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Batterie- und Brennstoffzellensysteme

Nebenaggregate

André Weber

Institut für Werkstoffe der Elektrotechnik IWE
Adenauerring 20b, Geb. 50.40 (FZU), Raum 314
phone: 0721/608-7572, fax: 0721/608-7492
andre.weber@kit.edu
www.iwe.kit.edu

Institut für Werkstoffe der Elektrotechnik

Fuel Cells
Cell Voltage, Internal Resistance and Fuel Cell Efficiencies

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thermodynamic efficiency $$\eta_{th} = \frac{\Delta G}{\Delta H} = 1 - \frac{T\Delta S}{\Delta H}$$

electrochemical efficiency $$\eta_{el} = \frac{U_{cell}}{U_{th}} = -\frac{nFU_{cell}}{\Delta G}$$

cell voltage and internal resistance

$$U_{cell} = U_0 - R_{cell} \cdot I_{cell} = U_0 - I_{cell} \cdot \sum_k R_{cell,k}$$

$$\sum_k R_{cell,k} = R_{cathode} + R_{electrolyte} + R_{anode} + R_{contact}$$

fuel utilization $$\beta_f = \frac{\text{used fuel}}{\text{provided fuel}}$$

fuel efficiency $$\eta_f = \frac{I}{I_m}$$

single cell ... stack

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reforming efficiency $$\eta_{ref} = \frac{\Delta H}{\Delta H_{fuel}}$$

el. system efficency $$\eta_{elS} = \frac{W_{el}}{nFU_{cell}}$$

electrical system efficiency $$\eta_{electrical} = \eta_{th} \cdot \eta_{el} \cdot \eta_f \cdot \beta_f \cdot \eta_{Ref} \cdot \eta_{elS} = \frac{\text{produced electrical energy}}{\text{provided chemical energy}}$$

system (el. p.)

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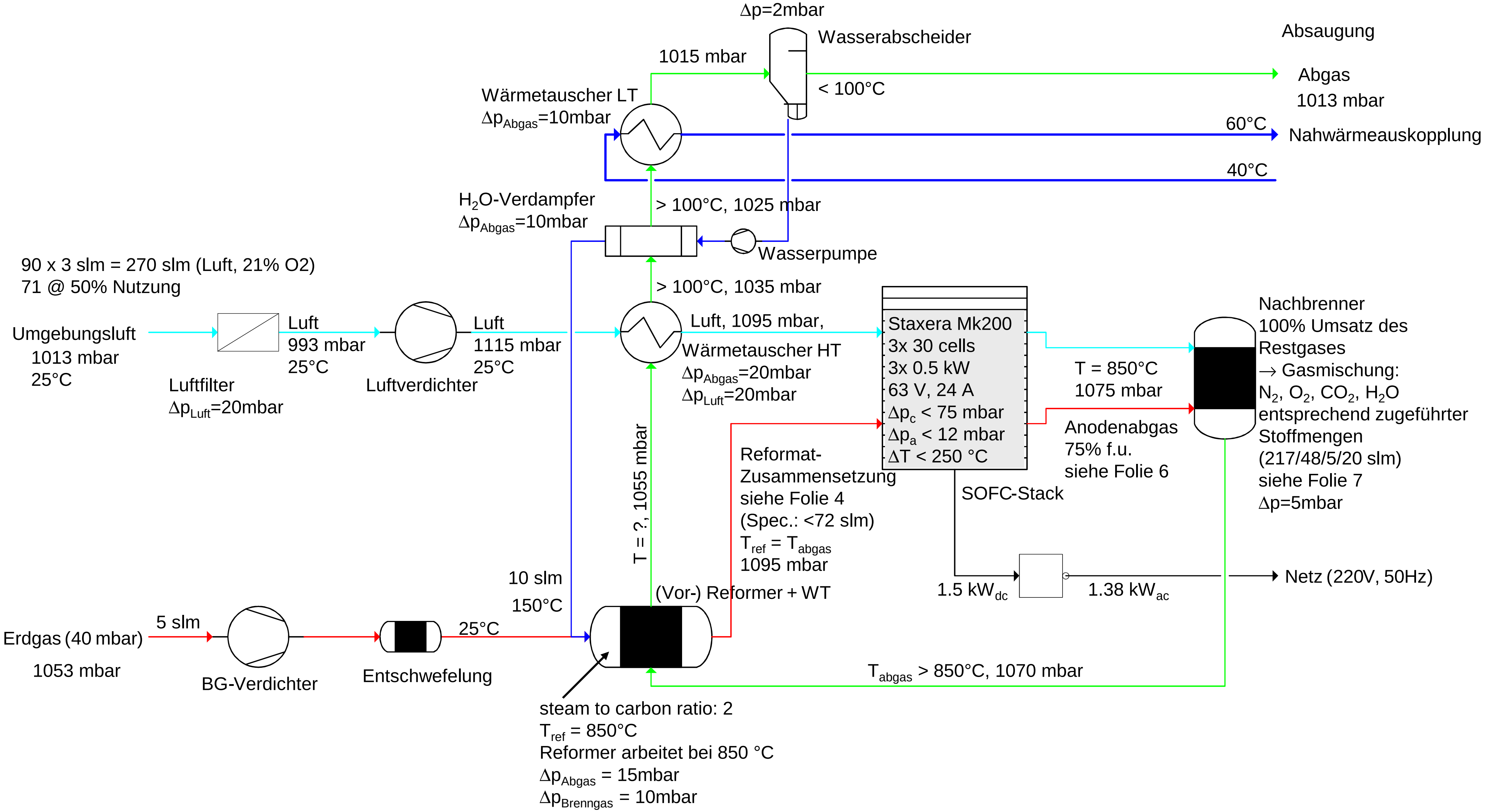
thermal system efficiency $$\eta_{thermal} = \frac{\text{usable heat}}{\text{provided chemical energy}}$$

total efficiency $$\eta_{tot} = \eta_{electrical} + \eta_{thermal}$$

CHP-system

SOFC Brennstoffzellenheizgerät
(Mögliche) Verschaltung der Komponenten



Stackmodul

The staxera integrated stack module (ISM) is a solid oxide fuel cell (SOFC) module according to DIN IEC 62282-2. The ISM consists of a SOFC stack within an insulated enclosure. It is intended for integration within a SOFC system or test station. The ISM converts chemical potential energy to electrical and thermal energy via an electrochemical process operating at a nominal temperature of between 700°C and 850°C.

Figure 1: Integrated Stack Module

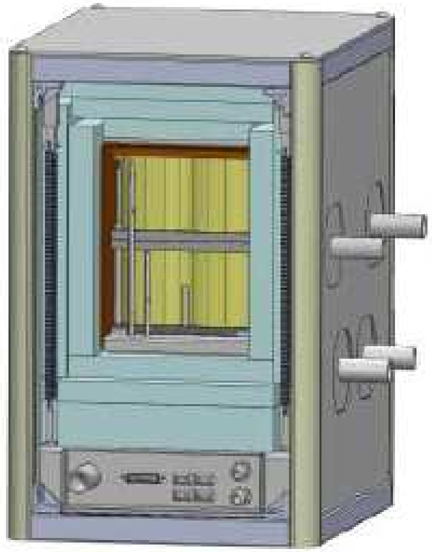
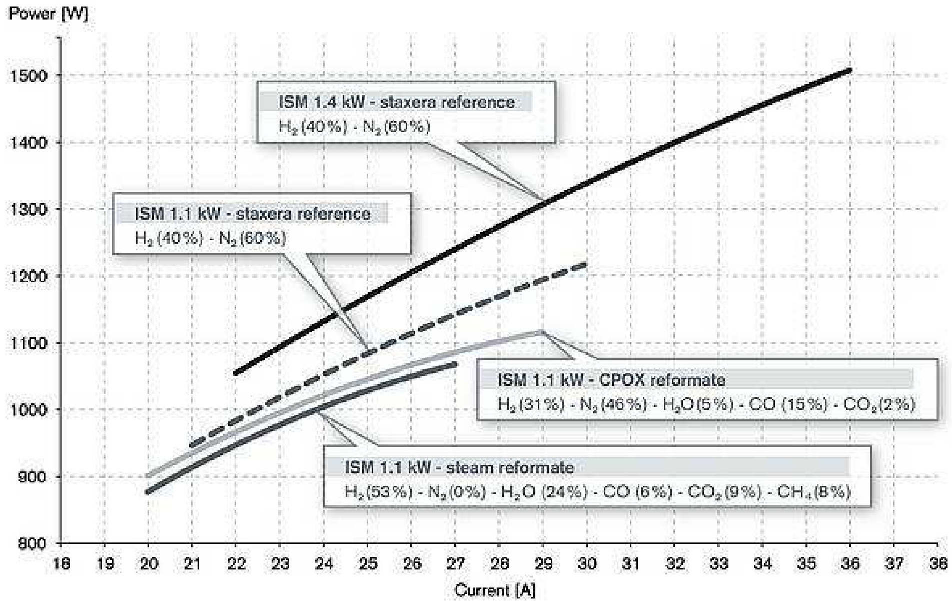


Figure 2: Cut-away view showing stacks



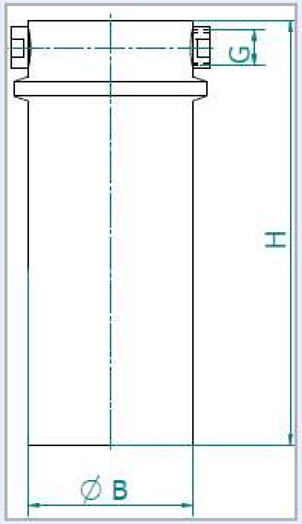
Entschwefelung

Cartridge Filter based Desulphurization Unit

The Desulphurizer removes sulphur contents of natural gas or LPG for usage in fuel cells or catalytic systems. Customized solutions for sulphur compounds like H_2S, COS, SO_2, THT or TBM are provided. The unit is constructed of two parts: the desulphurizer vessel and the filter cartridge that holds the adsorbent. Minimal pressure losses allow the usage of natural gas from a low-pressure grid.

Desulphurizer vessel

- ✓ Two-parts vessel with permanent installation in the gas path
- ✓ Quick opening for adsorbent exchange
- ✓ Connections from ½" to 1" internal thread
- ✓ Material: stainless steel
- ✓ Design pressure: 2 bar(a)



Desulphurization Vessel

Filter cartridge

- ✓ Vertical flow direction
- ✓ Gas-tight screwing in vessel (fast to exchange)
- ✓ 50 µm outlet filter
- ✓ Material: stainless steel

Adsorbent

- ✓ Adsorbents for ambient or elevated temperature levels (metal impregnated active coal or ZnO)
- ✓ Dimensioning according to customer's specification
- ✓ Removal of THT, mercaptan (thiol), H_2S, COS, SO_2 to S_{tot} < 1 ppm
- ✓ Lifetime depending on local conditions and sulphur loading

Types (Examples)	Cartridge volume (Liter)	Size øB x H (mm)
EBZ-DF-1-CF	1	90 x 400
EBZ-DF-5-CF	5	160 x 420
EBZ-DF-10-CF	10	220 x 510

Reformer

EBZ Reforming Unit

The Steam Reforming Unit is available in three standard sizes: 300 W, 1000 W and 5000 W referred to the heating value of the natural gas input. Other customized solutions are possible. The reforming unit consists of an electrical evaporator, a heated mixing zone and the heated catalyst bed. The unit can be used either as pre-reformer or for full fuel conversion depending on the equilibrium temperature.

