SHARED LEARNINGS FOR ACHIEVING HIGH-VOLUME HTE MANUFACTURING

TOPSOE

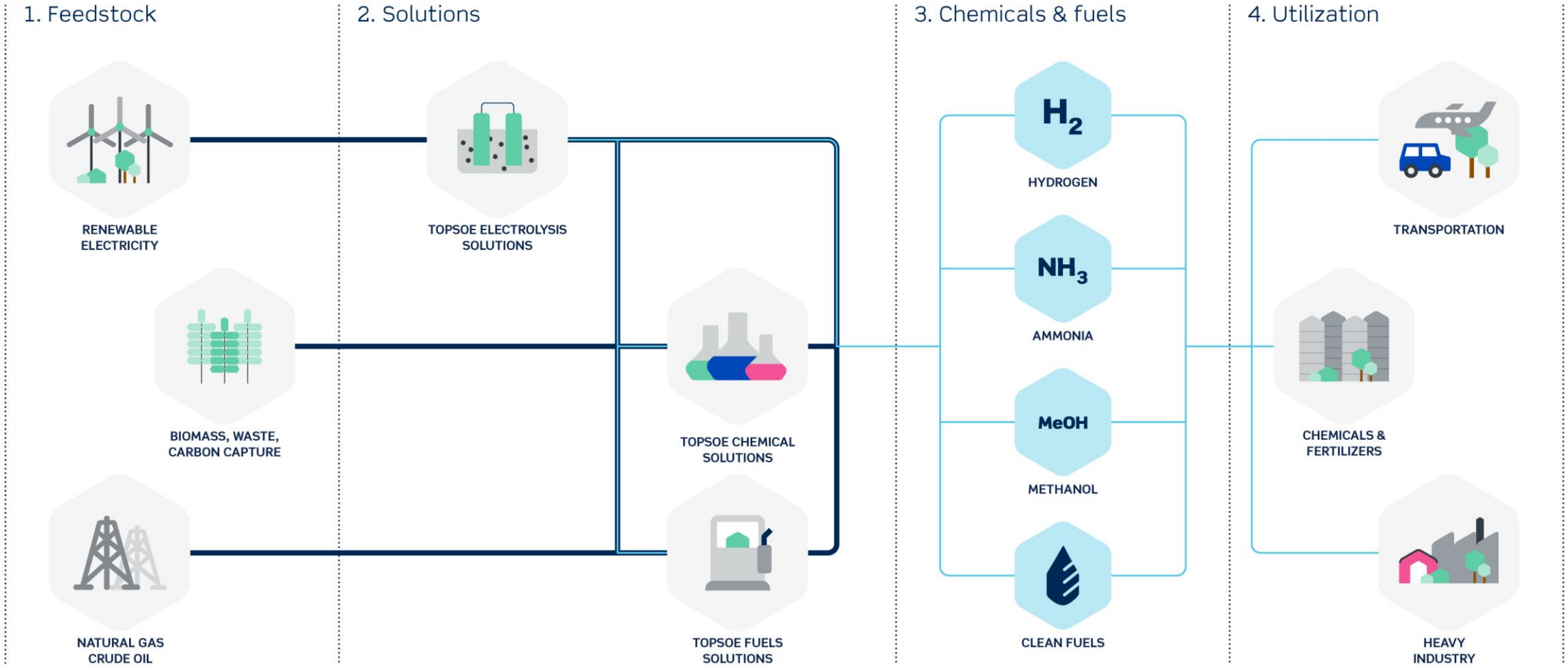
Head of Technology Development

Poul Georg Moses

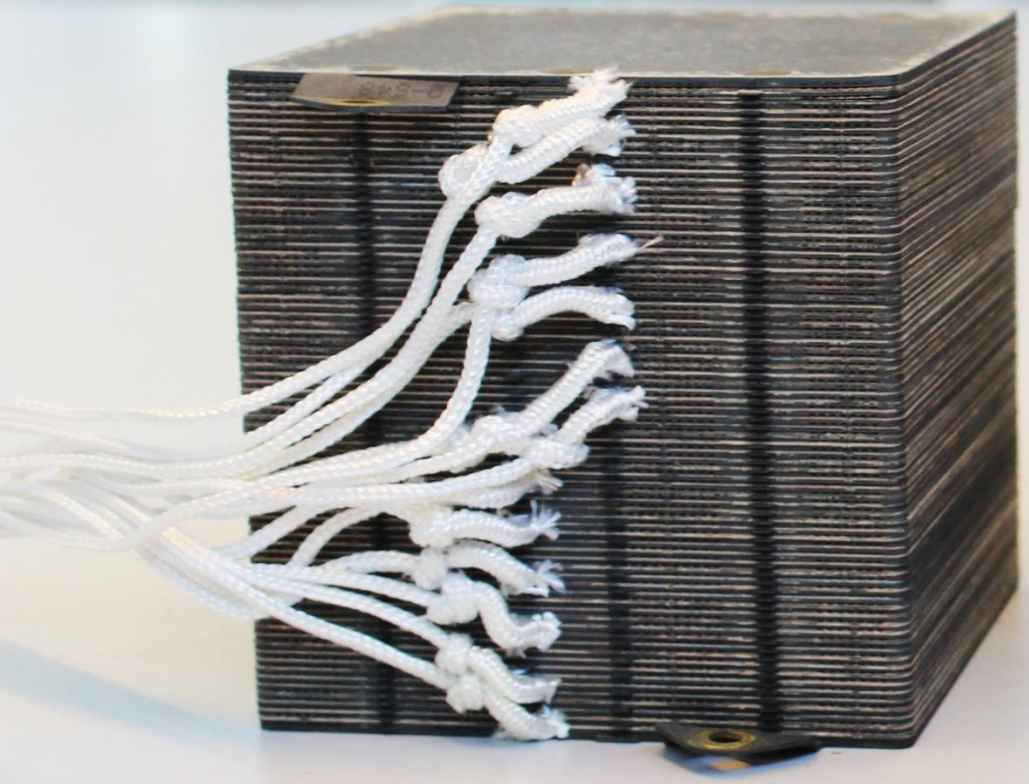
Story line

- Learnings from Pilot production of TSP-1 and eCOs business
- Going from small scale gas supply to Power 2 X
- SOEC for Power 2 X

Topsoe solutions accelerate the energy transition



Topsoe Stack Platform (TSP-1)

