SOFC SYSTEM DEVELOPMENT AT FRAUNHOFER IKTS

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Allimpex/IKTS-Workshops

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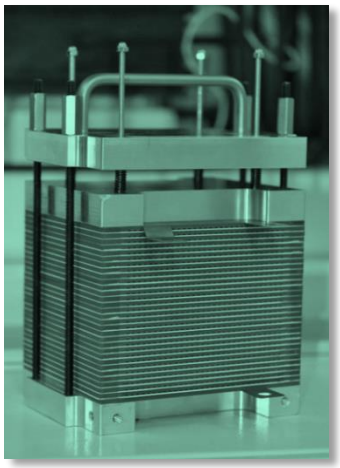

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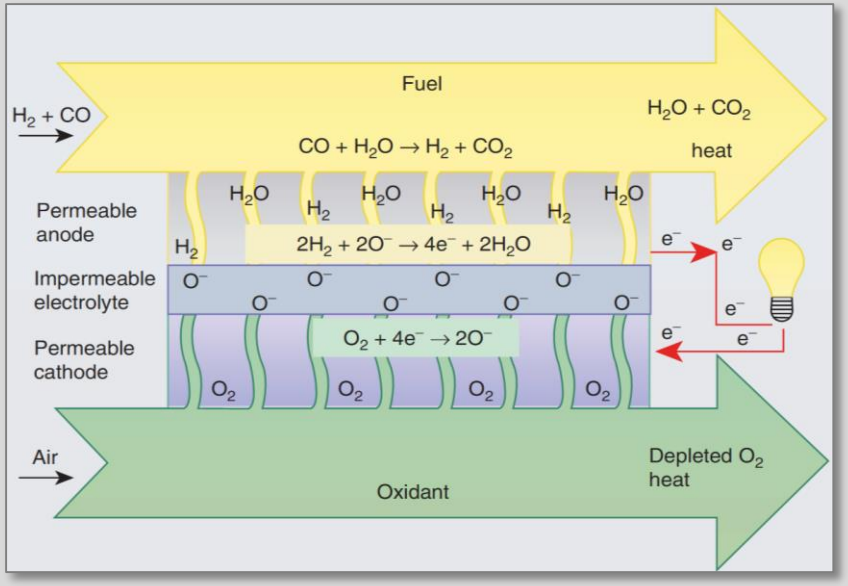
Outline

- Introduction
- SOFC Stack Technology at IKTS
- General System Engineering Approach & SOFC System Integration Examples
  - eneramic® - 100 W, LPG-fueled SOFC Power Generator
  - h2e® - 1 kW, NG-fueled SOFC/Battery-Hybrid System

SOFC Basics

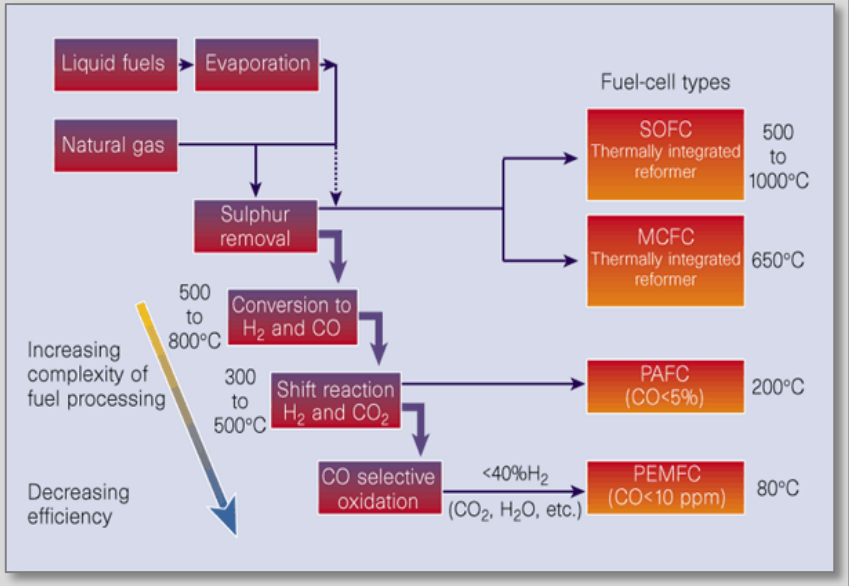
- SOFC = Solid Oxide Fuel Cell / Electrolyte = Dense Ceramics, Oxygen Ion Conductor

SOFC Working Principle



Source: Encyclopedia of Electrochemical Power Sources, Elsevier

Fuel Processing steps and their influence on FC complexity / efficiency.



Source: Nature 400, 619-621 (12 Aug. 1999), doi: 10.1038/23144

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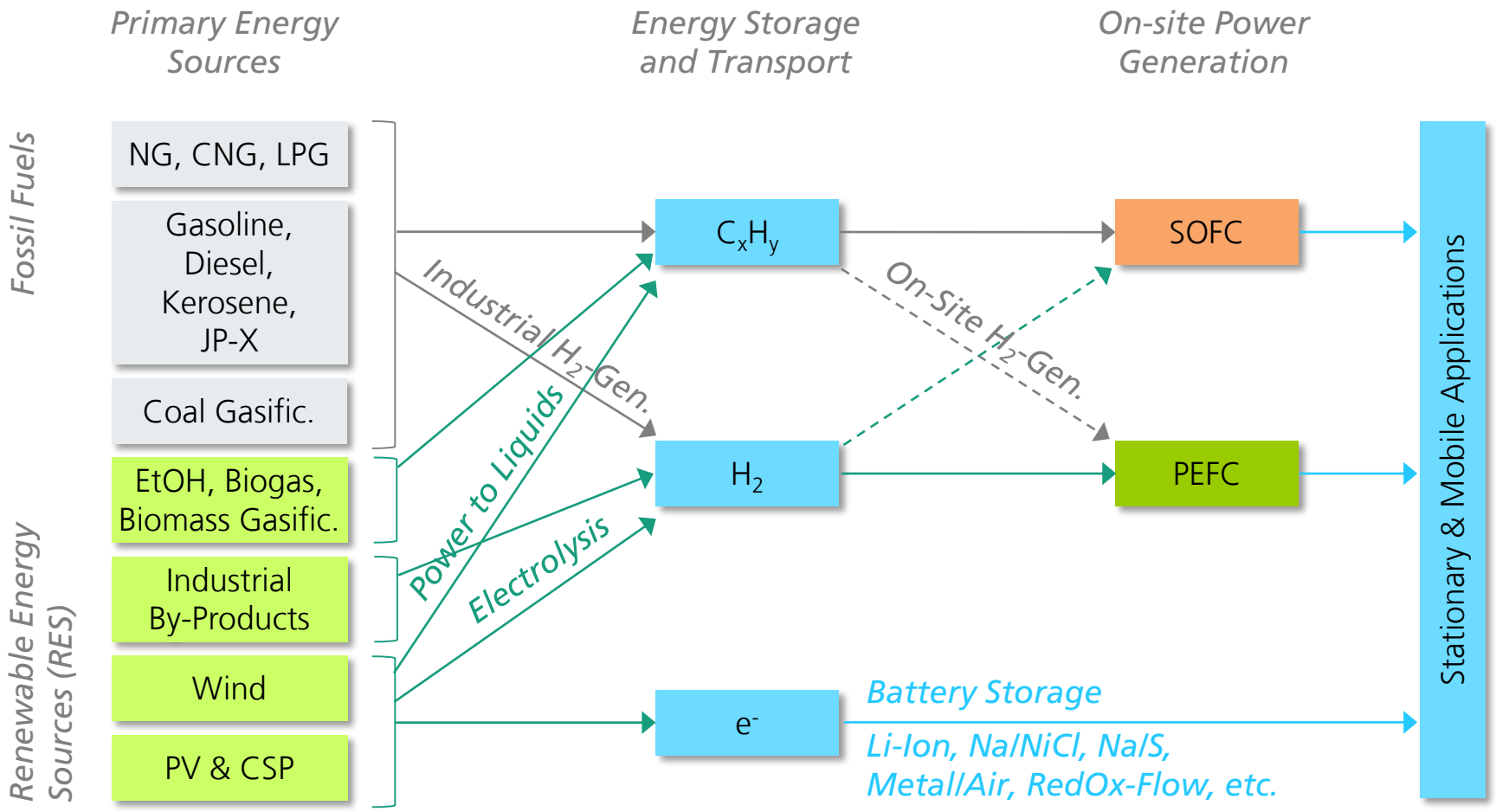
Fuel Cell based Energy Conversion Chains



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Stationary Fuel Cell Applications

- Distributed Power Generation
- Off-grid Power Generation
- Backup Power
- Electricity from Landfill Gas, Sewage Gas, Biodigesters, Ethanol
- Electricity from Biomass Gasification
- (Micro) Co-Generation: CHP & CCP
- District Heating / Cooling
- Distributed H_2-Generation (MCFC, Reversible FC)
- Stationary Energy Storage (Reversible FC)
- Virtual Powerplants, Smart Grids
- …

SOFC-Components and Services at IKTS

Complete Value Chain - „From Powder to Power“

Materials and Processes

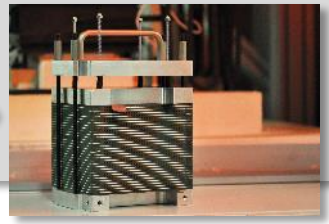
- Powders, Pastes, Foils
- Protective Coatings
- Characterization

