Karlsruher Institut für Technologie

Vorlesung Batterie- und Brennstoffzellensysteme

BSZ-Systeme 1

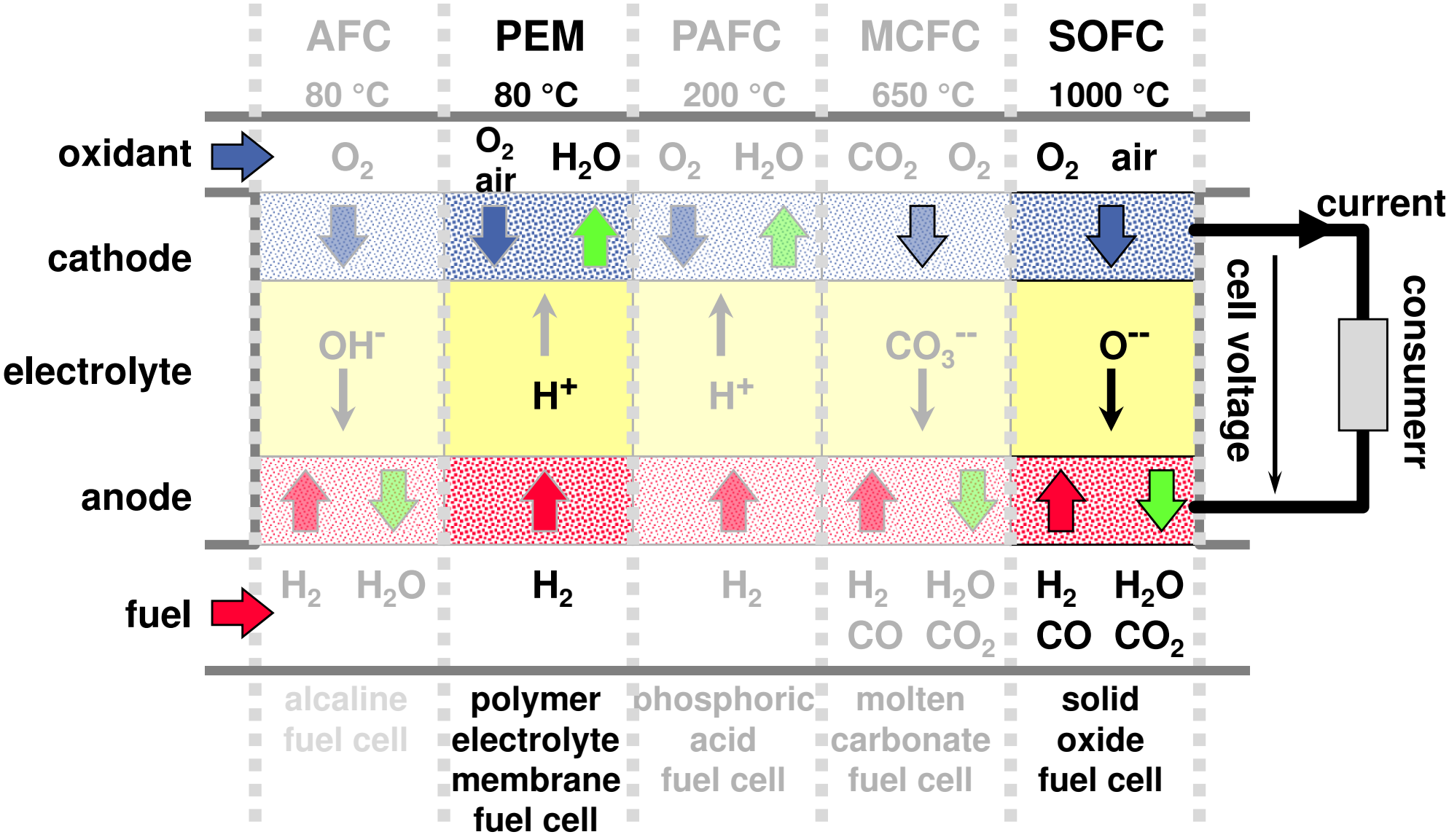
André Weber

Institut für Angewandte Materialien – Elektrochemische Technologien (IAM-ET)
Adenauerring 20b, Geb. 50.40 (FZU), Raum 314
phone: 0721/608-7572, fax: 0721/608-7492
andre.weber@kit.edu
www.iam.kit.edu/et

Inhalt

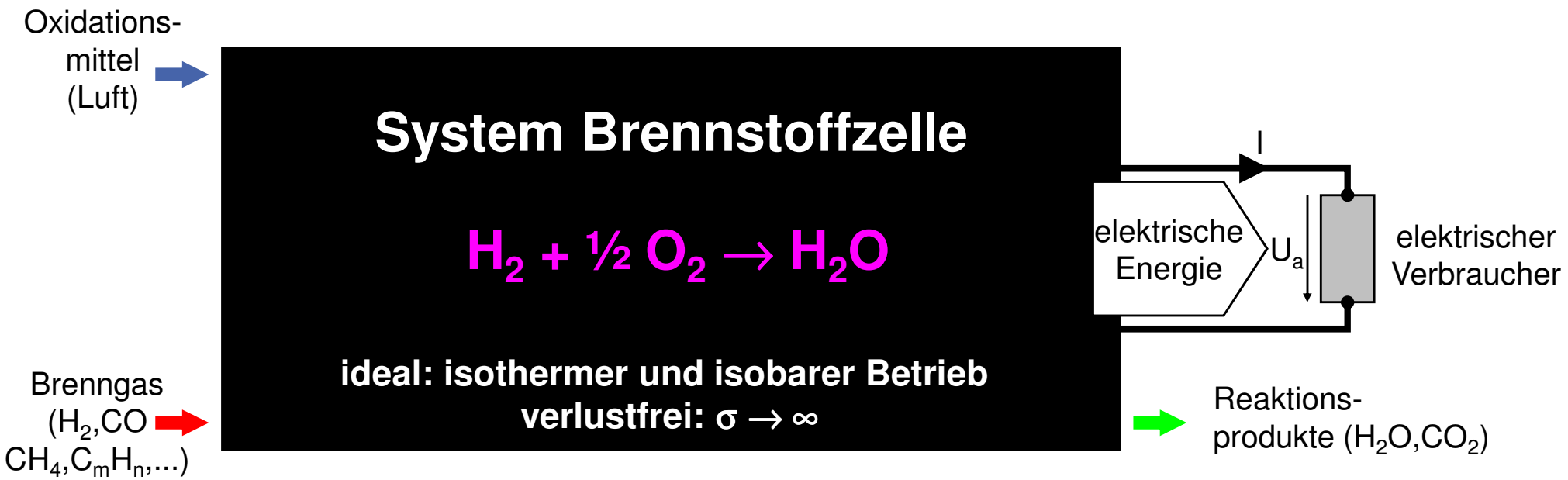
- Grundlagen
  - BSZ-Typen
  - Verluste und Wirkungsgrade
- BSZ-Systeme
  - stationäre (CHP-) Systeme (> 10 kW_{el})

