# Next generation $H_2$ technologies - Design, manufacturing, and operation of 10 kW rSOC system

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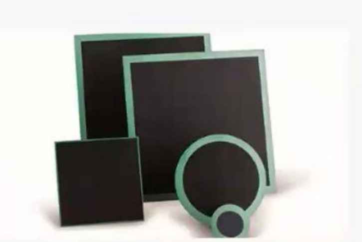
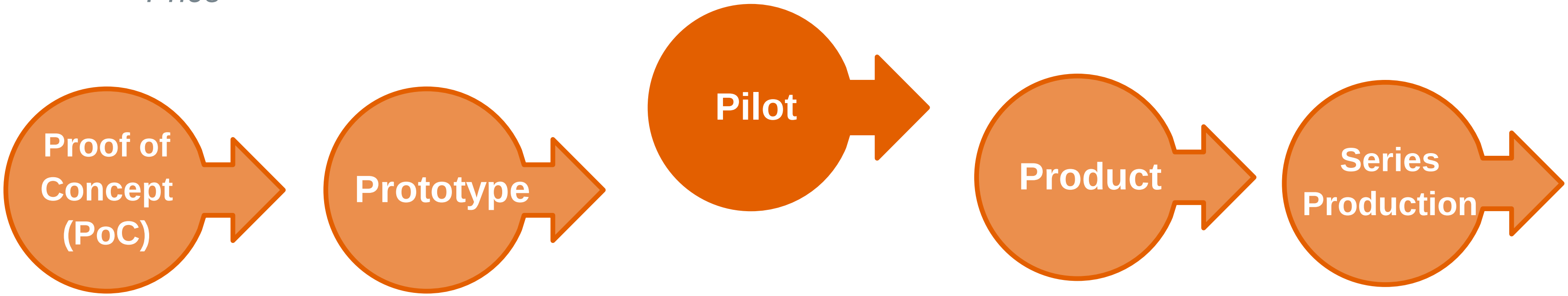
# Features of Reversible Solid Oxide Cell (rSOC)

- High operation temperature: 600-850$^{o}$C
- **SOC technology is reversible**: the same system can work both as a fuel cell and an electrolyser depending on the needs
- Fuel flexibility in SOFC mode and high efficiency (60%)
- SOEC has a **high electrical efficiency** in electrolysis mode (80-90%)
- SOEC has capability also for **co-electrolysis of steam and $CO_2$**
  - ✓ Enables more efficient power-to-X
- The most commercial electrolyser is alkaline
  - ✓ Process has low efficiency due to needed of high operation voltage.
- PEM based technology is more expensive than alkaline
  - ✓ Availability of Platinum and Iridium catalyst/metal
- SOC is a good technology for green, flexible and efficient energy systems
  - ✓ Less mature



# Motivation for rSOC system study

- Motivation is learning about new technology
  - ✓ Modelling, developing, testing and demonstrating
  - ✓ Finding system boundaries for optimized system
- End users main points of interest:
  - ✓ *Efficiency*
  - ✓ *Operation window*
  - ✓ *Lifetime of the system*
  - ✓ *Price*