Cell and Stack Components

- Electrodes, MEAs
- Contact Layers
- Glas Sealings

SOFC and SOEC Stacks

- CFY Mk35x, 10-40E
- HotBox-Integration
- Test & Characterization

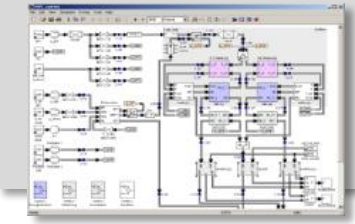


Reactors and System Components

- Reformer, Burner, HEX
- Membrane Reactors
- Sensors

CAD and Simulation

- System Concepts
- 3-D CAD Drafting
- Process Models
- Component Models



Customized Test-Rigs and Validation

- Customized Test-Rigs
- Assembly, Commissio-ning and Operation

System Engineering and Demonstration

- Proof-of-Concept
- System Prototypes
- Safety Concept, CE

Production Planning, Pilot Manufacturing

- Design to Cost
- Production Planning
- Pilot Manufacturing

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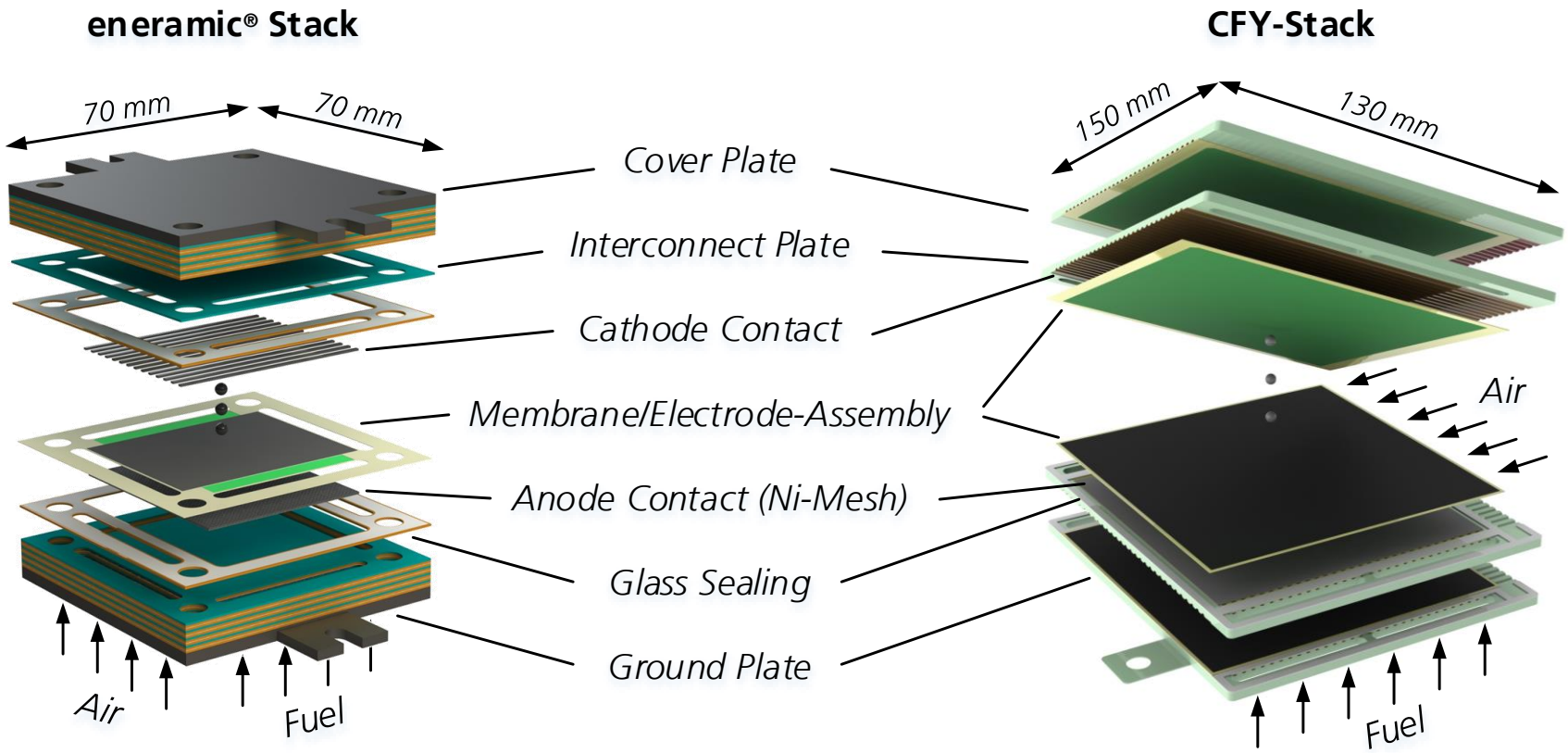
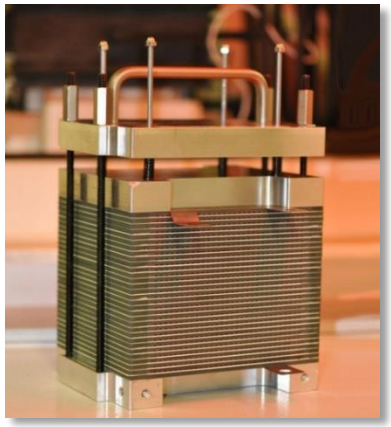
PART 1

SOFC STACK TECHNOLOGY AT IKTS

Planar SOFC Stacks based on Electrolyte Supported Cells



Planar SOFC Stacks based on Electrolyte Supported Cells

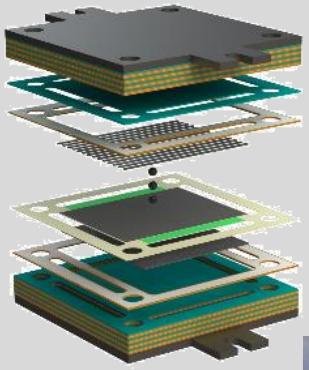


	eneramic® Stack (IKTS)	**CFY-Stack (IKTS / Plansee)**
Electrolyte	3YSZ (ESC), 90 µm	10ScSZ (ESC), 165 µm
Interconnect	CroFer 22 APU	CFY Alloy
Active Area per Cell	16 cm^2	127 cm^2
Rated Power per Cell	3,5 W_{el}	25-40 W_{el}
Standard Stack Size	20 / 30 / 40 Cells	10 / 20 / 30 / 40 Cells
Gross Power Range	70 .. 150 W_{el} per Stack	300 .. 1.200 W_{el} per Stack

SOFC-Stacks for System Integration & Plant Engineering

IKTS: eneramic-Stack

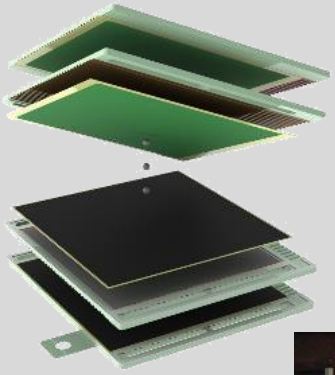
- ~ 3,5 W_{el} per Cell,
- ~ 50 .. 150 W_{el} per Stack,
- Elektrolyte: 3YSZ (ESC)
- Interconnect: CroFer 22 APU
- Active Area: 16 cm² / Cell

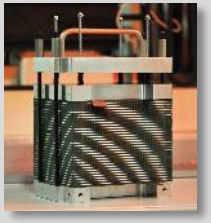


eneramic® by Fraunhofer

IKTS / Plansee: CFY-Stack

- ~ 30 W_{el} per Cell,
- ~ 300 .. 1.200 W_{el} per Stack,
- Elektrolyte: 10ScSZ (ESC)
- Interconnect: CFY
- Active Area: 127 cm² / Cell





PLANSEE

3rd Party SOFC-Technology

- Options for HotBox- and System Integration of 3rd Party Cells and Stacks
- Previous collaborative projects in the range ~50 .. 1.000 W_{el}

