Hydrogen Production

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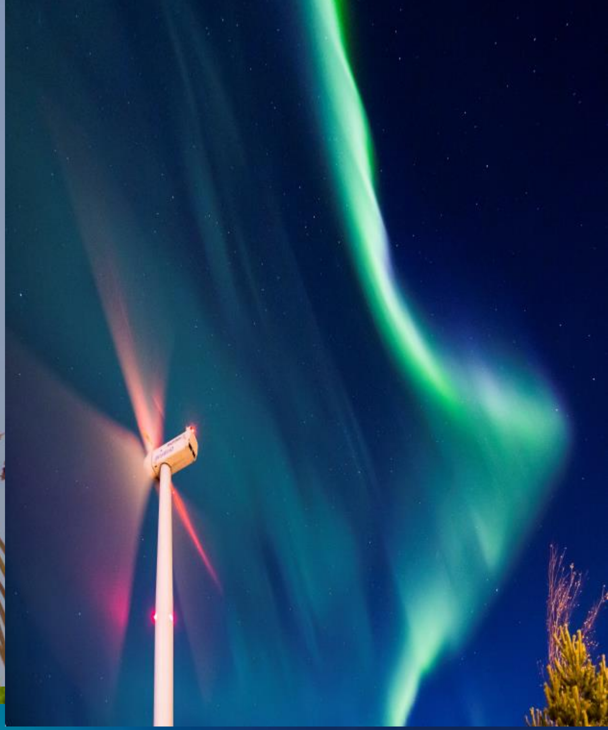


QUESTIONS – H_2 PRODUCTION

1. Why is there so much discussion about hydrogen?
2. Hydrogen production – why should we and how can we produce green and blue hydrogen?
3. How mature are the most sustainable routes to hydrogen and how their sustainability can be described?

HYDROGEN PRODUCTION

FUTURE PERSPECTIVE OF HYDROGEN

- Implementation of hydrogen as an alternative energy carrier
- Hydrogen as a sustainable feedstock for the industry
- Challenges and needs in hydrogen production for the future development remain – need for basic and applied research exist

WHY H_2?

- Clean energy carrier, fostering green transition
- Important molecule in various industrial fields
- Emission-free fuel for vehicles and energy production → Less harmful compounds
- Production from water and renewable raw materials, bio-based wastes and side-streams
- One of the driving forces for global economy in the future

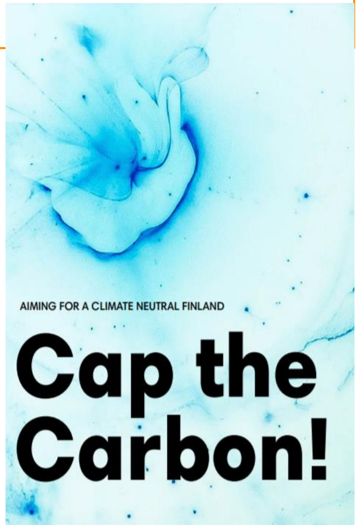
GOVERNMENT'S CLIMATE POLICY: CLIMATE-NEUTRAL FINLAND BY 2035

https://ym.fi/en/climate-neutral-finland-2035

The Chemical Industry Federation of Finland, 2021: Cap the Carbon! Aiming for a Climate Neutral Finland

- **10 of the most interesting technologies for achieving carbon neutrality in industry: ….New catalysts…**

HIILINEUTRAALI
KEMIA 2045
CARBON NEUTRAL
CHEMISTRY



https://kemianteollisuus.studio.crasman.fi/file/dl/i/ii4Qug/M40Mi5b-uqOweSbta2zDOA/Cap_the_Carbon_.pdf

- **Climate neutral Europe and the Green deal**
  - The 2050 carbon neutrality target
  - The 2030 target of 55% emission reductions legally binding
- **Finland: Carbon-neutrality by 2035**
  - The world's first fossil-free welfare society
- **The means to achieve the target**
  - New decisions on climate policy and nearly emissions-free electricity and heat production by the end of 2030s
  - Reducing the carbon footprint of building
  - Promoting circular economy and climate-friendly food policy
  - More taxes on environmentally harmful activities
- **The decline in biodiversity**
  - Reforming the nature conservation legislation
  - Increasing the funding for the protection of biodiversity
  - Promoting sustainable use of natural resources
- **Emissions reductions will be implemented in a way that is fair and just, both socially and regionally**

CAN FINLAND INCREASE CLEAN HYDROGEN PRODUCTION AND USE?

- **Good wind resources** (offshore/onshore)
- **A fairly strong electricity grid**
- **A full and working value chain for hydrogen**
- **Experience in large-scale industrial use of hydrogen**
- **Natural gas pipeline** to store/carry hydrogen
- **Cost-effective transport of hydrogen by trucks**
- **Large refinery and biofuel industry**
- **A major steel manufacturing company** reforming the steel-making process - **~30% increase in hydrogen production and use**
- Opportunity **to create wide range of new H_2-based businesses** throughout the hydrogen value chain

Six areas in clean hydrogen:

- Hydrogen production
- Hydrogen transmission & distribution
- Industrial applications of hydrogen
- Hydrogen for mobility
- Hydrogen for energy
- Residential applications of hydrogen

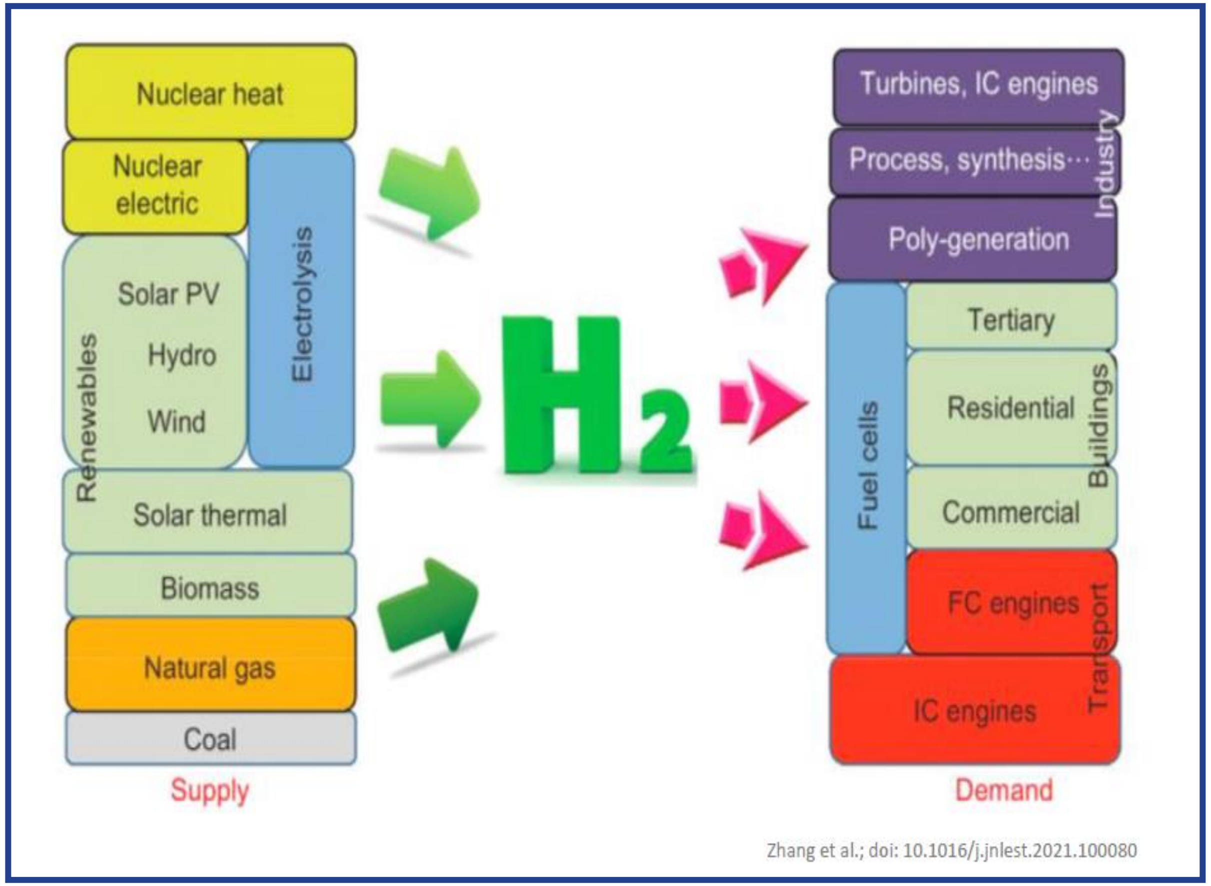
https://ym.fi/en/climate-neutral-finland-2035

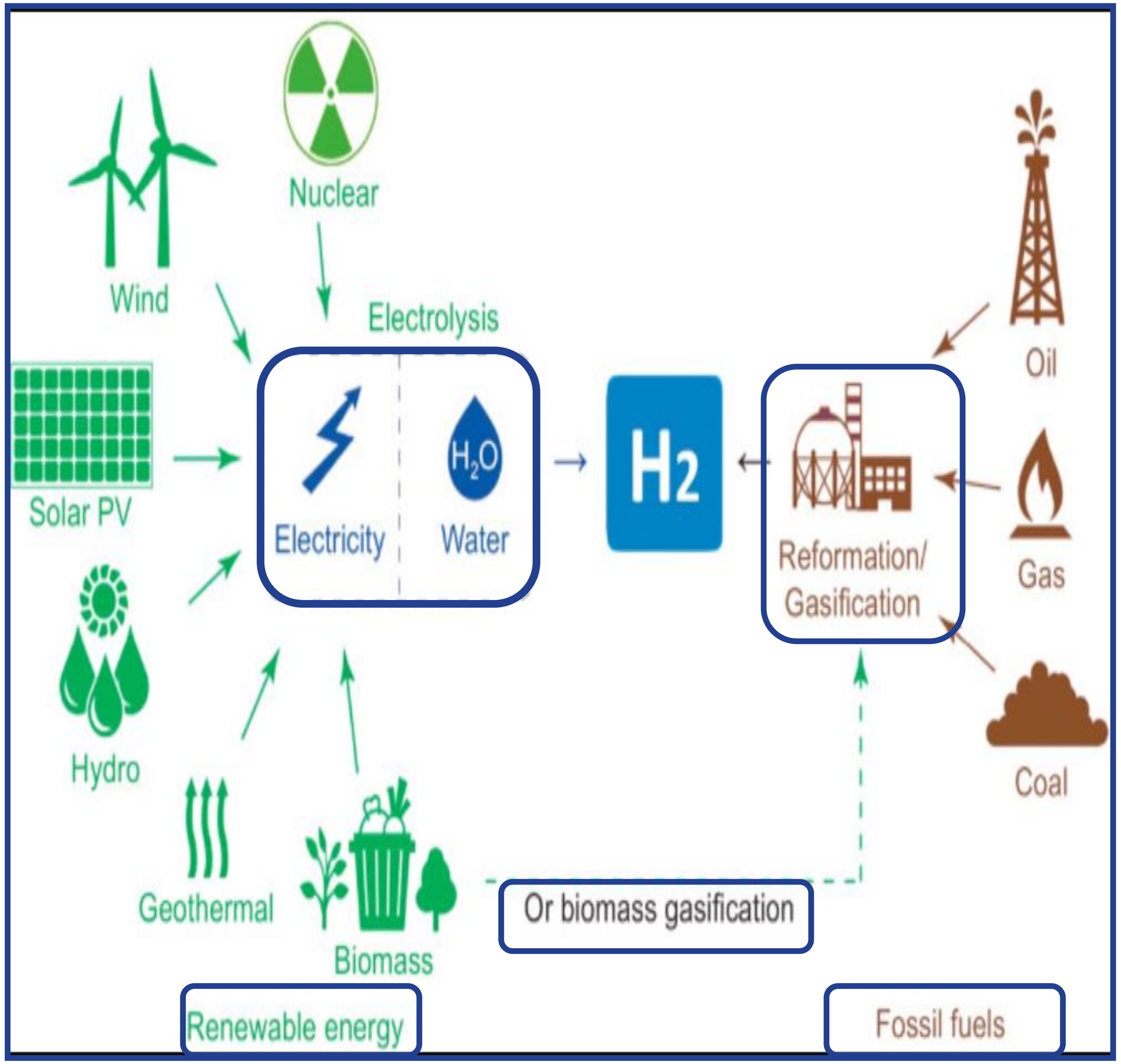
AGENDA 2030 AND THE 17 SUSTAINABLE DEVELOPMENT GOALS (SDG) & TODAY'S MEGATRENDS AND DRIVING FORCES

