

Session 3: how to guarantee uninterrupted operation of SOC systems

Power-to-Gas-to-Power as a key solution for continuous SOC operation

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Webinar Solid Oxide Cells: from materials to systems
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Outline

What is a SOC system?

Why is continuous operation preferable?

How is continuous operation possible for SOFC and SOEC systems?

Reversible SOC systems as a solution for uninterrupted operation

What are the dynamics related to the rSOC systems?

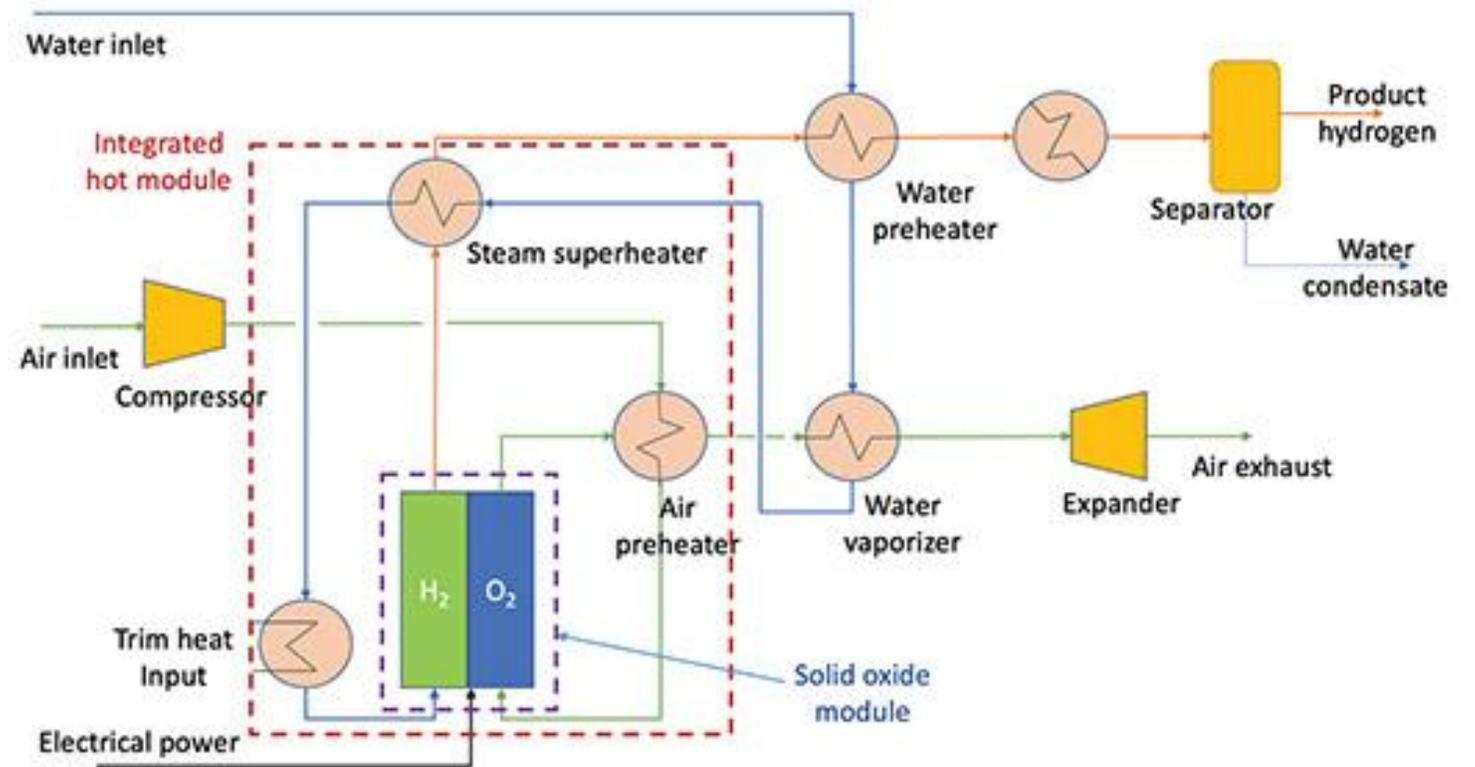
What the 24/7 ZEN project is studying?



Co-funded by
the European Union



SOC systems



Elements from the balance-of-plant

- Hot module
- Steam generator
- Heaters
- Heat Exchangers
- Compressor
- Blowers

Why is continuous operation preferable?

