



ARENHA

Ammonia fueled SOFC and steam electrolysis with different SOEC prototypes

Final workshop – 25 March 2025

Stefan Megel, Freddy Kukk



Contact: stefan.megel@ikts.fraunhofer.de

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862482

The present publication reflects only the author's views. The Commission is not responsible for any use that may be made of the information contained therein.

Overview

- Ammonia fueled SOFC system evaluation
- MK35x Stack assembly
- SOFC/SOEC performance map of MK35x stacks



- Elcogen SOEC cell development
- Elcogen short stack assembly and long-term test



- MK35x Stack module design, assembly and test
- E1500 Stack module design, assembly and test
- Conclusion





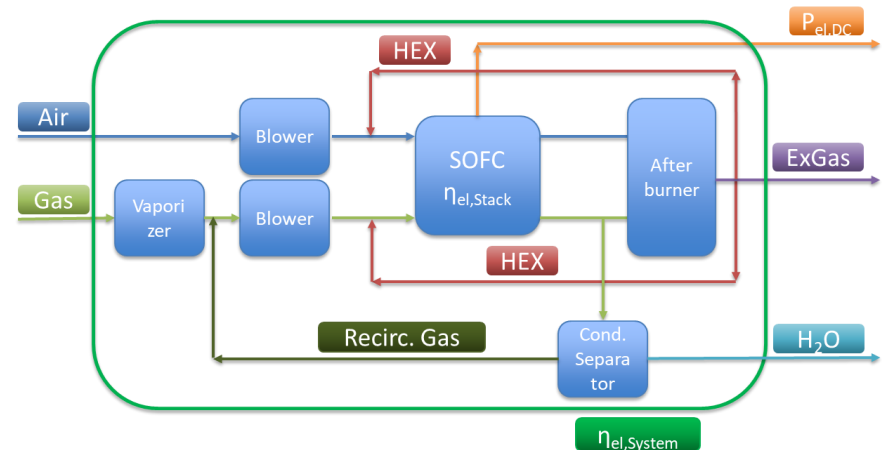
Ammonia fueled SOFC system evaluation

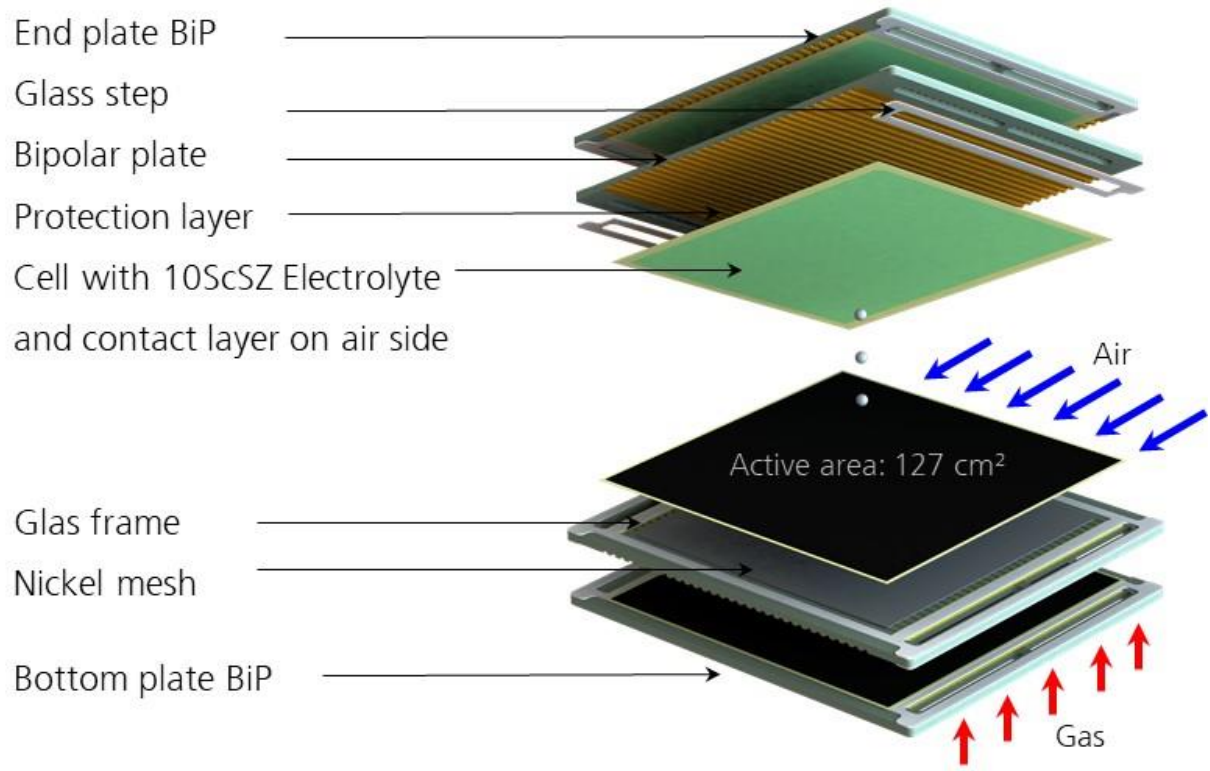


areNH3a



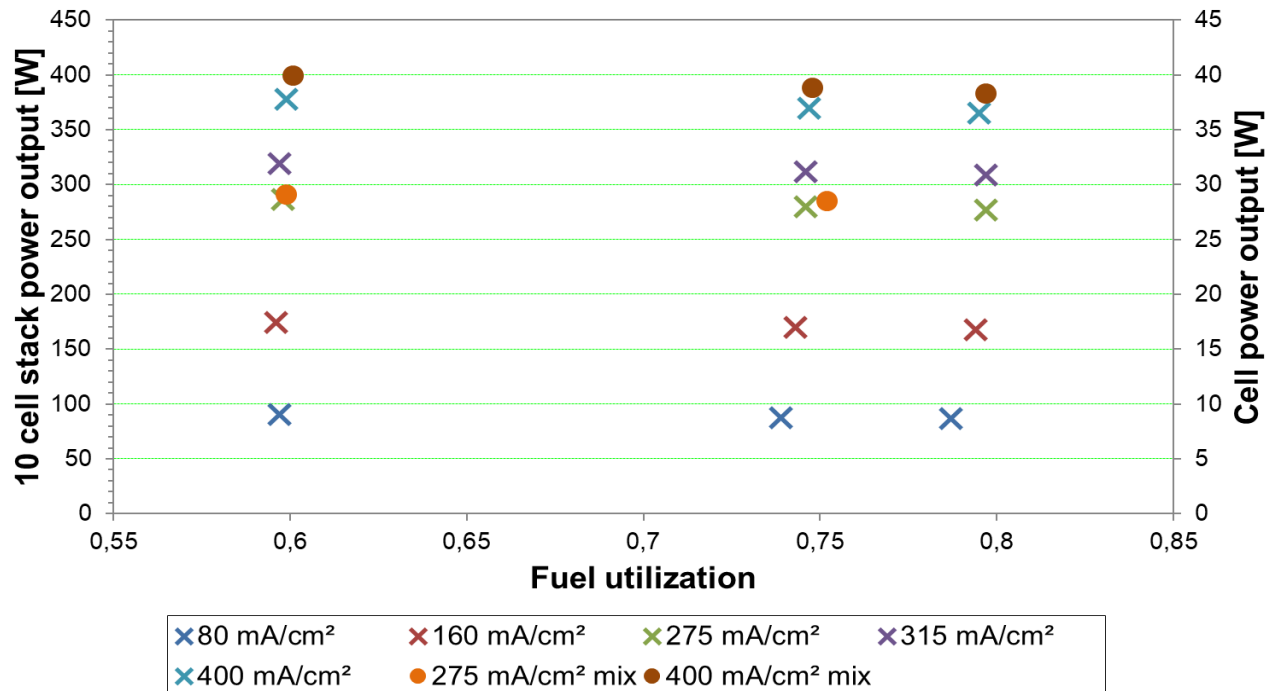
- Utilization of ammonia as fuel for SOFC
 - System evaluation
 - SOFC stack tests using ammonia
 - Check of NH3 cracking inside preheaters
- Electric efficiency (DC):
 - 51% with CPOx
 - 60% with anode gas recirculation
- Ammonia is a perfect CO₂ free fuel for SOFC