By Eeva Forman, SYKE, http://www.syke.fi/fi-FI/Asiantuntijat/Eeva_Furman(1877)

- Circular economy, Bioeconomy, Circular bioeconomy Low carbon society, Mitigation of climate change and biomass loss
- **Energy transition, Hydrogen economy**
- Renewable resources and energy
- Sustainable use of natural resources
- Sustainable production and products
- Integrated biorefineries of the future
- New value-added biofuels, biomaterials, biochemicals
- Enabling technologies, e.g., catalysts

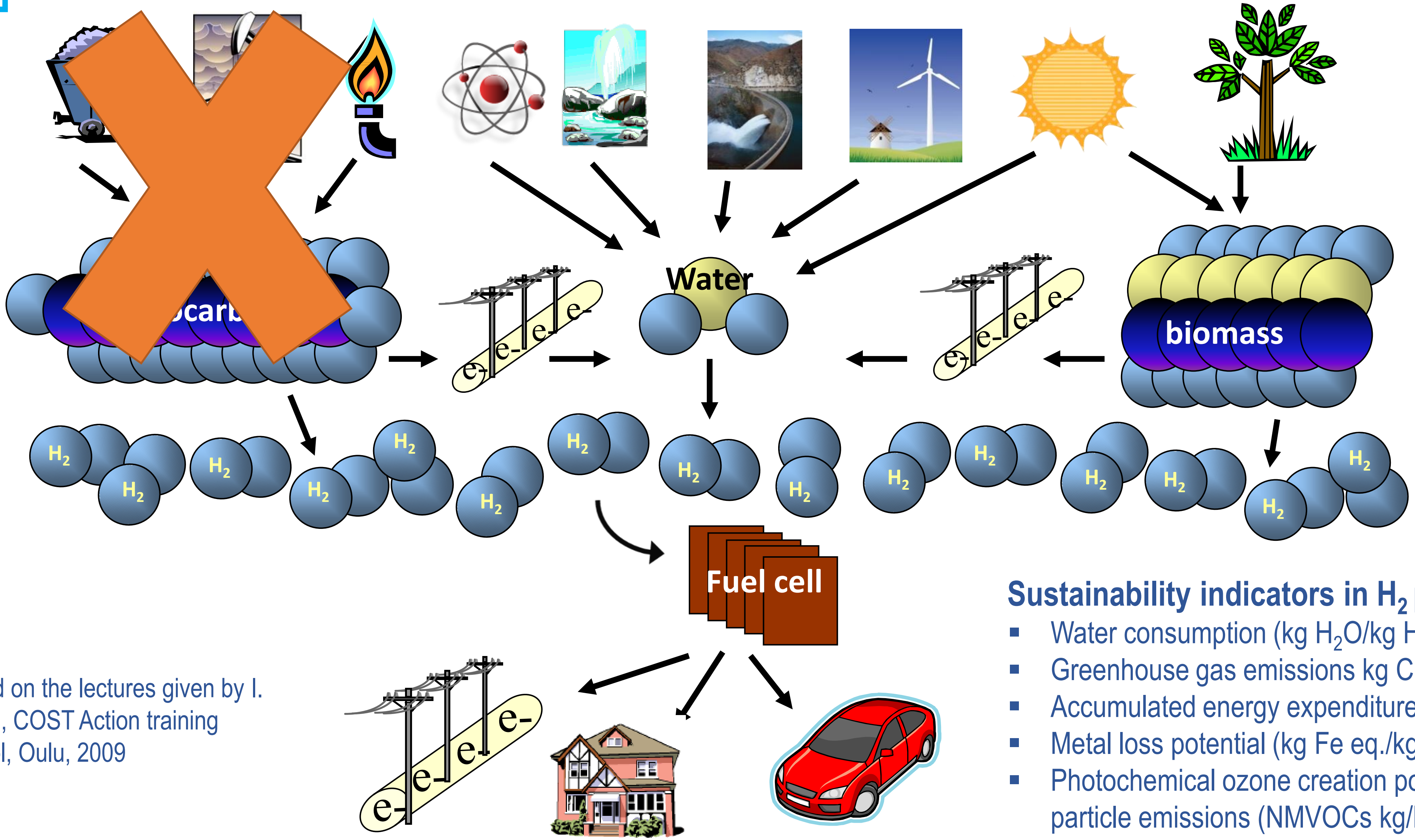
HYDROGEN SUPPLY AND DEMAND, CLEAN HYDROGEN PRODUCTION





Zhang B, Zhang A-X, Yao R, Wu Y-H & Qui J-S (2021) progress and prospects of hydrogen production: Opportunities and challenges. J. Electronic Science and technology 19, 100080

HYDROGEN – SOURCES AND USE, SUSTAINABILITY



Sustainability indicators in H_2 production:

- Water consumption (kg H_2O/kg H_2)
- Greenhouse gas emissions kg CO2 eq./kg H_2)
- Accumulated energy expenditure (MJ/kg H_2)
- Metal loss potential (kg Fe eq./kg H_2)
- Photochemical ozone creation potential (POCP) and particle emissions (NMVOCs kg/kg H_2)

Based on the lectures given by I. Kiriczi, COST Action training school, Oulu, 2009

HOW TO PRODUCE CLEAN AND GREEN HYDROGEN?

DIFFERENT COLOURS OF HYDROGEN

GREY From conventional production process (SMR) using natural gas i.e., the currently prevailing methods, which has unavoidable process emissions that cannot continue if 2050 net zero emission target is to be met

GREEN From electrolysis using exclusively renewable electricity for its production. This could be produced on-site or delivered through pipeline. Green hydrogen is the least GHG emitting process, but due to increased green electricity demand, faces challenges from high costs and insufficient access to renewable energy

YELLOW From electrolysis using the current available electricity mix of the grid. The attractiveness of this method is directly linked to the emission intensity of the electricity grid

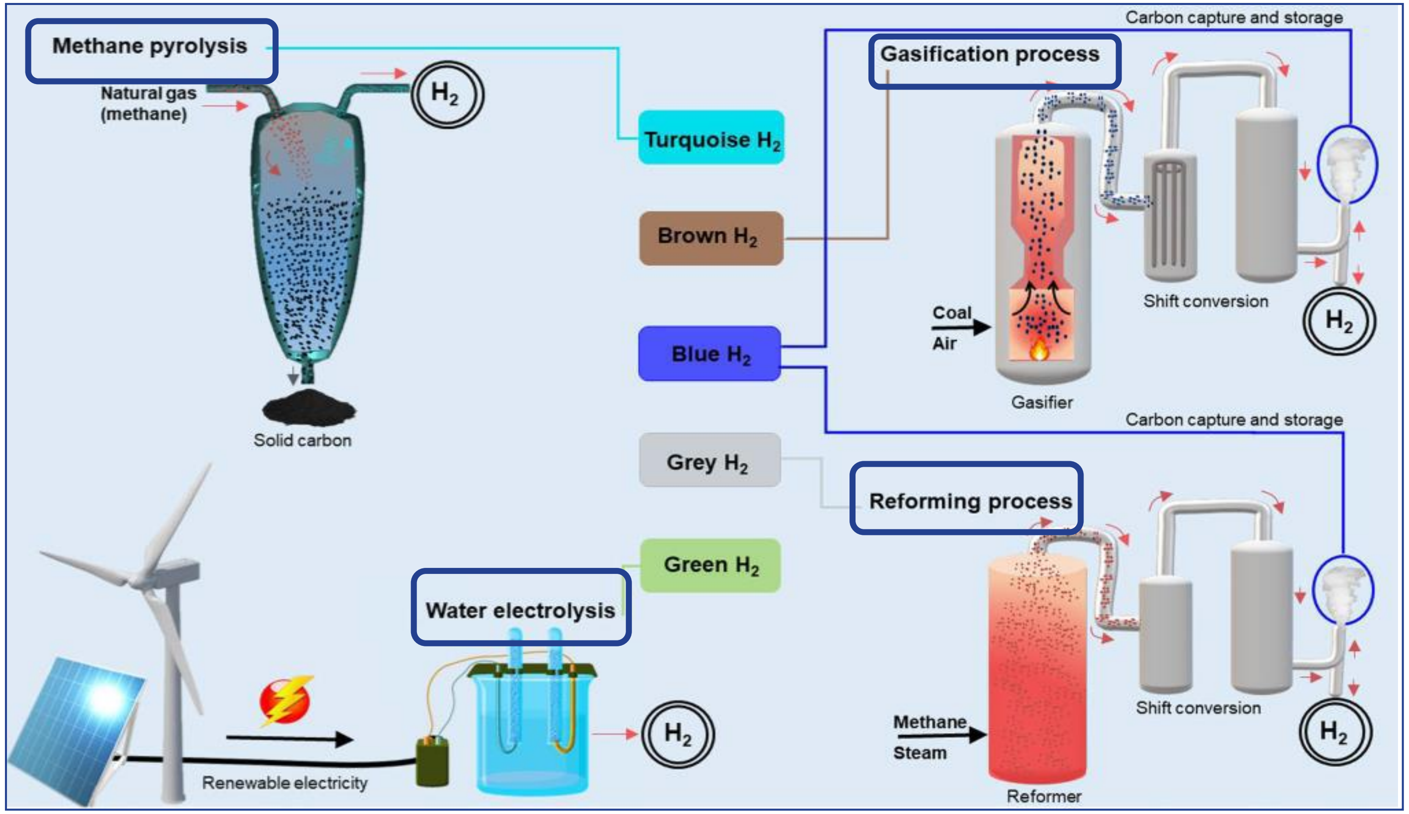
BLUE From conventional production process (SMR) using natural gas combined with Carbon Capture and Storage (CCS). This method is hampered by availability of adequate storage locations and potentially, cost.

