UiO : Department of Chemistry
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High Temperature Steam and CO_2 Electrolysis with Proton Conducting Ceramics

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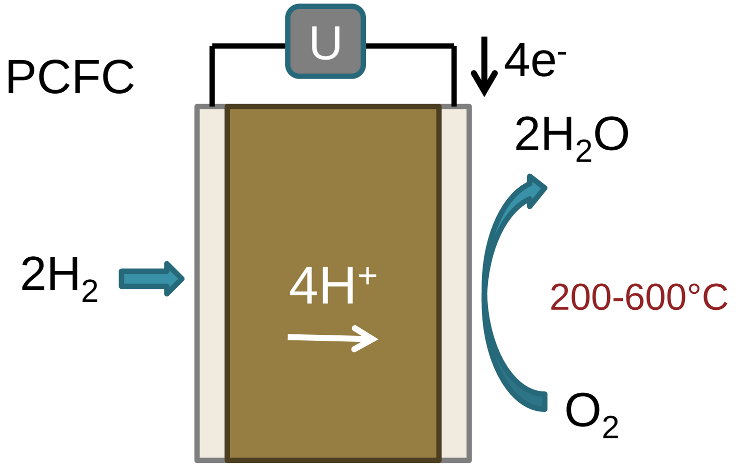
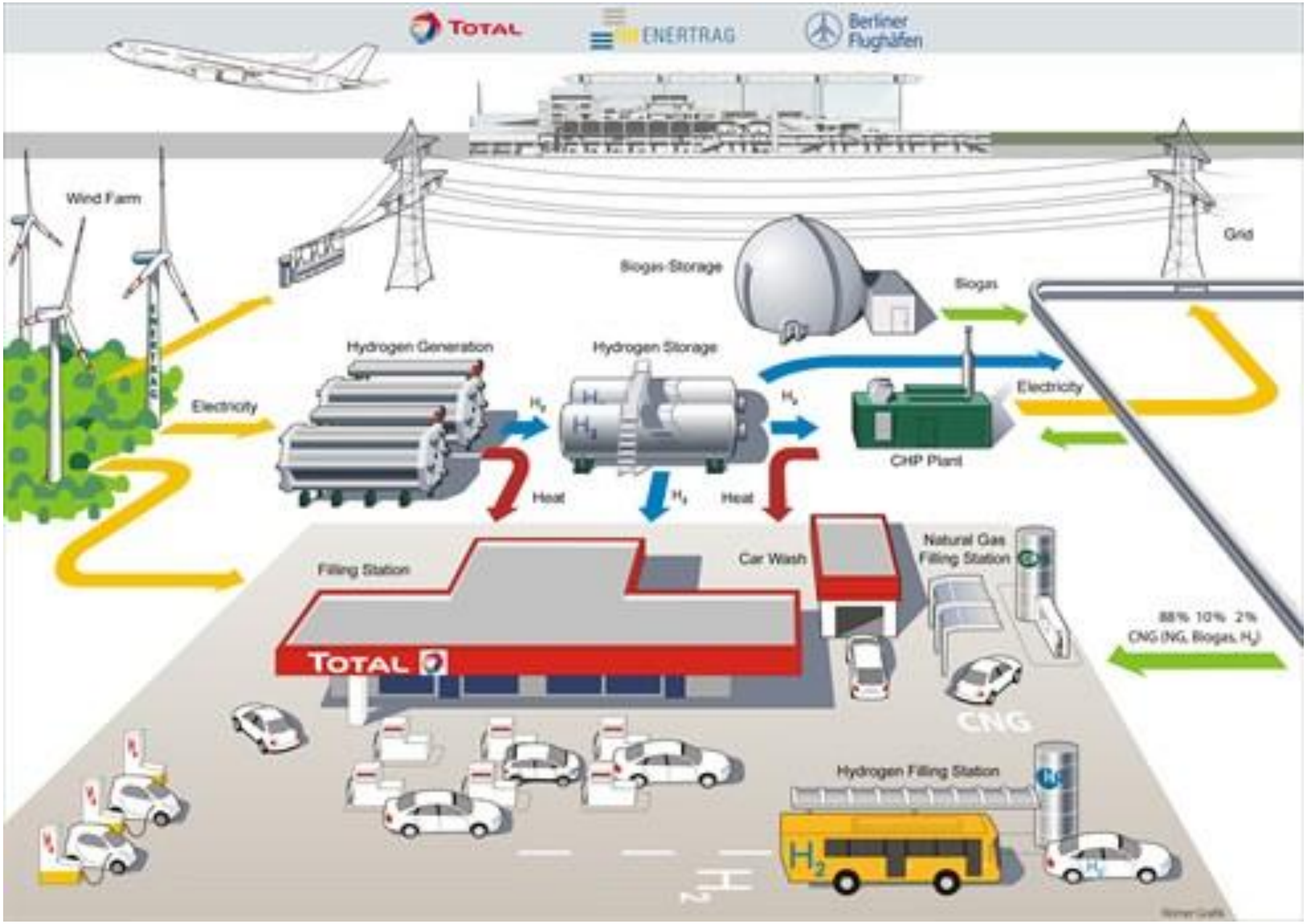