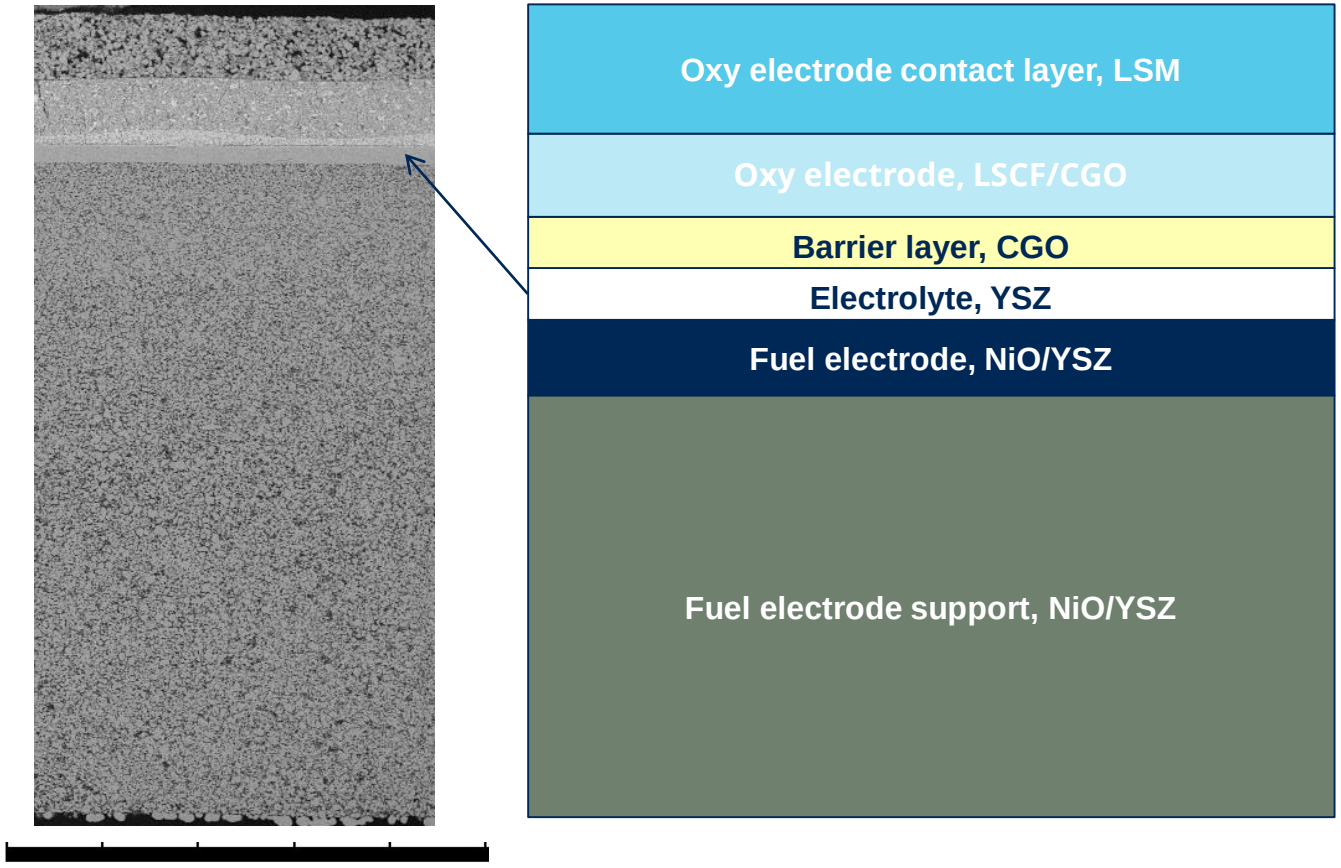


Internal fuel manifold
External air manifold
Compression free handling (cold)

Compact and robust casing

Composition of the Solid Oxide Cell in TSP-1

“Standard” configuration

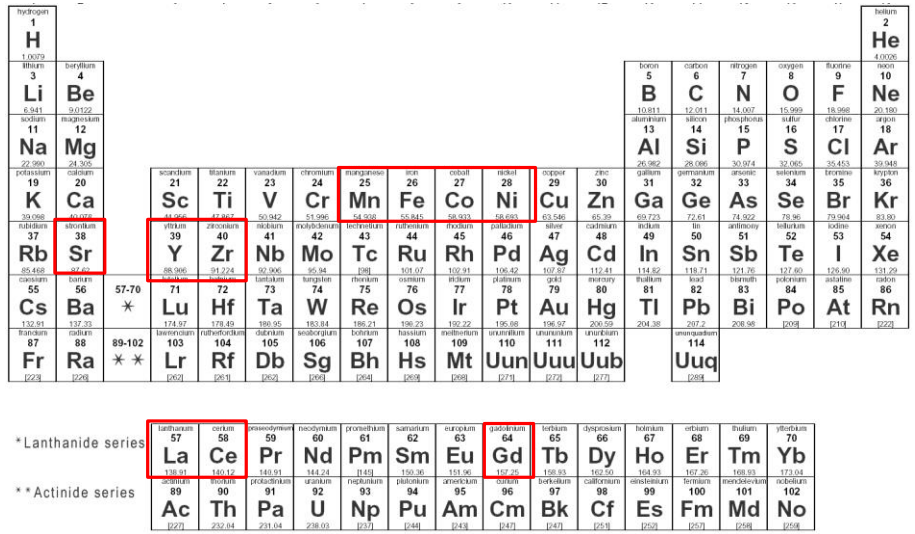


Abbreviations

- NiO = nickel oxide
- YSZ = yttria-stabilized zirconia, mixture of Y_2O_3 & ZrO_2
- CGO = gadolinia-doped ceria, mixture of Gd_2O_3 & CeO_2
- LSCF = lanthanum strontium cobaltite ferrite,

  $La_{1-x}Sr_xCo_yFe_{1-y}O_3$
- LSM = lanthanum strontium manganite,

  $La_{1-x}Sr_xMnO_3$



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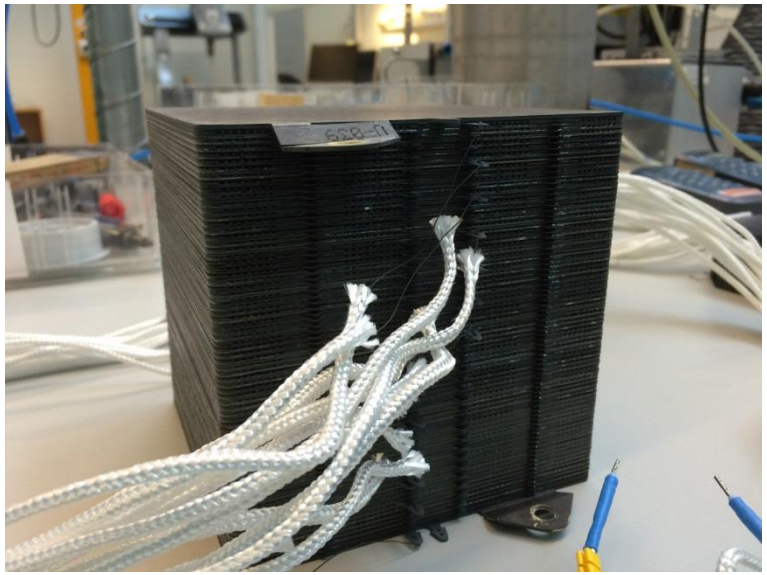
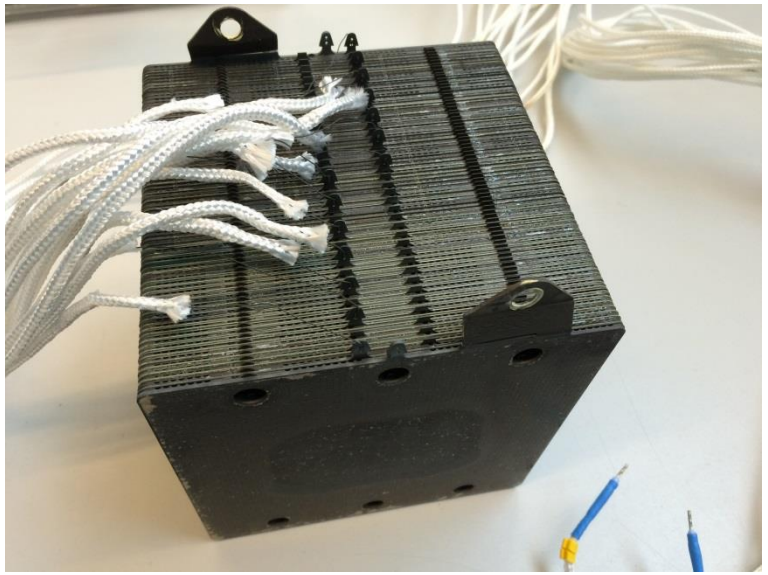
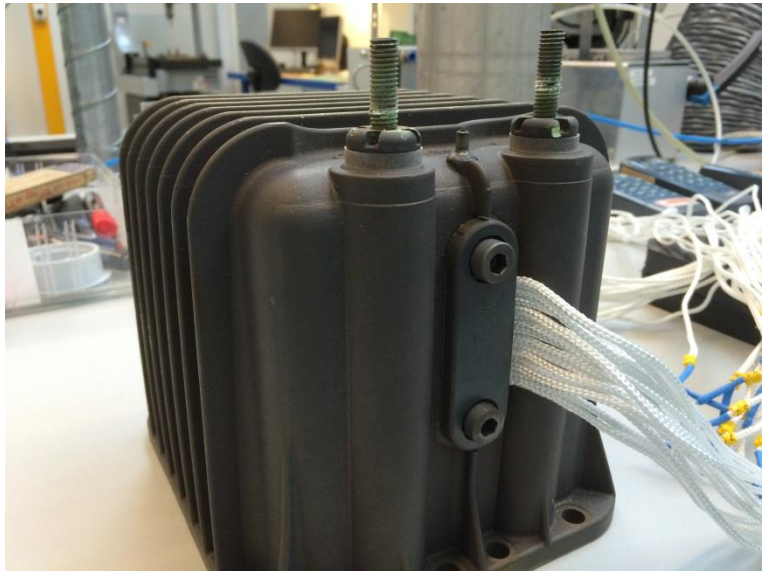
Topsoe Stack Platform (TSP-1)