Types of Fuel Cells



Elektrochemische Energiewandlung in Brennstoffzellen
Ideale und reale Brennstoffzelle

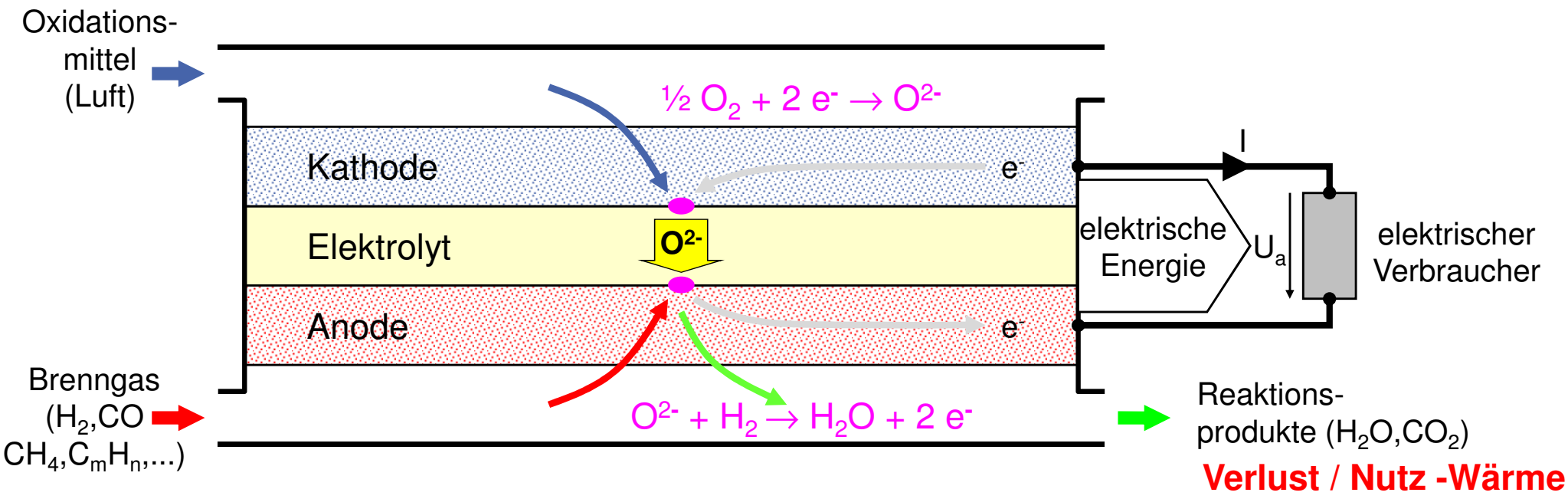
Ideale, verlustfreie Brennstoffzelle: $U_a = U_{th} = -\frac{\Delta G}{n \cdot F} = \left| \frac{\text{freie Reaktionsenthalpie}}{\text{umgesetzte Ladungsmenge}} \right|$



thermodynamischer Wirkungsgrad: $\eta_{th} = \frac{\Delta G}{\Delta H} = \frac{\text{freie Reaktionsenthalpie}}{\text{Reaktionsenthalpie}}$

Elektrochemische Energiewandlung in Brennstoffzellen
Ideale und reale Brennstoffzelle

Reale Brennstoffzelle: $U_a = U_{th} - \sum_k U_{v,k} \simeq U_L - I \cdot R_i(I)$ nichtlinearer Innenwiderstand R_i



elektrischer Nettowirkungsgrad: $\eta_{electrical} = \frac{\text{produzierte el. Energie}}{\text{zugeführte chem. Energie}}$

Elektrochemische Energiewandlung in Brennstoffzellen
Wirkungsgrade im Brennstoffzellensystem

thermodynamischer WG:

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

elektrochemischer WG:

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

Brenngasausnutzung:

$$\beta_f = \frac{\text{umgesetzter Brennstoff}}{\text{zugeführter Brennstoff}}$$

Faraday WG:

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

Reformerwirkungsgrad:

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

el. Systemwirkungsgrad:

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

el. Nettowirkungsgrad

$$\eta_{electrical} = \eta_{th} \cdot \eta_{el} \cdot \eta_f \cdot \beta_f \cdot \eta_{Ref} \cdot \eta_{elS} = \frac{\text{produzierte el. Energie}}{\text{zugeführte chem. Energie}}$$

