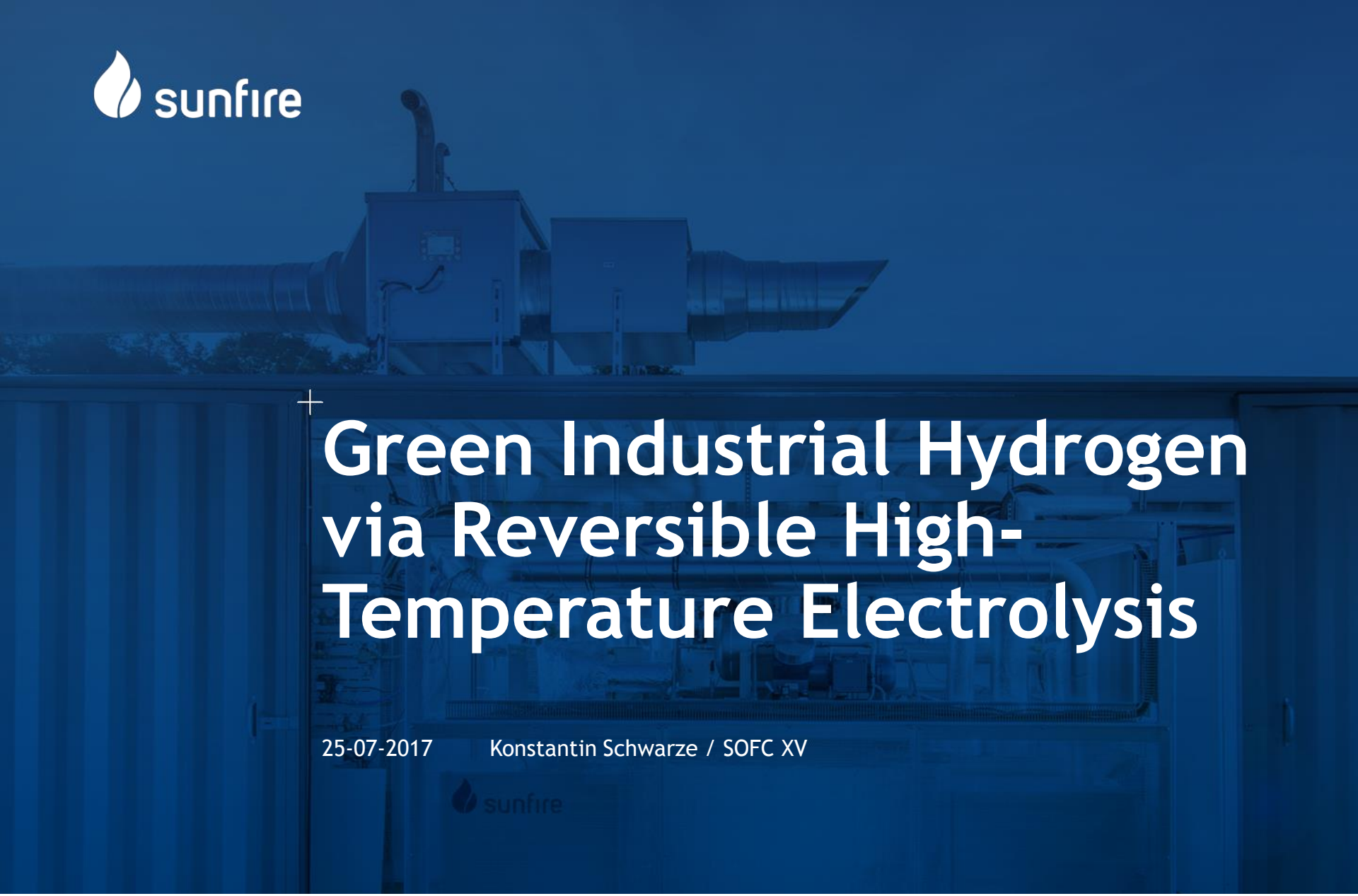


Green Industrial Hydrogen via Reversible High-Temperature Electrolysis

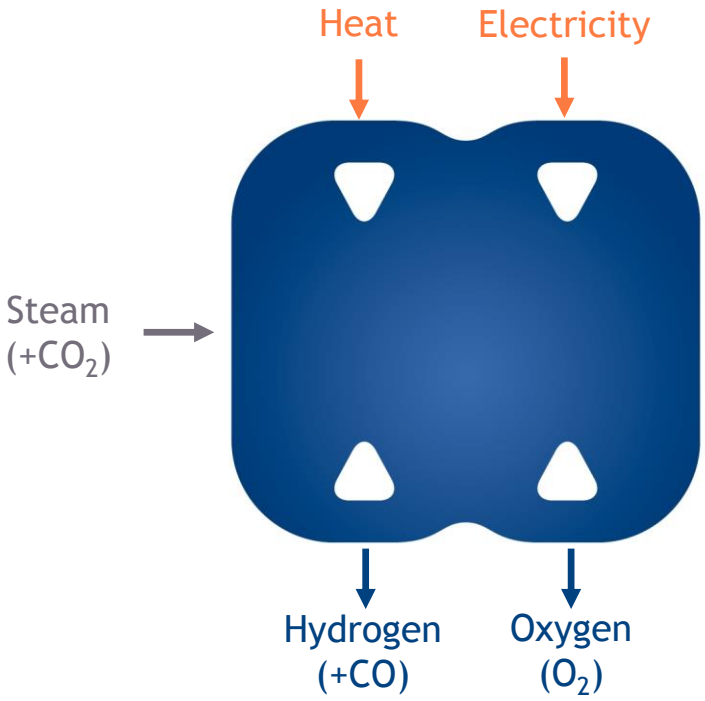
25-07-2017 Konstantin Schwarze / SOFC XV

Investors

Introduction

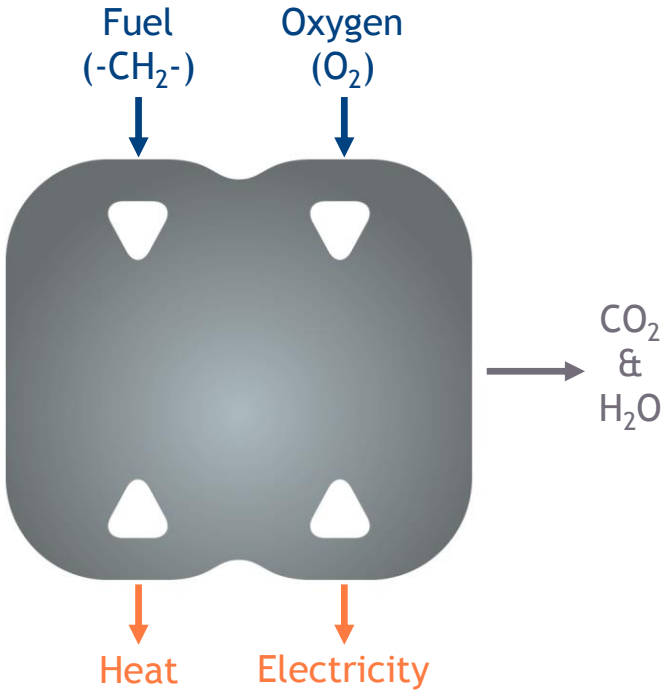
Solid Oxide Cells convert…

… electricity into **hydrogen**



Electrolysis Mode

… chemical energy into **electricity** and **heat**