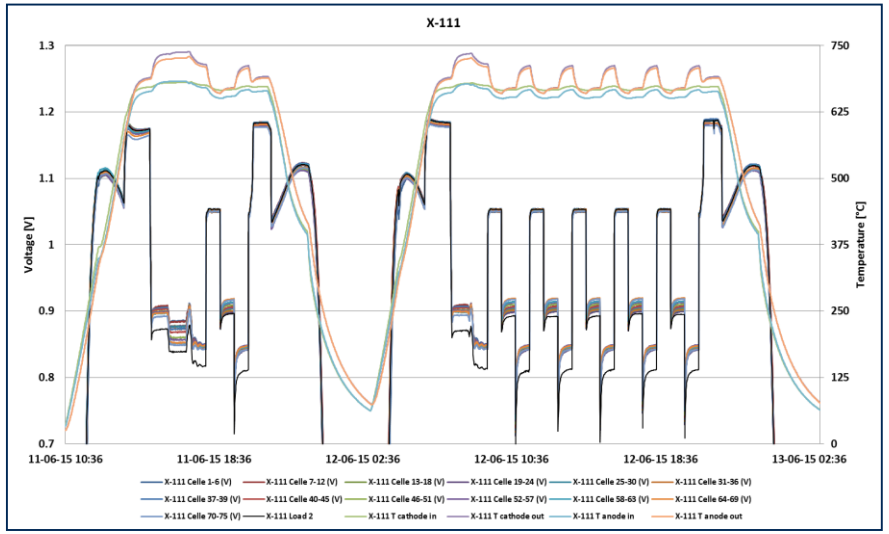
75 cells combined with interconnects, spacers and sealings in one stack







- Internal fuel manifold
- External air manifold
- Cell group voltage probing
- Compression free handling (cold)
- Robustness and leak tightness QA test in SOFC mode



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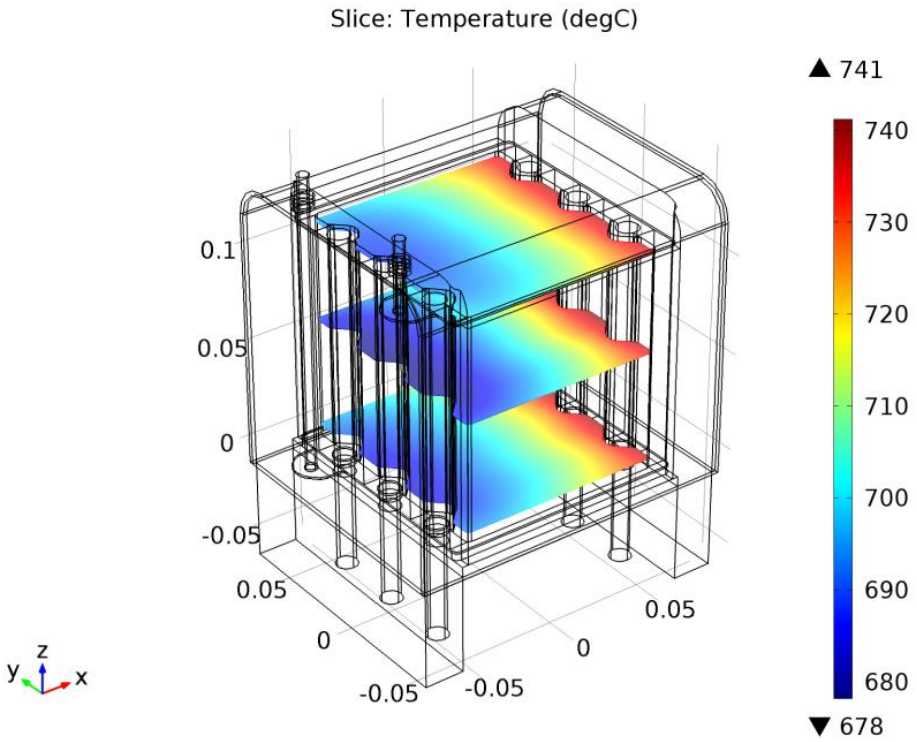
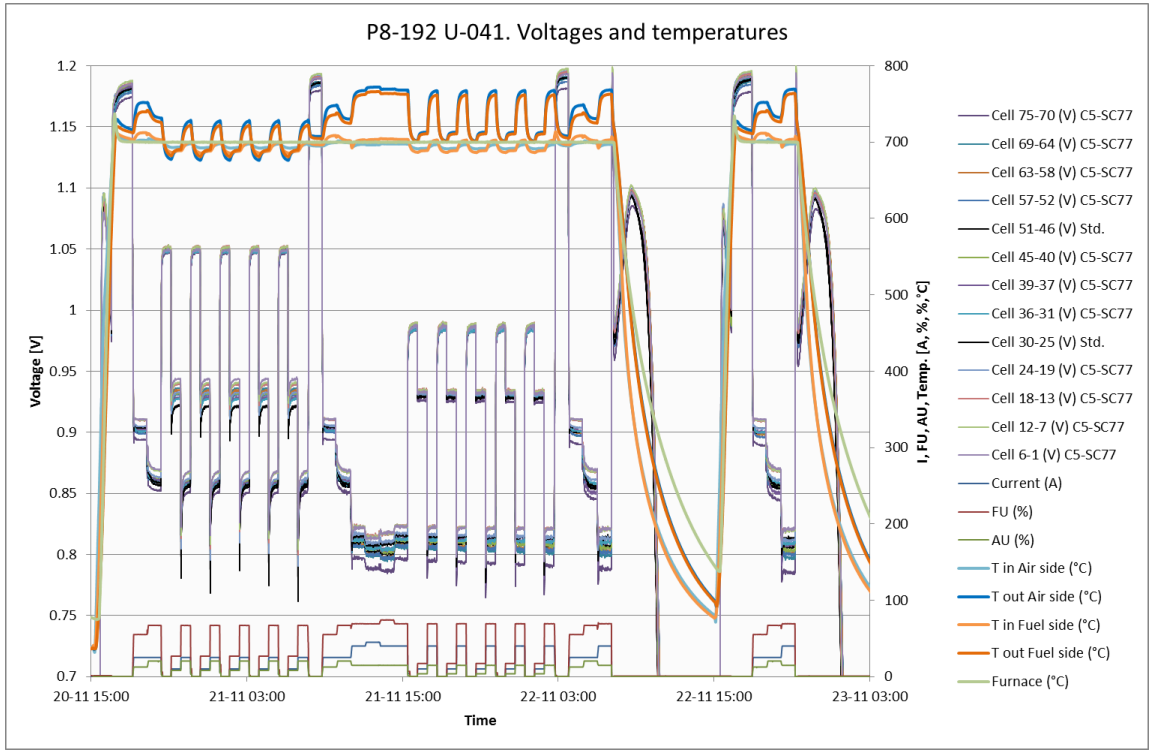
Quality, manufacturability, reliability, robustness





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Topsoe's COMSOL Solid Oxide Stack model

COMSOL Solid Oxide Stack model

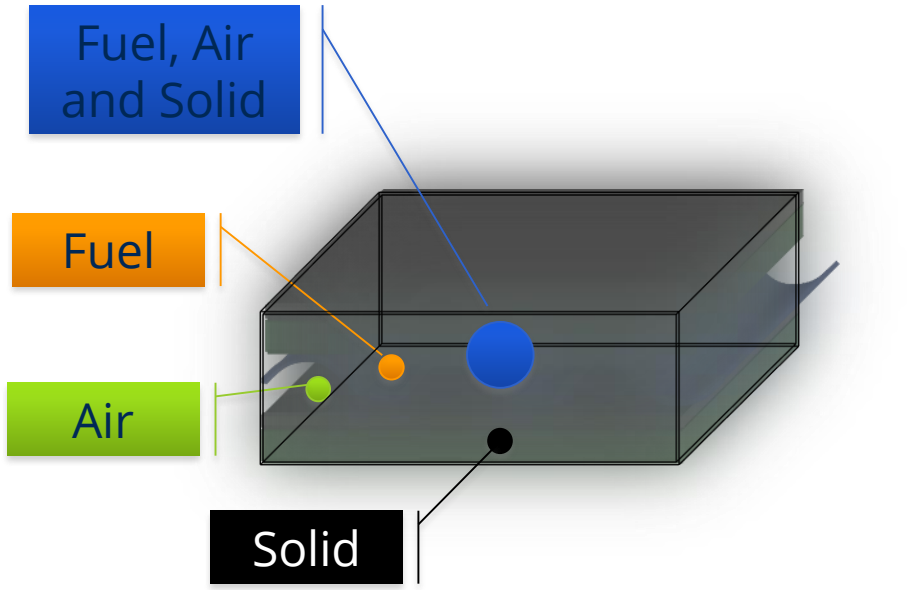
- Developed in Topsoe Fuel Cell (over 10 years)
- Further developed in Haldor Topsoe
  - *in cooperation with Resolvent I/S*

