WP1 Novel high temperature electrolysis

Final seminar 17.01.2024

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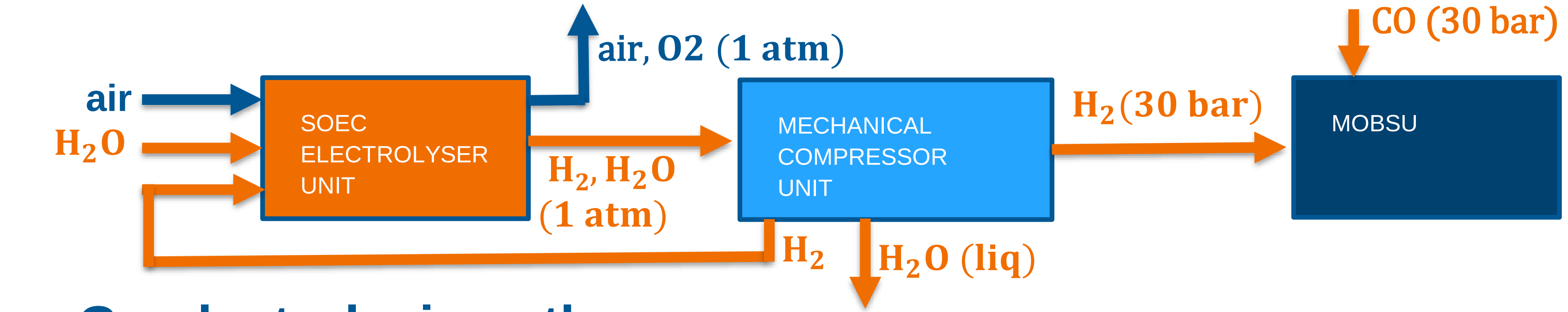
VTT Hydrogen Production

E-fuel WP1 Novel high temperature electrolysis

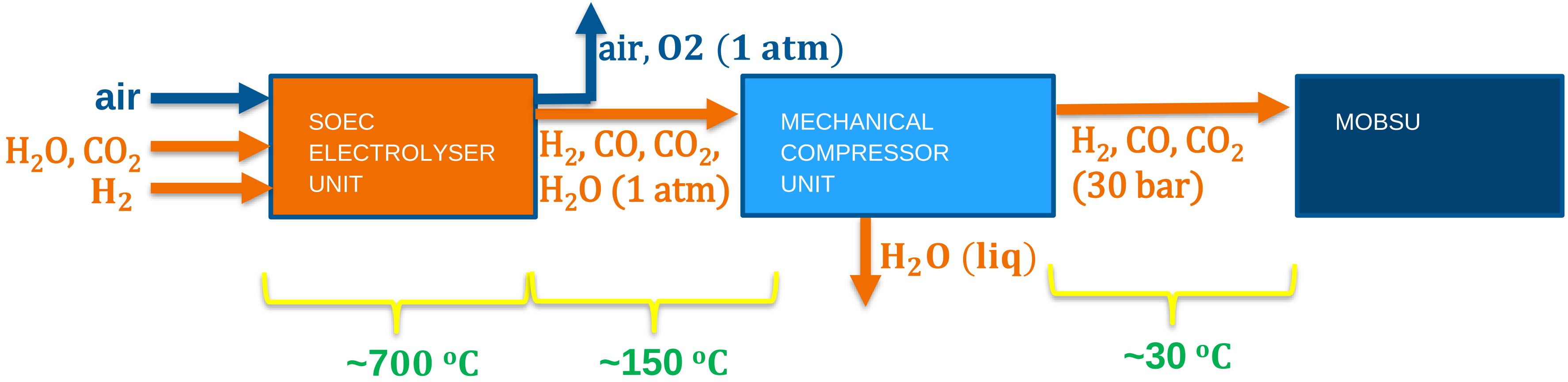
- **Main Objectives:**
  - Development and validation of the operation 10 kW size SOEC system
  - Development of interface between hydrogen production and compression system

- **WP1 is divided in 4 separate tasks with corresponding deliverables:**
  - T1.1 SOEC system proof of concept and operation validation
  - T1.2 SOEC downstream process development
  - T1.3 SOEC system modelling and heat integration
  - T1.4 SOEC stack characterization and degradation tests

Electrolysis pathway:



Co-electrolysis pathway:



WP1 Main research questions and goals

1. Building VTT's 10 kW size SOEC system with in-house developed technical solutions (e.g. super heaters, component placements, insulation etc.) *(T1.1, T1.3)*
2. Validation of the system operation and transitions between selected nominal points *(T1.1)*
3. Demonstrate highly instrumented SOEC system to investigate enthalpy and heat fluxes through the system and BoP components *(T1.1, T1.3)*
4. Investigate specific scientific questions like temperature distribution of the stack and system in different operation points and to develop low and high temperature heat recovery/utilization methods & heat integration *(T1.1, T1.3)*
5. Investigate and develop the interface between hydrogen production and compression system (automation, control and safety systems) *(T1.2)*
6. Develop system model "Digital Twin" for BoP components & electrolyser-compression system *(T1.3, WP7)*
7. Performing stack characterization and degradation tests to validate and estimate stack performance values *(T1.4)*

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T1.4 SOEC stack characterization and degradation tests

- All planned 3 tests were completed as planned.
  1. 3000 h+ long-term tests with Elcogen’s E350 (15 cells) stack
  2. 3000 h+ long-term tests with Elcogen’s E350 (15 cells) stack
  3. 3000 h+ test with Elcogen's E3000 (119 cells) stack
- Nominal long-term test conditions: 0.5 A cm^{-2}, RU: 40 %, Fuel side H_2 flush: 10-30 %, T=700 ^{O}C
- First E350 stack test (2 current collection points) started 25.5.2021 and lasted 3690 hours
- Second E350 stack test (8 current collection points) started 14.12.2021 and lasted 4008 hours
- Third test run for E3000 stack started with test station building and long-term test started 11.4.2022 and lasted 3245 hours

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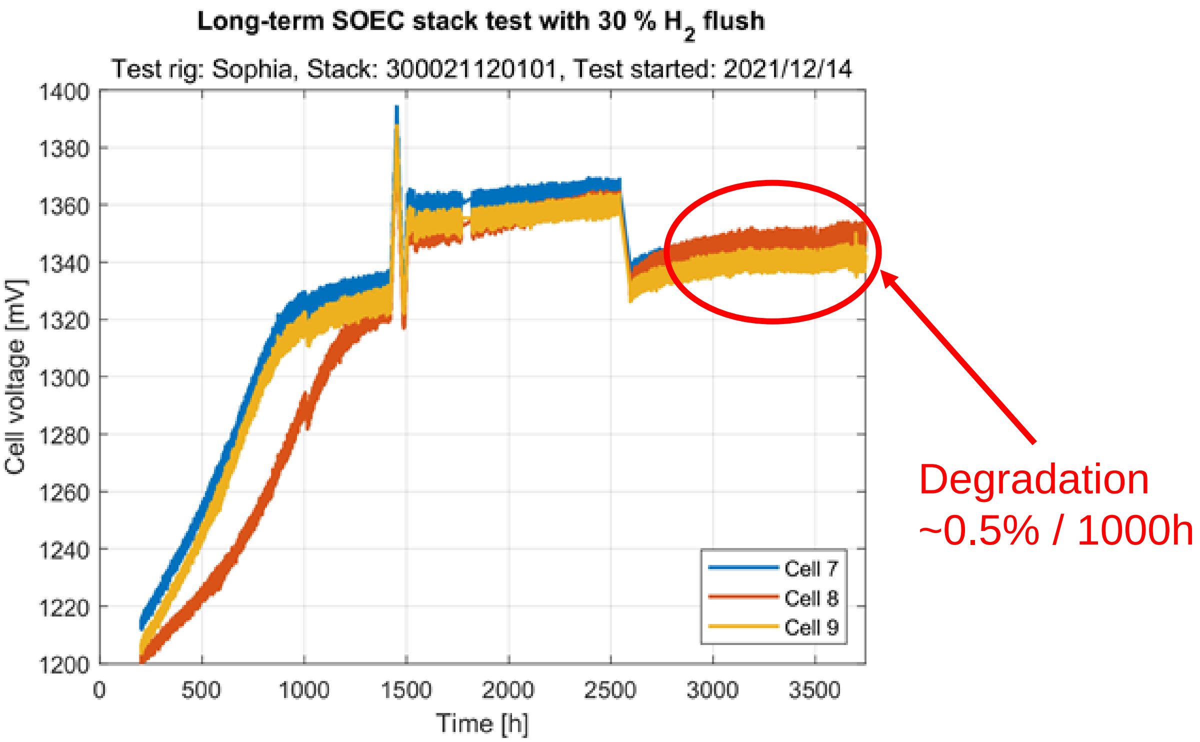
T1.4 SOE Stack testing at VTT