■ Improved cell by electrode optimization and optimized stack assembly

- SOFC performance map 10-cell MK35x stack @T=835°C, NH₃ vs H₂/N₂ mix



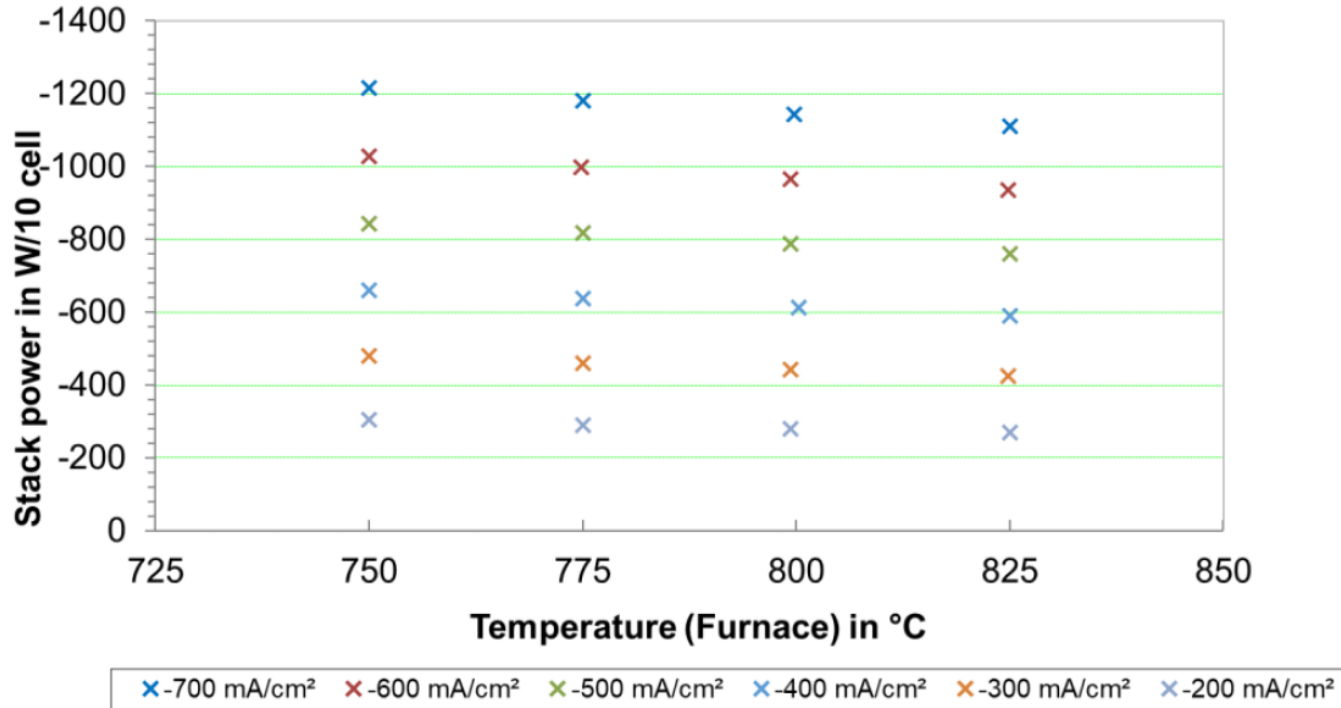
- Power output deviation NH₃ vs H₂/N₂ mix: 1-5%
- >50% NH₃ cracking at inlet pipes of test rig



SOEC performance map of MK35x stacks



- SOEC performance map 10-cell MK35x stack in steam electrolysis at 75% gas conversion at different temperatures