The Reforming Unit is designed in particular for the gas processing in solid oxide fuel cell (SOFC) systems. Here, the operation of a stack with partly internal reforming can be investigated systematically.

EBZ-SR-300 Steam Reforming Unit for 300 W_{LHV} methane / natural gas

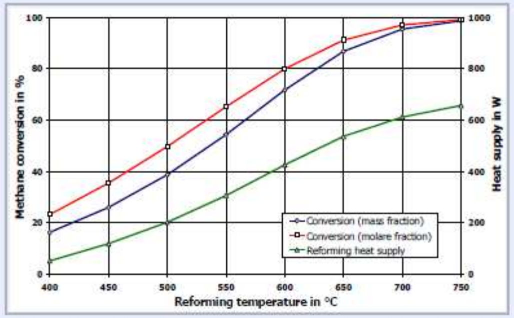
	EBZ-SR-300	EBZ-SR-1000	EBZ-SR-5000
Scale (based on LHV natural gas)	300 W	1000 W	5000 W
Steam-to-carbon-ratio		2 … 3	
Catalyst		Precious metal or nickel	
Max. outlet temperature		750 °C	
Pressure loss		< 100 mbar	
Max. heating power			
Reformer	500 W	1000 W	3000 W
Evaporator	250 W	500 W	2500 W
Dimensions *alternative dimensions on request*	L1: 440 / L2: 495 B1: 360 / B2: 180 H1: 300 / H2: 205 H3: 125 / H4: 185	L1: 640 / L2: 720 B1: 340 / B2: 200 H1: 410 / H2: 355 H3: 185 / H4: 80	L1: 680 / L2: 760 B1: 430 / B2: 255 H1: 435 / H2: 370 H3: 210 / H4: 110
Instrumentation	5 K-type thermocouples (reform. heater safety temperature, reactor inlet temperature, reactor outlet temperature, evapor. heater temperature, steam temperature)		6 K-type thermocouples (additional: evapor. heater safety temperature)
Fuel supply (NG)	0.05 … 0.5 $l_{N,STP}$/min	0.17 … 1.7 $l_{N,STP}$/min	0.85 … 8.5 $l_{N,STP}$/min
Water supply	5 ... 100 g/h	15 ... 300 g/h	75 ... 1500 g/h
Evaporator	Integrated		External
Design pressure	1 bar(g)	1 bar(g)	1 bar(g)
Design temperature	900 °C	900 °C	900 °C

Key features

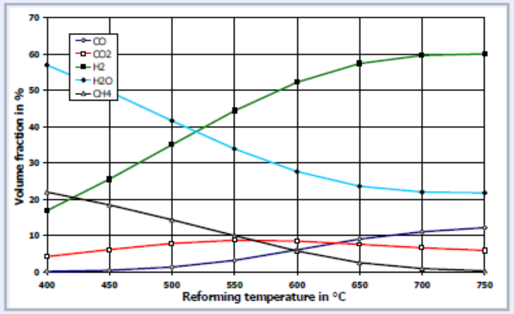
- ✓ Electrically heated reactor
- ✓ Precious metal or nickel catalysts
- ✓ Compact design
- ✓ High-temperature resistant materials up to 900 °C
- ✓ Low heat and pressure losses
- ✓ Integrated evaporator for homogenous steam supply

Fuels

- ✓ Natural gas / methane
- ✓ Ethanol / methanol
- ✓ LPG (propane / butane)
- ✓ Biogas



Methane conversion and heat demand of the reforming reaction (S/C=2.5, 2 kW_{LHV} natural gas)



Reformate composition in dependence on reforming equilibrium temperature (S/C=2.5)

Verdampfer / Befeuchter

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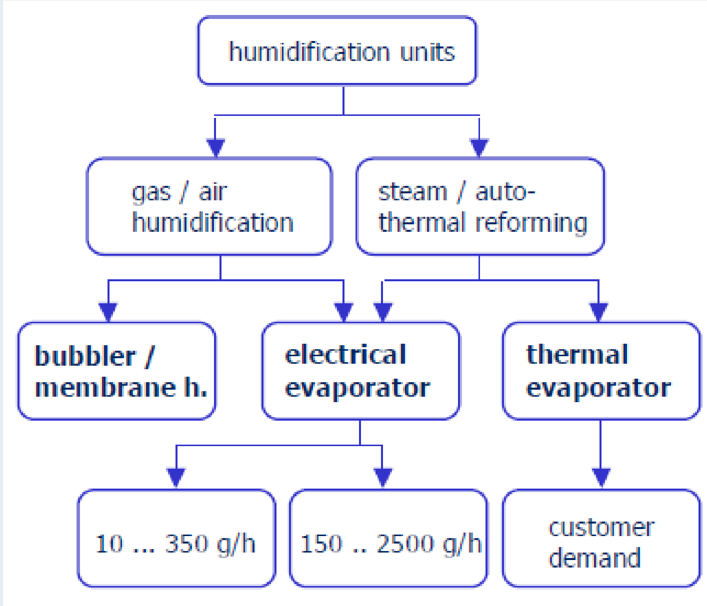
EBZ offers a broad variety of gas humidification solutions. EBZ bubbler and membrane humidifier guarantee a reliable and steady gas humidification. For applications requiring higher humidification rates (e.g. reformation of hydrocarbons) EBZ developed sophisticated evaporators. EBZ electric and thermal evaporators cover a steam generation range from 10 g/h up to 10 kg/h. EBZ evaporators are optimised regarding a highly homogeneous steam generation in a wide modulation range.


EBZ electrical evaporator type EE-DU2500 with single component case



Key features

- ✓ Various performance classes
- ✓ Compact design
- ✓ Homogenous steam generation
- ✓ Low fluctuations in cell OCV
- ✓ Special design for low flow rates
- ✓ Standard units as well as customized solutions

EBZ type / property	Bubbler unheated	Bubbler electrically heated	Membrane humidifier	Electrical evaporator	Thermal evaporator
Humidification in vol.-%	ca. 3	≤ 15	≤ 30	up to 100	up to 100
Volume flow gas in $l_{N,\,STP}$	≤ 30	≤ 30	-	-	-
Mass flow boundary in g/h	-	-	-	2.500	10.000

	Max. mass flow water in g/h (volume flow gas in l_n/min)	Nominal input rating in W	Steam (gas) outlet temperature in °C
Bubbler BU-70C	(20)	500	(30)
Electric evaporator EE-MZ100	100	150	200 - 350
Electric evaporator EE-MV250	250	400	200 - 350
Electric evaporator EE-MV500	500	750	200 - 350
Electric evaporator EE-DU2500	2.500	3.000	200 - 350
Thermal evaporator ET-PZ600	600	630	200 - 400
Thermal evaporator ET-PZ1500	1.500	1.575	200 - 400

Wärmetauscher

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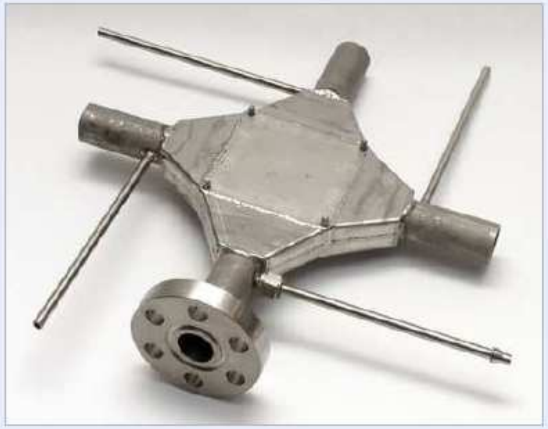
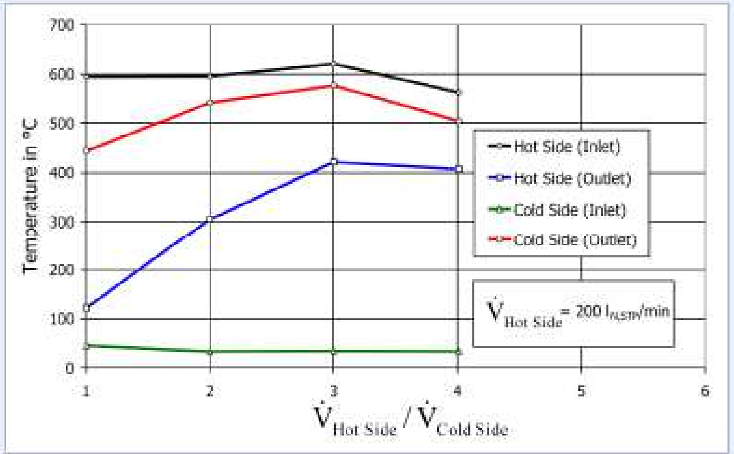


Heat exchanger EBZ-HX-05 with measurement ports for thermocouples (cross-flow design)

Type (Examples)	T_{max} (℃)	Heat transfer capacity (kW)	Length / Width / Height (mm)
EBZ-HX-03	950	0.3	100 / 60 / 25
EBZ-HX-05	950	0.5	160 / 75 / 30
EBZ-HX-1	950	1.0	280 / 150 / 55
EBZ-HX-3	950	3.0	230 / 150 / 35
EBZ-HX-5	950	5.0	300 / 160 / 50

Examples of heat exchangers

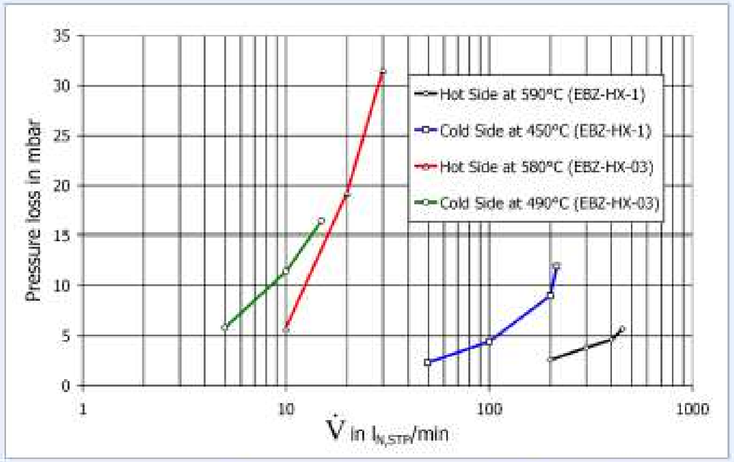


Performance of EBZ-HX-1

Example of application

- ✓ Plate heat exchanger in counter-flow design
- ✓ Maximum temperature: 850 °C
- ✓ Designed heat transfer capacity: 3 kW
- ✓ Task: preheating air for electrical gas heater
- ✓ Dimensions: 400 mm x 130 mm x 40 mm