H_2 for grid and transport




FuelCell
FCV-R

Hydrogen H_2

- Energy carrier
- Made from hydrogen rich compound + energy:
  - Reforming+shift from fossil ☹ or bio ☺. They have both H and energy.
    - $CH_4 + 2H_2O = CO_2 + 4H_2$ $C + 2H_2O = CO_2 + 2H_2$
  - Electrolysis (water/steam + electrical energy)
    - $2H_2O(g) = 2H_2 + O_2$

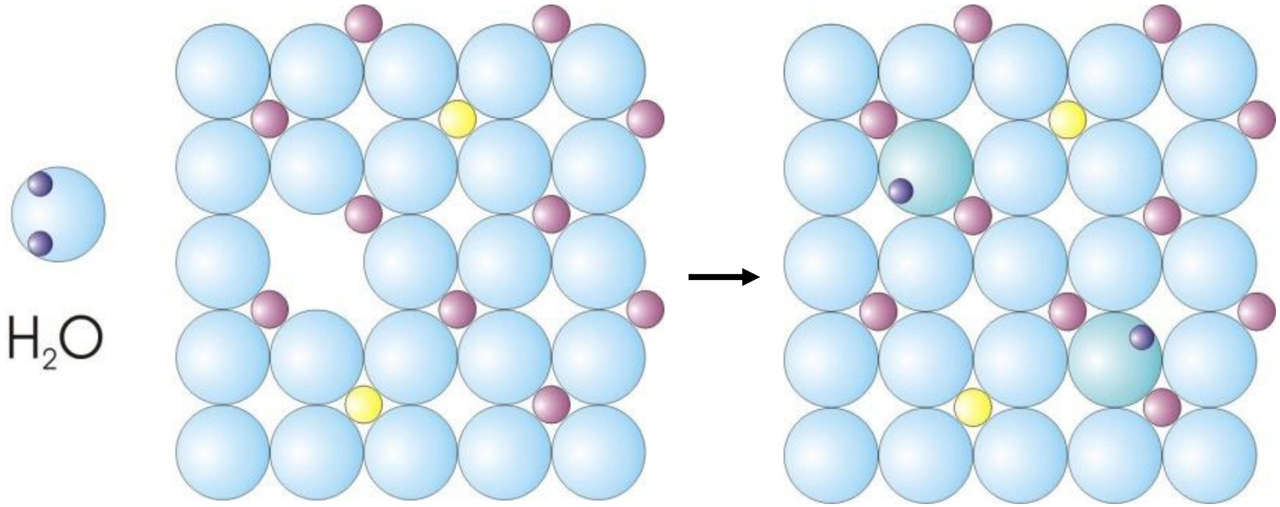
- $H_2O(l) = H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H^0 = +286$ kJ/mol $\Delta G^0 = +237$ kJ/mol
- $H_2O(g) = H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H^0 = +242$ kJ/mol $\Delta G^0 = +229$ kJ/mol

- Beneficial to use steam if heat generation (loss) is moderate

- Steam: Industry. Geothermal, solar, nuclear power.
- Electricity: Peak renewable

Acceptor doped oxides:

- Oxide ion conduction by oxygen vacancies
- Hydration at low *T* and high pH_2O gives proton conduction