- 2 long-term 3500h+ performance tests with Elcogen 15 cell stack were done
- 15 cell stack tests together with later E3000 stack (119 cells) tests were giving valuable information of stack performance to be utilized later with VTT's SOE system «Ressu» and Convion's demonstration unit



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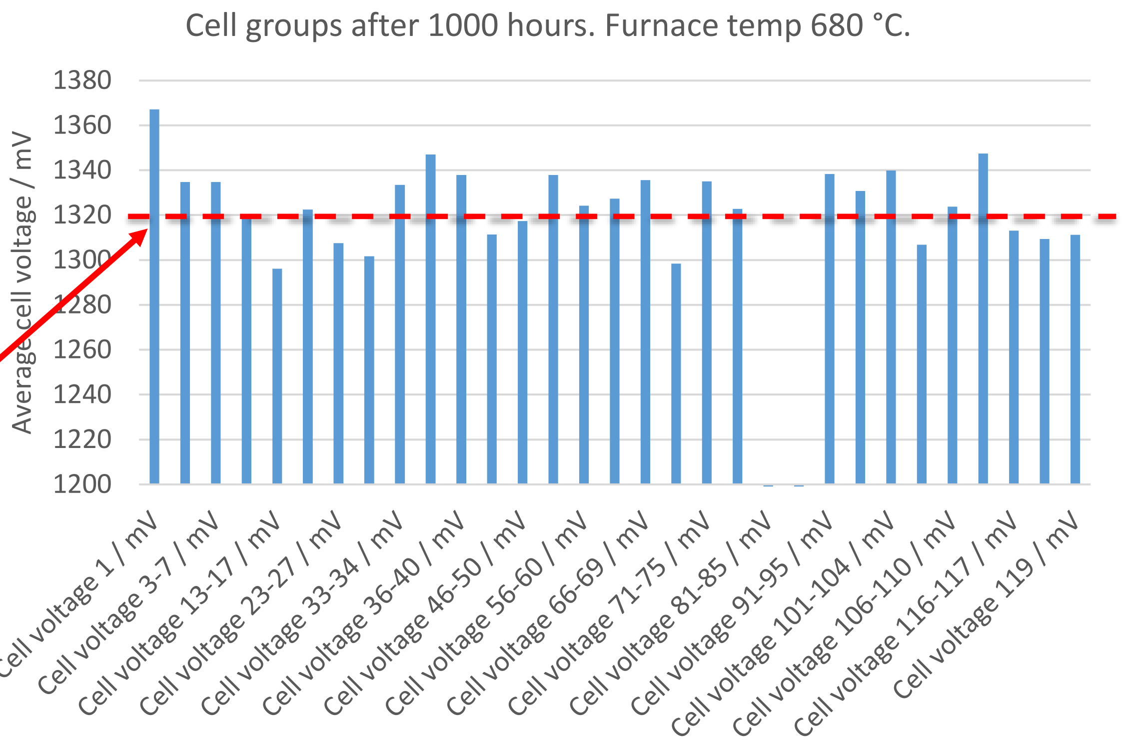
T1.4 SOE Stack testing at VTT

- Test station for Elcogen E3000 stack (119 cells) was built and 3000h+ long-term-test was finished Q3/2022
- @1000h: relative even cell voltage and temperature distribution, ΔT_{max} ~20 ^{O}C

Average cell voltage ~1320mV @1000h



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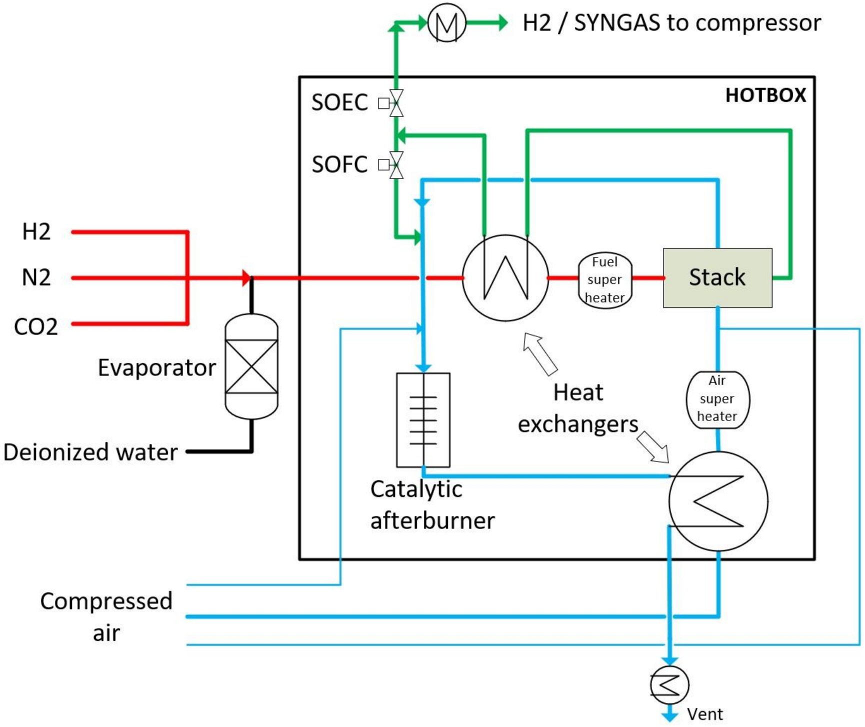
T1.1 SOEC System proof and operation validation

Simplifieds PI-diagram of VTT's highly instrumented Reversible SOC System Unit "RESSU"



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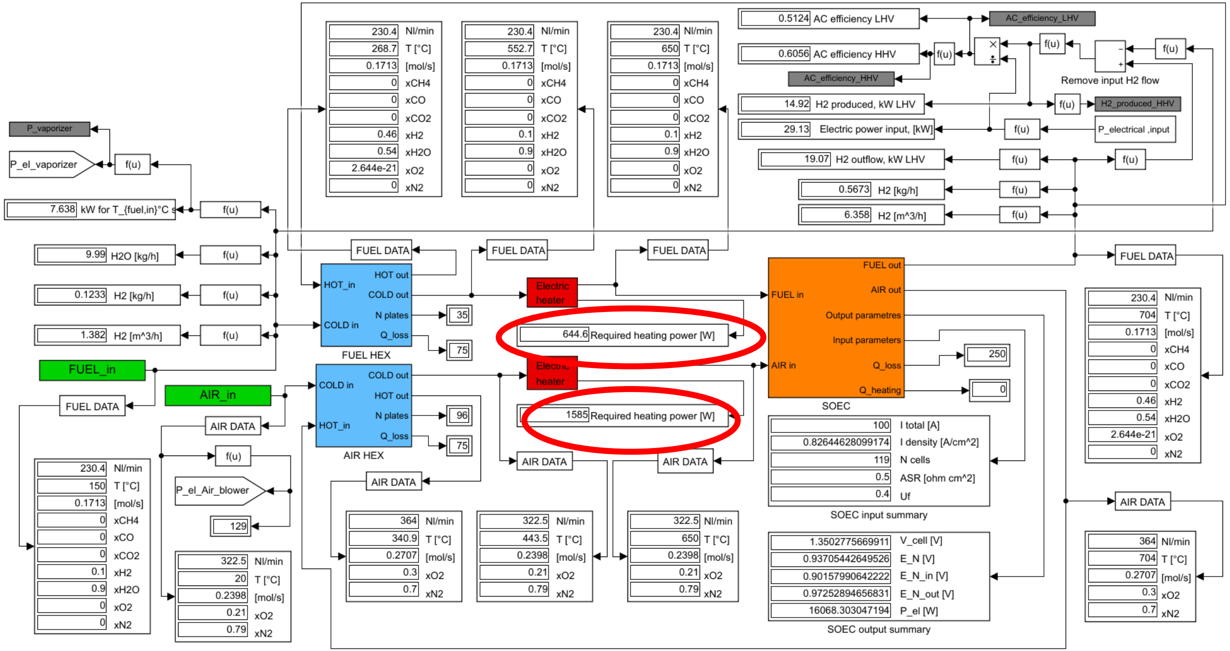
T1.3 SOEC system modelling and heat integration