EBZ-HX-3



Pressure losses of EBZ-HX-03 and EBZ-HX-1

Wärmetauscher II

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Application

- ✓ Cooling of exhaust gases with water or air
- ✓ Waste heat recovery / water heating
- ✓ Drying of hot gases / separation of condensate
- ✓ Gas temperature control

Key Features

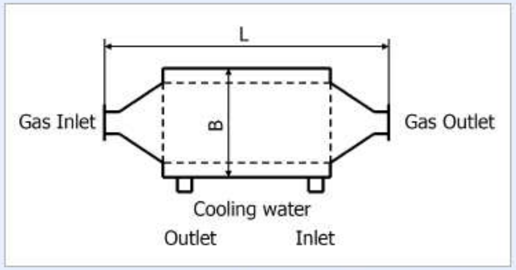
- ✓ Compact and flexible design
- ✓ Operation: cross-counter flow or cross-co flow
- ✓ Maximum temperatures:
  - up to 650 °C: one-stage economizer
  - up to 1000 °C: two-stage economizer
  - up to 1200 °C: economizer in tube bundle design
- ✓ Heat transfer capacity up to 40 kW
- ✓ Standard products for different heat capacities
- ✓ Pipe connections according to customer demand

EBZ-GC-650-2

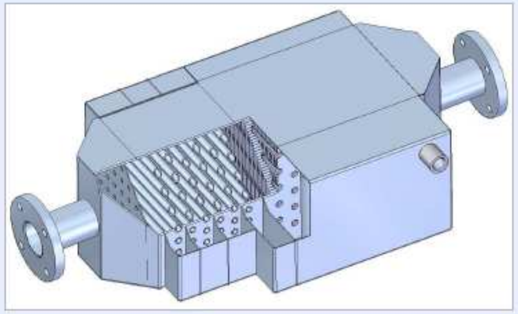
EBZ-GCX-1200-7
Cooling of exhaust gas above its dew point

Specification of standard economizers

Type (Examples)	T_{max} (°C)	Heat transfer capacity (kW)	L / B / Height (mm)
EBZ-GC-650-1	650	1.0	210 / 150 / 70
EBZ-GC-650-2	650	2.0	240 / 180 / 70
EBZ-GC-650-5	650	5.0	270 / 210 / 100
EBZ-GC-1000-1	1000	1.0	240 / 130 / 70
EBZ-GC-1000-5	1000	5.0	320 / 200 / 100
EBZ-GCX-1200-3	1200	3.0	265 / 130 / 75
EBZ-GCX-1200-7	1200	7.0	290 / 160 / 110



Economizer type EBZ-GC



Two-stage economizer EBZ-GC-1000

Restgasbrenner

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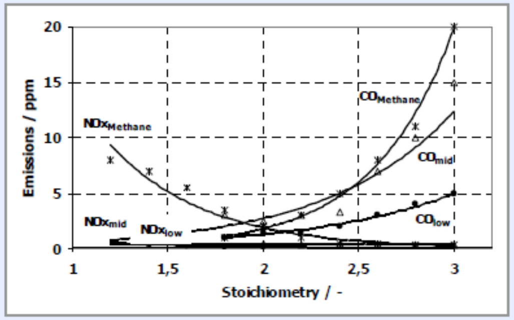
Application

- ✓ Burning of SOFC anode off gas
- ✓ Burning of other low caloric fuels
- ✓ Burning of natural gas for different processes

Key features

- ✓ Burning of both low and high calorific gases, from 3 MJ/m³ to 110 MJ/m³
- ✓ Admixing of auxiliary fuel for calorific values below 3 MJ/m³
- ✓ High power density up to 10 MW/m³
- ✓ 2-stage burning chamber for wide modulation range up to 1:10
- ✓ Very low CO and NO_x emissions < 10 ppm
- ✓ Robust operation even during fluctuations of gas flow or gas composition
- ✓ Temperature control by N type thermocouple



Measured emissions during burning of low, medium and high calorific gases

Complete 8 kW burner incl. ignition, premixing and insulation

Burning chamber

Types (Example)	EBZ-PMB-2	EBZ-PMB-5	EBZ-PMB-8
Materials	Porous media body: SiSiC Housing: stainless steel / Al_2O_3		
Power range	0.3-2 kW	0.5-5 kW	0.8-8 kW
Maximal outlet temperature	950 °C	1100 °C	1100 °C
Pressure loss	12 mbar	10 mbar	10 mbar
Diameter / Length	Ø 130 mm x 180 mm	Ø 170 mm x 230 mm	Ø 200 mm x 260 mm
Instrumentation	Burning chamber temperature (N type thermocouple) Flame barrier temperature (N type thermocouple) Mixing chamber temperature (N type thermocouple)		
Ignition	Ignition electrodes or glow plug		

Systemauslegung Luftzufuhr

Verlustleistung:

Luftbedarf:
3 nlm pro Zelle, 270 slm für 3 Stacks
Annahme: Luft wird im Stack von 650 auf 850 °C erwärmt

dies benötigt eine Leistung von 1233 W (siehe rechts),
d.h., der Stack wird mit 1233 W Leistung gekühlt

Bedarf für Zellreaktion
90 Zellen a 24 A Stromäquivalent
→ 35.8 nlm

O2: $$c_{pO2}(T) := \left[27.96 + 4.18\cdot\frac{T}{1000K} - 0.167\cdot\left(\frac{T}{1000K}\right)^2\right]\cdot\frac{J}{mol\cdot K}$$

N2: $$c_{pN2}(T) := \left[28.3 + 2.537\cdot\frac{T}{1000K} - 0.5443\cdot\left(\frac{T}{1000K}\right)^2\right]\cdot\frac{J}{mol\cdot K}$$

$$c_{pair}(T) := 0.21\cdot c_{pO2}(T) + 0.79\cdot c_{pN2}(T)$$

$$T_0 := 923K$$

$$T_1 := 1123K$$

$$w_{th} := \int_{T_0}^{T_1} c_{pair}(x)\,dx \qquad w_{th} = 6.138\times 10^3\,\frac{J}{mol}$$

$$fr_{air} := 270\,\frac{L}{min}$$

$$mfr_{air} := fr_{air}\cdot\frac{1}{22.4\,\frac{L}{mol}} \qquad mfr_{air} = 0.201\,mol\,s^{-1}$$

$$p := w_{th}\cdot mfr_{air} \qquad p = 1.233\times 10^3\,W$$

Gebläse für (Kühl-) Luftzufuhr (State of the Art)

Leistungs-/Energieaufwand Verdichter:
Δp = (1115 – 993) mbar = 122 mbar
270 slm = 16.2 m²/h (1013 mbar, 0°C)

Leistungsaufnahme: ~ 400 W

Leistungsabgabe (Volumenarbeit):

$$mfr_{air} := 270\,\frac{L}{min} \qquad mfr_{air} = 16.2\,\frac{m^3}{h}$$

$$V_1 := 270\,L$$

$$p_1 := 1013\,mbar$$

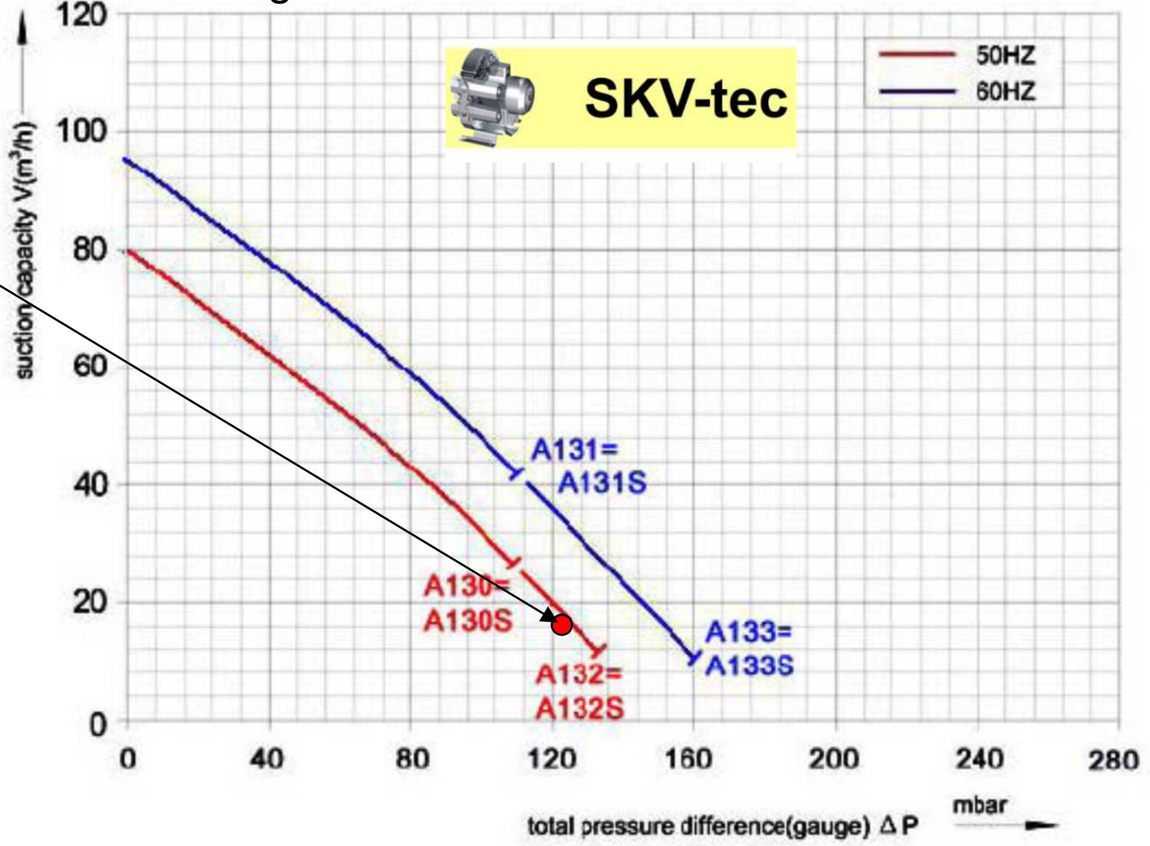
$$p_2 := p_1 + 122\,mbar$$

$$V_2 := \frac{p_1 \cdot V_1}{p_2} \qquad V_2 = 0.241\ m^3$$

$$W_{12} := -270\,\frac{L}{min}\cdot\frac{1}{V_{mol}}\cdot R\cdot 273.15\,K\cdot \ln\left(\frac{V_2}{V_1}\right)$$

