EFFECTS OF RENEWABLE ENERGY UNSTABLE SOURCE TO HYDROGEN PRODUCTION: SAFETY CONSIDERATIONS

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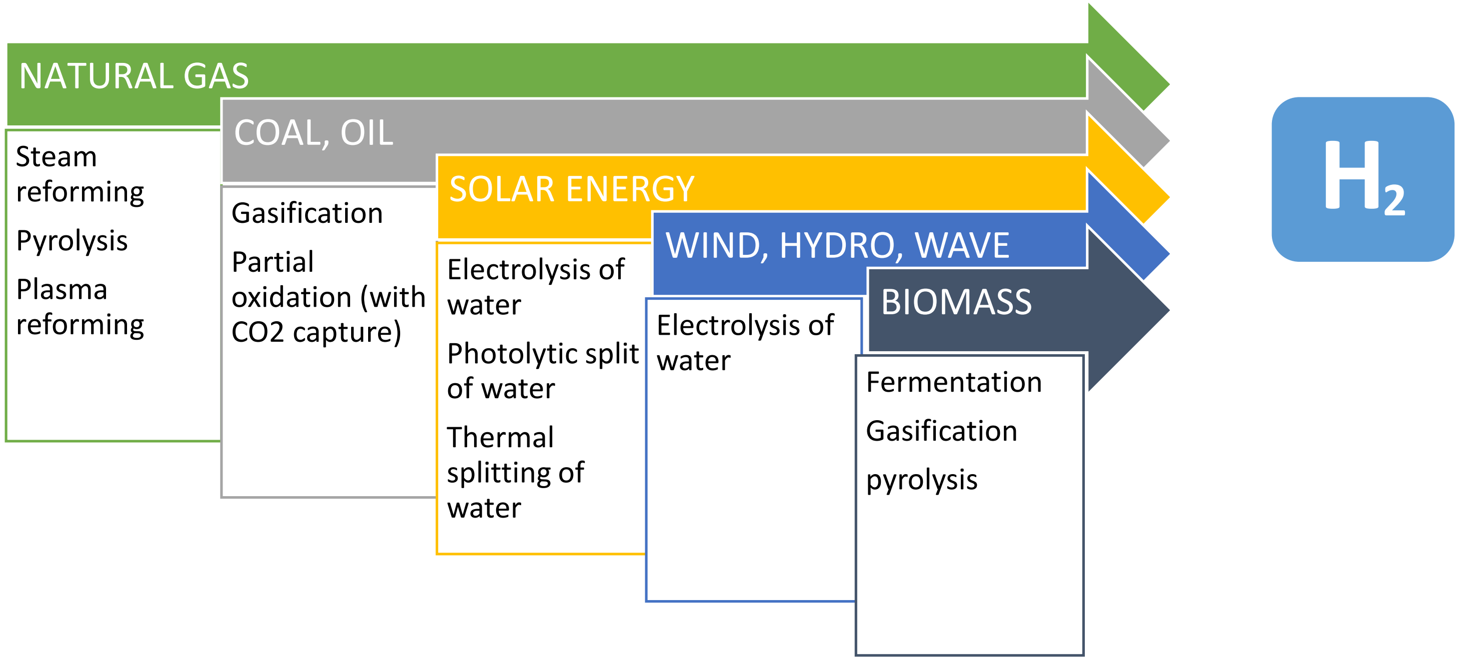
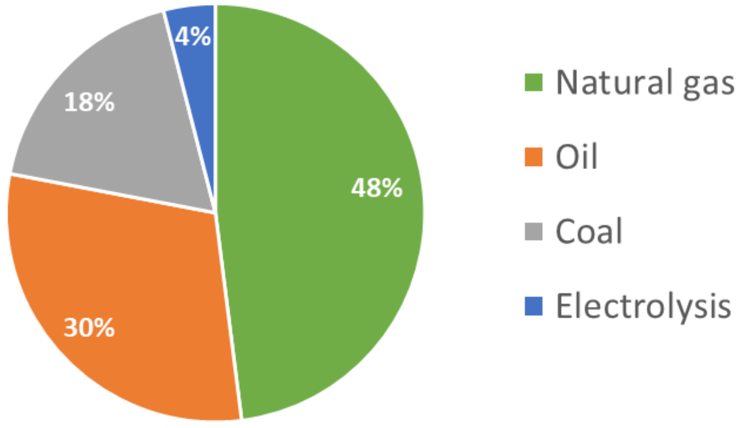
INTERNATIONAL CONFERENCE ON HYDROGEN SAFETY 2021