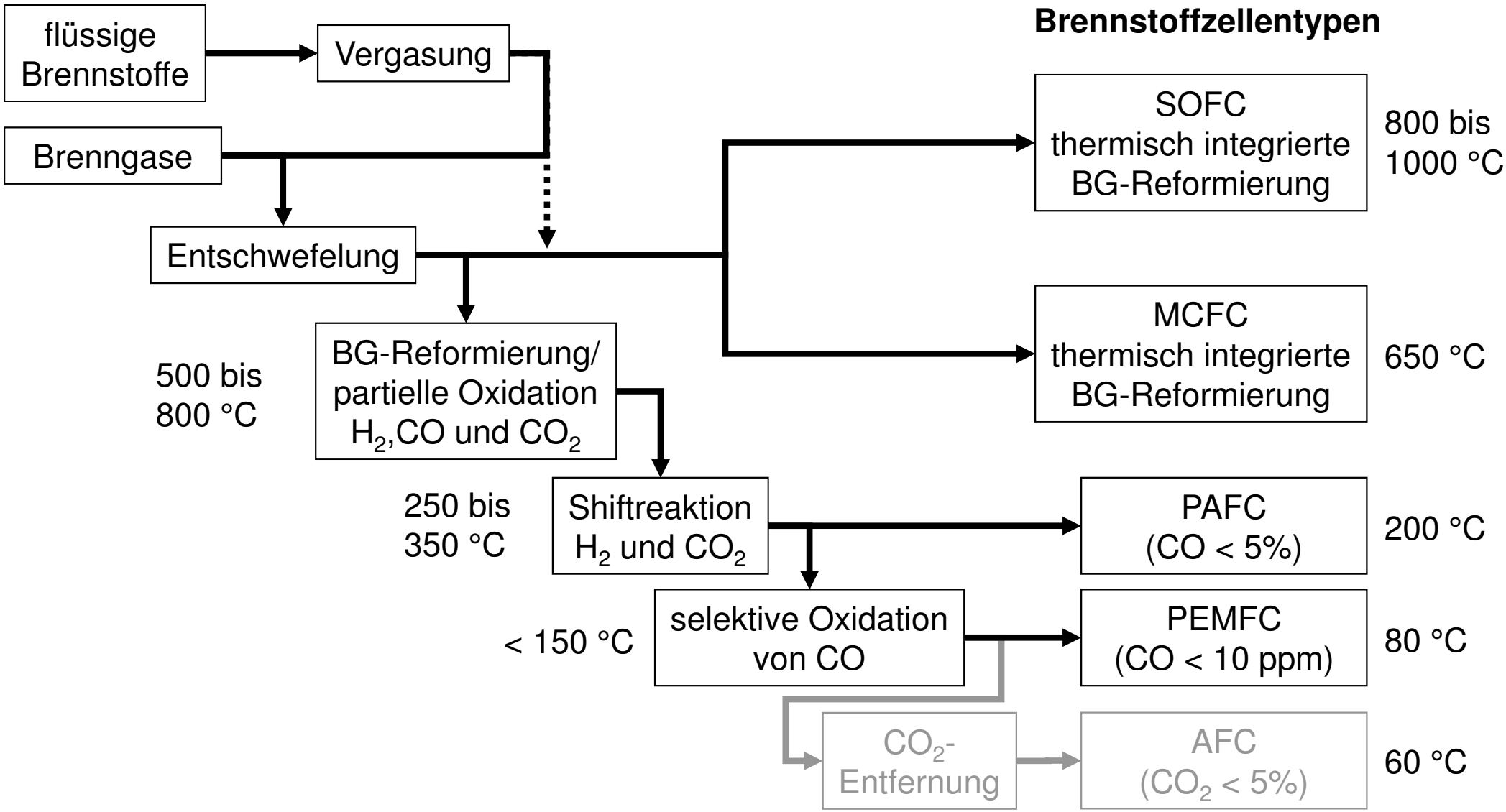
therm. Nettowirkungsgrad

$$\eta_{thermal} = \frac{\text{Nutzwärme}}{\text{zugeführte chem. Energie}}$$

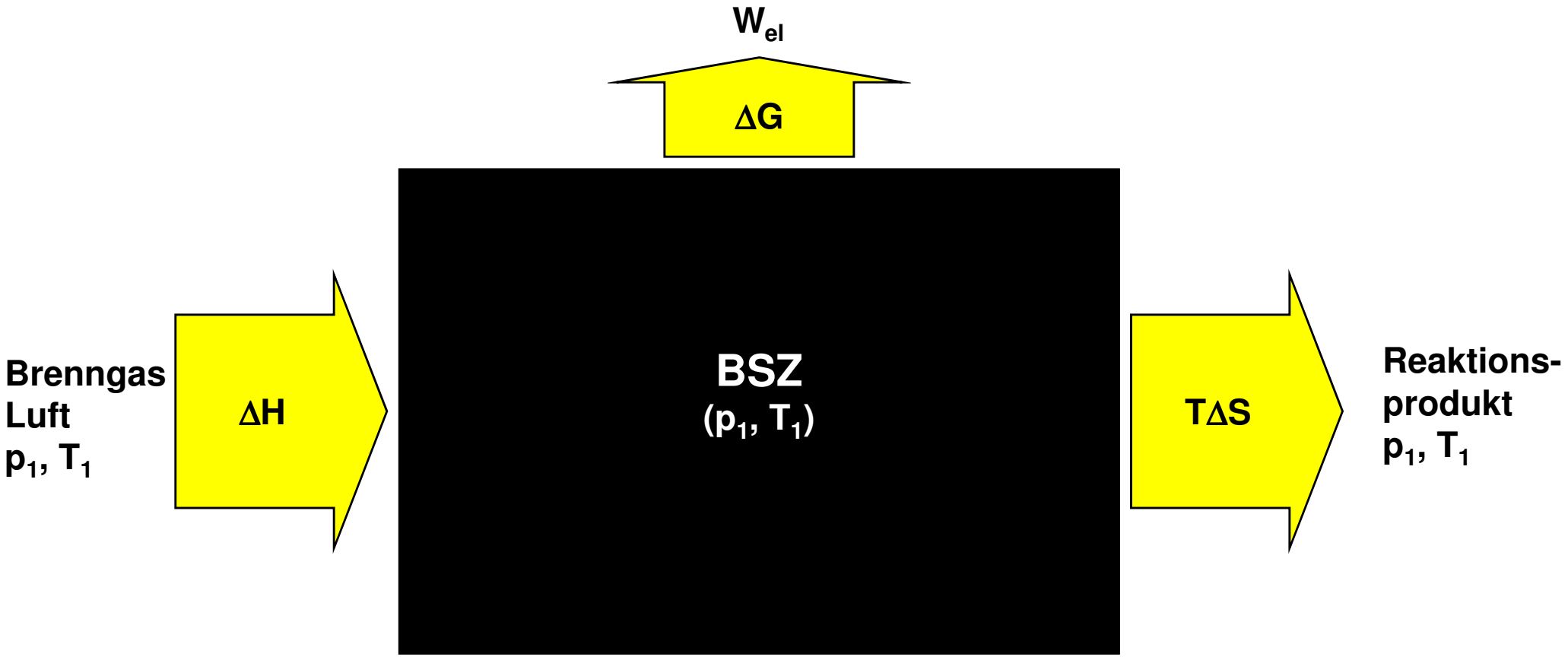