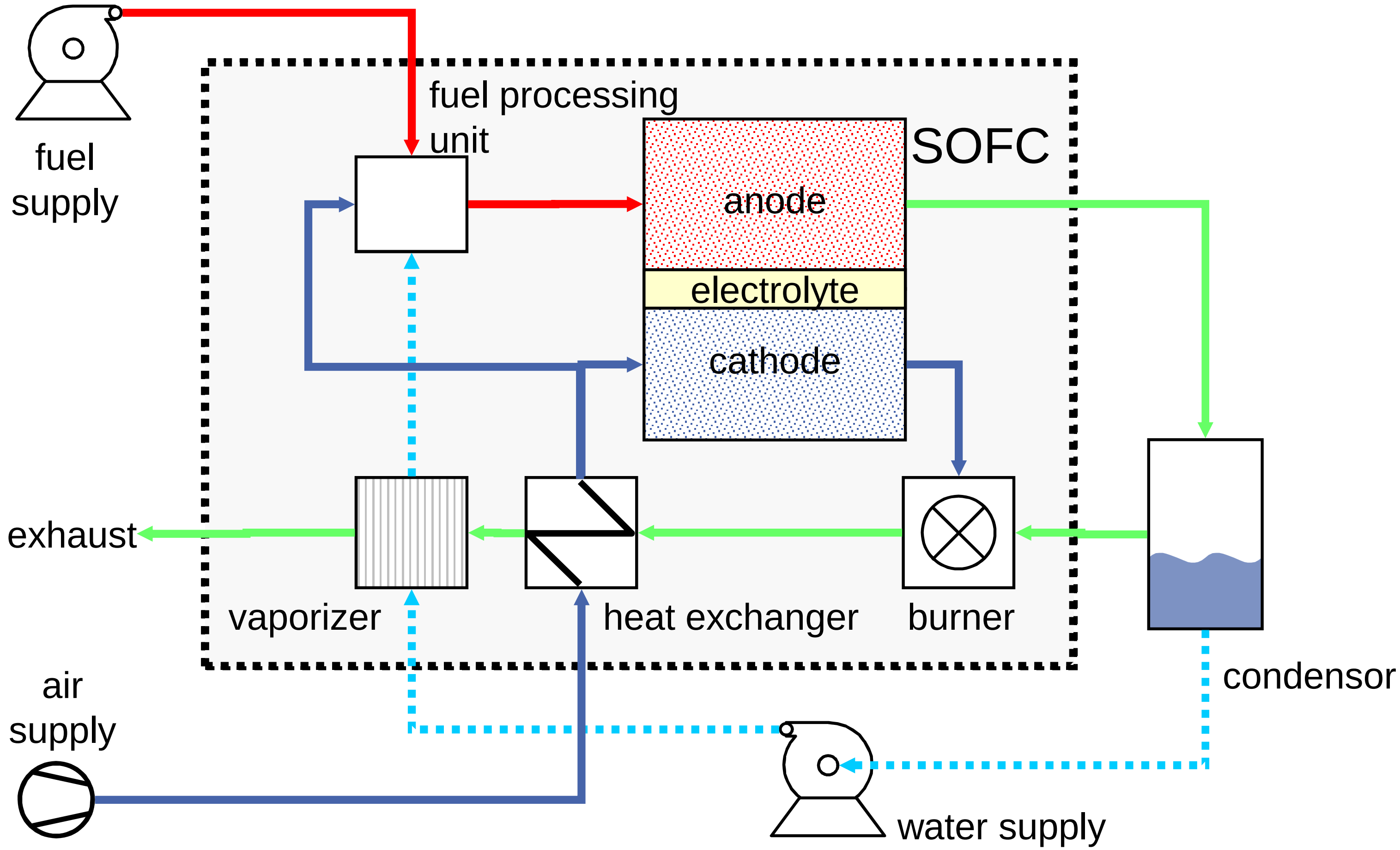
$$W_{12} = 51.851\ W$$

1-stufiger Seitenkanalverdichter



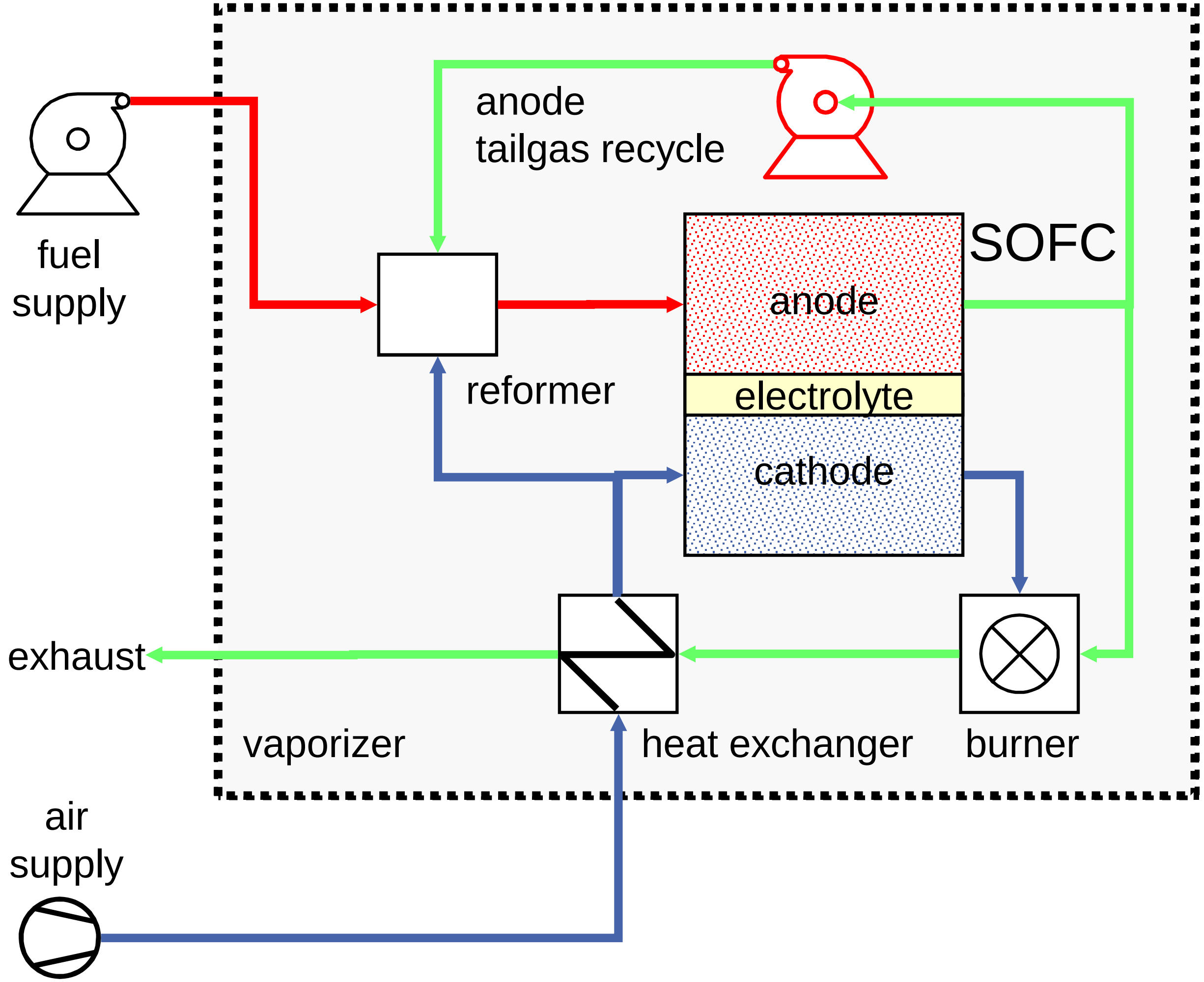
Modell Model Modèle	Kurve Curve Courbes	1 / 2-stufig 1 / 2-stage 1 / 2 - étage	Hz	kW	V	A	Max. Luftmenge Max. air Flow Débit max.	Druckbetrieb Compression mbar	Saugbetrieb Vacuum Vide mbar	dB(A)	Gewicht Weiggt Poids kg
SKV-NS-80-1-101	A 130 S	1	50	0,25	200-240	1,6	80	110	-100	53	9
	A 131 S		60	0,28		1,9	98	110	-110	56	9
SKV-NS-80-1-111	A 132 S		50	0,4		2,7	80	130	-120	53	11
	A 133 S		60	0,5		3,2	98	160	-150	56	11

SOFC-APU

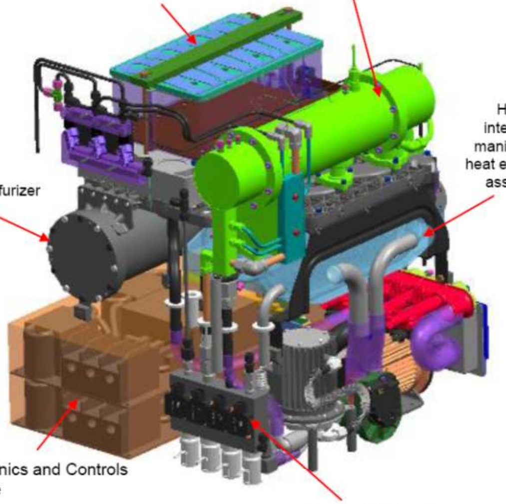


fuel supply
fuel processing unit
anode
electrolyte
cathode
SOFC
exhaust
vaporizer
heat exchanger
burner
condensor
air supply
water supply

SOFC-APU with Anode Tailgas Recycle

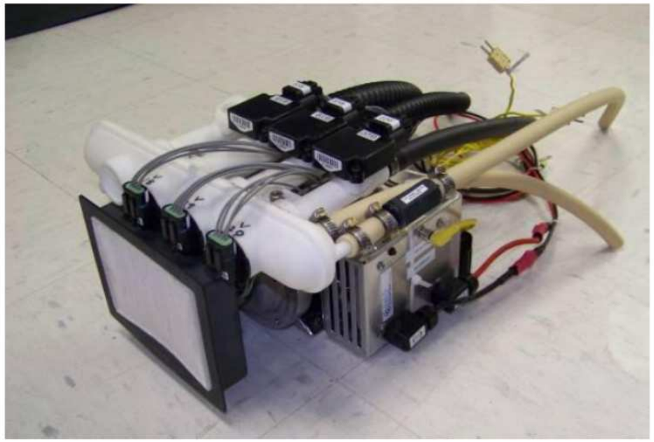


SOFC APU
Delphi DPS 3000D

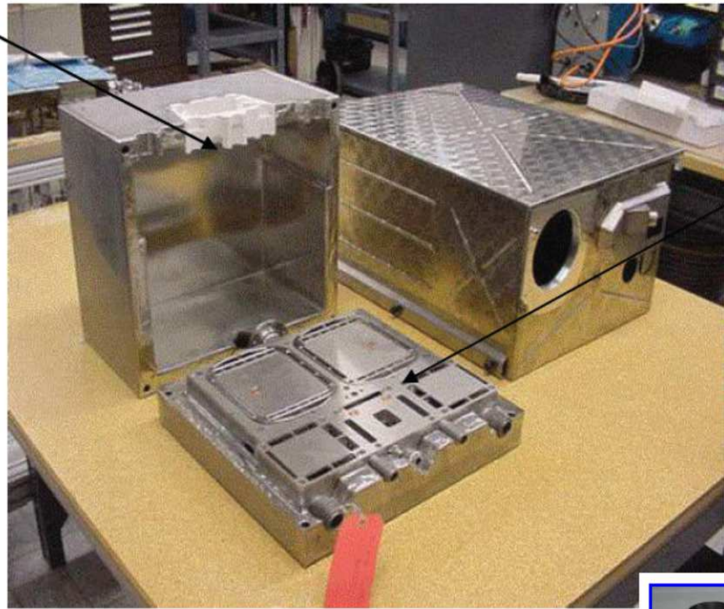


- High quality, reliable power: 110 V_{AC} and/or 12 V_{DC}
- High fuel efficiency: 40 to 50% higher than current gen set APUs
- Low noise: <60 dBa at 3 meters
- Ultra-clean, near zero emissions:
  - Meets Tier 4 Emissions standards for Non-Road Diesel Engines
  - For CO, less than 8 g/kWh
  - For NMHC and NO_x, less than 0.2 g/kWh
- On-board reforming capability