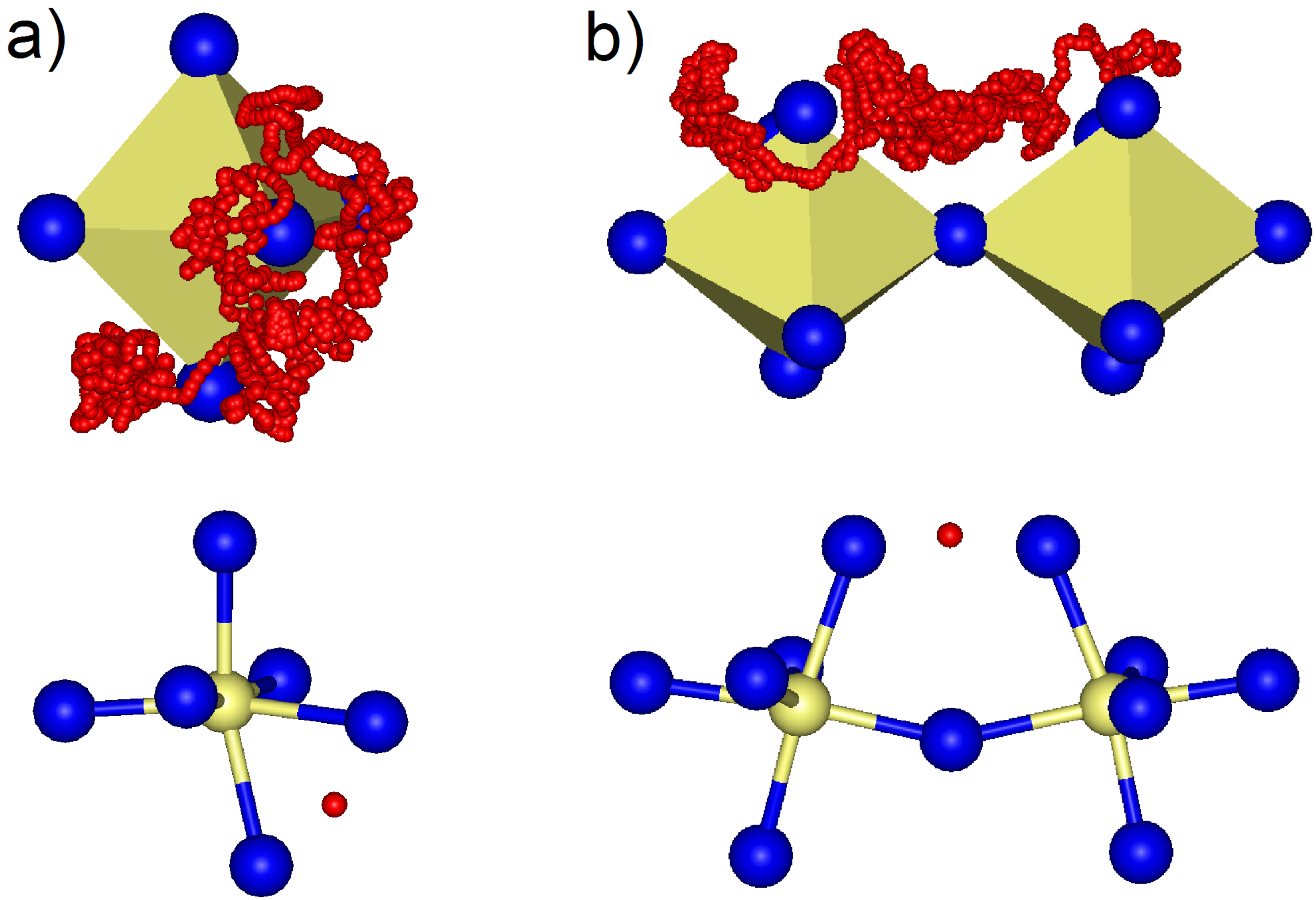


$$H_2O(g) + v_O + O^{2-} = 2OH^-$$

$$H_2O(g) + v_O^{\bullet\bullet} + O_O^x = 2OH_O^{\bullet}$$

Proton migration by rotation and jumps

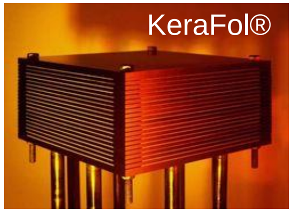
a) Intra- and b) inter-octahedral proton diffusion paths in a perovskite, by MD:



