The eneramic® Power Generator – A Reliable Fuel Cell Battery Hybrid System for Off-grid Power Supply

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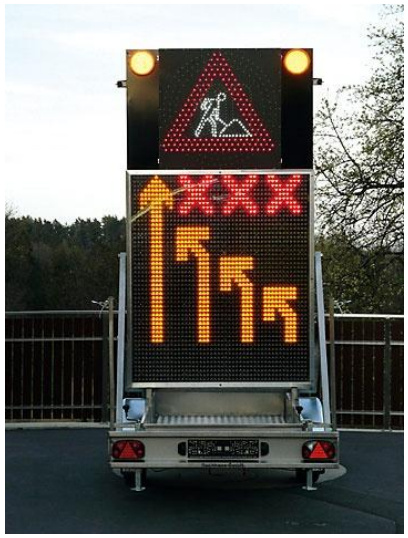
Need for **off-grid power** solutions …

- at low costs
- with long self-contained runtime
- independent from weather conditions
- protected against vandalism

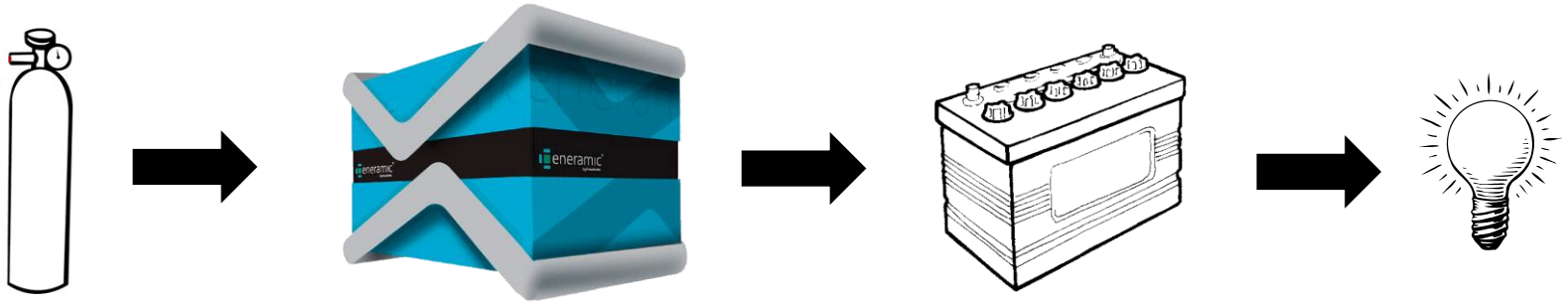


→ Insufficient market solutions

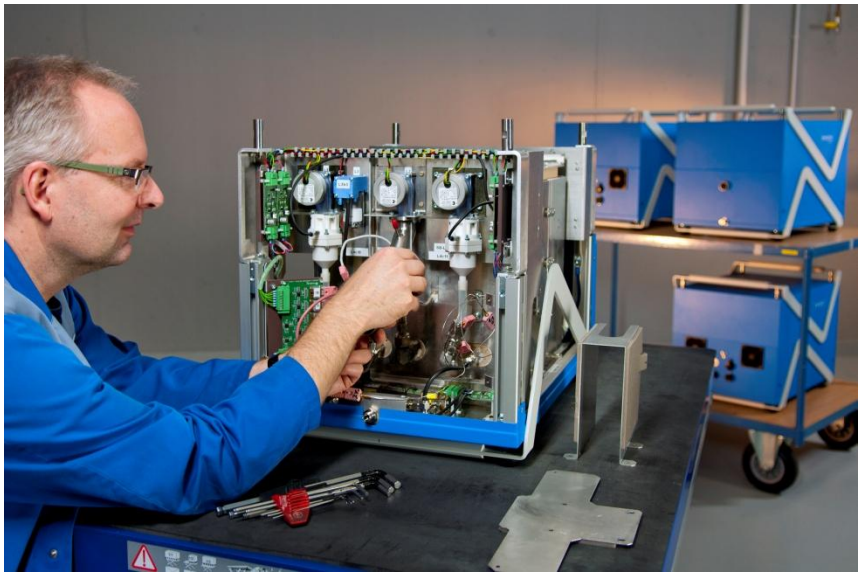
The eneramic® power generator
Technical specification

Description	Design specification
Technology	Fuel cell battery hybrid system
Operation	Fully automatic, immediately available
Nominal power	100 W_{net} @ 12 V
Fuel	Propane, butane and ethanol fuels
Durability	10,000 h & 250 cycles
Weight / Volume	30 kg / 50 l
Ambient temperature	-15°C up to 35°C



Outline

- System design
- Testing and optimizing operations
  - Core module and stack
  - System prototypes
- Next steps





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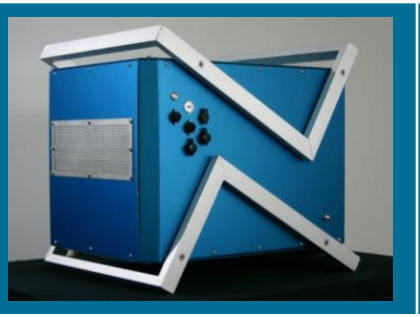
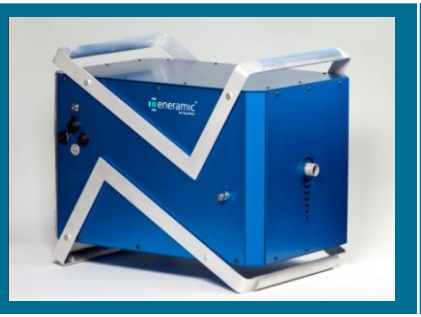
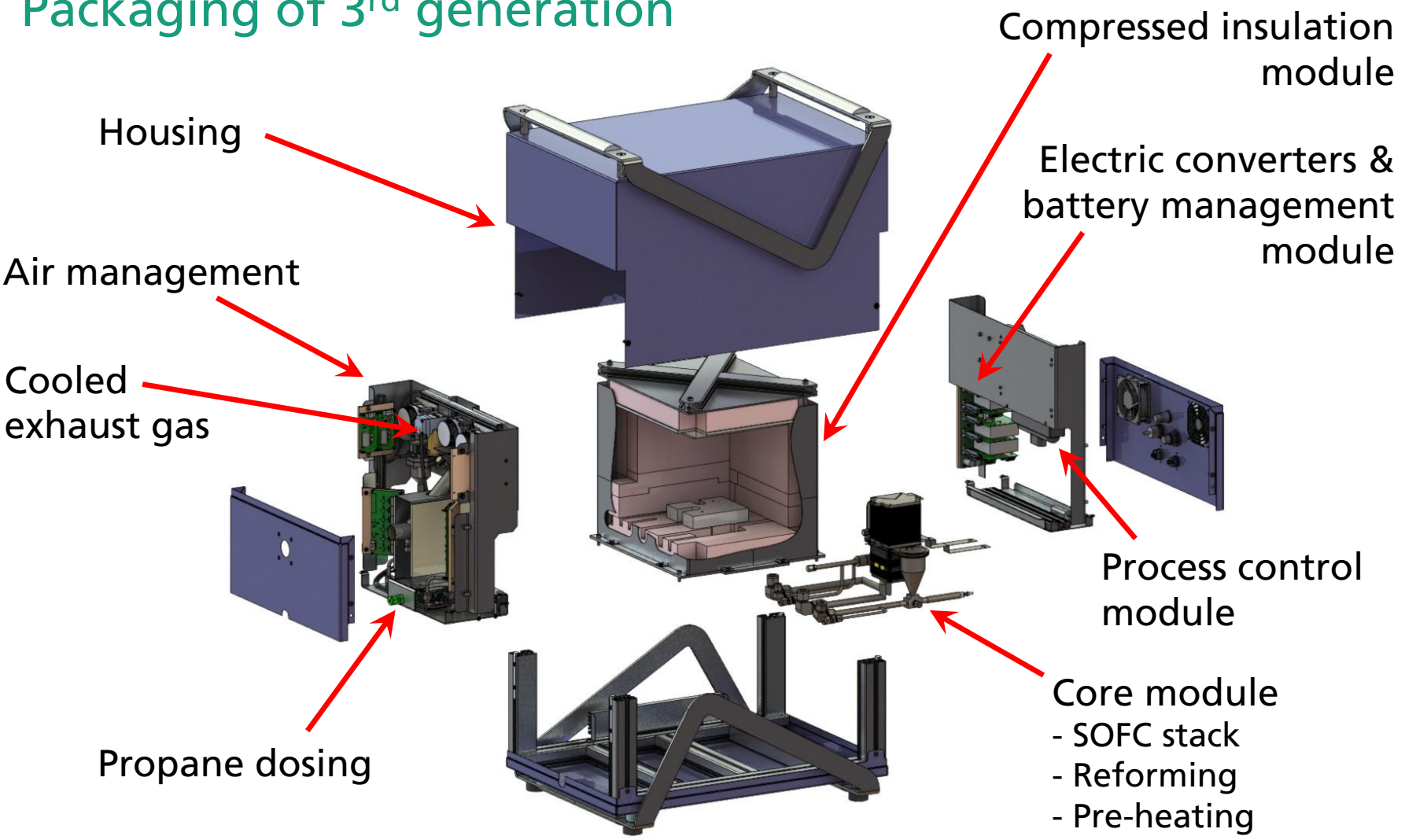
System design
eneramic® prototypes