TURQUOISE From methane pyrolysis. This method is currently least developed. It has the benefit of having no direct emissions but leads to increased natural gas consumption

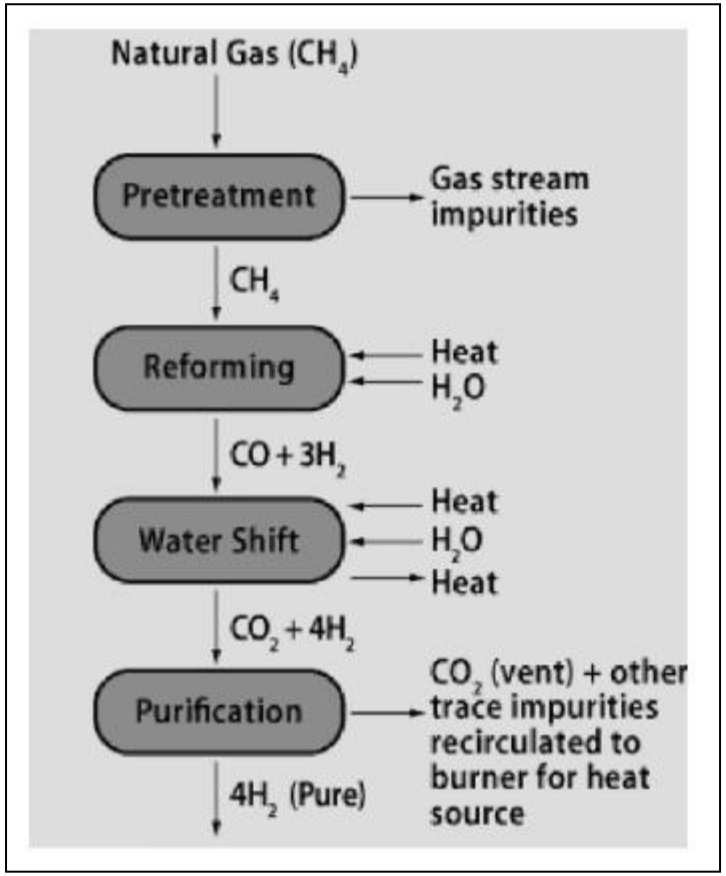
BROWN From coal gasification. This method is fossil fuel based and emits a significant amount of greenhouse gases

Osman et al. 2021; https://doi.org/10.1007/s10311-021-01322-8
IEA (2021) Global Hydrogen Review 2021, page 108; https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

- **In 2020, sources of hydrogen production were:**
  - Natural gas 59%, By-products 21%, Coal 19%, Oil 0.6%, Fossil fuels 0.7% (totally 90 Mt H_2)
  - Totally fossil-based CO_2 almost 900 Mt/year



HYDROGEN PRODUCTION – CONVENTIONAL PROCESSES



Bhandariet al. 2012; Life Cycle Assessment of Hydrogen Porduction Methods –A Review; IEK-STE

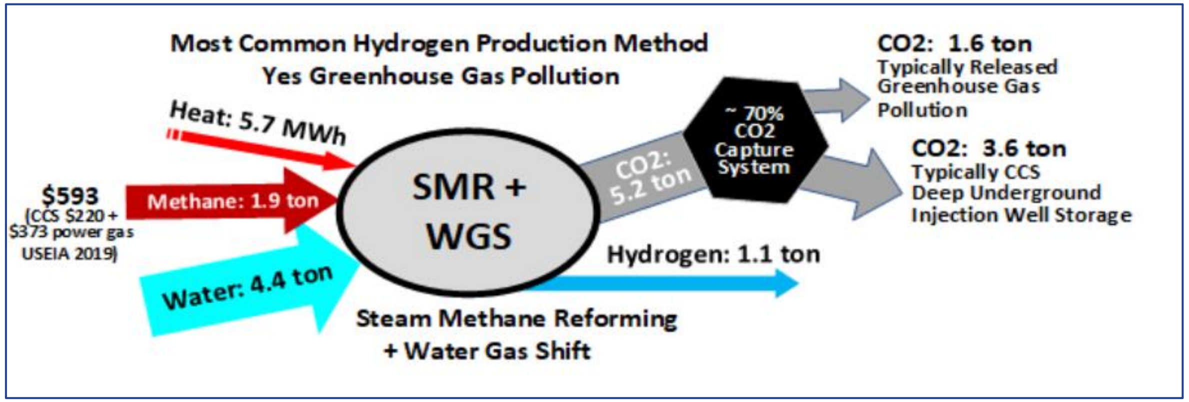
Reforming, Steam Methane Reforming (SMR)

- Methane and water vapour react over e.g., Ni/Al_2O_3 or Ni/Al_2O_3-ZrO_2 catalyst (strongly endothermic reaction; ΔH_{SR} = 206 kJ/mol) to hydrogen and carbon monoxide

  $CH_4 + H_2O$ + heat → $CO + 3\ H_2$
- Process conditions: 700 – 850 °C and 3 – 25 bar
- Additional H_2 production by the reaction of CO and H_2O via mildly exothermic (ΔH_{WGSR} = -41 kJ/mol) water-gas-shift reaction

  $CO + H_2O \rightarrow CO_2 + H_2$ + heat

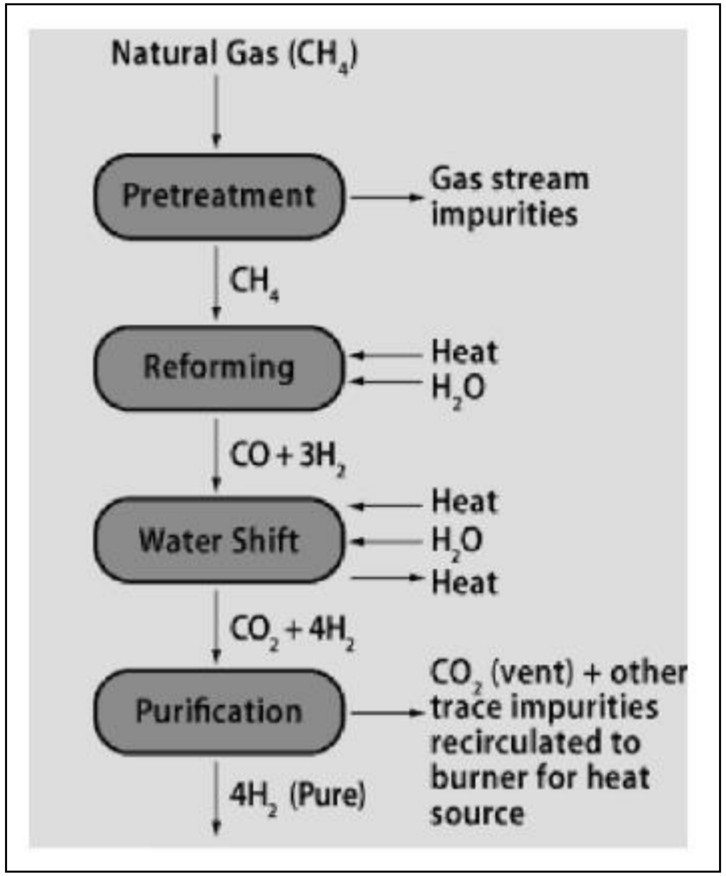
https://www.differencebetween.com/difference-between-steam-reforming-and-autothermal-reforming/



Goal gasification

- Endothermic conversion of carbon to CO and H_2
  - **$C(s) + H_2O$ + heat → $CO + H_2 + CO_2 + CH_4$** ΔH = 173 kJ/mol

HYDROGEN PRODUCTION – CONVENTIONAL PROCESSES



Bhandariet al. 2012; Life Cycle Assessment of Hydrogen Porduction Methods –A Review; IEK-STE

Autothermal reforming, ATR

- Methane and oxygen react (mildly exothermic reaction; ΔH_{ATR} = -24.5 kJ/mol) to hydrogen and carbon monoxide
- Methane is partially oxidized

  $$CH_4 + 0.5O_2 \rightarrow CO + 2H_2 + heat$$
  $$2CH_4 + O_2 + CO_2 \longrightarrow 3H_2 + 3CO + H_2O$$
  $$4CH_4 + O_2 + 2H_2O \longrightarrow 10H_2 + 4CO$$

  - Process conditions: 950 – 1050 °C and 30-50 bar

Dry reforming, DR

- A strongly endothermic reaction between methane and carbon dioxide to CO and hydrogen

  $$CH_4 + CO_2 \rightarrow 2CO + 2H_2 \qquad \Delta H_{DR} = 259 \text{ kJ/mol}$$

  - Ni-, Rh-, Ru-catalysts

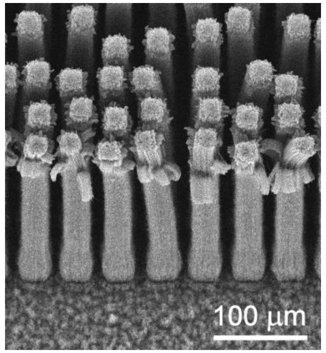
Partial oxidation, POX

- Mildly exothermic reaction of methane and oxygen to CO and H_2
  - $CH_4 + ½O_2 \rightarrow CO + 2H_2$ $\qquad \Delta H_{POX}$ = -36 kJ/mol