SOLID POWER

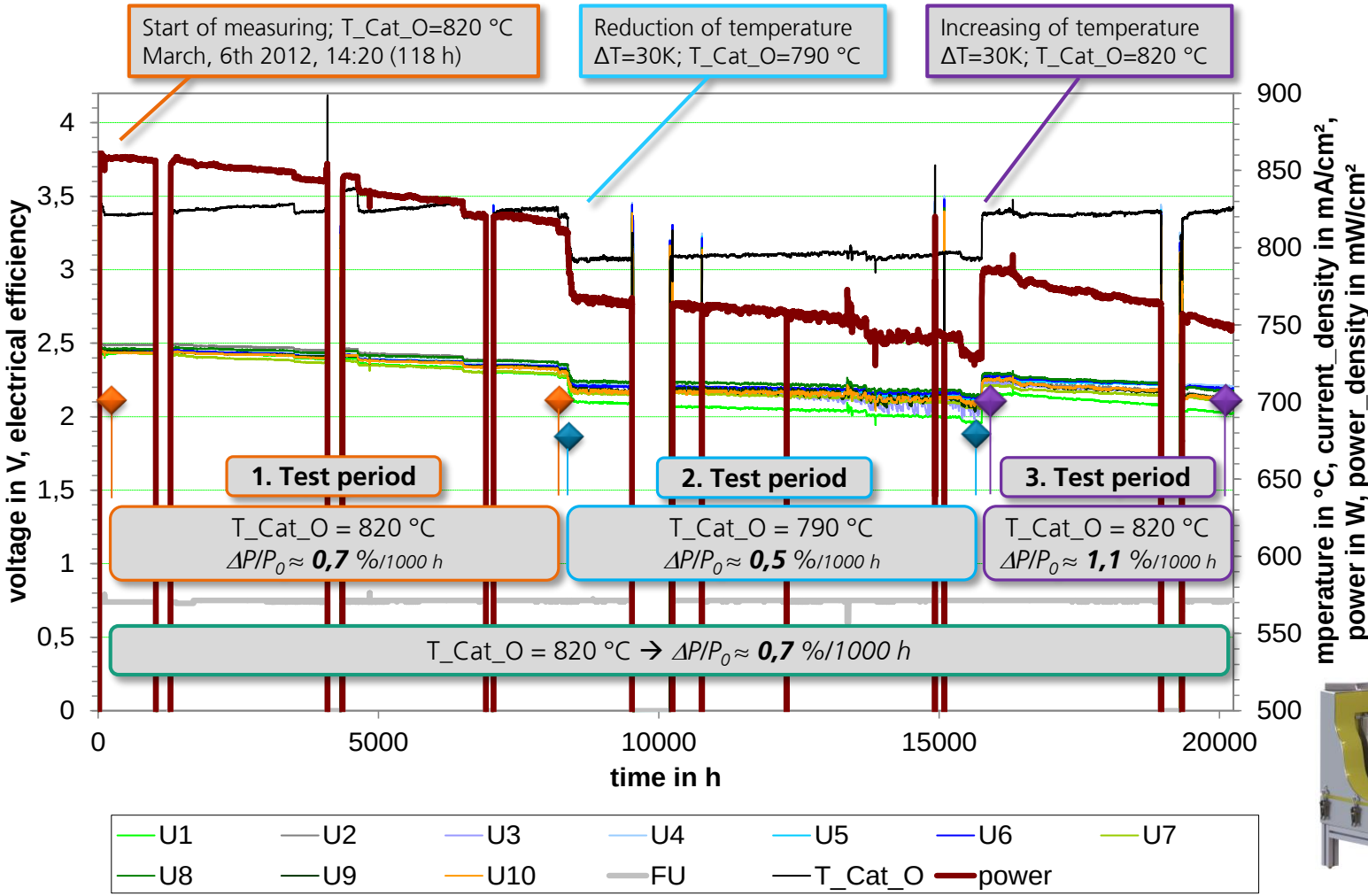
sunfire

elcogen

Versa Power Systems

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

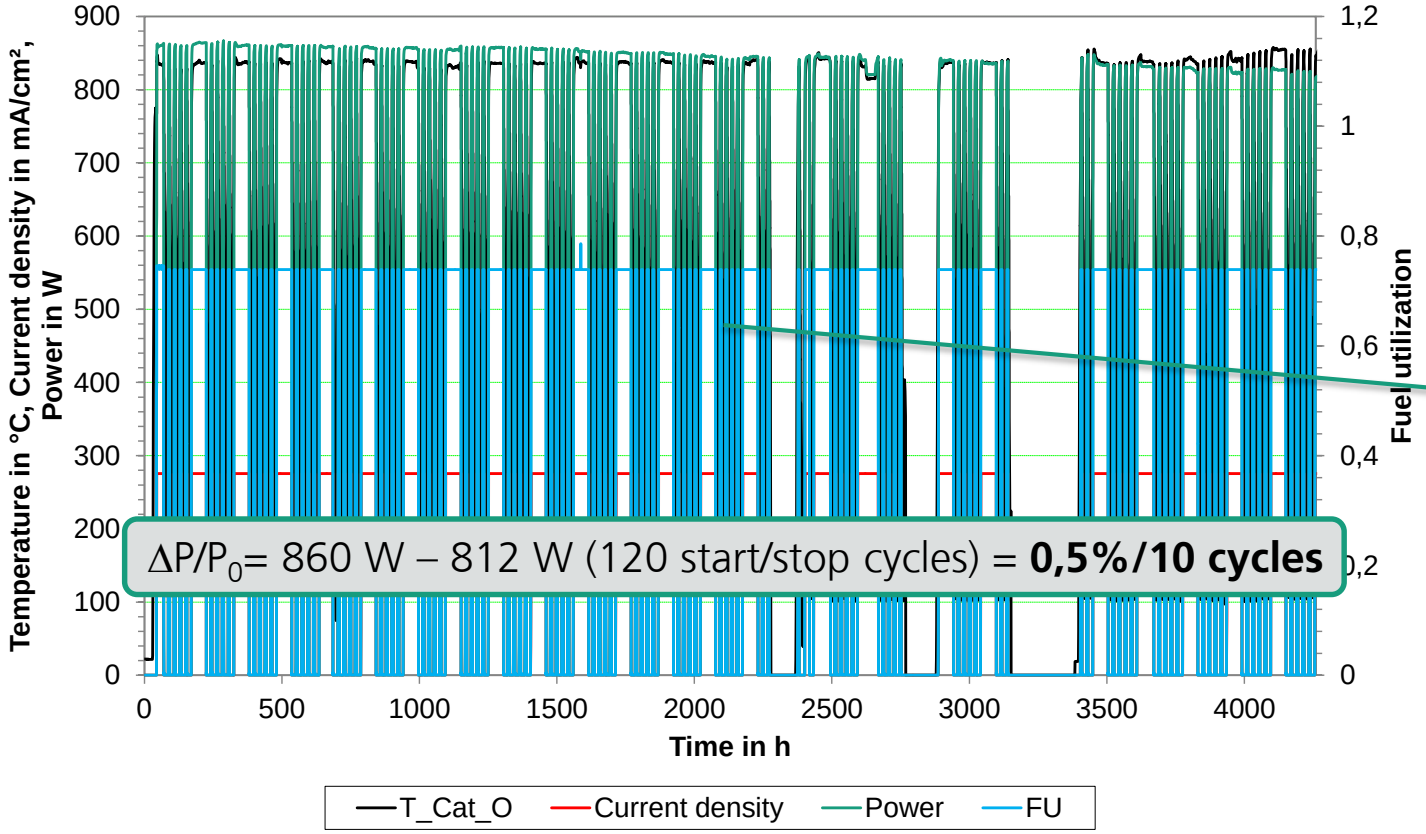
CFY-Stack Endurance Operation



PLANSEE
Fraunhofer IKTS

CFY-Stack Cyclisation Test

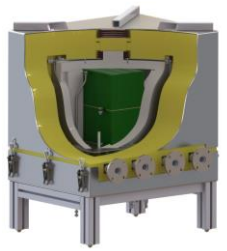
30-cell stack in HotBox operation: cycling without purge gas at anode side (2-4 K/min), operation point: @35 A, fuel: 40% H_2 in N_2, air: 80 sl/min, η_{FU}=75%



$\Delta P/P_0$= 860 W – 812 W (120 start/stop cycles) = **0,5%/10 cycles**

120 near-system cycles

incl. ~1.000 h rated power output



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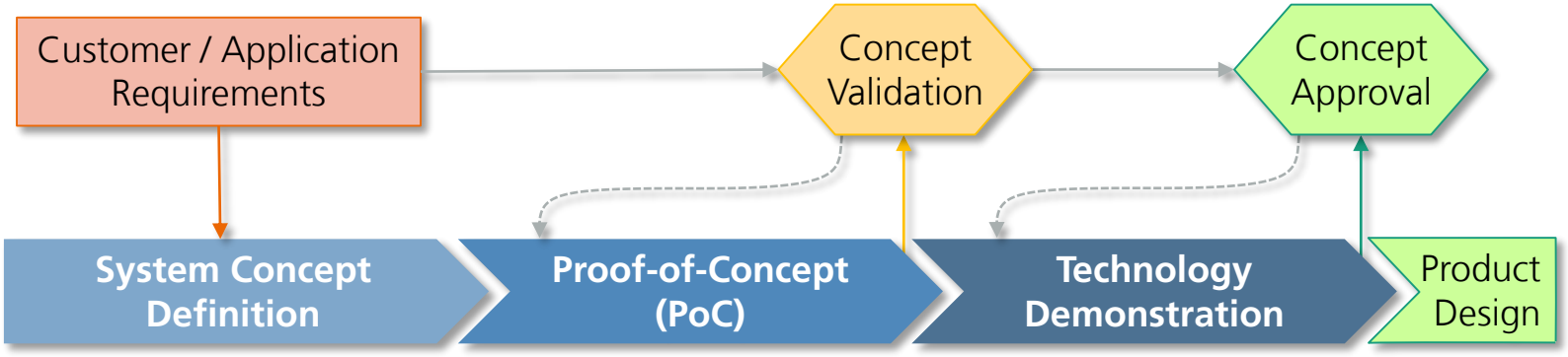
PART 2

SOFC SYSTEM INTEGRATION EXAMPLES

Generic System Development Approach



R&D Focus	Model-based conceptual study and preliminary system design	Development, commis-sioning and test of PoC-prototypes	Development, commis-sioning and test of demonstration proto-types
Objectives	System concept definition and component specification	Concept validation by laboratory tests	Concept approval by environment, reliability and lifetime tests
TRL after completion*	TRL 2 – Technology concept formulated	TRL 4 – Technology validated in lab	TRL 6 – Technology demonstrated in relevant environment

**) Technology readiness level according to Horizon 2020 – Work Programme 2014-2015 TRL definition:*
http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

Exemplary Development Tasks in Phases

Concept Definition

- Application Analysis
- Requirements Definition
- Model-based System Concept Determination
- Process Layout Calculation
- Multi-Physics Simulation Analyses
- Reactor and Component Layout
- Draft System CAD Study

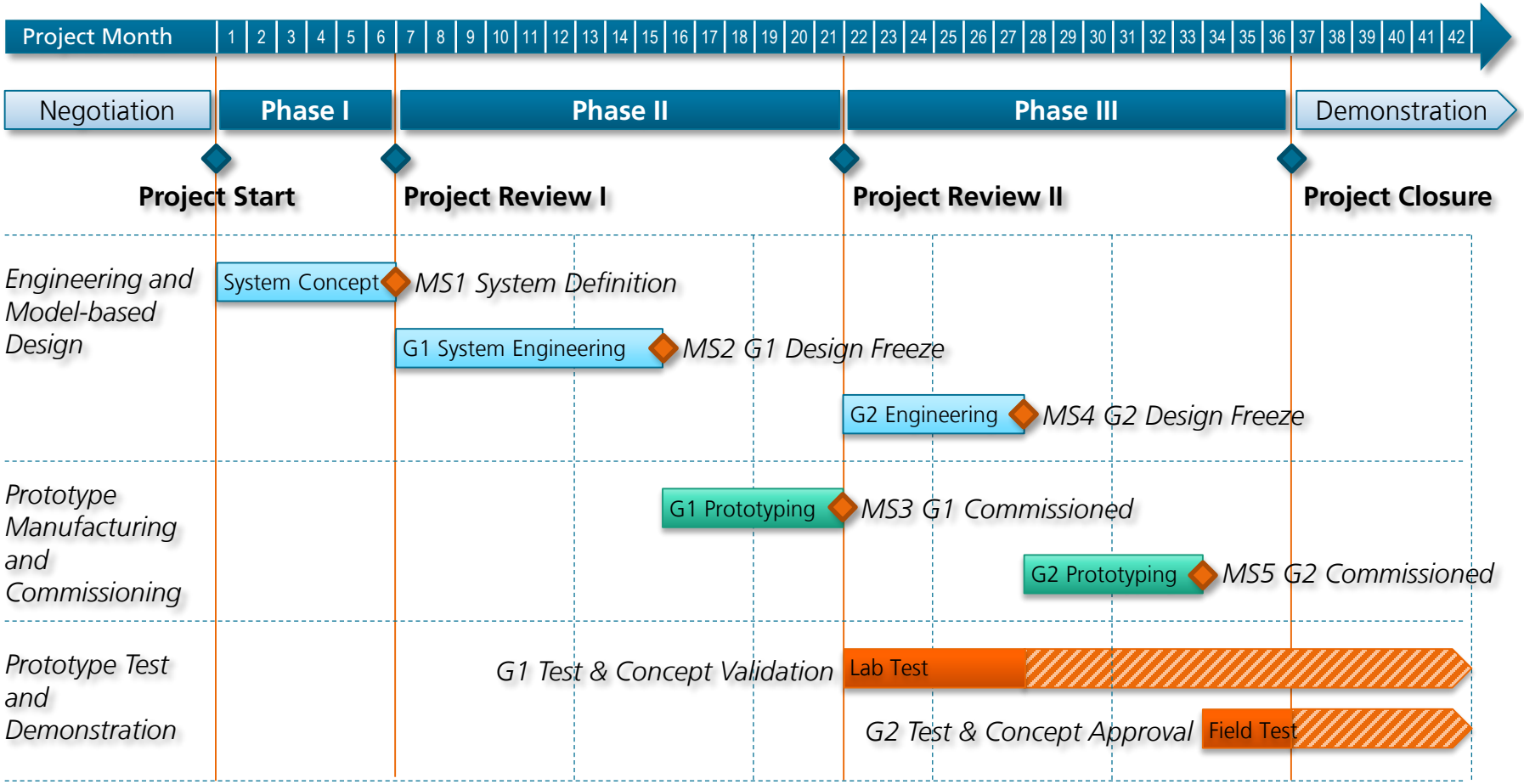
Proof-of-Concept (PoC)

- Component Design and Pre-Testing
- 3-D CAD Modelling
- Assembly Concept
- Parts Procurement and Manufacturing of Components
- PoC Prototype Assembly and Commissioning
- Concept Validation
- Characterization Tests

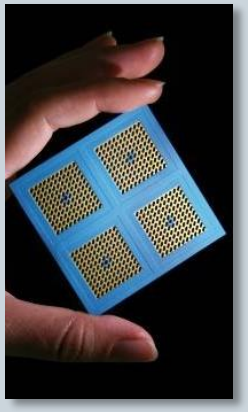
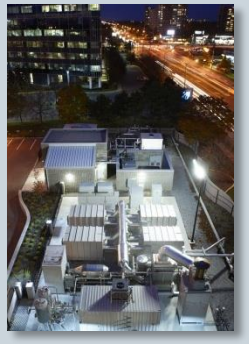
Technology Demonstration

- Concept Review
- Iterative, Model-based Design Optimization
- 3-D CAD Modelling and Design Freeze
- Parts Procurement
- Small-Series Prototype Manufacturing
- Prototype Commissioning and Delivery
- Prototype Testing for Endurance Operation, Cyclisation, etc.