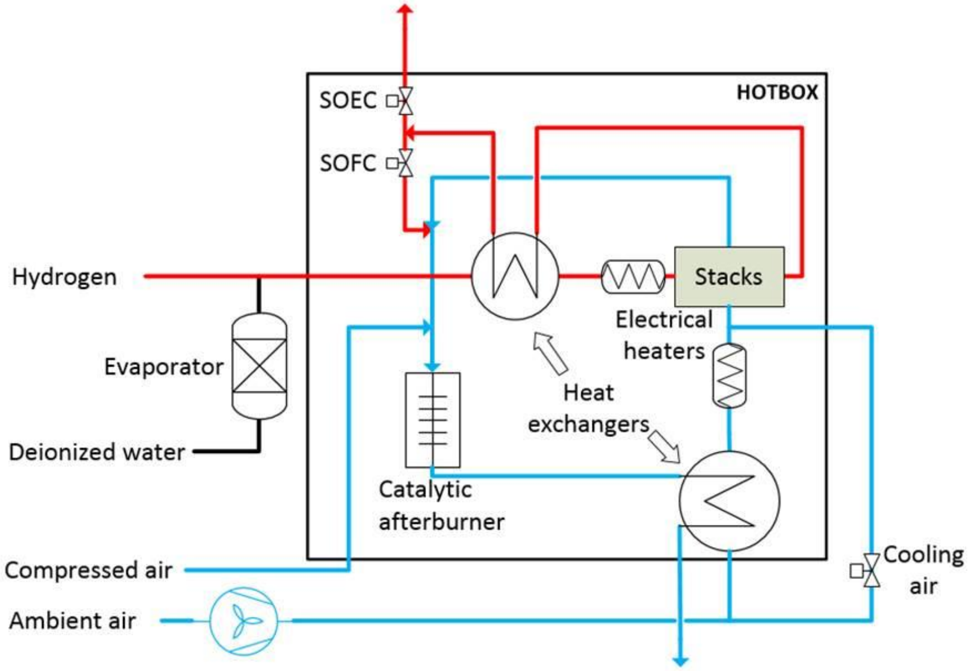


# rSOC pilot system design targets

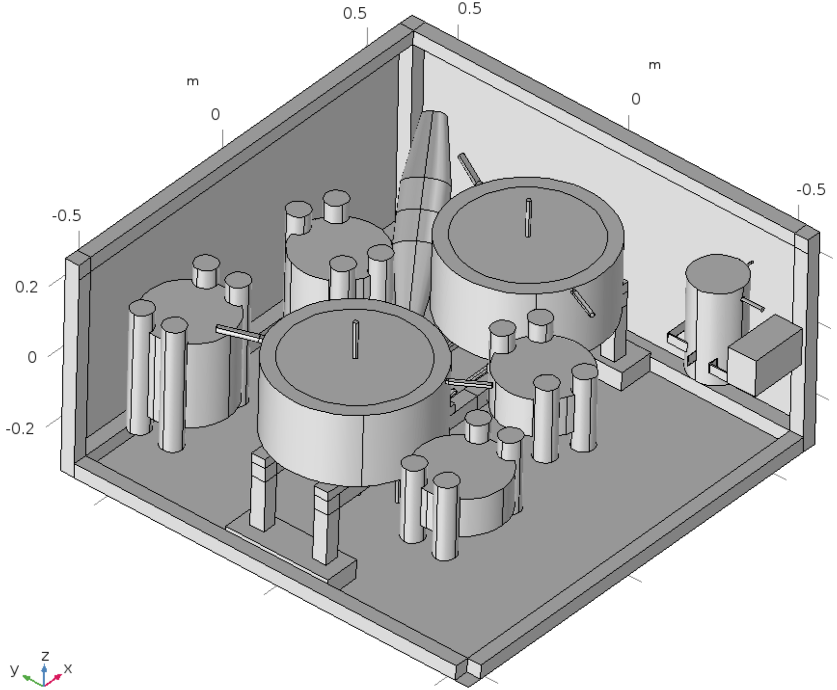
- Movable and “10 feet container” size
- 2-module 2-stack system with common gas supply
  - ✓ Designed to be scaled up
- Special attention to system heat management
  - ✓ Insulation, component placement and waste heat recovery
- AC electricity supply to local (in-house) electricity network
- Option for hydrogen compressor and storage in the future
- Highly instrumented system with 250+ measured variables: mass flow controllers (8), gas valves (10), bidirectional loads (2), humidity (2), pressure (13) and temperature (30+) measurements, cell voltages (50+)…
- Efficiency targets in multi-kWe scale:
  - ✓ 50 % in fuel cell mode (LHV, no hydrogen recycling)
  - ✓ 90 % in electrolysis mode (HHV)
- Long-term durability test of 2500 h including reversible cycles

# Simplified PI diagram of 10 kW rSOC system

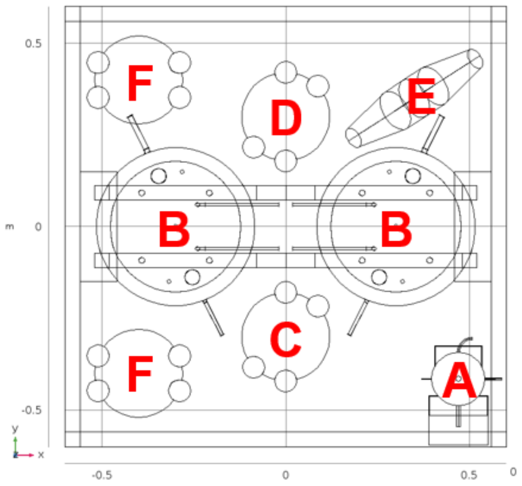
- Two stacks
  - ✓ EU Balance project
  - ✓ CEA, DTU cells
  - ✓ ~7 kWe SOEC (0.2 kg $H_2$/h)
  - ✓ ~2 kWe SOFC
- Operating temperature 700-750°C
- Hydrogen as fuel and product
- No reformer needed