- Geometrically

  Unique homogenization approach
  - **Stack** (75 cells + interconnects)
  - **Manifolding** and casing (flow + thermal enclosure)
  - **Current** connections (power)

- Physics

  *The model couples **gas flow, thermal, electrical, and chemical physics***



Y. Elesin, M. F. Madsen, T. K. Petersen, Topology Optimization based homogenization technique for stack designs with complex geometry, in EFCF, (2014) B1102

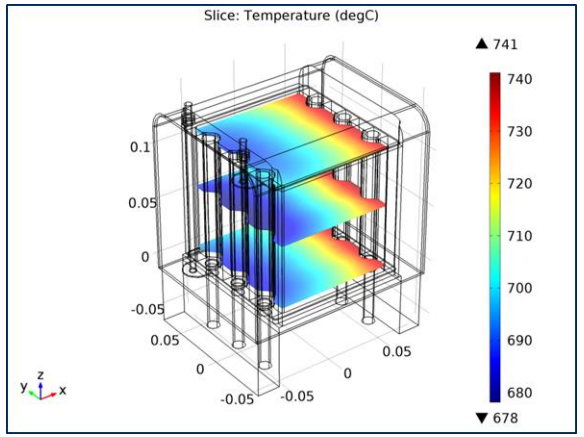
COMSOL Solid Oxide Stack model

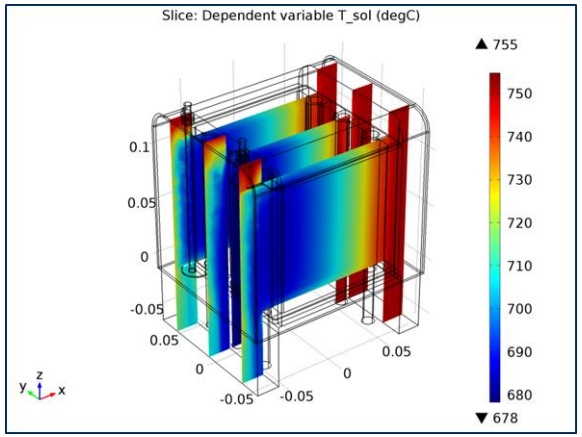
Output and evaluation possibilities

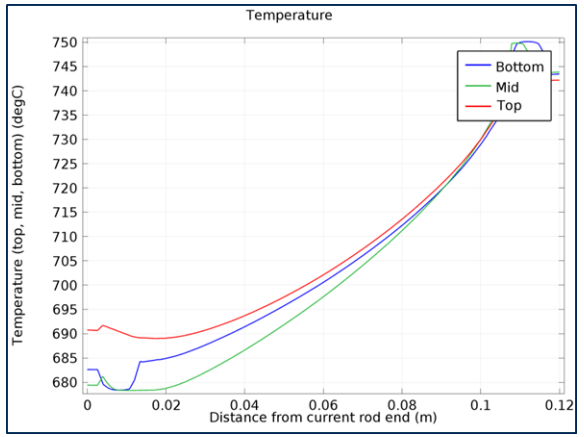
- **Operating conditions**
  - Temperature
  - Power, current density, voltage
  - **Gas composition**
  - **Fuel Conversion**

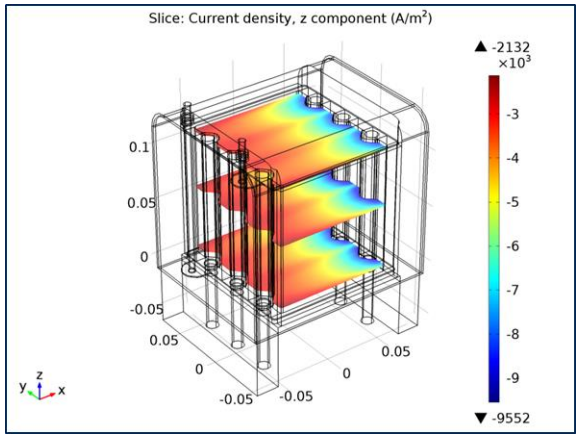
Other evaluation possibilities

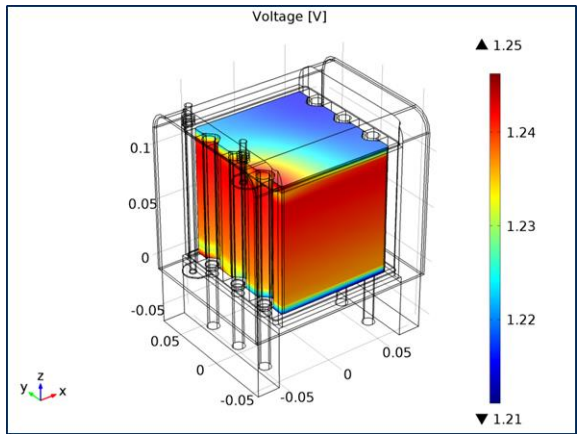
- **Stack design**
  - Flow configuration
  - Current paths
- **Cell design and material selection**
  - Conductivities of cell materials
  - Layer thicknesses and diffusion
  - Catalytic activity
- **System design**
  - Insulation strategies
  - Effect of external hot components