Gesamtwirkungsgrad

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

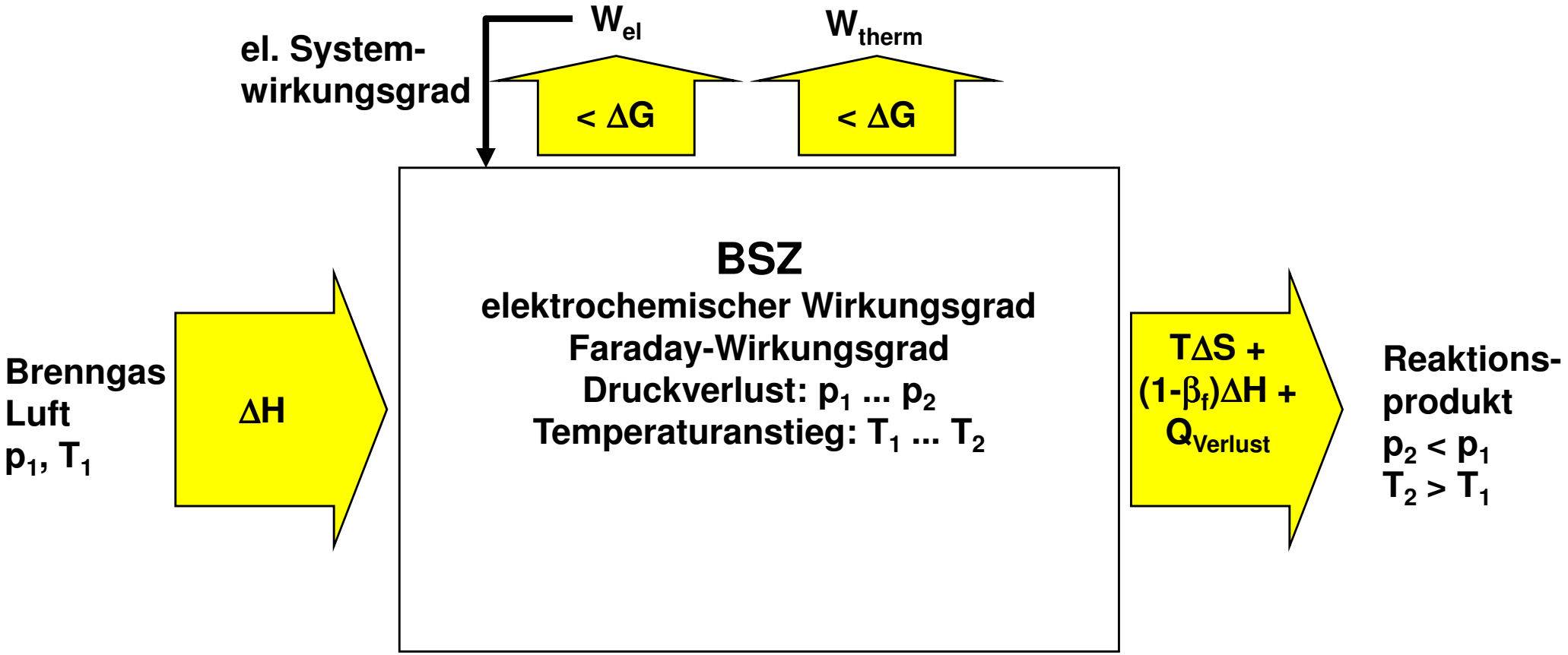
Brennstoffaufbereitung für verschiedene BSZ-Typen