- Increased current density from -600 mA/cm² to -700 mA/cm²



SOFC and SOEC performance map of MK35x stacks



Conclusion and outlook



- MK35x stack for SOFC and SOEC with wide temperature window 750-860°C
 - SOEC: up to -120 W/cell, increased current density -600 mA/cm² to -700 mA/cm²
 - SOFC: up to 40 W/cell, NH₃ operation comparable to H₂/N₂ mixtures
- Ammonia cracks at stainless steel surfaces >600°C
- Efficient ammonia fueled SOFC systems possible with MK35x stacks
 - Less BoP: HEX at afterburner and no separate cracker, low blower power
- High temperature is a favor for NH₃ operation (low nitridification)

- Next experimental stack test with GC of inlet gases
 - Presentation at SOFCIX Stockholm



Elcogen experimental cell development and long-term test





Objectives:

Development of new Elcogen SOEC cell designs:

- New materials in the hydrogen electrode active layer.
- Changes to hydrogen electrode active layer microstructure.
- New materials in the air electrode layer.

Results:

3 modifications to hydrogen active layer gave positive results:

- $Ni_{0.9}Fe_{0.1}/8YSZ$
- $Ni/(8YSZ)_{0.9}(GDC)_{0.1}$
- $Ni_{0.9}Fe_{0.1}/(8YSZ)_{0.9}(GDC)_{0.1}$

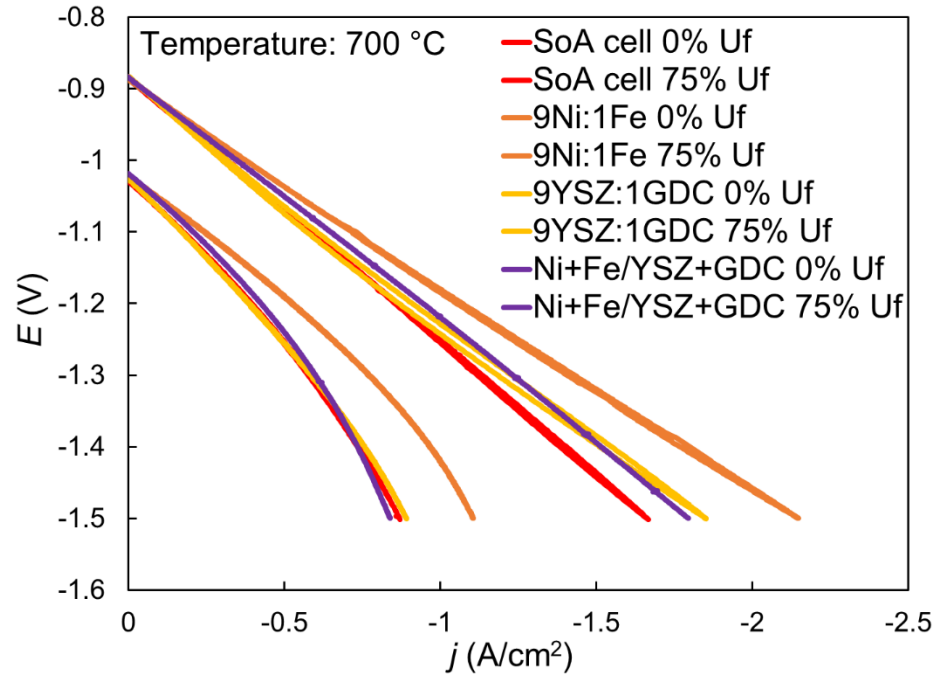


Figure 1. Single button cell performance test results at high and low fuel utilization.



Objectives:

- Validation of the single cell test results in a stack environment

Performance map test results:

- The $Ni_{0.9}Fe_{0.1}/8YSZ$ active hydrogen electrode
 - Fast stabilization
 - Stabilized by end of 1000-hour test
- Choice for the E1500 demo stack:
 - $Ni_{0.9}Fe_{0.1}/8YSZ$ hydrogen electrode active electrode
 - Thicker hydrogen electrode active layer