System prototypes			
Power output	95 W	100 W	105 W
Dimensions	710x510x490 mm	640x425x420 mm	590x420x380 mm
Total volume / Hotbox size	175 l / 60 l (~ 34 %)	115 l / 39 l (~ 34 %)	94 l / 39 l (~ 41 %)
Weight	71 kg	55 kg	36 kg
Produced units	1	1	4

System design

Packaging of 3rd generation



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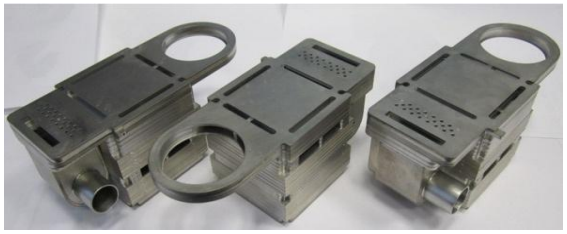
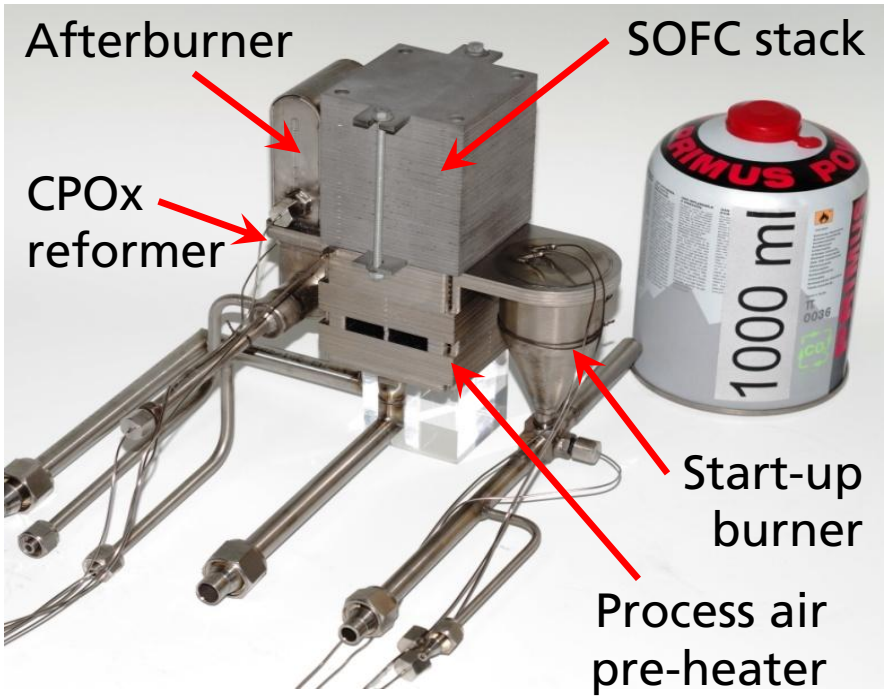
System design
Core module development

Developed core modules	Gen-1 	Gen-2 
Dimensions	70 x 200 x 180 mm	70 x 150 x 170 mm
Volume / incl. isolation	2.52 l / 60 l	1.79 l / 39 l
Total weight / Stack	5.5 kg / 2 kg	4.6 kg / 2 kg
New features	Cathode off-gas pre-heating	New burner and HEX design
Produced units	6	10

System design
Components of core module





- Multilayer concept for manufacturing
  → brazed metal sheet technology
- Ease and low cost fabrication
- Integrated manifolds
- Integrated combustion zone
- Reliable and gas-tight design with long-lasting components
  - ✓ >140 system cycles without leakage
  - ✓ > 5000 h operation at 850°C

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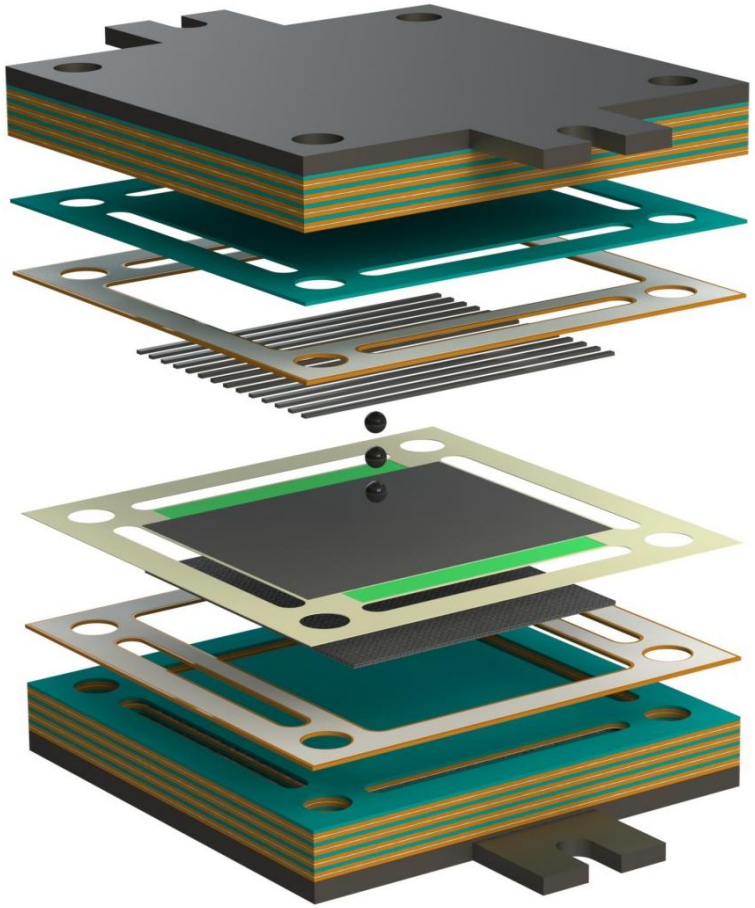
System design
SOFC stack



