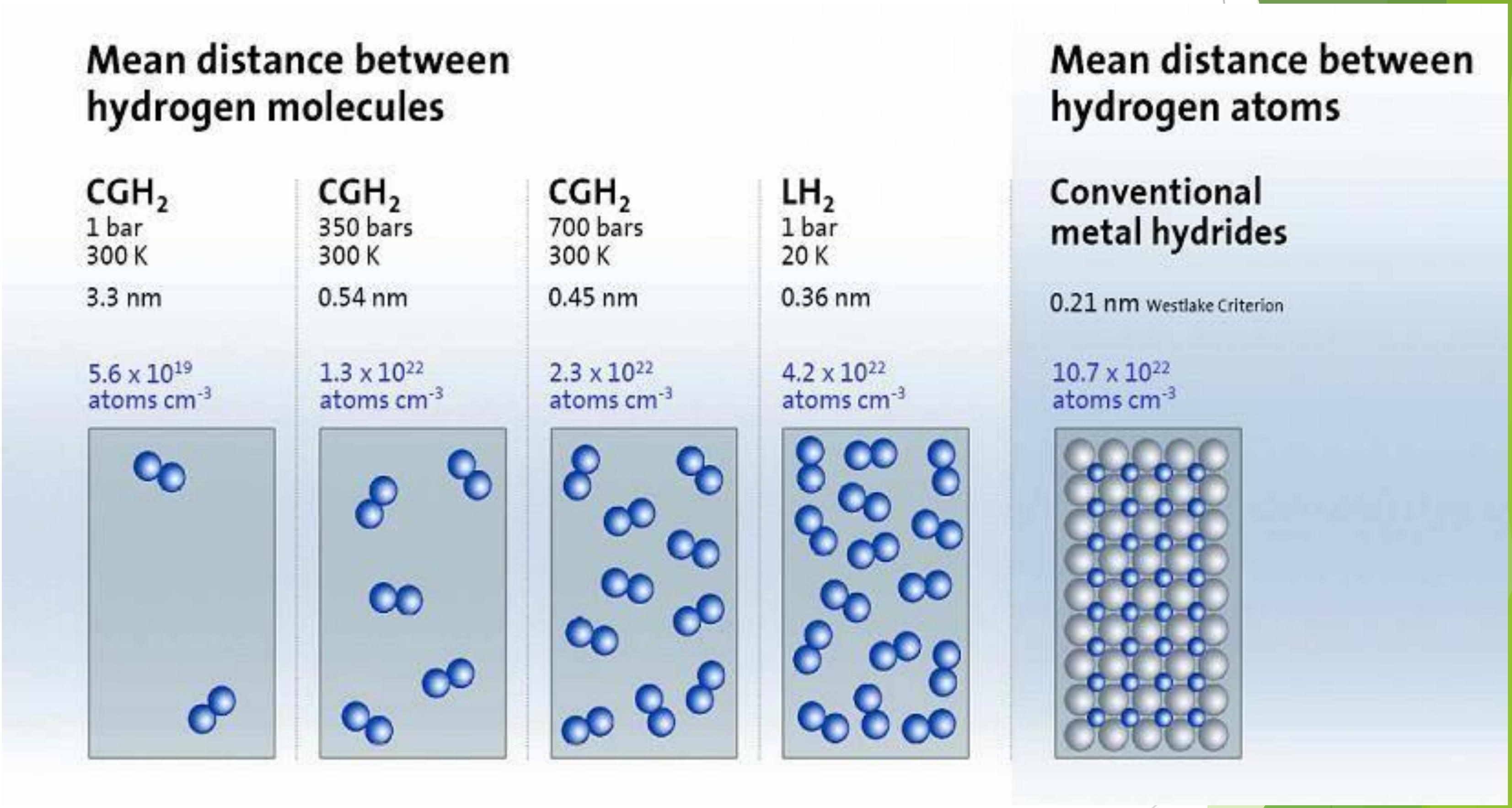
Low Heating Value

LH_2 8.5 MJ / liter

Gasoline 31.7 MJ / liter

Diesel 36 MJ /liter

Storage in solid materials: an interesting option



HYDROGEN STORAGE IN ROAD VEHICLES

- Pressures of 200, 350, 700 bar
- Made of composite materials in steel casings
- Material specifications
  - Mechanical durability (Piercing, crashing durability etc)
  - Low weight
  - Zero H2 permability
  - Efficient thermal behaviour
  - Use of parallel tank configuration
- Pilot application on public transportation vehicles

Hydrogen tanks used for on- board applications

Pros

- Big storage capacity
- Relatively low cost

Cons

- Safety, especially in transportation applications
- Incapable of working under changing pressure

H2 TRANSPORT & DISTRIBUTION

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H2 Large scale underground storage

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 46 (2021) 15671–15690

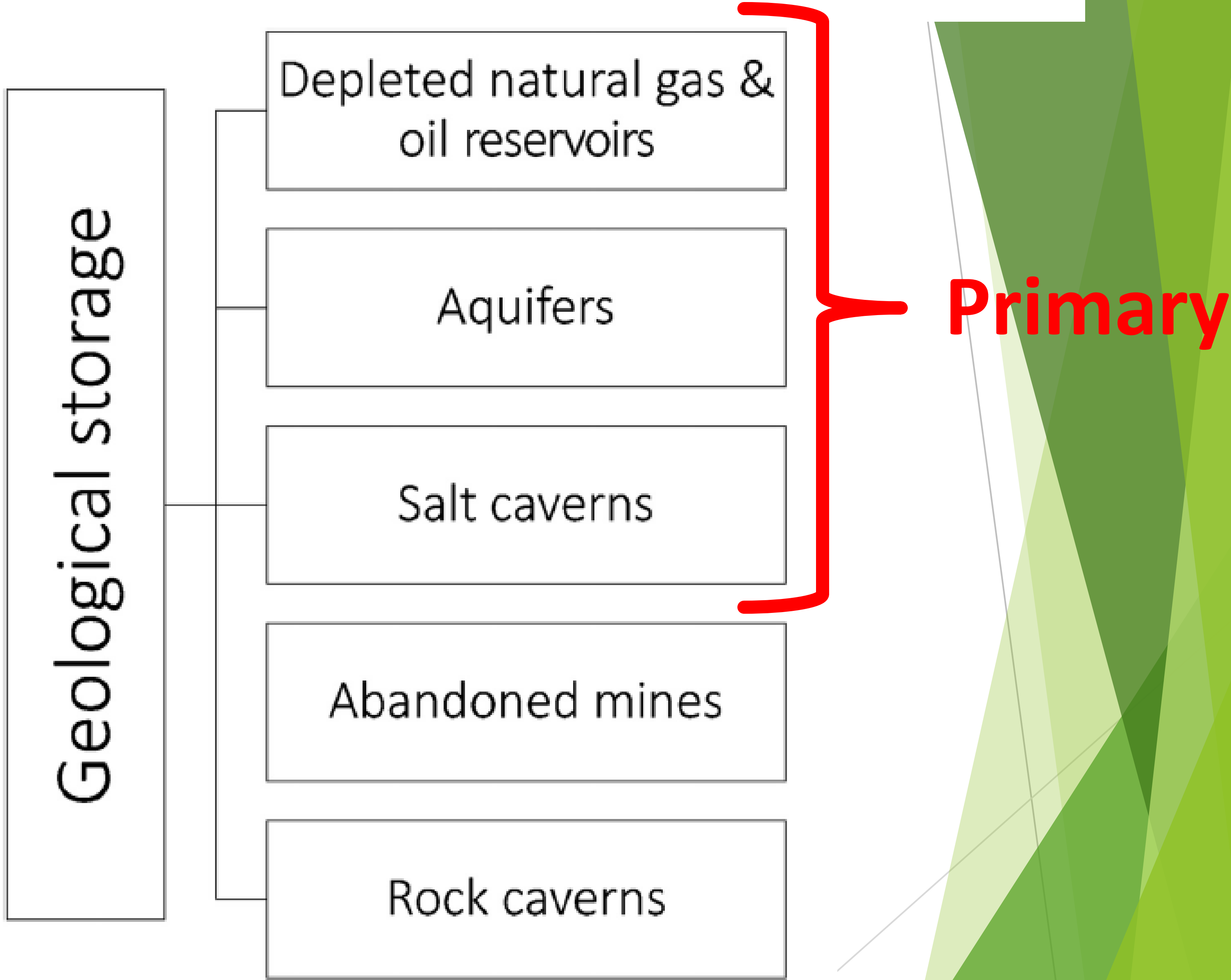


Fig. 9 – A scheme for types of geological storage.

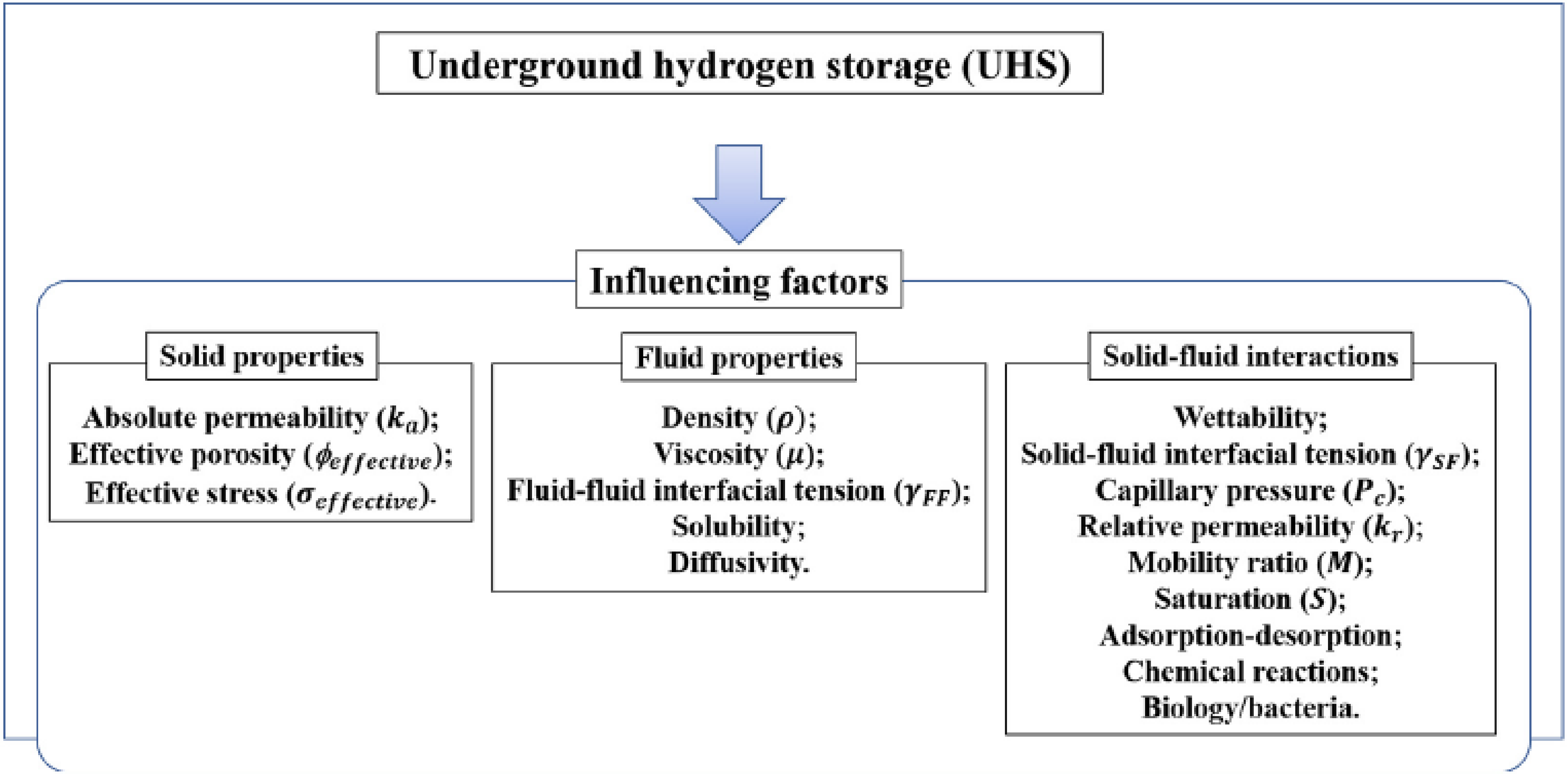
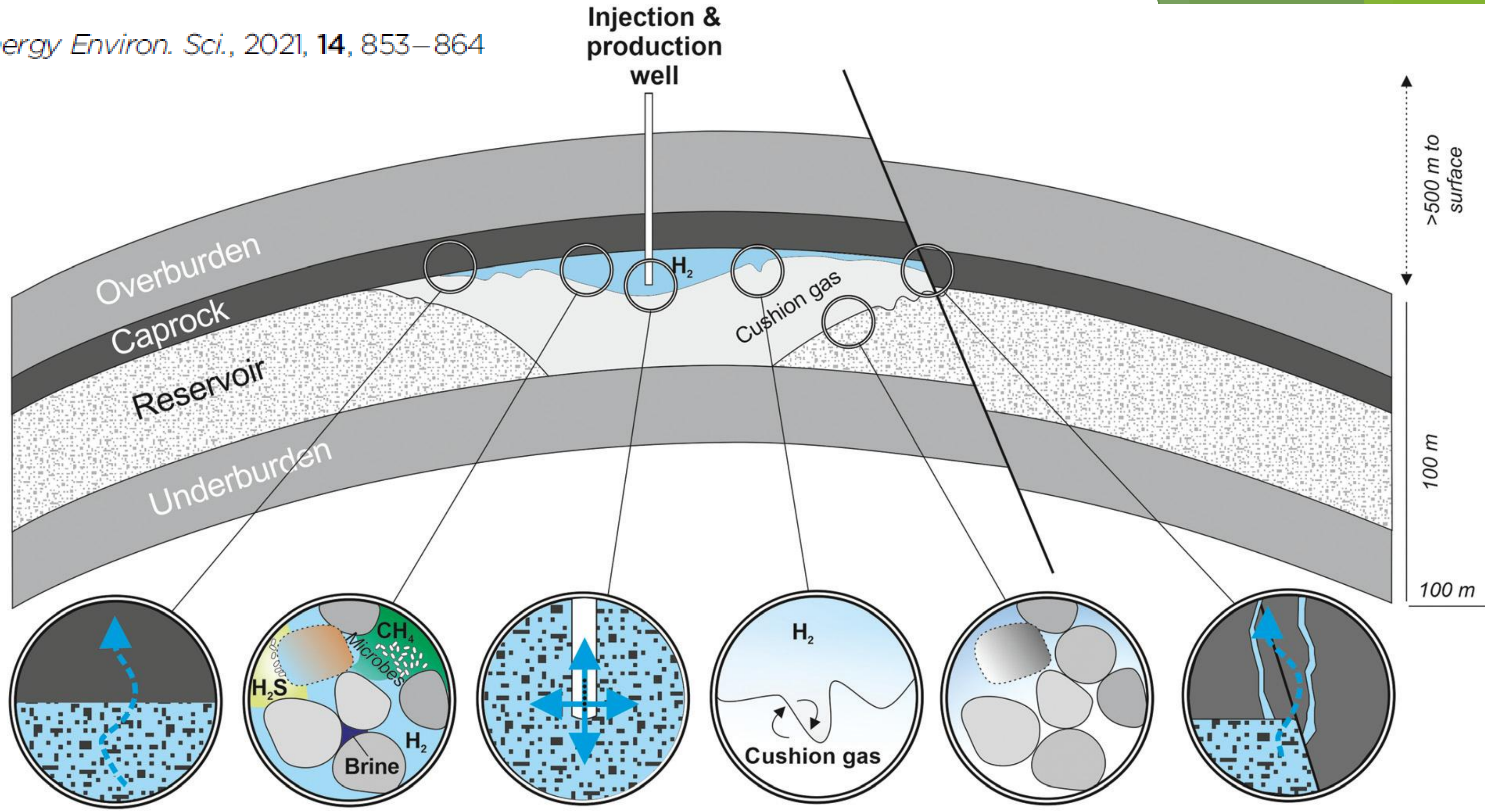


Fig. 1. Multi-scale parameters relevant in underground hydrogen storage.

Energy Environ. Sci., 2021, **14**, 853–864



Caprock:

- Diffusion
- Capillary leakage
- Fracturing
- Buoyancy pressure

Hydrogen plume

- Fluid-rock interaction
- Microbial activity
- Dissolution & residual trapping

Injection/production:

- P/T change
- Multiphase processes
- Stress/strain changes

H_2 - cushion gas:

- Unstable displacement & uncrontrolled lateral spreading
- Gas mixing

Cushion gas- brine

- Fluid-rock interaction
- Unstable displacement
- Dissolution & residual trapping

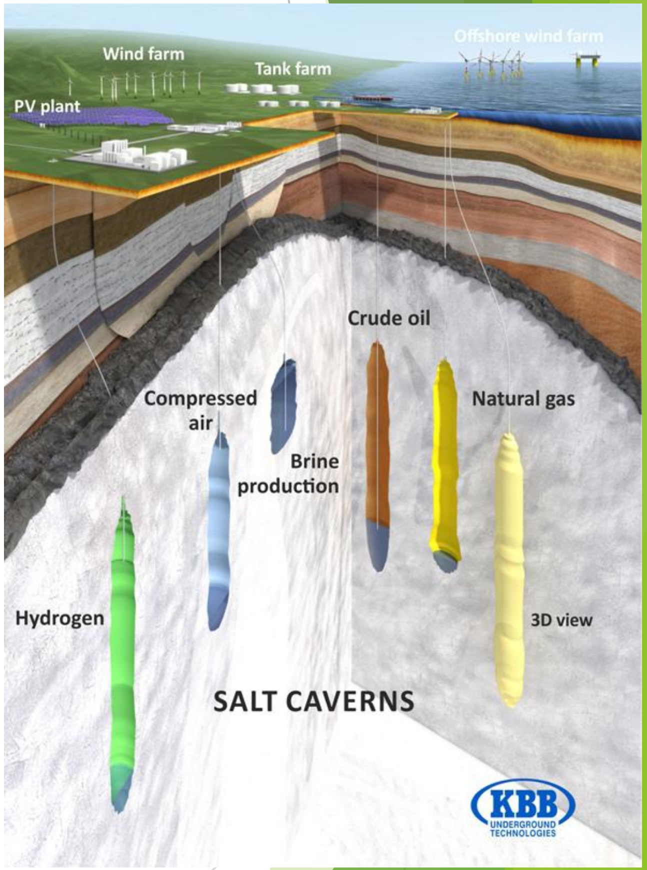
Structural geology:

- Fault leakage
- Far and near field stress changes
- Reactivation
- Overpressure

Fig. 2 Hydrogen storage in porous media highlighting all geological uncertainties considered in this paper. Note that both depth, formation thickness and horizontal do not represent scientifically justified ranges but are included to provide an idea of the magnitude of the operations.