Example of Simulink system model (stack current 100A BOL, evaporator max. steam flow 10kg/h, RU 40%), giving e.g. estimations for required heating powers for superheaters: Fuel SH 645W and Air SH 1585W (at that operation point)

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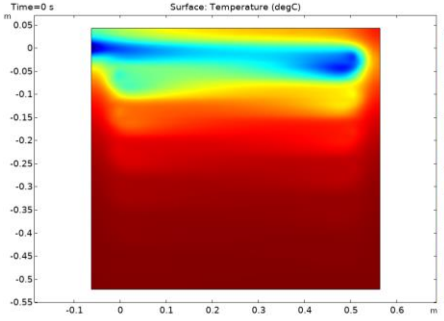
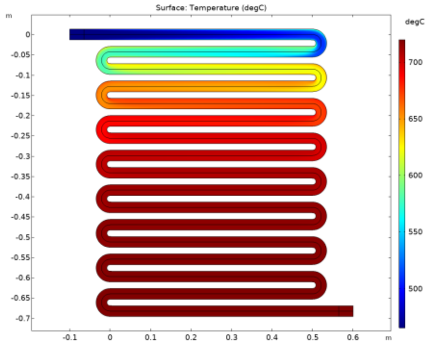
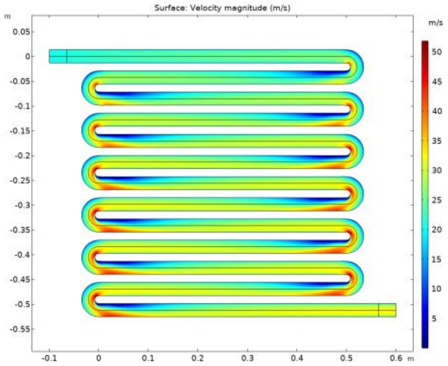
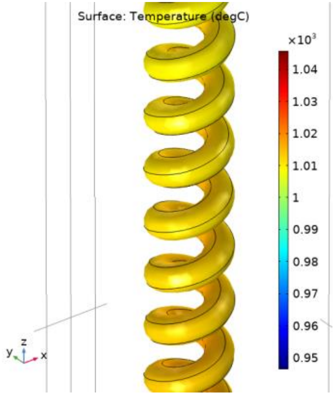
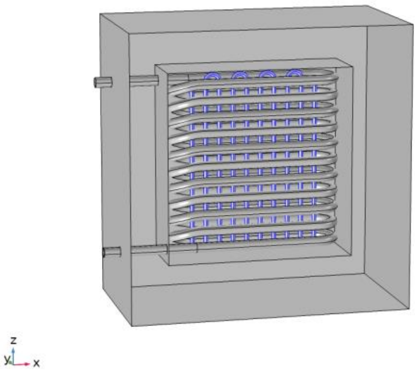
T1.3 SOEC system modelling and heat integration



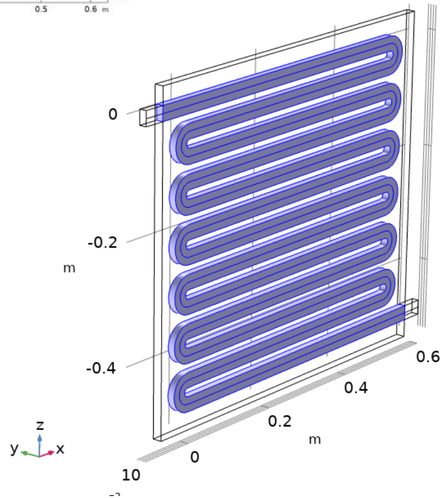








Modeling superheater properties (sizing, geometry, needed heating elements, heating power)



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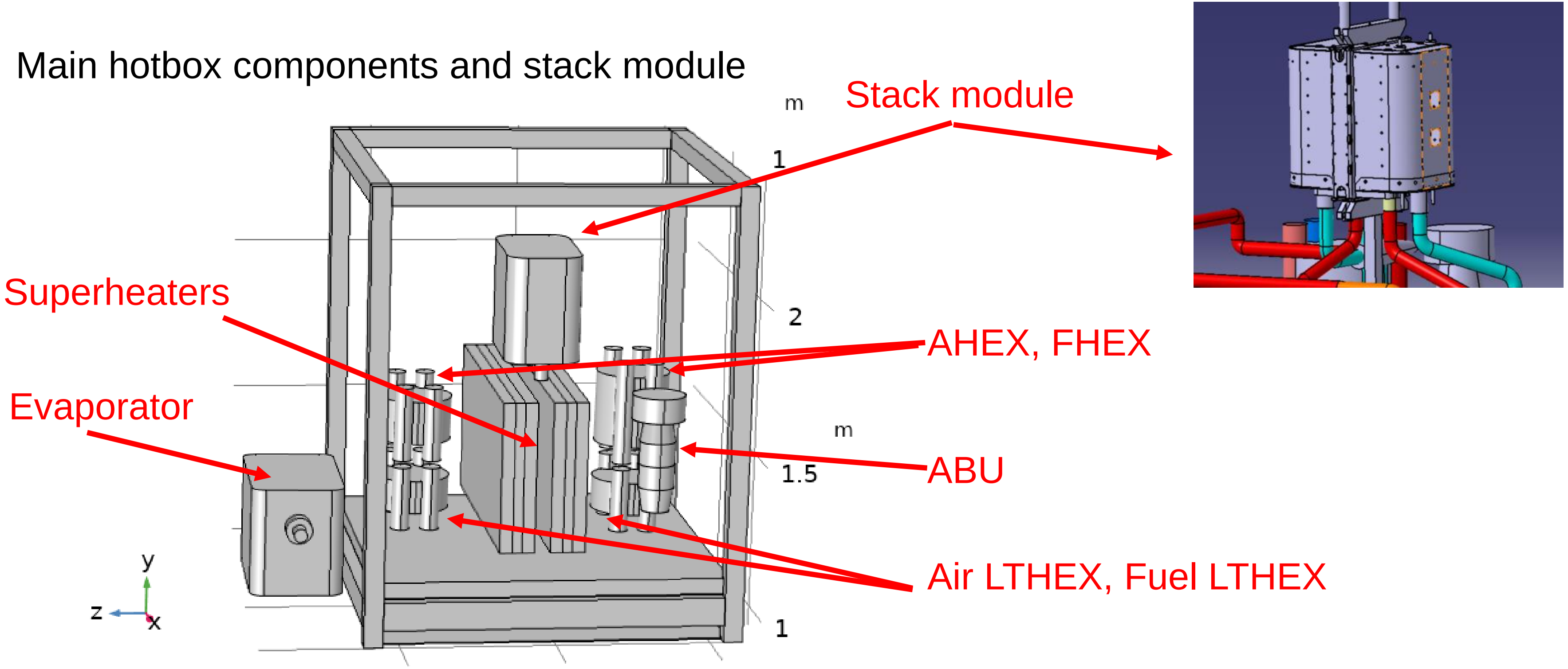
T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration

Main hotbox components and stack module



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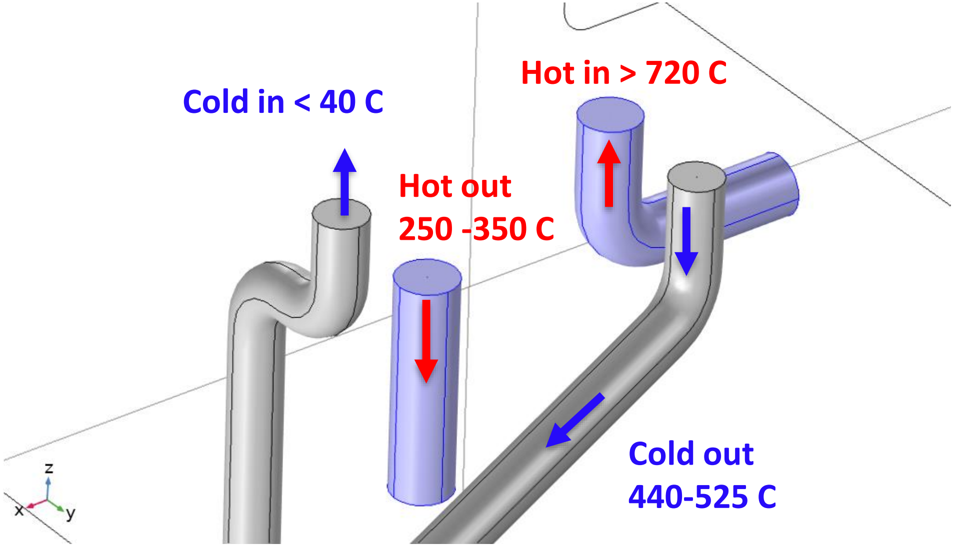
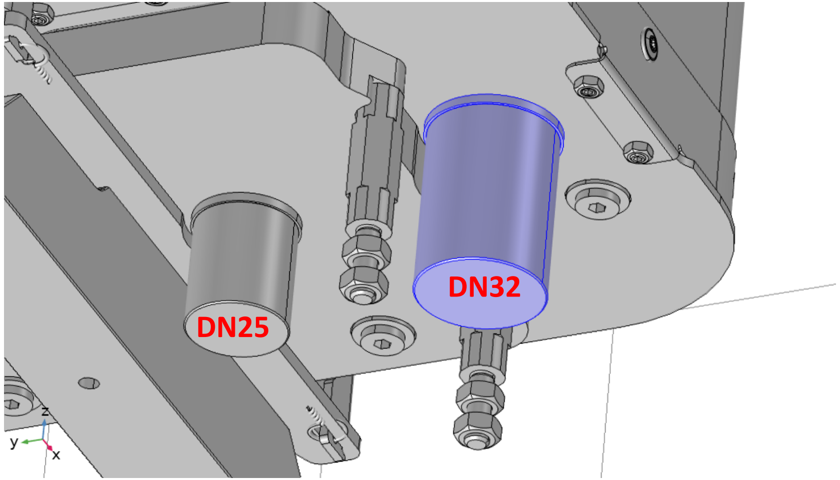
T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration



Temperatures of DN32 and DN40 tubes from the bottom of AHEX



Tubings in the bottom of the stack module: Stack air in (DN25) from superheater and Stack air out (DN32) to ABU in

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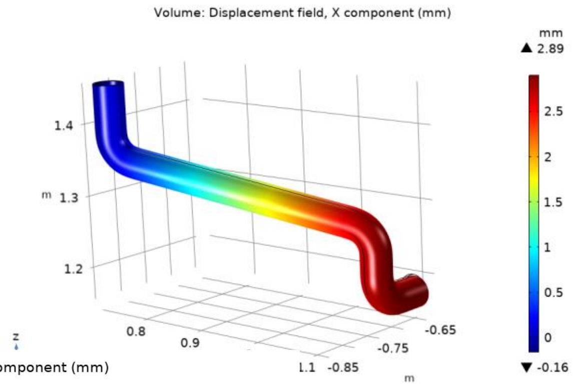
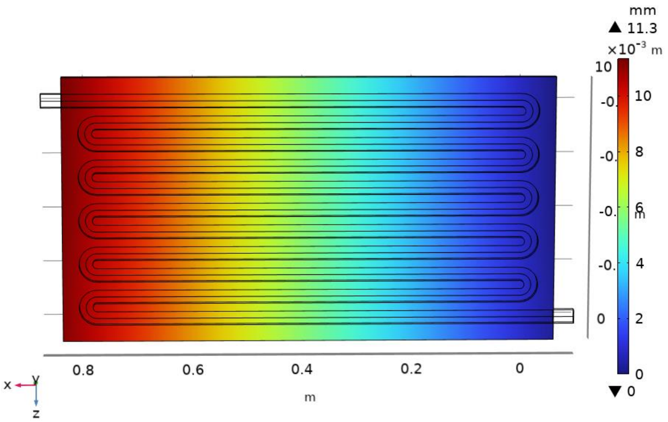
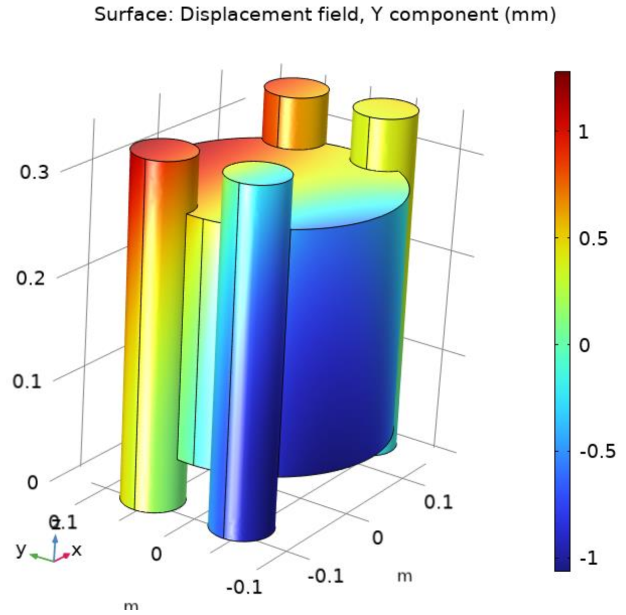
T1.3 SOEC system modelling and heat integration







Modeling thermal expansion of Air superheater, AHEX and the tubes between (20^{O}C → 750 ^{O}C)

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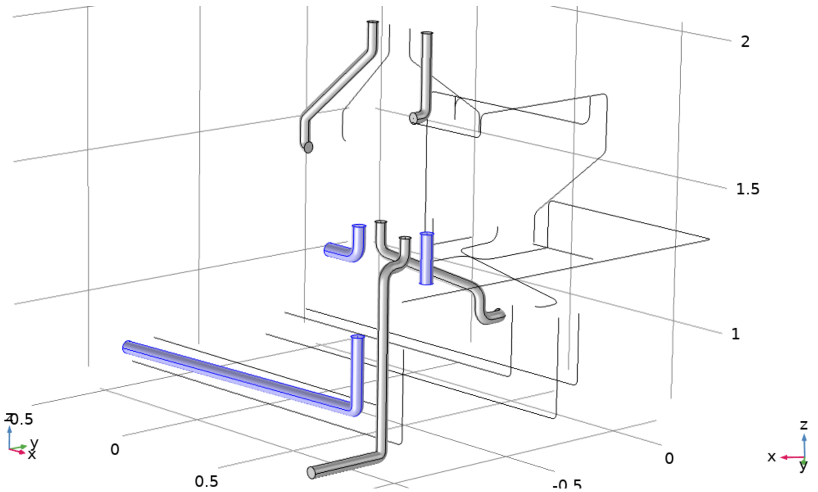
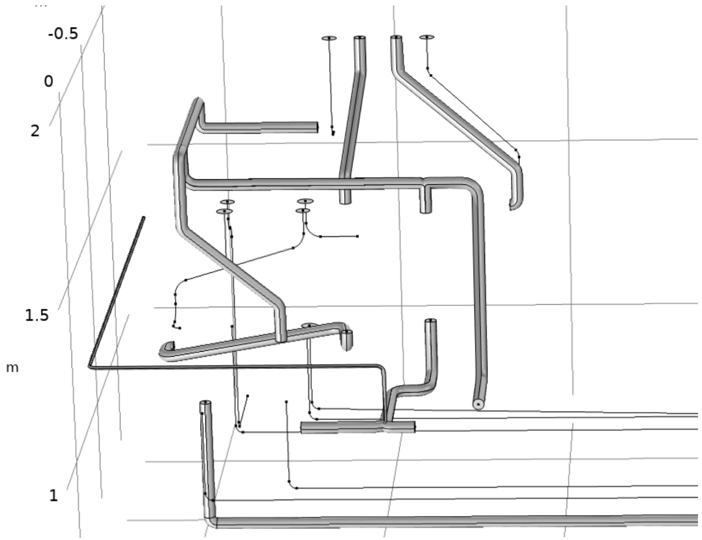
T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration



Air side main pipings with DN35 and DN40 tubes



Fuel side main pipings with DN25 and other pipings with 10 mm inner diameter tube

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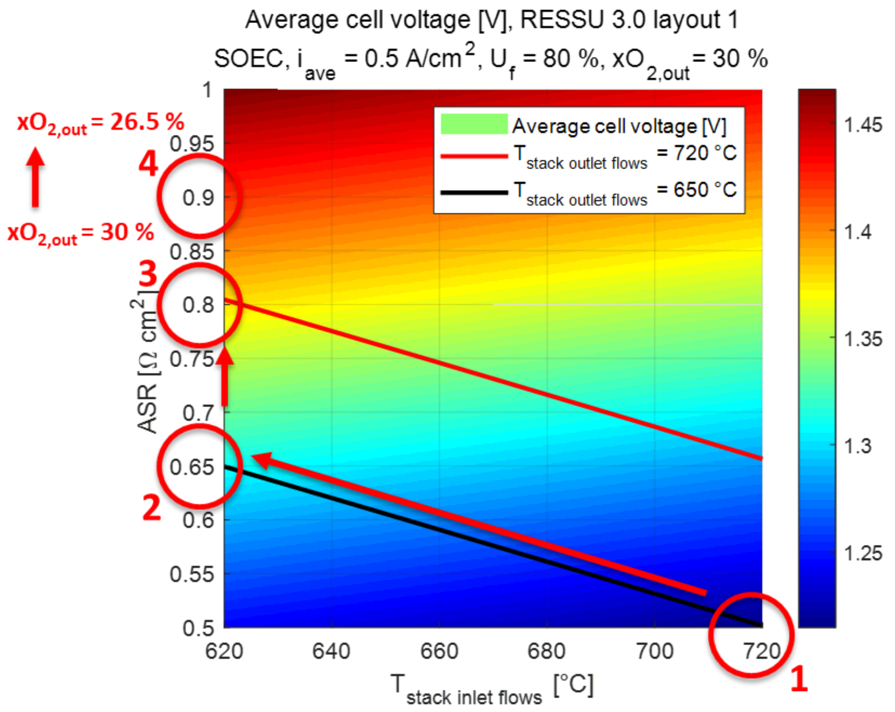
T1.3 SOEC system modelling and heat integration



	AC → H_2 HHV (%) (H_2 at 1 atm) (AC → DC, 84 %)	AC → H_2 (kWh/kg) (H_2 at 1 atm) (AC → DC, 84 %)	AC → H_2 (kWh/kg) (H_2 at 1 atm) (AC → DC, 84 %) (Free 150 C steam)	DC → H_2 (kWh/kg) (H_2 at 1 atm)	DC → H_2 HHV (%) (H_2 at 1 atm)
1	73.9	53.8	45.2	32.5	122.0
2	73.2	54.2	45.6	35.1	113.1
3	72.0	55.2	46.6	36.9	107.7
4	65.5	60.7	52.0	38.2	104.4

A method by which the E3000 SOE stack could be operated with a constant current in VTT’s SOEC system throughout its full life cycle and calculated SOEC system efficiency values.

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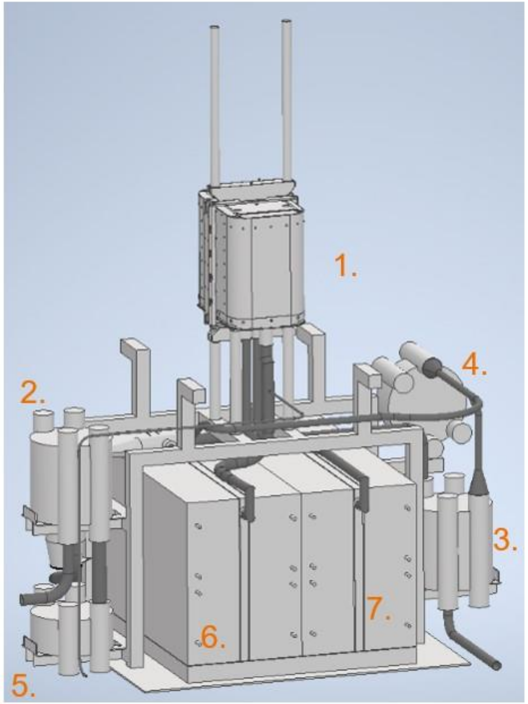
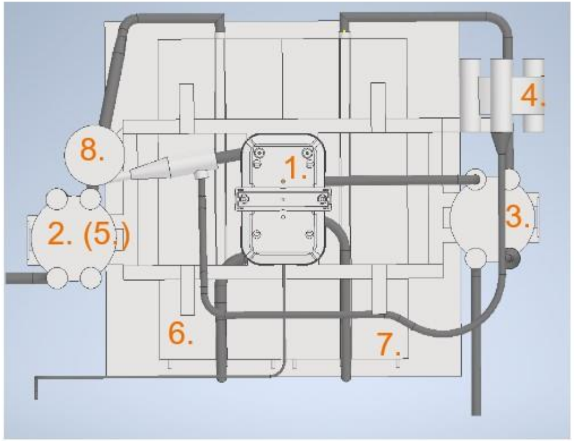
T1.1 SOEC System proof and operation validation





1. Stack module
2. Air HEX
3. Fuel HEX
4. Fuel cooler HEX
5. Air cooler HEX
6. Air Superheater
7. Fuel Superheater
8. Afterburner (ABU)