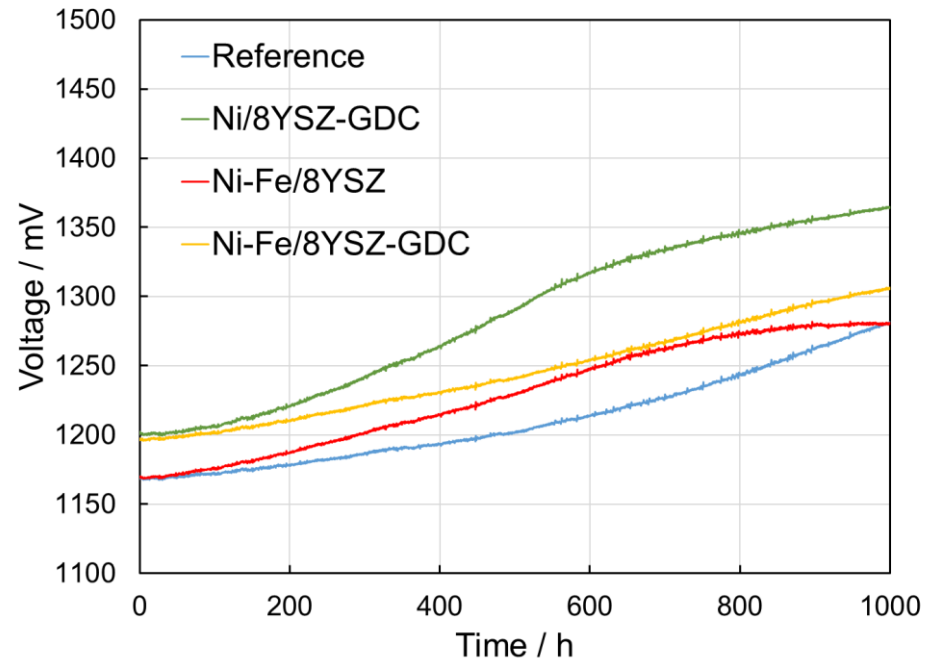


Figure 2. Short stack test results with the most potential cells



SOFC/SOEC performance map of E1500 stack



Assembly of the 5-kW stack:

- Manufacturing of the experimental SOEC with the chosen design was successful.
- 5-kW demo stack assembled and conditioned.
- Initial performance test in fuel cell mode presented.