"Safe Hydrogen for Net Zero"
Edinburgh on 21-24 September 2021

Hydrogen production - electrolysis

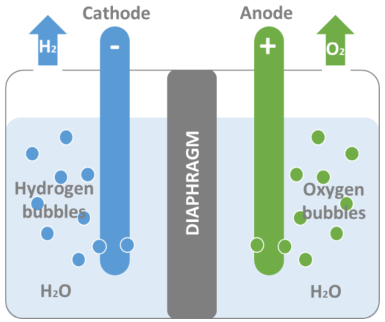




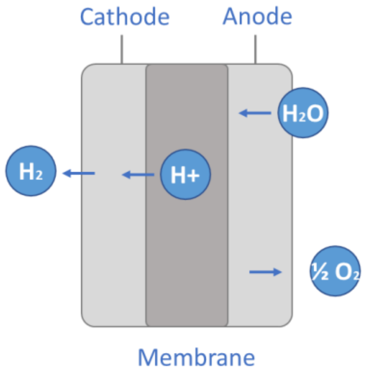
- Water electrolysis is a key technology for splitting water into hydrogen and oxygen by using renewable energy
- Solar and wind energy
  - the most widespread distribution
  - particular advantages, since the exceeding electrical energy produced can be stored in hydrogen, balancing the discrepancy between energy demand and production
- The main issue with the use of renewable energy is the unsteady distributed and intermittent local availability

Type of electrolysis

Alkaline water electrolysis (AEL)

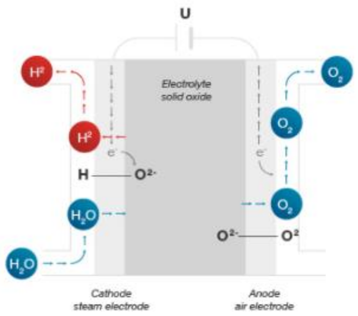


Proton exchange membrane electrolysis (PEM)



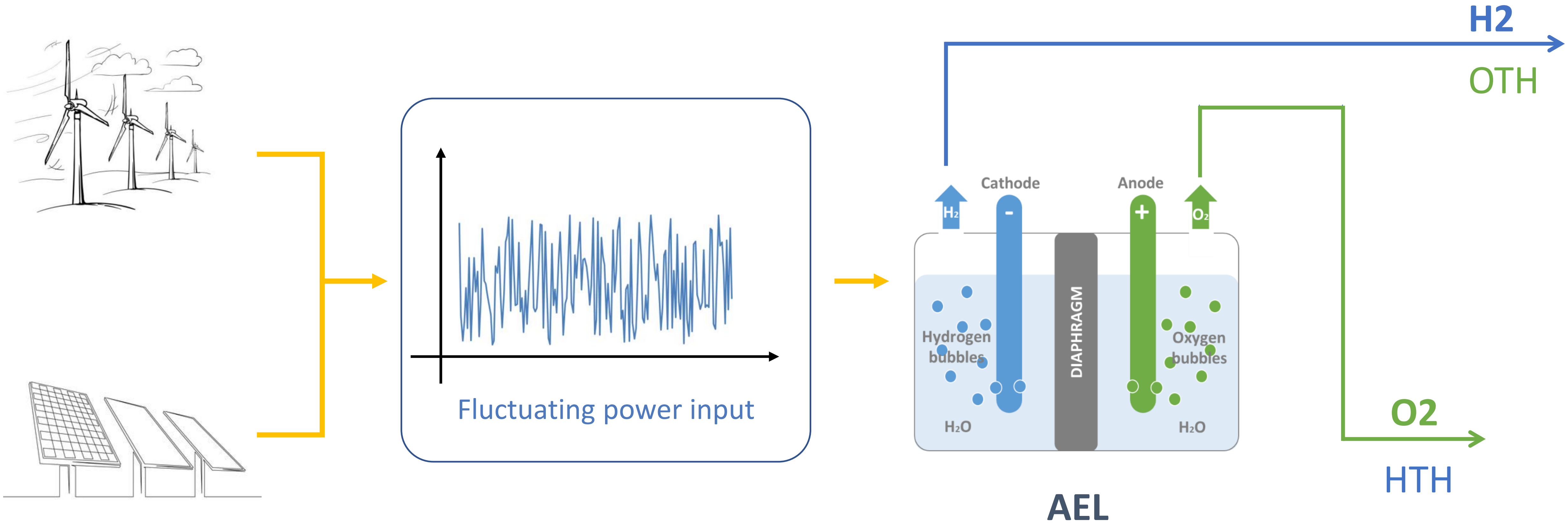
Low temperature

Solid oxide electrolysis (SOEL)