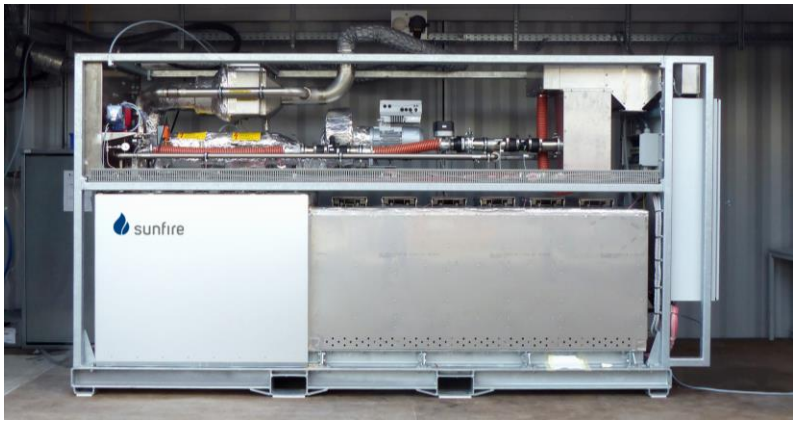


Power & Heat Mode

One Core - Multiple Products

+ Heat and Power for Households

+ Power and Heat for Commercial Buildings



+ Power for Remote Locations

+ Fuels and Gases for Mobility + Industry

RSOC State of the Art

RSOC Cooperation Sunfire / Boeing

BOEING

Electrolysis Mode – $H_2O \rightarrow H_2 + ½\ O_2 \rightarrow$ Produce and Store H2

