Solid Oxide Electrolysis
Overview of the technology and current developments at CEA

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Outline

- French National context
- H₂ production with low carbon footprint: interest of SOEL
- Current status and main challenges
- CEA activities and achievements
- Conclusion
- Acknowledgements
French national context: raise of hydrogen for energy transition

- **2016**: First public initiative for « hydrogen territories »
- **2018**: Governmental initiative for Hydrogen deployment
- **2019**: Pluriannual energy programmation and Energy-Climate law
- **2020**: Implementation aligned with EU Green Deal

**Quantified targets for clean H₂ in**

- **Industry**
- **Transportation**
- **Grid stability**

**Law, financial incentives defined to foster clean H₂ in**

- **Industry**
- **Transportation**

**QUANTIFIED TARGETS**

- **INDUSTRY**
  - Electrolysis capacity: 700 MW
  - Deployment will be based on overall CO₂ emissions and costs

- **TRANSPORTATION**
  - Refueling stations: ~100 in 2023, ~850 in 2028

RD20 - 1 October 2020 - Julie Mougin, CEA
Hydrogen production with low carbon footprint: interest of Solid Oxide Electrolysis (SOEL)

**HIGH EFFICIENCY TECHNOLOGY**

\[ \Delta H = \Delta G + T \Delta S \sim \text{constant} \]

\[ \text{H}_2\text{O} (g) \rightarrow \text{H}_2 (g) + \frac{1}{2} \text{O}_2 (g) \]

To electrolyse a water molecule the reaction overall energy \( \Delta H \) has to be provided either as electric energy or as heat.

- \( \Delta G \) is the minimum part of electric energy required for the electrolysis reaction, the rest can be provided as heat.
- The hotter the electrolysis operation, the lower the electricity demand:
  - High T: energy = 70% electricity, 30% heat
  - Low T: energy = 85% electricity / 15% heat
- Main advantage of SOEL with T range = 700-850°C

**FLEXIBILITY OF USE**

Same core technology for several applications:

- Hydrogen production
- Electricity production
- Fuel cell Module (SOFC)
- Reversible Module (rSOC)
- Co-electrolysis Module (co-SOEL)
- Co-electrolysis \( \text{CO}_2/\text{H}_2\text{O} \)
- Production of synthetic fuels Power to X
- Feedstack for industry, fuel for mobility, energy storage
- Stationary CHP Heat and power
- SOEL/SOFC reversible
- Renewable energies storage
- Feedstack for industry, fuel for mobility, energy storage
Current status of Solid Oxide Electrolysis (SOEL) and main challenges

Technology with no expensive noble catalysts

Modular technology

**Electrolysis cell** composed of:
- 2 electrodes (anode and cathode)
- One electrolyte
- Need of electricity (and heat)

**Stacking** of several electrolysis cells to increase the power

Integration of stacks into a **module** including 1st level Balance of Plant components
Can/will include several stacks into a module

Integration of modules into an **electrolysis system/plant** including all Balance of Plant components = electrolyser
Can/will include several modules into the electrolysis system/plant

Electrolyte (YSZ)
Electrode H₂ (Ni-YSZ)
Electrode O₂ (LSM-YSZ)
Current status of Solid Oxide Electrolysis (SOEL) and main challenges

**MAIN SYSTEMS IN OPERATION**

- **2014**
  1er SOEL system in operation at CEA
  - 1 stack – 1 Nm³/h of H₂ produced à 700°C
  - Efficiency measured 99%HHV

- **2017**
  Sunfire Grinhy system installed in a steelmaking plant in Germany
  - 150 kW - 40 Nm³/h of H₂

- **2018**
  1er rSOC system delivered to a customer (Sylfen-CEA)

- **2020**
  720 kW SOEL installed in August 2020 on the steel plant (Grinhy 2.0)
  - Will produce 100t of H₂ until end of 2022

- **2021**
  Multimodule rSOC to be installed in Italy
  - 16 Nm³/h H₂ produced in SOEL mode
  - 15 kWe in fuel cell mode

- **2022**
  Installation of a 2.6 MW SOEL unit in a biorefinery in Rotterdam (MULTIPLHY project)
Current status of Solid Oxide Electrolysis (SOEL) and main challenges