Salt Caverns for Gas Storage

- Used to store gases including hydrogen since the 1950s
- Sites have traditionally been developed after salt extraction by the chlorine industry
- Over 30 caverns in use in the UK today
  - mainly used for NG
  - 1 in use for hydrogen
  - internal wall properties prevent leakage and contamination of the hydrogen
- Lowest cost direct storage mechanism for large hydrogen volumes
- Possibility to use Larne salt caverns for hydrogen storage



NEEST

NEW ENERGY & ENVIRONMENTAL SOLUTIONS AND TECHNOLOGIES

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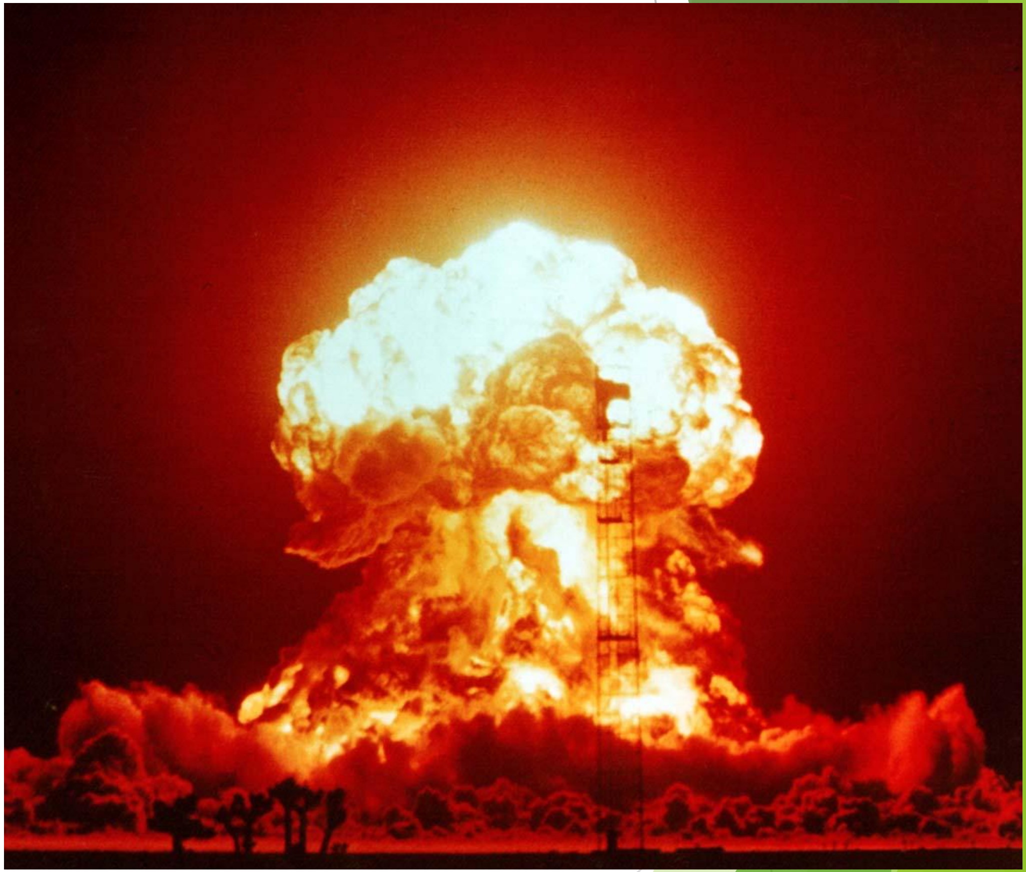
H2 APPLICATIONS: SAFETY

Typical examples - cases

Hydrogen Safety

- Is Hydrogen safe?
- What is a fuel?
- Explosive limits 4%-80%.
- Containment of the explosive mixture.
- Need for oxygen.



Hydrogen safety

- All fuels (or energy carriers) (like Gasoline, Coal, CNG, LNG, H_2) have „safety" issues (otherwise they wouldn't be used as fuels)
- According to the specific characteristics of each energy carrier, appropriate safety measures are developed
- Hydrogen is a (light) gas and shares similarities with natural gas
- The utilization and safety measures for natural gas are well known and may be considered as a good first approximation for the use of hydrogen

Hydrogen safety: Basic principle (as in all fuels)

Explosion conditions

- Fuel
- Oxygen
- Ignition source

All three factors must be present in sufficient quantity for a fire to occur

Always avoid ignitable mixtures and ignition sources

Grafik: www.sentronic.com

Hydrogen safety: Relevant material data

Basic principles - hydrogen data **(and for natural gas)**

- Lower and upper concentration limit for the ignition
  - 4 % ... 74% (4.1% ... 16.5%)
- Lower and upper concentration limit for the detonation
  - 13 % ... 65%
- Ignition temperature
  - 560°C (575 ... 640°C)
- Minimum ignition energy
  - 0.02 mJ (0.28 mJ)
- Density
  - 0.089 kg/m³ (air density: 1.225 Kg/m³) (0.83 kg/m³)

(EC) No. 1272/2008 [CLP]

Hydrogen safety

Thought experiment on Hydrogen Safety*

In your mind, go to your gas cooker, turn the knob and leave the room. What happens?

LPG

Gas out of the hob.
Denser than air so drops on top of the floor.
Builds up a mixture of gas and air on the floor till about 2 feet deep.
Spark in the back of the fridge.
Boom - Bye Bye kitchen.

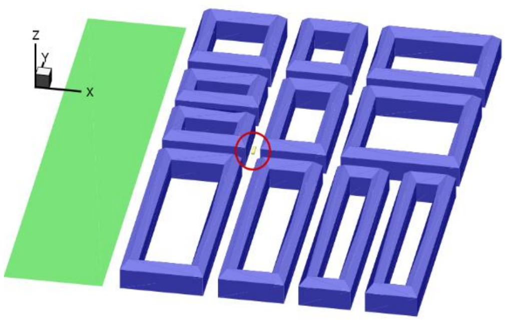
Hydrogen

Gas out of the hob.
Rises at a speed of about 67 km/h.
Hits ceiling finds a crack and escapes through the roof.
Does not build up a mixture of H2 and air.
Without hermetically sealing the room you cannot build this explosive mixture.
Generally, H2 is not very suitable to create explosive mixture which will then ignite.

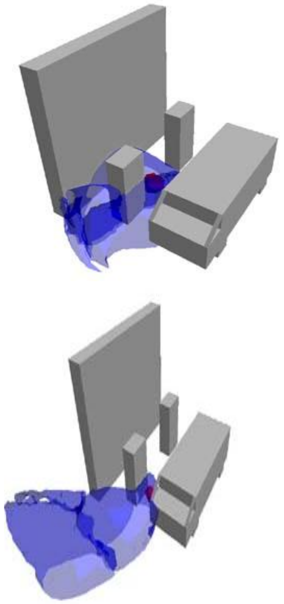
*adapted from Dr. Ch. Dunnill, Swansea Univ., UK

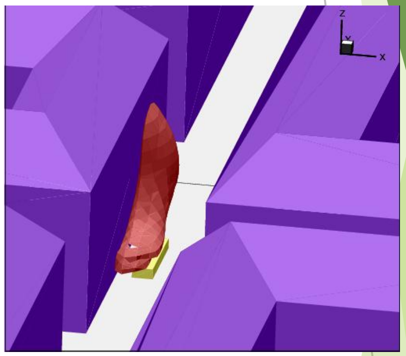
Simulation Tools: Storage Systems & Safety Studies

Safety analysis of hydrogen used as a fuel for vehicles



The 1983 Stockholm H_2 accident. Modeled site and truck carrying 4 kg of H_2 in 18x200 lt, 200 bar bottles





The 1983 Stockholm H_2 accident predicted lower flammability H_2-air cloud for 10 seconds after start of accident.

HySafe HyApproval

Hydrogen Safety: Summary

Summary

- Safe operation (as for other fuels) with hydrogen is possible
- Synergies / similarities between natural gas and H_2
- Set-up / installation of components in rooms is technically possible and can be safe
- Adapt safety concept according to the application – cost-effective solutions are possible

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HYDROGEN REFUELLING STATIONS (HRS)

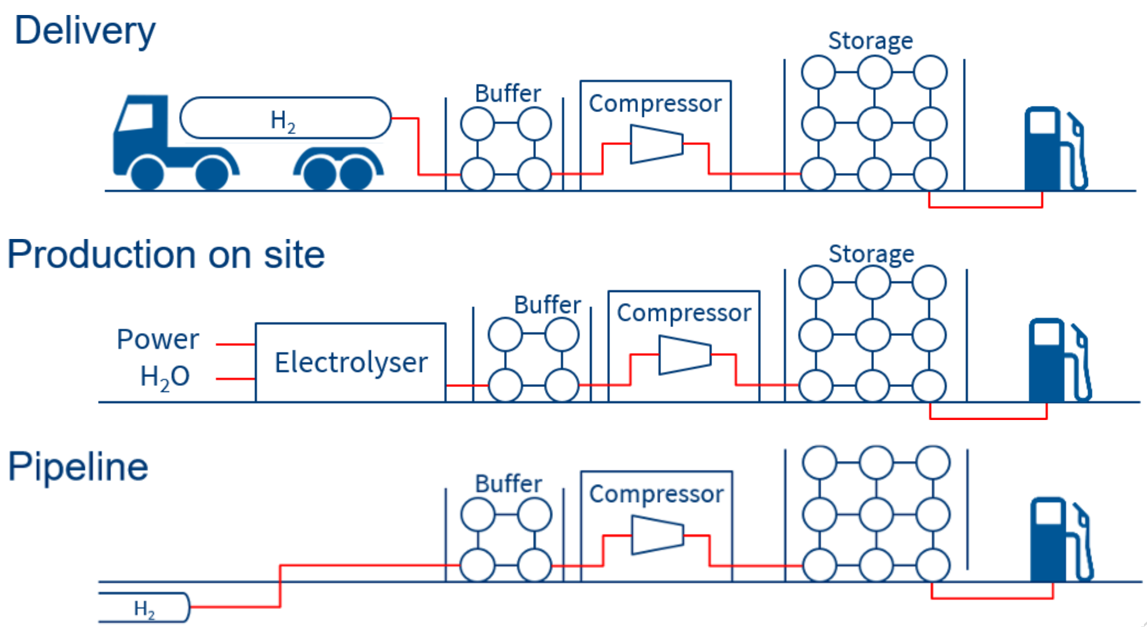
Hydrogen Refueling Stations (HRS) – EU

Typical Sub-systems HRS

Pilot Integrated Station H2 – NCSRD

Hydrogen Refueling Stations

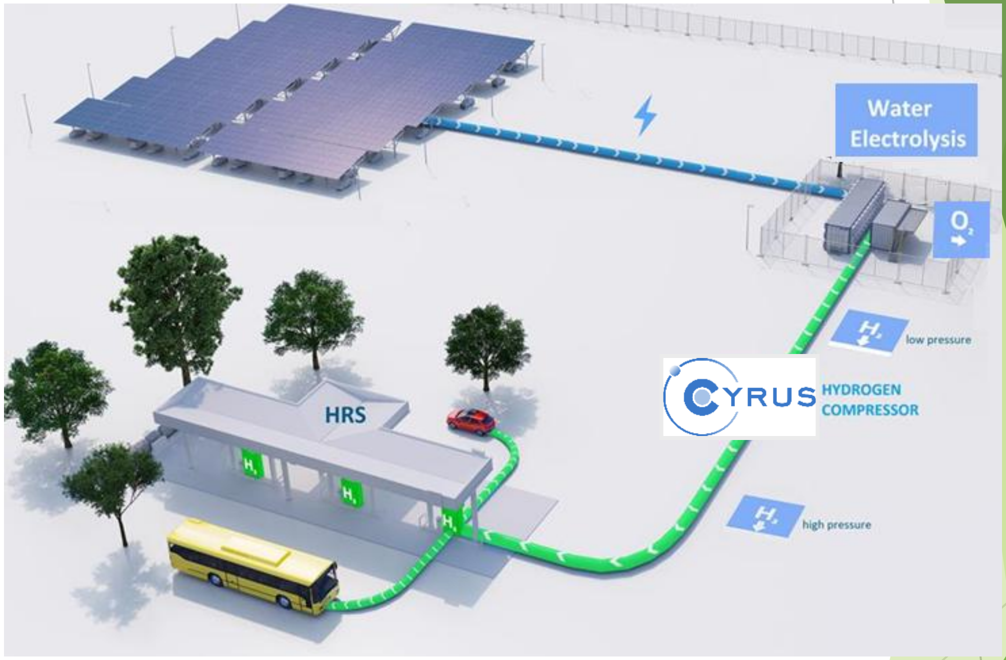
Hydrogen supply for refueling stations



THE H2TRANS PROJECT

H2TRANS main goal

Developing the first hydrogen refueling station in Greece and demonstrating hydrogen-powered vehicles



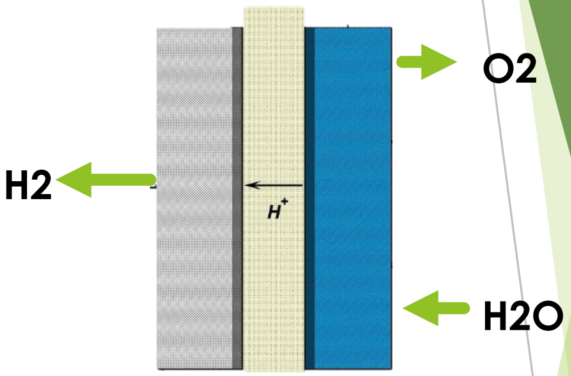
Parties involved:

- NSCR Demokritos
- NEEST
- ELFON
- XANTHIS
- CITIPOST

This work is co-financed by the European Regional Development Fund of the EU and Greek national funds under the call RESEARCH – CREATE – INNOVATE (project H2TRANS_T1EDK-05294).

The 4 subsystems

PV System



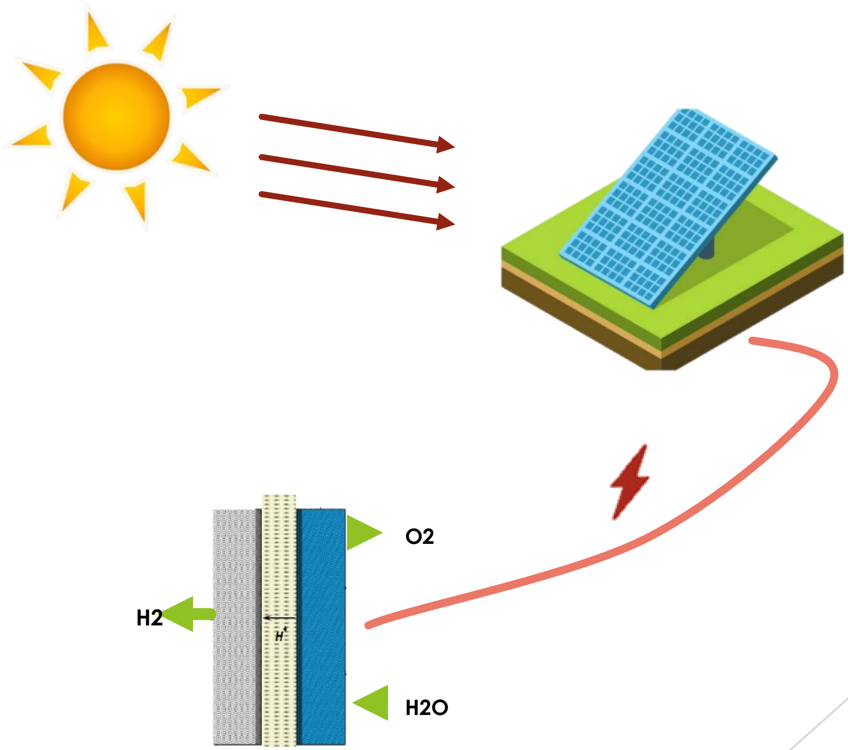
PEM Electrolysis Unit

H2 Vehicles

H2 Storage and compression

Photovoltaic System

- In order to improve the sustainability of the installation , the use of renewable energy sources is inevitable
- This ensures the minimization of CO_2 emissions of the system
- For the purposes of the project the installed power will be 20kWp



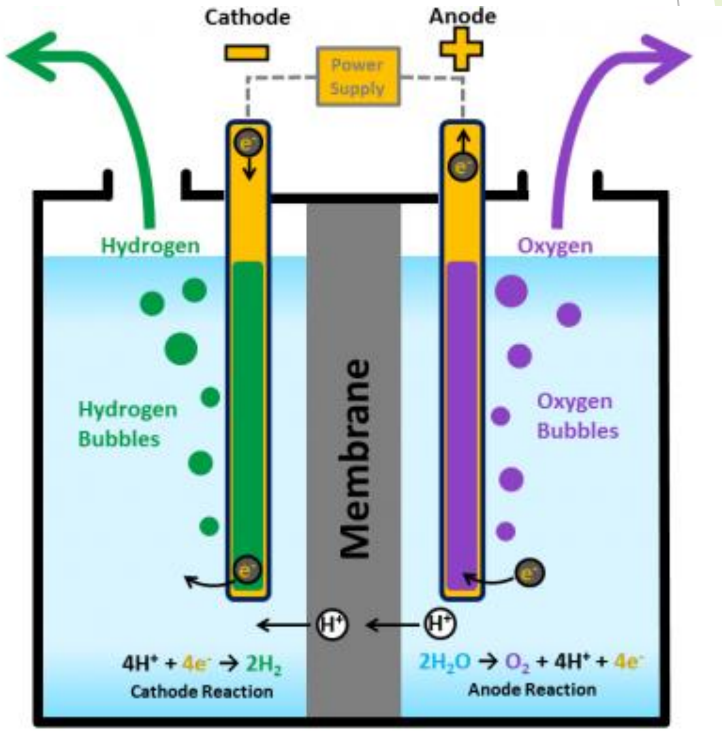
ΗΛΕΚΤΡΟΝ

Hydrogen production system

- **Electrolysis unit is powered by DC current produced by solar panels**
- **PEM Electrolyzers use a solid polymer electrolyte for conducting protons from the anode to the cathode**

<u>Working Principle of PEM Electrolysis:</u>

1. Water at the anode reacts to form oxygen and positively charged H2 ions which can pass through the membrane
2. Electrons flow via an external circuit
3. H2 ions combine with electrons of the external circuit to form H2 gas.



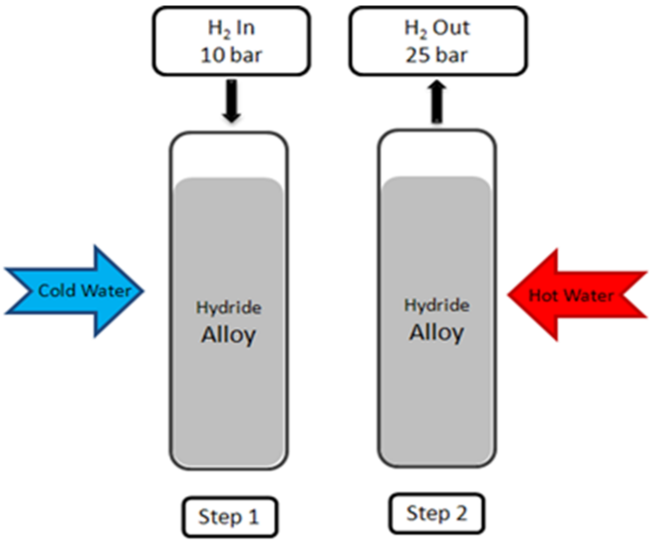
Working of PEM electrolysis

H2 storage system

- Different approaches: Gaseous, Liquid, Chemical storage
- H2TRANS utilizes storage in gaseous form
- Need for compression in order to store larger quantity in given volume
- By compressing H2 :
  - **increased density**
  - **minimized volume**
- Storage at 200 bar in stainless steel tanks
- Total station capacity: 120 Nm^3 (12 tanks of 10 Nm^3)

Hydrogen in gaseous form storage tanks

Compression system

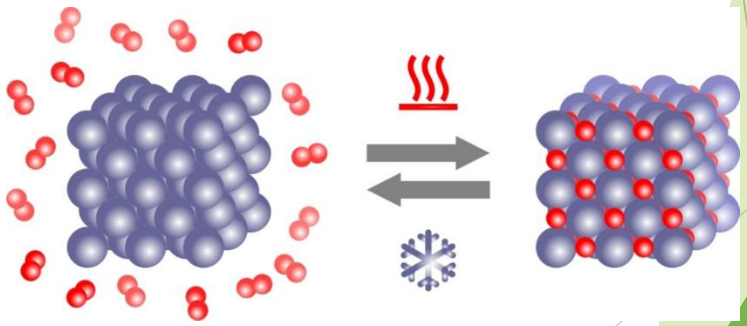


<u>Thermal Compression</u>

- Utilizing metal hydrides (MH) which store hydrogen chemically
- MH store hydrogen at low temperature & pressure
- MH release stored hydrogen when heated
- Energy needs minimized when there is external flux of heat such as waste heat
- Outlet pressure: <u>200 bar</u>

<u>Metal Hydride Compressor</u>

- No moving parts (low OPEX)
- Low noise
- Ideal for residential areas



Metal Hydride principle of operation

ΗΛΕΚΤΡΟΝ

Hydrogen powered Vehicles

- The FCEVs will be implemented by transforming electrical vehicles in a way that they can use fc for powering their electrical motor.
- Transformed vehicles include a scooter and a golf cart
- Compatibility of the fuel cell which will replace the battery, with the electric motor must be ensured
- Vehicles will have on board light weight 200 bar tank
- An ultra capacitor will be installed on board as well ensuring better response of the system
- Vehicles will also have a register and visualization system for monitoring the key performance indicators

Electrical vehicles suitable for fuel cell transformation

Hydrogen Refueling Station

ΗΛΕΚΤΡΟΝ

The Hydrogen Refueling Station (HRS) for small vehicles has already been developed at the premises of NCSR DEMOKRITOS (containerized solution)