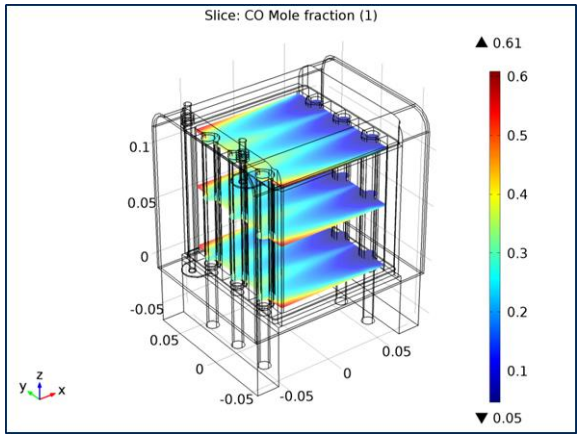








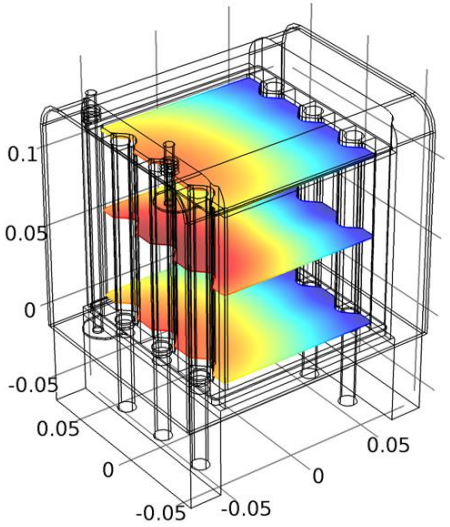


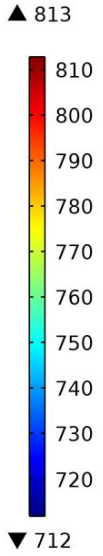


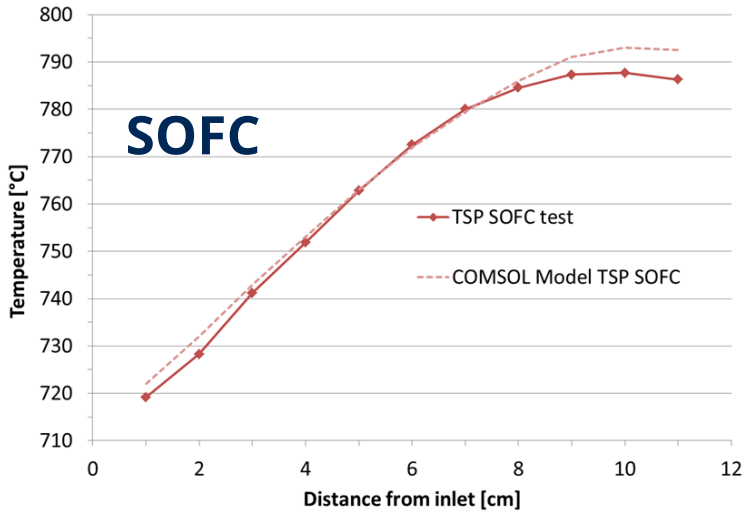
COMSOL Solid Oxide Stack model

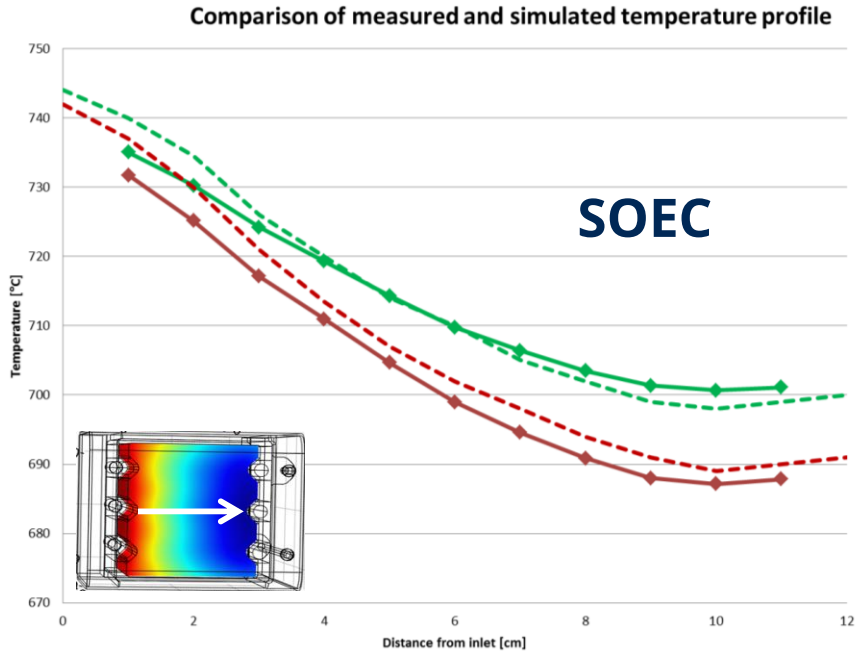
Verification against stack testing

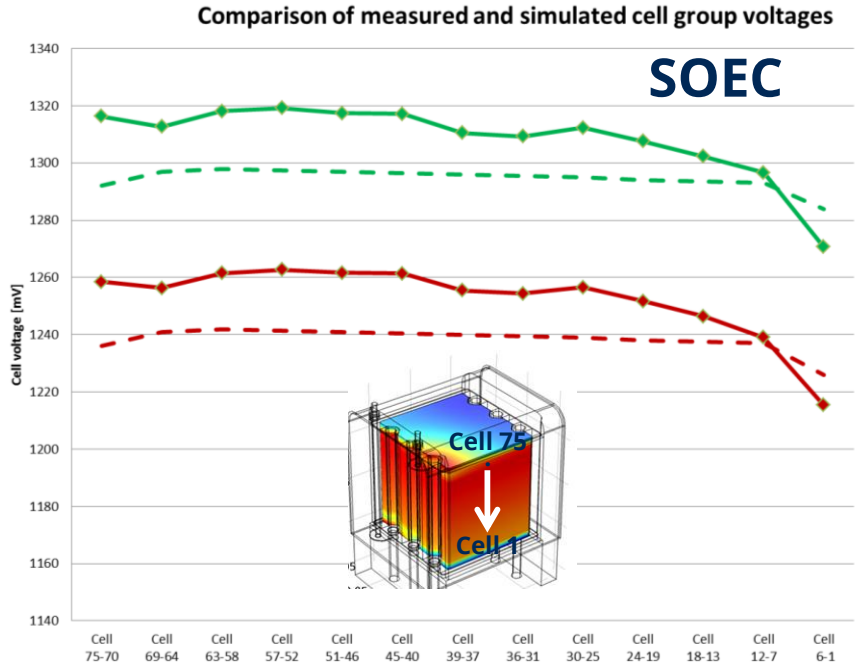
- Local gas composition and current density are not possible to measure
- Verification of COMSOL simulations through comparison with test data and post mortem analysis
  - Temperatures (difference less than 5°C)
  - Voltages (difference less than 20 mV)