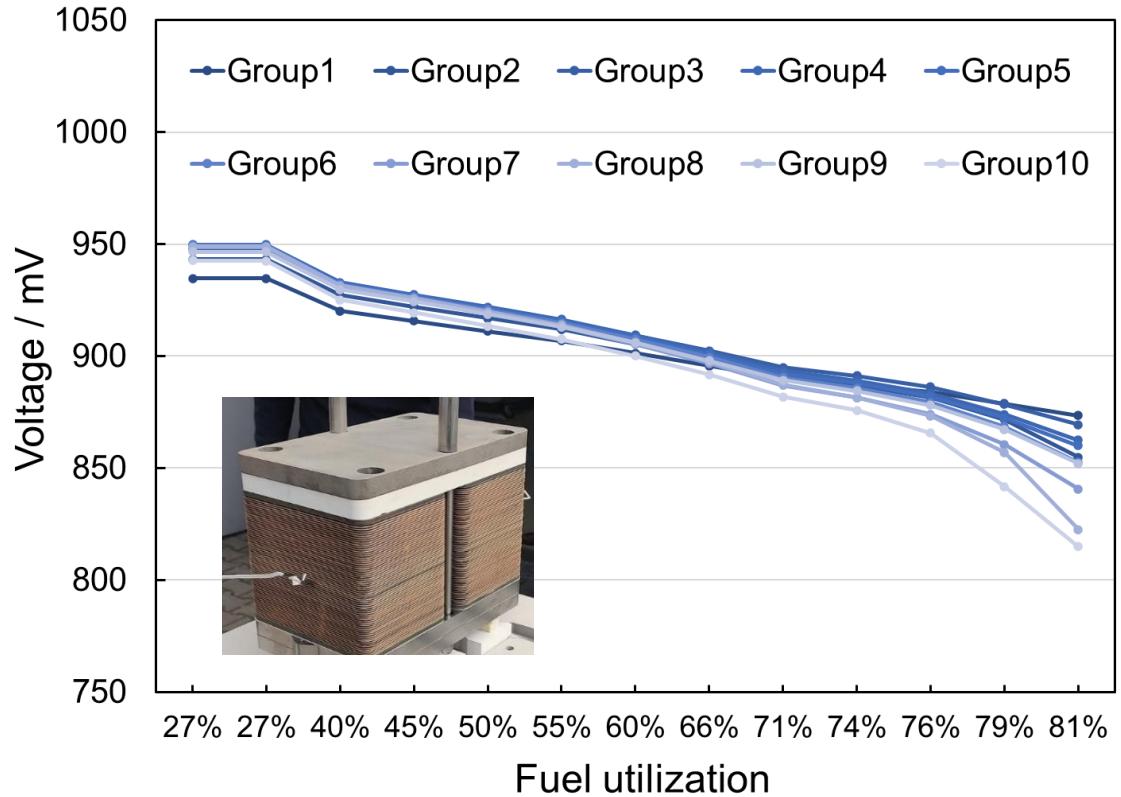


Figure 3. Preliminary demo stack performance test in fuel cell mode after conditioning.

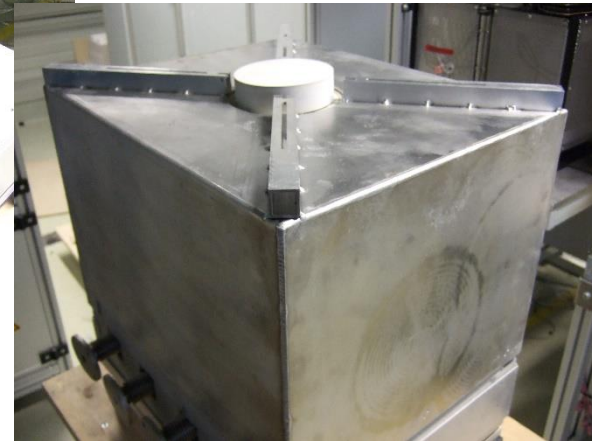
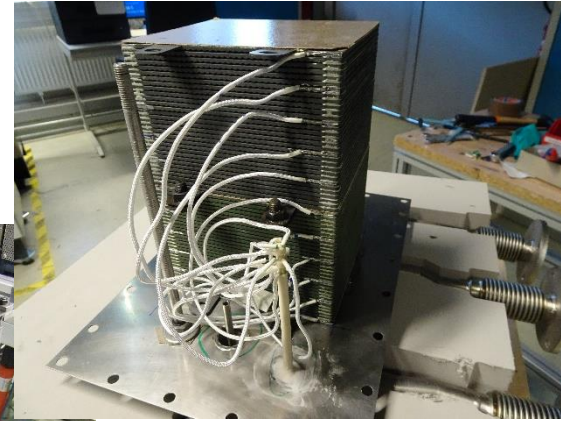
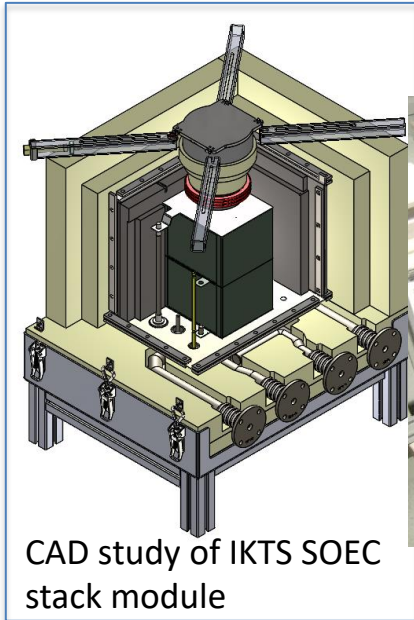