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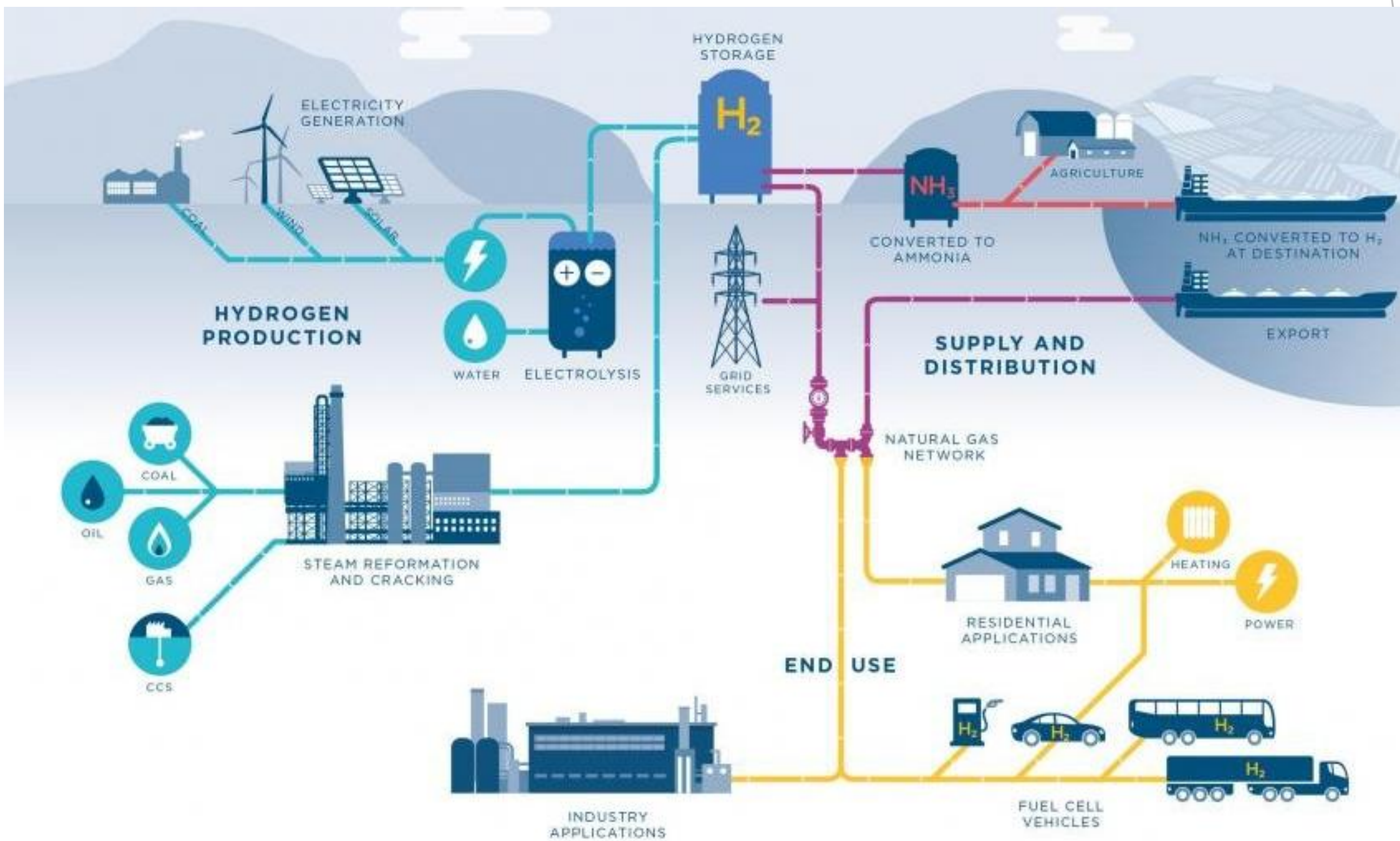
H2 APPLICATIONS & USE IN VARIOUS SECTORS

Transport (Light & Heavy Duty Vehicles, Ships, Trains…)

Industry (Hard to Abate Sectors)

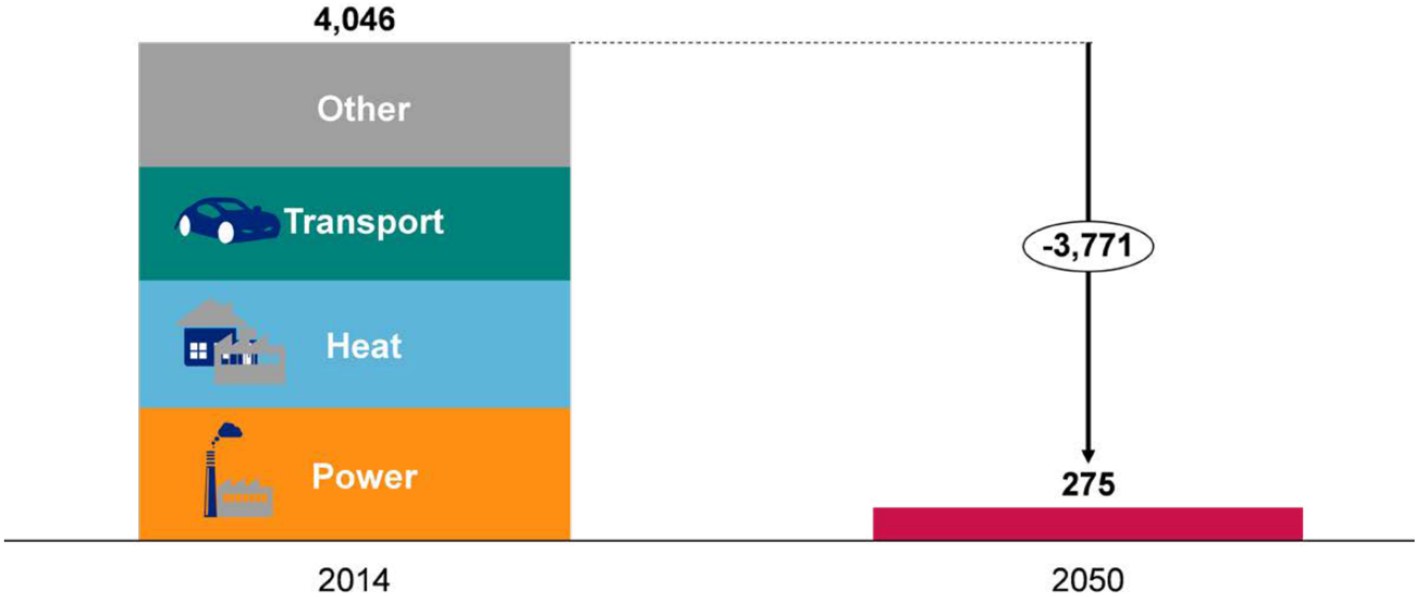
Fuel Cells – Use in ICEs

From H2 Production towards an H2 Ecosystem



Intensification of effort is needed

FIGURE 1 – THE SCALE OF EUROPE'S DECARBONISATION PROBLEM ($MtCO_2e$)



Source: 2016 National Inventory Submissions (Common Reporting Format) for EU, Norway and Switzerland.

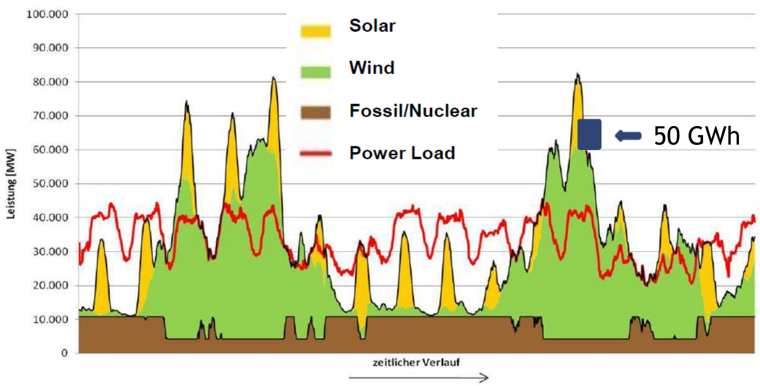
Source: Poyry point of view, fully decarbonising europe's energy system by 2050, May 2018

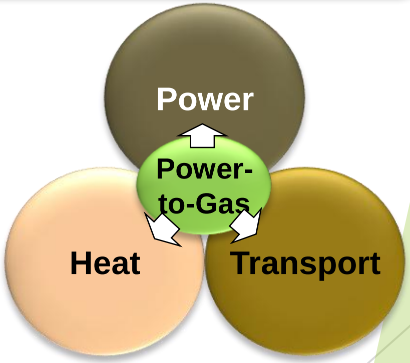
Power-to-Gas
From electric energy to gaseous fuels

Integration of renewables

Storage

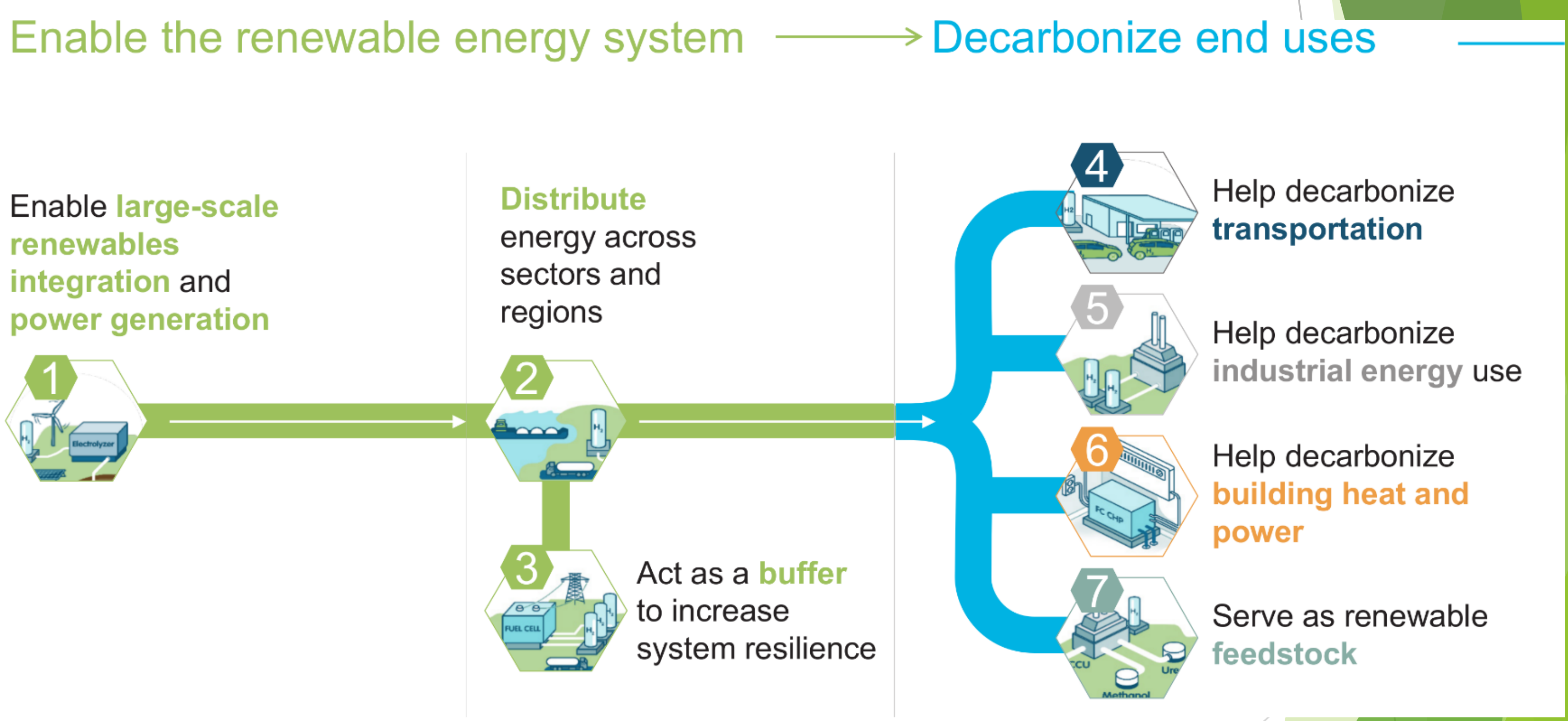
Power-to-X: Sector Coupling



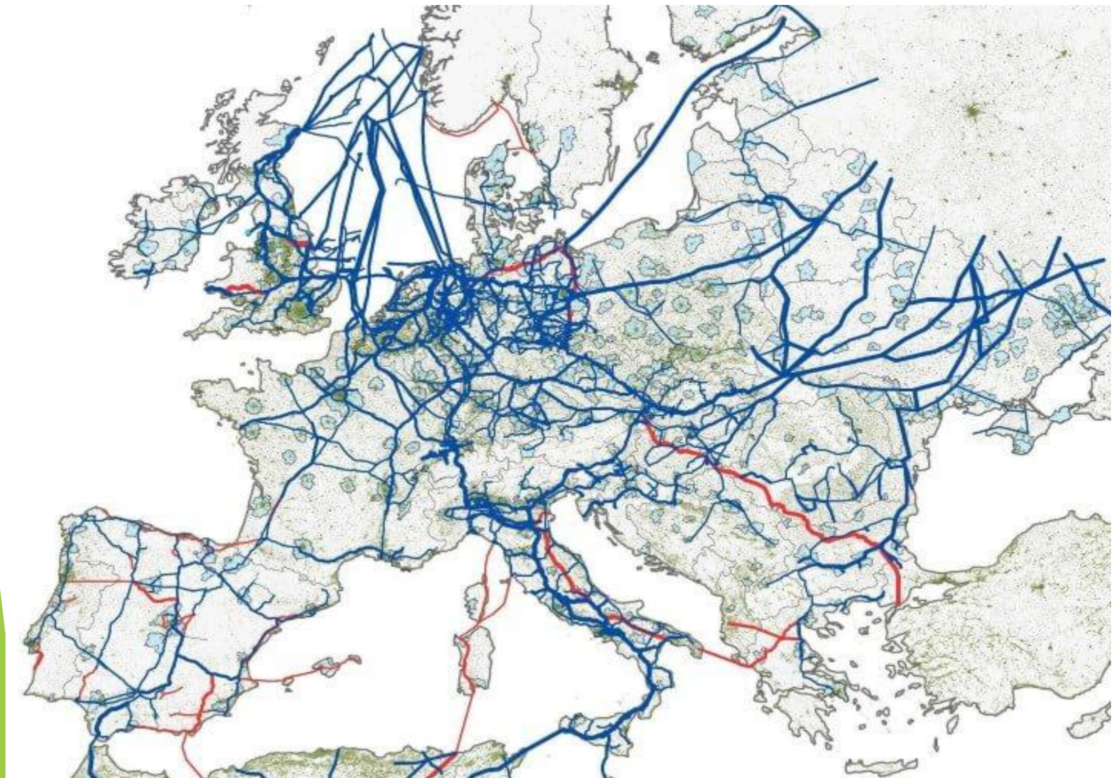


Source: BTU Cottbus, innogy

Hydrogen is key for the unification of the energy sector

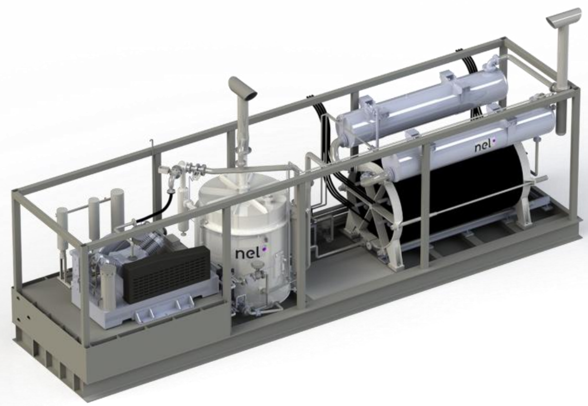


Gas network / pipelines:
A basis for carbon independence processes in energy



Opening the market via a series of appropriate initiatives

A "coalition" needed for 40 GW Electrolysers!



Europe is among the world leaders in this technology!

EU Regulatory Framework: Fit for 55

European climate law sets the reduction targets for net greenhouse gase emissions

- Ultimate goal: climate-neutrality by 2050
- Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

Fit for 55

- Proposals to revise and update EU legislation
- Framework for achieving the climate targets

–New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors

–Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

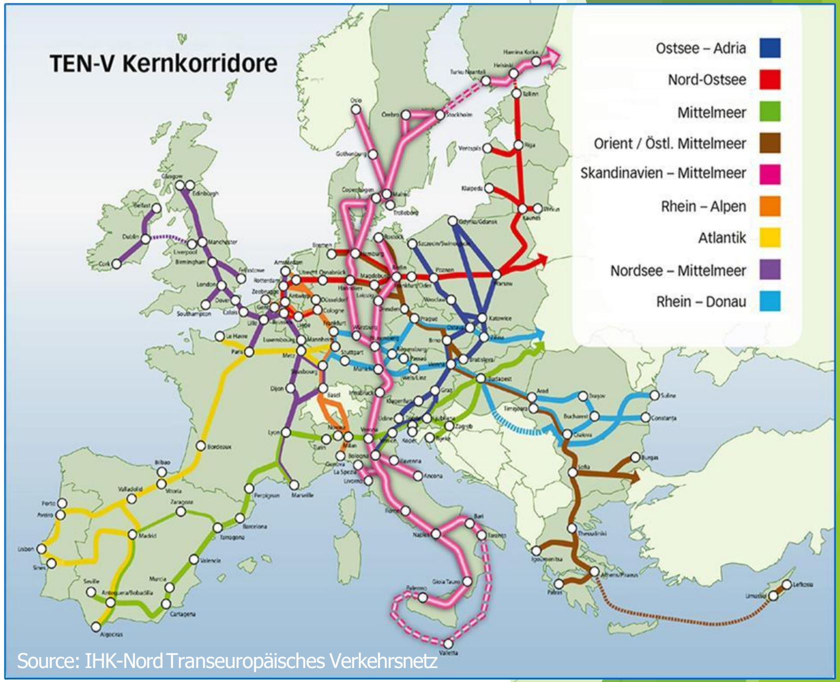
EU Regulatory Framework: AFID – Alternative Fuels Infrastructure Directive

- Adopted in 2014, on the development of alternative fuels' infrastructure in Europe for transport networks
- Implementation of AFID at the federal level (poor results)

AFIR[1] (Regulation) proposed in July 2021

TEN-T-comprehensive network & TEN-T-core network until 2030:

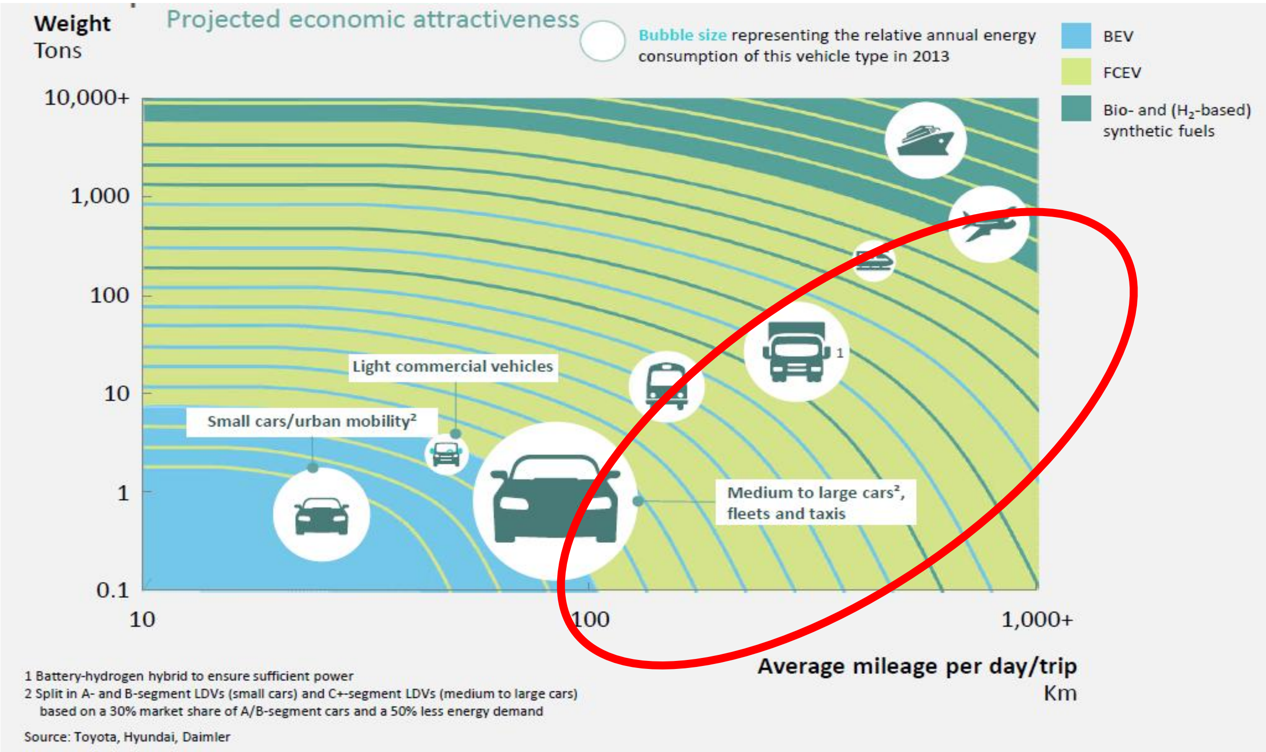
- Hydrogen dispensers (700 bar): max. 150 km distance in both driving directions
- Hydrogen dispensers for liquid hydrogen: max. 450 km distance in both driving directions