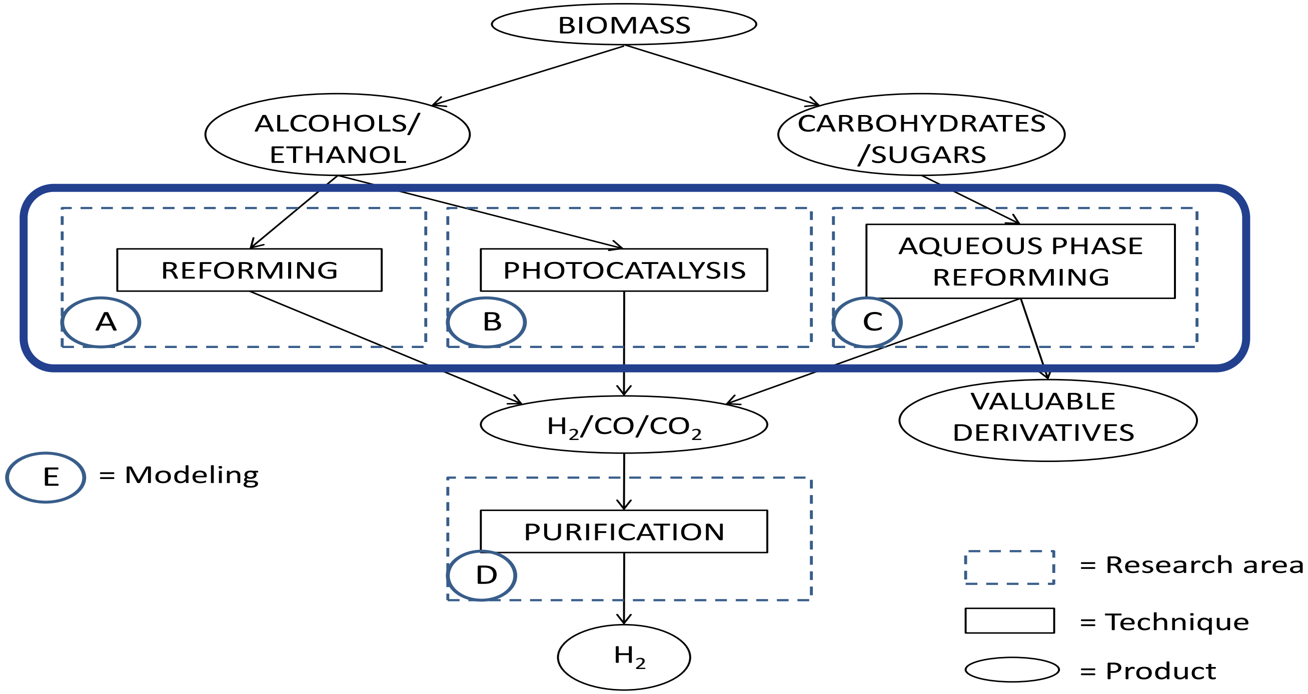
Water-gas-shift reaction, WGSR

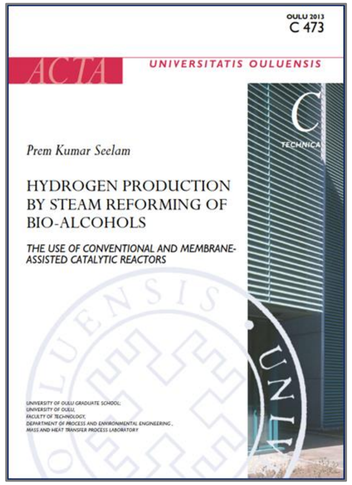
- Mildly exothermic (ΔH_{WGSR} = -41 kJ/mol) reaction of CO and H_2O to CO_2 and H_2
  - $CO + H_2O \rightarrow H_2 + CO_2 + heat$
  - Fe_2O_3-Cr_2O_3 and CuO/ZnO catalysts at 300 – 450 °C and at 200 – 250 °C, respectively

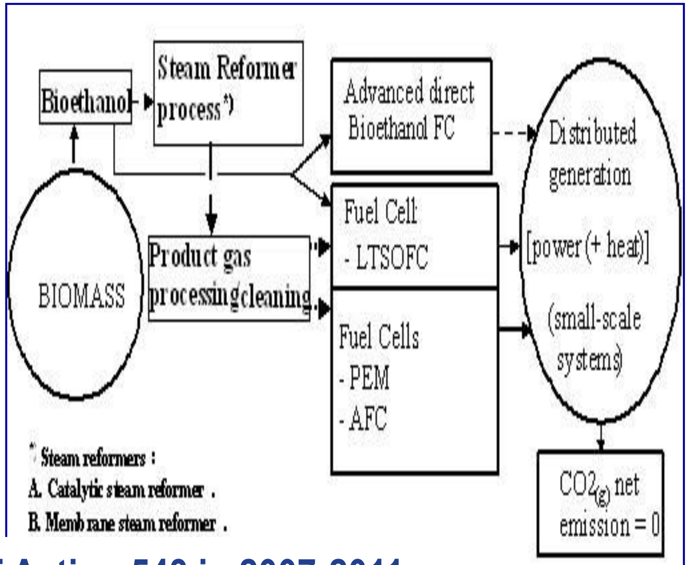
HOW TO PRODUCE H_2? – REFORMING & (PHOTO)CATALYSIS AND SUSTAINABILITY IN HYDROGEN AND BIOGAS PRODUCTION AT ECE/UOULU



- Use of industrial side streams, organic load in wastewaters and biomass in H_2 production
- Use of microreactors, H_2-selective membranes and CNT catalysts







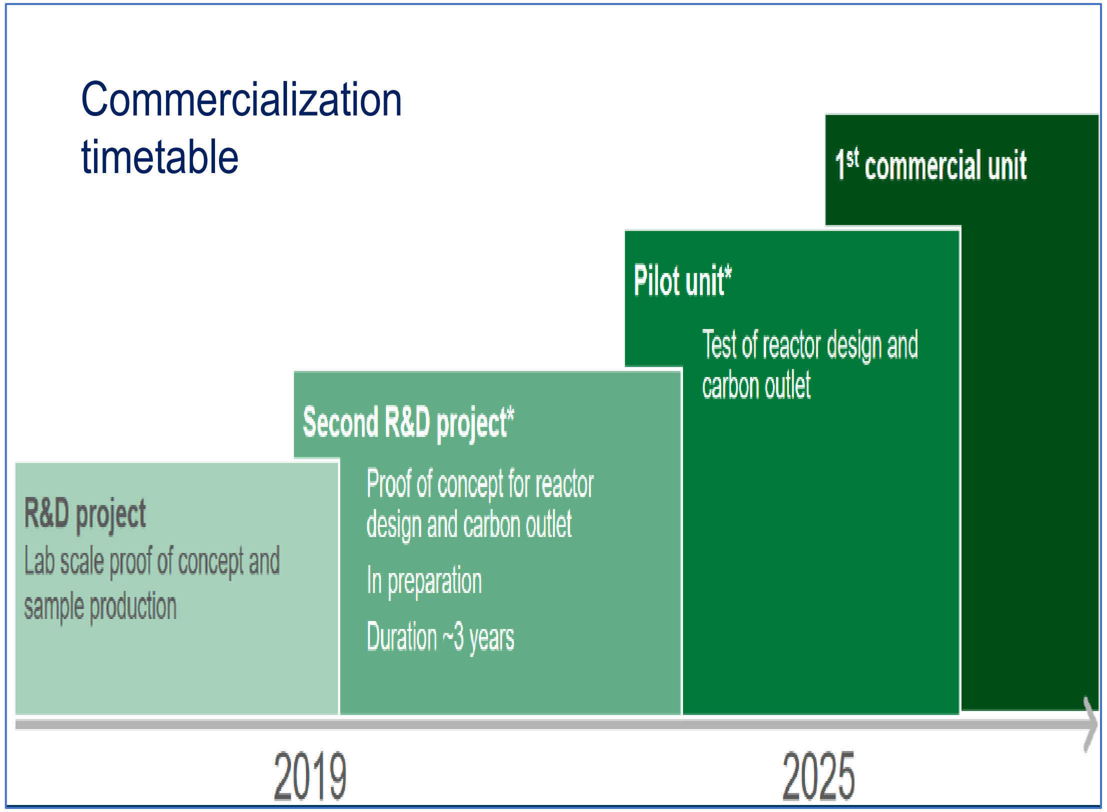
COST Action 543 in 2007-2011

HYDROGEN PRODUCTION – PHOTOCATALYTIC PRODUCTION OF H_2

Adv. Funct. Mater. **2011**, 21, 126; *JPCC*, **2011**, 115, 2805; *ACS Nano*, **2008**, 2, 1492; *Nano Res.* **2011**, 4, 360; *J. Photochem. Photobiol. A*, **2010**, 216, 115., *Catal. Comm.* **2009**, 10, 538; *Science*, **2001**, 293, 269; *ACS Appl. Mater. Interfaces,* **2011**, 3, 229; *Inorg. Chem.*, **2010**, 49, 2017.

- Hydrogen has been reported to be produced photocatalytically in the early 1970's, **UV + H_2O + semiconductive material → H_2**
- Waste streams containing organic substances, e.g. **alcohols and organic acids** may also be used for photocatalytic H_2 production
  - → **Combined water purification and energy production**
  - → **Energy by low costs**
- **Processes at low temperatures**
- **Immobilized and suspended catalyst systems**
- Catalyst materials can be taylored for a particular reaction due to a large variety of phases, doping and decoration
- Large variety of synthesis methods to tailor size, phase, stoiciometry (PVD/CVD, solid-state, wet chemical reactions)
- Reactios with visible light pose **green and renewable processes**
- **<u>Photocatalytic materials find use also in conventional catalysis, chemical sensors, nanoelectronics</u>**

METHANE PYROLYSIS



https://www.efzn.de/fileadmin/documents/Niedersaechsische_Energietage/Vortr%C3%A4ge/2019/NET2019_FF1_04_Bode_Rev1.pdf

- H_2 production through thermal decomposition, i.e., by pyrolysis of methane (mildly endothermic reaction)

$$CH_4(g) \longrightarrow C(s) + 2H_2(g) \qquad \Delta H_{DR} = 37\ \text{kJ/mol}$$

- Low energy demand
- Solid carbon as the 2nd product: carbon black, carbon fibres, carbon nanotubes
- Pyrolysis occurs on the surface of the carbon particles
- Several possible reactor designs (moving-bed, fluidized-bed and liquid bubble column)
- Image on the right depicts a moving-bed reactor:
- Counter current flow
- Electrically heated
- Process temperature between 800-1400 °C
- Present reactor concept are not mature for industrial use (TRL 4-6)

WATER ELECTROLYSIS (WE) AND ITS HISTORICAL BACKGROUND

- WE is a process which uses electricity **to split water into hydrogen and oxygen**
- The process produces **clean energy with oxygen as the only by-product**
- The generated H_2 can be injected into grid, used in a fuel cell or in chemicals and fuels production
- The **energy demand for WE process** can be supplied by electrical or thermal energy
- WE is an **old technology known for over 200 years**
- **In 1789**, Dutchmen Adriaan Paets van Troostwijk (1752–1837) and Jan Rudolph Deiman (1743–1808) observed the decomposition of water into a mixture of “combustible air” and “life-giving air” caused by electric discharges between two gold electrodes
- The phenomena of water decomposition initiated by direct current was observed by two Englishmen William Nicholson (1753–1815) and Anthony Carlisle (1768–1840) in 1800
- The **basic physical law of electrolysis** was discovered in 1834 by the **English scientist Michael Faraday** (1791–1867)