Fuel Cell Mode – $H_2 + ½\ O_2 \rightarrow H_2O \rightarrow$ Use H2 to Produce Power

H_2 Storage

H2

Sunfire Reversible SOFC Stack

Power in from the Grid During Electrolysis Mode

Power Out to the Grid During Fuel Cell Mode

Facility Grid

H2 H2O

H_2 Compression

H2 H2O

RSOFC System

Desalination/ Deionizer Unit

Potable/ Sea Water Inlet

Process Water Storage Tank

System Highlights

BOEING

- Electricity storage for autonomous electricity supply during day and night (PV connected)
- Application: Autonomous power supplies (e.g. islands), smart grids
- 2 x 80 kW SOEC power input and 2x 20 kW SOFC power output (H_2 based)
- Roundtrip efficiency ca. 45 %
- Highlights:
  - ✓ Worlds first thermally self-sustained SOEC system at representative scale
  - ✓ First demonstration of RSOC technology at system level
  - ✓ Automatically controlled electricity storage and release → filling level of H_2 vessel

Commissioning at sunfire site, Germany

RSOC installation at Navy base in Los Angeles, USA

The GrInHy Concept

GrInHy Project

GrInHy
Green Industrial Hydrogen

- EU funded project (04/2016 – 03/2019)

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

SALZGITTER FLACHSTAHL
A Member of the Salzgitter Group

BR&T-E

sunfire

POLITECNICO DI TORINO 1859 1906

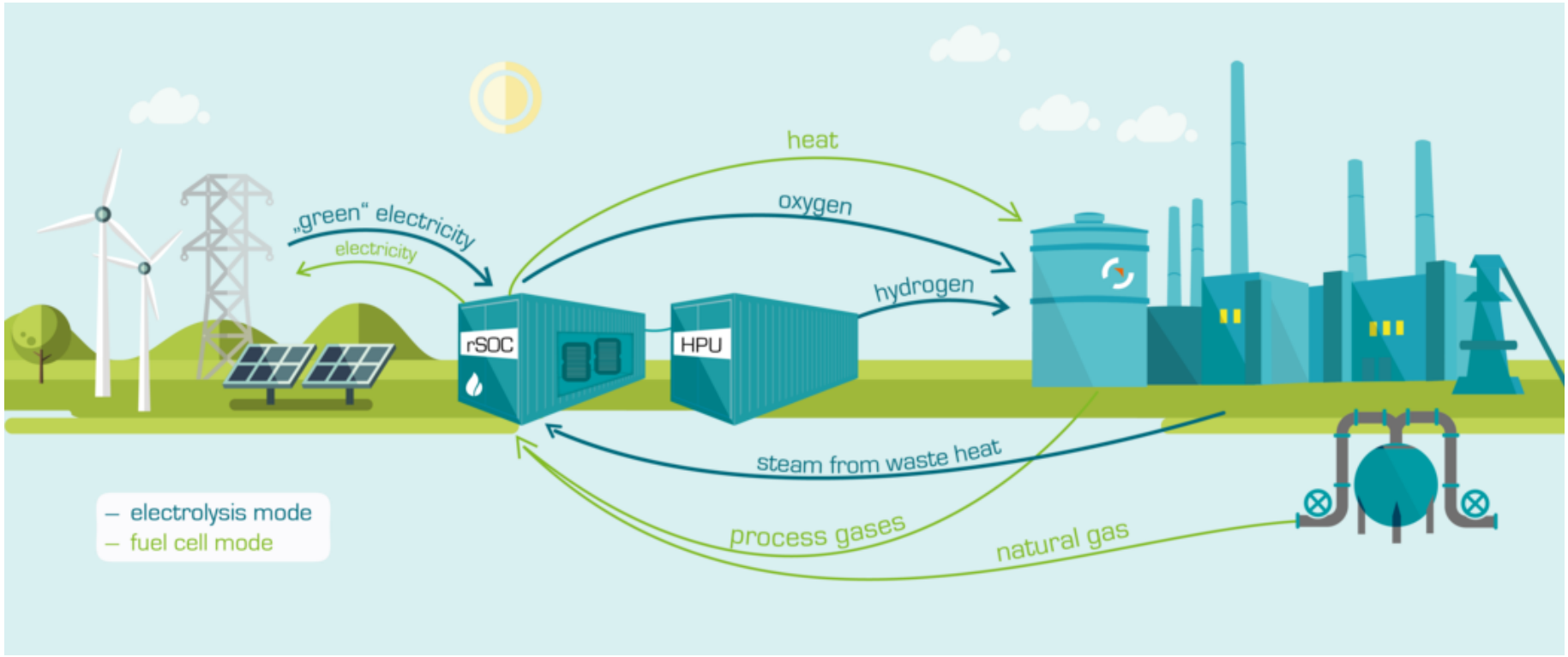
VTT

EIFER

ipm

- Objectives:
  - Overall electrical efficiency of at least 80 $\%_{LHV}$
  - Scaling-up the SOEC unit up to 150 kW_{el}
  - Operation > 7,000 h while meeting hydrogen quality standards of the steel industry
  - Integration of a reversible operation mode (fuel cell mode) with natural gas as feedstock
  - Integration in a relevant industrial environment

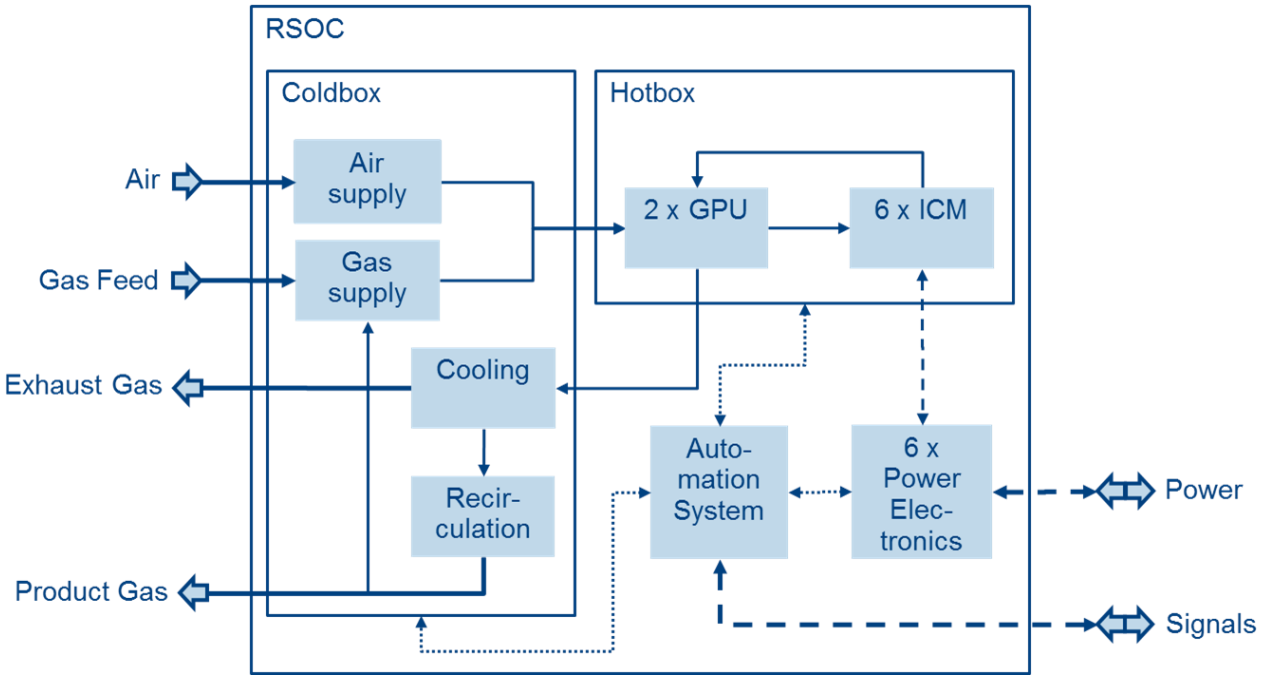
RSOC Integration in an Iron and Steel Work