Top plate with current plug

Interconnect

Sealing frame

Contact ribs

Cell

Nickel meshes

Sealing frame

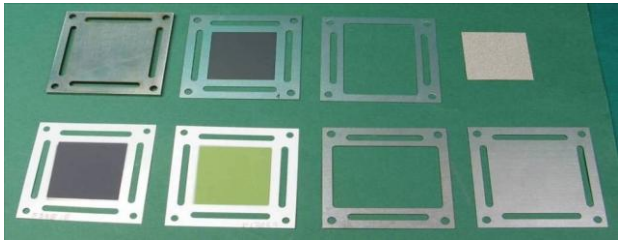
Bottom plate with current plug

Planar stack technology

- Crofer 22 APU interconnect
- 3YSZ based electrolyte supported cell
- SiO_2-Al_2O_3-BaO sealing glass

Cost-effective fabrication

- Laser cutting
- Screen printing, dispensing



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Outline

- System design
- Testing and optimizing operations
  - Core module and stack
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- Next steps

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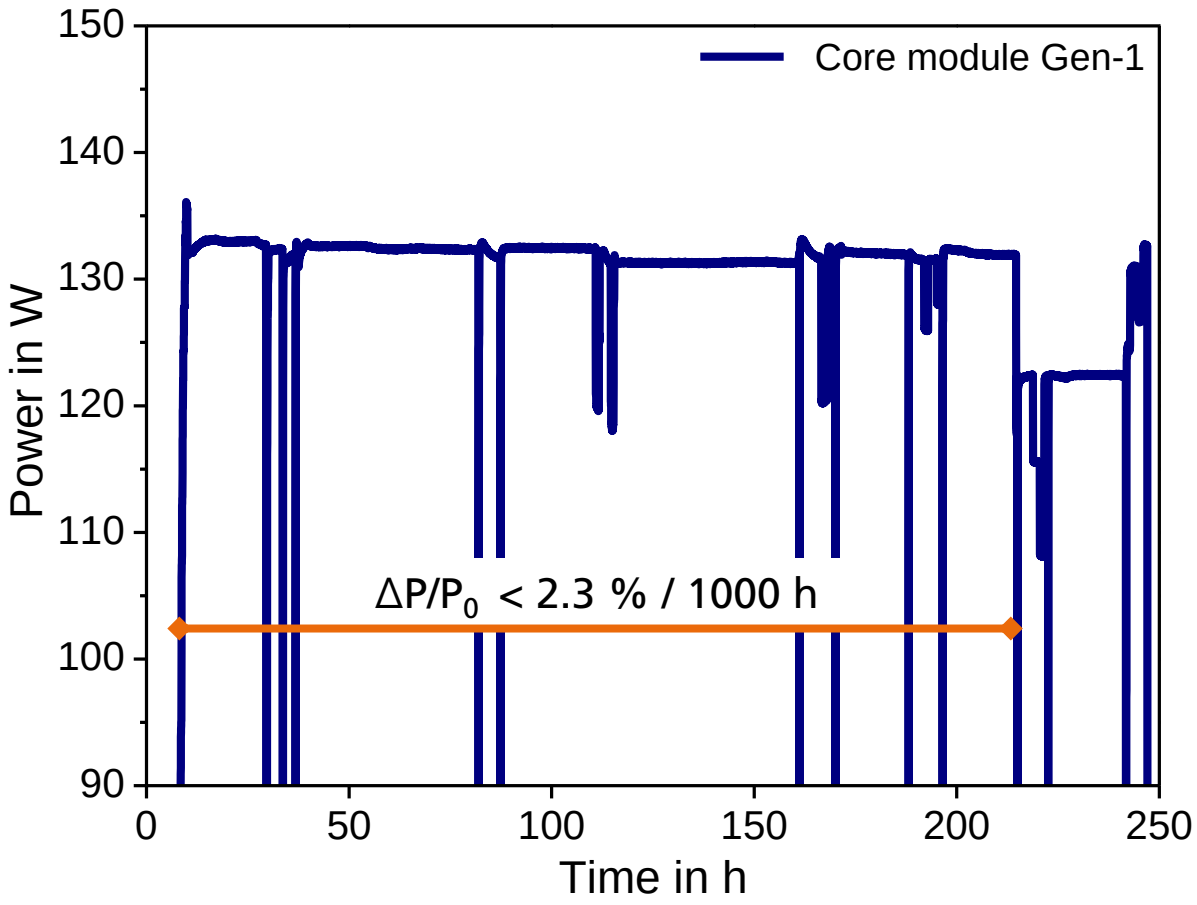
Core module testing – Gen-1

Short term lab testing – Results shown at 36th ICACC 2012

40-cell stack with Ni/GDC anode, system operation with propane



Test conditions

- Stack temperature was set to 855°C
- Const. current mode → 288 mA/cm²

Results

- Problems with test rig caused several shutdowns
- Degradation

  $\Delta P/P_0 < 2.3$ %/1000 h

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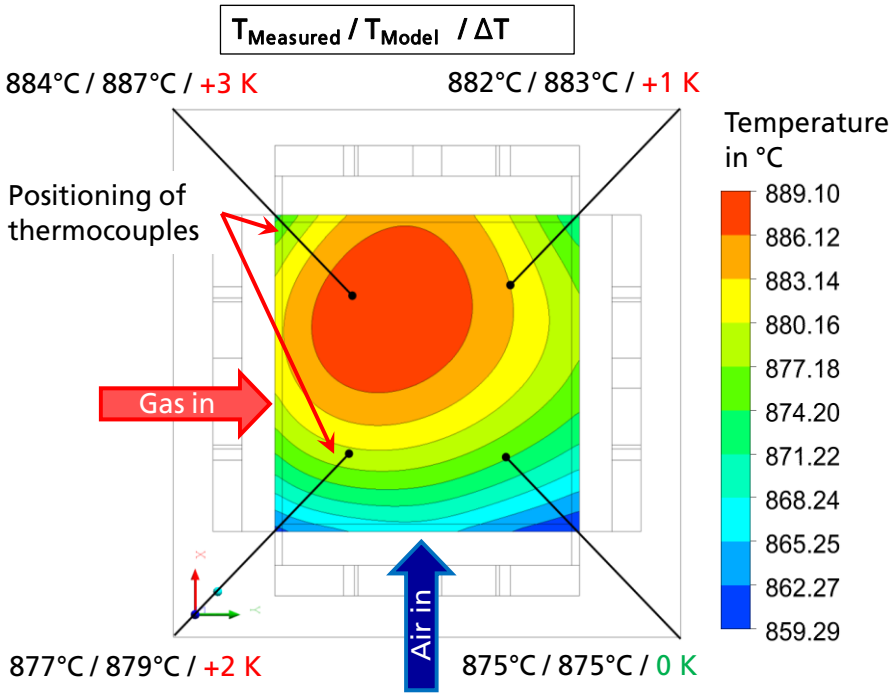
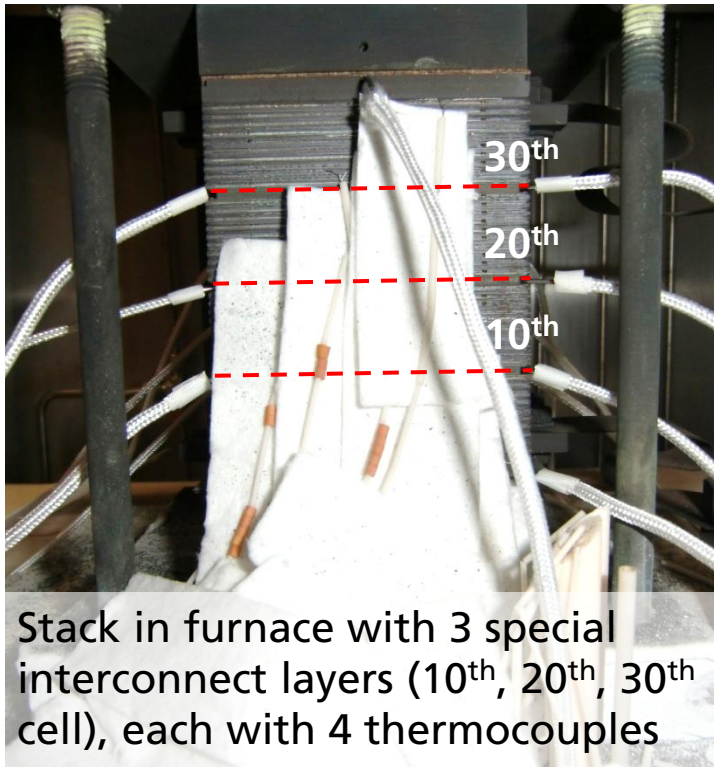
Stack testing in furnace and in core module