Detailed component placements in the final design of VTT's SOEC system

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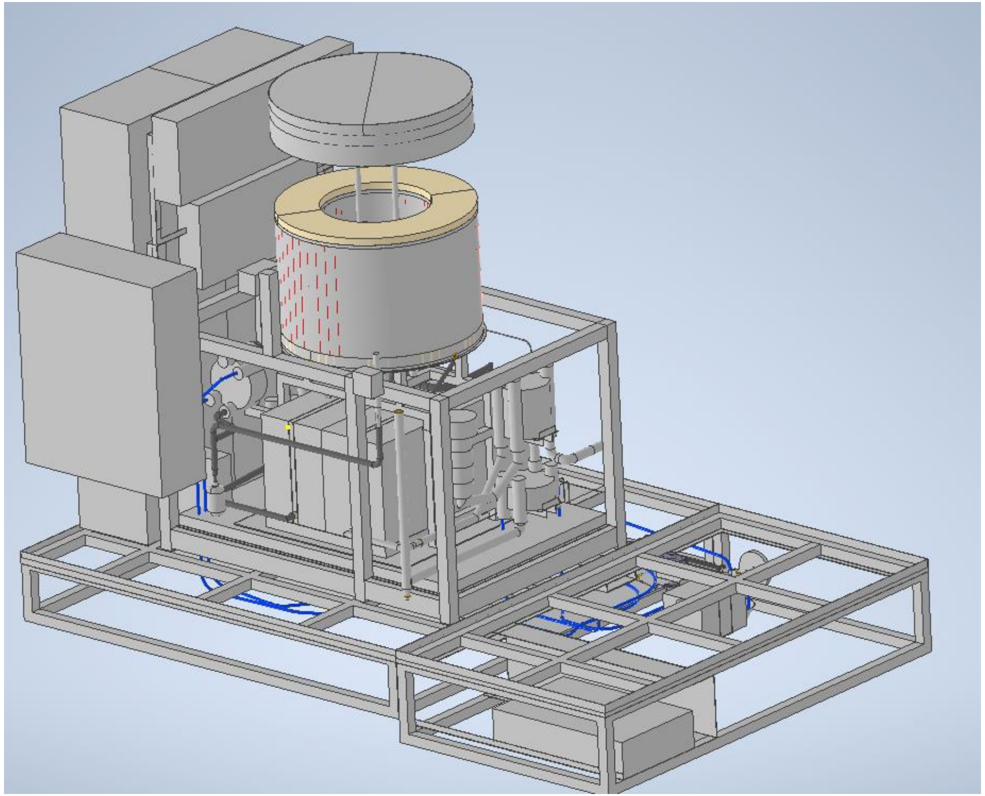
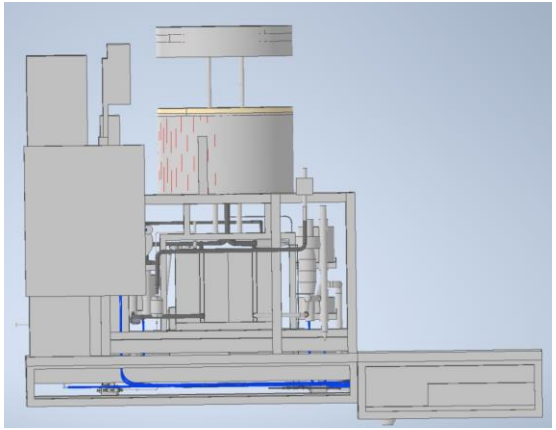
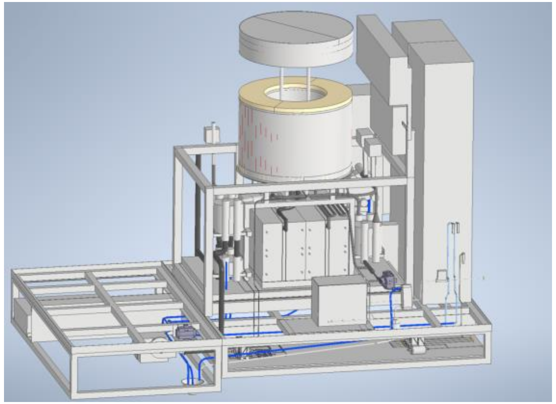
T1.1 SOEC System proof and operation validation







AutoCAD images of the VTT’s SOEC system

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T1.1 SOEC System proof and operation validation

A steel and aluminium frame of the SOEC system and preliminary fitting of superheaters.

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T1.1 SOEC System proof and operation validation

Installing superheaters and heat exchangers

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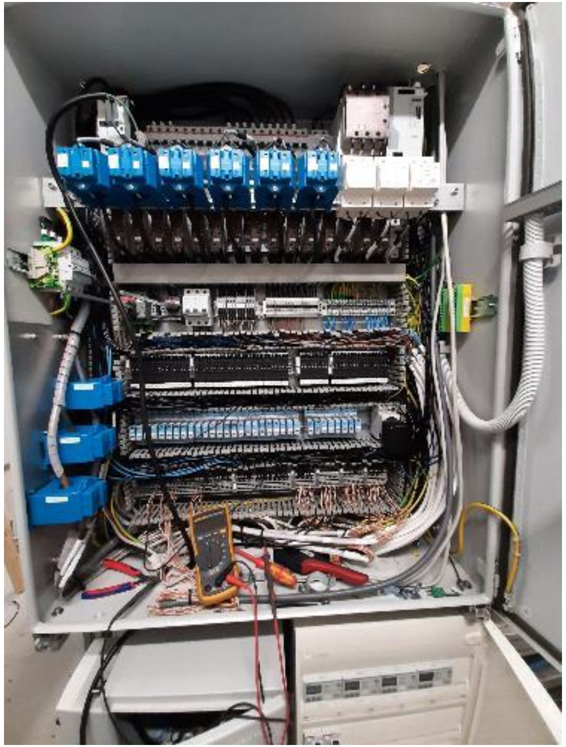
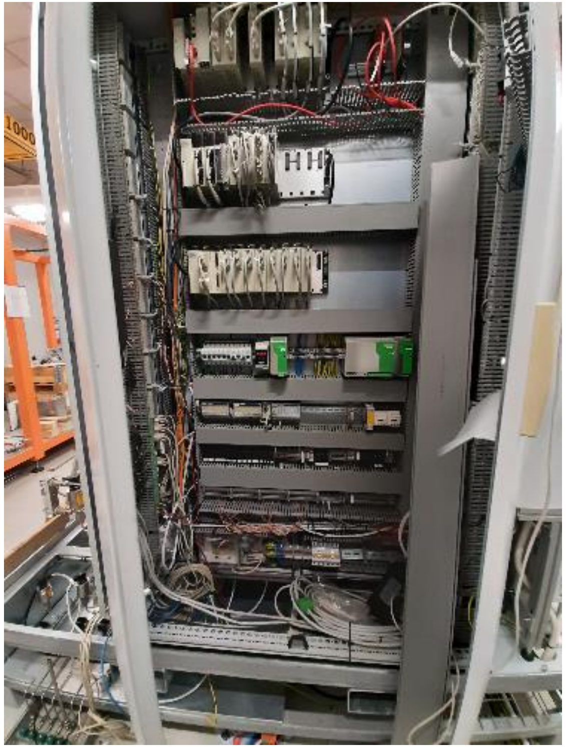
T1.1 SOEC System proof and operation validation


Automation control cupboards installed to SOEC system

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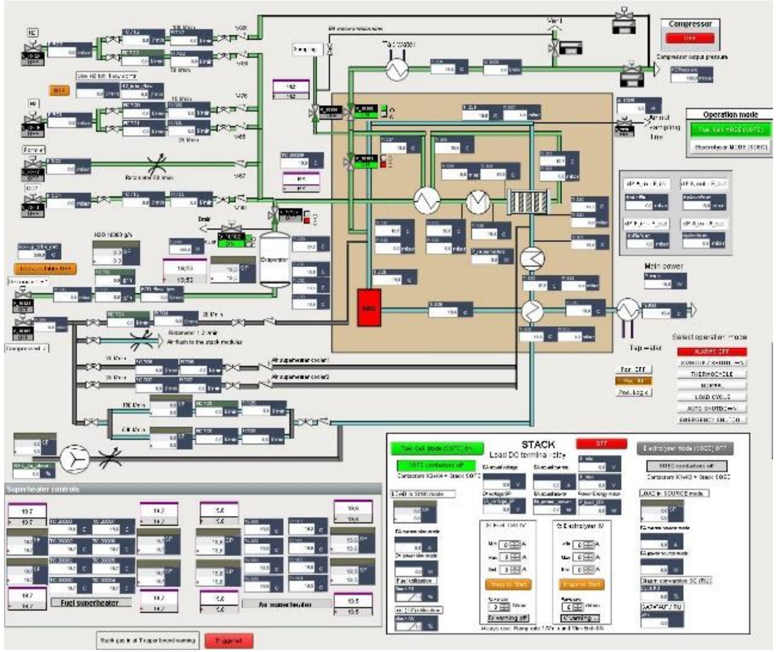
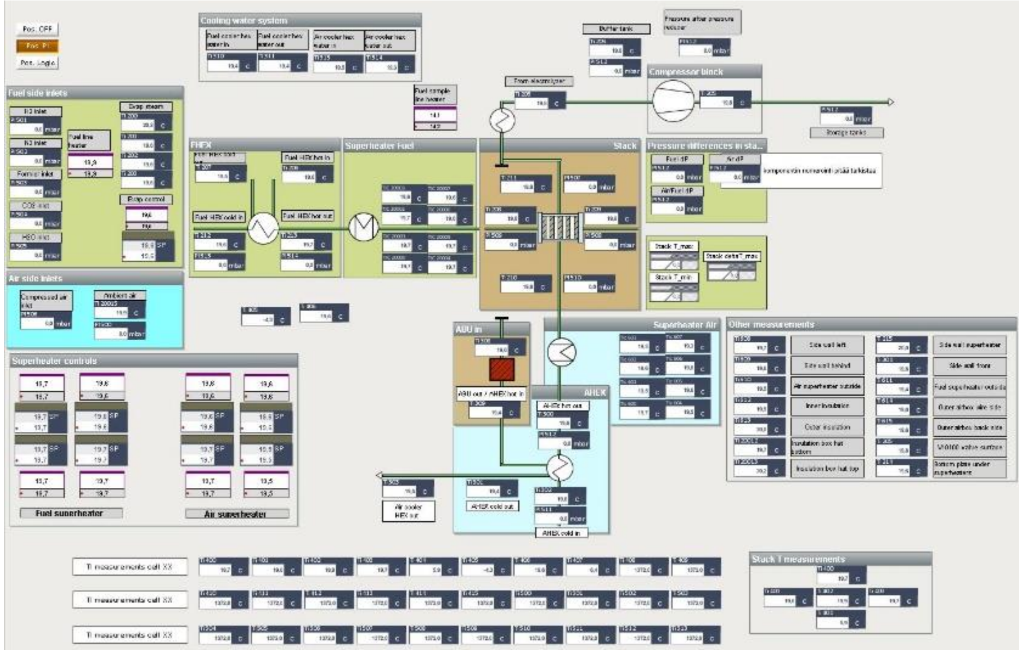
T1.1 SOEC System proof and operation validation