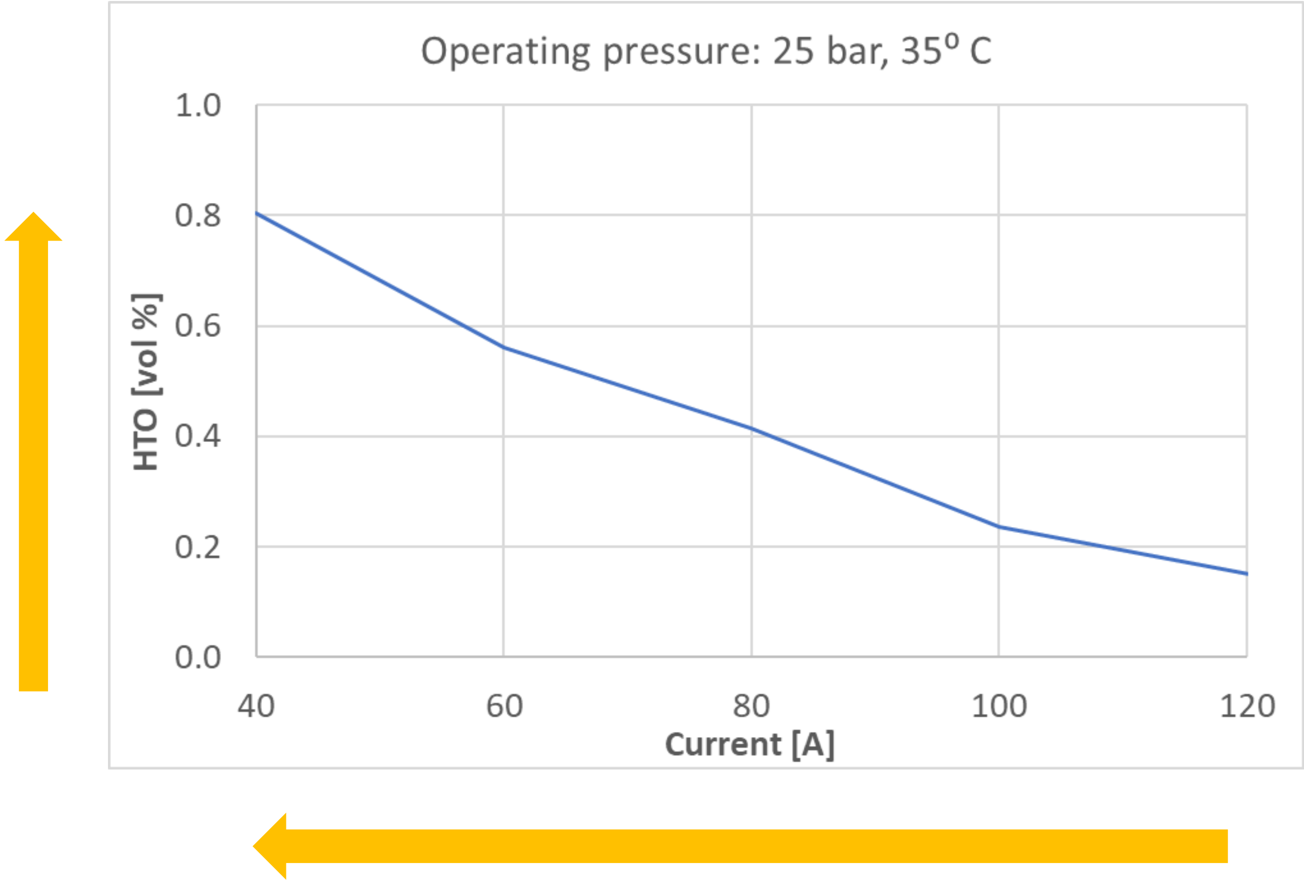


High temperature

Electrolyser + fluctuating power input



HTO: amount of hydrogen in oxygen

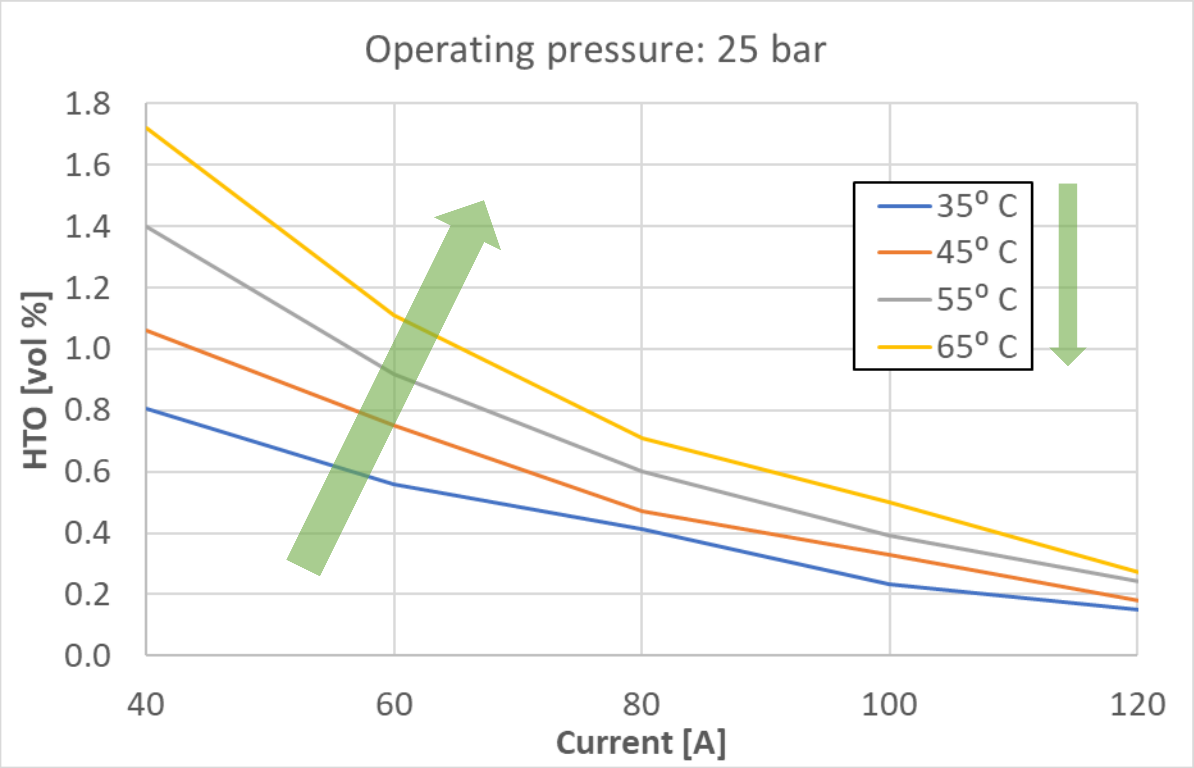


Alkaline water electrolysis

Increase in HTO as the current decreases:

- H2 molecules produced at the electrodes join up more slowly to form bubbles
  - ➢ the molecules are held inside the cell for a longer period of time
    - ➢ thereby contributing to the increase in the hydrogen diffusion rate through the diaphragms
- HTO trend is exponential with the decrease in current
  - ➢ associated with a considerable decrease in the production of hydrogen at low currents due to the parasitic currents through the electrolyser stack