# Placement of the hot box components

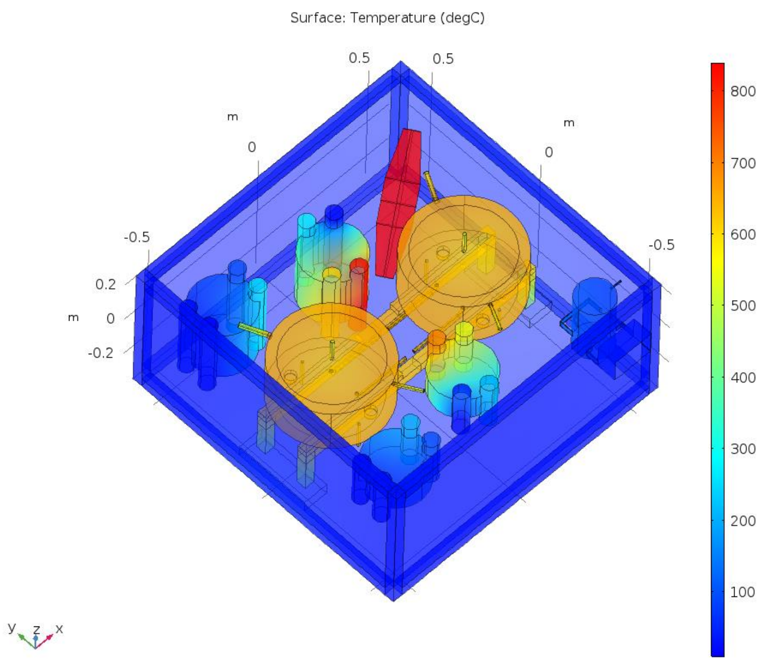



Size: 1.2 m x 1.2 m x 0.8 m ≈ 1 $m^3$

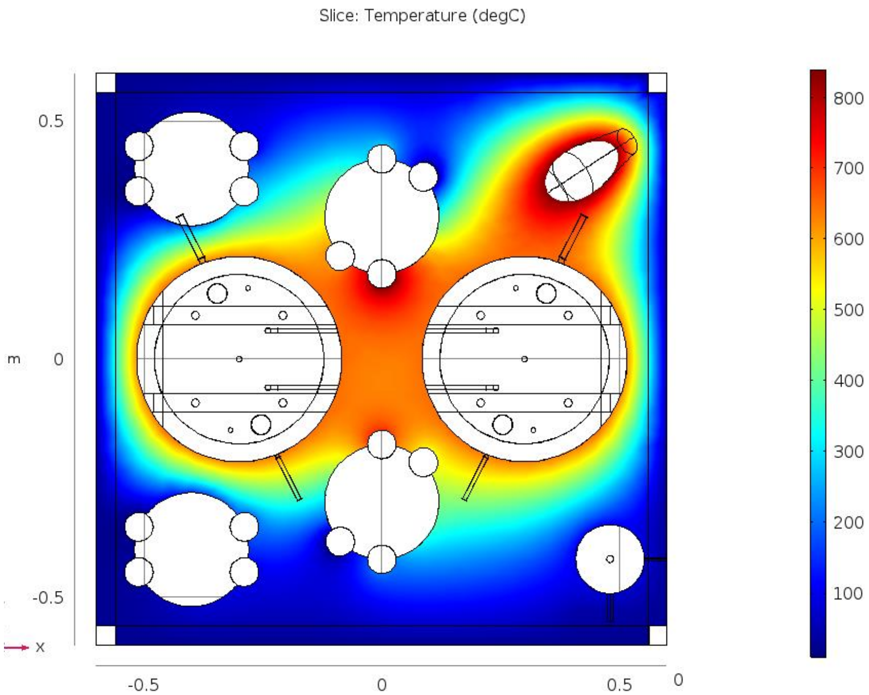



A: Evaporator
B: Stack modules
C: Fuel heat exchanger
D: Air heat exchanger
E: Catalytic afterburner
F: Outlet gas coolers