System dynamic

- Cold start-up → 10-30 h to reach targeted temperature and stabilized BoP
- Hot standby mandatory between operation phases
- System cool down only for maintenance

Efficiency and energy consumption

- Each period of non-production implies a system efficiency loss
- Hot standby consumption → 5-15% of nominal power

Material degradation

- Higher risk of accelerated degradation if frequent start/stop or thermal cycling (mechanical stress → contact loss, cracking, delamination risk)



Continuous operation for SOEC systems

H2 production

Electricity from the grid

- Carbon intensity of the current energy mixture
- Electricity from only 2 EU countries meeting the RFNBO* emission threshold

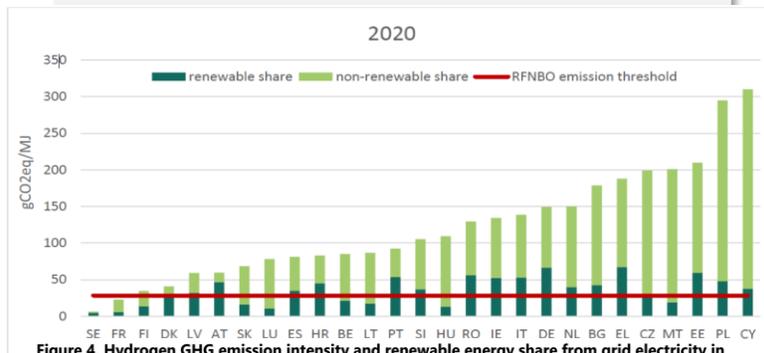


Figure 4. Hydrogen GHG emission intensity and renewable energy share from grid electricity in 2020 for different countries in EU¹⁸.

Green H2 production

Electricity from the grid with certified PPA*

- Contract signed with a RES plant that must be located nearby.
- Until 2029, monthly match of electricity consumption and production. From 2030, hourly match.
- Increase of the LCOH if excess of electricity from RES plant.
- Use of energy from the wholesale electricity market if lack of production

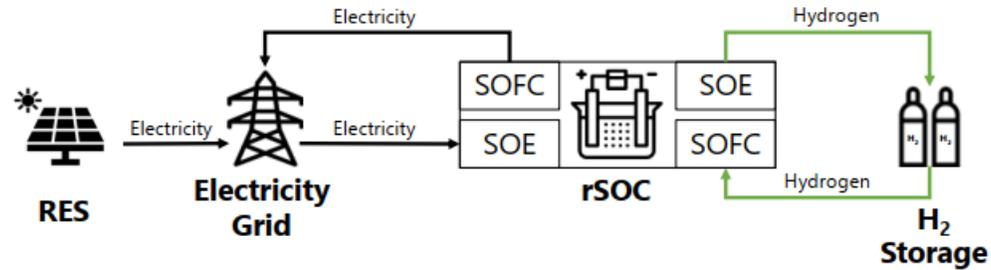
Green H2 production

Direct RES connection + electricity storage

- Additional CAPEX and land usage for the RES plant and the batteries
- Low production if no connection to the electricity from the grid

Ref: Hydrogen Europe Clean Hydrogen Monitor 2022

Reversible systems as a solution



Maximized Operational Utilization

- Higher annual operating hours
- Better capital utilization
- Reduced idle time
- One stack instead of two separate systems

Reduced Balance-of-Plant Duplication

- Shared stack housing
- Shared heat exchangers
- Shared high-temperature components
- Reduced footprint
- Lower total CAPEX

High Round-Trip Efficiency

- SOEC efficiency: ~75–85% (HHV basis, system dependent)
- SOFC efficiency: ~55–65% electrical
- rSOC round-trip efficiency: ~40–55%
- Increased if waste heat is available