Developed automation control system and HMI.

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T1.1 SOEC System proof and operation validation

The installation of cylinder-shaped insulation dome over the stack module.

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T1.1 SOEC System proof and operation validation

The BoP hotbox module was filled with granule sealing material and cylinder-shaped insulation dome was installed over the stack module.

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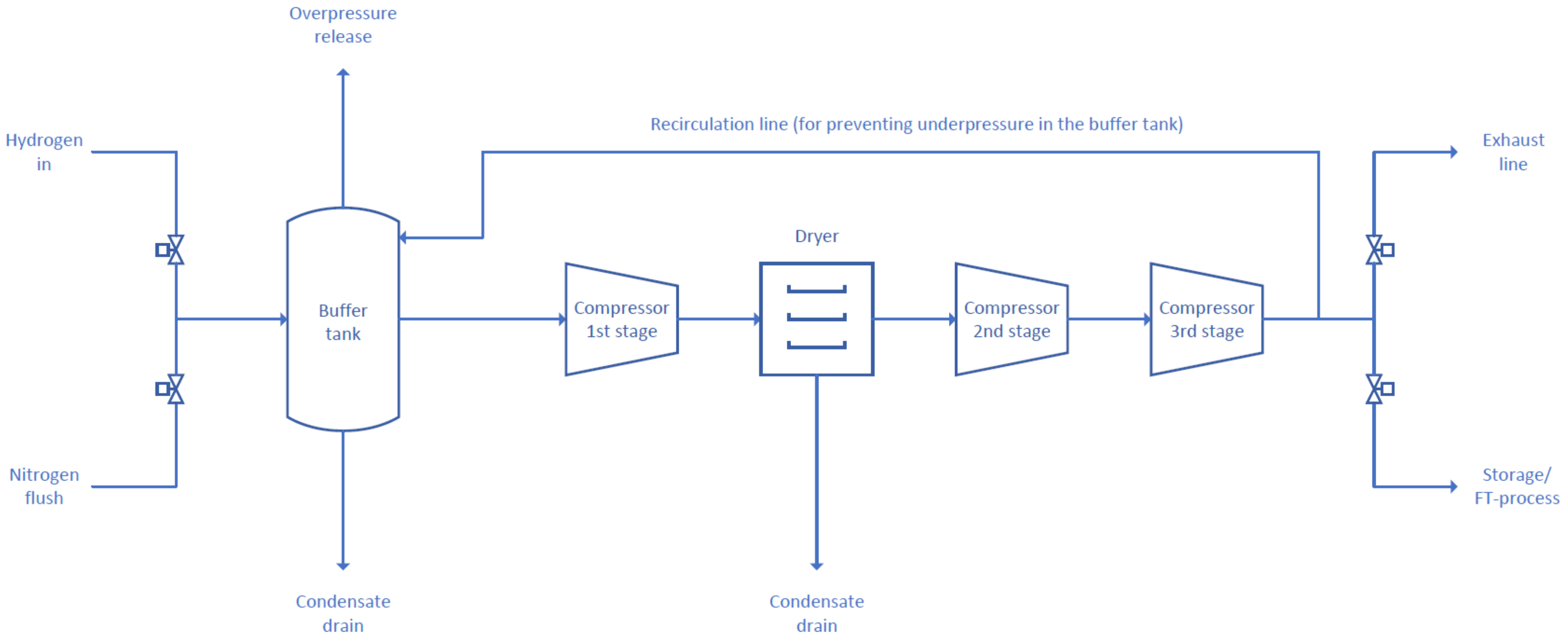
T1.2 SOEC downstream process development



Process flow diagram of the compressor system including the main process components.

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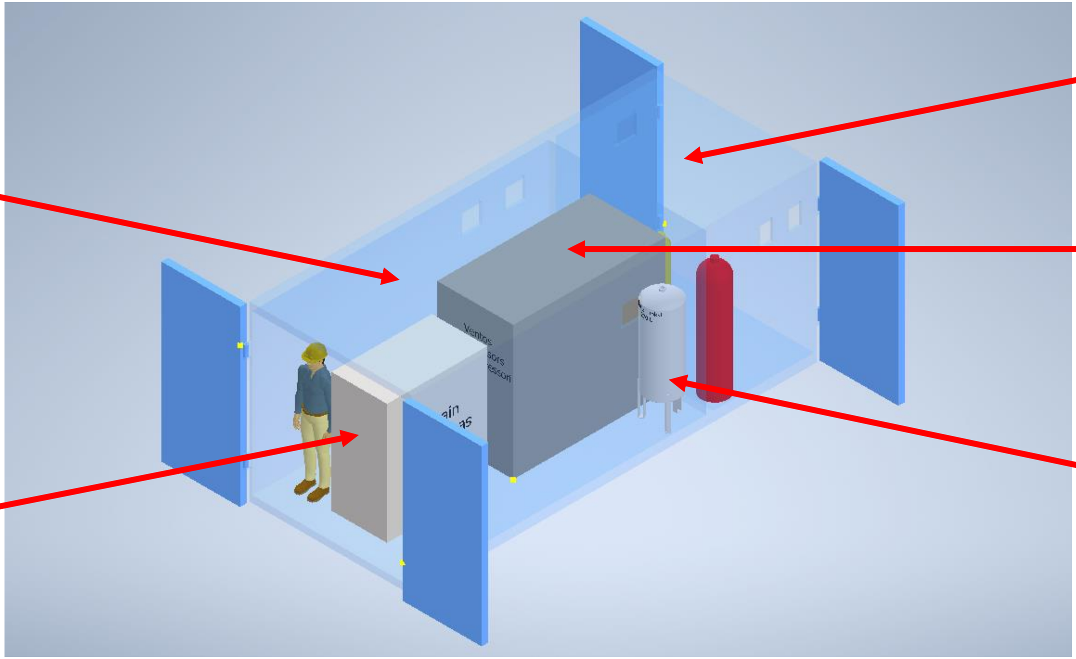
T1.2 SOEC downstream process development

Compressor room (ATEX)

Control room (automation, GC)



Compressor unit

H_2 dryer unit

H_2 Buffer tank

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T1.2 SOEC downstream process development

Process room (ATEX zone 2)	Equipment room
Hydrogen compressor	Main switchboard
Hydrogen gas dryer	Automation center (main)
Inlet buffer tank	Automation center (compressor)
Piping	Automation center (dryer)
Valves	Indoor air blower
Process sensors	Indoor air gas sensors (2x H_2 + O_2)
Indoor air blower	Room heater (2 kW) + thermostat
Indoor air gas sensors (2x H_2 + O_2)	Gas control panel
Room heater (3 kW) + thermostat	Dryer’s chiller unit
	Gas chromatograph