Delphi-APU
Nebenaggregate



Process Air Delivery System



Hotbox

hot reformate desulfurizer

process air blower

Anode Tailgas Recycle Pump

SOLID OXIDE FUEL CELL – AUXILIARY POWER UNITS

Motivation: Reduction of heavy duty truck idling costs and emissions

Solution

➔ ***SOFC APU*** concept based on solid oxide fuel cell technology

➔ Fuel: diesel, electrical net efficiency: 35%

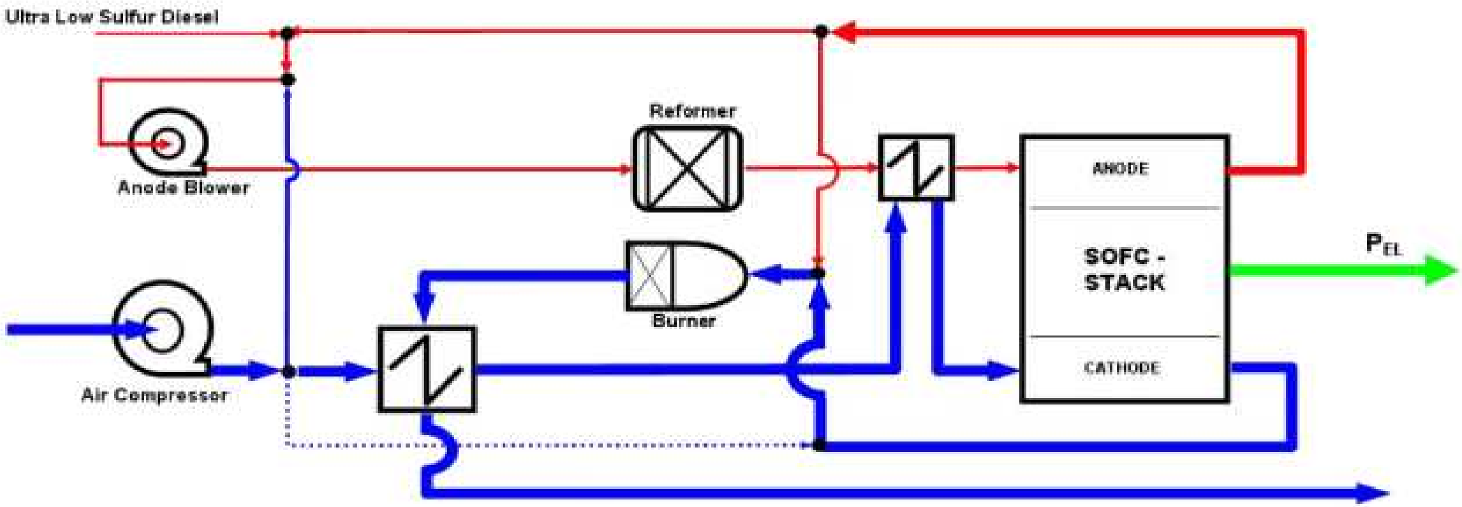
➔ Functions: cabin climatisation, electrification, engine pre-heating

APU Development Program

➔AVL initiated the development program together with Topsoe Fuel Cell (TOFC) in 2002

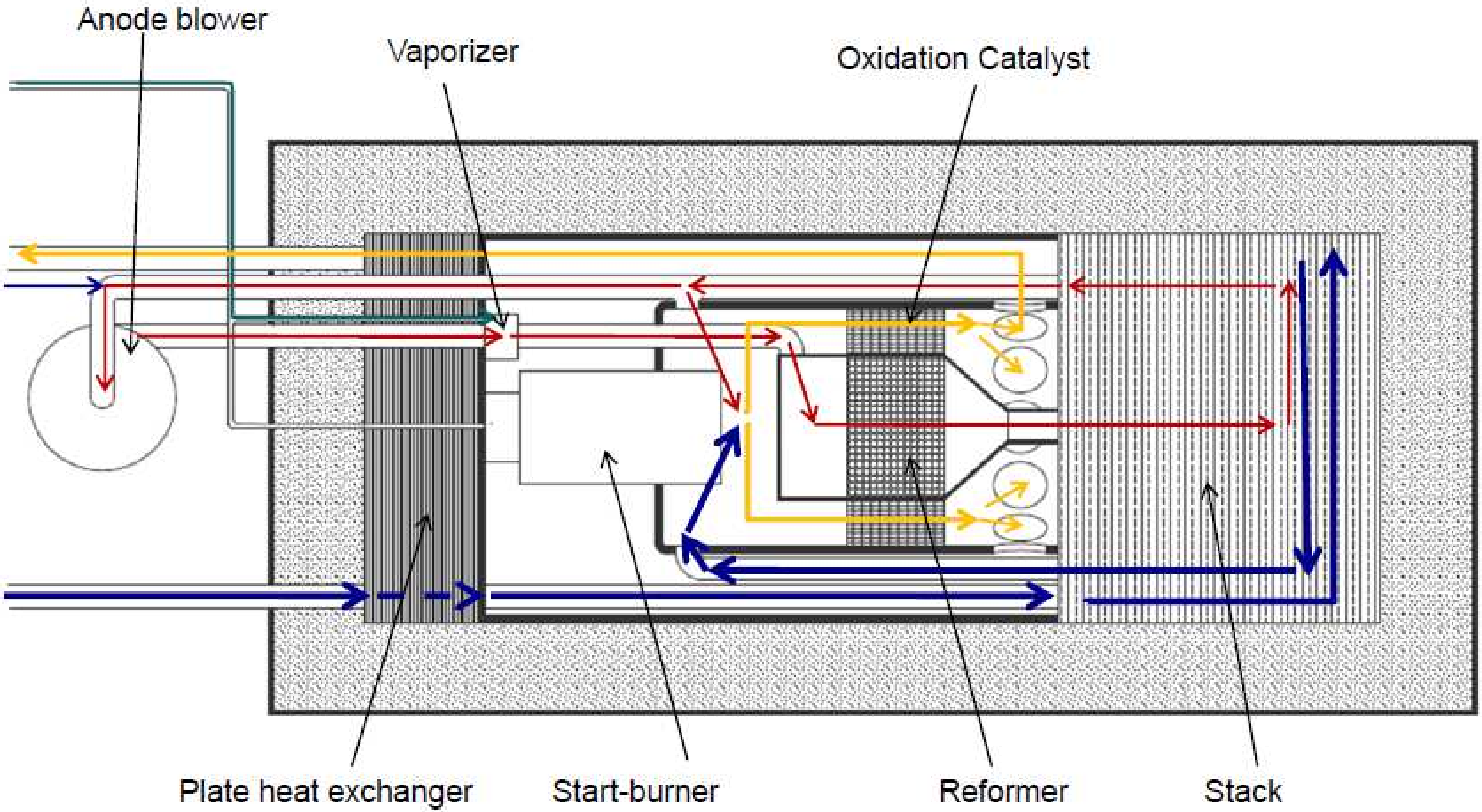
➔primary focus in 2002 was the technical feasibility (1kW proof-of-concept system)

➔after successful proof-of-concept the focus was shifted to the development of competitive end-customer products