HTO in relation with temperature

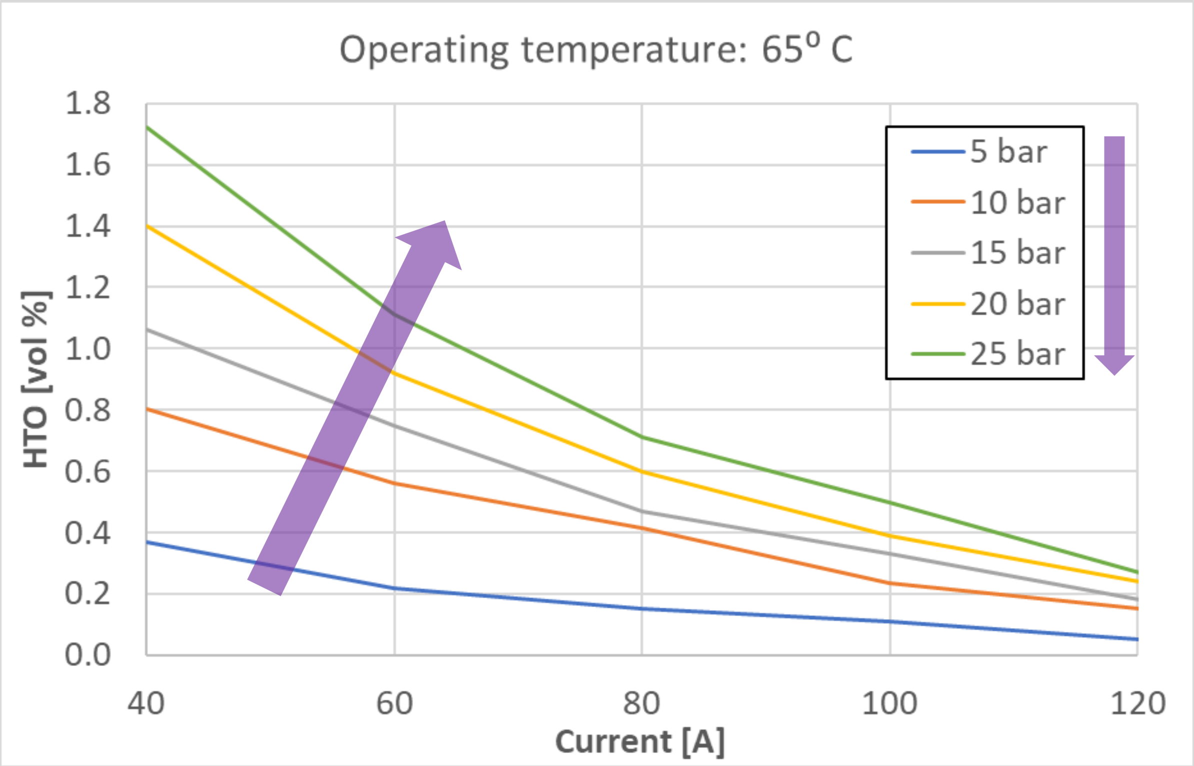


At 120 A current, the HTO is 80% greater at 65° C (0.27 vol.%) compared to 35° C (0.15 vol.%)

Increase in HTO as the temperature increases

- Quasi-linear trend for each current
- The temperature increase in the electrolysis stack leads to an increase in the diffusion rate for the small gas bubbles through the diaphragms
- When the process temperature increases, the thermal energy available in the system also increases and the particles, including the gases, increase their mobility.

HTO in relation with pressure



At 5 bar, the HTO value for 40 A is 0.36 vol.%, whilst for a pressure of 25 bar and the same current level, it is approximately 4.8 times greater, that is 1.72 vol.%

Increase in HTO as the pressure increases

- HTO level increases quasi-proportionally
- The higher is the pressure, the lower is the volume of the gas bubbles generated in the electrolysis
  - ➢ This decrease in the size of the bubbles leads to a greater migration of hydrogen through the electrolyte pathways and diaphragm pores

HTO vs. OTH

- OTH trends with current, temperature and pressure are equivalent to the HTO

- HTO is 10-30 times greater than the OTH (for small size alkaline electrolysers HTO is usually 3-7 times greater than the OTH)
  - the hydrogen molecules, in addition to being lighter than the other elements, are also smaller and therefore have a greater fugacity and diffusivity through the electrolyte pathways and stack cell diaphragms, compared to oxygen.

- The best operating conditions to minimize HTO and OTH are basically those in which the electrolyser is operating at a low pressures and high currents

- The experiments confirm the lower is the pressure level, the lower is the gas impurities

Safety and technical regulations

- All the devices relevant for hydrogen production must to be complied with **ATEX directives**
  - the essential health and safety requirements and conformity assessment procedures, to be applied before products are placed on the EU market
  - covers equipment and protective systems intended for use in potentially explosive atmospheres (mixture of air with dangerous substances in the form of gases, vapor, mist or dust)

- The relevant Standard document is the **ISO 22734** (Hydrogen generators using water electrolysis)
  - defines the construction, safety, and performance requirements of modular or factory-matched hydrogen gas generators, using electrochemical reactions to electrolyze water to produce hydrogen