Stack module development for 5 kW SOEC prototypes





- Assembly of SOEC stack modules with IKTS stacks

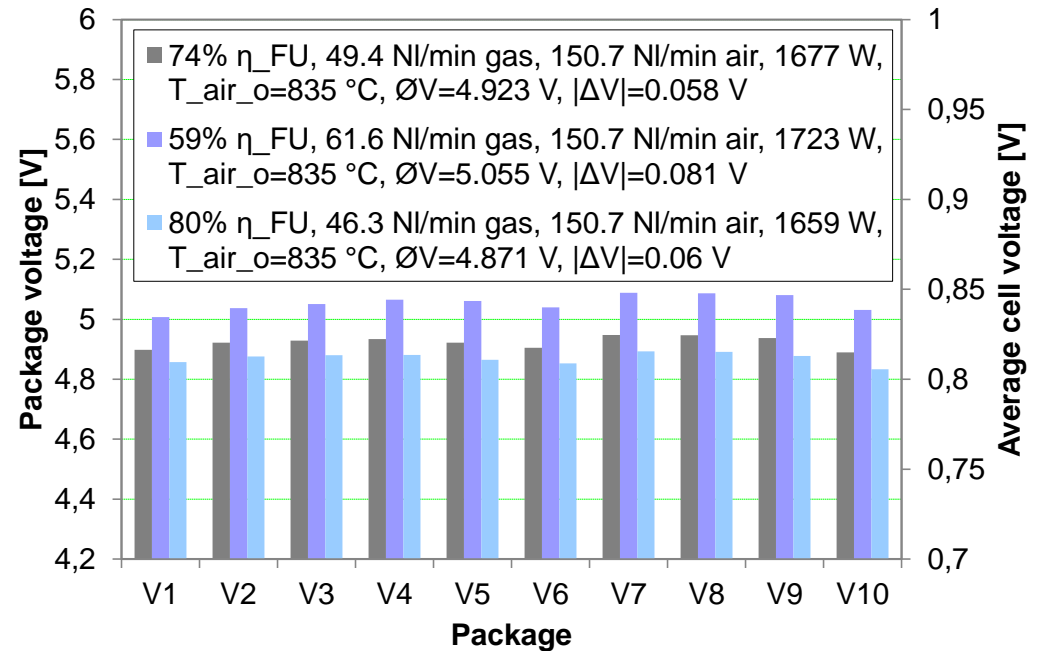


- Assembly with no problems



SOFC operation @35 A, $T_{ref}=835^{\circ}C$, 40 %H₂ in N₂

- Power in reference point:
 $P_{el}=1677 W_{el}$
- Variation of fuel flow
from 60% to 80%
- Perfect result
- Homogeneous gas supply

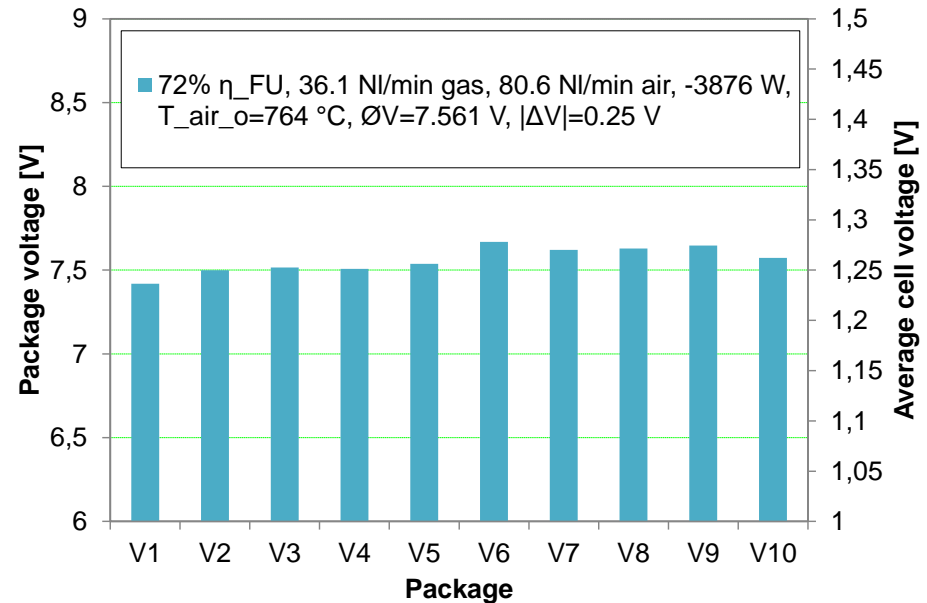




SOEC operation in Co-electrolysis mode @-50 A (part load)