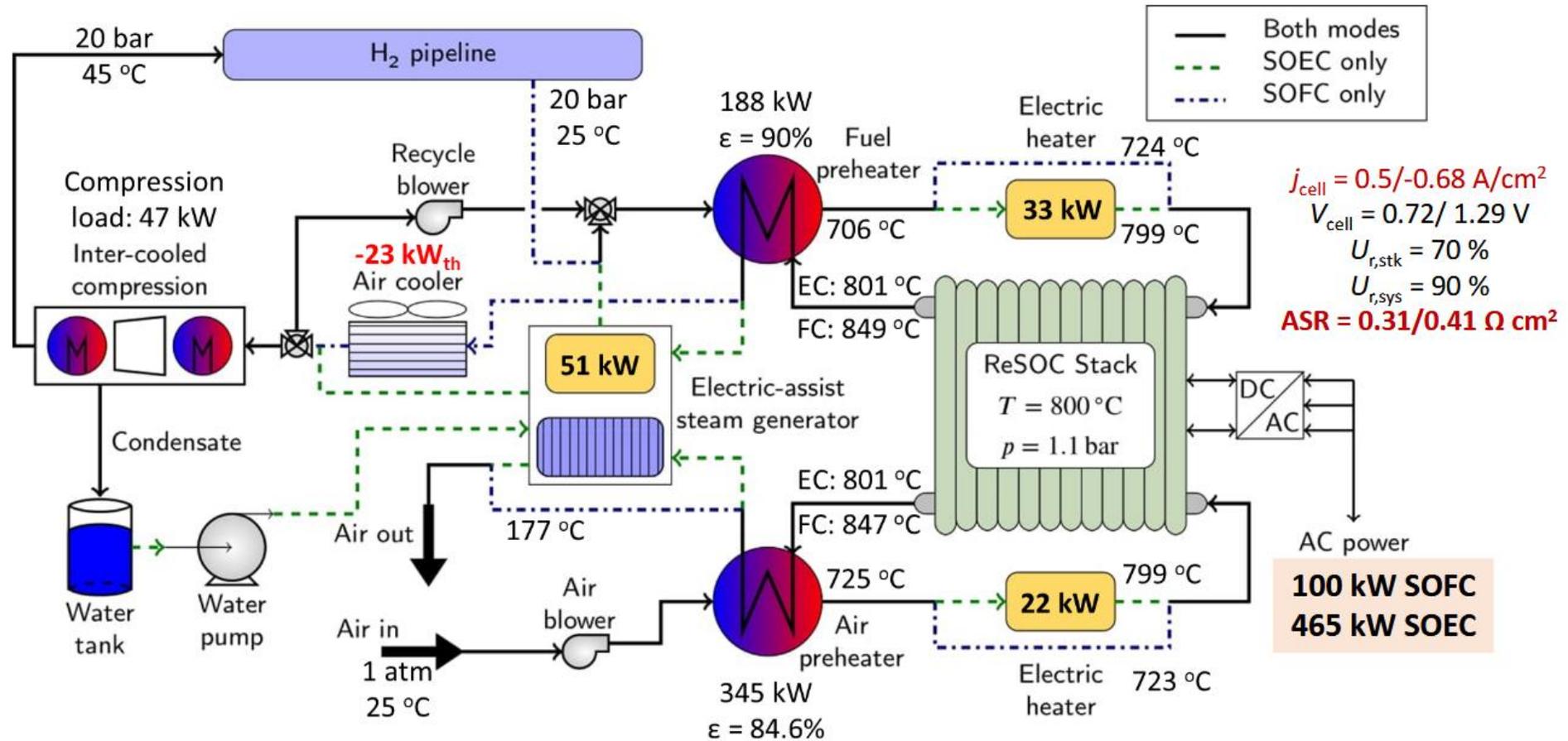
Enables Long-Duration Energy Storage

- Multi-hour to multi-day storage
- Seasonal storage potential
- Grid balancing at large scale
- Energy shifting across markets

Grid Flexibility & Ancillary Services

- Absorb excess renewable electricity
- Provide dispatchable power when needed
- Offer grid frequency regulation
- Participate in arbitrage markets