From K.-D. Kreuer, 2008

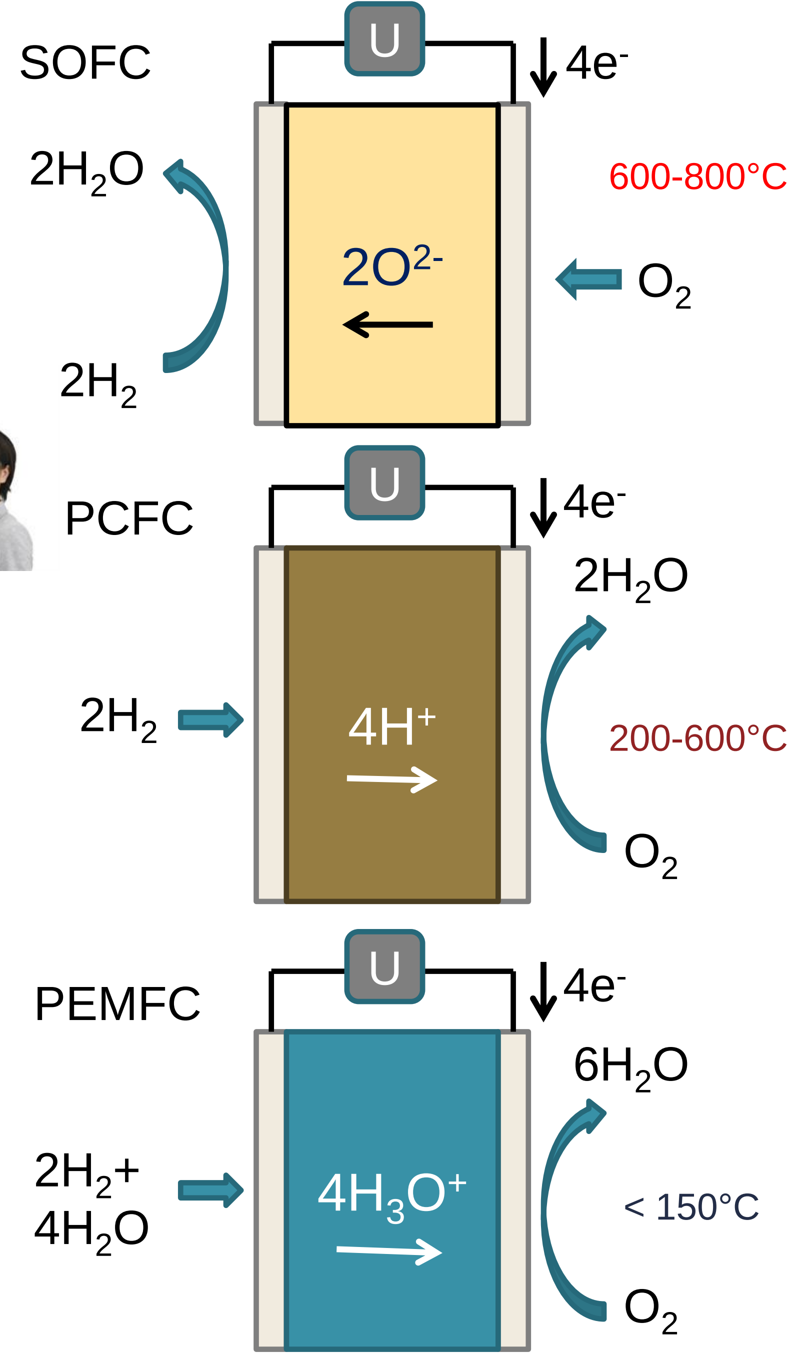
Solid-state fuel cells

- Examples with H_2 as fuel
- SOFC: High T, low fuel utilisation, anode oxidation