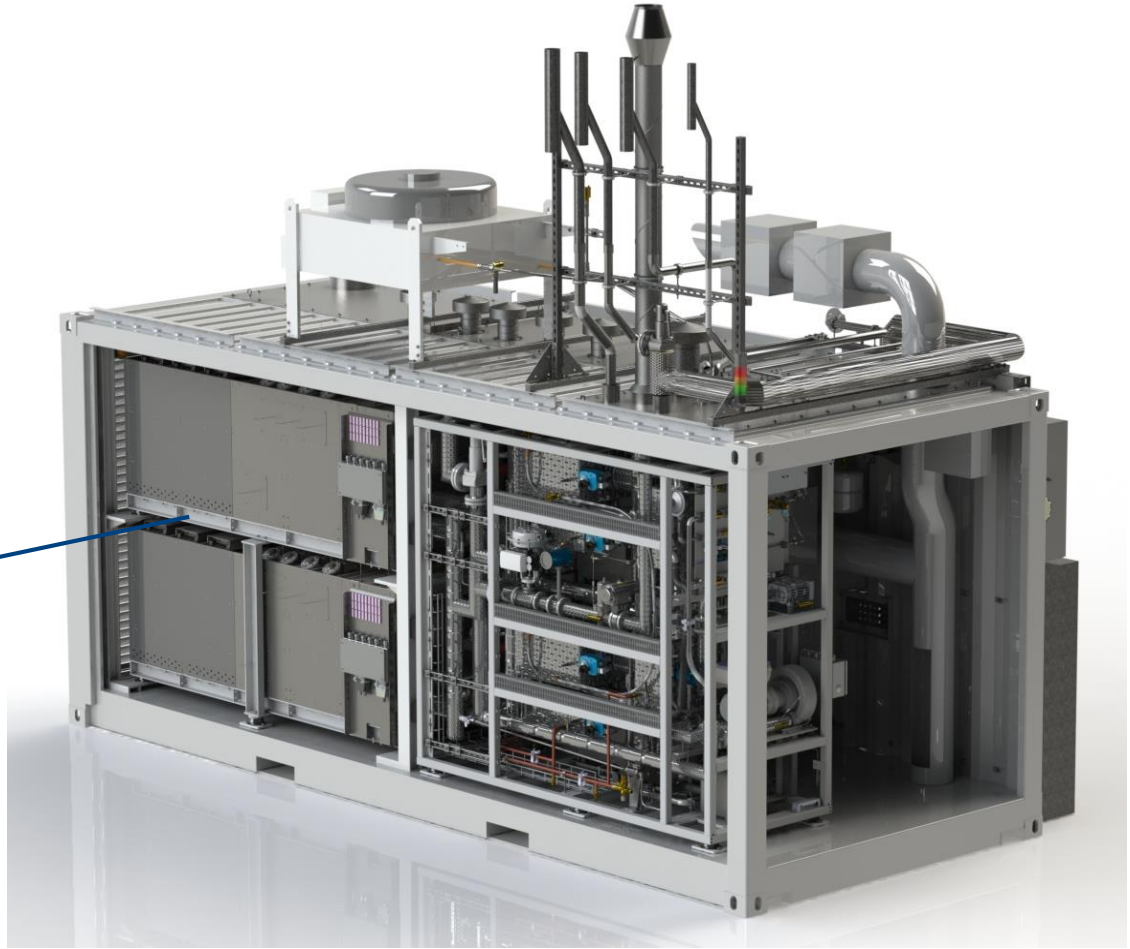
GrInHy System Layout

RSOC System Layout

- System consists of RSOC Unit and Hydrogen Processing Unit
- RSOC Layout:



RSOC Layout



Technical Data RSOC Unit

Operation Mode	EL Mode	H2-FC Mode	NG-FC Mode
AC Power Input	142,9 kW ± 8 %	-	-
AC Power Output	-	30 kW ± 10 %	25 kW ± 10 %
H2 Production	40 Nm^3/h ± 5 %	-	-
Steam Consumption	45 kg/h ± 2.5 kg/h	-	-
H2 Consumption	-	21.3 Nm^3/h ± 15 %	-
NG Consumption	-	-	5.3 Nm^3/h ± 15 %
Dynamic Range	50…125 %	30…100 %	30…100 %
Gross Efficiency AC	84 % ± 2 % points	47 % ± 2 % points	50 % ± 2 % points

Technical Hydrogen Processing Unit

+ The HPU by BR&T-E compresses and dries the Hydrogen to feed it to the onsite pipeline

