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ACCELERATING INDUSTRIAL ELECTRIFICATION

# SOLID OXIDE ELECTROLYZER DEVELOPMENT AT TNO FEEDSTOCK

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## CONTEXT & TRL LEVEL

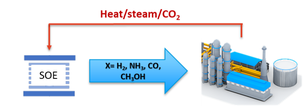
Solid Oxide Cell (SOC) electrolysis will play an important role in the electrification of the chemicals, and fuel industry, contributing to the reduction of their reliance on fossil fuel feedstocks. The integration of high temperature steam and $CO_2$-electrolyzers in industrial processes with readily available waste heat and renewable electricity allows for highly efficient green hydrogen production and methods for $CO_2$ utilization. The latest developments in SOC electrolyzer systems reach a TRL 6 with the current development of 1-2MW scale systems integrated in industrial sites. However, remaining technological challenges remain at lower TRL (2-5) to improve stack and system cost, lifetime, scale up toward 100MW and pressurized operations for industrial integration.

The ambition of TNO is to develop the next generation SOC electrolyzer technology that can provide high performance and low-cost technological options, with the focus on 1) high temperature $CO_2$-electrolysis and co-electrolysis of steam and $CO_2$ for industrial $CO_2$-re-use processes for the generation of green fuels and chemicals and 2) large scale high temperature steam electrolysis for hydrogen generation in existing industrial infrastructure, like refineries or ammonia plants. TNO aims is his SOC technology development program is to assist the whole value chain, from cell manufacturing to end-users, by making the technology economically viable. In line with this ambition, the SOC technology R&D activities concentrate on cell and stack technology development and techno-economic and business case studies on SOC technology integration in the industrial environment. Within 5 years from today, TNO aims with its collaboration with technology supply chain partners and end-users of the SOC electrolyzer technology, to deliver pilot installations integrated at industrial production sites at higher power capacity (multi MW-scale).

## OBJECTIVES

- Reduce of CAPEX cost of the SOC-electrolyzer system to < 500 €/kW (< 150 €/kW for SOE-stack) and OPEX cost (< 2 €/kg $H_2$-equivalent).
- Robustness of operation of SOC-electrolyzer stacks.
  - Sufficient operating life-time (> 60,000 hours)
  - Improved compatibility of stack and balance-of-plant operations
  - Robustness under contaminations and carbon formation resistant
- Upscaling of SOE technology on cell, stack and system levels towards multi-MW systems.
- Stack/system operations under pressurized conditions (> 3-10 bars).
- Pilot integration for applications for hydrogen, syngas, carbon monoxide and chemicals (ammonia, methanol) production.
- Sustainability of the supply chain of SOE.
  - Reduction of critical raw materials
  - Mass manufacturing process

SOE Integration in industry P2X




**KPI'S SOE FOR INDUSTRIAL IMPLEMENTATION**

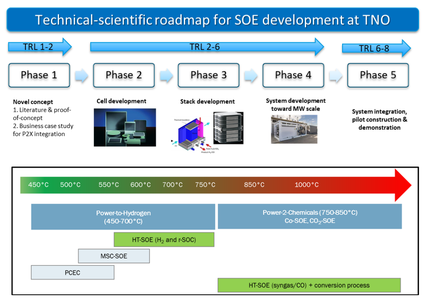
*Clean Hydrogen Joint Undertaking, SRIA, 2021-2027*

- System/stack cost< 500/150 €/kW
- Current density: ≈ 1.5 A/cm²
- Lifetime: > 60,000 hours
- Technology scale-up > 100 MW
- Match pressurized conditions of P2X processes (70-200 bars)

**APPLICATIONS**

- Fertilizer plants
- Refineries
- Energy Storage
- Steel (DRI)
- Methanol
- Fuel Plants
- Waste-2-Chemicals

Technical-scientific roadmap for SOE development at TNO




## OPPORTUNITIES

- Scale-up SOE cell and stack design and manufacturing expertise for planar SOC up to 30x30 cm (800 cm² active area).
- Electrochemical characterization on single cell and stack level (up to 3.5 kW) under steam, $CO_2$ and co-electrolysis for hydrogen, CO and syngas production.
- System design and business cases for the generation of green hydrogen, syngas, carbon monoxide and chemicals (ammonia, methanol).