Analysis and optimization of stack temperatures





Stack in furnace with 3 special interconnect layers (10th, 20th, 30th cell), each with 4 thermocouples

Simulated stack temperatures (30th layer)
→ Critical peak especially for sealing materials

Many thanks to Gregor Ganzer for the simulation

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Stack testing in furnace and in core module

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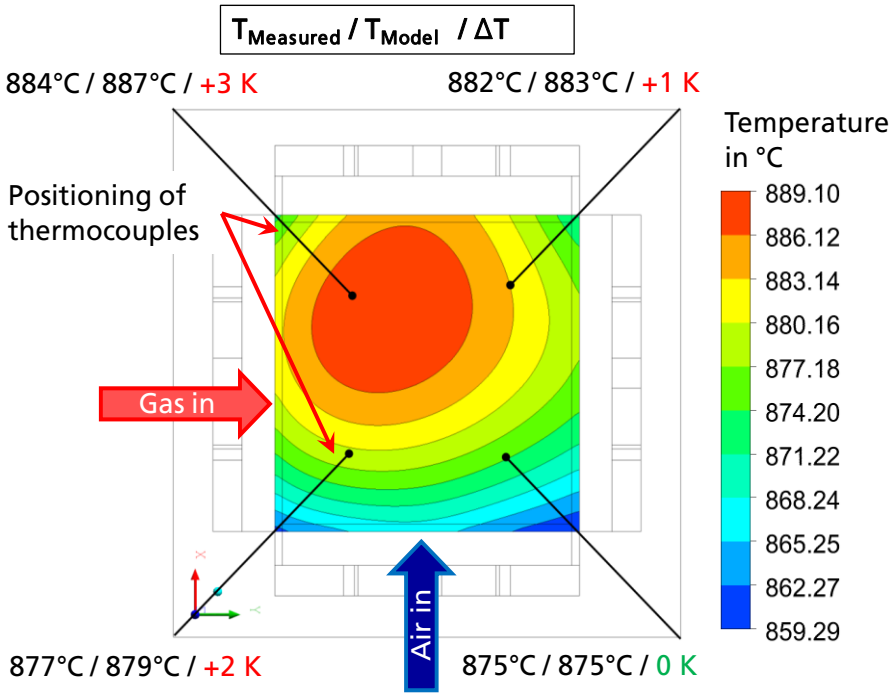

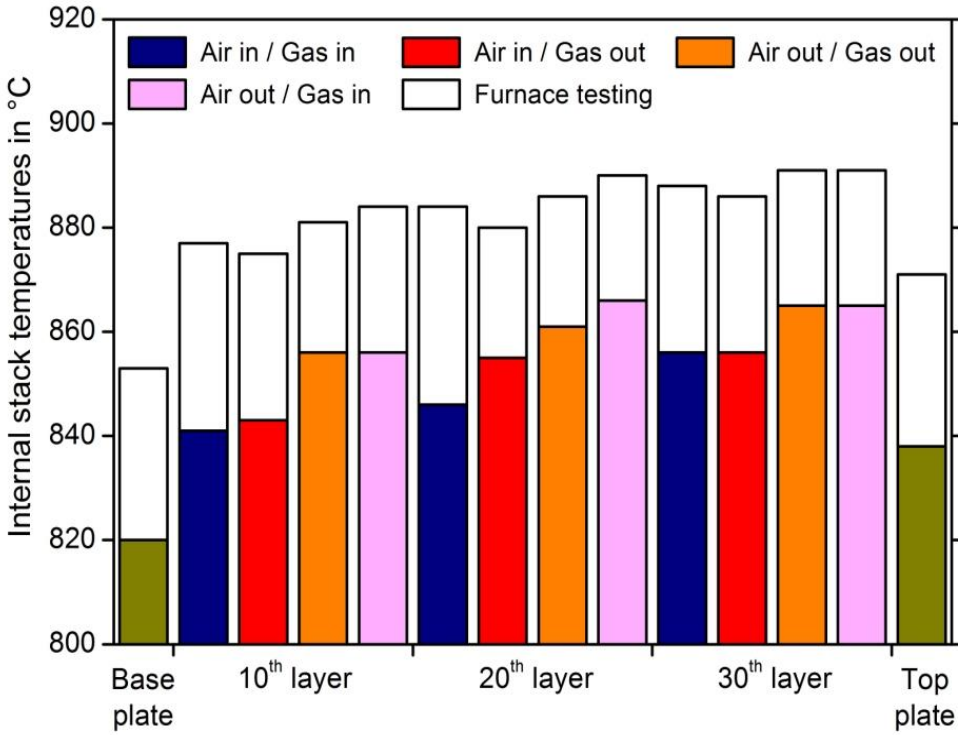

Simulated stack temperatures (30th layer)
→ Critical peak especially for sealing materials