Source: IHK-Nord Transeuropäisches Verkehrsnetz

[1] On 19 October, the European Parliament adopted in plenary session its position on the Alternative Fuels Infrastructure regulation (AFIR) proposal

Hydrogen for transportation / car industry



Source: H2 Council

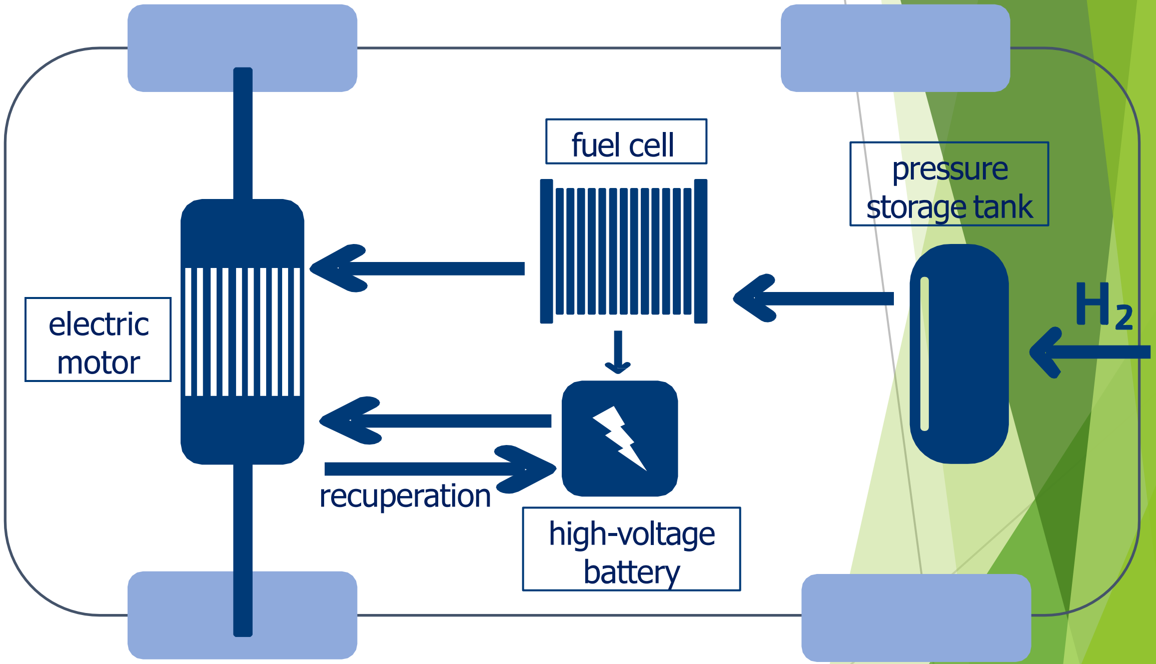
The FC-Vehicle market: Overview

Type	Passenger car	Bus	LD-Truck	HD-Truck	Garbage truck	Forklift
Range [km]	400 – 650	Ca. 400	Ca. 400	Ca. 400 (– 1200)	Ca. 500	Ca. 6 h
Pressure [bar]	700	350	700	350/700 (liquid)	350 / 700	350
Fuel capacity [kg]	4 – 6	35 – 40	4 - 5	> 35	10-20	1,5 - 2
Fueling time [min]	3 – 5	Ca. 10	3 – 5	Ca. 10	Ca. 10	< 3
Fuel consumption [kg/100km]	Ca. 1	6 – 10	1 – 1,5	7 – 10	7 - 10	0,3 kg/h
						

source: www.faun.com, 2020; www.still.de, 2020; Hyundai, 2020; Toyota, 2020; www.auto-motor-und-sport.de

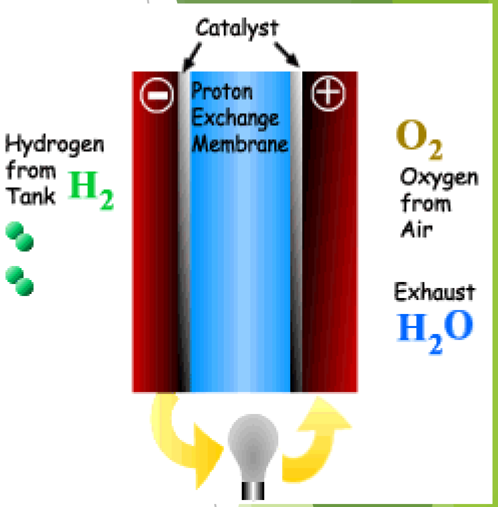
Fuel Cell Vehicle Technologies

- Full electric drive, no hydrogen combustion
- Additional low-capacity high voltage battery for recuperation
- CGH_2 (350 bar / 700 bar) is standard, future utilization of LH_2 is open
- Hydrogen pressure tanks type 3 (standard in mobility) and type 4 (lighter/newer) are the most used
- Tanking times from approx. 5 to 15 minutes



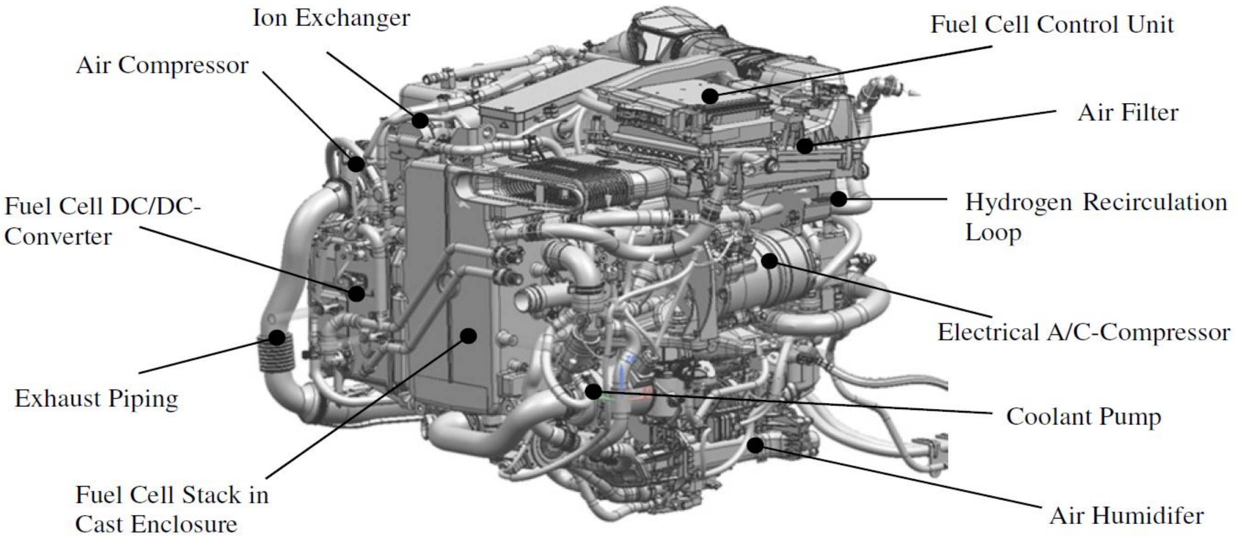
Fuel Cells

- Electrochemical Equipment operating similar to Batteries
- Consume Hydrogen and Oxygen to produce:
  - Electrical Energy
  - Heat
  - Water
- They are not RES, but a conversion equipment for power which has been stored in the form of a fuel (Hydrogen, Methane, Natural Gas, Methanol)
- Capital Cost between € 2,000 – € 5,000 / kW
- When the fuel is “green” hydrogen, the only emission is water
- When hydrocarbons are used FCs emit CO_2 but in significantly lower quantities compared to ICEs (ca. 1kg CO_2 per m^3 H_2)



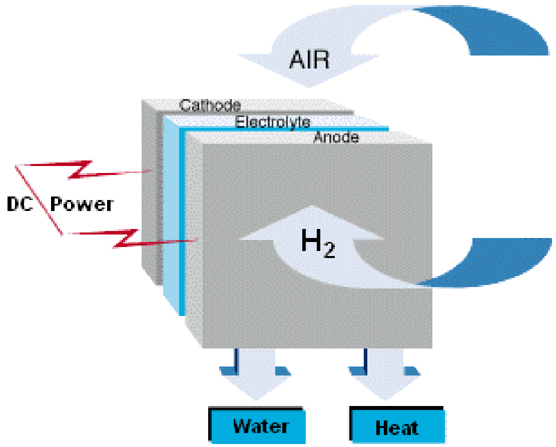
The electrolyte: special polymer or similar material, allowing ions to pass trough it, but is not permeable from electrons

Fuel cells may keep the value chain in Europe!



Source: Daimler

Fuel cells in vehicles



- Reversed process of electrolysis. Here hydrogen reacts with oxygen to produce electricity and water
- Electricity is then used to power an electric motor
- FCEVs* are essentially electric vehicles
- FCEVs and BEVs** are not always competing technologies
- FCEVs can be considered complementary to BEVs

Fuel Cell Vehicle Technologies: Types of Tanks

Compressed hydrogen gas

› Five different types of tanks:

RCS

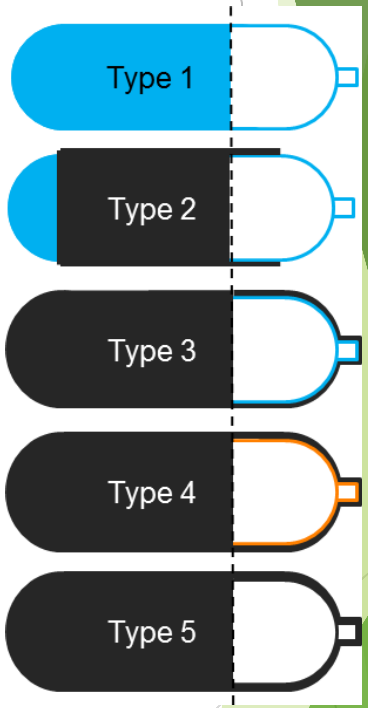
–Type 1: Metal tank (steel, aluminum)

–Type 2: Metal container partially wrapped on a resin soaked fiber ("hoop wrap")

–Type 3: Metal container fully wrapped on a resin soaked fiber ("full wrap")

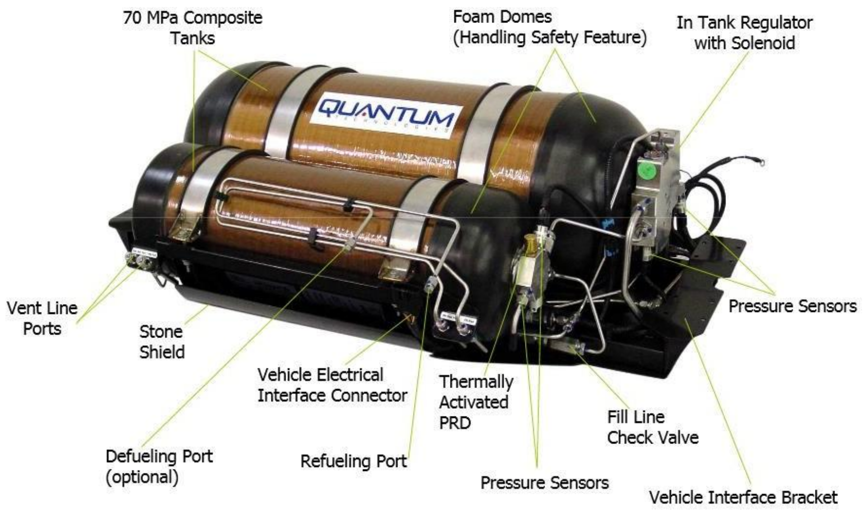
–Type 4: High density polymer liner fully wrapped on a resin soaked fiber

–Type 5: All-composite, linerless tank (prototypes)



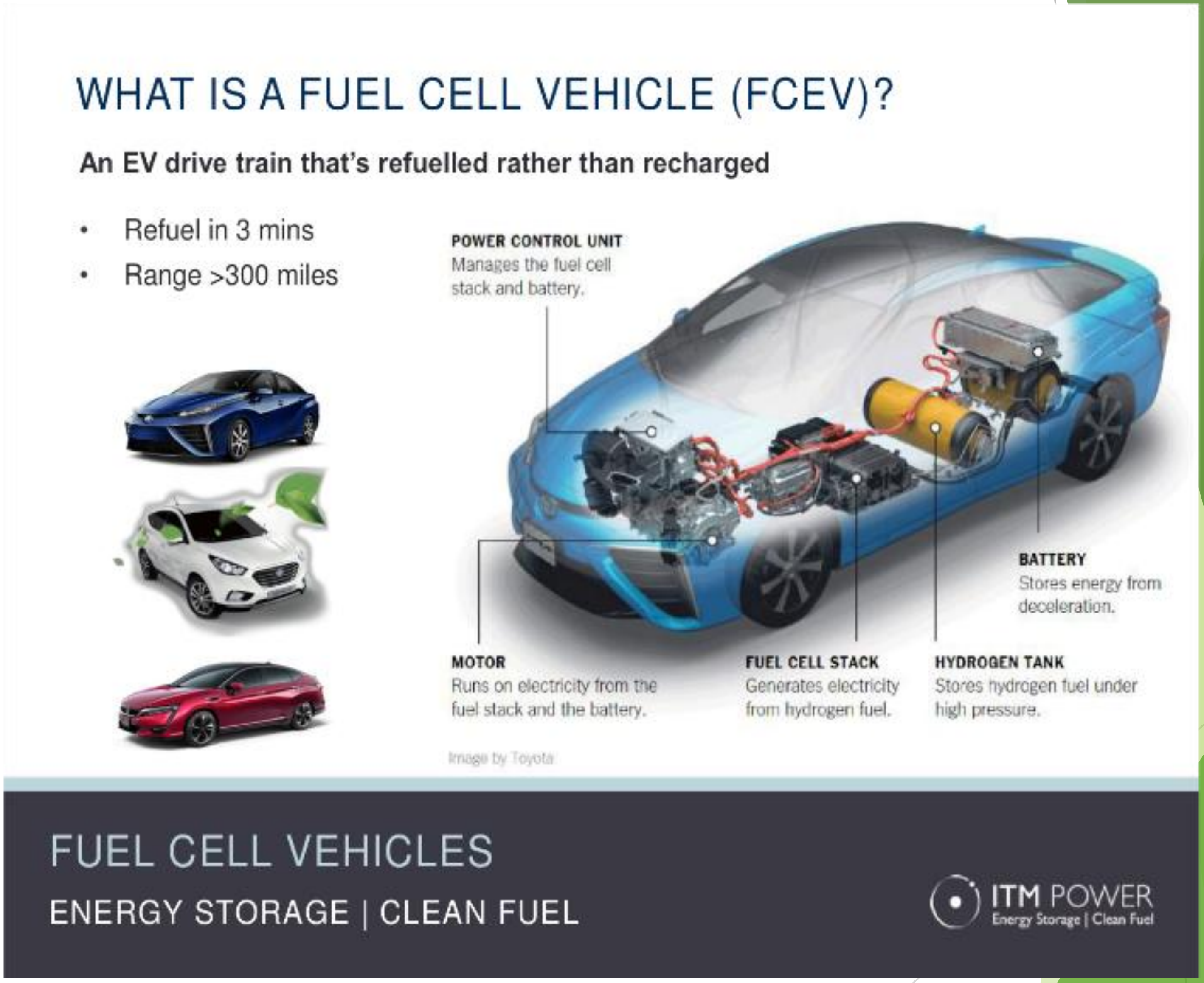
Fuel Cell Vehicles: Types of hydrogen tanks

Compressed hydrogen gas container assembly



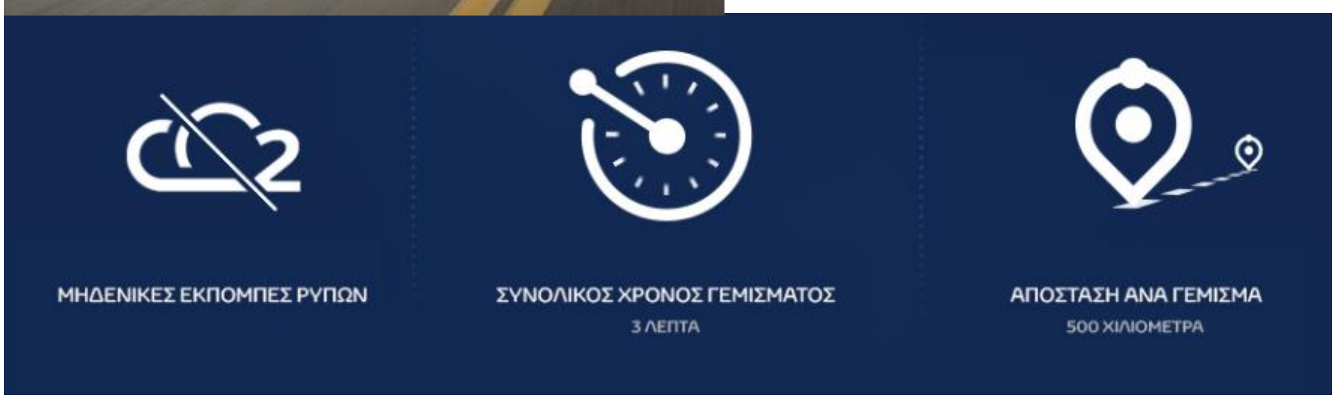
Source: Quantum

Type 3 tank


WHAT IS A FUEL CELL VEHICLE (FCEV)?
An EV drive train that's refuelled rather than recharged
• Refuel in 3 mins
• Range >300 miles
POWER CONTROL UNIT
Manages the fuel cell stack and battery.
BATTERY
Stores energy from deceleration.
MOTOR
Runs on electricity from the fuel stack and the battery.
FUEL CELL STACK
Generates electricity from hydrogen fuel.
HYDROGEN TANK
Stores hydrogen fuel under high pressure.
Image by Toyota
FUEL CELL VEHICLES
ENERGY STORAGE | CLEAN FUEL
ITM POWER
Energy Storage | Clean Fuel

TOYOTA MIRAI

First mass produced FCEV



EARLY MARKETS- SPECIAL TRANSPORTATION APPLICATIONS

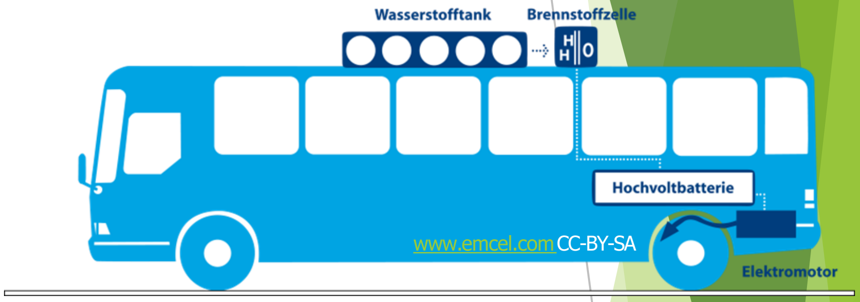
Fuel cell powered forklift

- **An early market for hydrogen vehicles is the forklift market**
- **Already entered the market by being used in warehouses, ports and industrial zones**
- **Value proposition of productivity gains**
- **In order for hydrogen to get traction in different segments there are several alternative routes**