# Model of the component surface temperatures (left) and insulation material temperature (right) (SOFC mode)



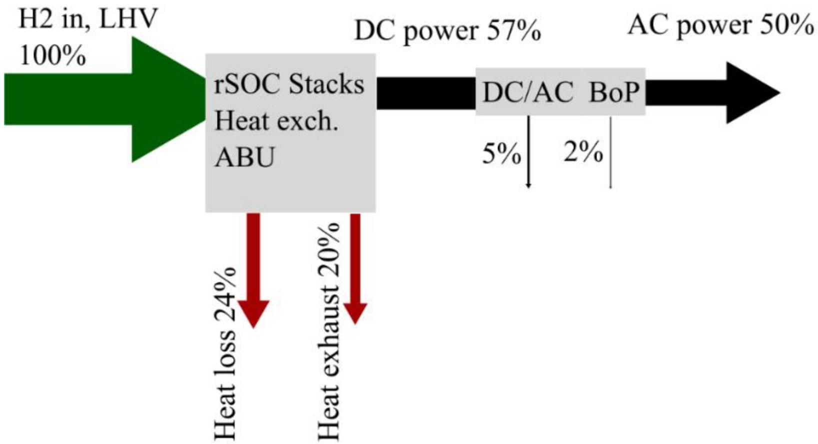

Component surface temperature




Insulation material temperature

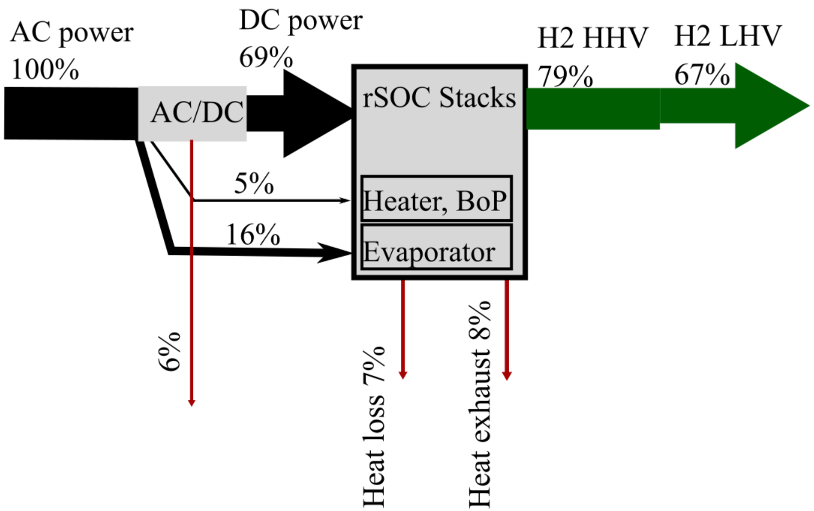
# Nominal points and calculated efficiency (SOFC)

- **SOFC nominal point:**
  - ✓ $H_2$ 100 %
  - ✓ $U_f$ = 80 %
  - ✓ i = 0.4 A/cm$^2$
  - ✓ $T_{stack\ outlet}$ = 700 °C
  - ✓ **$H_2$-to-AC 50 % (LHV)**
  - ✓ $H_2$-to-AC 43 % (HHV)



# Nominal points and calculated efficiency (SOEC)

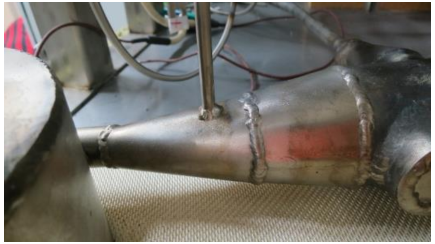
- <u>**SOEC nominal point:**</u>
  - ✓ $H_2/H_2O$ = 10/90
  - ✓ SC = 80 %
  - ✓ i = 1 A/cm$^2$
  - ✓ $T_{stack\ inlet}$ = 700 °C
  - ✓ $T_{stack\ outlet}$ > 700 °C
  - ✓ **AC-to-$H_2$ if steam production included**
  - ✓ 67 % (LHV)
  - ✓ 79 % (HHV)
  - ✓ **AC-to-$H_2$ if steam production excluded**
  - ✓ 80 % (LHV)
  - ✓ 94 % (HHV)



# rSOC system construction

Stack module
cover plate

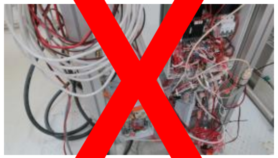
Coiled gas preheating tubing

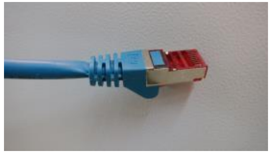


ABU inlet
tubing

# Digitalization with Modbus RTU protocol

- Lot of signals (250+): mass flow controllers (8), gas valves (10), bidirectional loads (2), humidity (2), pressure (13) and temperature (30+) measurements, cell voltages (50+)…
- Benefits of digitalization: better reliability, higher accuracy, more developed signal processing, smaller size, reduced signal noise…