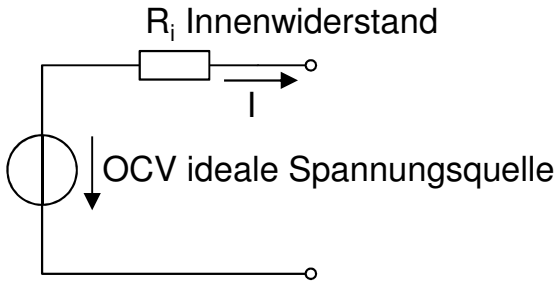
Ideale verlustfreie BSZ

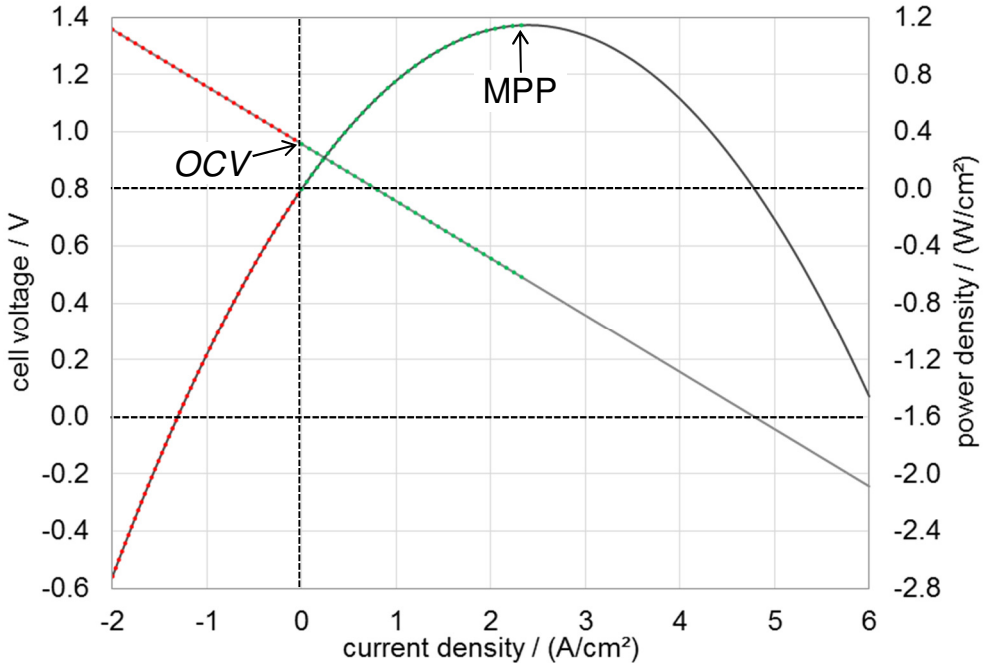


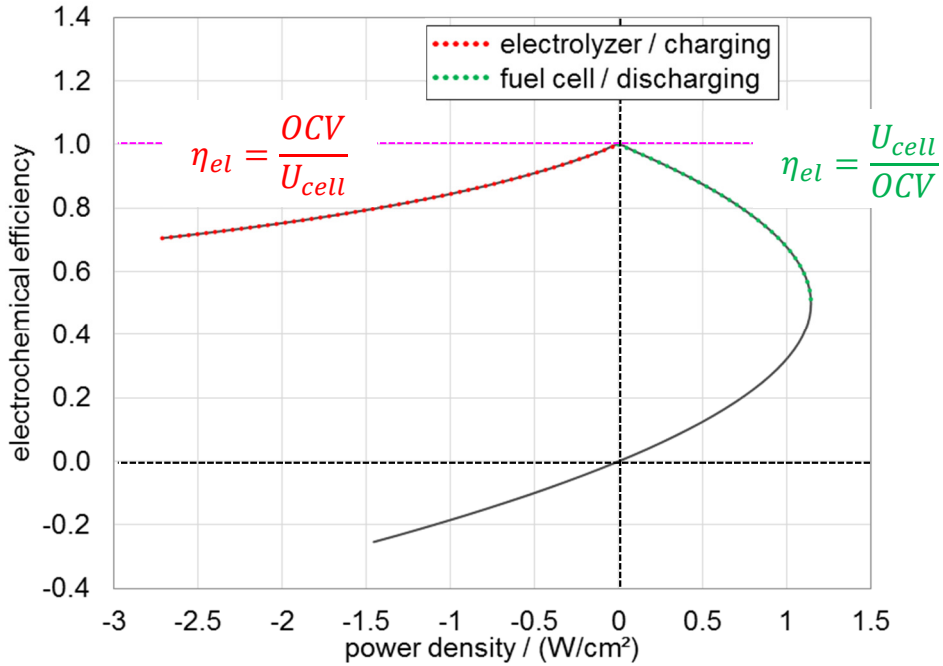
Verlustbehaftete BSZ



Betriebsbereiche

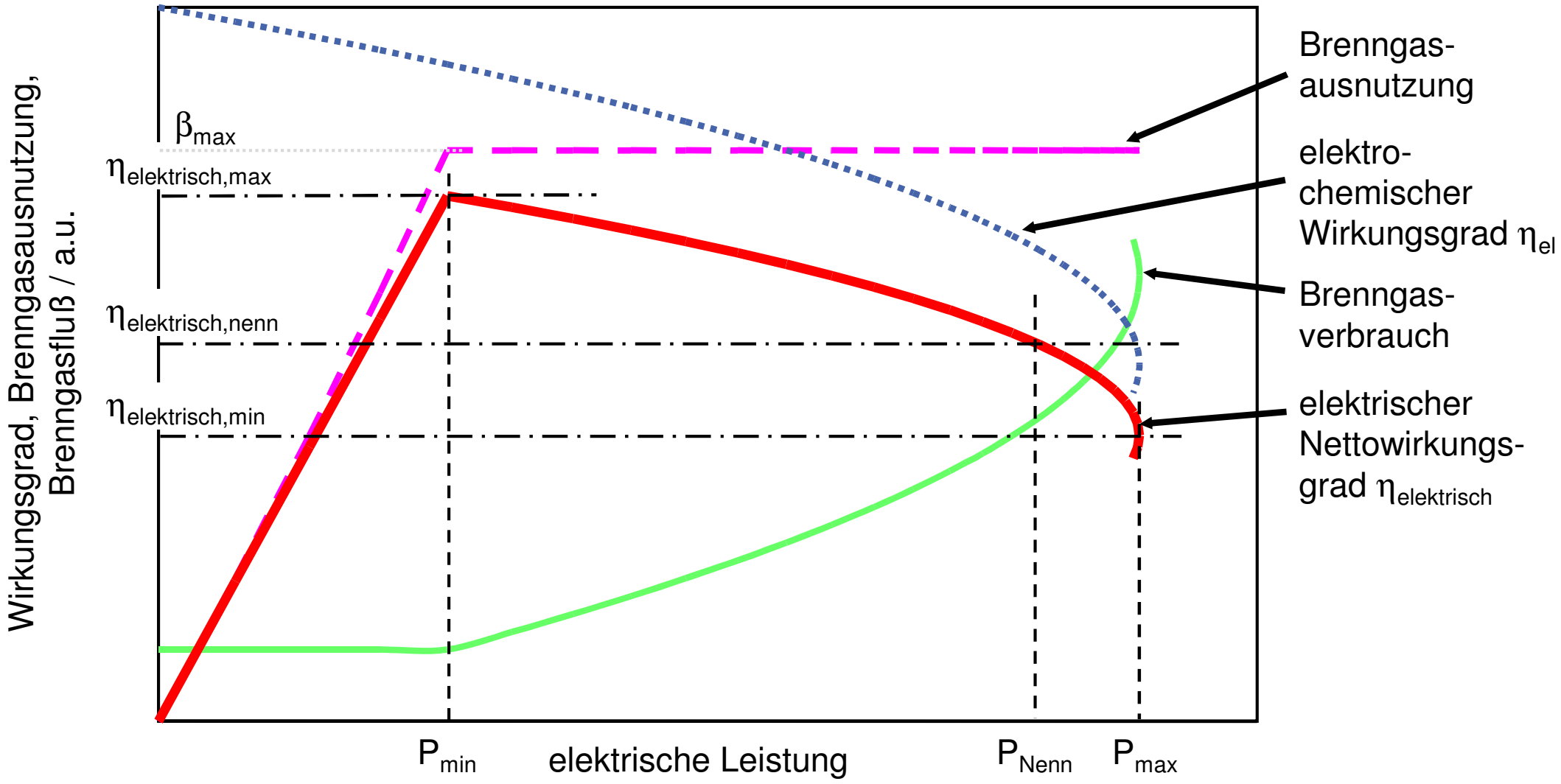




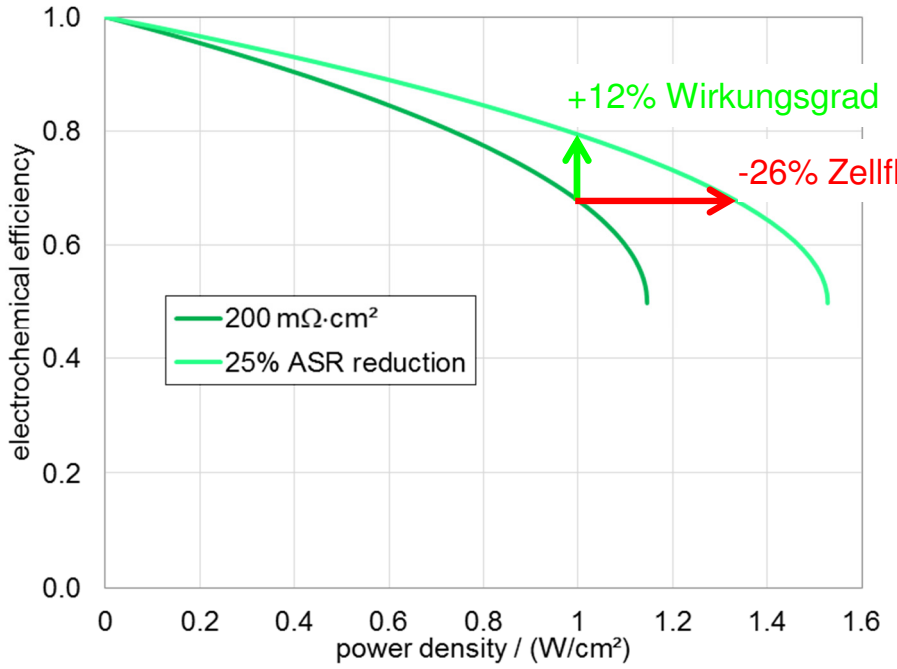


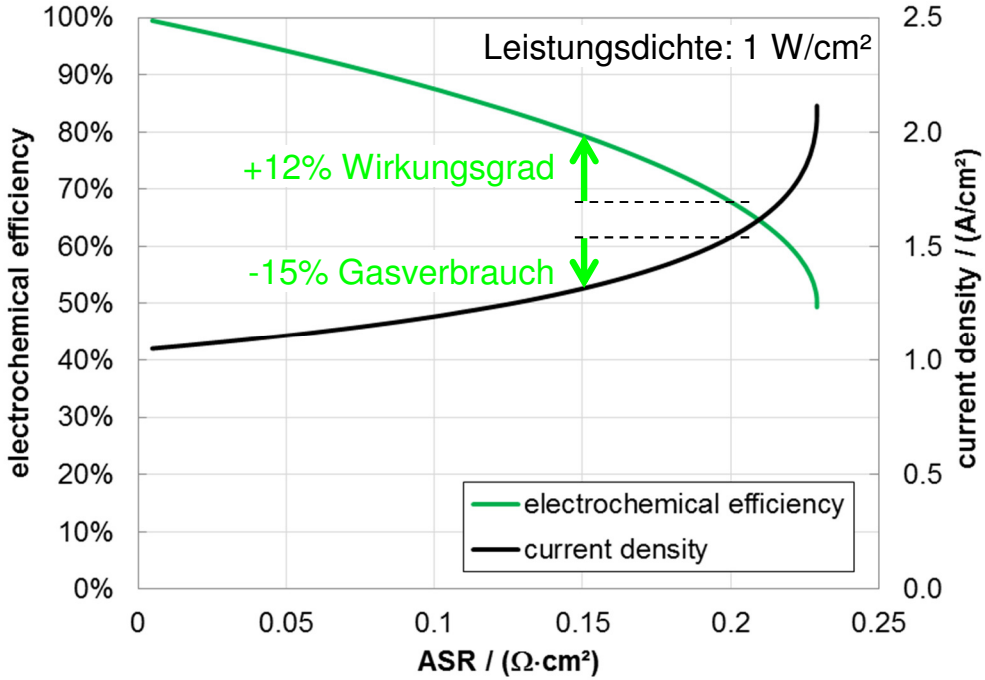