Previous and modified temperatures in the core module

Many thanks to Gregor Ganzer for the simulation

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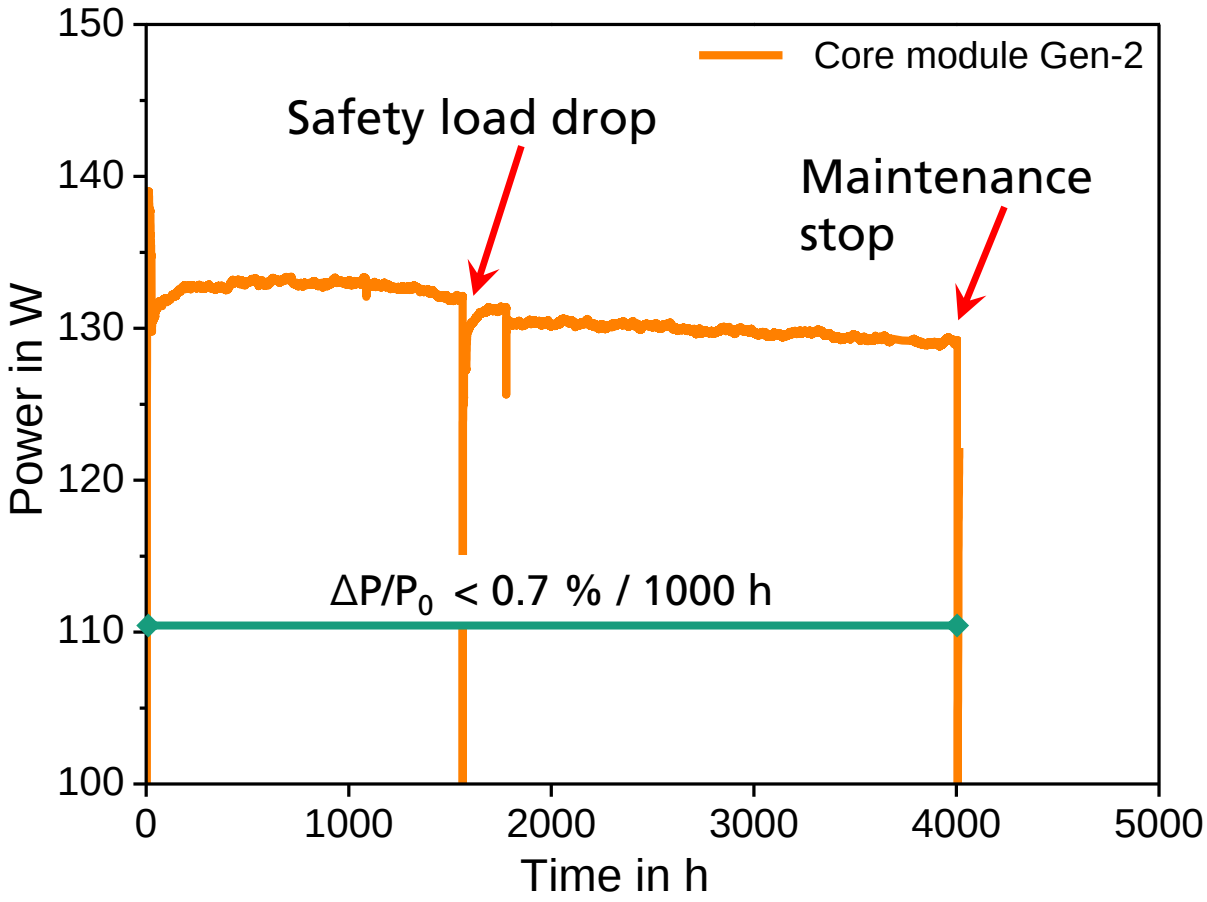
Core module testing – Gen-2

Durability testing for 5000 h

40-cell stack with Ni/GDC anode, system operation with propane



Test conditions

- Stack temperature now reduced to 840°C
- Const. current mode → 295 mA/cm²

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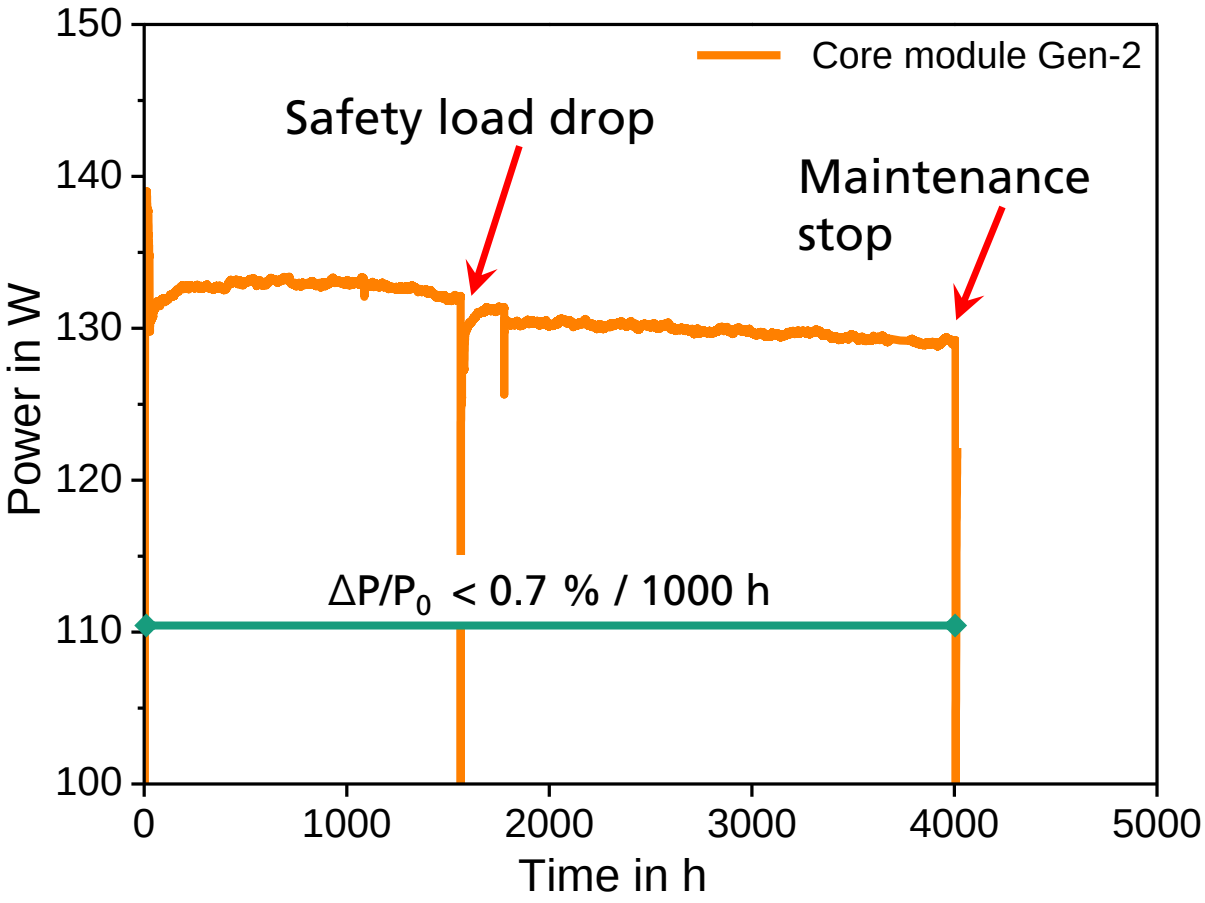
Core module testing – Gen-2

Durability testing for 5000 h

40-cell stack with Ni/GDC anode, system operation with propane



Results

- Degradation

  $\Delta P/P_0 < 0.7$ %/1000 h
- Reduction of stack temperature = reduced degradation