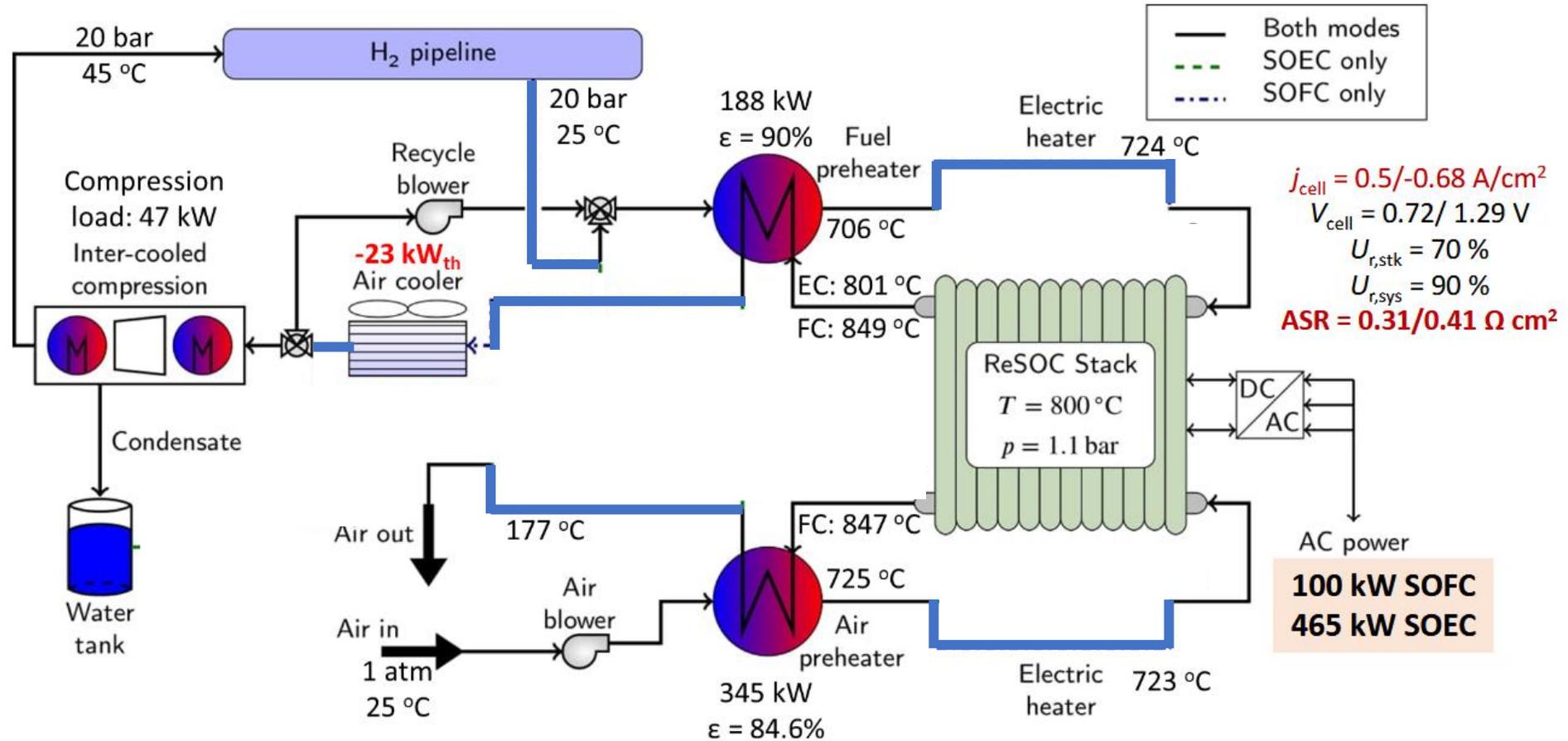
Reversible systems as a solution



https://netl.doe.gov/sites/default/files/netl-file/24FECM_SOFC_Vaeth.pdf

Reversible systems as a solution

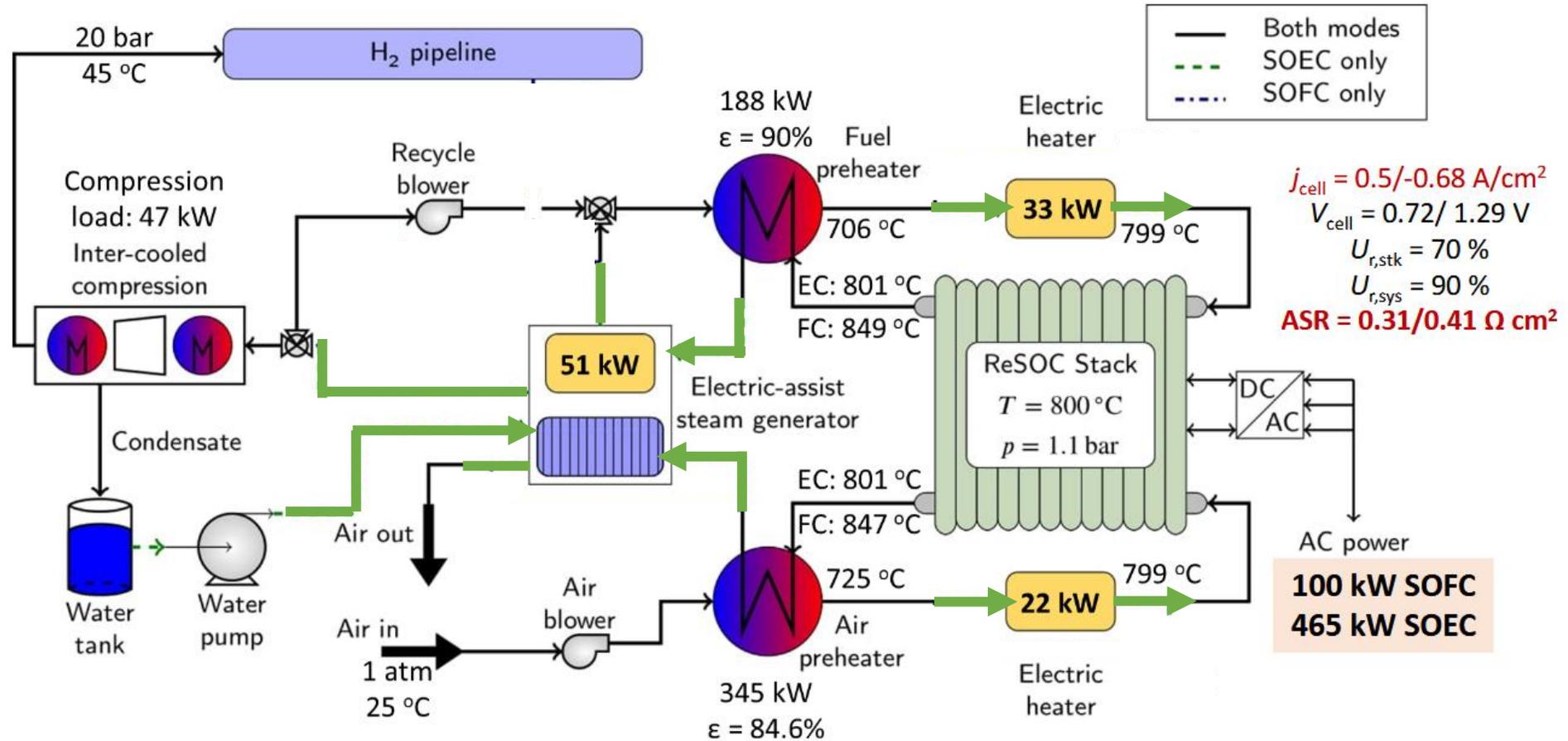
SOFC mode



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Reversible systems as a solution