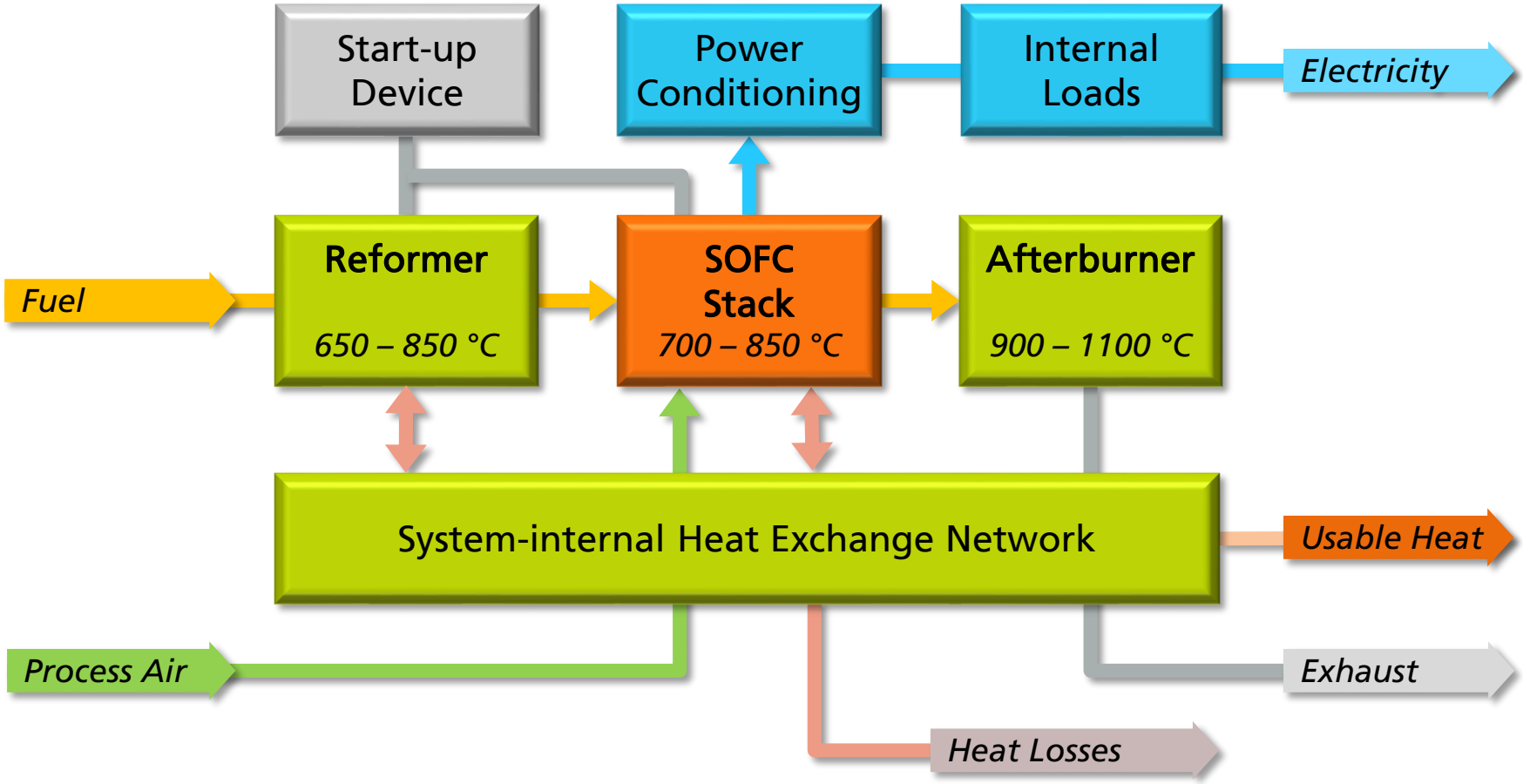
Exemplary Project Timeline



Fuel Cell Systems at IKTS

1 W	10 W	100 W	1 kW	10 kW	1 MW
hand-held		*portable*		*stationary*	
Hydrogen	Butane	LPG	Natural Gas	Biogas	NG / Biogas
PEFC	**SOFC**	**SOFC**	**SOFC**	**SOFC**	**MCFC**
					
Ceramic Multilayer	Bundled Microtubes	Planar Mini-Stack	Integrated Stack Module	CFY Stack Technology	DFC® Technology

SOFC System Integration
Generic Approach



SOFC System Integration Examples

eneramic & h2e Project Characteristics & Scope

	eneramic® by Fraunhofer	h2e
Funding	**Internal program**, funded by the Fraunhofer Future Foundation	**Contract research**, assigned by h2e Power Systems Pvt. Ltd., based in Pune, MH, India
Duration	June 2007 – August 2015	January 2013 – June 2016
Market Segment	**Off-grid power generation** for industrial applications (low power / long runtimes), e.g. traffic control systems, corrosion protection, surveillance systems, etc.	**micro-CHP** for 24/7 power supply and hot water preparation in interference-prone grids, e.g. for small businesses, clinics, housing, rural applications, etc.
System Description	**LPG-fueled 100 W_{el} SOFC power generator** (SOFC/battery-hybrid)	**NG-fueled 1 kW_{el} SOFC µCHP system** (SOFC/battery-hybrid, optional heat use)
Commercial Exploitation	Commercialization through a **corporate spin-off** with third-party investment, NewCo to be operable in 2016	Contracted project includes **IP- and technology transfer** for local manufacturing and commercialization by the customer

SOFC System Integration Examples

HotBox Concepts for Planar SOFC (100 W .. >1 kW)

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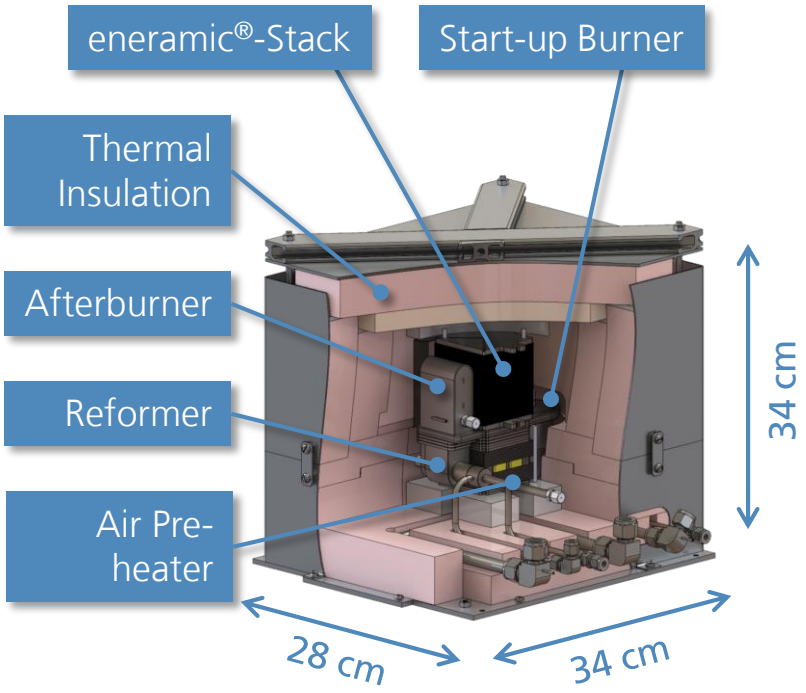
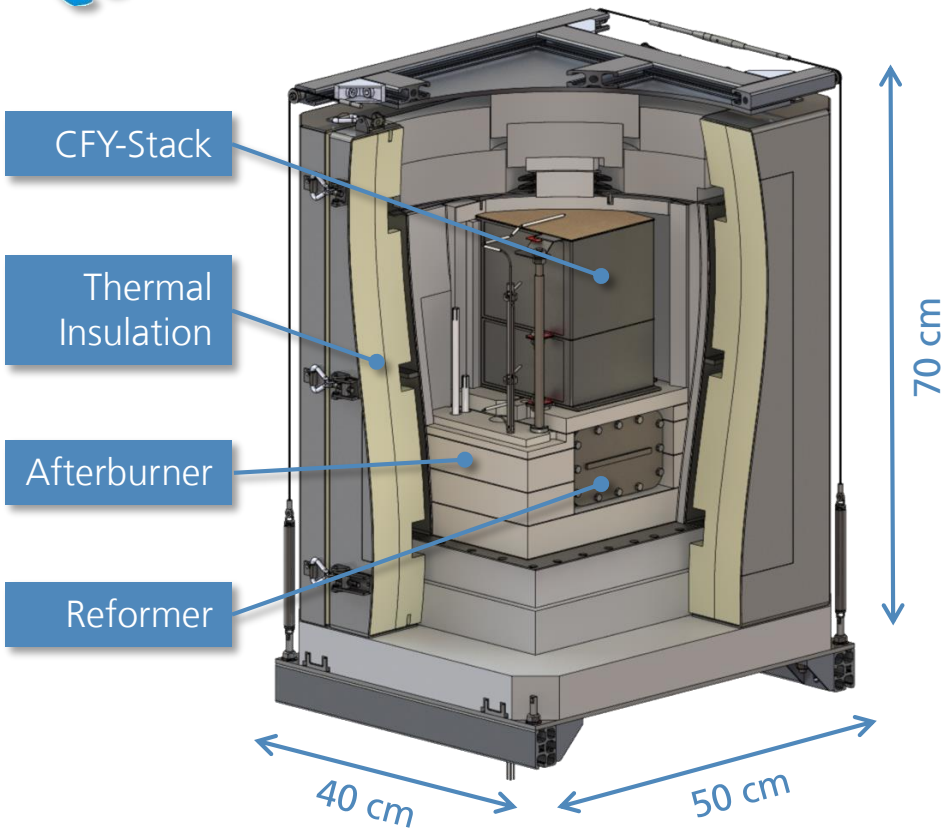
h2e





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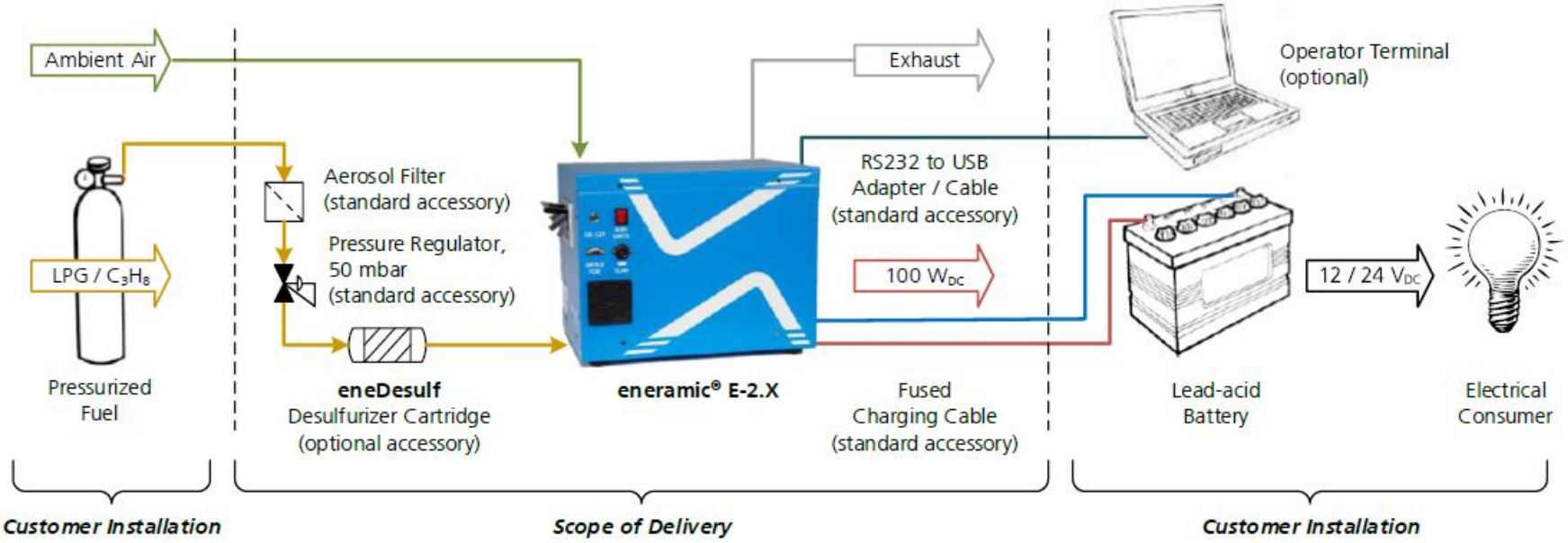
SOFC System Development - eneramic®