WATER ELECTROLYSIS (WE)AND ITS HISTORIC BACKGROUND

- **By 1902** there were more than **400 industrial electrolyzers** already in operation worldwide
- **In 1940**, **the first large electrolysis plant** with a capacity of more than 10,000 m^3 H_2/h, built by the Norwegian company Norsk Hydro Electrolyzers, went into operation
- **In 1948** the first pressurized electrolyzer was manufactured
- **In 1966**, the first solid polymer electrolyte membrane electrolyzer was built
- **In 1972**, the development of solid oxide electrolyte electrolyzers was started
- Today several companies are active in the manufacture and development of electrolysis technologies: Proton, Hydrogenics, Giner, and ITM Power being leaders in the field
- **Water electrolysis, WE**

$$H_2O(l) \rightarrow H_2(g) + 0.5O_2(g) \qquad \Delta H = 286 \text{ kJ/mol}$$

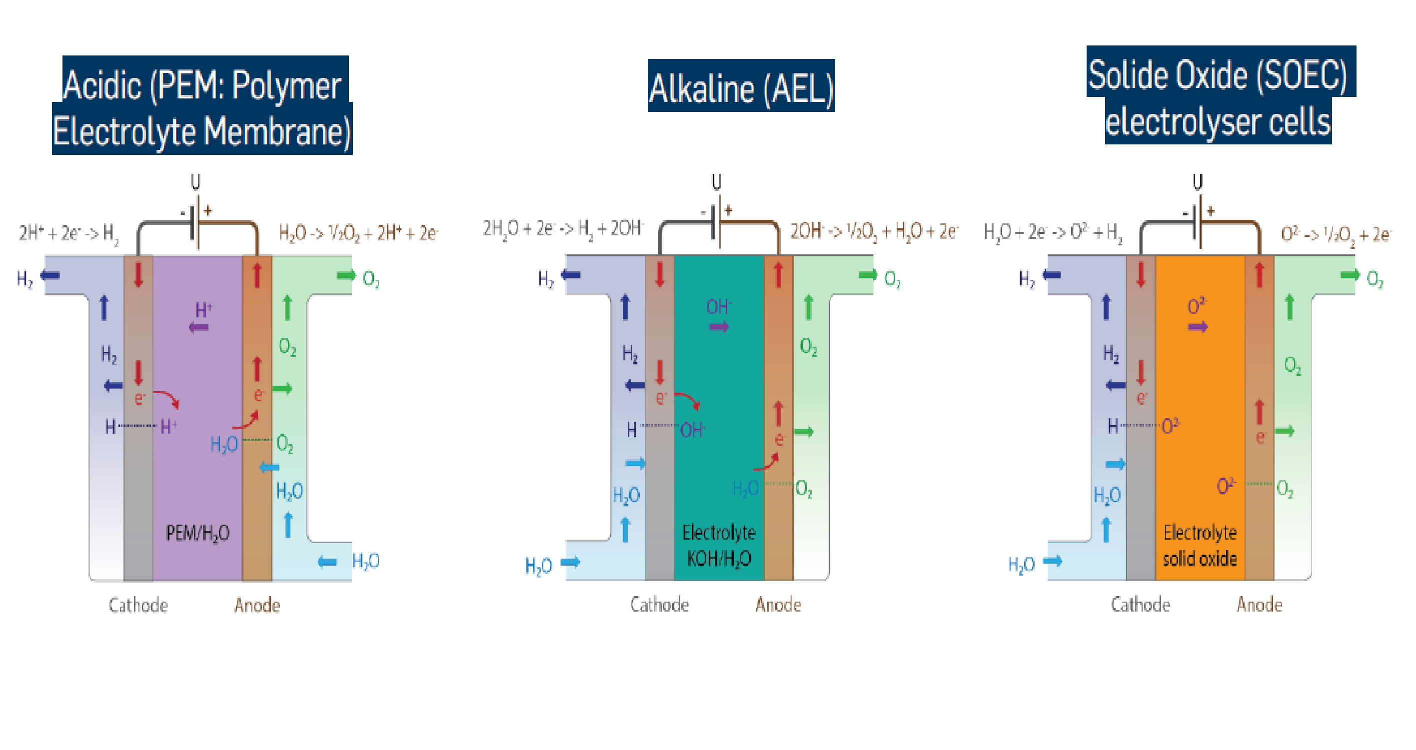
  - High energy demand, water as a raw material
  - Endothermic ($\Delta H > 0$) and non-spontaneous ($\Delta G > 0$) chemical reaction

DIFFERENT APPROACHES FOR WATER ELECTROLYSIS IN INDUSTRIAL SCALE

- Alkaline Electrolyzers (AEL)
- Proton exchange membrane electrolyzers (PEM)
- Solid oxide electrolyzer cell (SOEC)

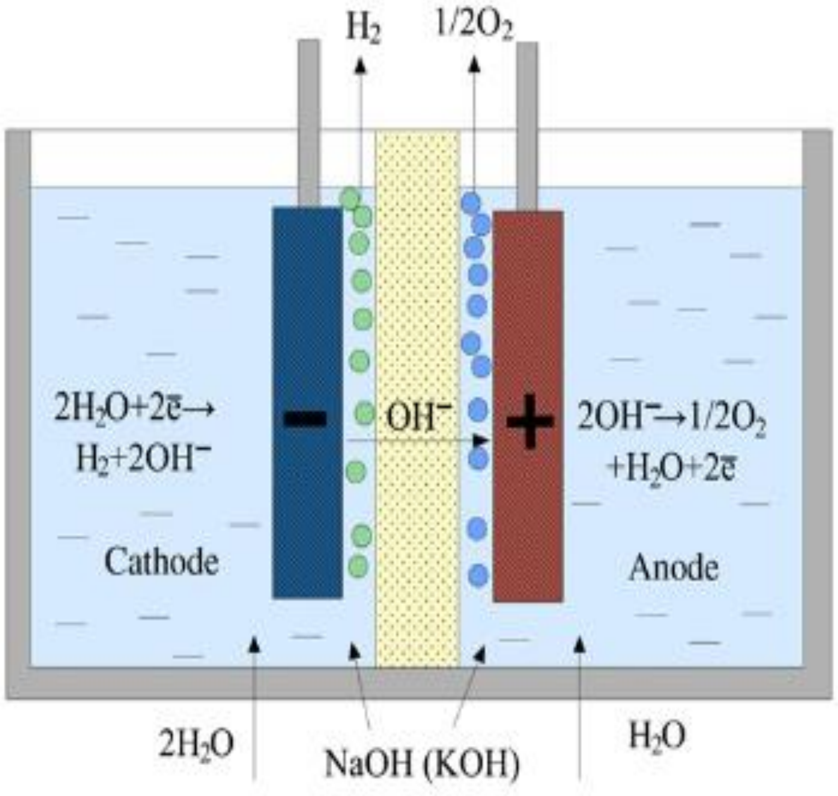
PEM, AEL, AND SOEC ELECTROLYSIS

Technology	ALK	PEM	SOEC
Maturity	Commercialized	Commercialized	Research & Development
Installed Capacity range as of 2020 in Europe (kW) [19]	50-5000	100-6000	150
Average Electricity Input ($kWhel/kgH_2$) in by 2030 [20]	51	47	41
Investment Costs EUR/kW[20] [21]	800-1500	900-1850	2200 – 6500
Average output H_2 pressure [bar] [21]	10	35	10
Average Operating Temperature (°C) [20]	60-80	50-70	700-800
Electrical Efficiency (LHV, %) [20]	65-68%	57-64%	72-88%
Max H_2 production rate (Nm_3//h) [21]	10	5	5



Ausfelder et al.; 978-389746-237-3

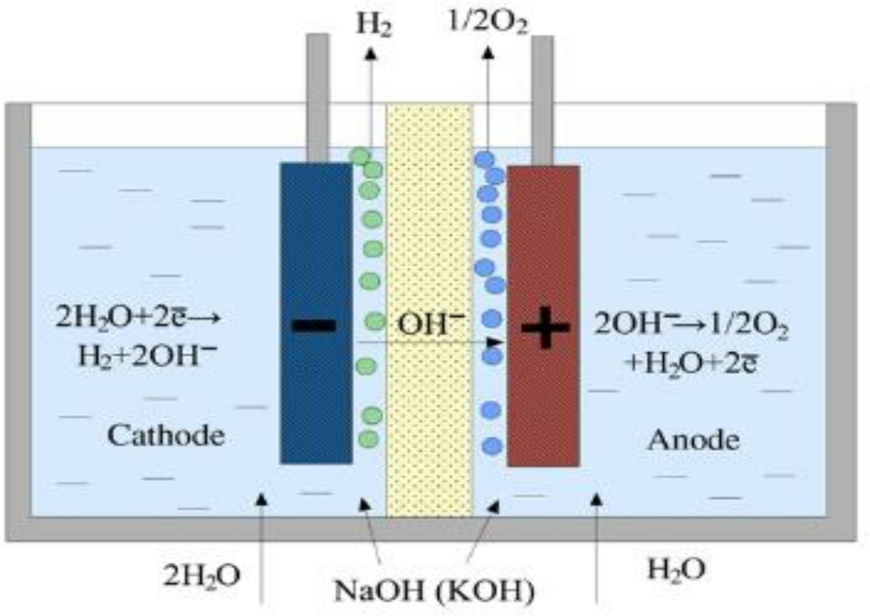
ALKALINE ELECTRO-LYZERS, AEL IN WATER ELECTROLYSIS



10.1016/B978-0-444-56352-1.00002-7

- **The most mature technology**
- **It has been applied for large-scale hydrogen production** in the industries since the beginning of the 20th century
- Conventional AEL are usually operated at current densities in the range of 300–500 mA/cm^2 and at corresponding cell voltages in the range of 1.9–2.4 V
- **Operating temperature:** 70-90 °C, and in either atmospheric or elevated pressure
- **Higher efficiency and product purity (99.5+% H_2 purity)**
- **System efficiency:** 60-80% depending on system size, purity and pressure levels
- **Pressurized AEL (up to 15 bar)** produced compressed hydrogen that is ready for grid injection with minimal energy input
- **But they are more expensive (20-30%) than the atmospheric systems**
- AEL cell is made of two electrodes that are immersed completely in 30 wt.% aqueous KOH electrolyte
- **The electrodes are made of nickel or nickel plates**

AEL: PROS AND CONS



Pros:

- Durability, maturity, availability and comparatively low specific costs

Cons:

- **Low current densities**: significantly influence specific system size and H_2 production costs.
- Low operating pressures

- A microporous diaphragm separates the anode and cathode.
- Direct current is applied to the AEL, H_2 and OH ions evolves at the cathode according to the following reaction:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

- The OH ions are migrating through the microporous separator and are oxidized at the anode according to the following reaction:

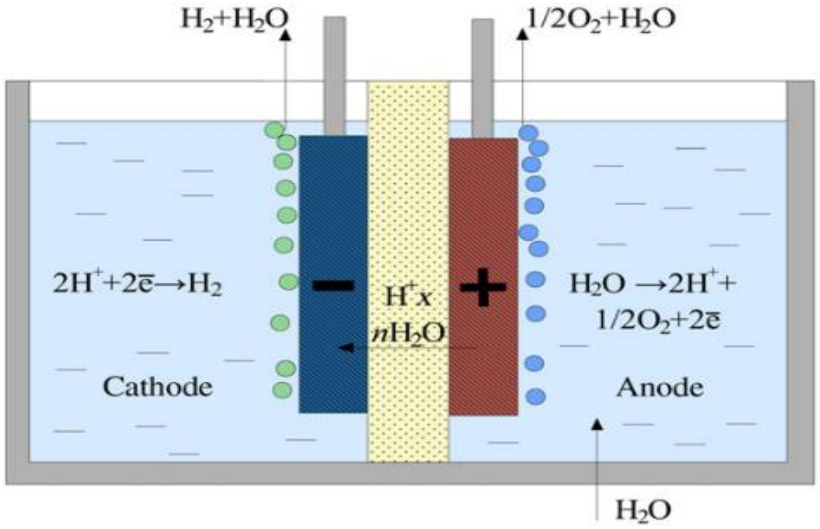
$$2OH^- \rightarrow 1/2O_2 + H_2O + 2e^-$$

- **Water is consumed but not KOH** and therefore water has to be supplied continuously (neglecting physical electrolyte losses)