Parameter	Value
Input Pressure	20 mbar(g)
Output Pressure	8 bar(g)
H2 Output	54 Nm^3/h
H2 Purity	Dew Point: -60 °C N_2: < 200 ppmv O_2: < 1 ppmv
AC Nominal Power	20 kW

RSOC Test Results

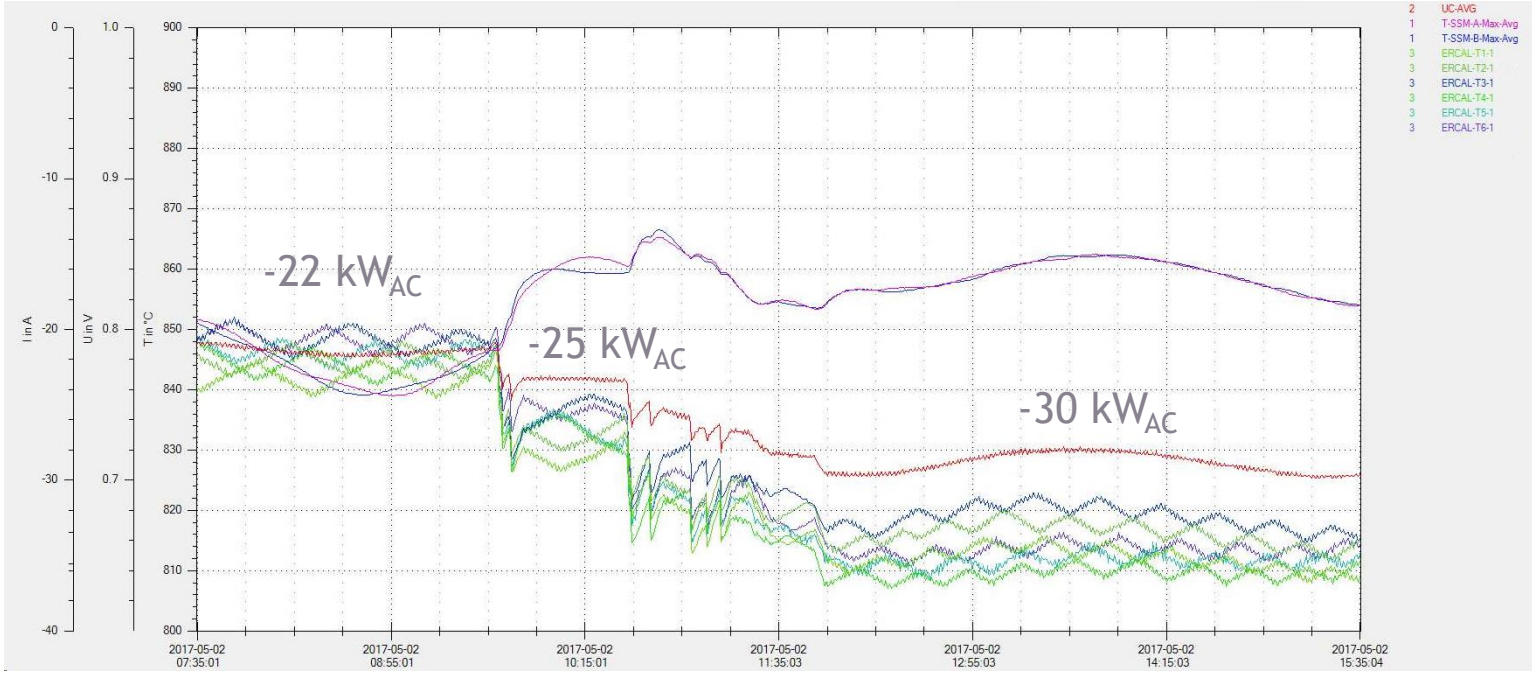
Lab testing

- Tested Units: GrInHy RSOC + 2 identical commercial prototypes
- Lab tested w/o HPU or integration in other processes
- About 1000 hours testing each
- Relevant load points were established in fully automated operation