SOEC mode



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Dynamics from rSOC systems

Switching between SOFC and SOEC modes

- Reversing current direction
- Changing gas flows and utilization
- Rebalancing thermal gradients
- Adjusting air/fuel flow ratios
- Maintaining near-thermal-neutral operation

Electrical dynamics (ms – s)

- Current changes respond almost instantly
- Cell voltage shifts immediately with load
- Double-layer and electrochemical kinetics effects
- Power electronics dominate response speed

Thermal dynamics (min – h)

- Large thermal inertia (ceramics + steel)
- Stack temperature response → minutes
- Full system temperature shifts → tens of minutes to hours
- Slow heat-up and cool-down
- Internal temperature gradients during load changes
- Risk of thermo-mechanical stress

Gas composition dynamics (s – min)

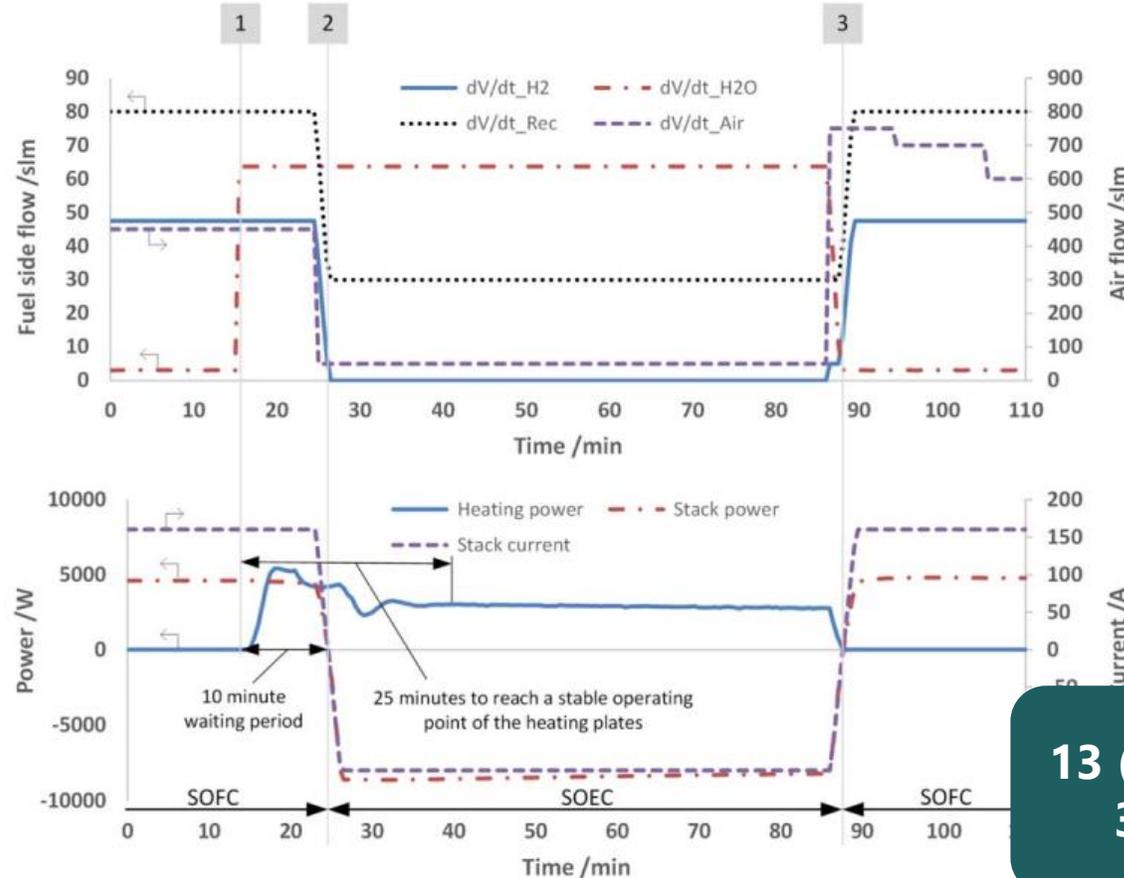
- Gas residence time and manifold volume create delays
- Risks of steam/fuel starvation during fast ramps
- Thermal oscillation if air flow is not well controlled
- Slow dynamic of the steam generator