10.1016/B978-0-444-56352-1.00002-7

PROTON EXCHANGE MEMBRANE ELECTROLYZERS, PEM

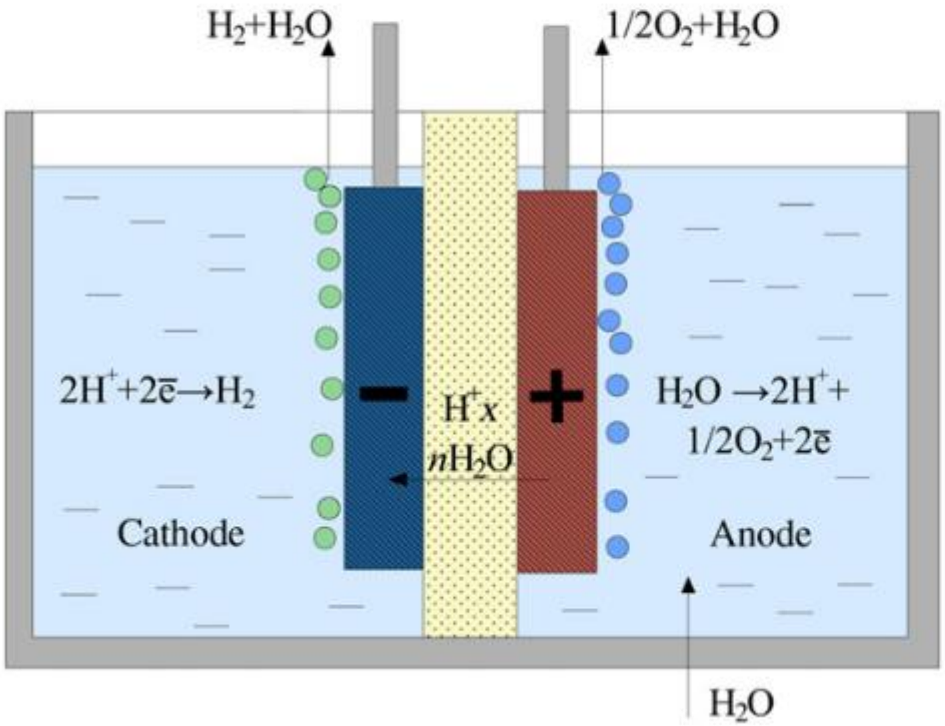
- PEM development started in 1966 by General Electric
- **First commercialization was in 1978**
- **System efficiency 60-70%**
- Operation: 60-80 °C, 30-60 bar, voltage range: 1.6-2 V
- **H_2 purity: 99.99+%**



- Solid polymeric membrane is used as electrolyte
- PEM systems are usually operated at current densities of 1–2 A/cm^2, which is about a factor of 4 higher compared to AEL
- At the anode, pure water is oxidized to O_2 and release protons that flow through the membrane and are reduced at the cathode to form H_2 according to the following respective reactions:
  - $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$
  - $2H^+ + 2e^- \rightarrow H_2$

10.1016/B978-0-444-56352-1.00002-7

PEM: Pros and cons



10.1016/B978-0-444-56352-1.00002-7

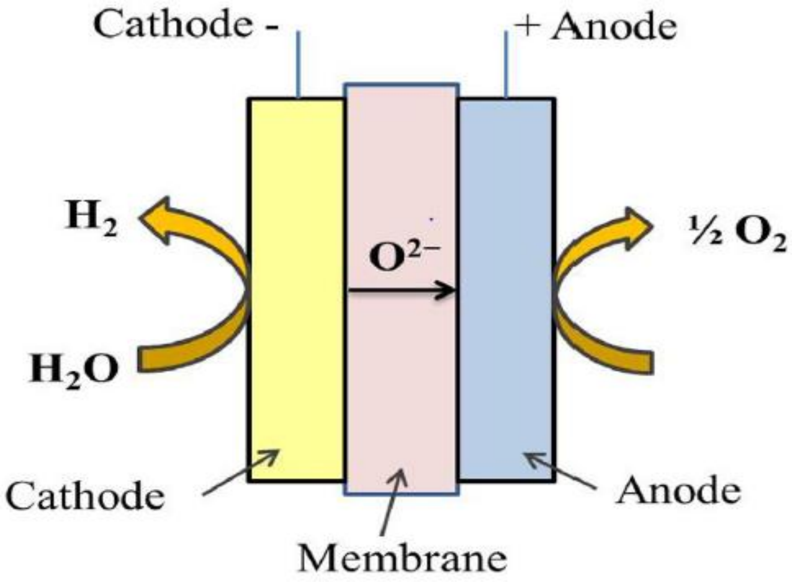
Pros:

- Faster cold start, higher flexibility, and better coupling with dynamic and intermittent systems compared to AEL
- Can produced highly compressed hydrogen

Cons:

- **High cost of the catalyst support materials and the membrane**

SOLID OXIDE ELECTROLYZER CELL , SOEC

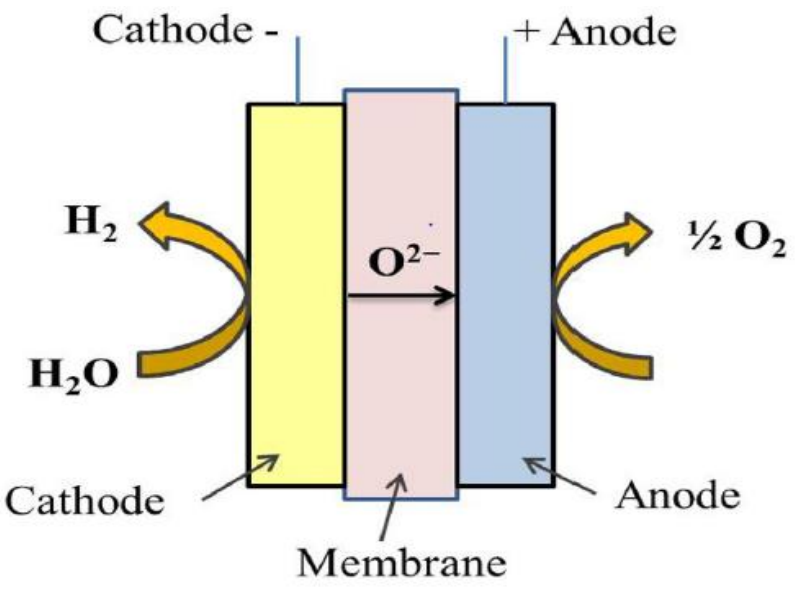


10.1016/j.mset.2019.03.002

- SOEC is at early stage of development
- A thin, dense solid oxide layer is used as electrolyte
- The core SOEC components are usually made up of ceramic materials
- SOEC uses waste heat instead of part of the electricity needed in the process
- SOEC operates under high temperature (800-1000 °C): higher efficiency (>90%) compared to AEL and PEM
- The solid electrolyte is typically made up of ZrO_2 doped with 8% Y_2O_3
- At the cathode, steam is reduced to produce H_2:

$$H_2O + 2e^- \rightarrow H_2 + O^{2-}$$

SOEC: PROS AND CONS



10.1016/j.mset.2019.03.002

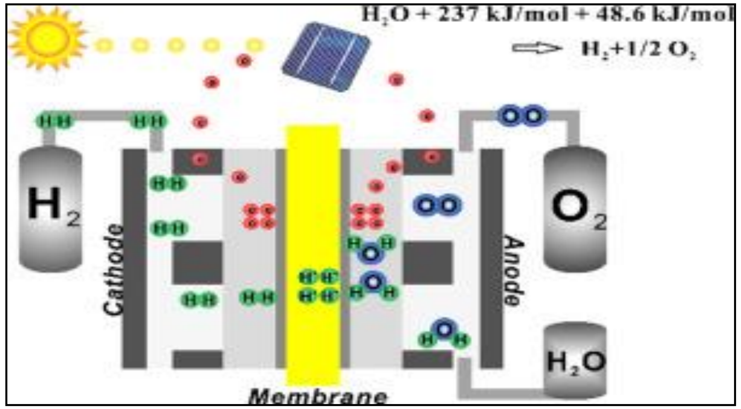
Pros:

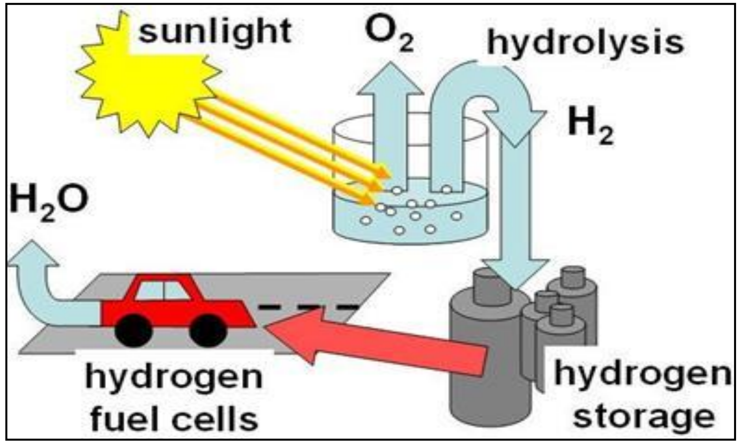
- Significant increase in ionic conductivity and the rates of electrochemical reactions due to high-temperature operation
- **Reduction in total electricity demand that can be compensated by supply of thermal energy**

Cons:

- **Material decomposition and short-term stability**
- Difficult to operate with fluctuating and intermittent power