→ Very good repeatability has been found

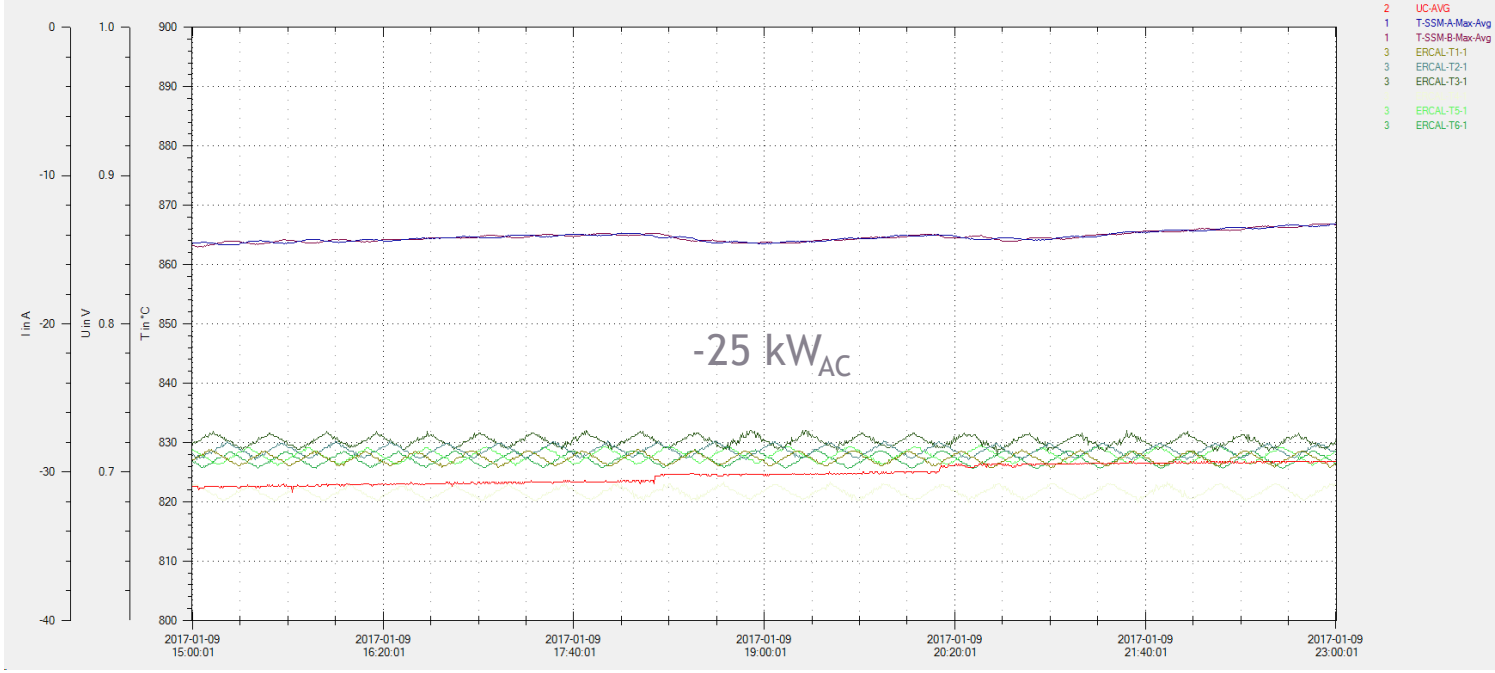
H2-FC Results

- Power target reached: 30 kW_{AC} @ > 0.7 V/cell, 0.27 A/cm^2
- Gross AC Efficiency 45 $\%_{LHV}$ @ full load, 50 $\%_{LHV}$ maximum @ part load
- High fuel utilization > 95 %
- Part load ability achieved