The case of Fuel Cell Buses

Advantages

- Approx. 400 km range and short refueling times
- Route planning as for diesel buses
- Flexible to use
- No local emissions, low global emissions



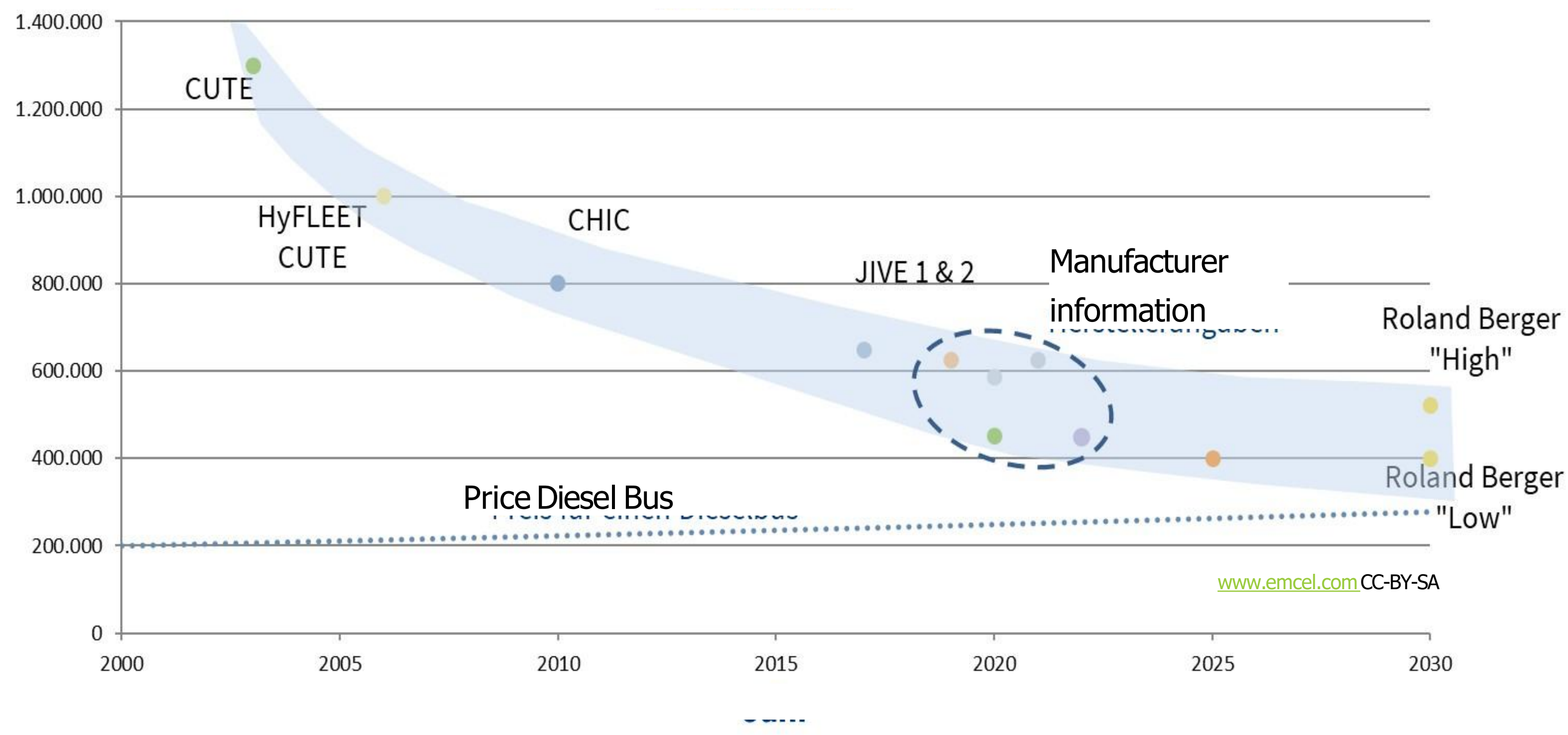
Disadvantages

- Acquisition costs (as of today)
- Establishment of own hydrogen infrastructure (start-up costs)

Consequence / possible solution

- Shared use of hydrogen refueling stations, also public
- Hydrogen filling station in operator mode

The FC-Bus market: 20 years of proven technology



Hydrogen Trains

World premiere: Alstom's hydrogen trains enter passenger service in Lower Saxony

"This is a revolution for @Alstom and for the #FutureOfMobility.

The world's first #hydrogen #fuelcell train is entering passenger service and is ready for serial production" emphasises Henri Poupart-Lafarge, Chairman & CEO of Alstom

16 September 2018

Switzerland: 1000 hydrogen trucks ordered for the 5 coming years

Hydrogen vehicles available in the market

Renault HyKangoo: 300 km range, plug-in-battery with 5 kW range extender, ca. 200 pcs

Hyundai NEXO, 800 km range
Hyundai ix 35: 600 km range, 300 pcs in Europe

Toyota Mirai: 650 km range, market introduction in Japan in 2015, > 4,000 pcs by now

Mercedes GLC: starting 2019, fuel cell with plug-in-battery, 500 km range (50 km by battery)

Hydrogen buses / trains

FC bus hotspot at RVK Cologne

- Today: 16 FC buses in Germany in operation, 80 in Europe
- Additional 140 FC via EU project JIVE and 150 via JIVE 2 by 2020/21
- "JIVE hotspot" NRW: Cologne (45) and Wuppertal (20)

Source: RVK

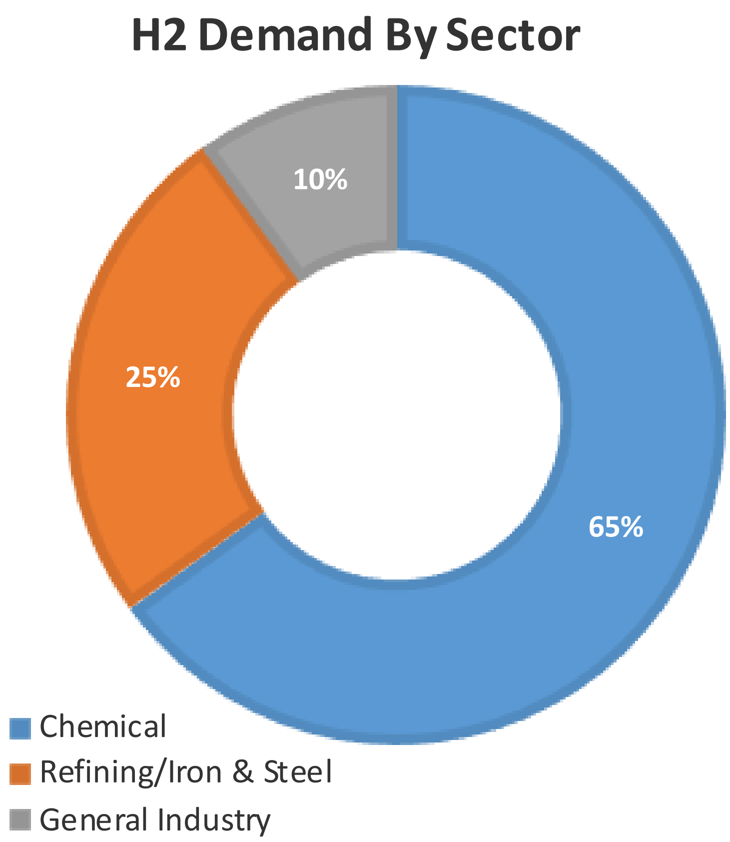
Prototype of Alstom FC train

- About 100 FC trains in Germany by 2021 on non-electrified railway tracks
- CO_2 mitigation: 40 % (H2 from natural gas compared with diesel)
- Suppliers from NRW
- Application of FC trains in NRW under preparation

Source: Alstom

HYDROGEN DEMAND BY INDUSTRY

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	• Ammonia • Polymers • Resins
REFINING	• Hydrocracking • Hydrotreating
IRON & STEEL	• Annealing • Blanketing gas • Forming gas
GENERAL INDUSTRY	• Semiconductor • Propellant fuel • Glass production • Hydrogenation of fats • Cooling of generators



Green Steel - role of EU

The EU evolved starting with coal and steel

European Coal and Steel Community	Treaty of Rome	Treaty of Maastricht	„Green Steel" redefines Europe's global role
1951	1957	1992	2020?

NEEST

NEW ENERGY & ENVIRONMENTAL SOLUTIONS AND TECHNOLOGIES

TETHYS WEBINAR – GREEN HYDROGEN PRODUCTION

Dr. Manos Zoulias

Dr. Athanasios Stubos

Dr. Emmanuel Stamatakis

MAJOR ISSUES FOR A WIDE MARKET DEPLOYMENT OF H2

The Infrastructures Issue

Intl. Cooperation - Legal Framework

Regulations, Codes & Standards (RCS)

UNDERSTANDING RISKS AND OVERCOMING BARRIERS

Main issues to be addressed

- Fuel and refuelling infrastructure: Location and accessibility of site and fuel supply. Security of fuel source.
- Vehicle supply: Currently few commercial models exist and slightly more variants of buses and trucks
- Cost competitiveness: Driven by the limited number of suppliers currently manufacturing FCEVs. Costs are expected to be lowered as more manufacturers enter the market
  - ➢ In transport, the competitiveness of hydrogen fuel cell cars depends on fuel cell costs and refuelling stations while for trucks the priority is to reduce the delivered price of hydrogen. Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels.

Hydrogen as Energy Carrier

- All components of the technology (Hydrogen & Fuel Cells) exist.
- Further R&D priorities related to H2 include issues in production, storage and distribution, compression…
- The issue of infrastructures remains open…

Hydrogen Fueling and Electric Charging of Vehicles in Germany

2018, JULY, 12TH | JOCHEN LINSSEN, MARTIN ROBINIUS, THOMAS GRUBE, MARKUS REUSS, PETER STENZEL, KONSTANTINOS SYRNANIDIS, DETLEF STOLTEN

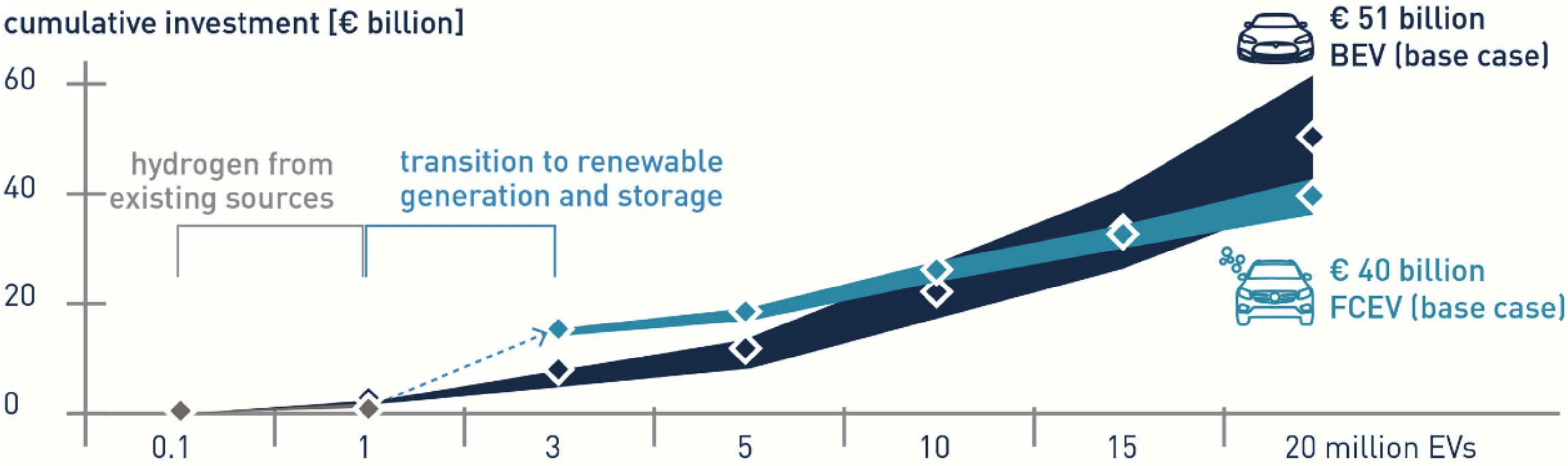
6th Hellenic Forum for Science Technology and Innovation, Athens Greece

j.linssen@fz-juelich.de

Institute of Electrochemical Process Engineering (IEK-3)

Cumulative Investment

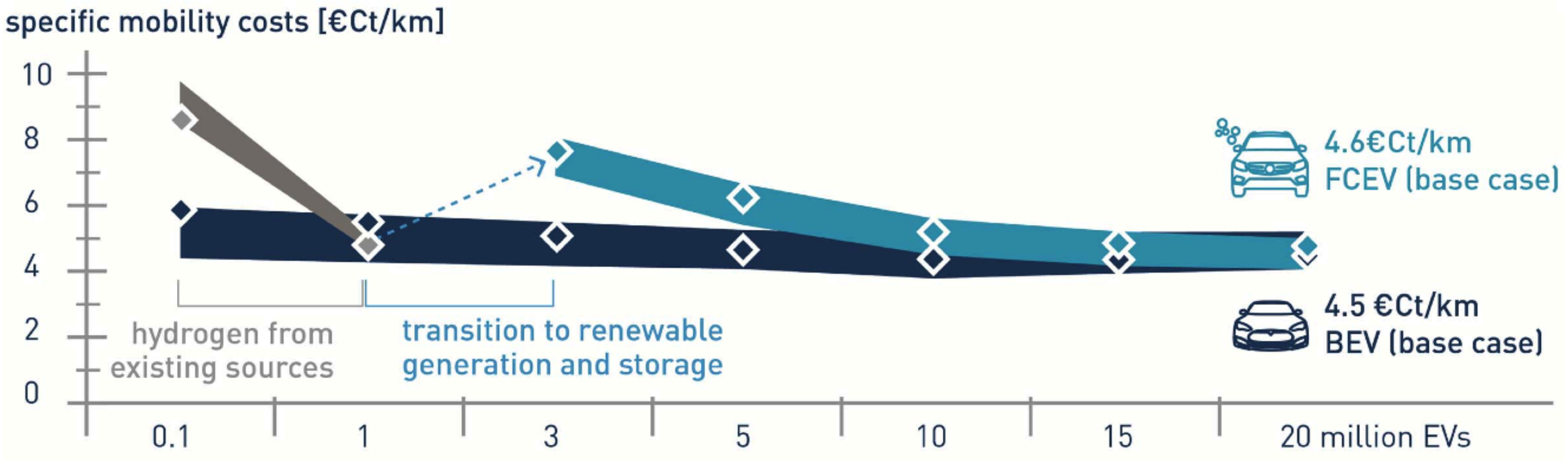
Infrastructure Roll-Out



- Hydrogen more expensive during the transition period to renewable electricity-based generation
- High market penetration: battery charging needs more investment than hydrogen fueling
- For both infrastructures investment low compared to other infrastructures

	Investment [€ billion]
Renewable electricity generation scenario	374
Electric grid enhancement plan 2030	34
Federal transport infrastructure plan 2030	265
Hydrogen fueling infrastructure	40
Electric charging infrastructure	51

Comparison of Mobility Costs

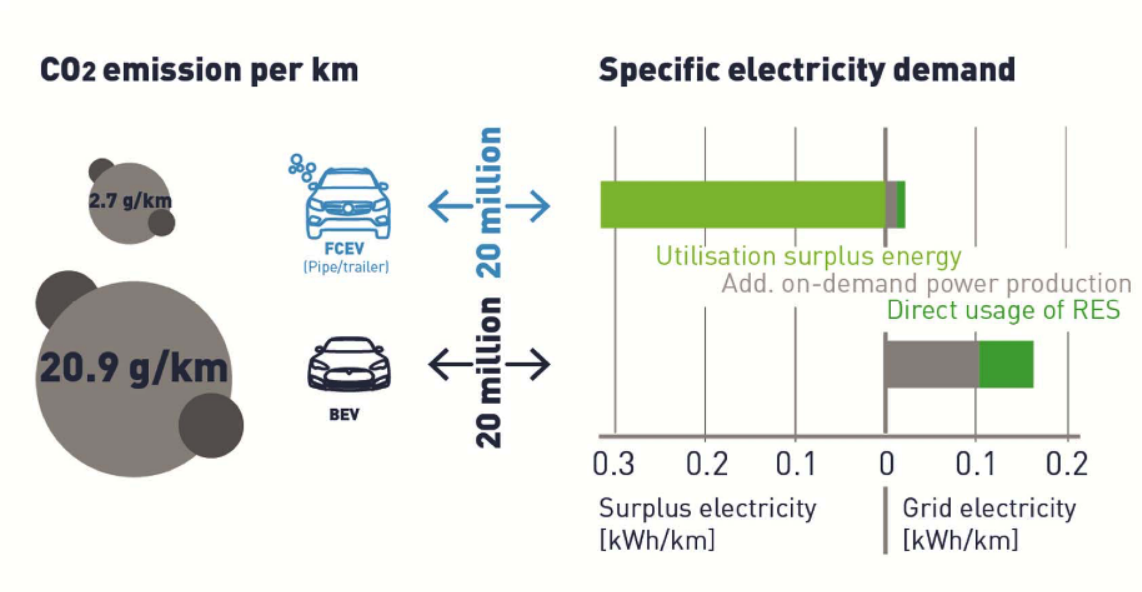


vehicle purchase and operation costs excluded

- For small vehicle fleets, i.e. 0.1 million cars, BEV fuel costs are significantly lower compared to FCEVs.
- Increase for hydrogen between 1 and 3 million cars results of switching to exclusive utilization of renewable energy for hydrogen production via electrolysis
- Mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km → the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.