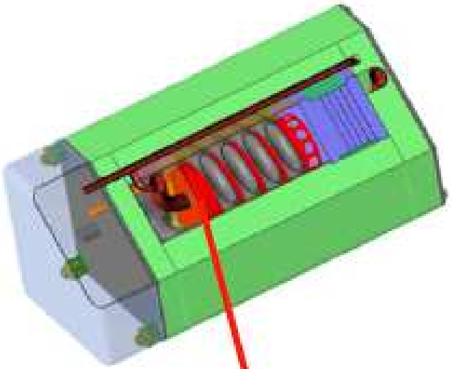


AVL SOFC APU

AVL SOFC APU – Packaging Concept

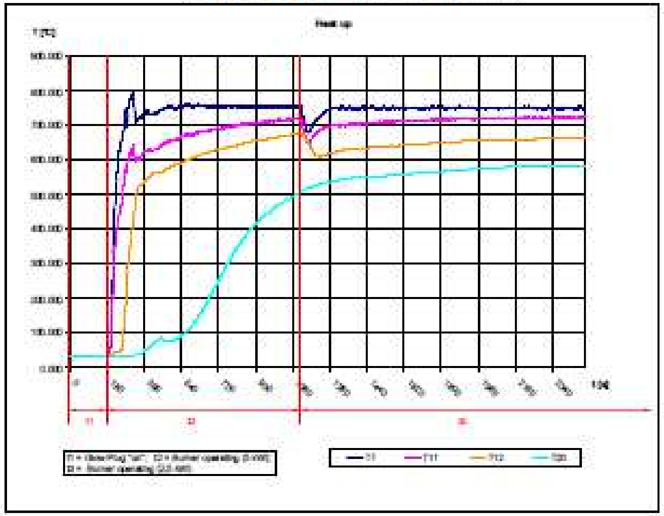


System Development – „Integrated Reformer – Burner“

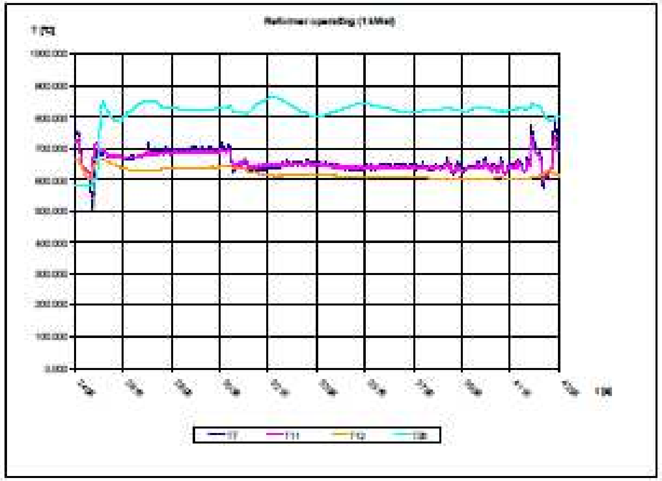


- ►System start-up
- ►Syngas generation
- ►Off gas cleaning

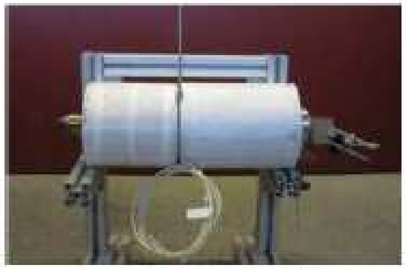
Start-up in 18min



Stable diesel reformer operation



AVL DIESEL REFORMER Development

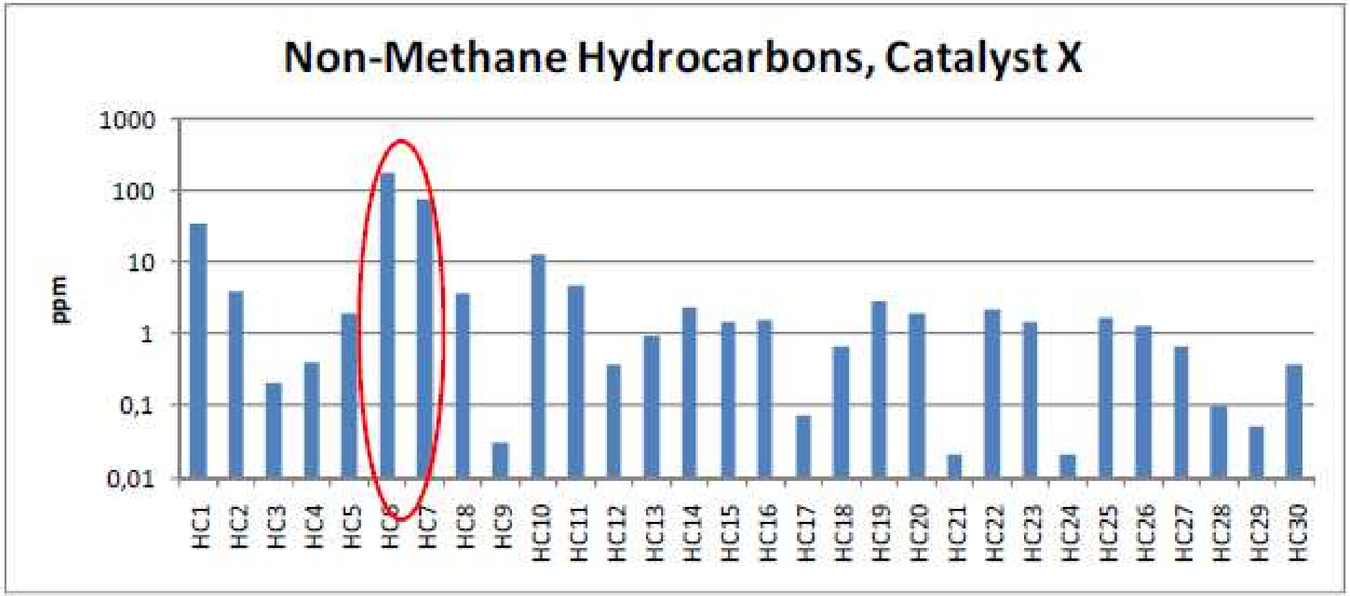


Stand alone reformer

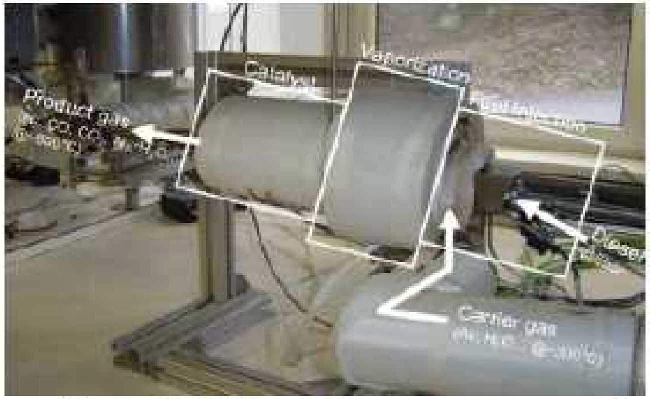
Catalysts

APU Reformer

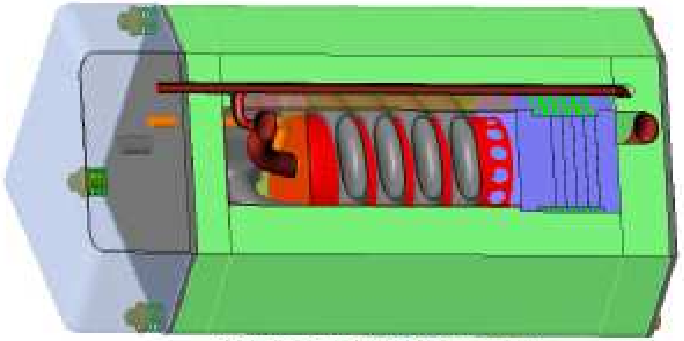
- ➔ **AVL was forced in 2010 to change catalyst supplier**
- ➔ **Catalysts from 3 suppliers have been screened**
- ➔ **Gas quality with new supplier already close to old results**
- ➔ **Together with catalyst supplier formulation will be further optimized to improve gas quality**
- ➔ **Typical gas quality: <300ppm NMHC, <35ppm C6+, no carbon detectable in product gas**



APU DEVELOPMENT FOCUS

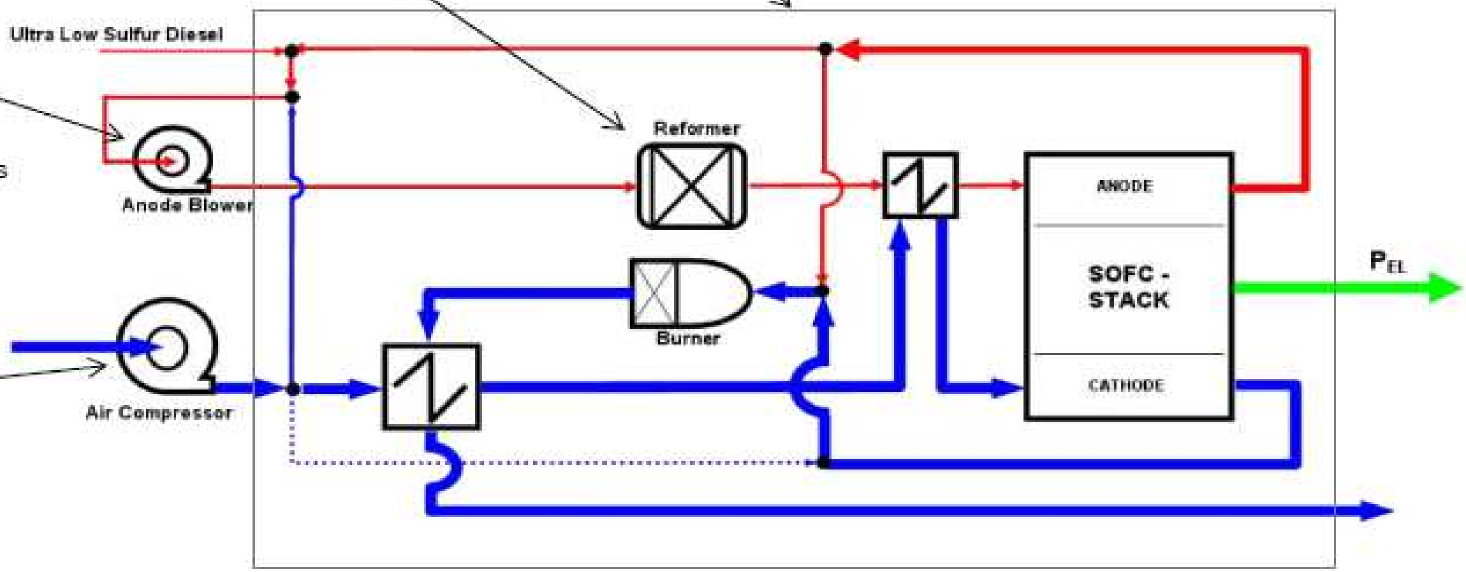


AVL Gen3 AT Diesel Reformer


3kW SOFC APU (80L, 70kg)

- ⇨ System development (e.g. combined reformer-burner development)
- ⇨ Development of metal-supported stack technology with partners
- ⇨ Durability and reliability development
- ⇨ Compressor development (air and anode recirculation)
- ⇨ Diesel reformer development
- ⇨ Control system development

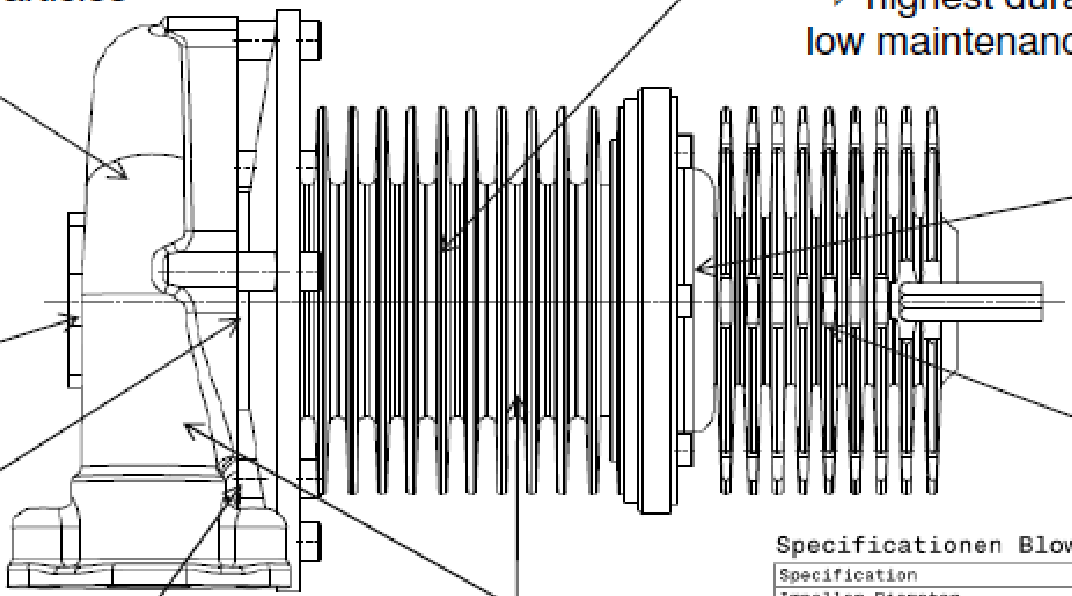

AVL Schrick FC Blowers

EXAMPLE OF RECIRCULATION BLOWER (3kW APU)