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Core module testing – Gen-2

Durability testing for 5000 h

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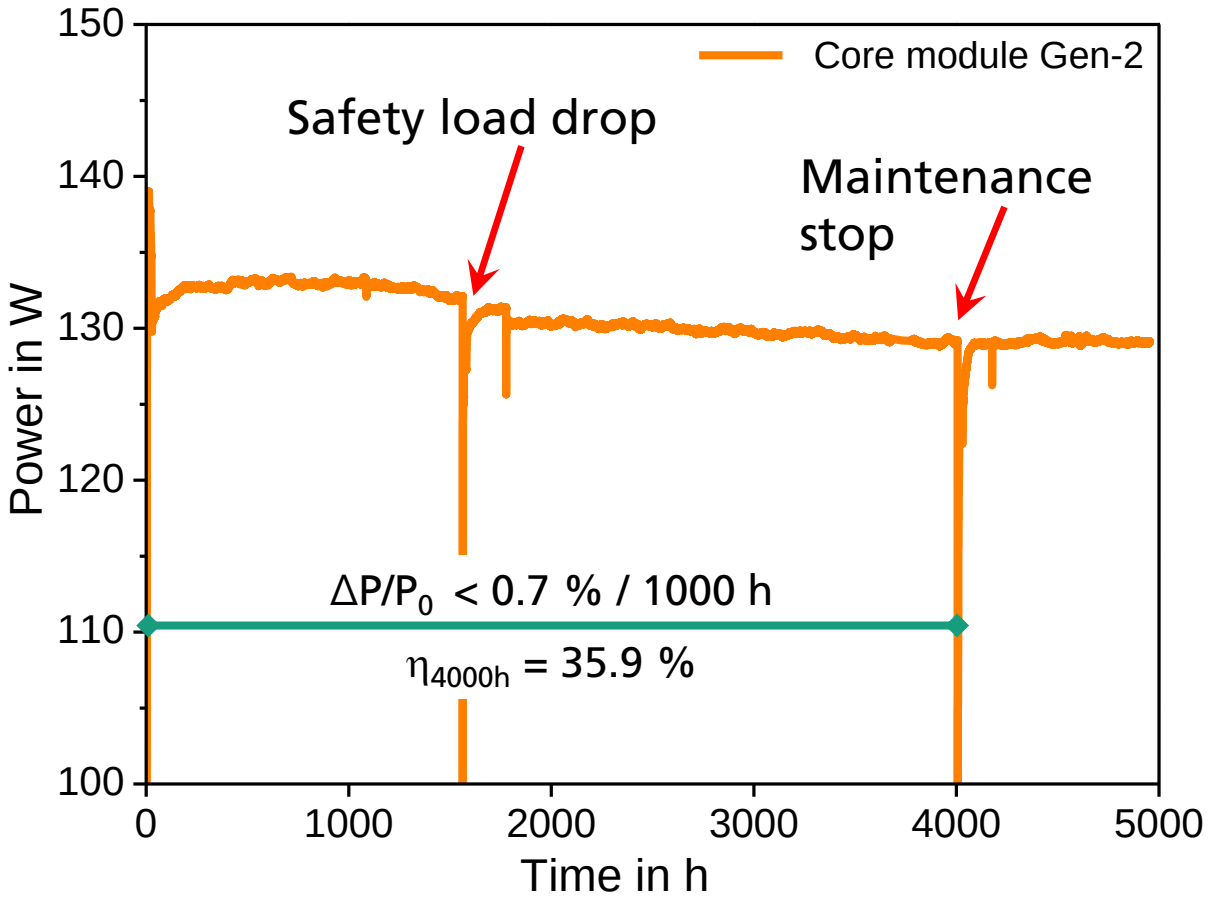

Further testing with adjusted parameters

- Const. current mode → 313 mA/cm²
- Increased fuel input
- Stack efficiency → η_{5000h} = 33.9 %
- Lower electric efficiency but enhanced lifetime

Results

- Up to now → no degradation

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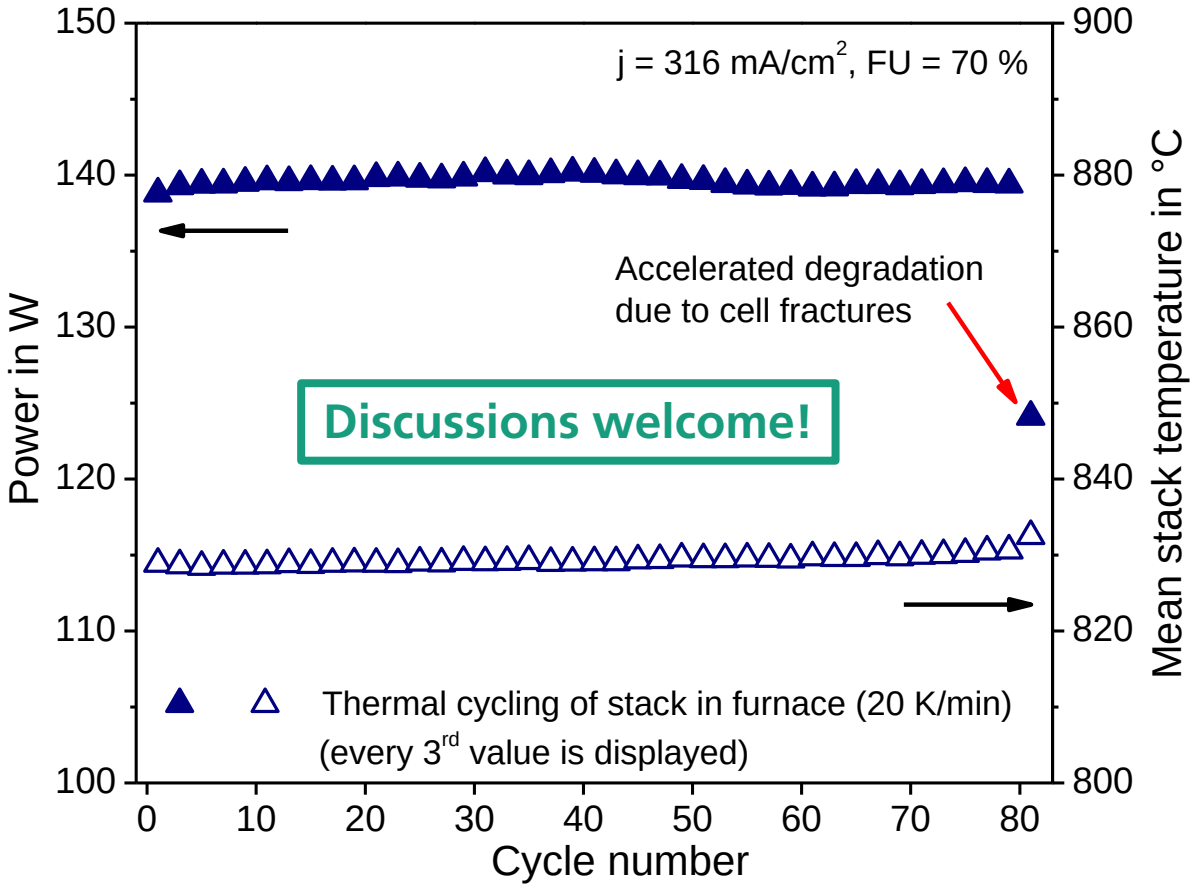
Stack testing in furnace

Thermal cycling as life-time limiting issue?

40-cell stack with Ni/GDC anode, stack operation with H_2/N_2



Test conditions

- 1 cycle per day
- Const. current mode

Results

- No degradation up to 75 cycles → then rapid cell fracture
- Fracture mechanism are uncertain (hotspots, substrate damages, ...)