Dynamics from rSOC systems

Study of the transition durations for a 5/15 kW SOFC/SOEC system

1/ Increase of the H₂O steam flow + increase of the stack temperature

2/ Change of the air and H₂ flows + switch from positive current to negative



13 (25) min → SOFC to SOEC
3 min → SOEC to SOFC

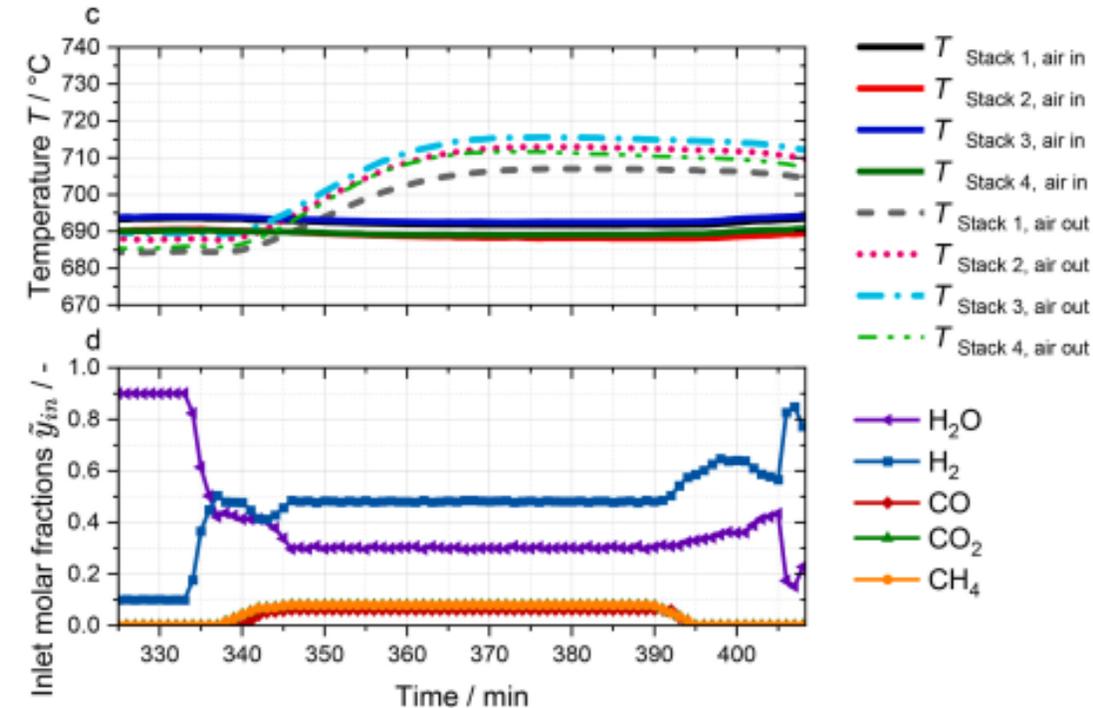
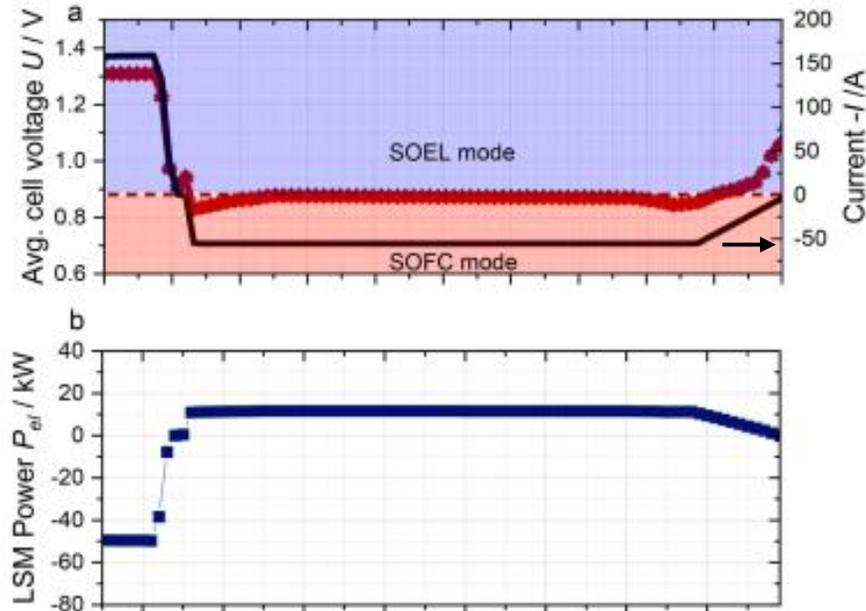
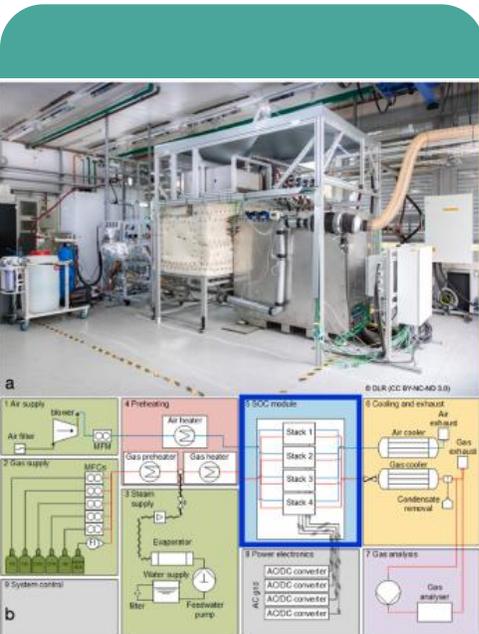
Figure 11. Switching procedure between fuel cell and electrolysis mode. From full fuel cell operation with a stack current of 160 A, the system is switched to electrolysis operation with -160 A. After 60 min under these operating conditions, it has been switched back to the fuel cell operation with 160 A. The upper part of the diagram shows the gas flows and the lower part the stack current, the power of the stacks and the heating plates.