## CHALLENGES

- Improve efficiency, robustness, cost and sustainability of SOE cell and stack components (e.g. electrodes, cell design, IC coatings, etc) for a viable integration of industrial scale steam, $CO_2$ and co-electrolysis technology.
- Development of a novel pressurized-stack technology (without pressure vessel) for integration on P2X processes.
- Scale-up of stack technology toward multi-KW scale and pilot integration.

## ROADMAP TOWARDS 2030

2024: High efficient, robust and scale-up cell technology
2026: Proof-of-concept pressurized-stack
2027: Scale-up stack design with 800 cm² active area
2028 : Pilot installation integrated at industrial site
2030: Demonstration of industrial waste steam, heat and $CO_2$ valorization to chemicals

## INFRASTRUCTURE/PARTNERS

The R&D activities are performed in a newly created open innovation lab, called the Faraday Lab, including SOC manufacturing and testing facilities. The SOC manufacturing line is based on low-cost tape casting and screen-printing manufacturing techniques. The electrochemical testing facilities include multiple test stations for single cell testing from button cell to potentially 30x30 cm² cell area and short stack testing up to 10 kW.

Solid Oxide Cell manufacturing facilities

Solid Oxide Electrolysis testing facilities (cells/stack)

## RESULTS / PROJECTS

TNO is involved and coordinates multiple subsidies projects with a large range of international partners involved in the development of the SOE technology (academic institutes, system suppliers and end-users).

| NEWSOC | HERSO | Nextlevel SOE | ECCM Kickstart | OUTFOX | PressHyous | NXTGEN – High Tech |
|---|---|---|---|---|---|---|
| FCHJU project *2019-2023* Joint effort of 15 EU partners to develop the next generation of SOC unit and stack (TRL2-4) TNO contribution: **CRM reduction & performance improvement** with a novel Co-free air electrode design | TKI gas *2021-2023* Cost reduction of stack and system to accelerate SOE technology integration in the industry - Cell and stack development for **pressurized operation** up to 10 bar (TNO) - Simplified Balance-of-Plant and TEA (Hygear) | TKI Electricity *2022-2023* **Feasibility study** on the integration of SOE systems in large industries: - **$H_2$ production** in ammonia plant at OCI - **Syngas ($H_2$/CO) and green $H_2$** integrated with blue $H_2$ and downstream e-fuels at BP; - **Carbon monoxide (CO)** production at Air Liquide | NWO *2022-2023* Exploring scale-up of cell size via **modeling activities** (UT, KIT) & **electrochemical validation** on multiple scale (TNO) Project supported by Shell (end user) and Sunfire (system developer) | Hydrogen Europe *2023-2027* **Scale-up of SOE stack** for green $H_2$ production - **Scale-up cell (TNO)** and stack technology for the development of 80kW module - Prototype testing on-industrial site (Shell) Collaboration between TNO (coordinator), VTT OY, politecnico di Milano, Fondazione politecnico di Milano, Elcogen, Elcogen OY, Convion OY, Shell | Hydrogen Europe *2023-2026* Development of **pressurized SOE stacks** - 20kW SOE stack with pressure vessel (30 bar) - **Proof-of-concept P-stack (TNO)** with differential pressure between air and fuel side (10 bar) Collaboration between CEA(coordinator), TNO, VTT OY, EPFL, Elcogen, Genvia, Hygear | RVO project *2023-2028* Development of the **next generation of electrolyzer technology** - Novel components development - Novel manufacturing process & technology - **Validation of novel SOE concept at (TNO)** Collaboration between TNO (Petten & Holst), Admatec, Delft IMP, SparkNano en VSParticle, Bosch, Demcon, Magneto, VDL, TUD, TU/e, UT |

In the last 4.5 years, milestones in the development of SOE technology has been achieved at TNO

- HT-SOE cells operating at 1.9 A/cm² at Thermal neutral electrolysis voltage (1.3V).
- Lifetime time testing up to 2300h, with a degradation rate < 30 mV/kh.
- Scale-up of the SOE cell and stack design with 800 cm² cell area.