ELECTROLYSIS AND PHOTOCATALYSIS - COMPARISON

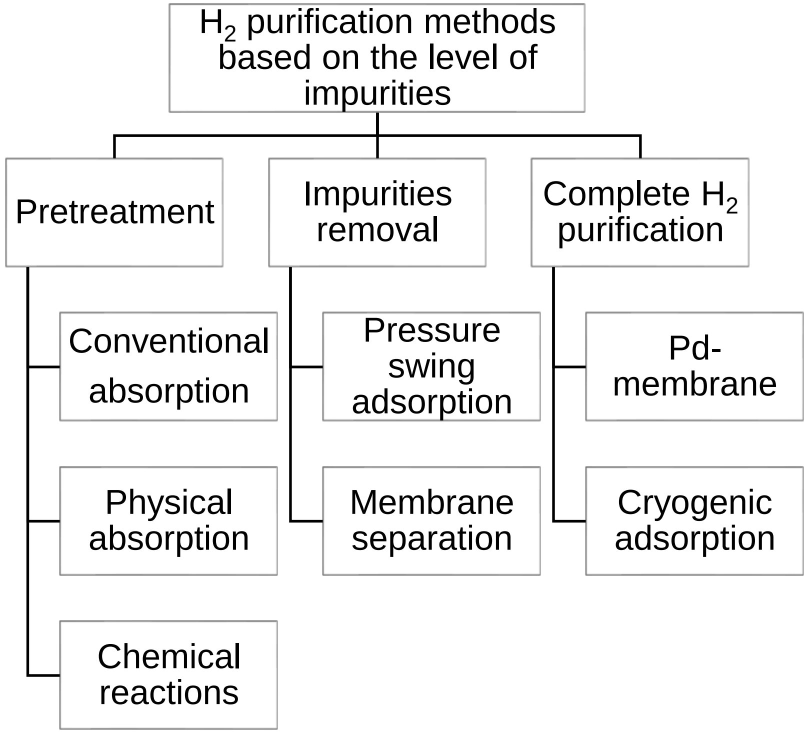




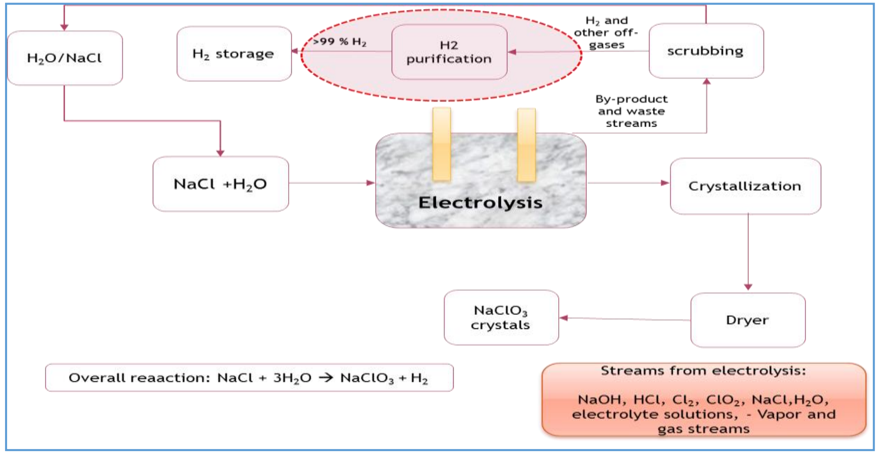
- **Hydrolysis** (electrolytic water splitting) is technology to produce hydrogen using energy from renewable source (solar light, wind, hydropower).
- The reaction has a standard potential of −1.23 V.
- **Efficiency** of modern hydrogen generators is measured by energy consumed per standard volume of hydrogen (MJ/m^3).
- **Practical electrolysis** (using a rotating electrolyser at 15 bar pressure) consume 50 kilowatt-hours per kilogram (180 MJ/kg), 15 kilowatt-hours (54 MJ) more is needed if the hydrogen is compressed e.g. for use in hydrogen cars
- Hydrogen can be produced using **photocatalysis**, i.e., **water splitting** (under research) and from **organic molecules** (e.g., ethanol, organic load in wastewaters) in aqueous phace (under research) using **UV or solar light** and **semiconductive photocatalysts**

H_2 PURIFICATION

- Hydrogen has to be purified before it is used e.g., in chemical industry, transportation, in fuel cells.
- **Hydrogen purification can be done mainly with three methods**:
  - Chemical (e.g. ,adsorption, absorption)
  - Physical (e.g., metal hybrides, cryogenic)
  - Selective diffusion (vaious types of membranes)
- Typically, it is purified by using a **pressure swing adsorption** (PSA) - purity higher than 99.99% is obtained.
- The adsorbents used most often are e.g., **activated carbon, silica gel, alumina and zeolites.**
- Another widely used purification method is **membrane purification**: 1) Inorganic membranes (metallic or ceramic membranes) and 2) organic membranes (polymeric membranes)
- **The selection of H_2 purification technique** is solely dependent on the operating conditions, specifications and the end use requirements
  - **Criteria:** low T and p, O_2 and Cl_2 resistance, easy operation, high selectivity and fluxes, durability.



H_2 stream purification from a chlorate process: possible purificaion steps needed after the water scrubbing unit:



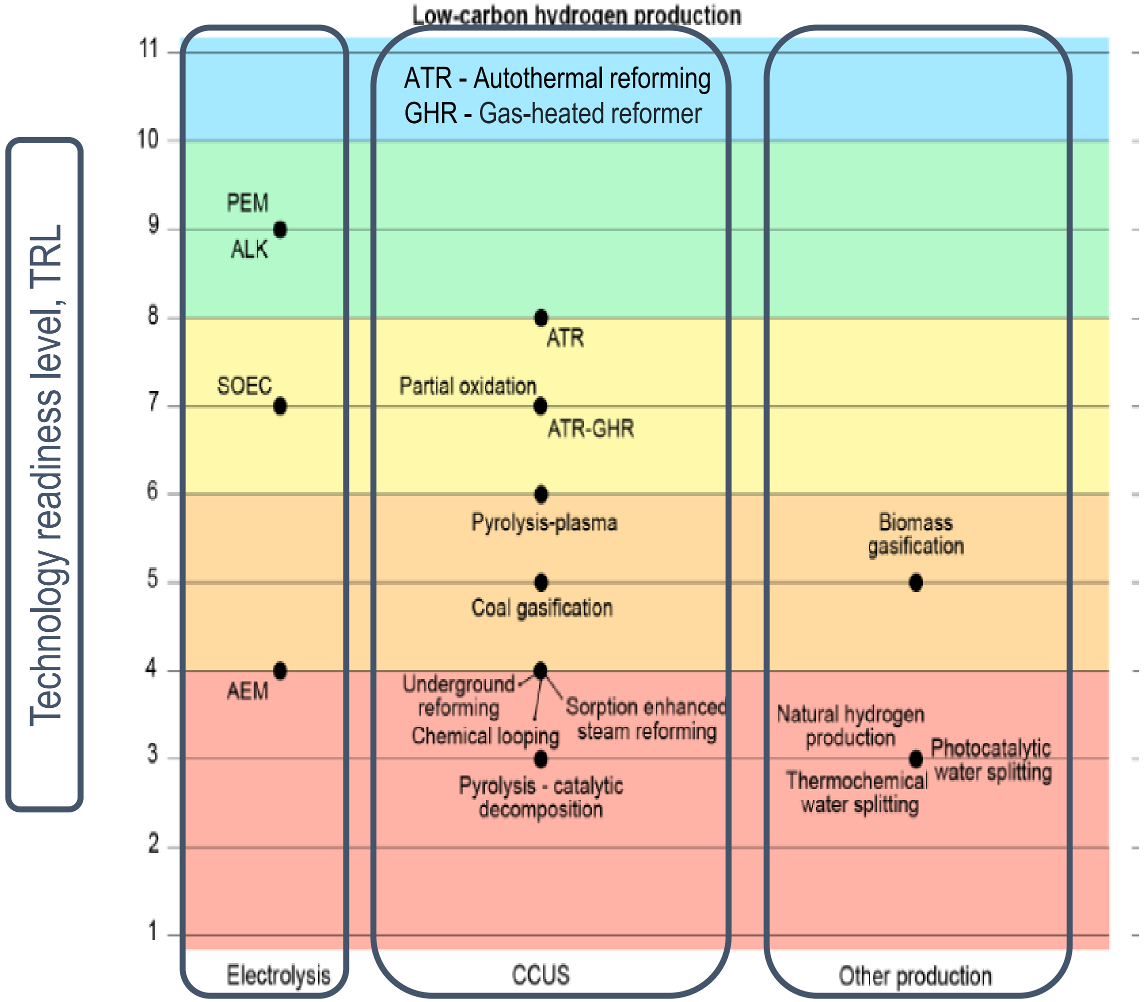
HYDROGEN PRODUCTION – TECHNOLOGY READINESS LEVEL, TRL

TECHNOLOGY READINESS LEVEL (TRL)

TRL	Definition
9	Actual system "flight proven" through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
7	System prototype demonstration in a space environment in a space environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
5	Component and/or breadboard validation in relevant environment
4	Component and/or breadboard validation in laboratory environment
3	Analytical and experimental critical funsciotn and/or charateristic proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed/reported

Rybicka, J.; Journal of Cleaner Production 112 (2016) 1001-1012; http://dx.doi.org/10.1016/j.jclepro.2015.08.104

TRL OF KEY HYDROGEN PRODUCTION TECHNOLOGIES



HYDROGEN PRODUCTION – TECHNOLOGY READINESS LEVEL, TRL

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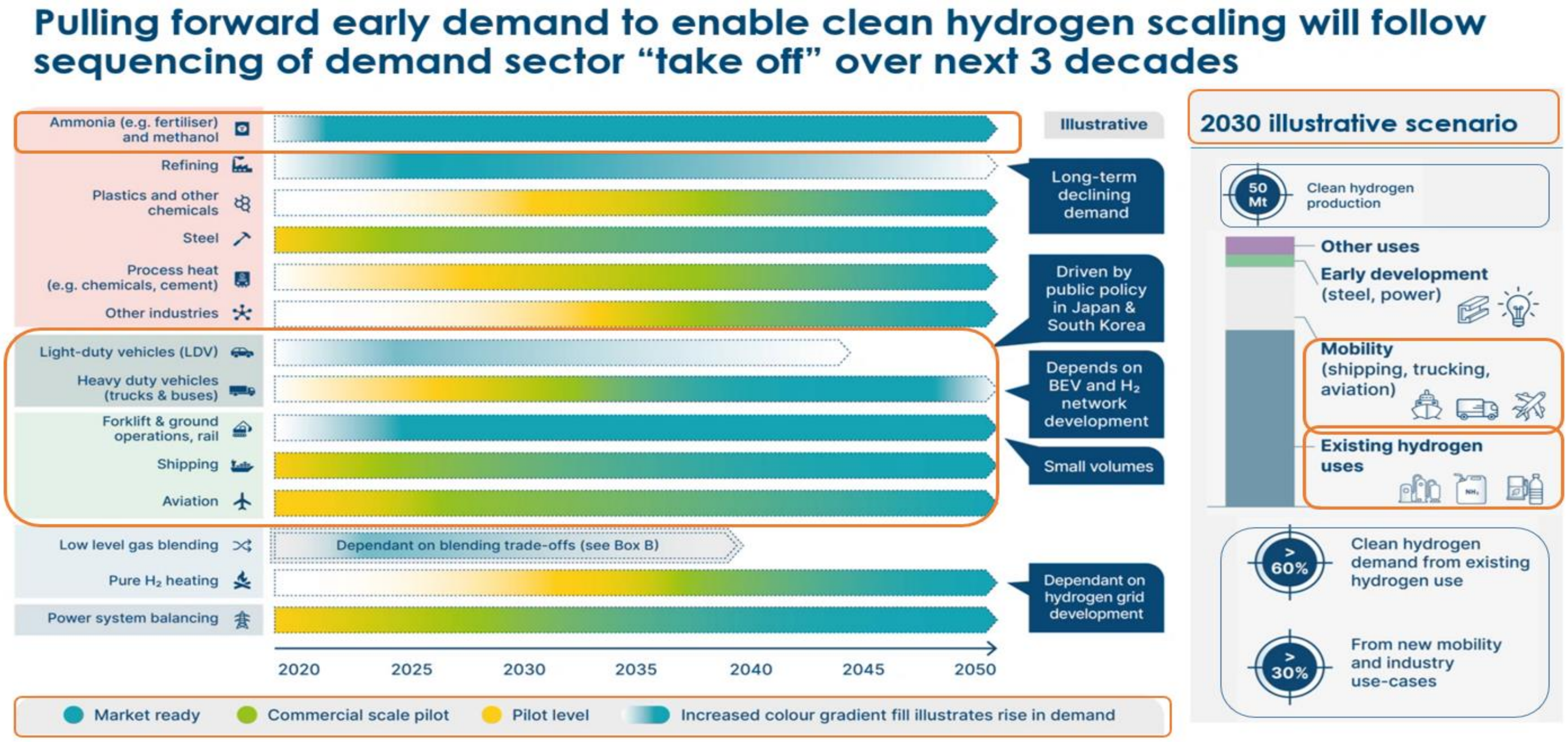
Figure 3.4 Technology readiness level of technologies along the low-carbon hydrogen value chain

https://iea.blob.core.windows.net/assets/04dc5d08-4e45-447d-a0c1-d76b5ac43987/Energy_Technology_Perspectives_2020_-_Special_Report_on_Clean_Energy_Innovation.pdf; page 75