OCV: open circuit voltage (Leerlaufspannung)
MPP: maximum power point
η_{el}: elektrochemischer Wirkungsgrad

Elektrischer Nettowirkungsgrad als Funktion der Leistung



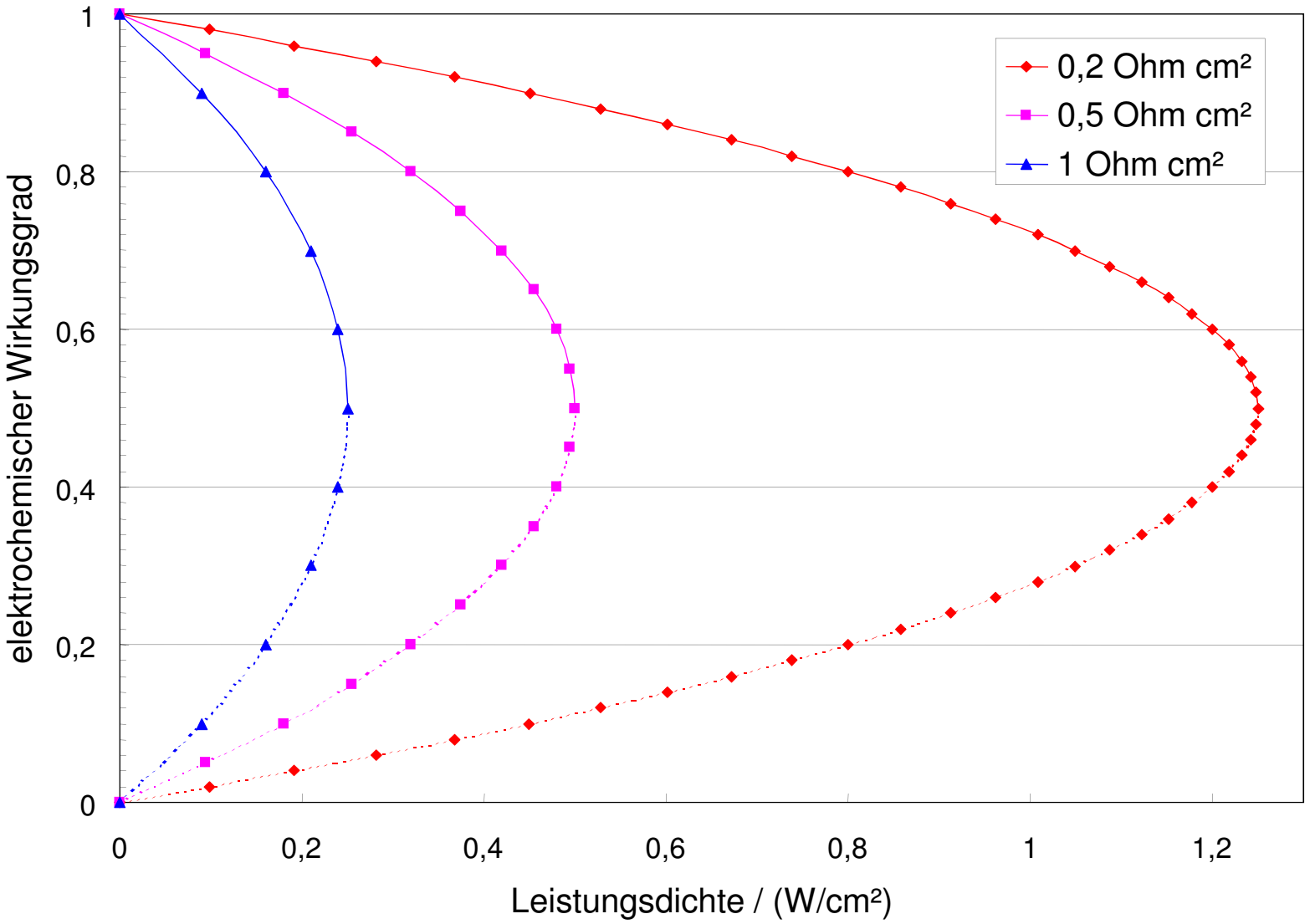
Elektrochemischer Wirkungsgrad
Einfluss des Innenwiderstandes der Zelle





ASR: area specific resistance (flächenspezifischer Widerstand in Ω·cm²)