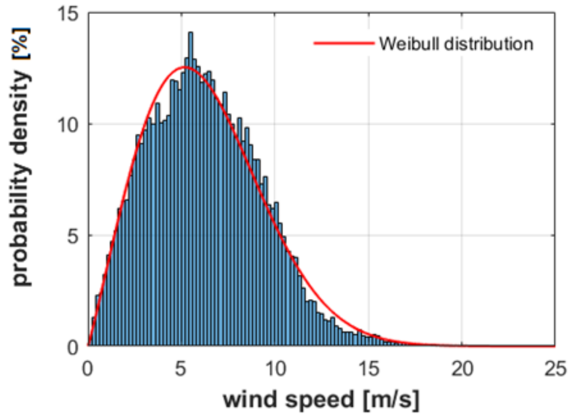
- Fuel Cell and Hydrogen Joint Undertaking (FCH JU), with the support of the European Hydrogen Safety Panel (EHSP), organized a workshop focused on the safety aspects of electrolysis technology
  - A typical cause of fires and explosion in alkaline chlorine electrolysis is the accidental creation and ignition of flammable gaseous mixtures (hydrogen-chlorine, hydrogen-air/oxygen)

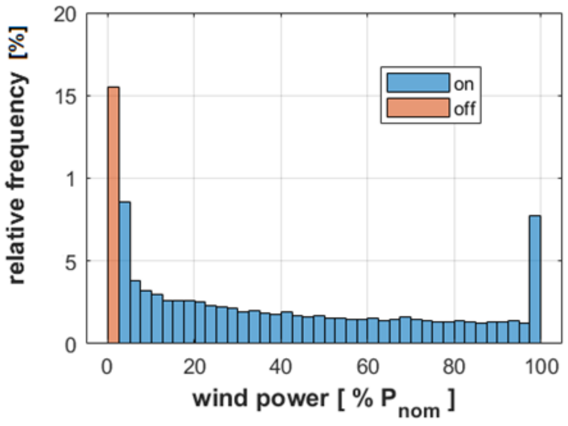
Safety and technical regulations

- In the recent accident (2019) at the alkaline electrolyser in Gangneung, Korea, the introduction of hydrogen into the oxygen stream was not caused by membrane perforation, but gases cross-over under low power operating conditions
  - Such cross-over was not detected and the typical catalytic oxygen removal system was not installed
  - an explosive mixture of hydrogen and oxygen formed in the hydrogen storage containers was ignited by an unknown source

Renewable power data input

- Wind energy input: variable power data (NREL Wind Prospector web site) series reproducing the renewable power must be given as input to the electrolyser

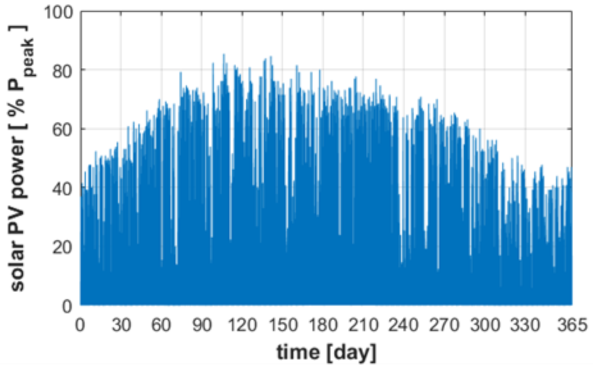


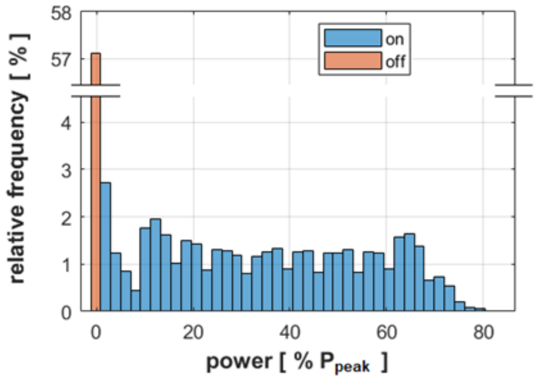


$$P_{wt} = \begin{cases} 0\,, & v_w < v_{ci} \text{ or } v_w < v_{co} \\ (a_1\, {v_w}^3 + a_2\, {v_w}^2 + a_3\, v_w + a_4)\, P_{wt,nom}, & v_{ci} \le v_w \le v_r \\ P_{wt,nom} & v_r \le v_w \le v_{co} \end{cases}$$

$$a_1 = -\,2.715\; 10^{-3}\; (^{m}/_{s})^{-3}, a_2 = 6.138\; 10^{-2}\; (^{m}/_{s})^{-2}, a_3 = -\,0.2950\; (^{m}/_{s})^{-1}, a_4 = 0.4318$$

- PV input: a site located in the New York state (USA) was chosen since it is characterized by seasonal power variability