Product Concept and Applications



Industry

Leisure

Security

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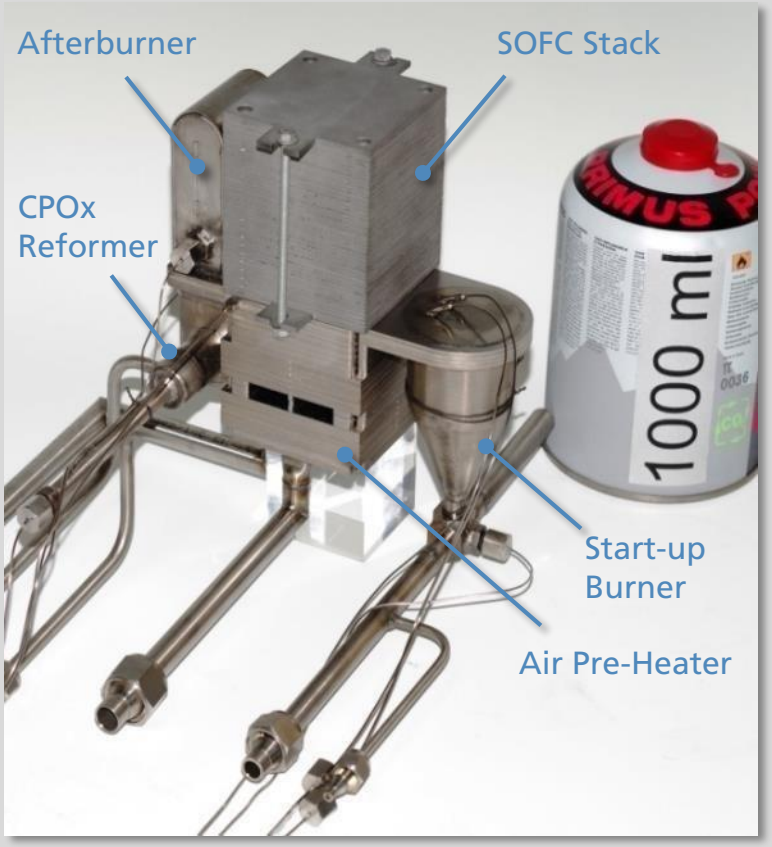
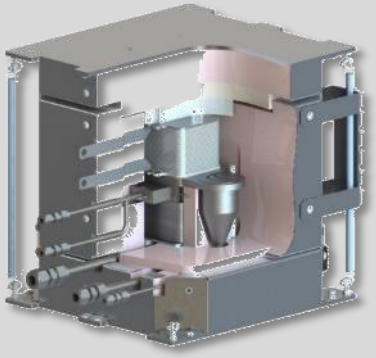
SOFC System Development - eneramic®
Sub-Tasks Accomplished

Core Module



HotBox



System Integration

Demonstrations / Field Trials

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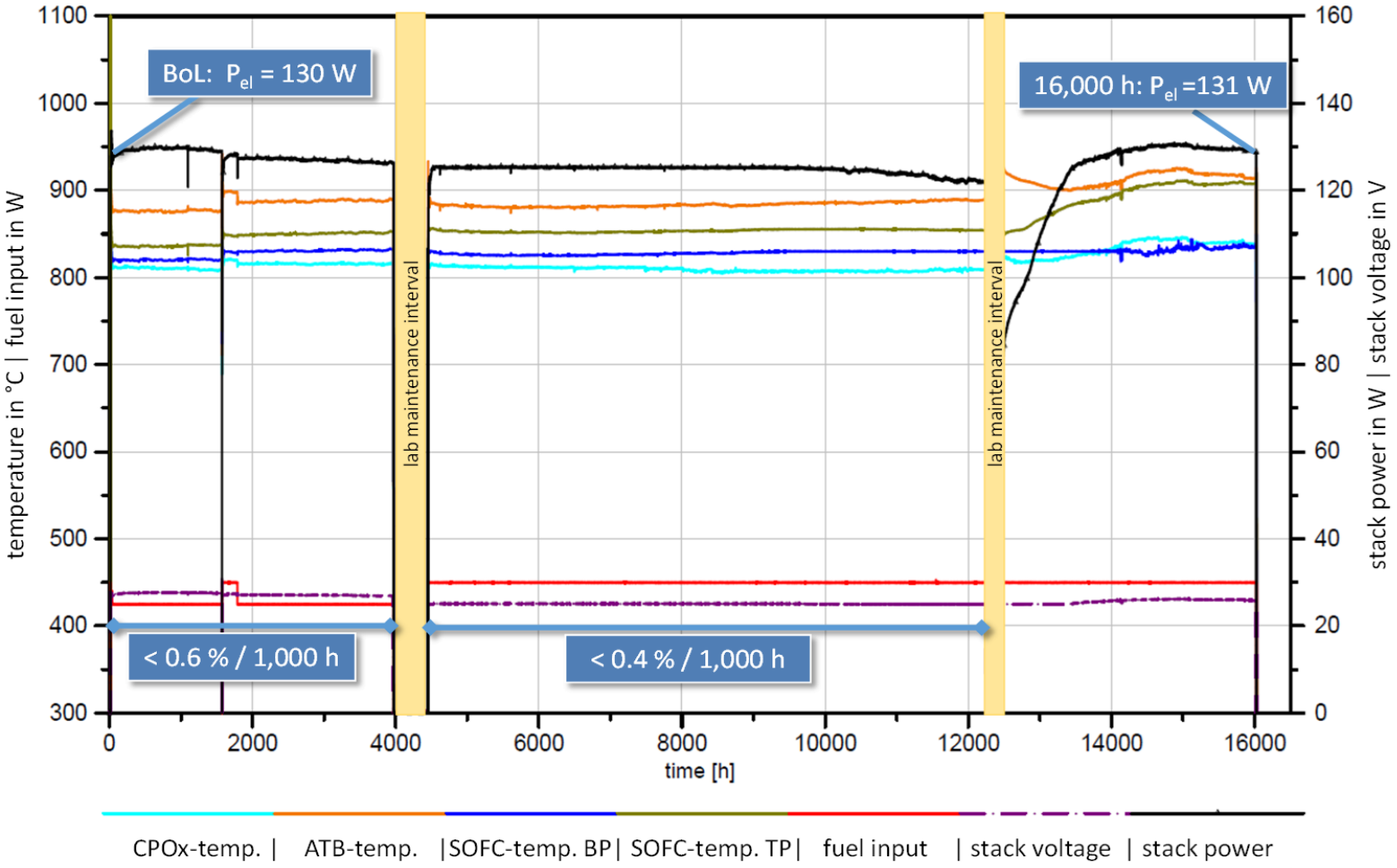
HotBox Endurance Operation



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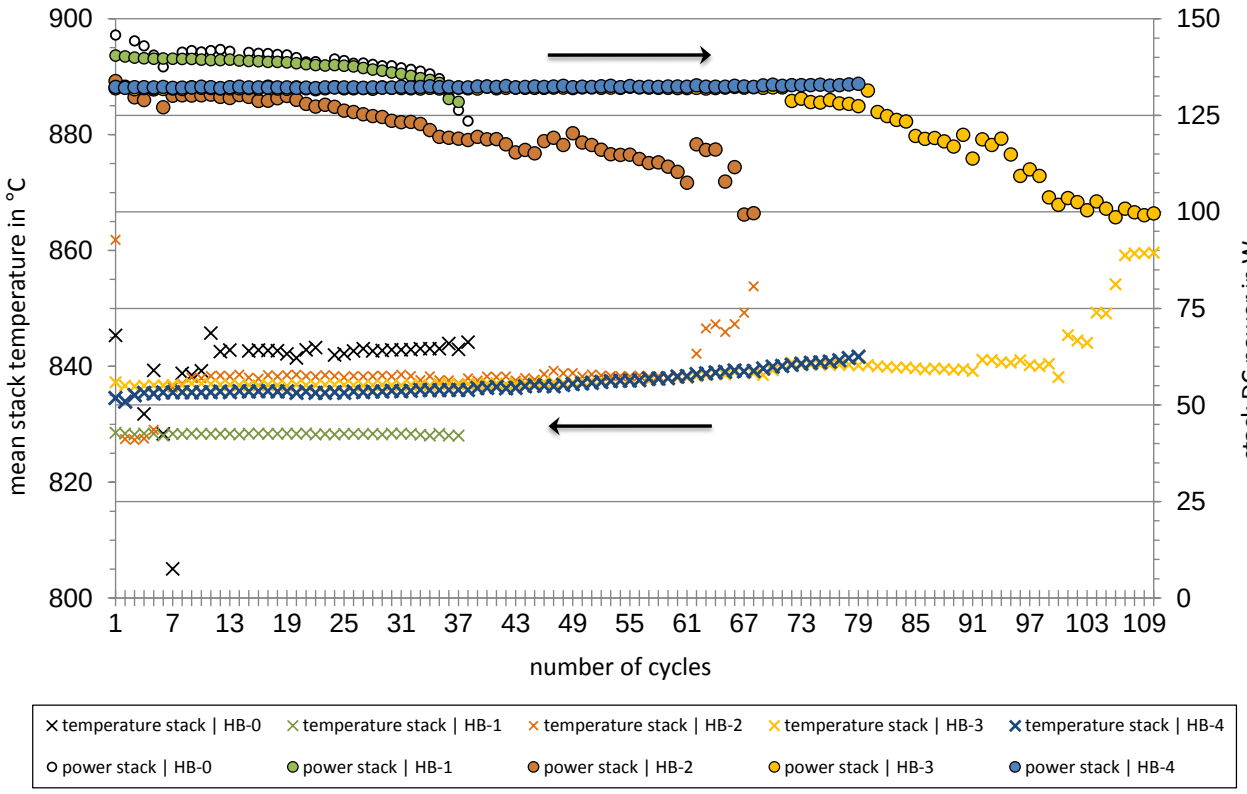
HotBox Cyclisation Test

Different HotBox generations operated in const. current/power mode, heating rate @ 10 K/min, propane/butane fuels