Elektrochemischer Wirkungsgrad in Abhängigkeit der Leistungsdichte

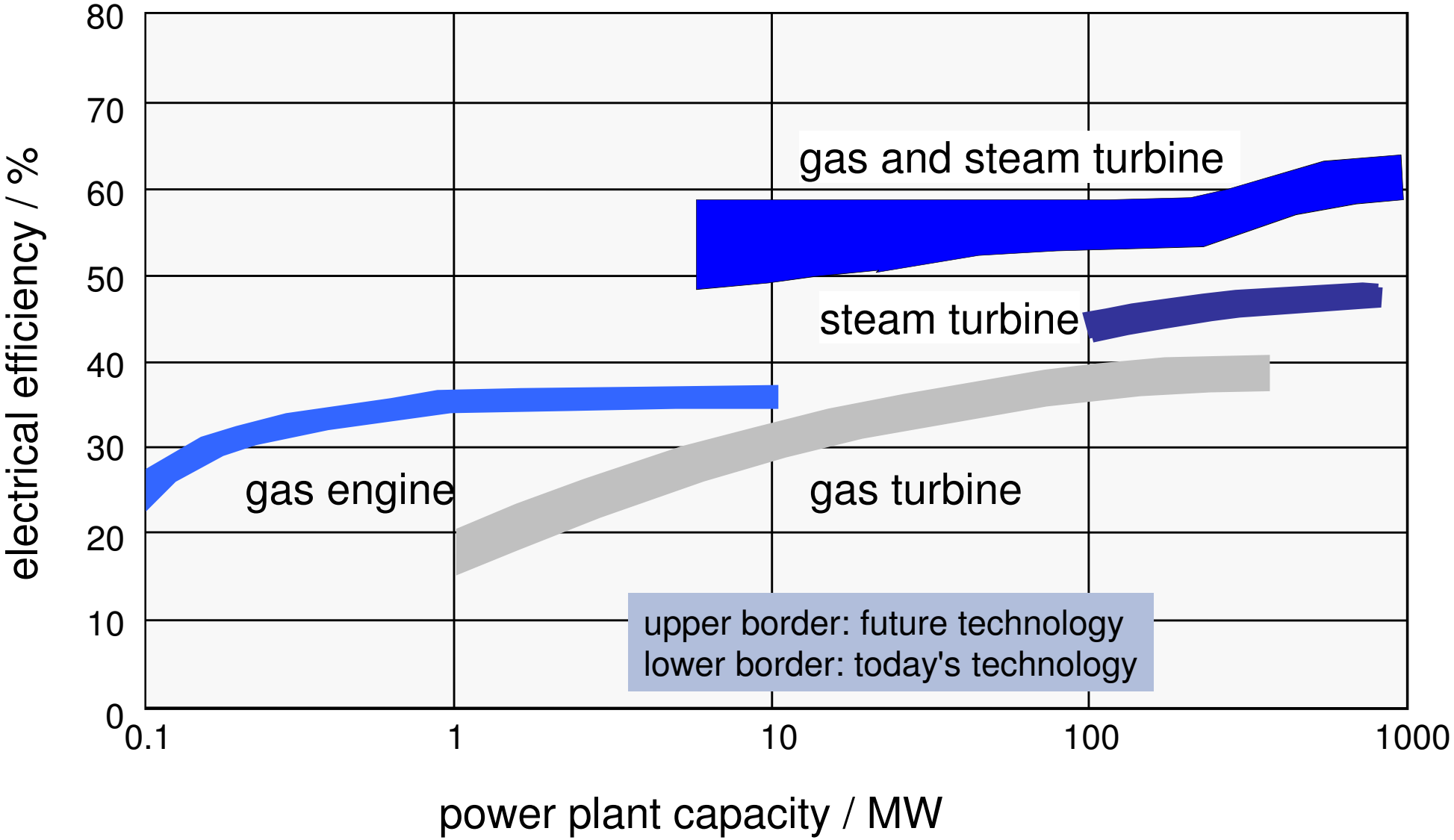


Anwendungen für stationäre BSZ-Systeme

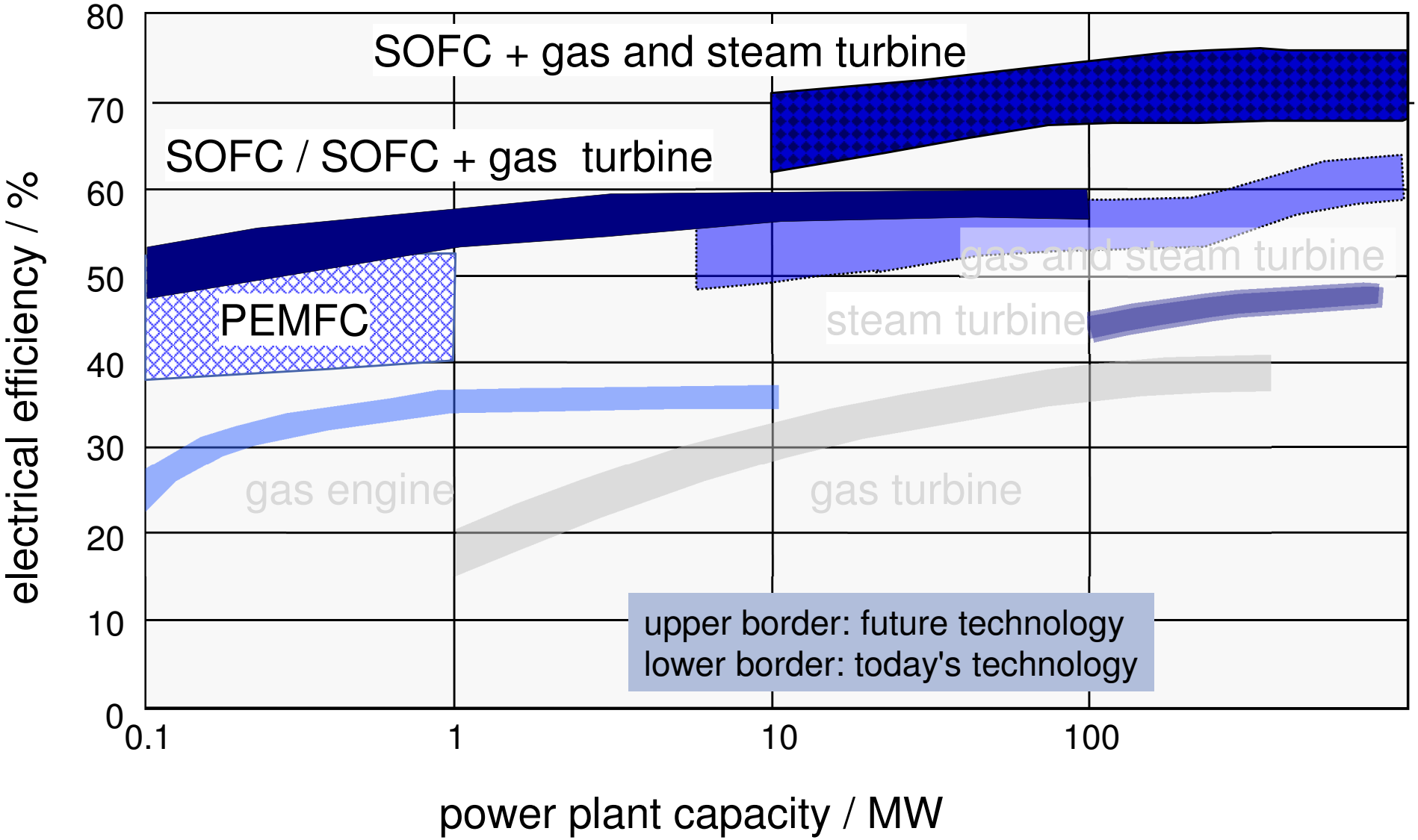
Anlagentyp	P_{el}	Einsatz/Standort	Produkte*	BSZ-Typ
Kraftwerk	> 1 MW	Stromerzeugung	el. Energie, Fernwärme	PAFC/MCFC/SOFC
ind. Kraftwerk	> 100 kW	Industrie	Prozeßdampf, el. Energie	PAFC/MCFC/SOFC
Chemischer Reaktor	> 100 kW	chem. Industrie	H_2, CO, ... , el. Energie	SOFC
BHKW	> 100 kW		el. Energie + Nahwärme	PAFC/MCFC/SOFC
BSZ-Heizgerät / BHKW	5 - 100 kW	Mehrfamilienhaus, Bürogebäude	Nahwärme, el. Energie (Kälte)	PEMFC/SOFC
BSZ-Heizgerät	1 - 3 kW	beheiztes EFH	Nahwärme, el. Energie	PEMFC/SOFC
BSZ	1 - 5 kW	klimatisiertes EFH	el. Energie (+ Kälte)	PEMFC/SOFC
netzunabhängige BSZ	3 -10 kW	Gebäude	el. Energie	PEMFC/SOFC
BSZ	~ 1 kW	EFH	el. Energie	PEMFC/SOFC