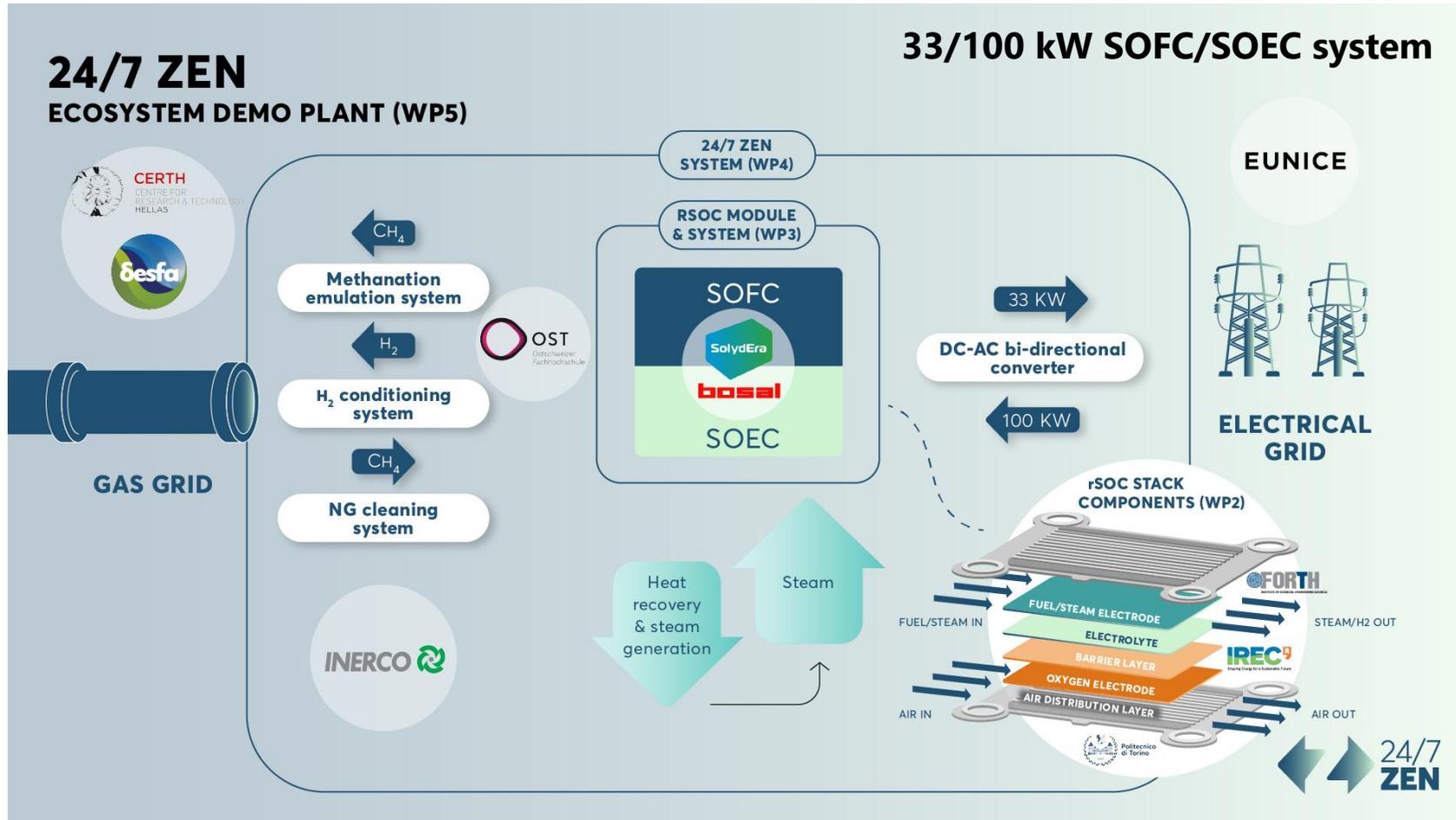
Dynamics from rSOC systems

Study of the transition durations for a 25/75 kW SOFC/SOEC system

30 min → SOEC to SOFC



24/7 ZEN rSOC system



24/7 ZEN rSOC system

Use Case 1: Hydrogen

- On-grid configuration with injection of the power in SOFC mode
- 10 kW PV installation on the building
- H₂ storage into bundles