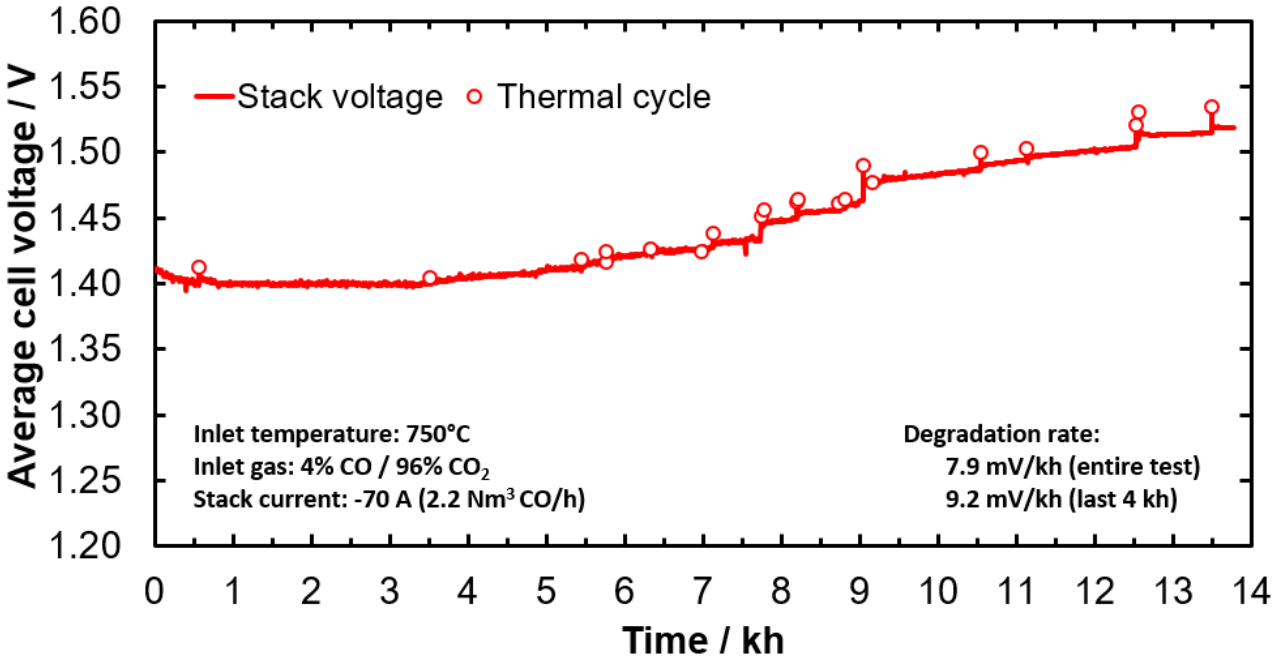


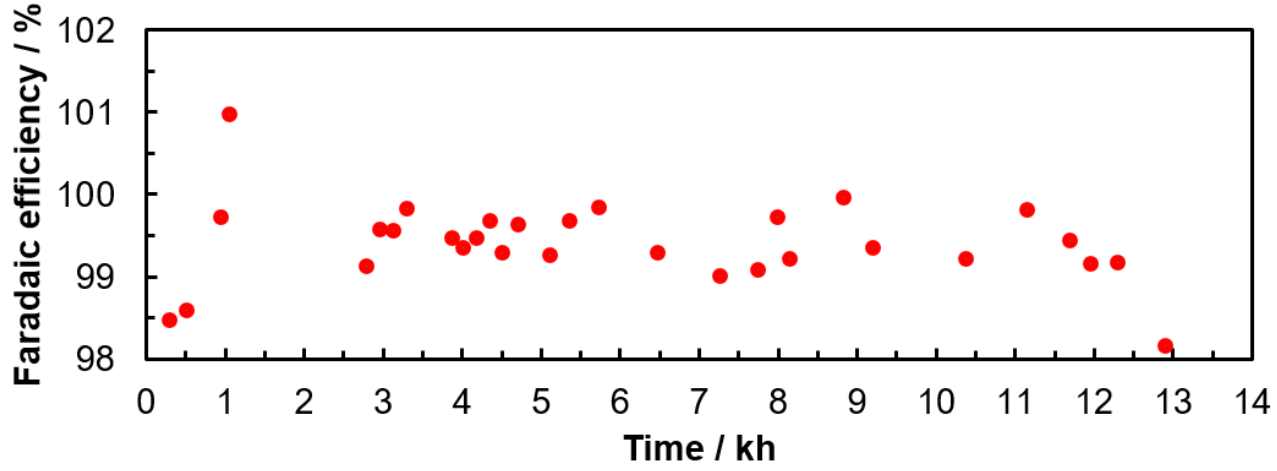


Component level development

High Temperture Contact Resistance Measurement for Interconnects

Stack lifetime improvements in dry CO_2 electrolysis





14 000 h operation in CO_2 electrolysis

30 000 Nm³ (35.5 t) CO produced

20+ thermal cycles

3.44 kWh electricity per Nm^3 CO

Degradation rate:
7.9 mV /1000 h

Faradaic efficiency:
99 ± 1%

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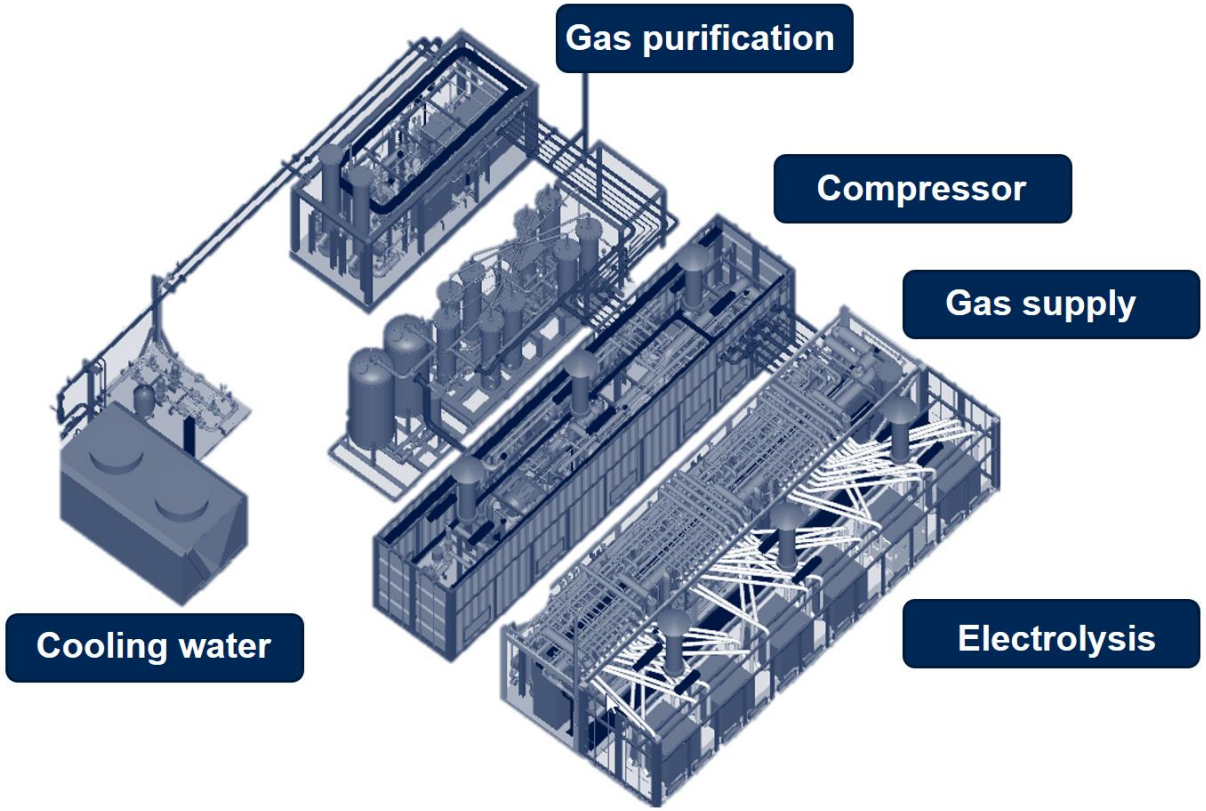
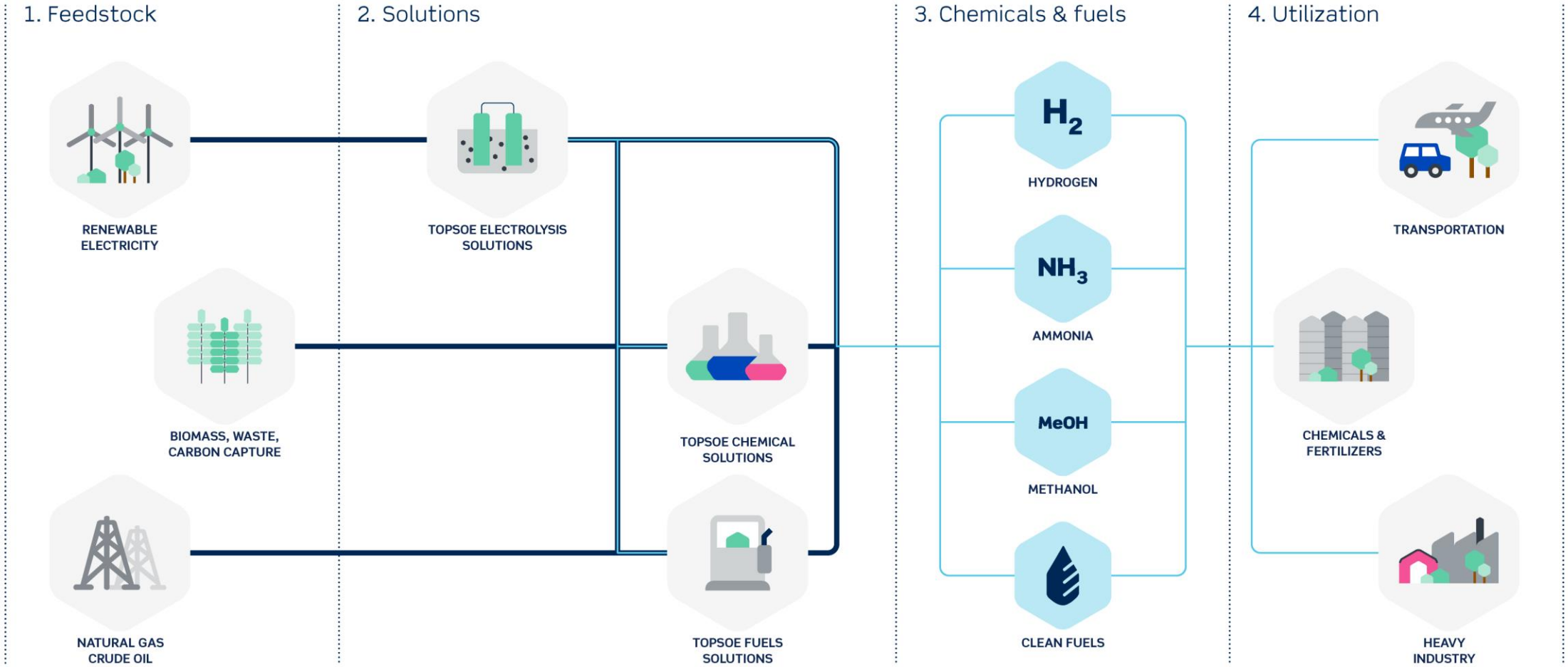
eCOs (96 NM3/h CO)