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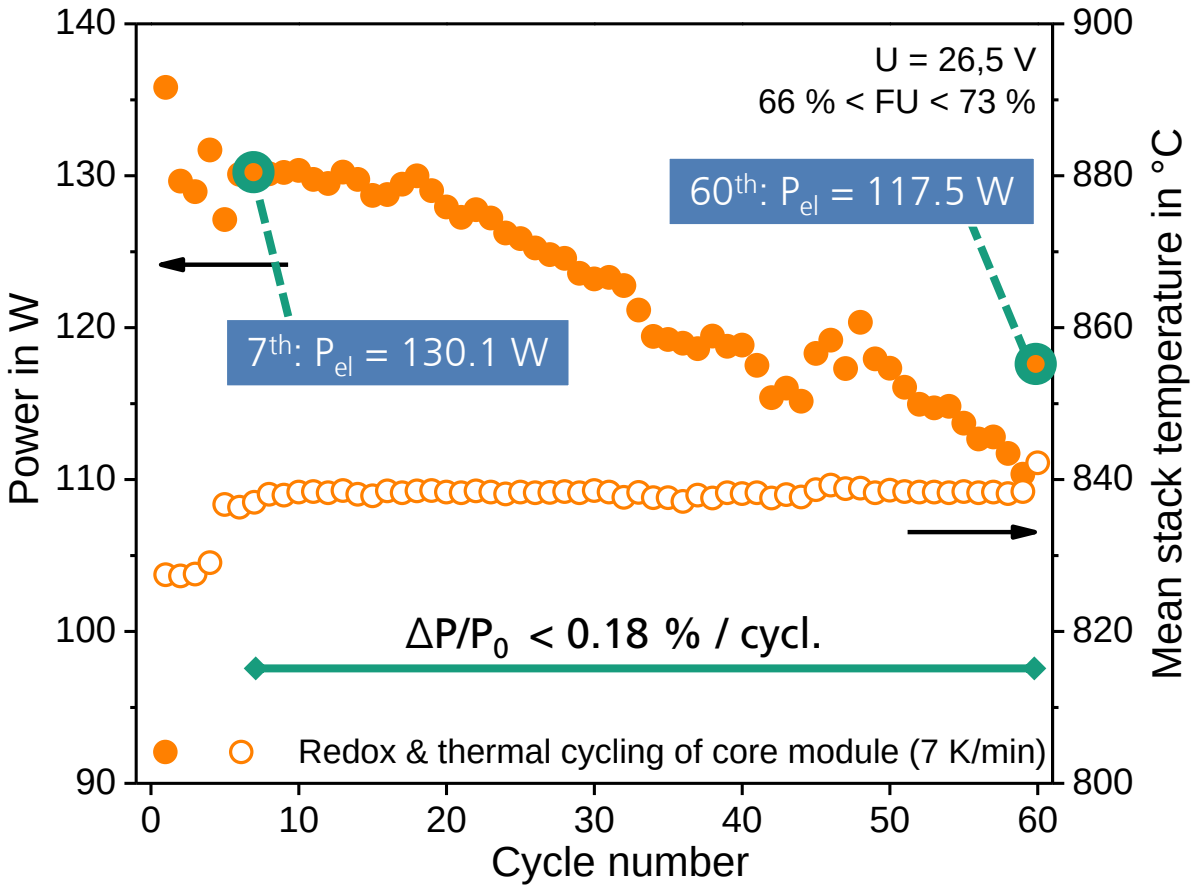
Core module testing – Gen 2

Thermal cycling as life-time limiting issue?

40-cell stack with Ni/GDC anode, system operation with propane



Test conditions

- Automated start/stop cycling in test bench
- Const. voltage mode

Results

- Power degradation due to losses in upper cells
- No cell fractures
- Degradation

  $\Delta P/P_0 < 0.18$ %/cycl.

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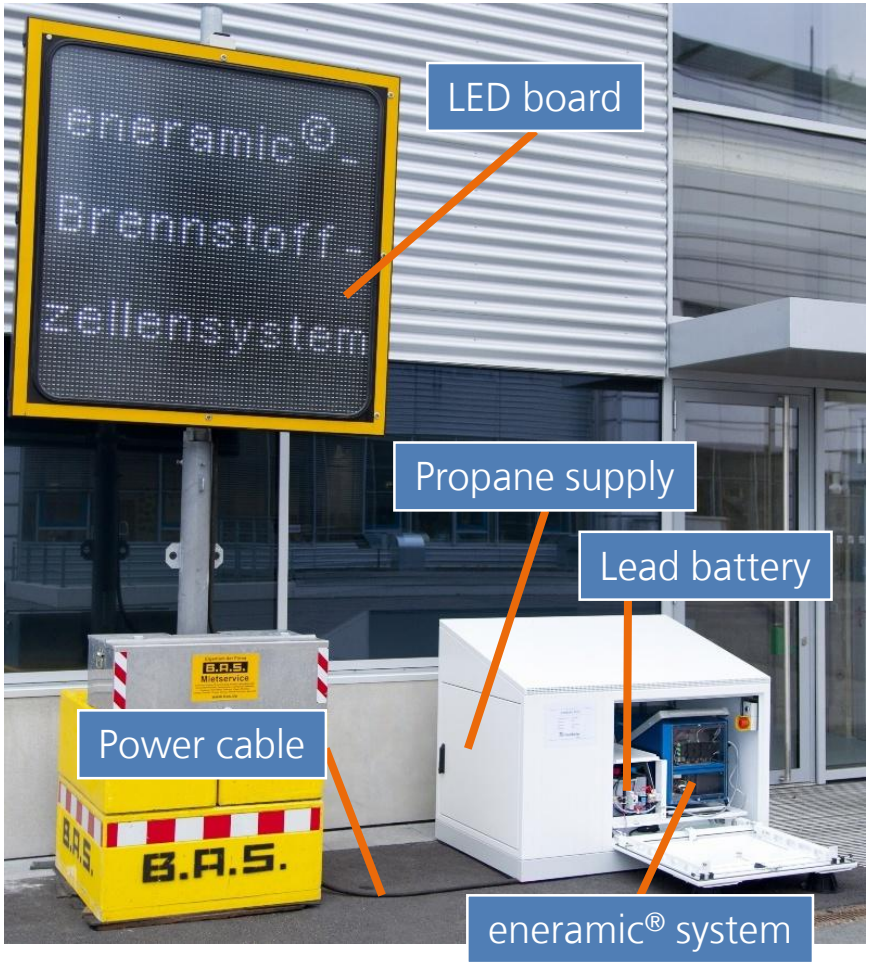
Testing of eneramic® system prototypes

Preparation for field testing with LED information board



Operation of eneramic® system in metal box

- Protection against weather and vandalism
- Gas supply with 2 x 11 kg gas bottles
- Space for two powerful lead batteries

Aims

- System operation for more than 500 h with more than 10 cycles
- Operation between -5 to 20°C

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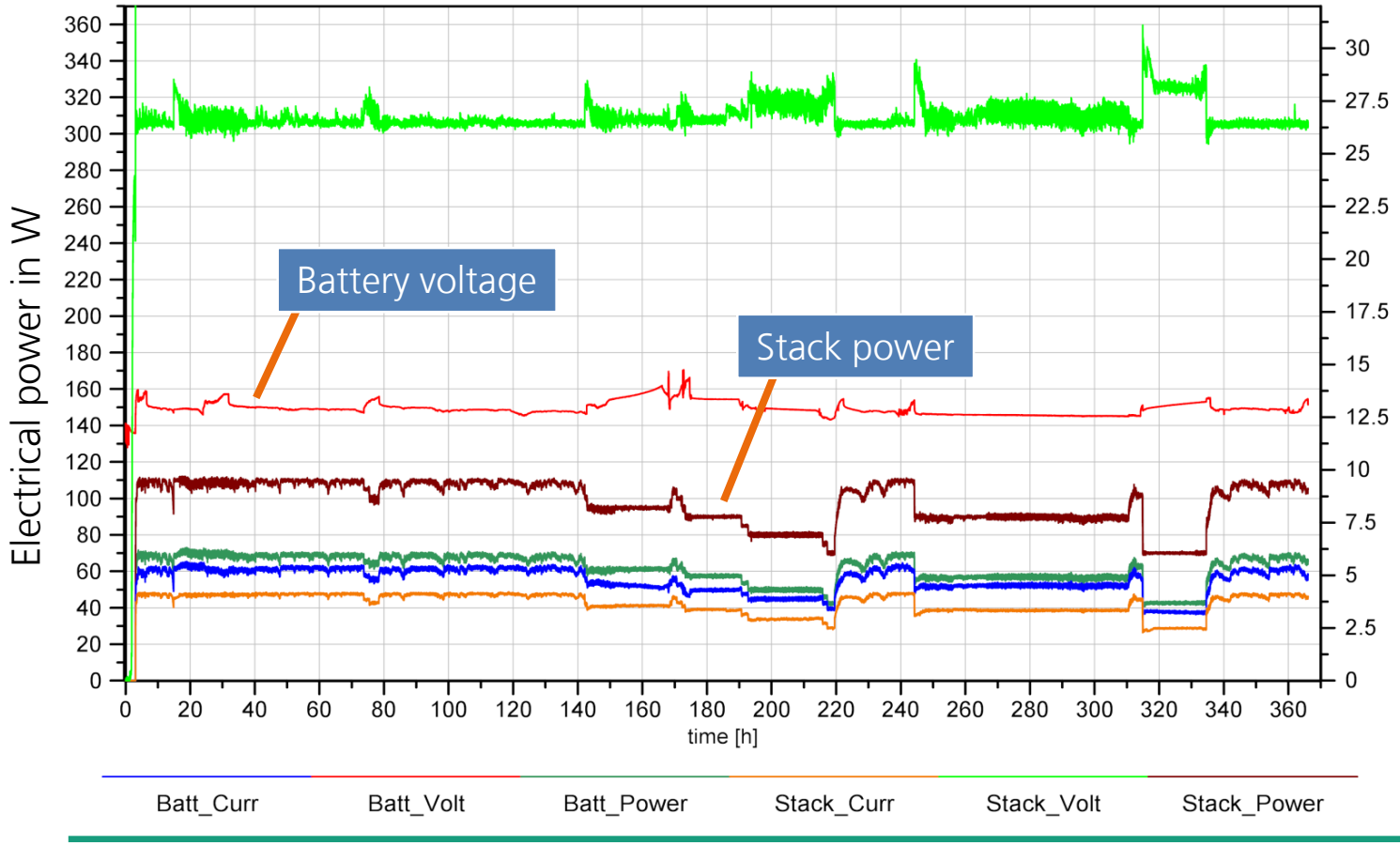