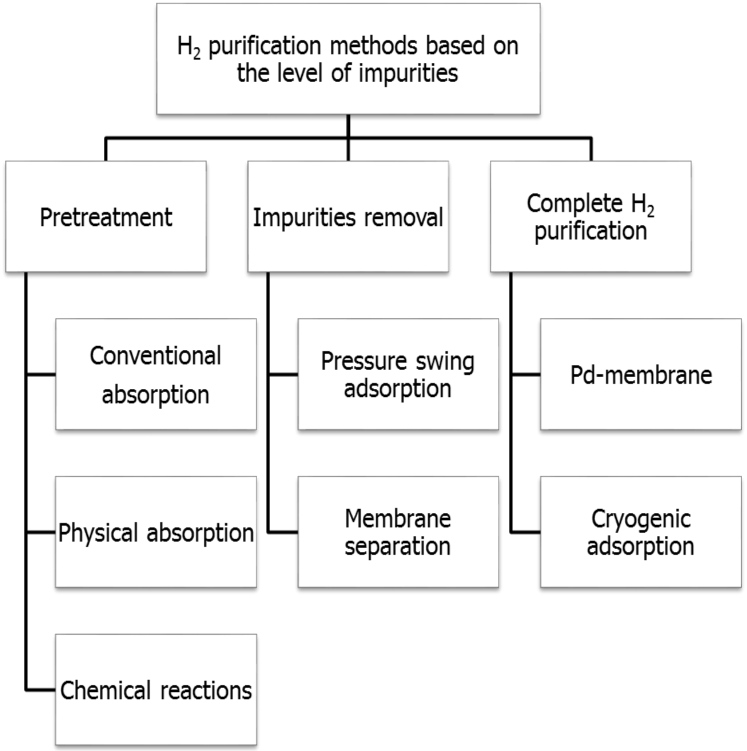
Notes: Technologies included are at large prototype or at a more advanced stage. CCUS = carbon capture utilisation and storage. For more detailed information on individual technology designs for each of these technologies, and designs at small prototype stage or below, please visit: www.iea.org/articles/etp-clean-energy-technology-guide.

HYDROGEN AS AN ENABLER OF ENERGY TRANSITION



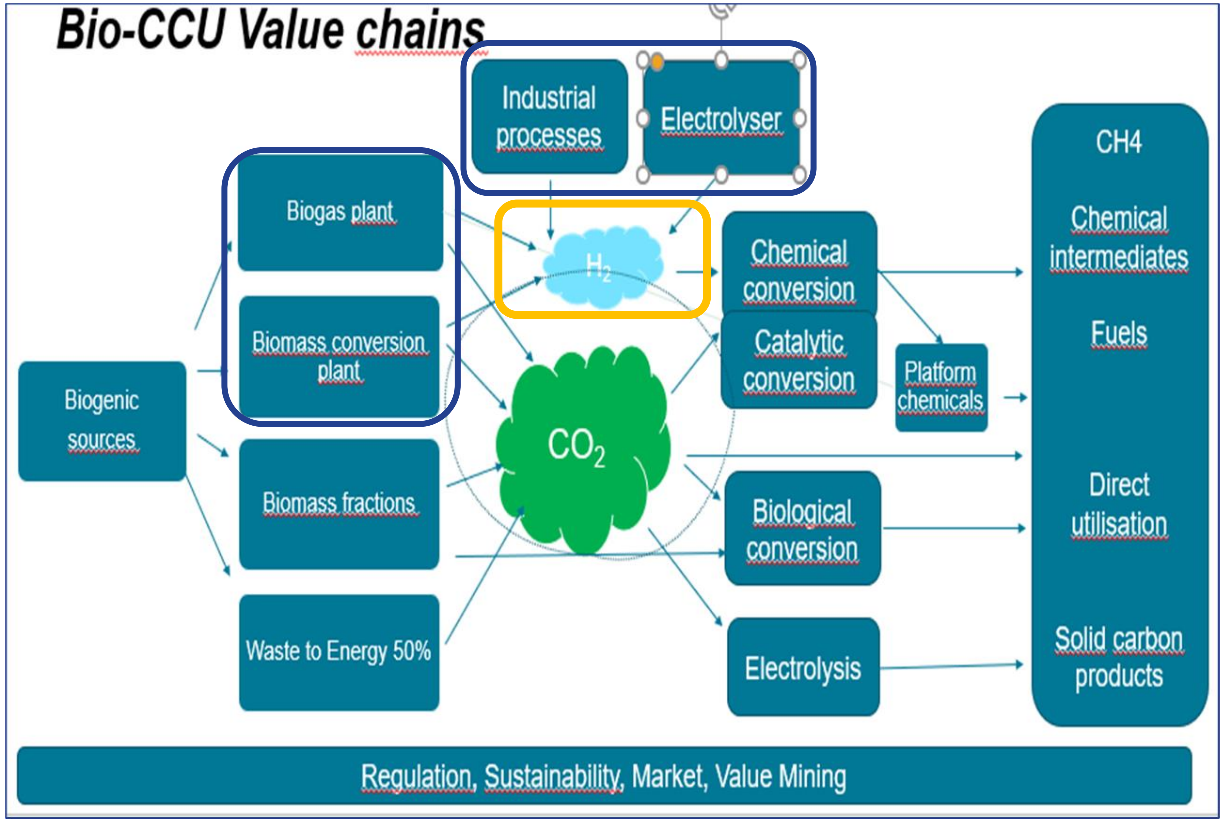
SOURCE: SYSTEMIQ analysis for the Energy Transitions Commission (2021)

H_2 VIA REFORMING & PHOTO-CATALYSIS FROM INDUSTR-IAL SIDE STREAMS AND BIOMASS AT ECE/UOULU



- **Reforming** in H_2 production over nanostructured base metal (e.g., over conventional catalysts, CNTs, nanofibres) catalysts.
- **Photocatalytic** H_2 production over non-PGM nanomaterials.
- **Catalytic routes** from biomass, industrial gases (including CO_2), organic load in WWs, water to fuels (e.g., hydrogen, alcohols, hydrocarbons)
- **Purification of gaseous streams** using membrane technology and hybrid systems (e.g., photocatalytic membranes and membrane reactors).
- **Catalyst deactivation studies** in reactive conditions (poisoning, structural changes).
- **Sustainability assessment analyses**.
- Thermodynamic calculations and reactor design.

THE BIO-CCU PROJECT AT ECE/UOULU



Tampere University · UNIVERSITY OF OULU · LUT University · HELSINGIN YLIOPISTO · Luke LUONNONVARAKESKUS

ECE/UOULU:

- **CO_2 purification** - Development of membrane gas purification for CO_2 containing effluent streams (e.g., low-grade biogas)
  - Modification of waste materials to membranes
- **Hydrogen sourcing** – Development of catalysts for biogas upgrading to hydrogen (link to on-going GREENE project)
- Development of **new circular material-based catalysts and conversion routes** for green fuel production (P2G, P2C)
  - Modification of waste materials to catalysts and membranes
  - Applications of hybrid technologies (catalytic membranes, adsorption/catalysis)
- **Process modelling and simulation**
  - Development of mechanistic models for selected process concepts (mass and energy balances)
  - Sensitivity analysis, flexibility/controllability of processes
- Support in **techno-economic analysis and life cycle assessment**
  - Integrating the process developments and process models to TEA/LCA

FOSSIL FREE BIOHYDROGEN AND CLEAN ENERGY FROM BIOGAS – GREEN AT ECE/UOULU

- The project supports the **hydrogen economy**, self-sufficiency and **local energy production** and contributes to the **carbon neutrality 2035 target** in Finland.
- The goal is to develop a new **thermochemical method** that utilizes biogas in the production of fossil-free biohydrogen.
- The developed method enables the utilization of **biogas in hydrogen production** in an atom- and energy-efficient way in order to promote low-emission, flexible and efficient decentralized energy production.
- The development includes **reactor design** including pre-treatment, analytics and automation, the **development and testing of carbon-resistant and sulphur-tolerant catalysts**, and pilot-scale equipment **construc**

Doc. Esa Muurinen, Doc. Satu Pitkäaho, UOulu Environmental and Chemical Engineering Research Unit
www.oulu.fi/environmentalengineering/greene

Kestävää kasvua ja työtä -ohjelma
Vipuvoimaa EU:lta 2014–2020
Euroopan unioni
Euroopan aluekehitysrahasto

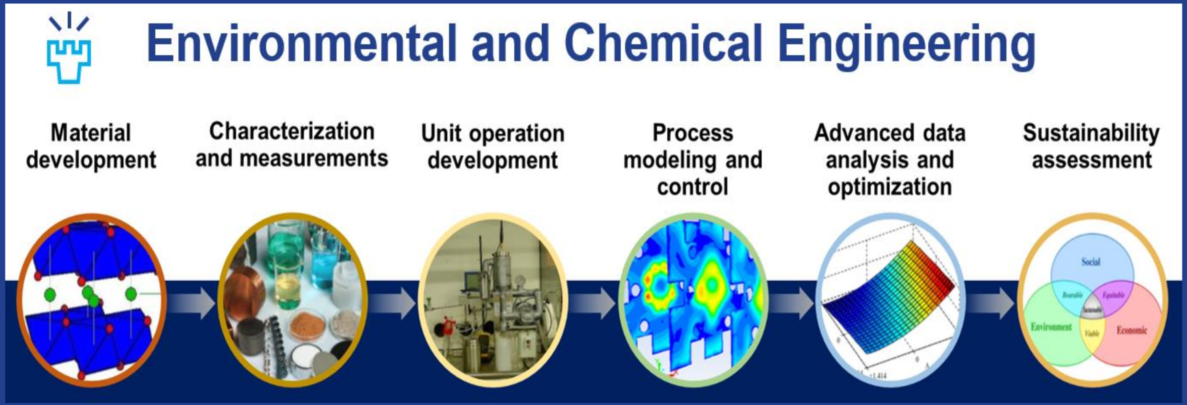
HYDROGEN PRODUCTION QUESTIONS

1. Why is there so much discussion about hydrogen?
2. Hydrogen production – why should we and how can we produce green and blue hydrogen?
3. How mature are the most sustainable routes to hydrogen and how their sustainability can be described?

Many thanks!

Environmental and Chemical Engineering Research unit, ECE

https://www.oulu.fi/environmentalengineering/



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