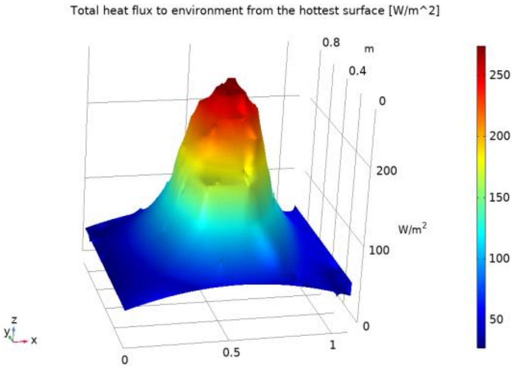



# Heat insulation

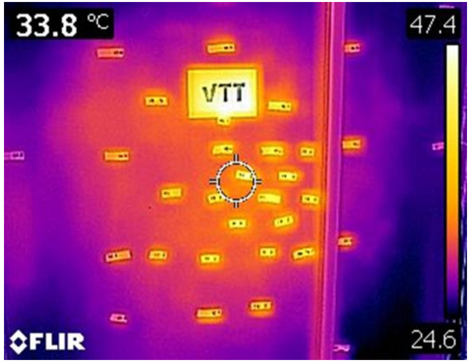
- First single component insulation
- Secondly hot box was be filled with microporous ceramic insulation material

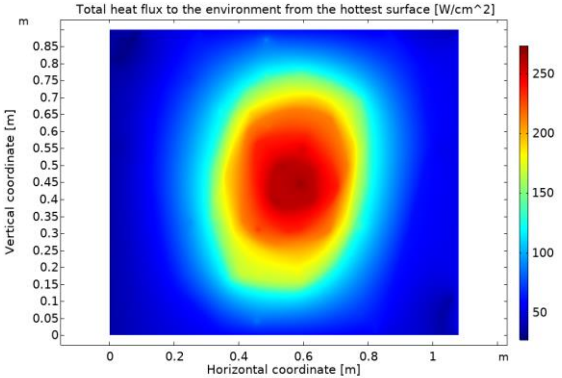
# Heat losses of rSOC system

- The total heat loss from rSOC system at 700 $^{O}$C is in order of 440 W.
- The design point value for total heat loss (in system model) was about 850 W at the design point
- Based on heat loss analysis we should reach quite good system level efficiency values for both SOFC and SOEC operation modes







# Measured system level SOEC efficiency

VTT

$$\eta_{AC\ to\ H_2}(HHV\ or\ LHV) = \frac{HHV\ or\ LHV\ of\ produced\ H_2}{Total\ AC\ power\ input}$$

- Where *Total AC power input = AC power input for electrolysis + AC power input for heaters + AC power input for evaporator*
- The *AC power input for electrolysis* includes all AC power consumed by the power supply. This term also takes into account the voltage losses outside the stack, the power consumption of the power source, and the AC/DC conversion efficiency

| rSOC system level | AC power for steam production included | Free 150 $^oC$ steam flow assumed |
|---|---|---|
| AC to $H_2$ efficiency (HHV) | 71 % | 81 % |
| AC to $H_2$ efficiency (LHV) | 60 % | 69 % |

# Conclusions

- Movable 10kW reversible solid oxide cell (rSOC) system has been modelled and demonstrated in pilot scale
- System run 5000h+
- Reversibility and dynamic operation in system level
  - ✓ Transitions between SOFC and SOEC modes was proven
- Multi-stack multi-module rSOC system operation has been demonstrated
- Efficiencies were very good for prototype
  - ✓ SOFC +50% (LHV)
  - ✓ SOEC +80% (HHV)
- System efficiency can be improved in a larger system:
  - ✓ Hydrogen recycling: ~ 5-10%
  - ✓ Pre-heat the water: up to 2 %
  - ✓ Reduction of heat loss (negligible): 7 %
  - ✓ More efficient AC/DC converter  (currently 89%)

# Acknowledgements


- Reversible solid oxide cell, stack and system research as a part of BALANCE EU project (https://www.balance-project.org) has been funded by H2020 under the grant agreement 731224.
- The development work for movable rSOC system has been done as a part of Finnish national Smart Otaniemi project (https://smartotaniemi.fi)
- Our partners for cell and stack production:

beyond
the obvious

Thank you!

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