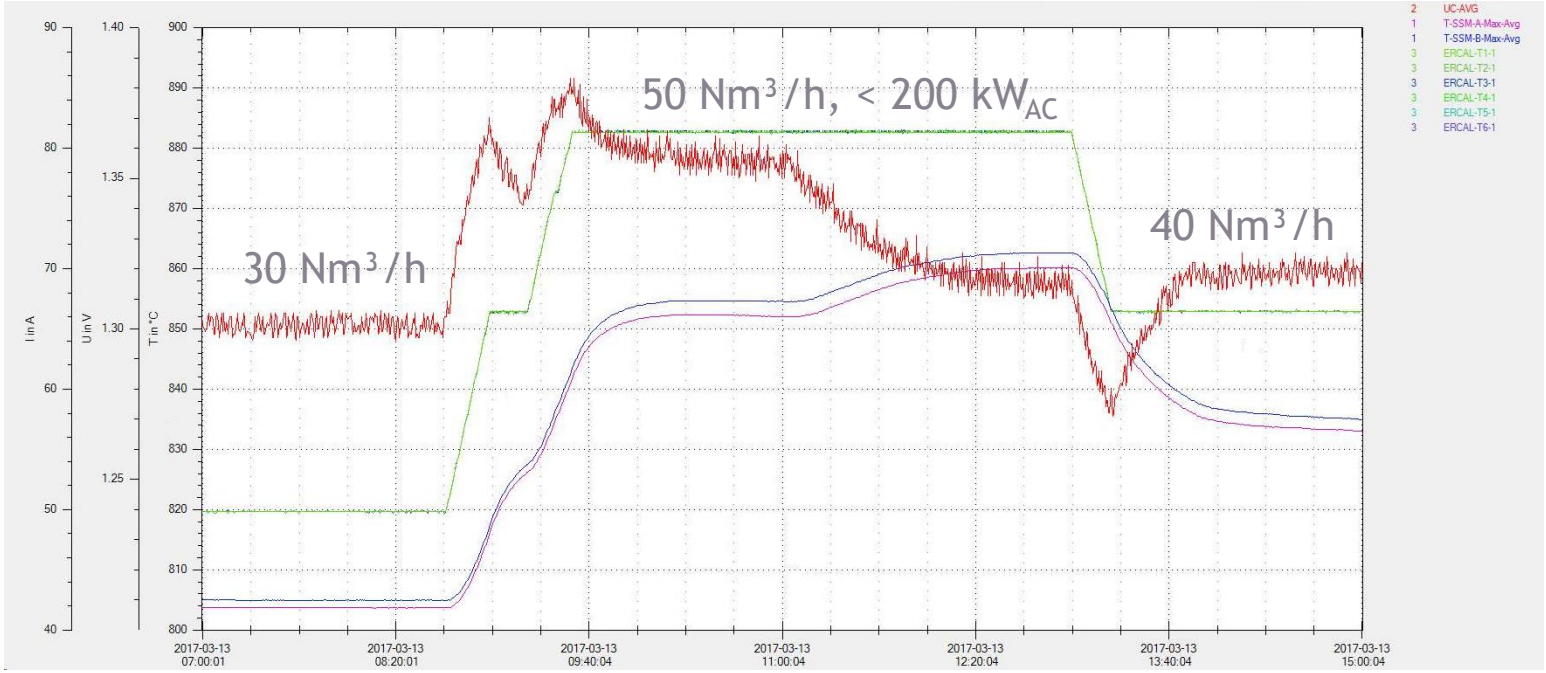
NG-FC Results

- Power target reached: 25 KW_{AC} @ > 0.7 V/cell, 0.23 A/cm^2
- Gross AC Efficiency 50 $\%_{LHV}$ @ full load, 52 $\%_{LHV}$ maximum @ part load
- High fuel utilization of > 85 %
- Part load ability achieved, but at relatively low efficiencies at deep part load



Electrolysis Results

- Hydrogen output targets reached: 40 Nm^3/h, including overload (50 Nm^3/h) and peak load 200 kW_{AC}
- Gross AC Efficiency 80 $\%_{LHV}$ @ full load, > 75 $\%_{LHV}$ minimum @ part load and overload
- Systems shows very good operability and dynamics



Conclusion & Acknowledgement

Conclusion

+ High consistency between specification and test results was reached
+ Reaching the typically higher efficiencies in part load seems difficult
+ In Electrolysis mode efficiency is 2 % points lower than predicted

+ Reason for deviation between specs and test results
    1. Thermal losses higher than predicted
        → Next generation hotbox will be more compact an comes with enhanced thermal insulation
    2. Power electronics efficiency only 90 %
        → Bidirectional power electronics with a high dynamic/voltage range operate in suboptimal load points: use of different unidirectional power electronics
    3. Systematic error in power measurement
        → Deviations between high-end lab measurements and more cost efficient online measurement: possibly recalibration needed

Conclusion

+ The prototypes were successfully operated as Electrolyser and Fuel Cell with Hydrogen and Natural Gas

→ **It is the worlds largest High-Temperature Electrolyser Unit**

+ Possible further enhancements elaborated
+ Next step: Long term testing, operation in industrial environment

Acknowledgement

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THANK YOU!

ENERGY
EVERYWHERE

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