HB-0 (2013)
- ΔP_{avg} = 8.2% / 10 cycles

HB-1 (2013)
- ΔP_{avg} = 7.9% / 10 cycles

HB-2 (2013/14)
- ΔP_{avg} = 3.4% / 10 cycles

HB-3 (2014)
- ΔP_{avg} = 2.6% / 10 cycles

HB-4 (2015)
- ΔP_{avg} = 1.3% / 10 cycles

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SOFC System Development - eneramic®

Evolution of Prototype Systems

				
Prototype Series	**E-1.0** Laboratory Sample	**E-1.1** Proof-of-Concept	**E-1.2 / E-1.3** Demonstrator Series	**E-2.0** Pre-Commercial Unit
Net Power Output	**95 W_{el}** 12 V_{DC}	**100 W_{el}** 12 V_{DC}	**100 W_{el}** 12 V_{DC}	**110 W_{el}** 12 or 24 V_{DC}
Fuel Input, Efficiency	35,3 g/h **21 $\%_{LHV}$**	48,8 g/h **16 $\%_{LHV}$**	35,5 g/h **22 $\%_{LHV}$**	35,8 g/h **24 $\%_{LHV}$**
Volume, Weight	175 l 71 kg	115 l 55 kg	94 l 36 kg	55 l 23 kg
No. of Units, Availability	1 05 / 2012	1 01 / 2013	9 06 / 2014	> 15 07 / 2015

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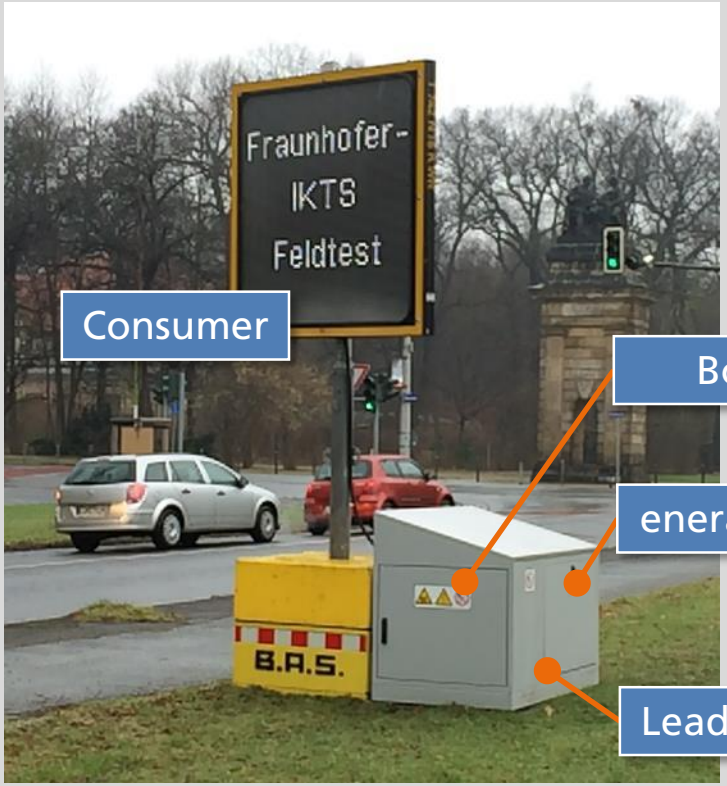
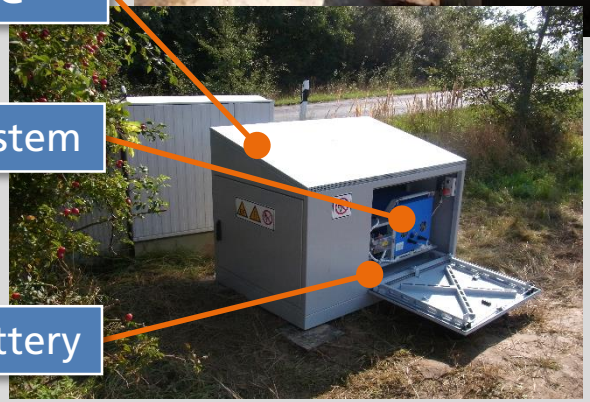
Sample Applications

- Remote Traffic Control Devices



- Cathodic Corrosion Protection



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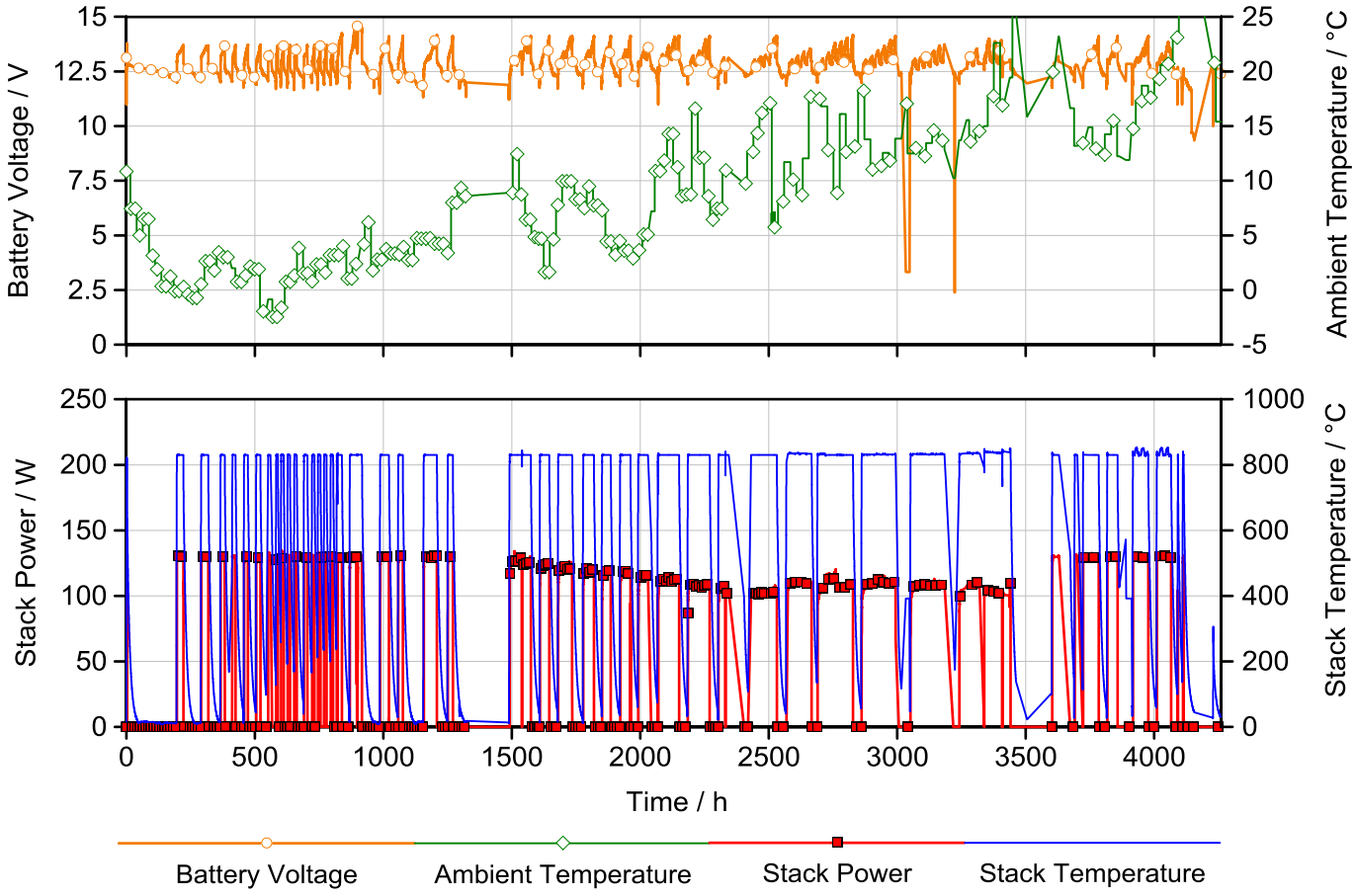
Sample Field Trial - Traffic Control Panel