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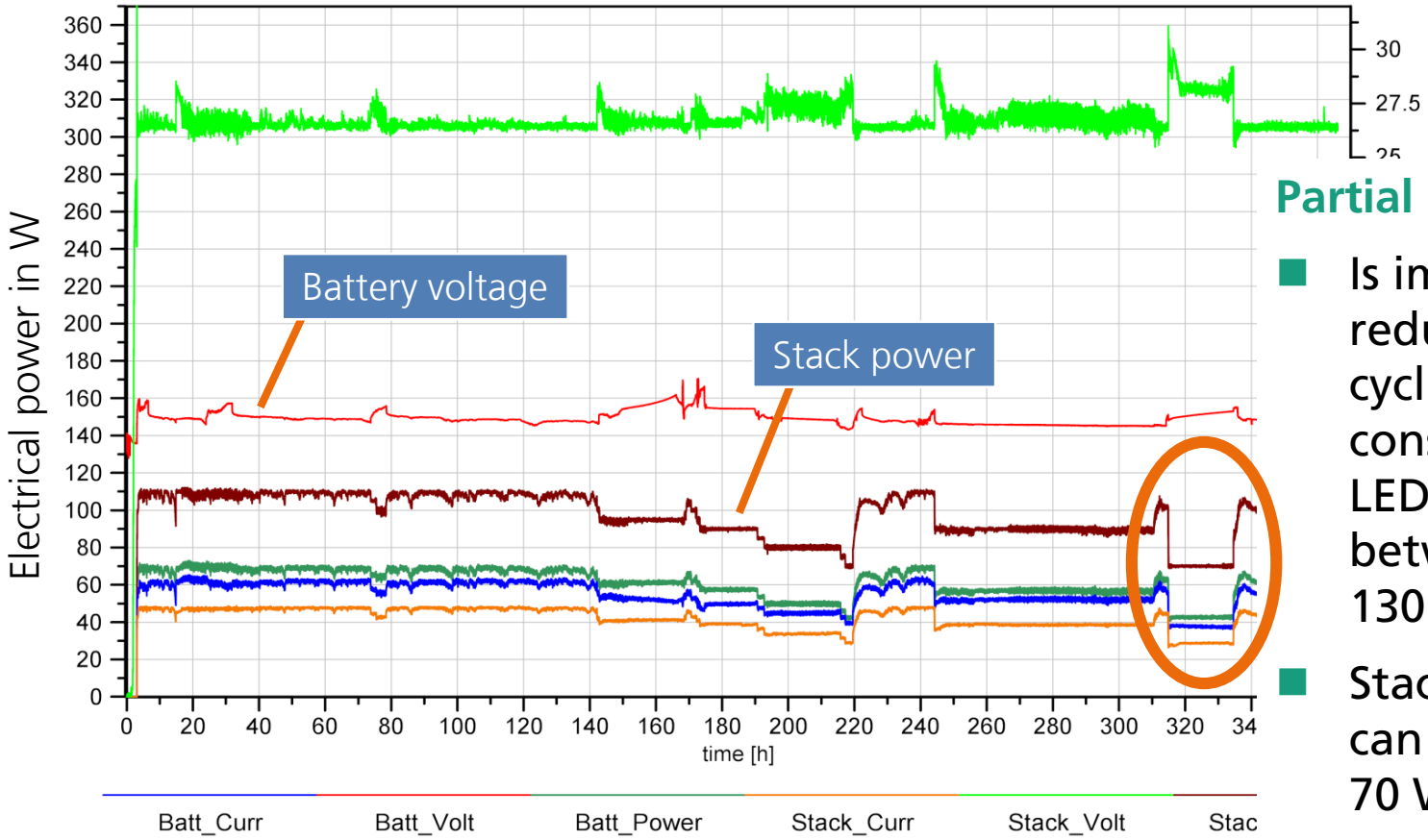

Partial load behavior

- Is important to reduce system cycling as power consumption of LED board varies between 20 and 130 W
- Stack gross power can be reduced to 70 W

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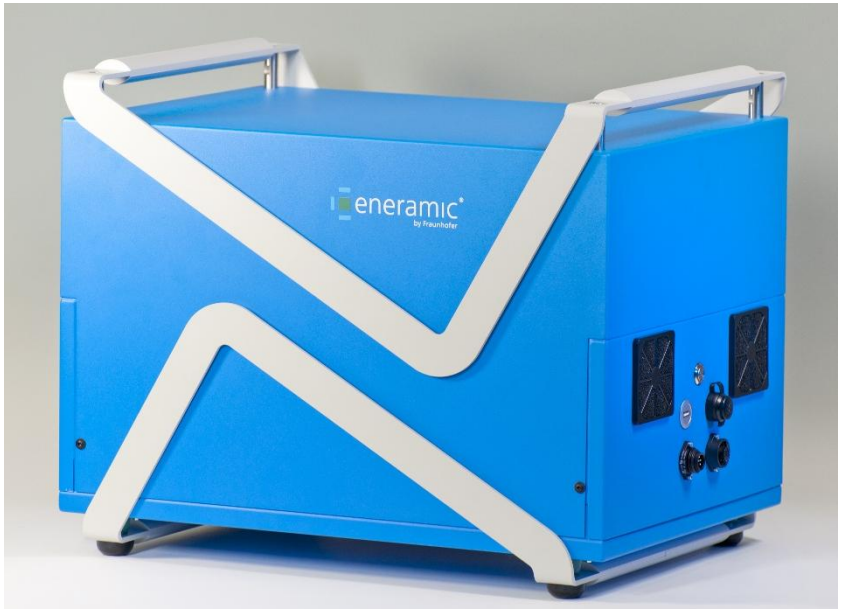

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Next steps

- Validation of the safety concept with TÜV (German technical inspection association)
- Application testing under real weather conditions with traffic guidance system
- Environmental tests
- Improving power density, cycleability and losses of power electronics
- Improving manufacturing costs
- Market launch with partners in 2015

Thank you for your attention.

The eneramic® by Fraunhofer project team.

Thanks for financial support of

Fraunhofer future foundation

Contact

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