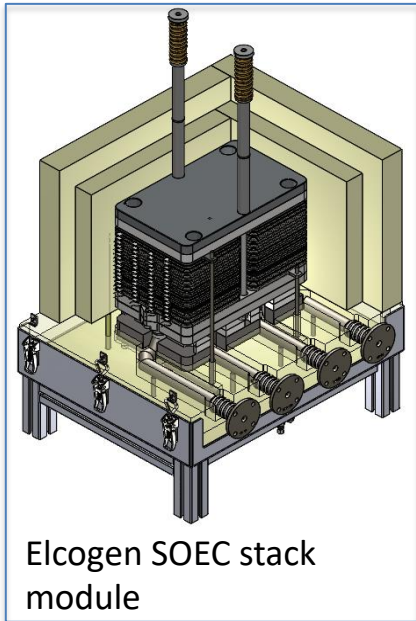
- Gas composition: 10% H₂, 56 % H₂O, 10 % CO, 24% CO₂
- H/C=2 with 20 % reducing gas
- Comparable values for steam electrolysis (i.e.: 80%H₂O in 20 % H₂)

- SOEC prediction with 120 W/cell
>7 kW possible
- More than 25 NI/min H₂ from MK355 SOEC prototype





- Assembly of SOEC stack modules with Elcogen stacks

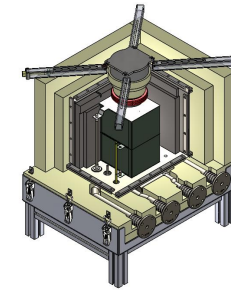


- Assembly with no problems
- Nice come together in Dresden
- Test at a test rig planned

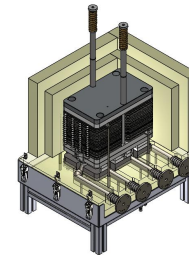


areNH₃a

Conclusion



- Stack tests with new cells: increased max. current density to -700 mA/cm^2
- Up to -120 W/cell can be converted to H_2
- -115 W/cell @ $T_{\text{ref}}=800^\circ\text{C}$, -700 mA/cm^2 , $\eta_{\text{FU}}=75\%$
- Wide temperature window $750\text{-}860^\circ\text{C}$ (Fuel: 80% H_2O in 20% H_2 , Air: 30 NI/min)
- 2x30-cell MK35x stack module commissioned for 25 NI/min H_2 production at CNH₂ for Haber Bosch



- Single cell tests with experimental electrodes: Addition of iron to hydrogen electrode increased performance
- Short stack test with multiple experimental cells showed that the addition of iron also decreased stabilization time in the stack.
- E1500 stack assembled and commissioned
- E1500 stack module test at IKTS

Fraunhofer-IKTS activities

(Exploitation)

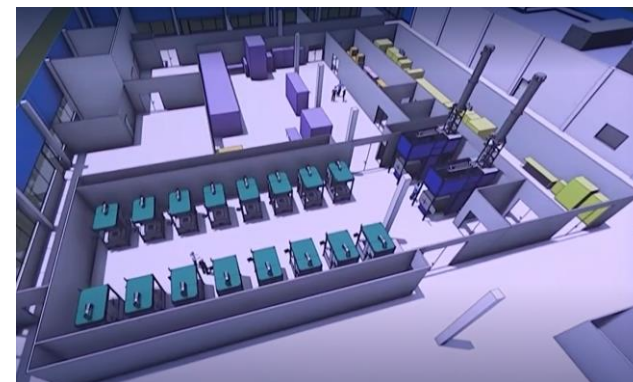
Strategic partnership with ThyssenKruppNucera for SOE-stack module



Strategic partnership with ThyssenKruppNucera for SOE-stack module



- 2025 pilot line at IKTS Arnstadt for 8 MW/a → ThyssenKruppNucera
- R&D of MK35x stacks and stack module at IKTS
- Increase capacity for MK35x stack in future
- Successful exploitation!
- Searching for users of MK355 stack modules





Advanced materials and Reactors for Energy storage through Ammonia



areNH3a

Thank you for your attention