- PCFC: Intermediate T, high fuel utilisation, no anode oxidation

- PEMFC: Low T, water management, cooling challenges

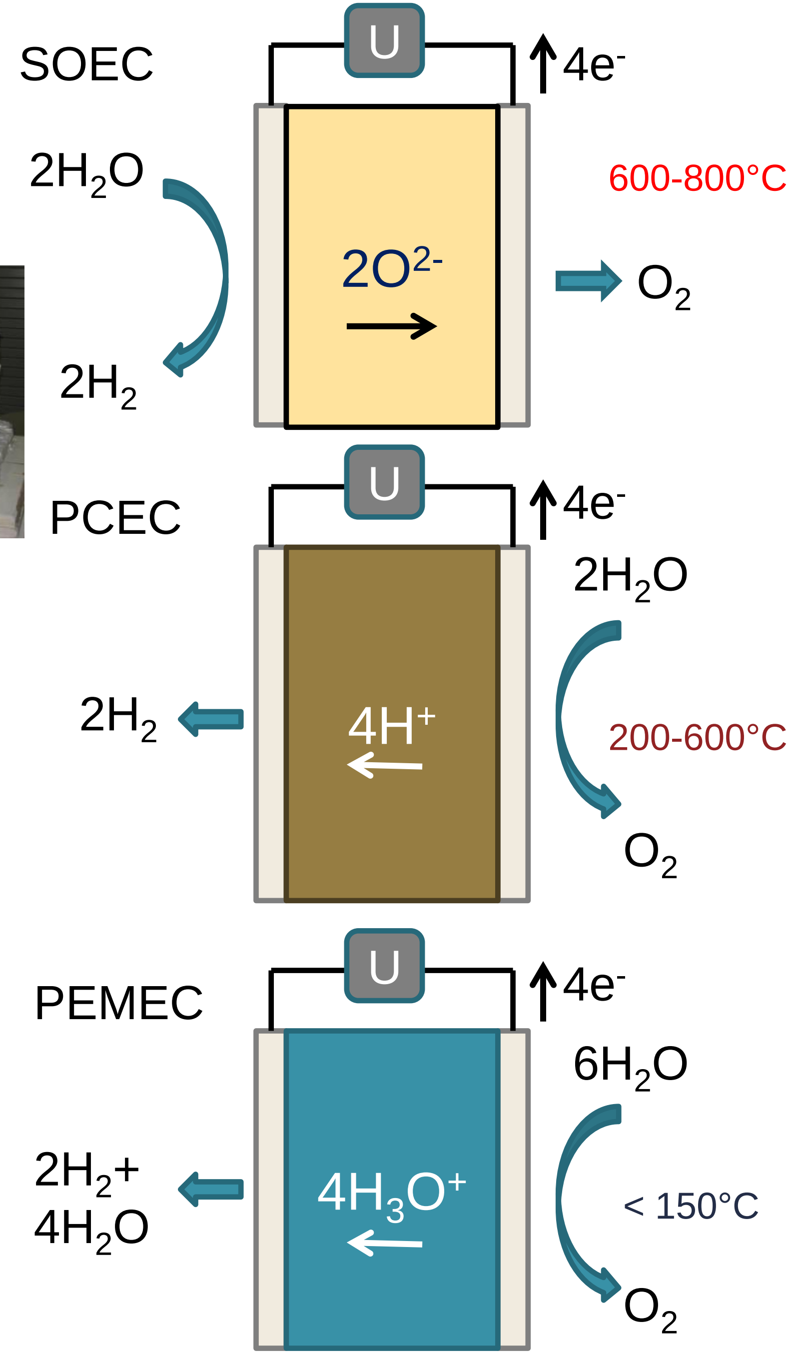


Solid-state electrolyser cells

- SOEC: Utilises steam&heat
- Produces wet H_2

- PCEC: Utilises steam&heat
- Produces dry H_2 directly
  - Metallic H_2 electrode and support not exposed to oxidising conditions
  - Also standalone H_2 compression

- PEMEC: Uses liquid water
- Produces wet H_2



Co-electrolysis; From CO_2 and renewable electricity to liquid fuels

- *Co-electrolysis* of CO_2 and steam to syngas:

  $CO_2 + 2H_2O = CO + 2H_2 + 3/2O_2$

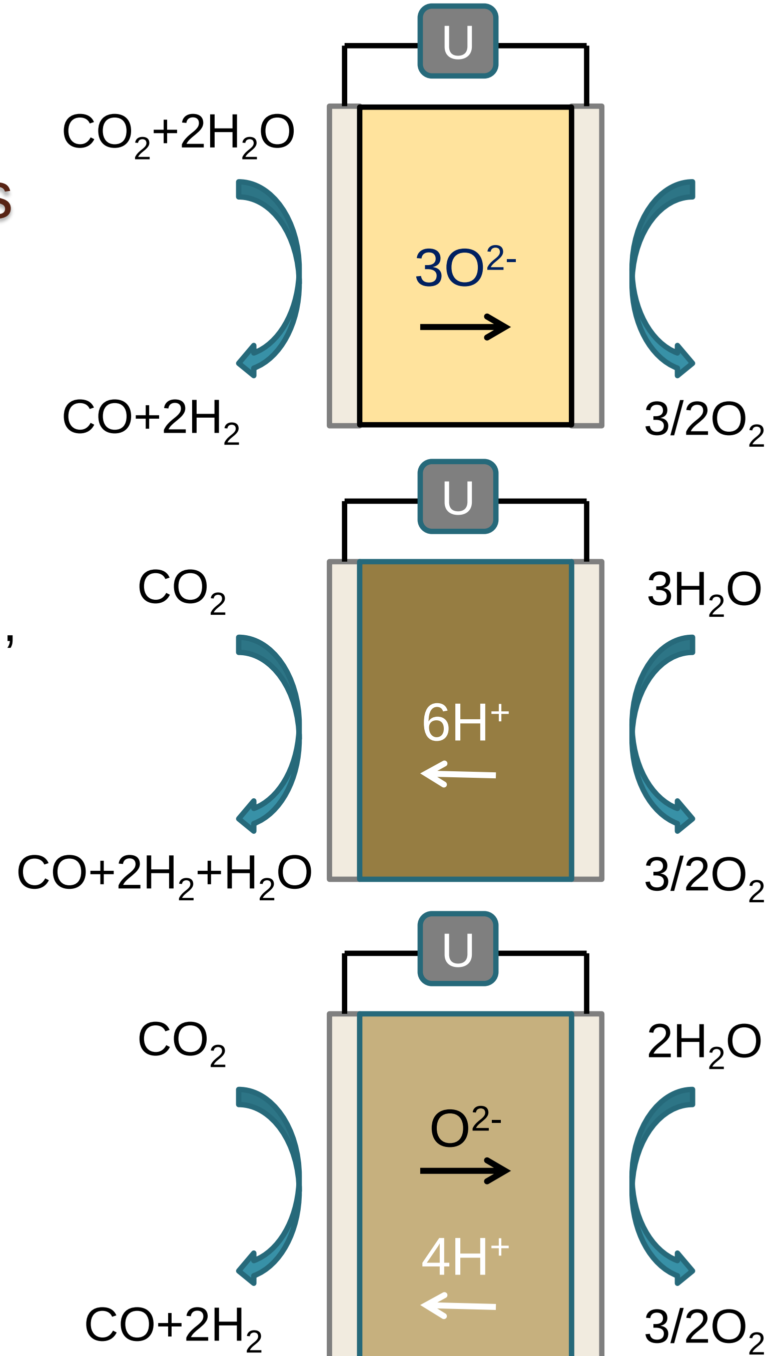
  for further production of liquid fuels, e.g.,

  $CO+2H_2 = CH_3OH$

  $2CO+4H_2 = CH_3OCH_3$ (DME) + H_2O

- Pure H^+ conductor less suitable here

- $H^+ + O^{2-}$ *co-ionic* conductivity is OK and gives new operational possibilities