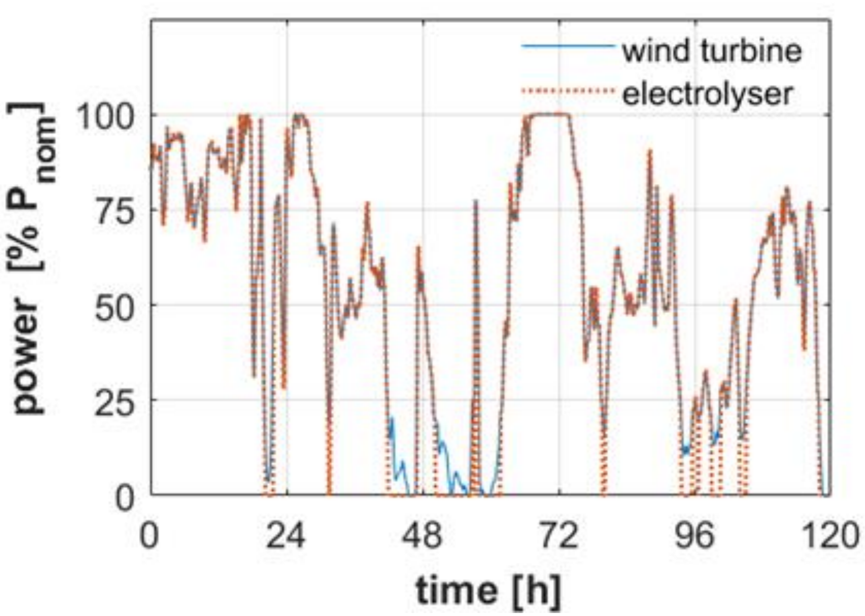


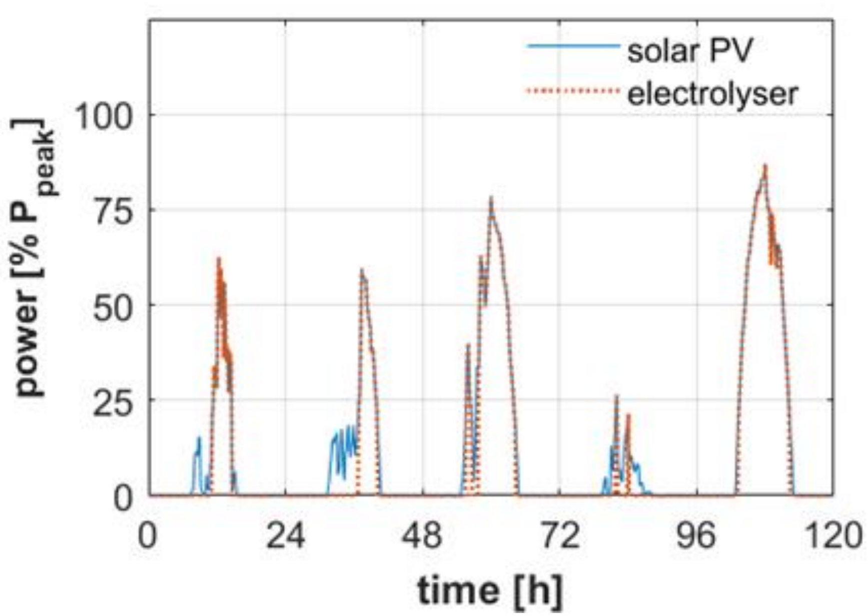


Renewable power data input

- The wind and PV nominal power were set equal to the electrolyser nominal power
- The electrolyser must work in a power range of 20-100% nominal power to avoid safety issues
  - ➢ As a result, two electrolyser annual power input profiles were obtained respectively for the cases of wind and solar PV sources

- The electrolyser power input follows the renewable power when possible and it is characterized by a high variability and frequent on-off