eCOs™



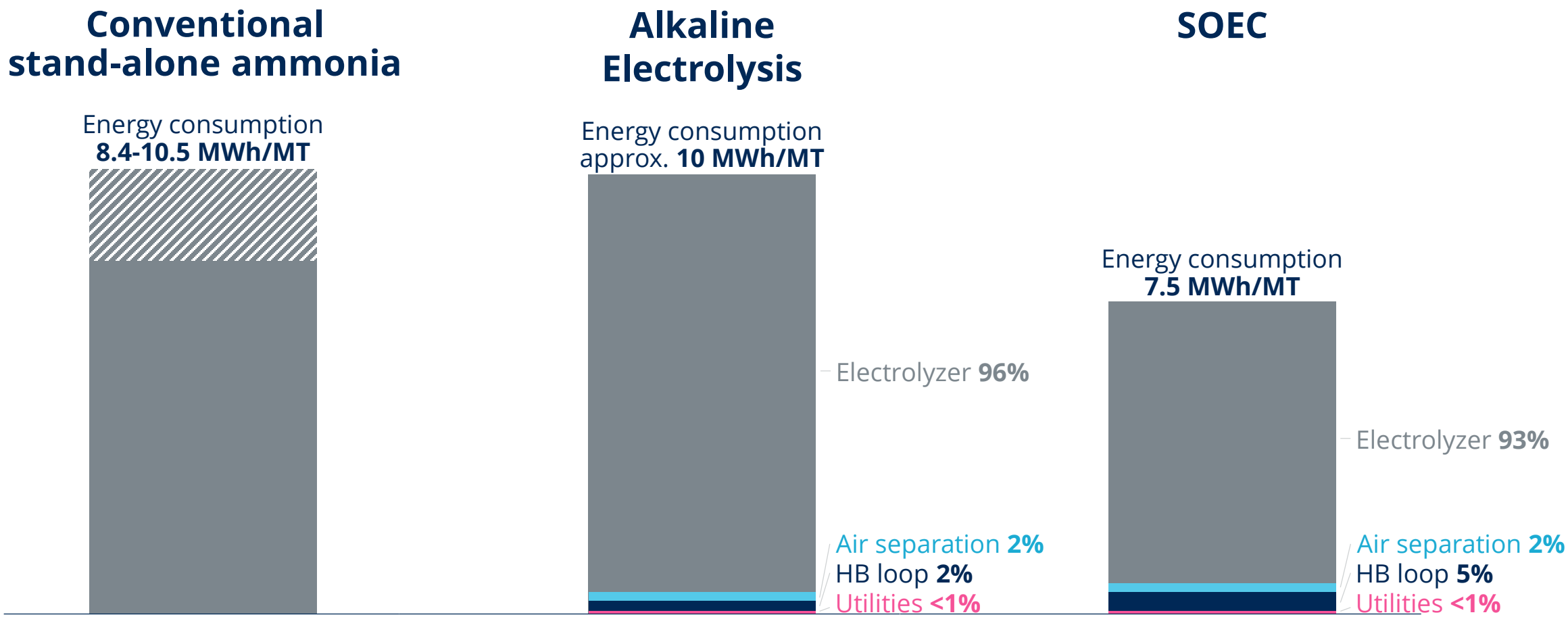

Iron & steel
7%
Cement
3%
Chemicals & petrochemicals
6%
Aviation
2%
Shipping
2%

Topsoe solutions accelerate the energy transition



TiGAS
15500 barrels per day of gasoline

Electrolysis efficiency advantages becomes huge at plant level – Illustrated for ammonia production by 25% energy savings per ton ammonia produced



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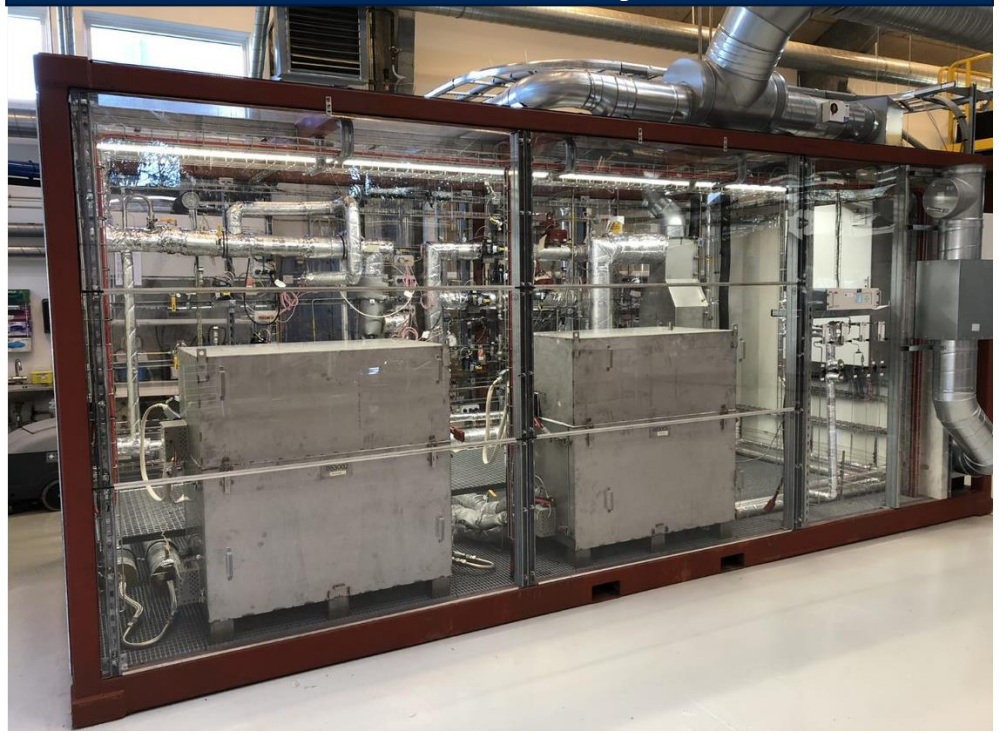
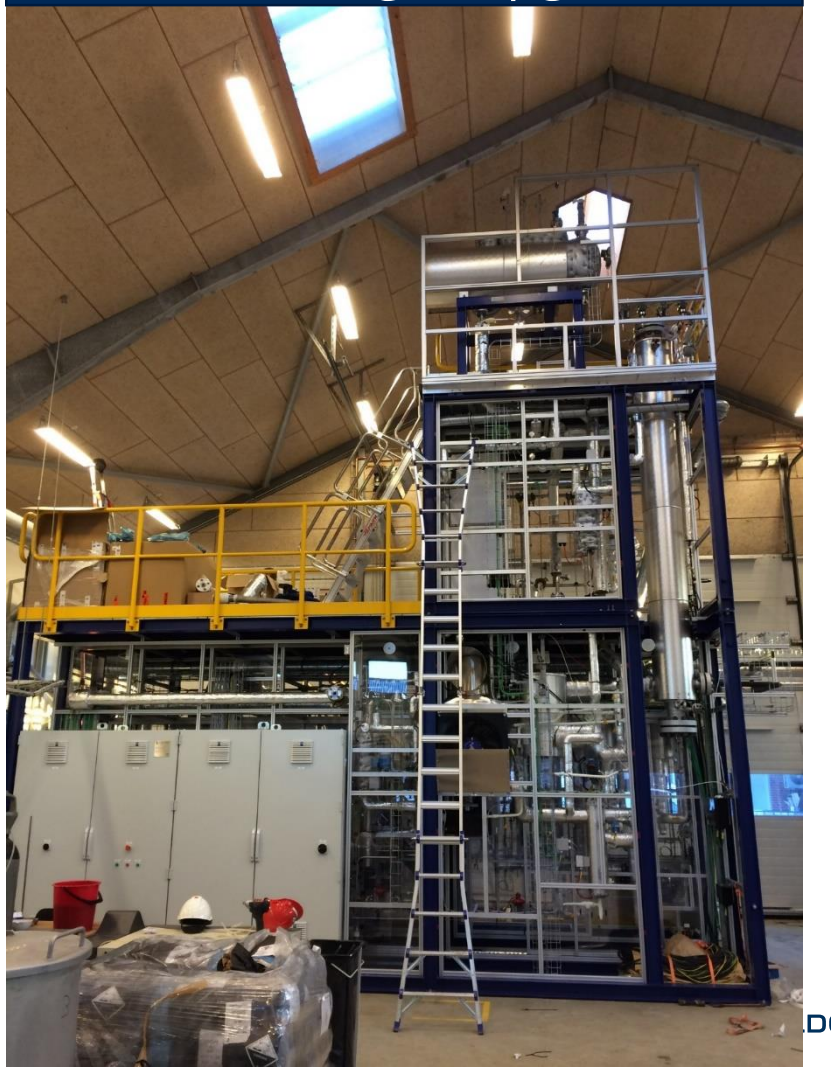
Pilot site at Aarhus University Denmark