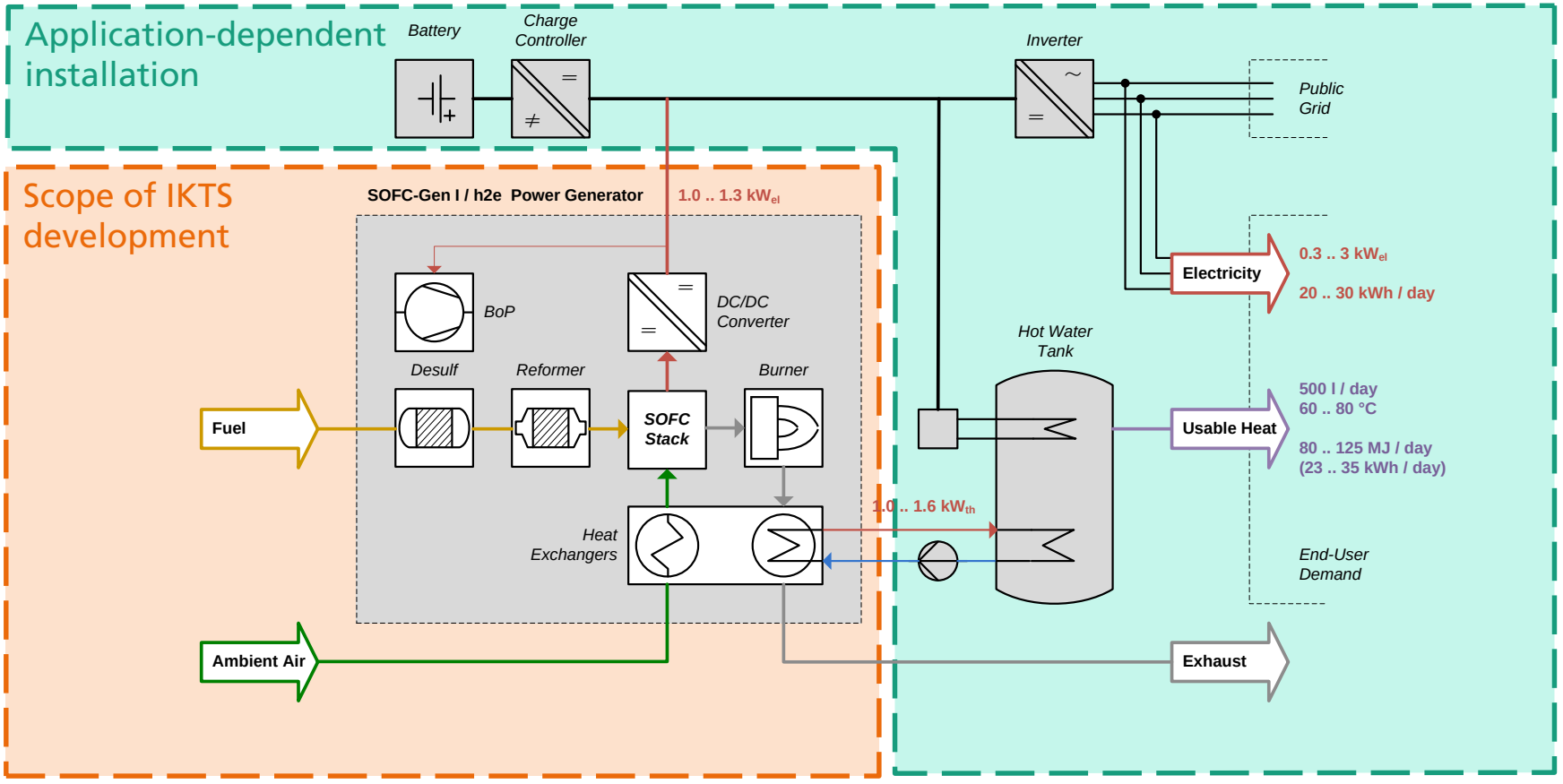
C_{Batt} = 160 Ah

$P_{Consumer}$ = 25 .. 70 W

~50 start/stop cycles

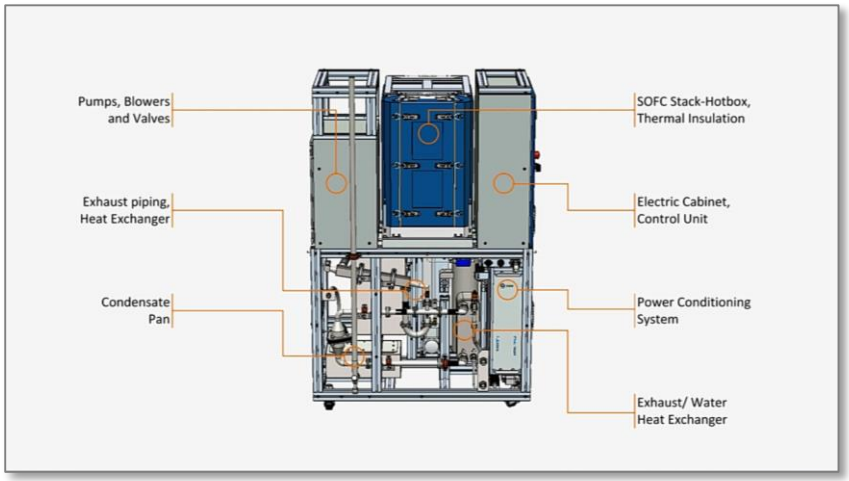
SOFC System Development - h2e®

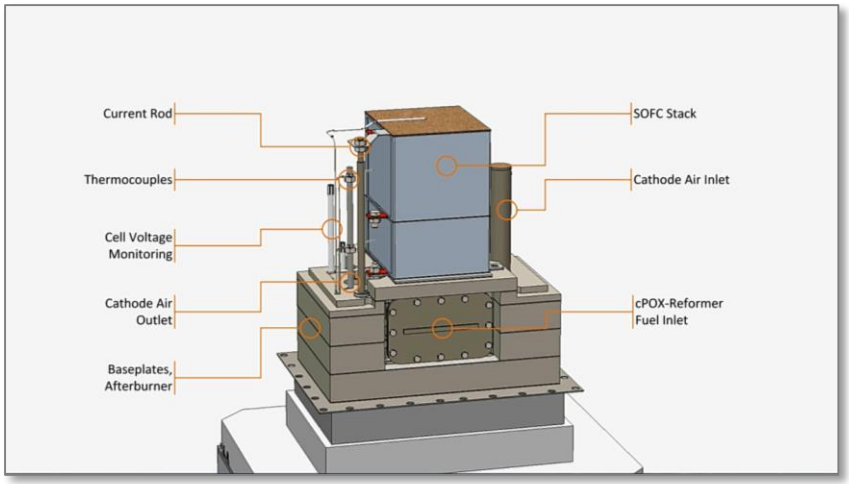
System Concept



SOFC System Development - h2e®

Proof-of-Concept Prototype (3-D CAD-Model)

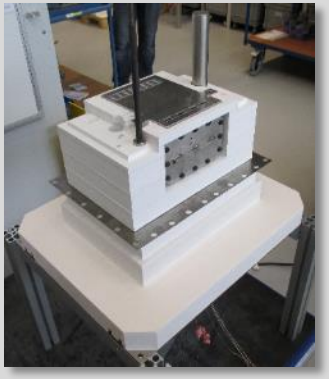
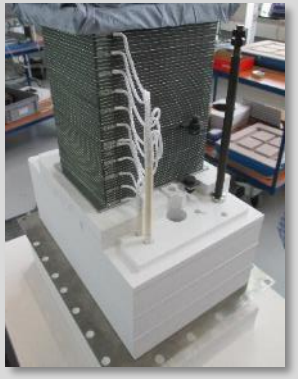




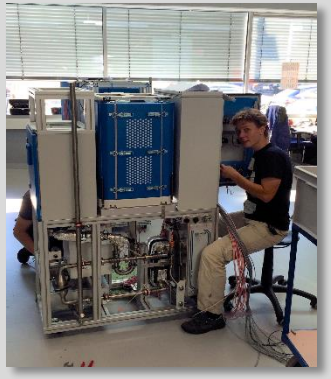
SOFC System Development - h2e®

Achievements of Project Phase I (1)

- HotBox-Integration / Pre-Testing

- System Integration / Proof-of-Concept

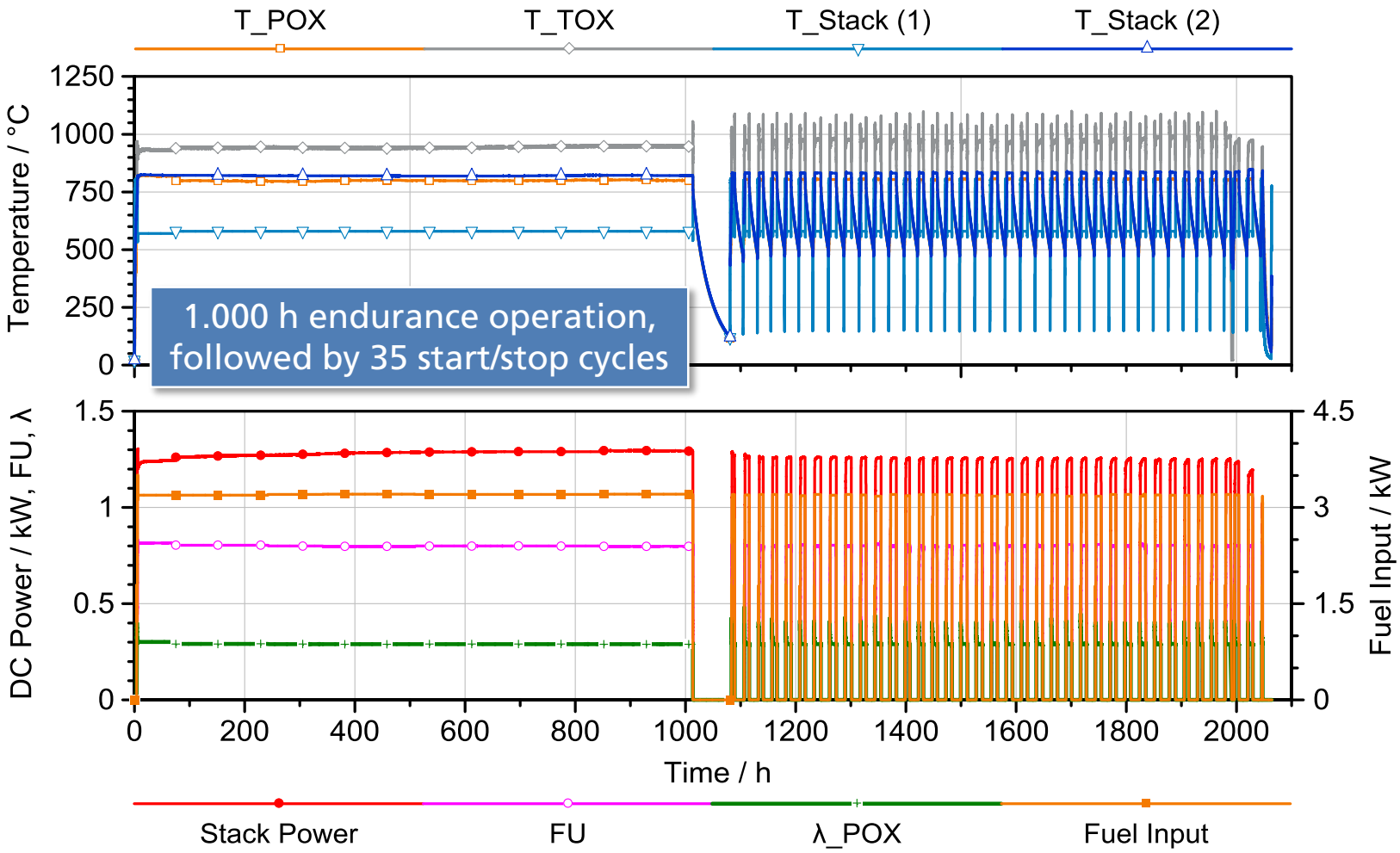
SOFC System Development - h2e®

Achievements of Project Phase I (2)