JÜLICH Forschungszentrum

CO_2 Emissions & Electricity Demand

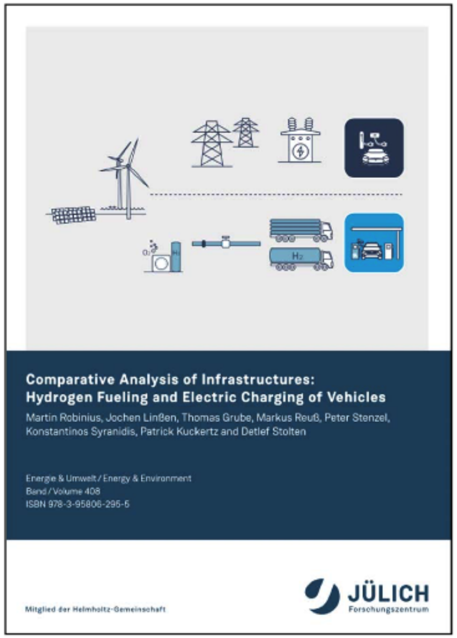


- Efficiency of charging infrastructure is higher, but limited in flexibility and use of surplus electricity
- Fueling infrastructure for hydrogen with inherent seasonal storage option
- Low specific CO2 emissions for both options in high penetration scenarios with advantage for hydrogen, well below the EU emission target after 2020: 95 g_{CO2}/km

JÜLICH Forschungszentrum

Full Report Available

http://hdl.handle.net/2128/16709



Project team:

Martin Robinius, Jochen Linßen, Thomas Grube, Markus Reuß, Peter Stenzel, Konstantinos Syranidis, Patrick Kuckertz and Detlef Stolten

Funded by H2 MOBILITY FUELLING HYDROGEN

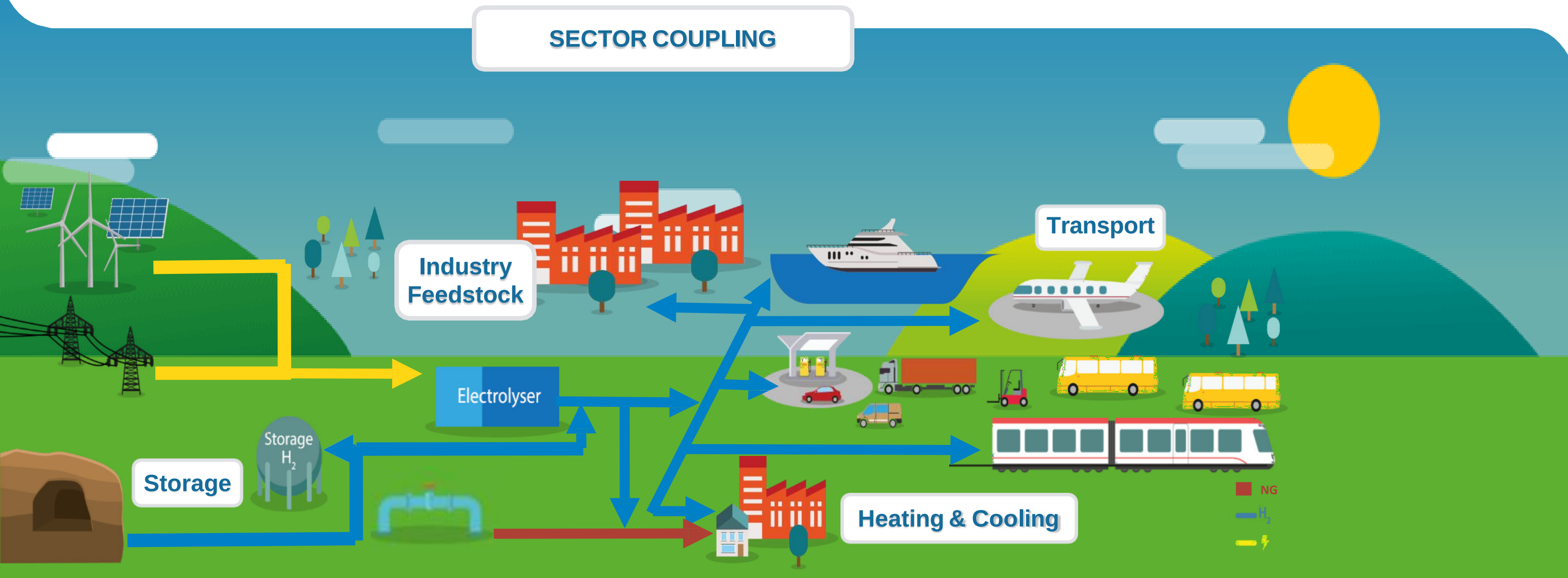
EC - FCH JU Regions & Cities Initiative
Application Packages for:

Buses, Heavy Duty Trucks, Trains
Bikes, Scooters, Garbage Trucks, Sweepers
Boats, Ferries, Ships, Port Operations Equipment
Commercial Buildings, Residential mCHP, Off-grid Power, Industrial Use Cases
P2H: Green H2, Electric Grid Services, H2 in NG Grid

Alternative Fuels Based on H2: Ammonia, Methanol, Synthetic Fuels…

The hydrogen economy

Hydrogen allows more renewables in the energy system and enables sector-coupling



Speed of change

- New York 1900
- First car in 1885, petrol from the pharmacy

- New York 1913

And safety is important, but so is fear of change…

“A new source of power… called gasoline has been produced by a Boston engineer. Instead of burning the fuel under a boiler, it is exploded inside the cylinder of an engine…

The dangers are obvious. Stores of gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline might attain speeds of 14, or even 20 miles per hour. The menace to our people of [vehicles of] this type hurtling through our streets and along our roads and poisoning the atmosphere would call for prompt legislative action even if the military and economic implications were not so overwhelming… the cost of producing [gasoline] is far beyond the financial capacity of private industry… In addition the development of this new power may displace the use of horses, which would wreck our agriculture.”

US Congressional Record, 1875

THANK YOU

UNDERSTANDING RISKS AND OVERCOMING BARRIERS

Main issues to be addressed

- Fuel and refuelling infrastructure: Location and accessibility of site and fuel supply. Security of fuel source.
- Vehicle supply: Currently few commercial models exist and slightly more variants of buses and trucks
- Cost competitiveness: Driven by the limited number of suppliers currently manufacturing FCEVs. Costs are expected to be lowered as more manufacturers enter the market

> ➢ In transport, the competitiveness of hydrogen fuel cell cars depends on fuel cell costs and refuelling stations while for trucks the priority is to reduce the delivered price of hydrogen. Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels.

Some numbers / case studies

Electrolyzer: needs approx. 50 kWh to produce 1 kgH2

Energy content of Hydrogen: 33 kWh per kgH2

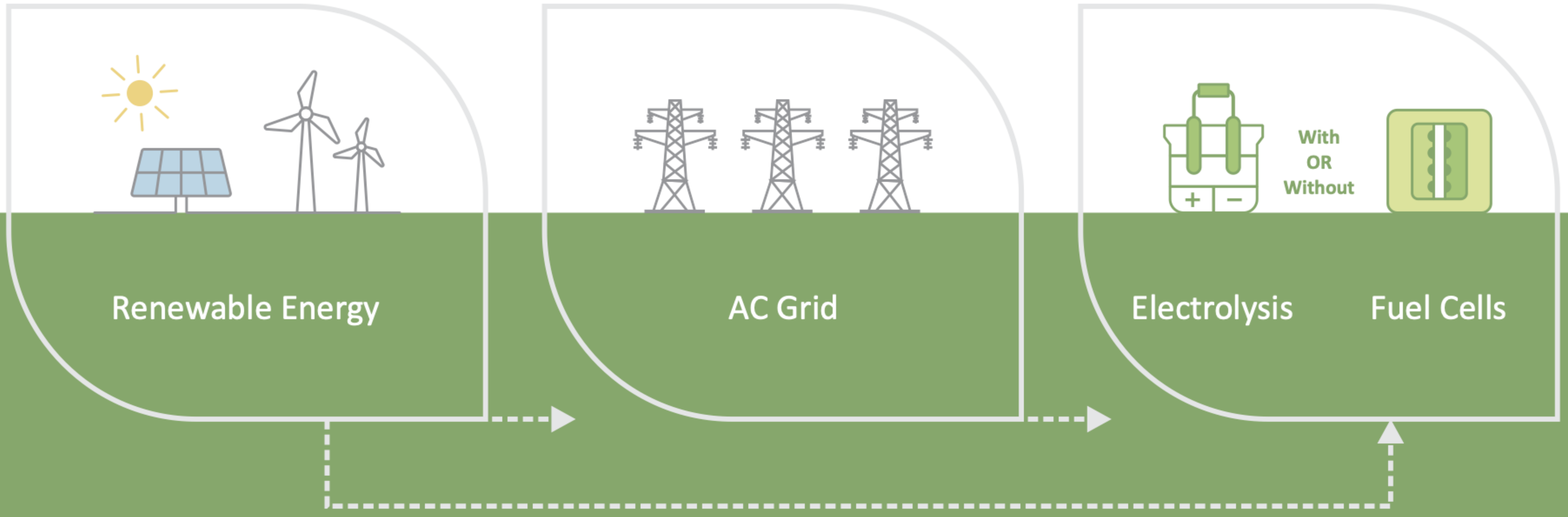
Fuel Cell: 60% efficiency i.e. provides approx. 20 kWh per kgH2

Green Hydrogen – basic considerations

- Costs for producing green hydrogen have fallen 50% since 2015 and could be reduced by an additional 30% by 2025
- Producing green hydrogen by electrolysis needs a huge amount of electricity, which means a mind-blowing increase in the amount of RES (mainly wind and solar power) to meet global targets
- On March 16, 2023, the EC set out new plans to stimulate and support investment in sustainable hydrogen production through a European Hydrogen Bank (EHB) in order to bridge the investment gap for the EU to reach its ambitious REPowerEU targets of producing 10 million tonnes of green hydrogen by 2030

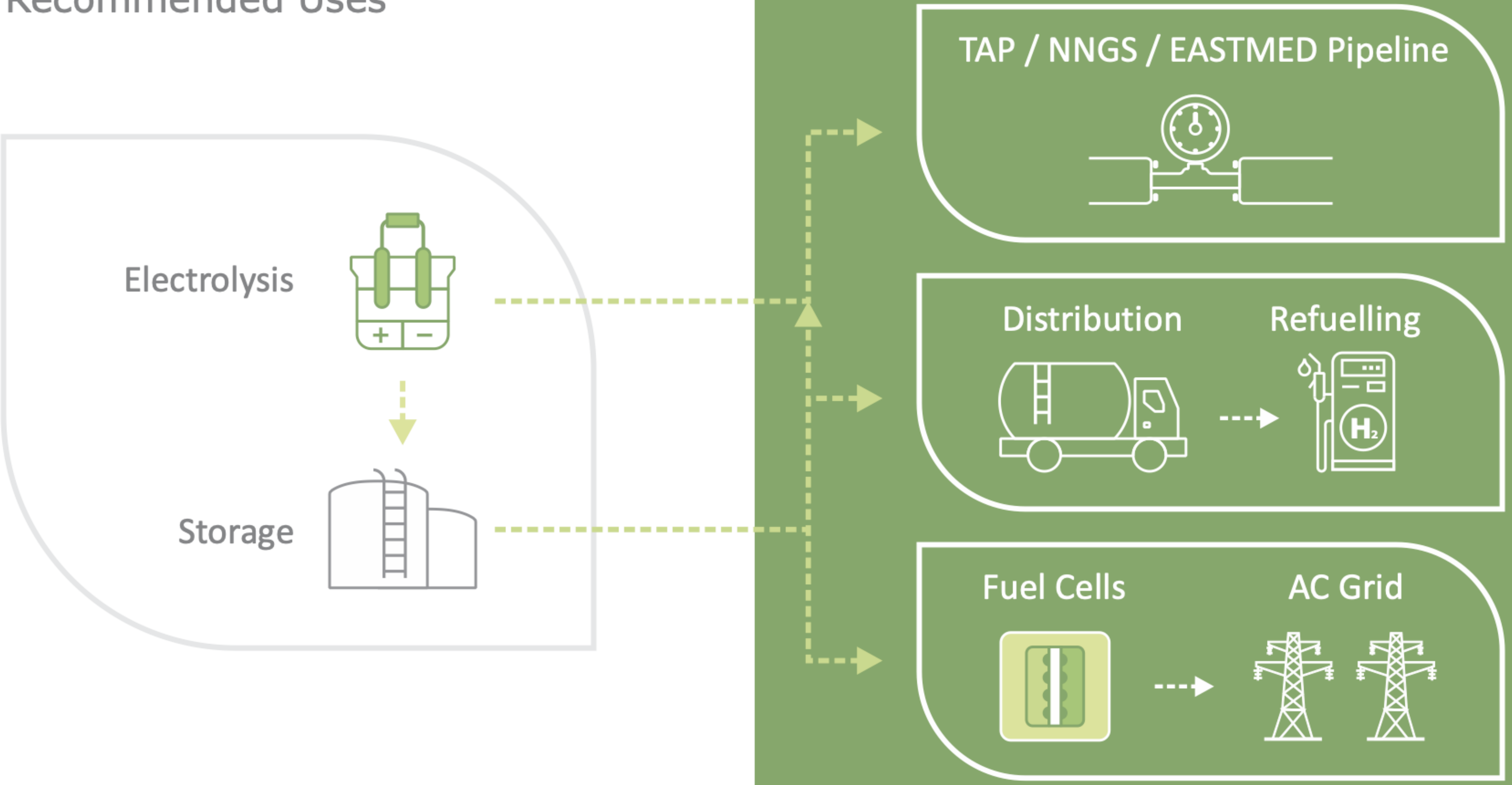
Green Hydrogen

Summary



Case Study 50MW

Recommended Uses



Case Study 50MW

A. Green Energy From Stand Alone PV

ASSUMPTIONS

- About 150 MW PV station is required
- About 180 thousand sq.m for PV station
- 1 thousand sq.m for Hydrogen production
- 10 hours daily operation
- 10 tn/day production H_2

Case Study 50MW

B. Green Energy From AC Grid

ASSUMPTIONS

- Green certificates or PPAs are required (energy from e.g. 250 MW PV stations)
- AC grid connection is required
- 1 thousand sq.m for Hydrogen production
- Up to 24 hours daily operation
- 24 tn/day production H_2

Case Study 50MW

C. AC Grid Balancing

ASSUMPTIONS

- AC grid connection is required
- Fuel cells (FC) are required
- Up to 24 hours daily operation
- 60% efficiency for FC

STORAGE / DISTRIBUTION OF HYDROGEN

Compressed Gas

Liquefaction - Cryocompression

Solid Materials

Underground Storage

Hydrogen - Storage issues

- ✓Gas under normal conditions
- ✓Density (0 °C) 0.0899 kg/m^3 (12 times less than air)
- ✓Low Boiling Point (20K)
- ✓Safety (under specific conditions)

Hydrogen Storage

Under normal temperature and pressure conditions, 1 kg of hydrogen will occupy a volume of 12.15 m^3 and an energy content of 33.5 kWh. Hydrogen presents HIGH energy per unit mass 140MJ/kg but LOW energy density per volume: 12.7MJ/m^3

For hydrogen to become a competitive energy carrier, its volume density must be increased → **reducing the volume that hydrogen occupies under normal conditions**

Compressing the gas (increasing the temperature)
→ *Compressed Hydrogen Storage*

Decreasing the temperature below the critical point
→ *Cryogenic Hydrogen Storage*

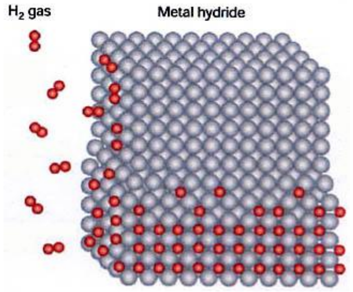
Decreasing the repulsion interaction between the hydrogen molecules by creating bonds with another material.
→ *Solid-State Hydrogen Storage*

HYDROGEN STORAGE

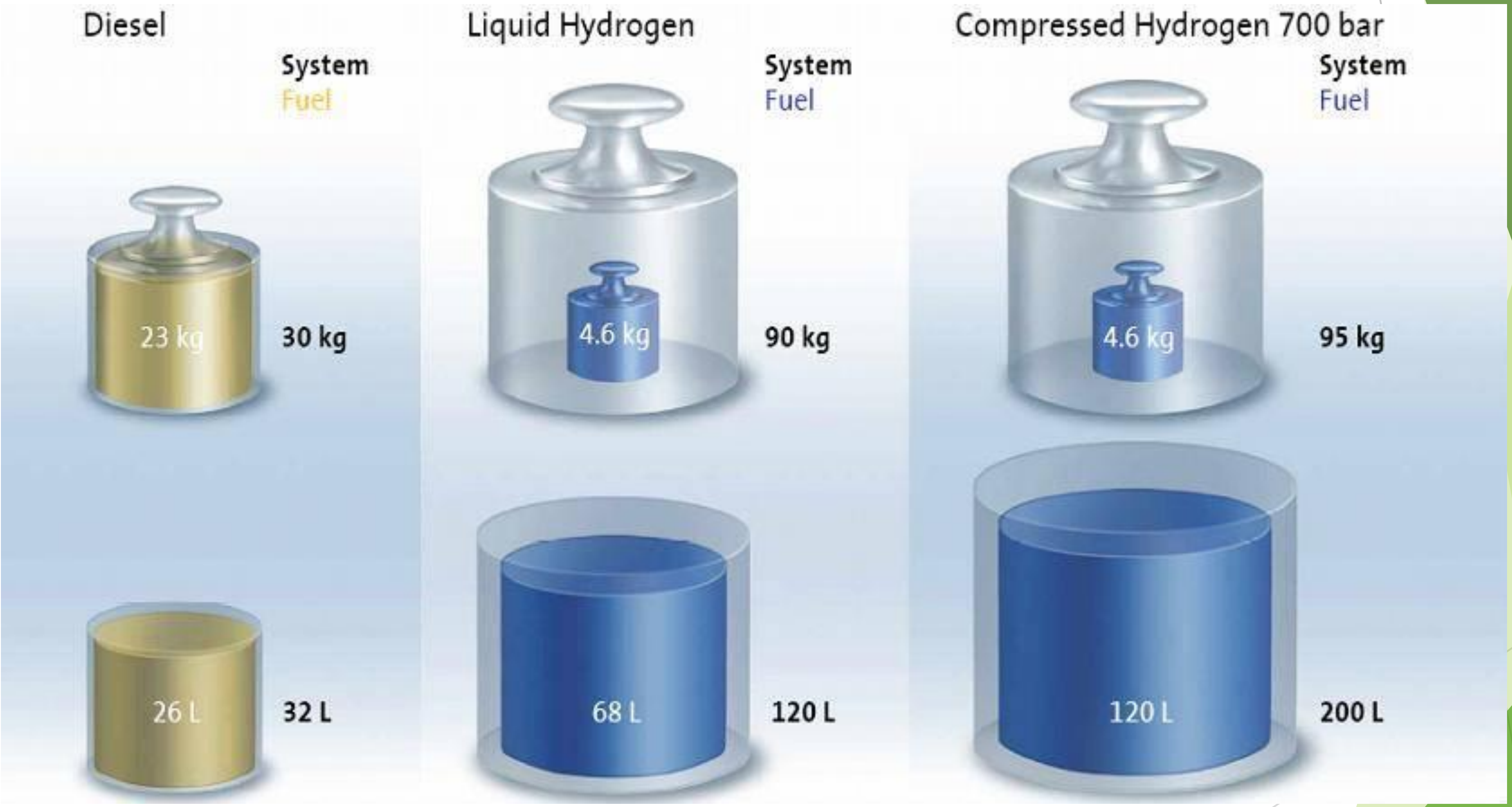
- One of the major issues regarding hydrogen is its storage
- High energy density per weight / Low energy density per volume

3 main ways to store hydrogen:

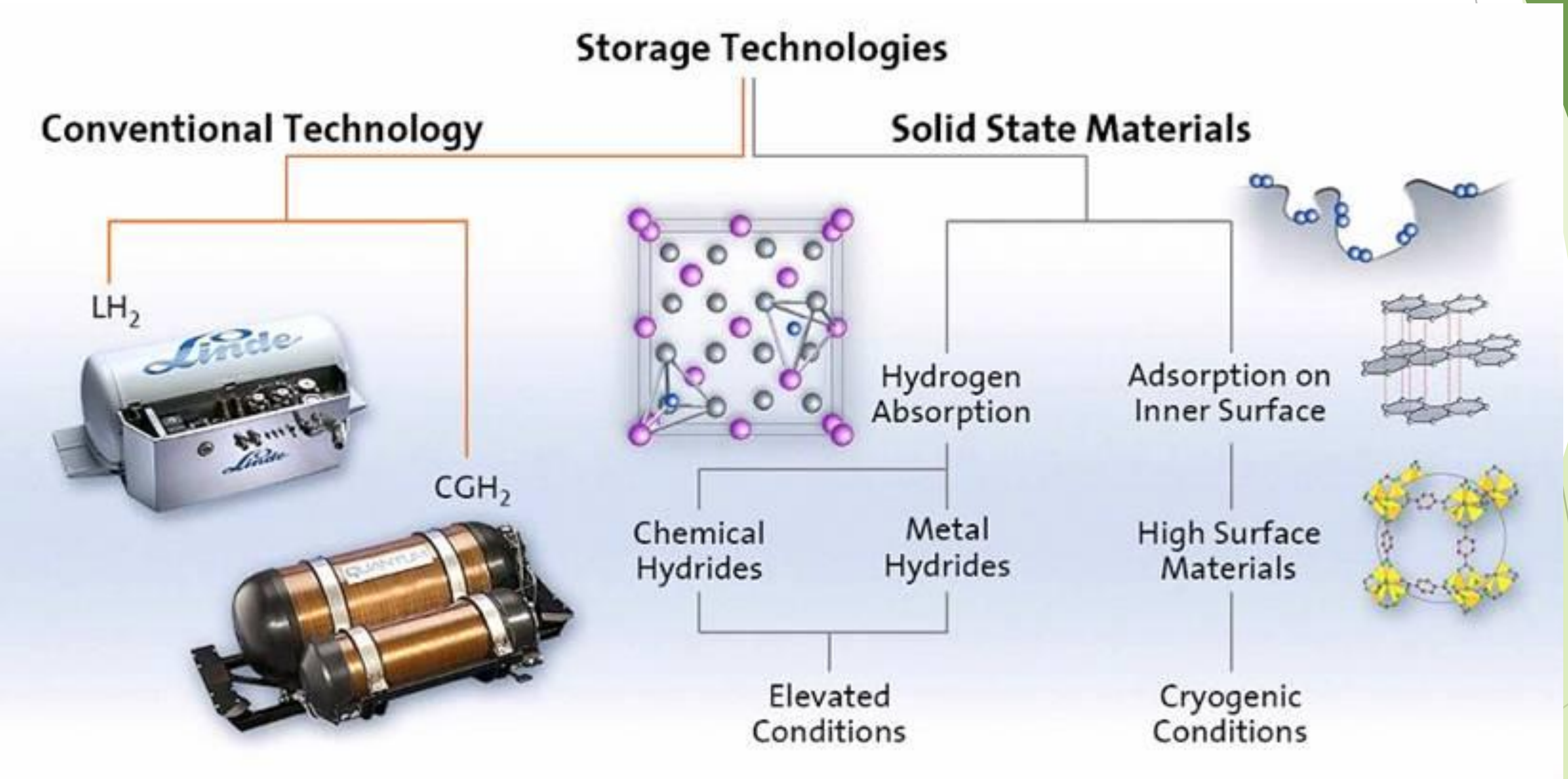
- Storage as a compressed gas: By compressing H2, the volume it occupies is reduced thus resulting in higher energy density per volume
- Storage as a liquid: Liquid hydrogen is cryogenic and boils around -252.882 °C.
- Chemical Storage: H2 can be chemically stored in substances like ammonia or various hydrides