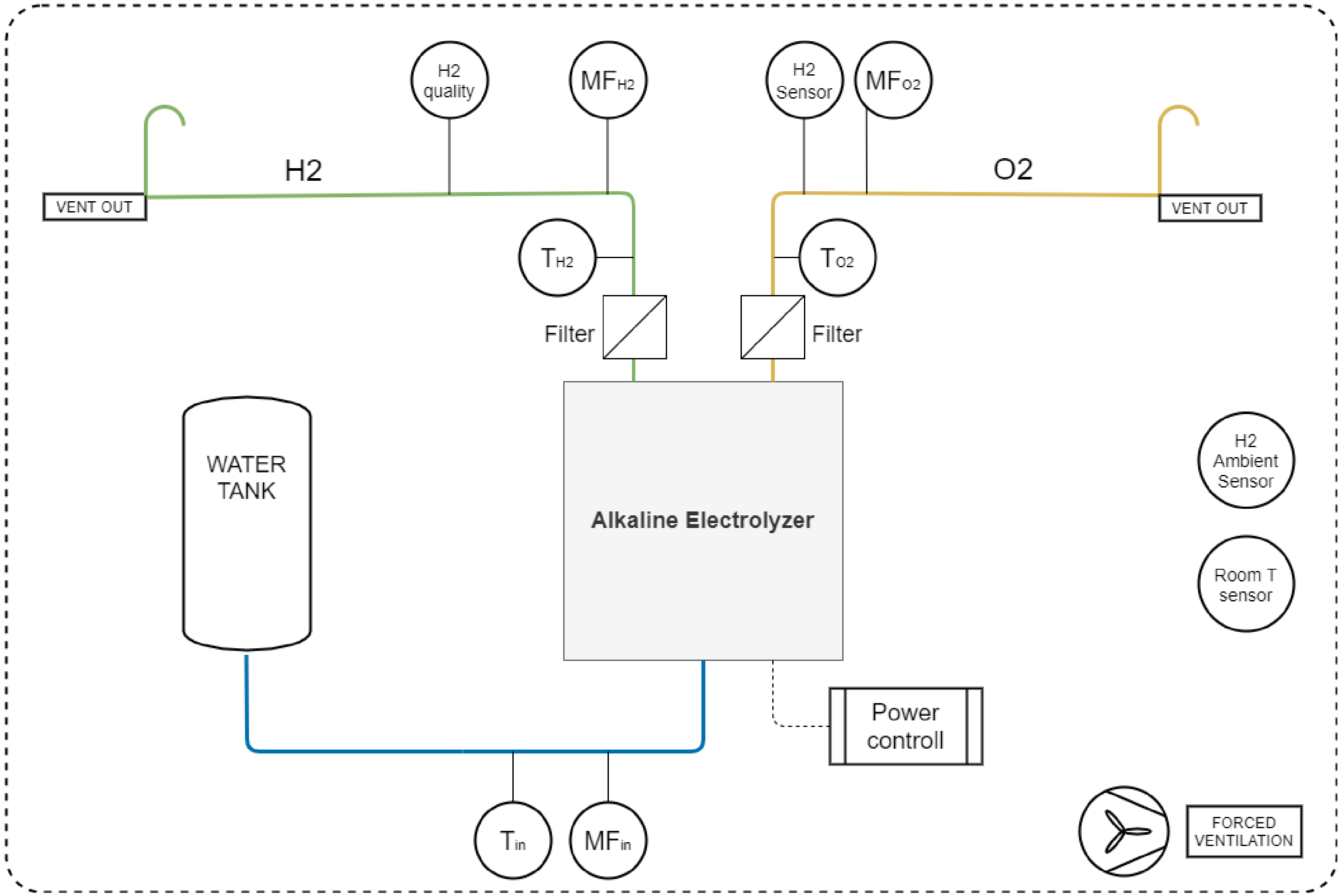
Experimental set-up: hydrogen production

Installed power	35 kW
Hydrogen production rate	4.4 Nm^3/h
Oxygen production rate	2.2 Nm^3/h
Hydrogen delivery pressure	2.0 barg
Hydrogen delivery quality	99.5% ± 0.3% dry basis

McPhy

- ~ 5.3 kWh of electric energy are required per Nm^3 of H2 (including energy losses)
- For safety reason, the unit can produce H2 included in the range 25÷100% of nominal flowrate
- Shutdown procedure when the pressure > 2.5 barg
- Shutdown procedure when the electrolyte (containing H2) temperature = 80 °C
- Two additional pressure swithes to stop the system at very high pressure (i.e. 5 barg)
  - ➢ two safety valves release hydrogen or oxygen to the dedicated vent lines

Laboratory layout



Future experimental activities

- Tests on polarization curve
  - ➢ to determine the change in the stack voltage with the variation in the supplied current under steady-state conditions at constant reference temperature and pressure

- The electrolyser will then be tested:
  - o under dynamic protocols consisting of potential sweeping with different with short holds to simulate alternating power operation
  - o under a variable input power that simulates the renewable power assigned by the power control

- The aim of the tests is to evaluate the effects of the dynamic operation on the hydrogen quality and possible safety issues