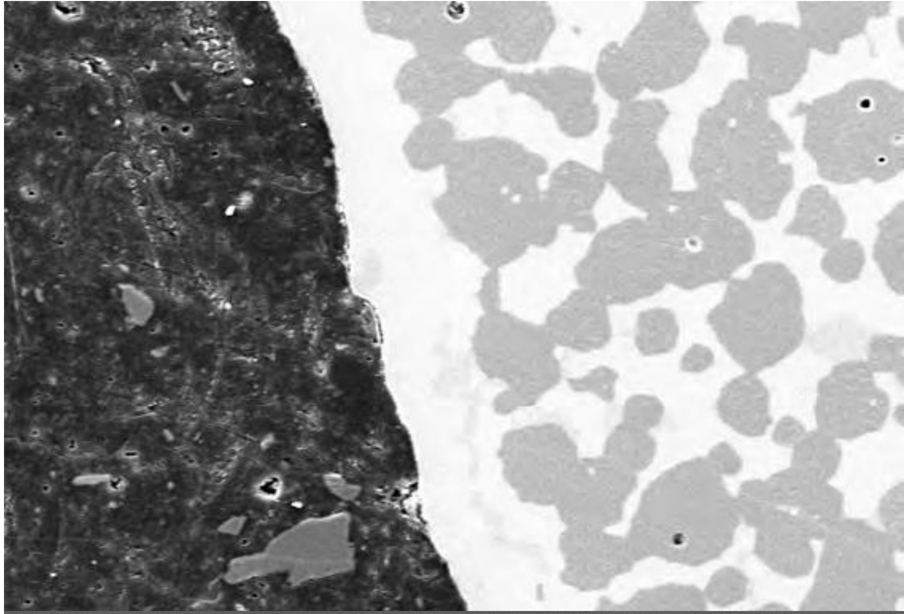


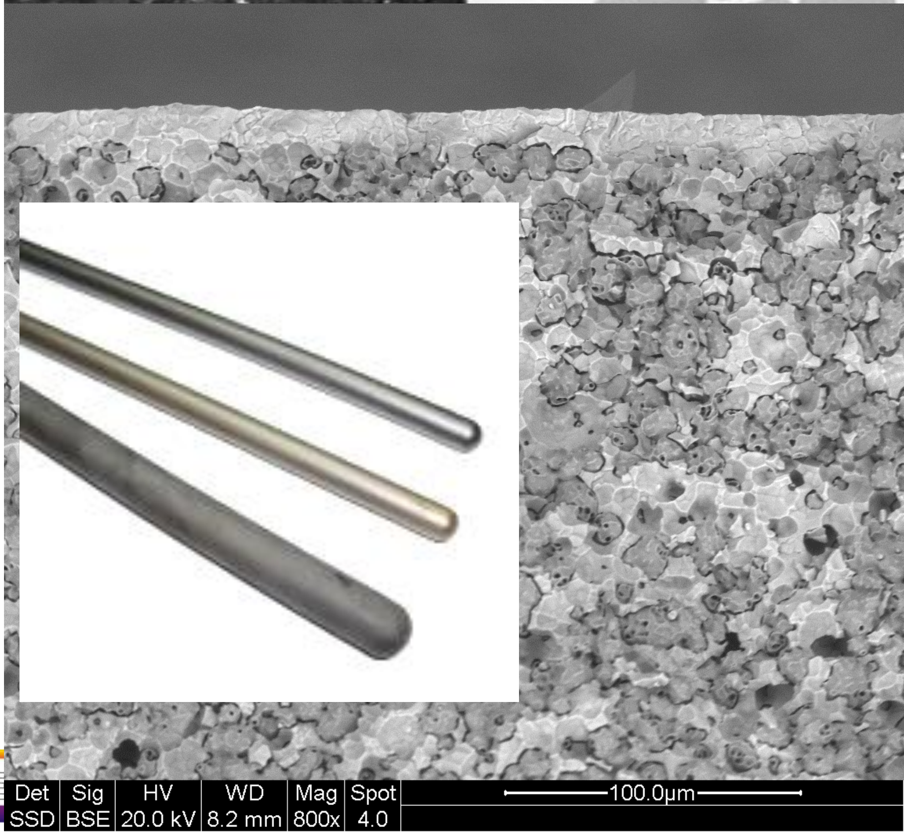
Anode-supported Y-doped $Ba(Zr,Ce)O_3$ (BZCY):

- CoorsTek/Protia:
- Reaction sintering:

  $BaCO_3/BaSO_4 + ZrO_2 + CeO_2 + Y_2O_3$ (+NiO)

- Slip-cast/extrude BZCY-NiO composite
- Spray/dip/spin on BZCY electrolyte precursor
- Co-sinter
- Reduce NiO to Ni in H_2
  - Sufficient porosity for PCFC, PCEC with H_2
- 10 mmØ, 1 mm wall, 20 µm BZCY, 30 cm
- Bubble-free at 2 bar overpr. in isopropanol
- Development of O_2 side electrodes





UiO + SINTEF projects on PCECs

- METALLICA
  - RCN EnergiX
  - Proton Ceramic Electrolyser Cells (PCECs) on metallic supports
  - BZY electrolyte, alloy supported H_2-side electrodes (cathode), PLD…
  - Project leader: Marit Stange (SINTEF)

- Electra
  - EU FCH JU
  - Tubular segmented cermet-supported PCECs
  - 7 partners (3 NO, 1 FR, 2 ES, 1 IC)
  - Project coordinator: Truls Norby (UiO)

- Fundamental supporting projects; FOXCET, …

Conclusions; PCECs

- Production of H_2 from renewables
- Grid balance and transport
- Utilise steam in SOECs and PCECs
- PCECs produce dry H_2 directly
- PCECs can do electrochemical compression of H_2 directly
- Co-electrolysis of CO_2 by co-ionic electrolytes
- Perovskite proton conducting ceramics, BZCY
- Challenges: Moderate proton conductivities, chemical expansion, sintering
- Develop oxygen-side electrodes