H2 Tank Mass & Volume (autonomy ~600 km)



H2 Storage Technologies



“Conventional” Technologies

Minimize Heat Inflow (300 K → 20 K)

↓

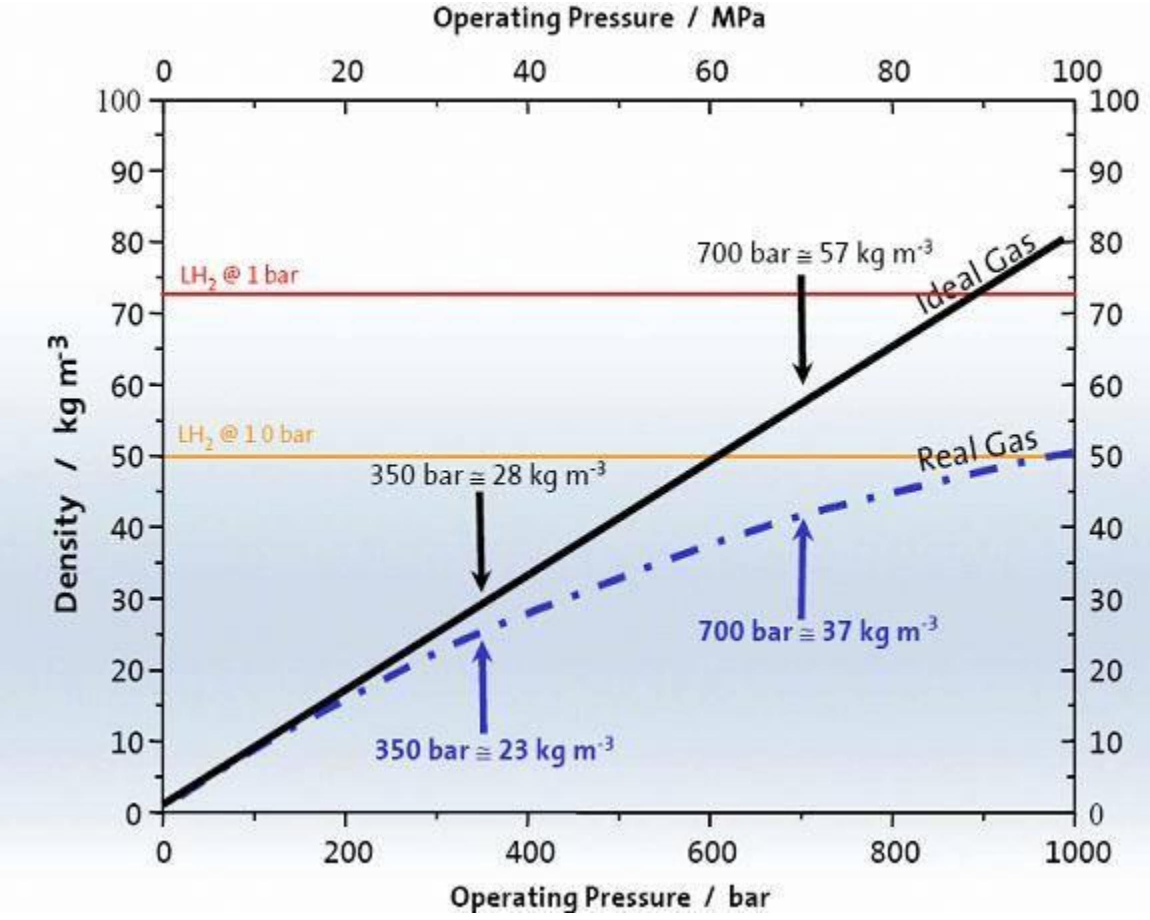
Optimize Volume / Surface Ratio

Pressure Vessel Equation (700 bar)

↓

Optimize Geometry

H2 density



General Challenge

Low Volumetric Density

↓

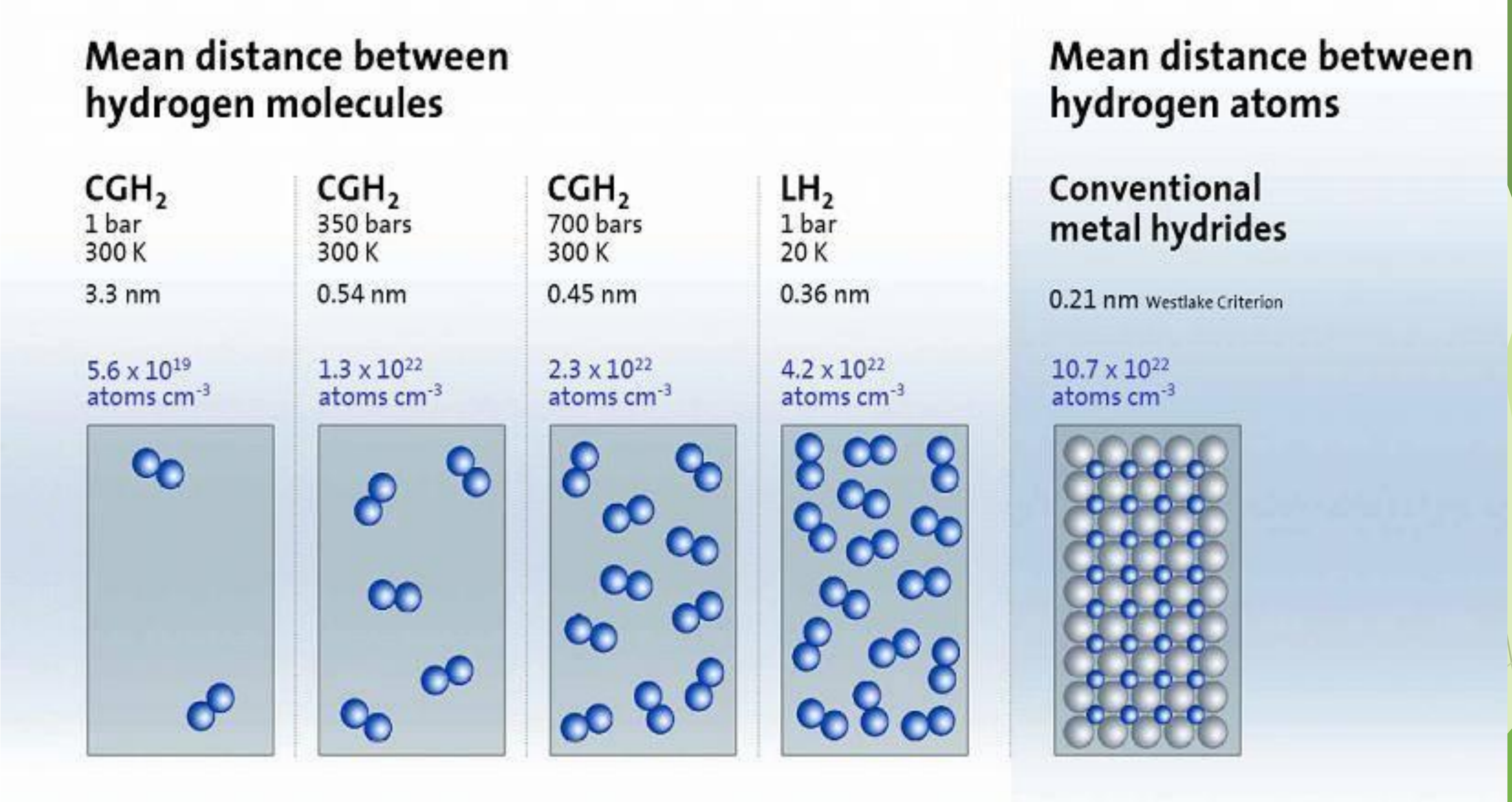
Low Heating Value

LH_2 8.5 MJ / liter

Gasoline 31.7 MJ / liter

Diesel 36 MJ /liter

Storage in solid materials: an interesting option



HYDROGEN STORAGE IN ROAD VEHICLES

- Pressures of 200, 350, 700 bar
- Made of composite materials in steel casings
- Material specifications
  - Mechanical durability (Piercing, crashing durability etc)
  - Low weight
  - Zero H2 permability
  - Efficient thermal behaviour
  - Use of parallel tank configuration
- Pilot application on public transportation vehicles

Hydrogen tanks used for on- board applications

<u>Pros</u>

- **Big storage capacity**
- **Relatively low cost**

<u>Cons</u>

- **Safety, especially in transportation applications**
- **Incapable of working under changing pressure**

H2 Large scale underground storage

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 46 (2021) 15671–15690

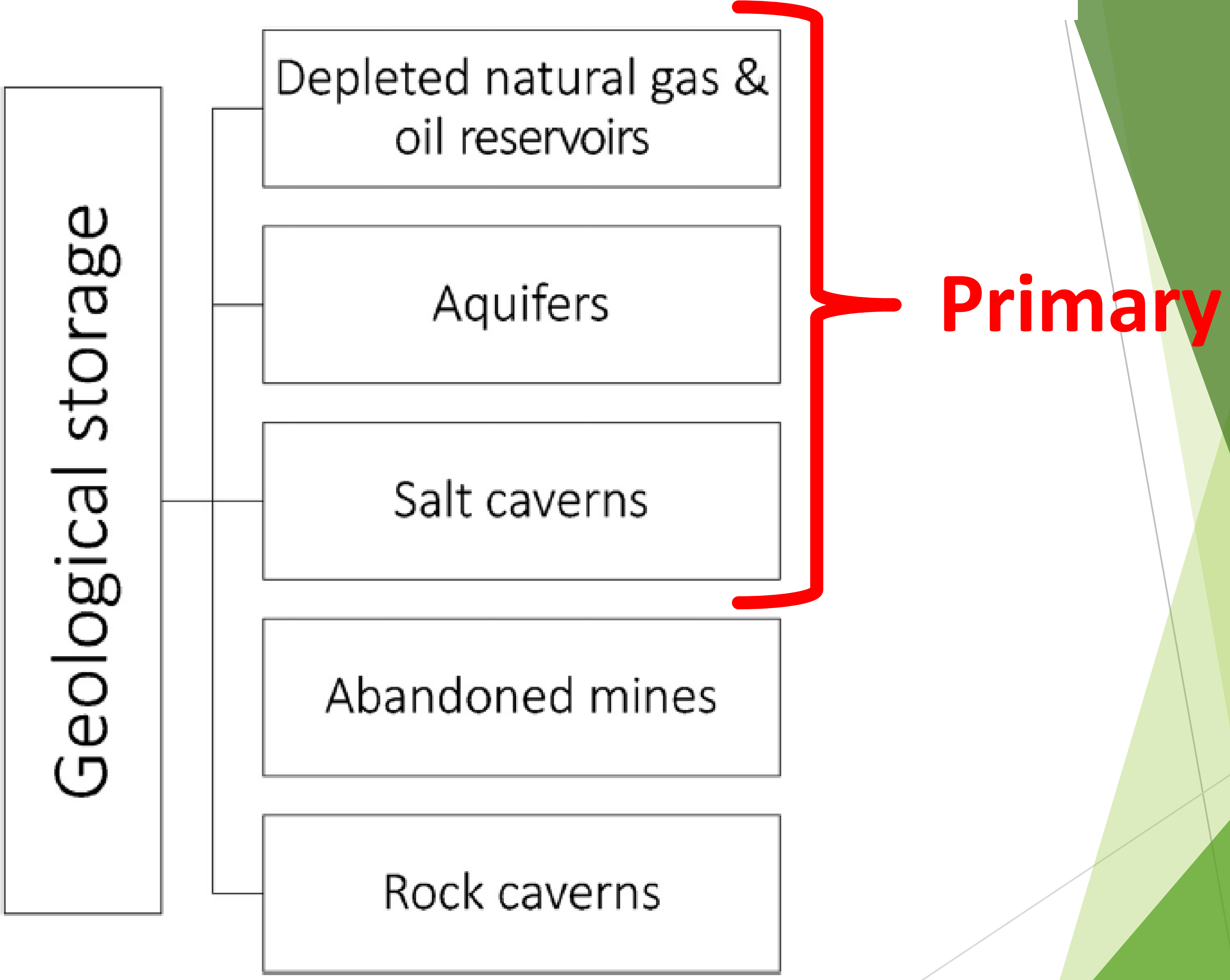


Fig. 9 – A scheme for types of geological storage.

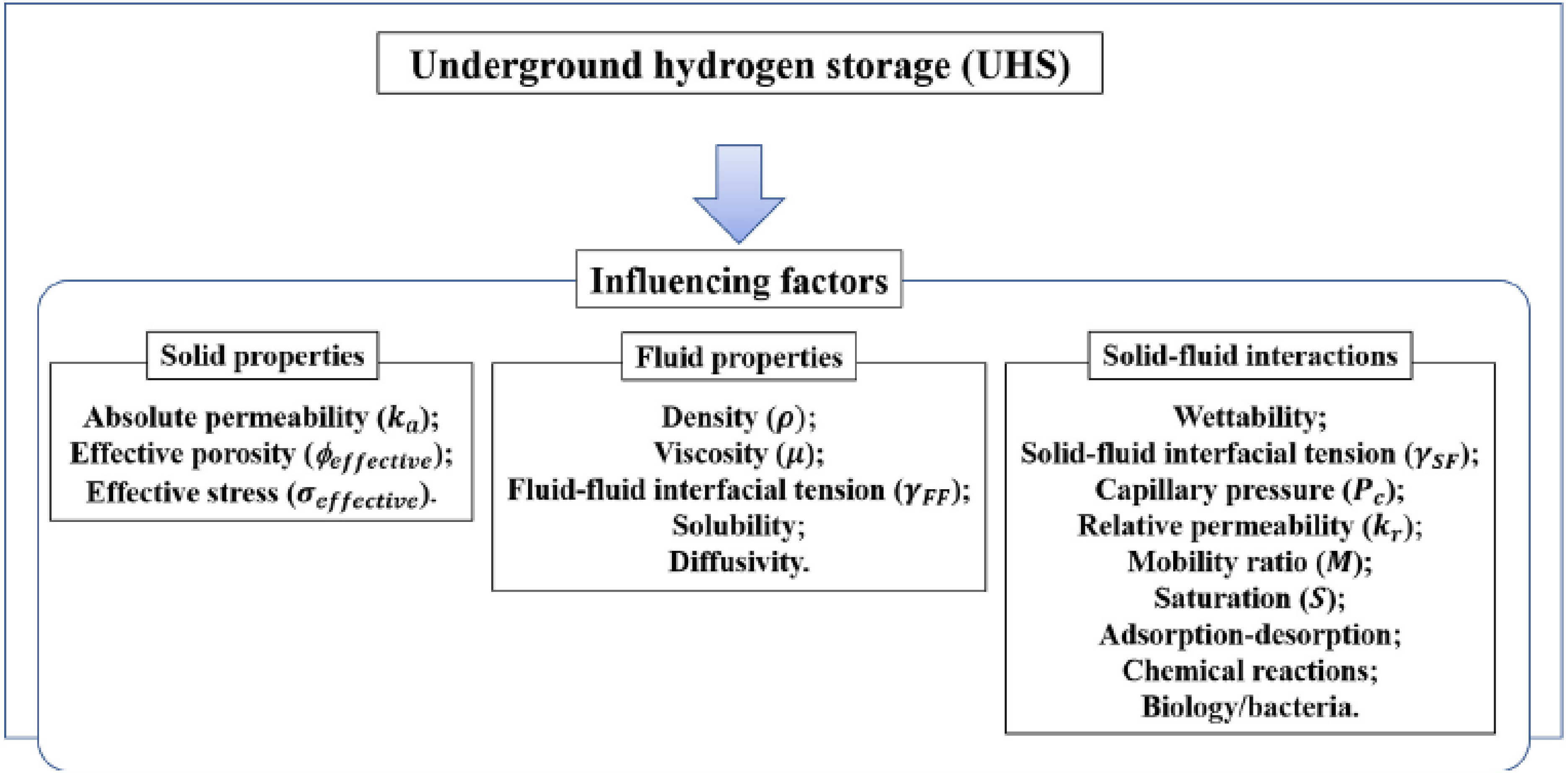


Fig. 1. Multi-scale parameters relevant in underground hydrogen storage.

Energy Environ. Sci., 2021, **14**, 853–864

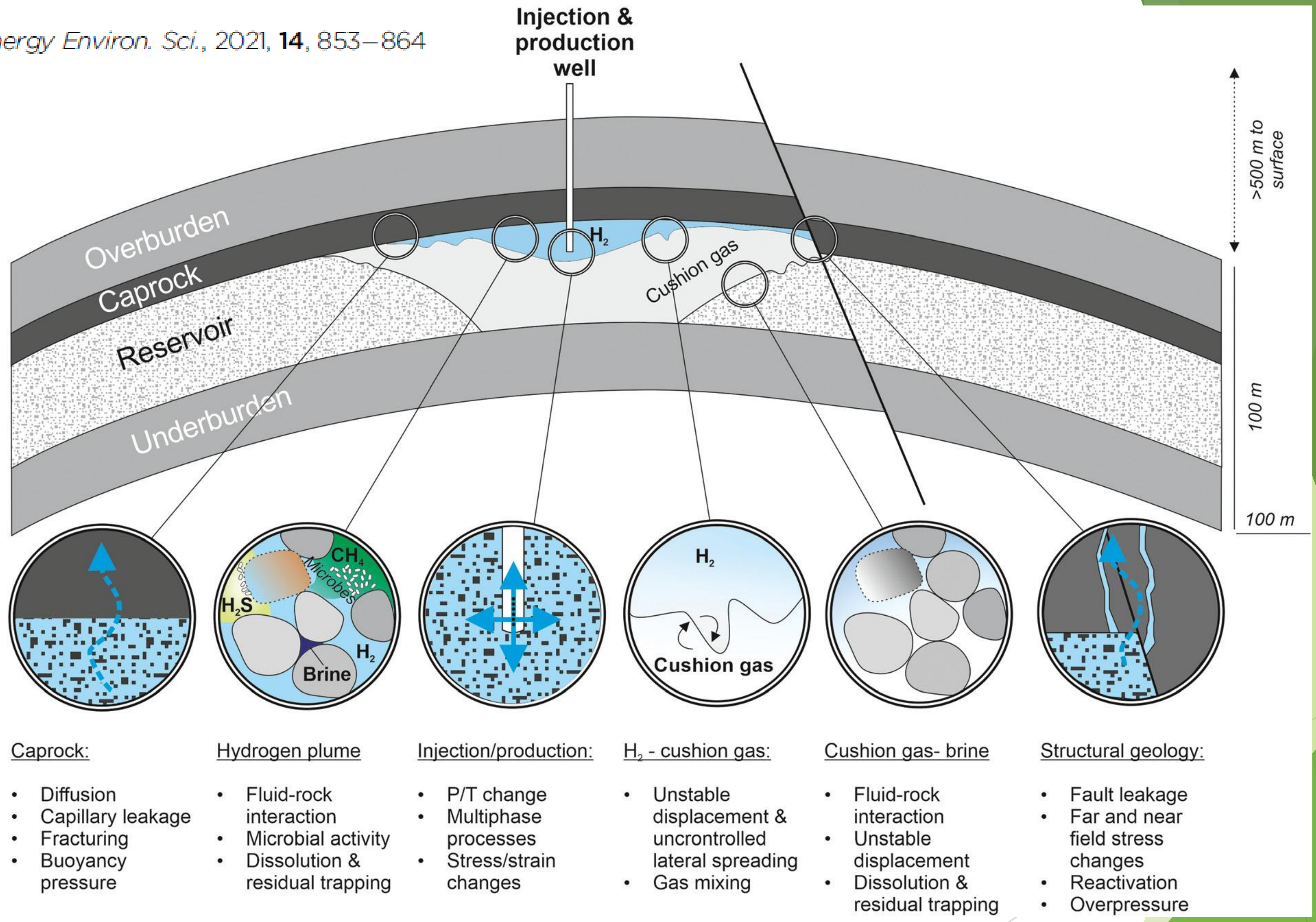
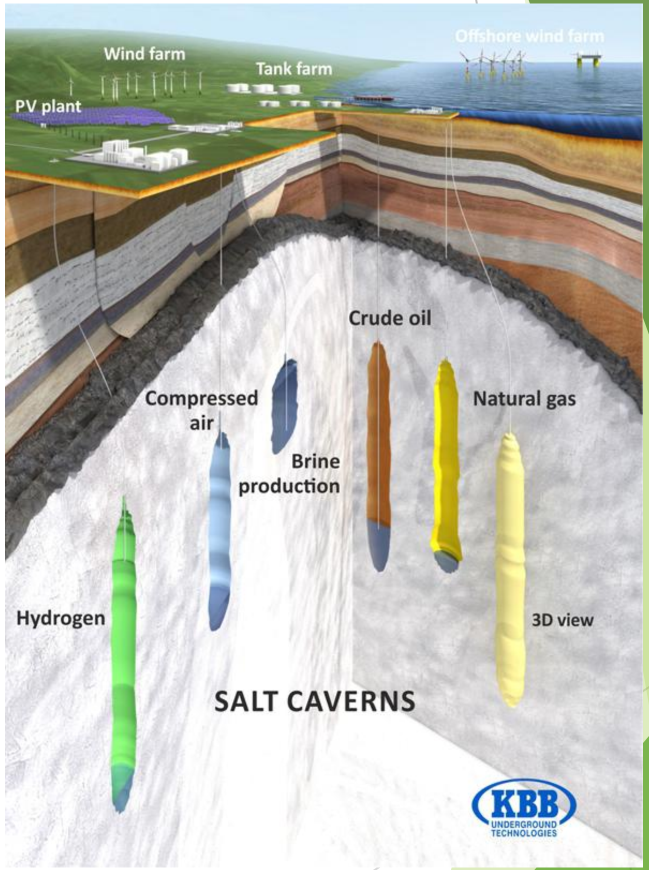


Fig. 2 Hydrogen storage in porous media highlighting all geological uncertainties considered in this paper. Note that both depth, formation thickness and horizontal do not represent scientifically justified ranges but are included to provide an idea of the magnitude of the operations.