50 kW Ammonia synthesis



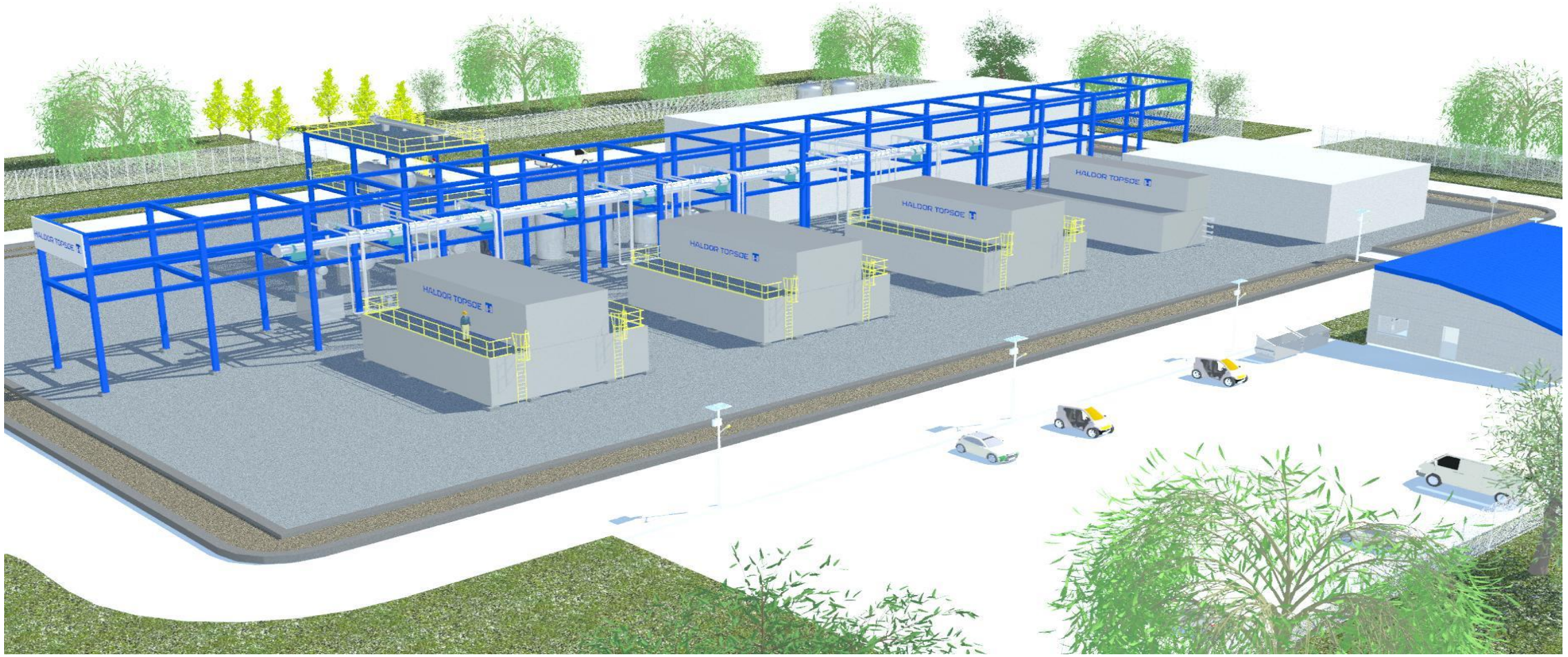
50 kW Biogas upgrade



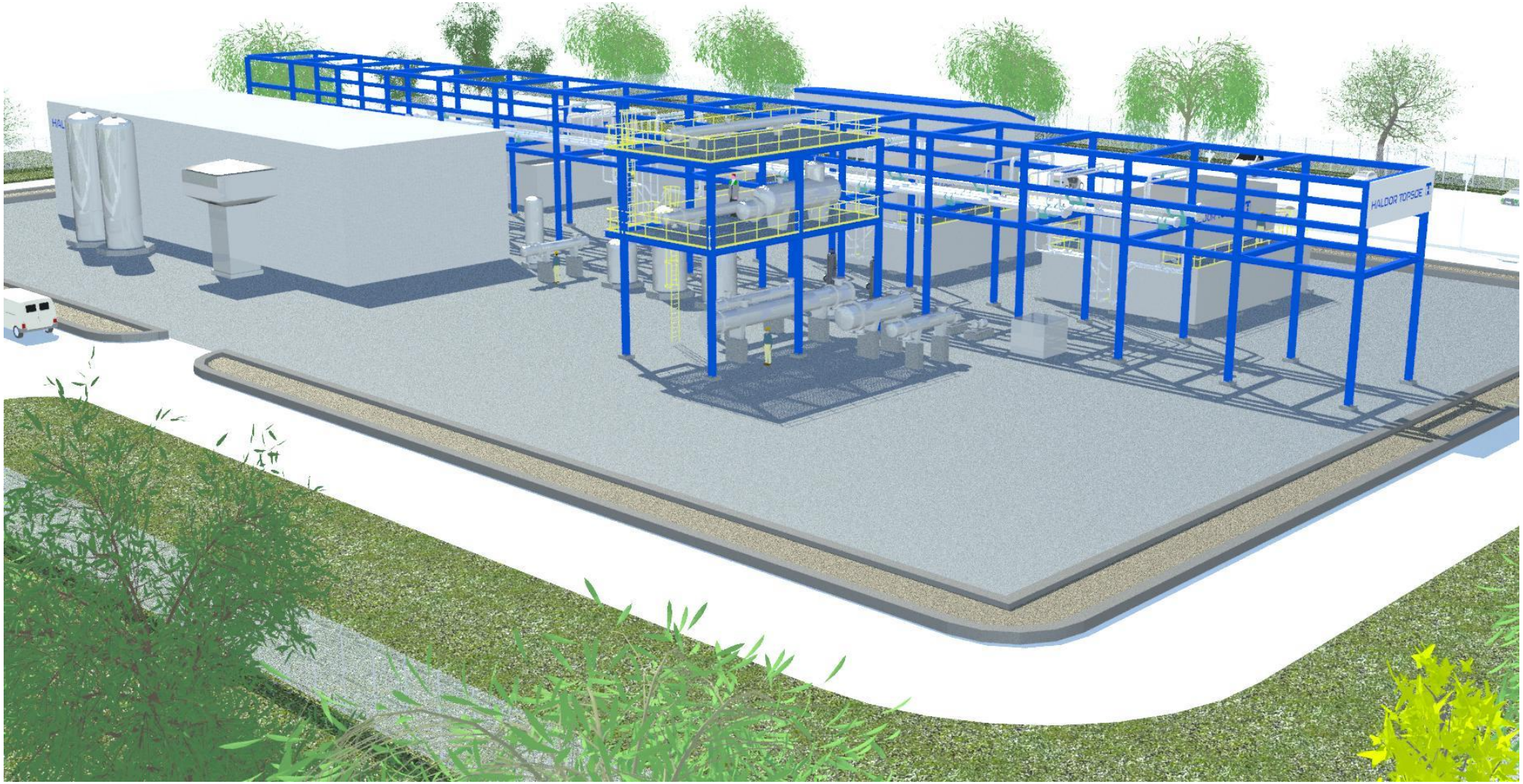
From small scale SOEC to Power-2-X

Significantly increased output, pressurized operation, standard production methods

Industrial SOEC plant



Industrial SOEC plant



Questions?

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