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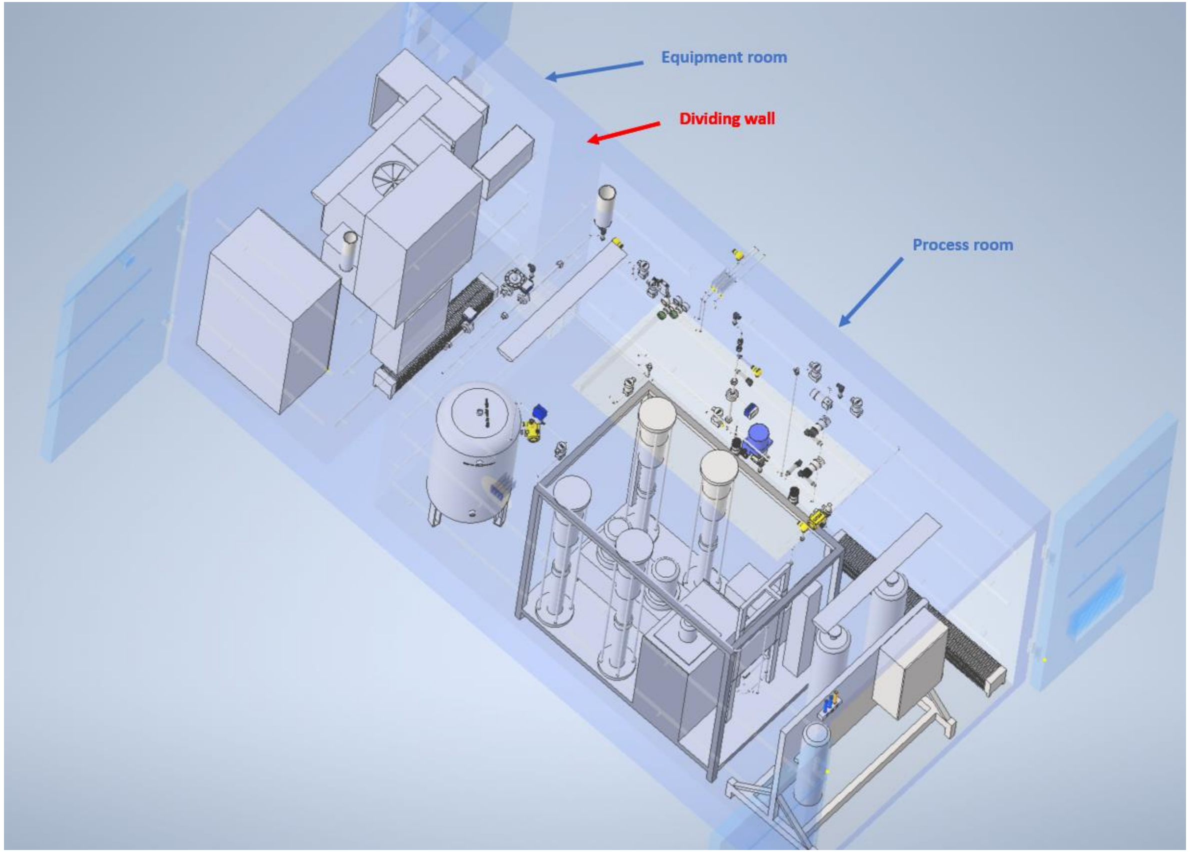
T1.2 SOEC downstream process development



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T1.2 SOEC downstream process development

20ft container where the hydrogen compression system is being built.

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T1.2 SOEC downstream process development

Hydrogen gas dryer

Hydrogen gas compressor (3 stage)

Buffer tank (Compressor inlet)

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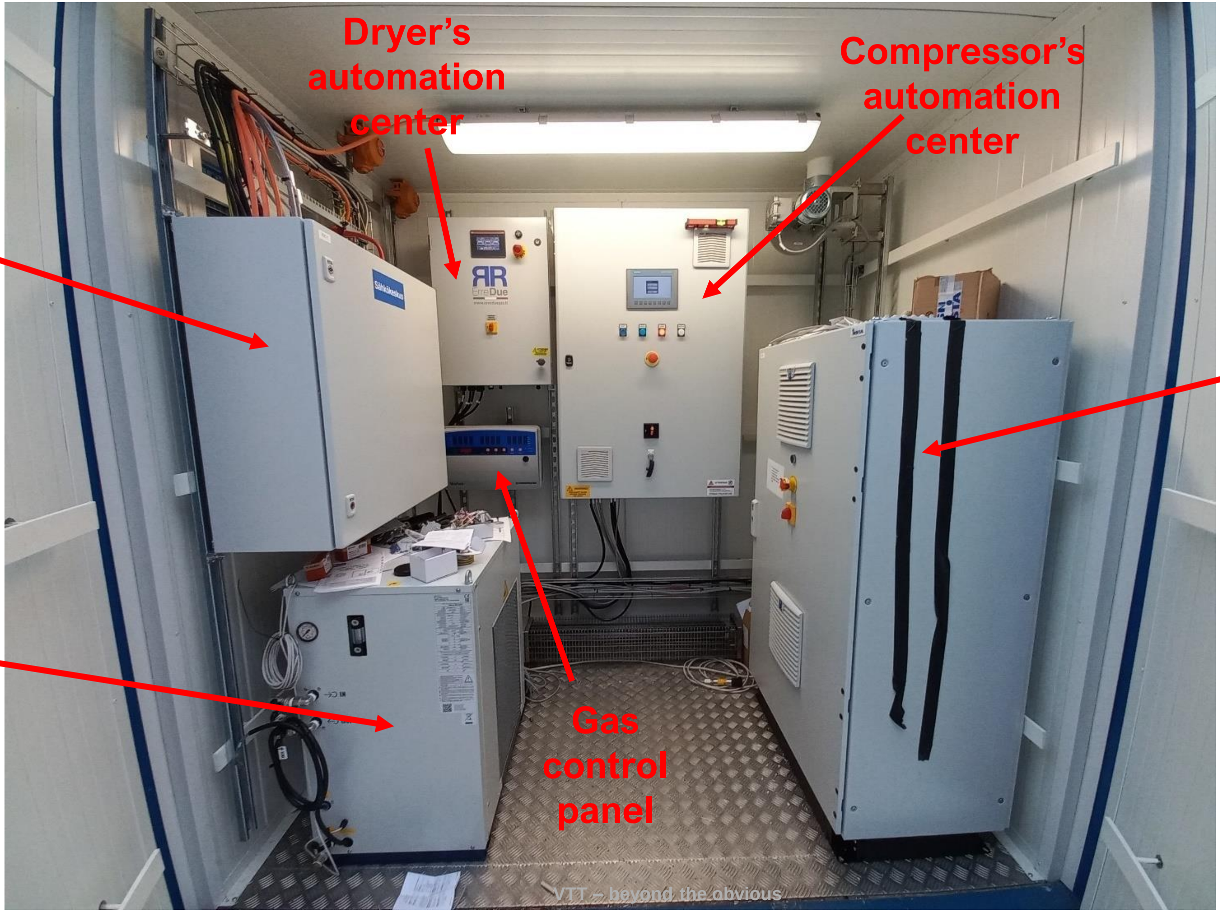
T1.2 SOEC downstream process development

Container main switchboard

Chiller unit of the hydrogen gas dryer



Container's automation center

WP1 Summary

- ***T1.1 and T1.3:*** A 10kW size Solid Oxide Electrolyser (SOEC) system with Elcogen E3000 stack was designed, built and tested at VTT. The preliminary testing showed that the performance values were very similar compared to the stack performance results. Also control and safety systems, automation and Human Machine Interface (HMI) for VTT’s SOEC system were built and tested successfully.
- ***T1.2:*** Hydrogen compressor and auxiliary components were designed and built and HAZOP analysis was done – the automation system building is still in progress. Elcogen’s mechanical compressor testing was completed at VTT's premises
- ***T1.4:*** All tests were finished successfully: two 3000h+ long-term tests with Elcogen's 15 cell stack and one 3000h+ test with Elcogen's E3000 (119 cells) SOEC stack

→ more details in deliverables *D1.1-D1.4*

Thank you for your attention. Any questions?

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