**STATUS**

**Cells and Stacks**
- High performances: current density of 0.6 A/cm² and above at the thermoneutral voltage (1.3V)
- Durability: degradation < 2%/1000h

**Modules and Systems**
- First demonstration systems installed
- Upscaling and in-field deployment for various use cases

### Ambitious improvement of key parameters

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<th>No</th>
<th>Parameter</th>
<th>Unit</th>
<th>SoA</th>
<th>2020</th>
<th>2024</th>
<th>2027</th>
<th>2030</th>
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<td>Electricity consumption @ nominal capacity</td>
<td>kWh/kg</td>
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<td>Heat demand @ nominal capacity</td>
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<td>Capital cost</td>
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<td>(€/kW)</td>
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<td>O&amp;M cost</td>
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<td>Footprint</td>
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<td>Degradation @ U_{IN}</td>
<td>%/1,000hrs</td>
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<td>Current density</td>
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<td>9</td>
<td>Use of critical raw materials as catalysts</td>
<td>mg/W</td>
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<td>10</td>
<td>Roundtrip electrical efficiency</td>
<td>%</td>
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<tr>
<td>11</td>
<td>Reversible capacity</td>
<td>%</td>
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Source: Strategic Research and Innovation Agenda, Final Draft, Hydrogen Europe, 07/2020
Cell optimization to reach the best combination of performance/durability with an approach combining

On the whole value chain, from cell to system through stack and module; for different usages & operating modes

**High performance cell:**
- ~ + 15% of i at 1.3V as compared to SoA cell
- Understanding of phenomena responsible of degradation

**Source:** Monaco et al., J. Electrochem. Soc. 166 (15), (2019) F1229-F1242
Thermal integration at the SOEL system scale

- No need of high temperature heat source to reach high efficiency
- A heat source at 150°C to generate steam is sufficient
- High efficiency measured in SOEL mode thanks to:
  - Highly efficient heat exchangers
  - Operating point slightly exothermic

J. Mougin, 12th European SOFC&SOE Forum 5-8 July 2016, Luzern, A0605 (2016)
High pressure SOEL operation

- up to 30 bar in the lab at cell level
- Pressurized operation allows to:
  - reach higher current densities and steam conversion
  - Shift limiting current to higher current densities
  - Most important impact between 1 and 6 bar

Direct consequence on efficiency:

- Double benefit:
  - Cell/stack level: performance
  - System benefit:
    - One $\text{H}_2$ compression step avoided
    - Higher steam conversion

*L. Bernadet, et al., Electrochimica Acta 253 (2017)*
Co-electrolysis operation at system level

- From H₂O + CO₂, production of syngas (H₂+CO)
- Performances close to those measured in pure SOEL

Syngas composition can be tuned to fit with downstream chemical synthesis process
- P2X: synthesis of CH₄, methanol, DME, ...

M. Reytier, et al., IJHE 40/35 (2015) 11370–11377

rSOC operation at system level

- 3 operating modes: SOEL, SOFC-H₂, SOFC-CH₄
- 9 operating points defined + a standby point
- Evaluation of the transition times

Quick transitions
- in less than 10 min

HIGH TEMPERATURE ELECTROLYSIS (SOEL): TECHNOLOGY WITH MANY ASSETS

- High efficiency technology, with potential for excellent level of performance
- High flexibility technology: co-electrolysis, reversible operation
  - which opens up additional applications to pure production of H₂ such as P2X and renewable energy storage
- High adaptability technology with appropriate BOP & management strategies:
  - No need for a high T heat source
  - Ability to operate with intermittent energy sources, and under pressure 10-30 bar
- Potential to be a "game changer" to produce low cost H₂:
  - ~ 2 € / kg or even less for large units ~ 100 MW
  - ~ 7 € / kg for small decentralized units ~ 100 kW
- Less mature than low-T technologies, but demonstrators now out of the laboratory worldwide, and power growing exponentially
- Technology transfer of CEA stack technology in progress

FRENCH ROADMAP

- 300 kW in 2022
- 2 MW in 2024
- ~100 MW in 2027 and beyond
ACKNOWLEDGMENTS

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Europe H2020 – FCH-JU (Sophia, Eco, REFLEX, Balance, NewSOC projects)

National Research Agency – ANR (Django and Ecoreve projects)

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Thank you for your attention

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