AVL SCHRICK

Advantages of radial Blowers for FC Applications



Specificationen Blower

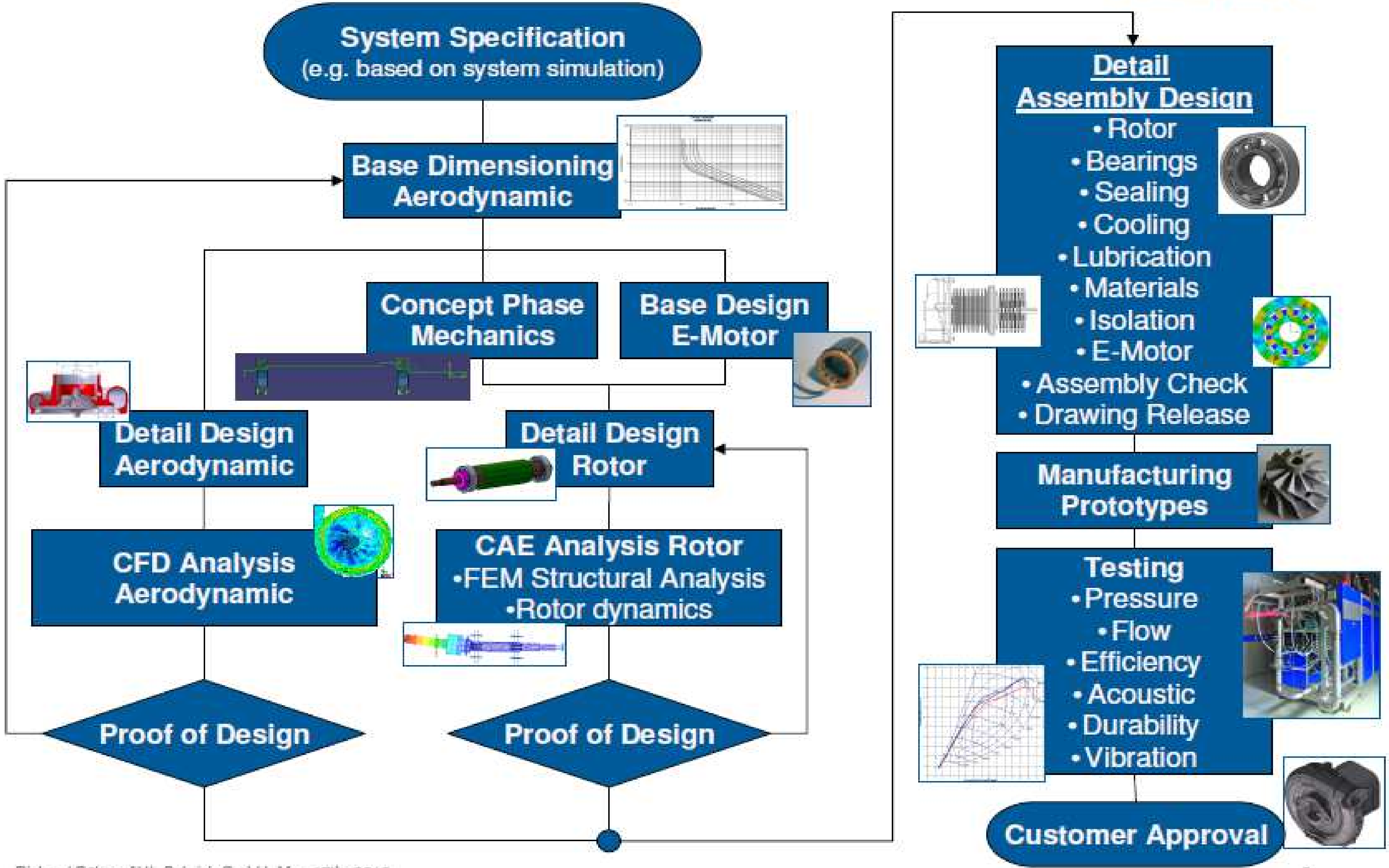
Specification	Value	Unit
Impeller Diameter	72	mm
Typ	radial	
max. RPM	35000	1/min
max. Medium Temperature	400	°C
Pressure Ratio (at Tmax)	1.055	
Mass Flow	0.5 .. 5.5	g/s
max. Aerodynamic Output	50	W
isentropic efficiency	ca. 60	%

Specificationen Drive

Specification	Value	Unit
Typ	BLDC Motor, sensor less	
Number of Poles	12	
rated voltage	24	V
max. Power Output	750	W
Clutch	magnetic clutch with separating can, hermetic gas sealing	

Prototypes available in late 2010!

FLOW SHEET OF FC BLOWER DEVELOPMENT

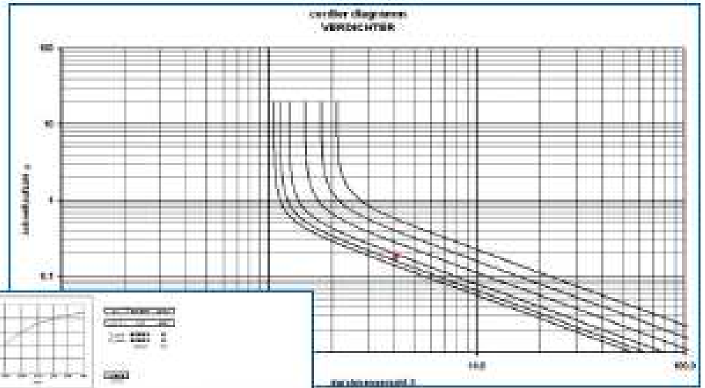


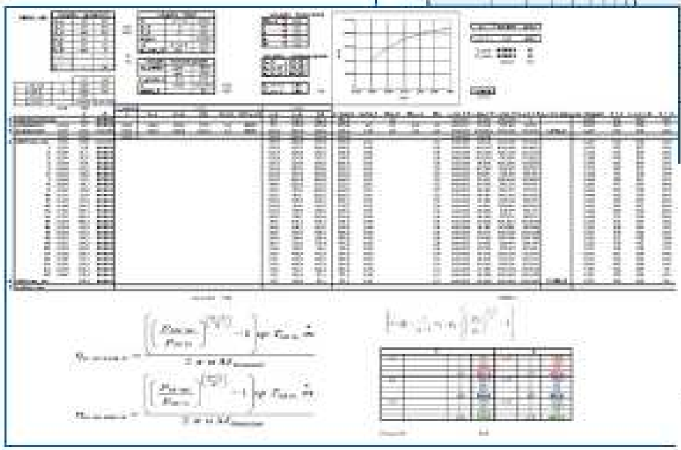
DEVELOPMENT OF BOOSTING COMPONENTS

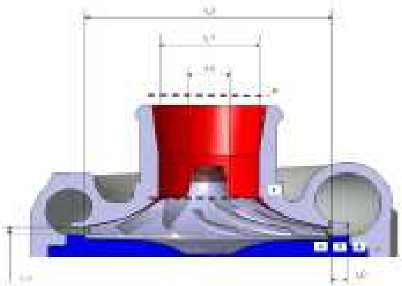
Base design of turbo compressors

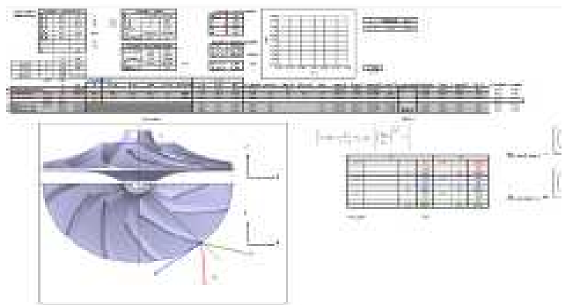
- Base dimensioning (diameters, trim, inlet-/ outlet angles etc) based on 1-D calculation
- Detailing
  - ➔Turbine and compressor blades (2D or 3D)
  - ➔Complete impeller with-w/o splitter blades
  - ➔Diffuser
  - ➔Volute

For given operation point (mass flow, pressure ratio) and boundary conditions (e.g. max. outer diameter or max. rpm)









DEVELOPMENT OF BOOSTING COMPONENT

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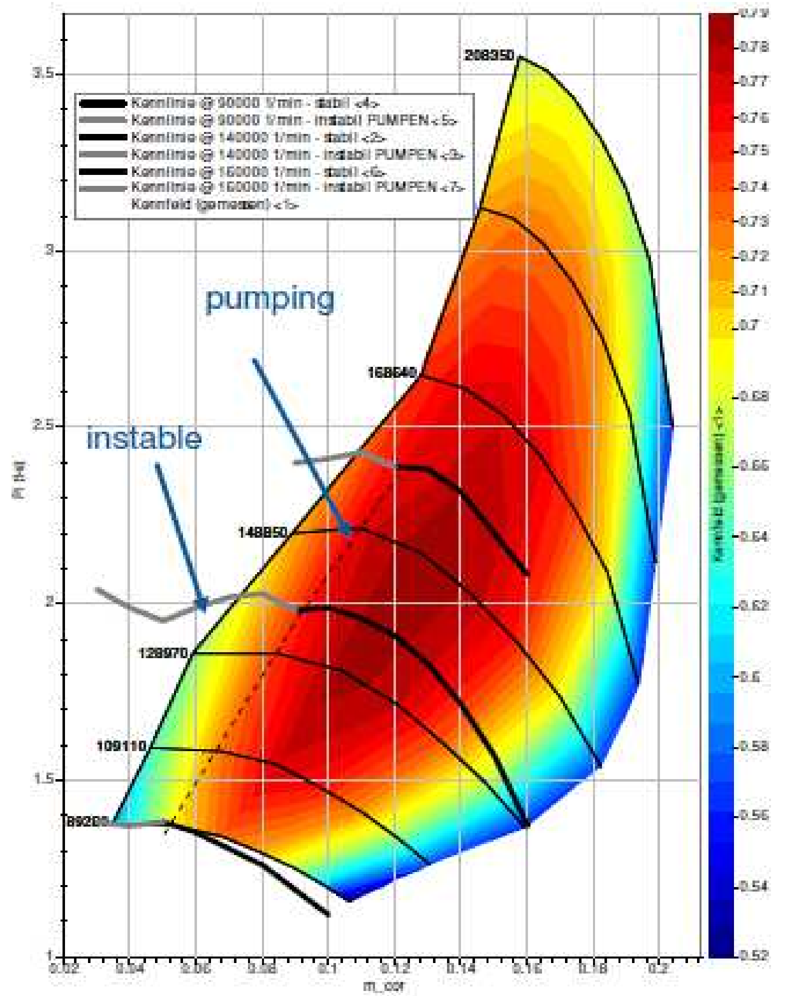
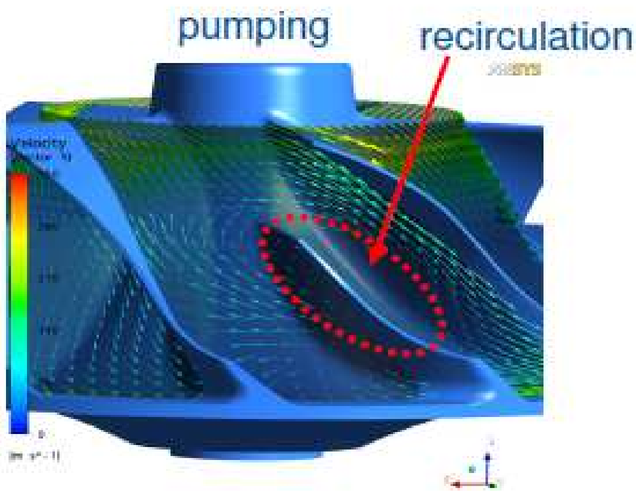
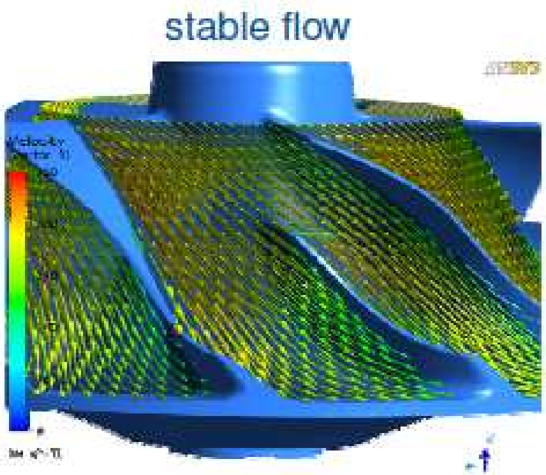
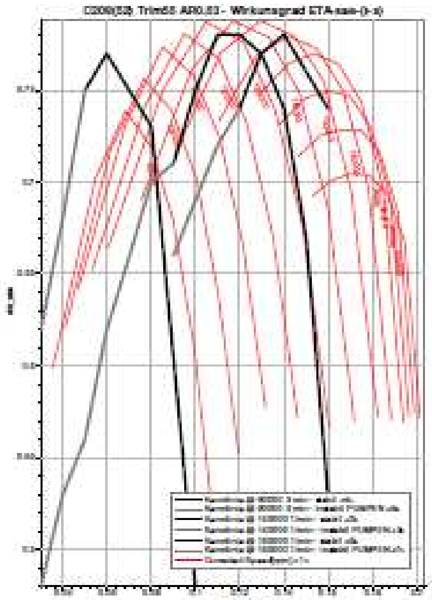
CFD Analysis