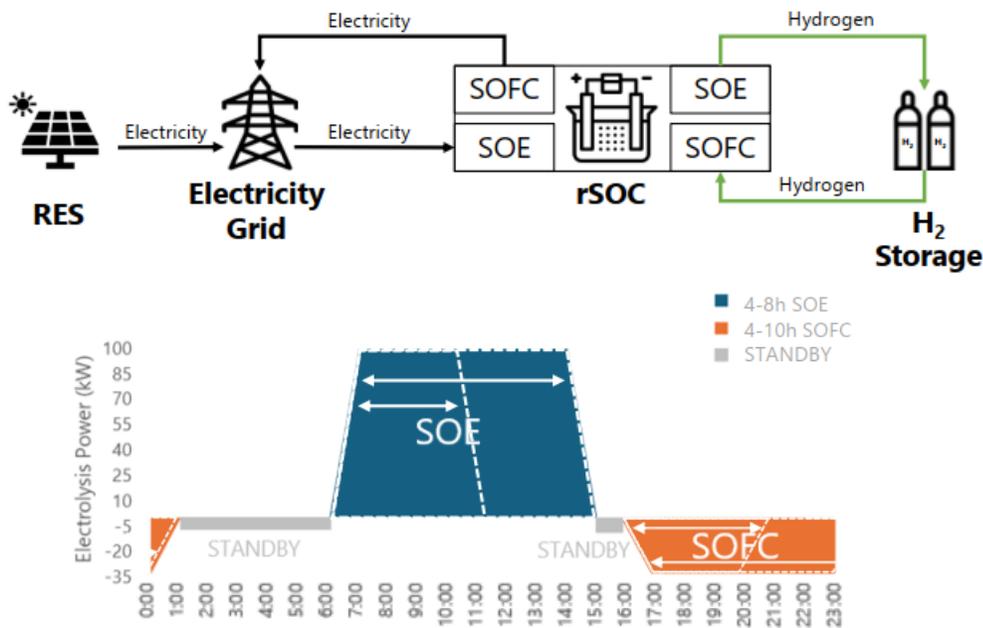


Figure 2: Daily operation profile of hydrogen use case.

Use Case 2: Natural Gas

- On-grid configuration with injection of the power in SOFC mode
- Natural gas as fuel supply

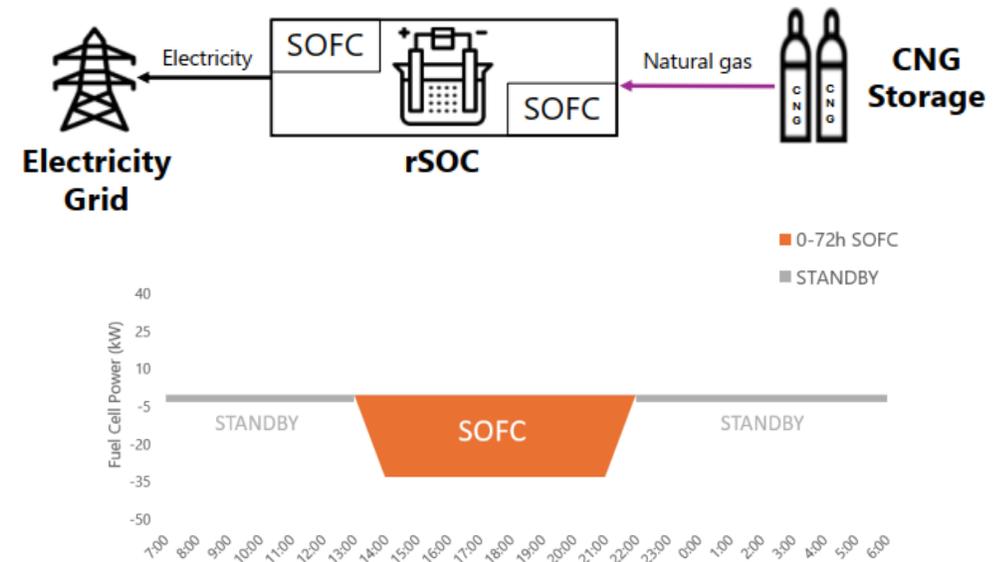


Figure 4: Daily operation profile of natural gas use case.

Conclusions

Uninterrupted operation allows to increase the system efficiency and decrease the production cost.

Reversible SOC system are a good alternative to maximize the system usage and act as grid balancing and long-term energy storage.

System dynamics allow rapid transitions from one mode to the other.

The 24/7 ZEN project will validate electricity and gas injection into the grid and gas network with a 33/100 kW SOFC/SOEC system.



Thank you!



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Follow the prototype
installation on [LinkedIn](#)
www.24-7zenproject.eu



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