Salt Caverns for Gas Storage

- Used to store gases including hydrogen since the 1950s
- Sites have traditionally been developed after salt extraction by the chlorine industry
- Over 30 caverns in use in the UK today
  - mainly used for NG
  - 1 in use for hydrogen
  - internal wall properties prevent leakage and contamination of the hydrogen
- Lowest cost direct storage mechanism for large hydrogen volumes
- Possibility to use Larne salt caverns for hydrogen storage



An integrated hydrogen refueling station for light vehicles incorporating MH-based compression technology

European Union
European Regional Development Fund
HELLENIC REPUBLIC
MINISTRY OF DEVELOPMENT AND INVESTMENTS
SPECIAL SECRETARIAT FOR ERDF & CF PROGRAMMES
MANAGING AUTHORITY OF "COMPETITIVENESS" PROGRAMME
EPAnEK 2014-2020
OPERATIONAL PROGRAMME
COMPETITIVENESS
ENTREPRENEURSHIP
INNOVATION
ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη
Partnership Agreement
2014 - 2020
Co-financed by Greece and the European Union

The role of small scale H_2 refueling stations

- Alternative fuels and e-mobility should play a decisive role in the decarbonization of transportation
- What goes first? Hydrogen vehicles or infrastructure?
- A way to address this dilemma is the gradual development of stations which could meet the demand for hydrogen of smaller vehicle fleets, or of vehicles such as scooters, hydrogen bicycles

THE H2TRANS PROJECT

H2TRANS main goal

Developing the first hydrogen refueling station in Greece and demonstrating hydrogen-powered vehicles

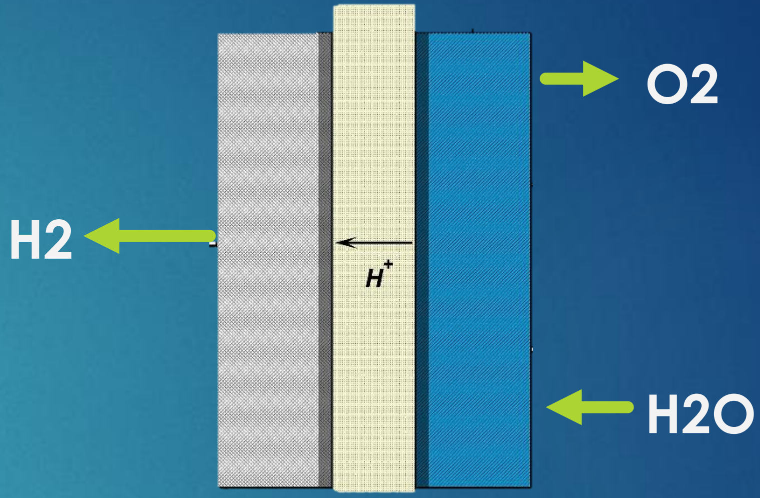
Parties involved:

- NSCR Demokritos
- NEEST
- ELFON
- XANTHIS
- CITIPOST

This work is co-financed by the European Regional Development Fund of the EU and Greek national funds under the call RESEARCH – CREATE – INNOVATE (project H2TRANS_T1EDK-05294).

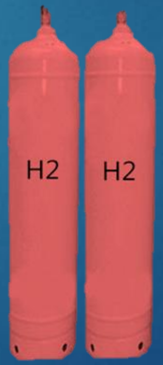
The 4 subsystems

PV System



PEM Electrolysis Unit

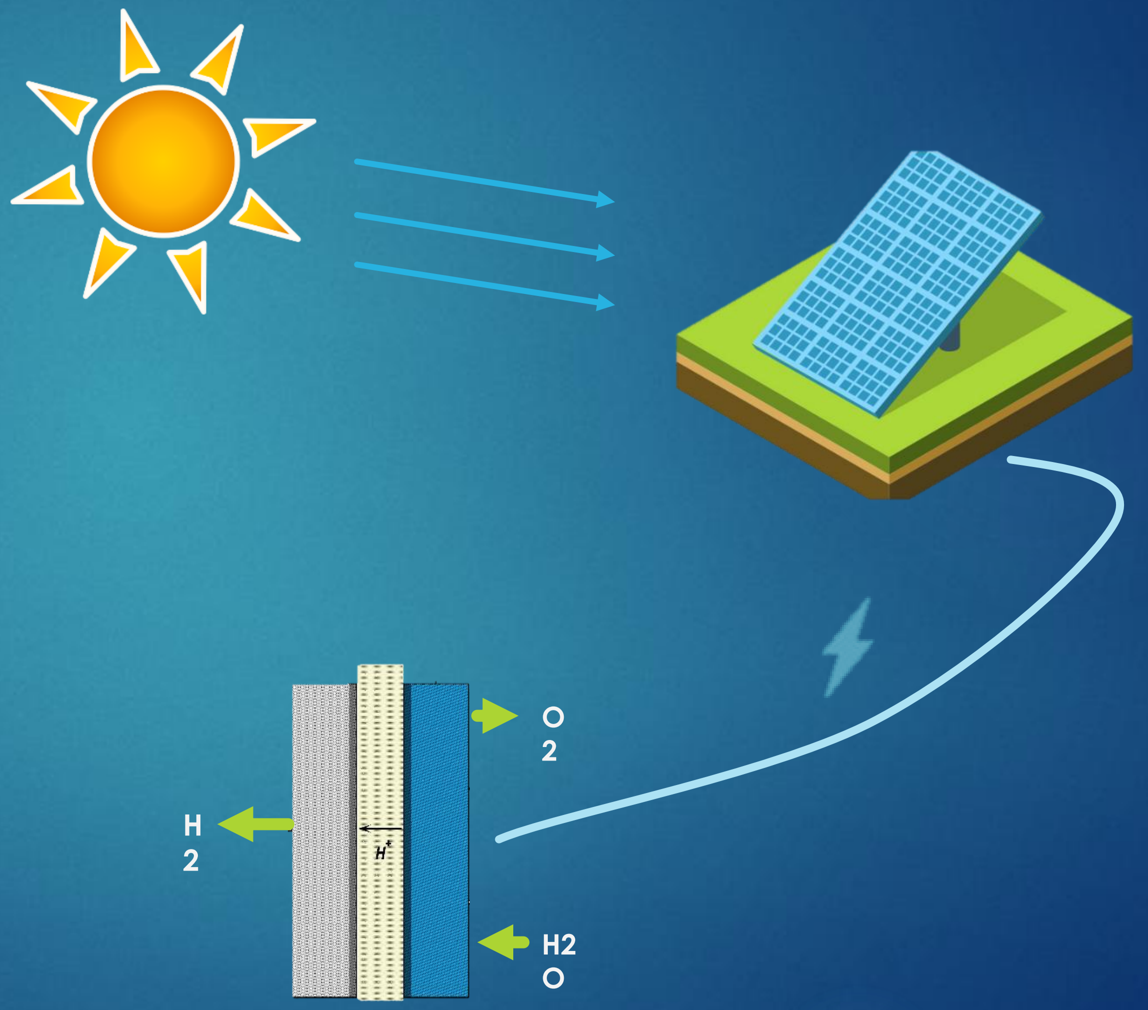
H2 Vehicles



H2 Storage and compression

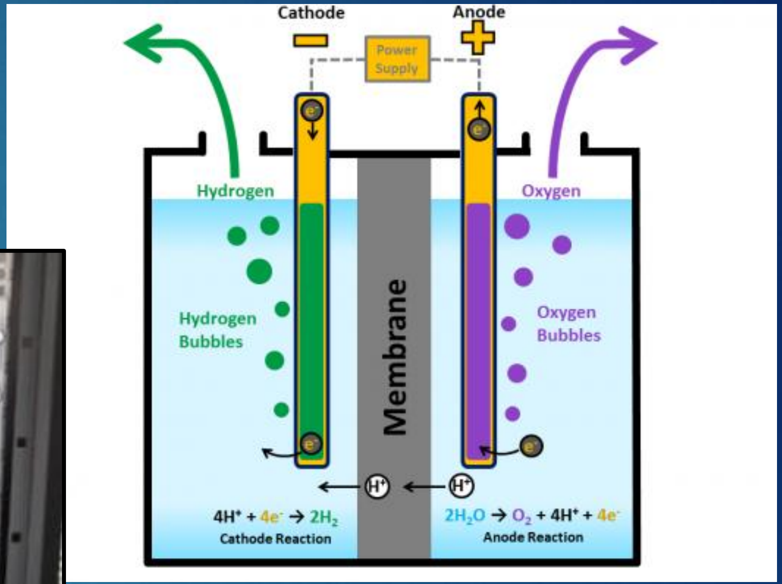
Photovoltaic System

- In order to improve the sustainability of the installation , the use of renewable energy sources is inevitable
- This ensures the minimization of CO2 emissions of the system
- For the purposes of the project the installed power is 23 kWp



Hydrogen production system

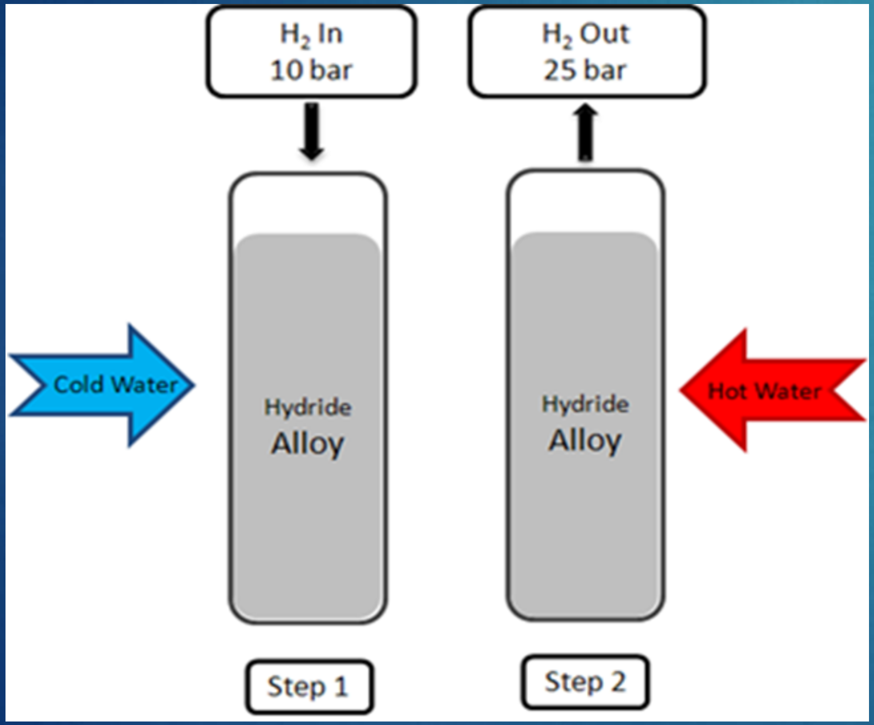
- **Hydrogen is produced by a PV powered PEM electrolysis stack**
- **Hydrogen exits the electrolyser at 16 bar**
- **Mean H2 production rate: 127g/h**

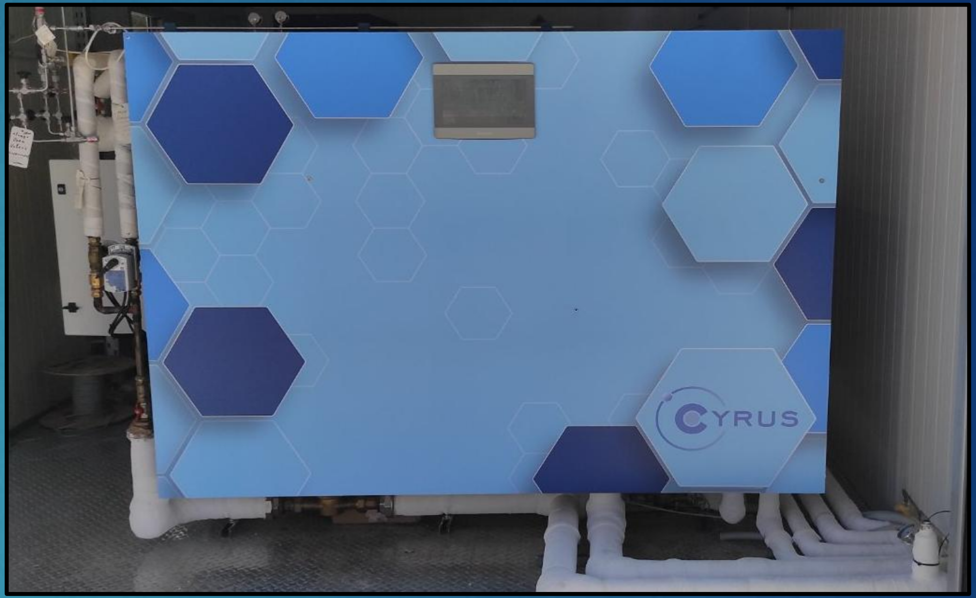


Compression system

Metal Hydride Compressor

- Use metal hydrides (MH) which store hydrogen chemically
- MH may store hydrogen at low temperature & pressure
- MH release stored hydrogen when heated
- Energy costs minimized when there is external flux of heat such as waste heat

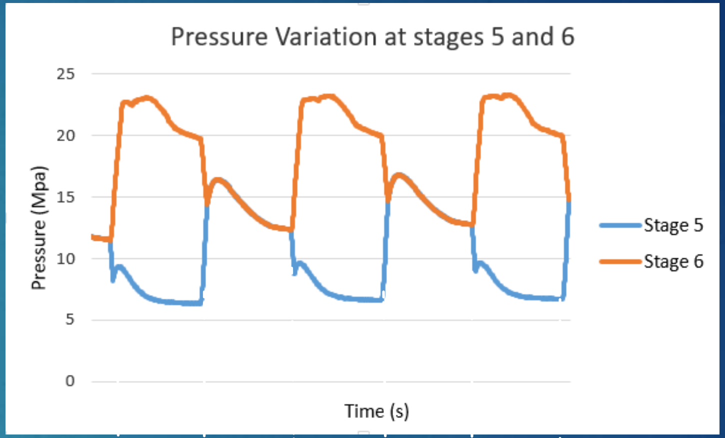


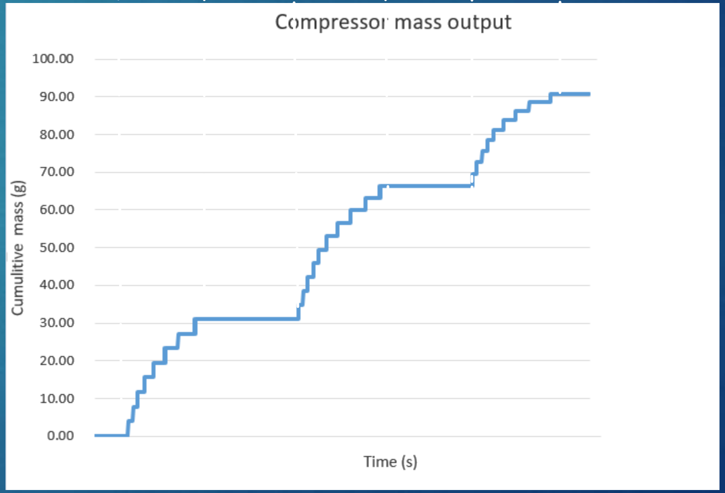


- Outlet pressure: 200 bar
- Compression is driven by reversible thermal processes
- Heating and cooling achieved by resistances and heat pump
- Completely automated operation
- No moving parts (low OPEX)
- Low noise
- Ideal for residential areas

Compression stages

- Compressor stages are successively heated and cooled
- The desorption pressure of each stage should match the absorption pressure of the next stage
- The succession of phases in each stage is achieved autonomously
- Output pressure at 220 bar with the current capacity at 250 g/h





H_2 storage & utilisation system

- Different approaches: Gaseous, Liquid, Chemical storage

- H2TRANS utilizes storage in gaseous form - the storage compartment consists of two parts :

  - Low pressure (buffer) storage at 16 bar (electrolyzer outlet)

  - High pressure storage at 200 bar(after the MH compressor)

  - Total station capacity: 120 Nm³ (12 tanks of 10 Nm³)

- Hydrogen is dispensed at 200 bar - The dispenser has an interactive interface

Operation results

Mean hydrogen **flow from electrolyser** = **130 g/h**

Total **compressed hydrogen flow** =Up to **250 g/h**

Total hydrogen **capacity of vehicles** in terms of weight = **161 g**

The station can serve the current fleet twice every three hours

- Obviously a much larger fleet can be served once on a daily basis
- Attention should be paid at matching the electrolyzer and the compressor output flows since there is the risk of creating a bottleneck. This can be addressed by experimenting with different temperature ranges, in order to increase the compressor's output
- The completely automated function of the station has been established
- Due to both the electrolysis' and the compressor's modular design, scaling up the system is a rather simple task

Hydrogen Refueling Station

The Hydrogen Refueling Station (HRS) for small vehicles has already been developed at the premises of NCSR DEMOKRITOS (containerized solution)

Hydrogen Powered Vehicles

- The FCEVs will be implemented by transforming electrical vehicles in a way that they can use fc for powering their electrical motor.
- Transformed vehicles include a scooter and a golf cart
- Compatibility of the fuel cell which will replace the battery, with the electric motor must be ensured
- Vehicles will have on board light weight 200 bar tank
- An ultra capacitor will be installed on board as well ensuring better response of the system
- Vehicles will also have a register and visualization system for monitoring the key performance indicators

www.h2trans.gr
www.facebook.com/H2Trans
https://twitter.com/h2trans
https://www.linkedin.com/company/h2trans/

Co-financed by Greece and the European Union

This work is co-financed by the European Regional Development Fund of the EU and Greek national funds under the call RESEARCH – CREATE – INNOVATE (project H2TRANS_T1EDK-05294)