- First SOFC System Commissioned in India

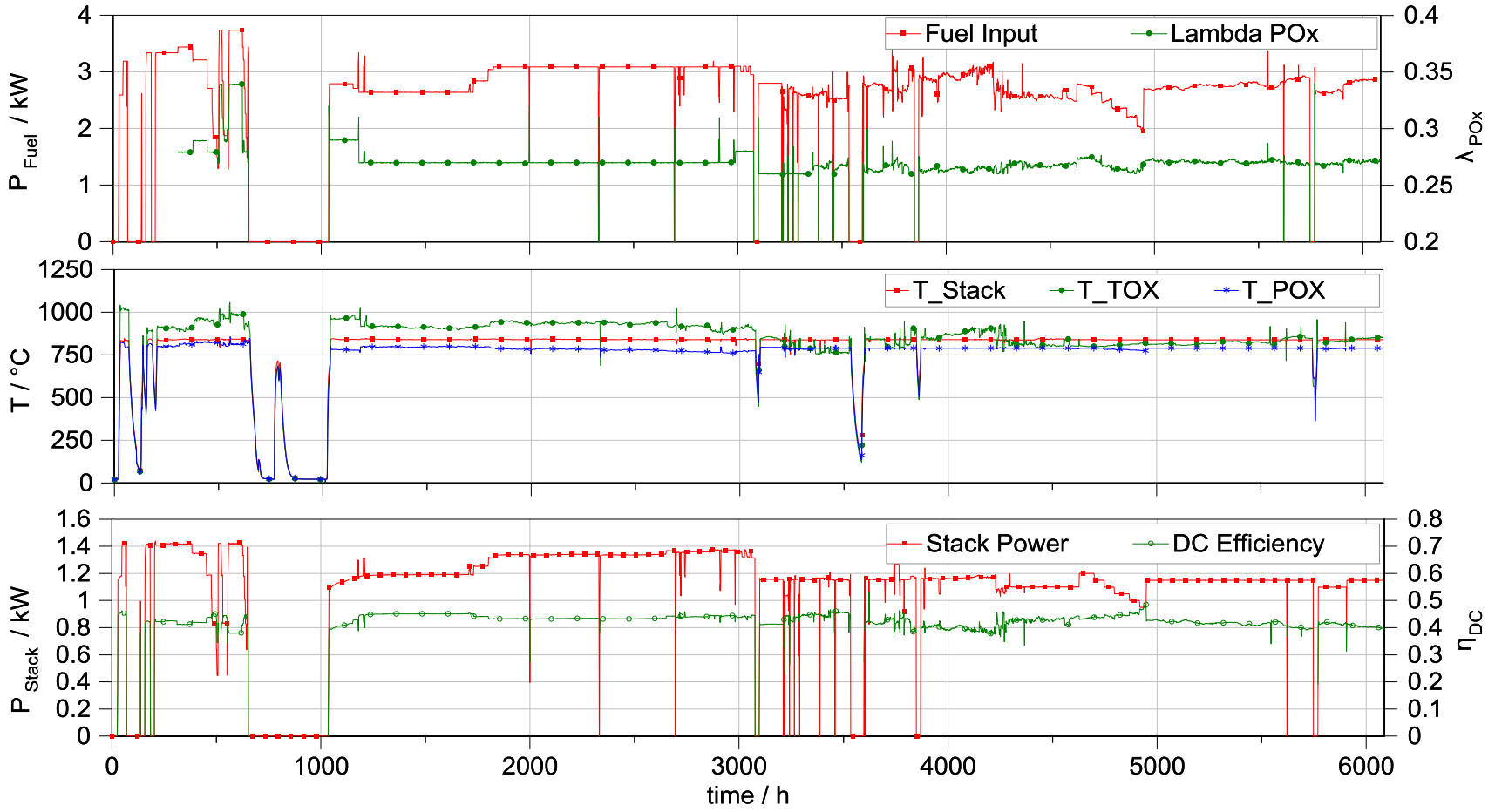
SOFC System Development - h2e®

HotBox Concept Validation



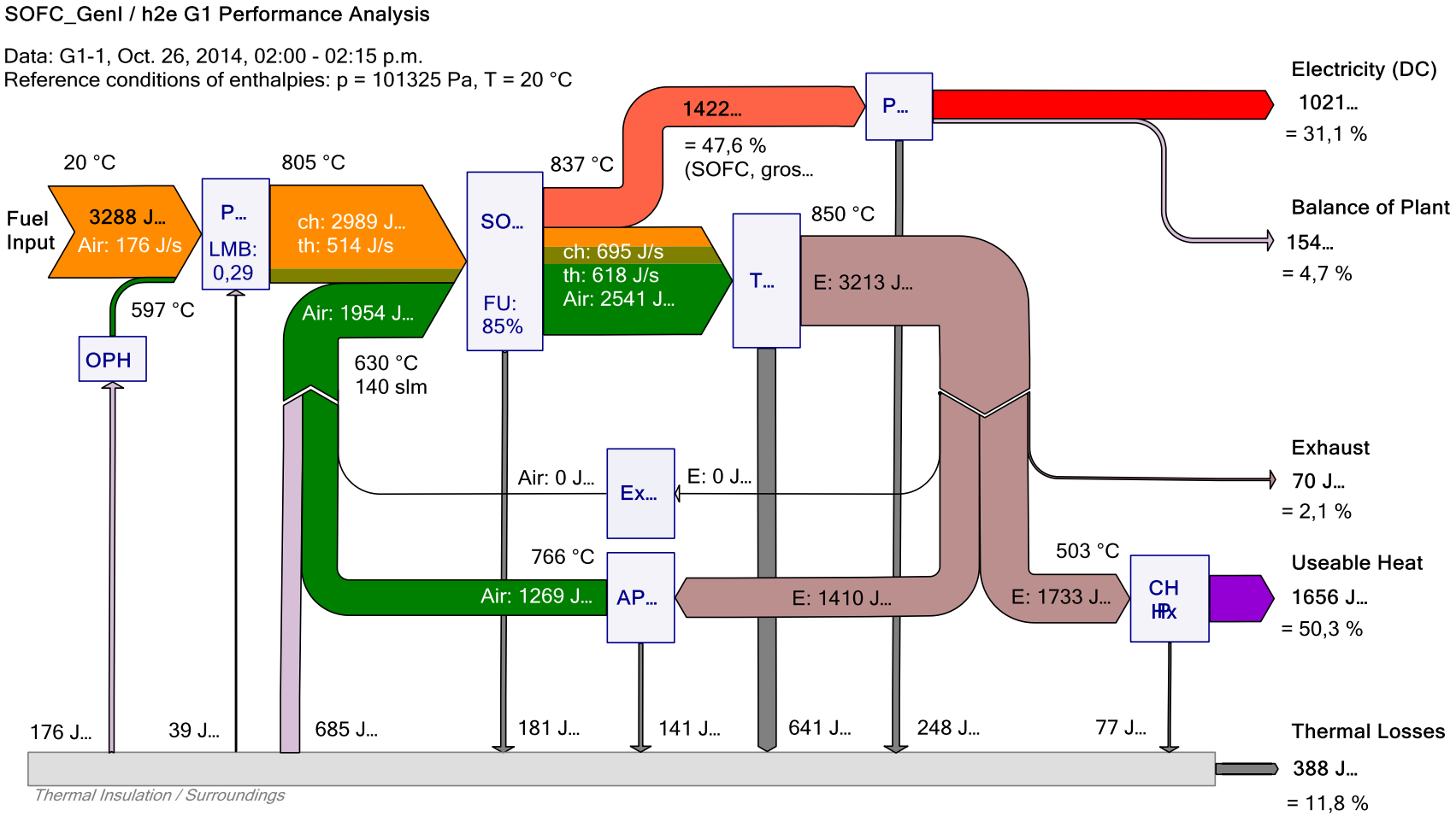
SOFC System Development - h2e®

Initial PoC Prototype Test



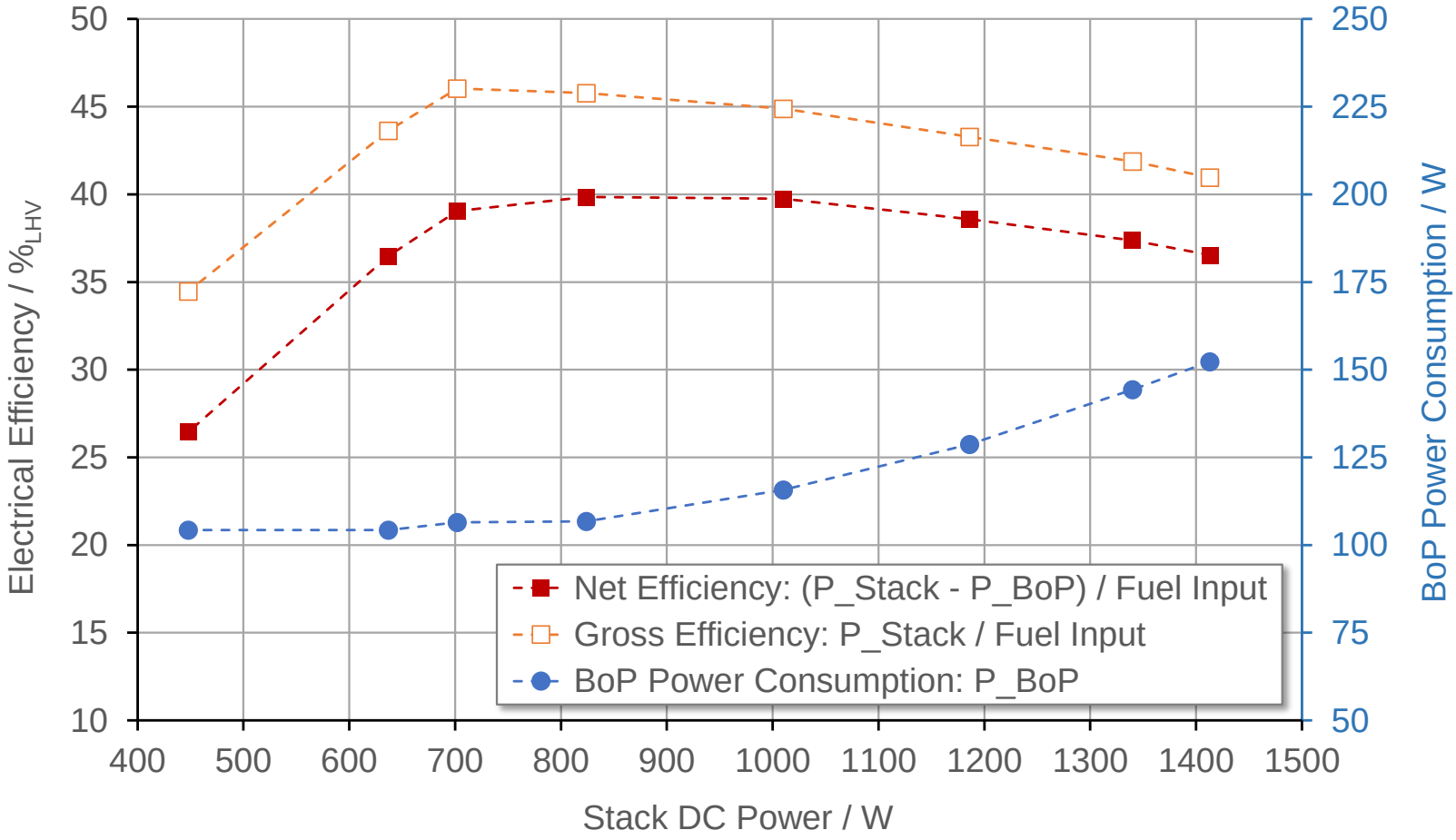
SOFC System Development - h2e®

PoC Prototype Performance Analysis



SOFC System Development - h2e®

PoC Prototype Part-Load Performance



Summary eneramic® & h2e®

	eneramic® by Fraunhofer	h2e
Project Status Summary	1. Proprietary stack technology, core components and system concept developed	1. CFY-stack successfully integrated into a compact and robust HotBox design
	2. Prototype system development advanced to the pre-commercial stage	2. Two proof-of-concept (PoC) prototype systems commissioned / in operation
Achieved Maturity Level	3. Readiness for marketing demonstrated by field trials / business case validation	3. High-performance SOFC system based on POX demonstrated ($85\%_{FU}$, $43\%_{eff,gr}$)
	4. CE-Certification acc. to IEC 62282 and EMC directive prepared	4. PoC prototype system shipped to customer for test and demo activities
Upcoming Activities	5. Pilot manufacturing for demo activities and field trials started in July 2015	5. Project Phase II (initiated): development of improved demonstration prototypes
	6. Corporate spin-off for commercial deployment to be operable in 2016	6. Technology Transfer and start of local manufacturing / commercialisation

Conclusion

- IKTS has developed SOFC stack technology platforms and system concepts for SOFC power generators – **from materials development to near-product systems.**
- A top-down requirements definition / bottom-up system engineering process was established – **from customer ideas to prototype demonstrations.**
- Proven engineering process, test infrastructure and tool-chain is available for new development projects – **from hand-held devices to stationary plants.**
- Future contract research and system integration projects may be based on
  - eneramic® technology platform (100 .. 500 W)
  - CFY SOFC stack technology by IKTS / Plansee SE (500 W .. 100 kW)
  - Client's proprietary cell / stack technology
  - Third-party fuel cell products

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