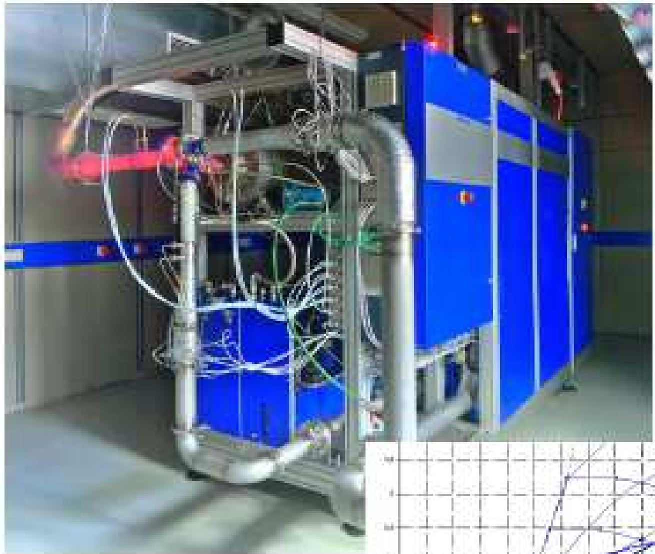
→ 3D-CFD calculation (ANSYS CFX), stationary or transient

→ Calculation of compressor maps:

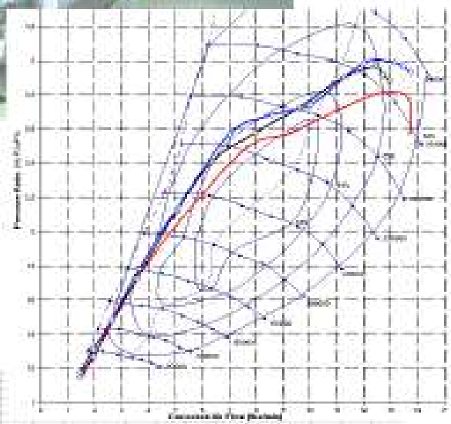
- → Speed
- → Efficiency
- → Pressure ratio
- → Mass flow

TESTING AND MANUFACTURING OF FC BLOWERS

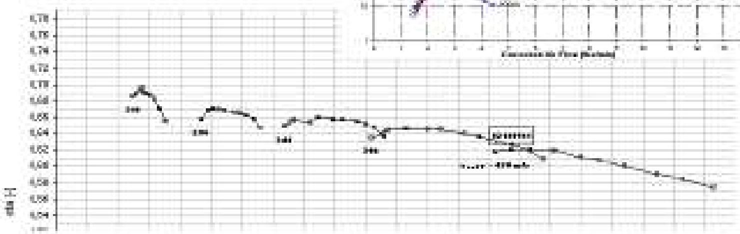
Hot Gas – Test Rig



Compressor maps



Efficiency lines



Manufacturing of prototypes

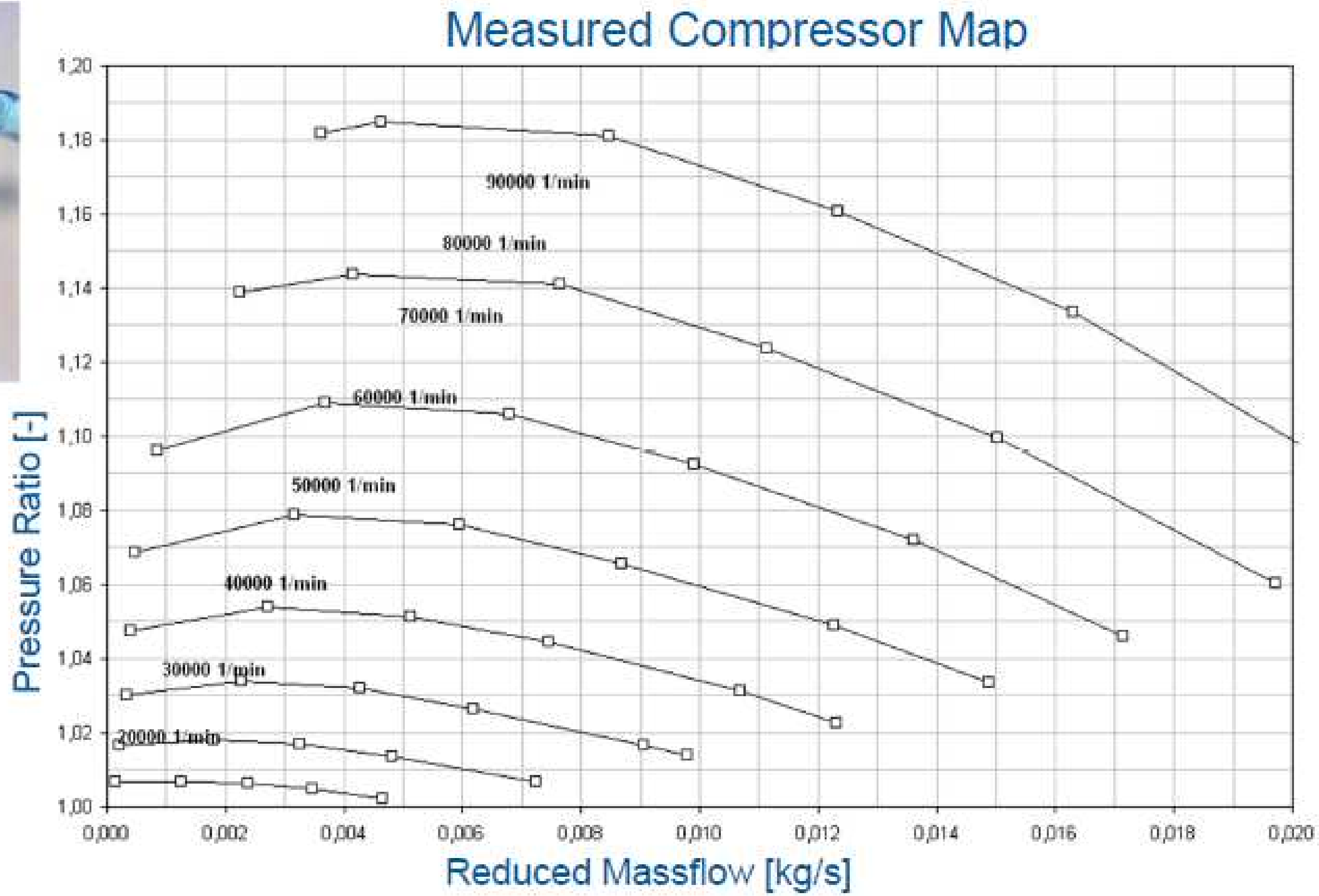
Manufacturing capabilities

- Blower and bearing housings
- Impellers
- Blower shafts
- Manifolds
- Blower assembly

Materials

- Cast steel and iron alloys
  - e.g. GGG50, 1.4849, D5S
- Nickel base alloys (corrosion & temperature resistive)
  - e.g. Inconel 713C, MAR 246
  - Titanium alloys

AVL SCHRICK Anode Blower

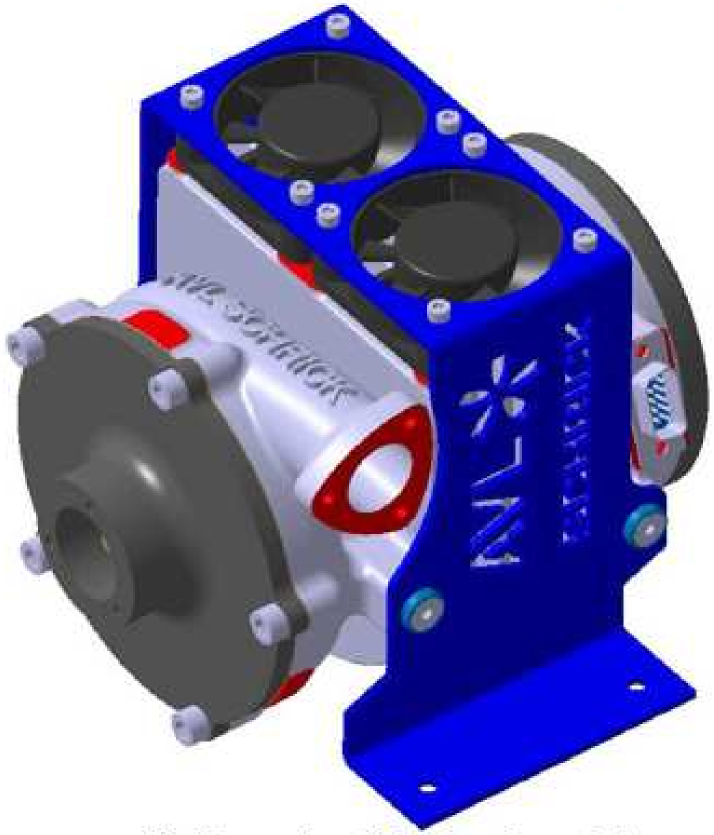


Intensive test program will be performed in next weeks/months

AVL SCHRICK Fuel Cell Blowers

FC Blower Properties

- Very compact Design
- Functional integrated Housing & E-Motor



Air Blower (available in ~8 weeks)

Anode Blower

- Low Heat Radiating Area
- Efficient Cooling and Lubrication
- Suitable for Hydrogen containing Media
- Up to 500℃ Medium Temperature