* Reihenfolge entsprechend Wichtigkeit/Vorrang

Net electrical efficiencies of power generating systems (using natural gas)



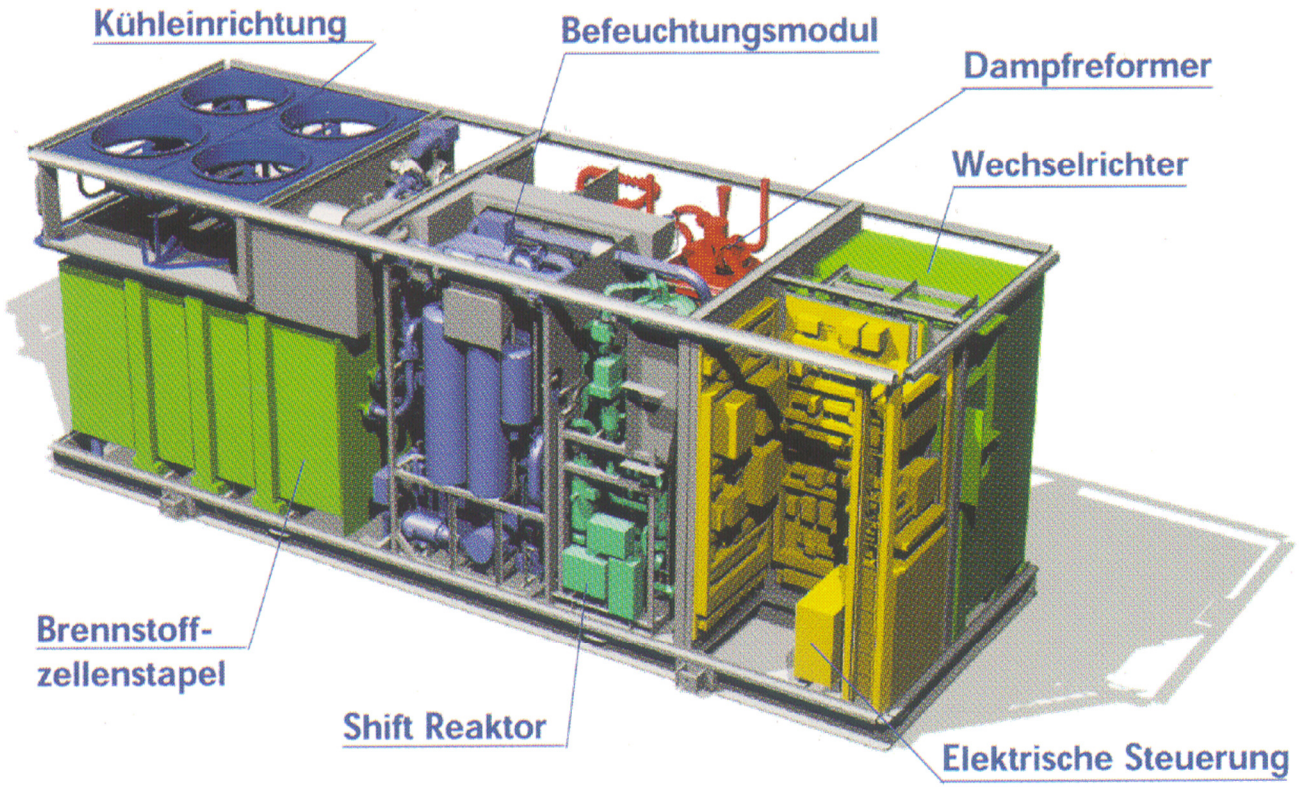
Net electrical efficiencies of power generating systems (using natural gas)



Alstom/Ballard PEMFC

Brennstoffzellen-Typ:	PEMFC
Betriebstemperatur:	80°C
elektrische Leistung:	250 kW
thermische Leistung:	237 kW
el. Nettowirkungsgrad*:	35 - 40%
Brennstoff:	Erdgas

*angestrebt



Brennstoffzellensysteme für die dezentrale Energieversorgung
Alstom Ballard PEMFC - Feldtest in Mingolsheim (EnBW)

Betriebsdaten zum 24. Oktober 2003:

- Inbetriebnahme 09.09.2002
- Betriebsstunden 2002 3.600 h
- Betriebsstunden 2003 3.500 h
- Betriebsstunden ges. 7.100 h

Energie:

- Elektrische Energie 786 MWh
- Thermische Energie 852 MWh

- Zeitl. Verfügbarkeit ca. 65 %
- Wirkungsgrad el. ca. 32-33 %
- Wirkungsgrad ges. ca. 60-70 %

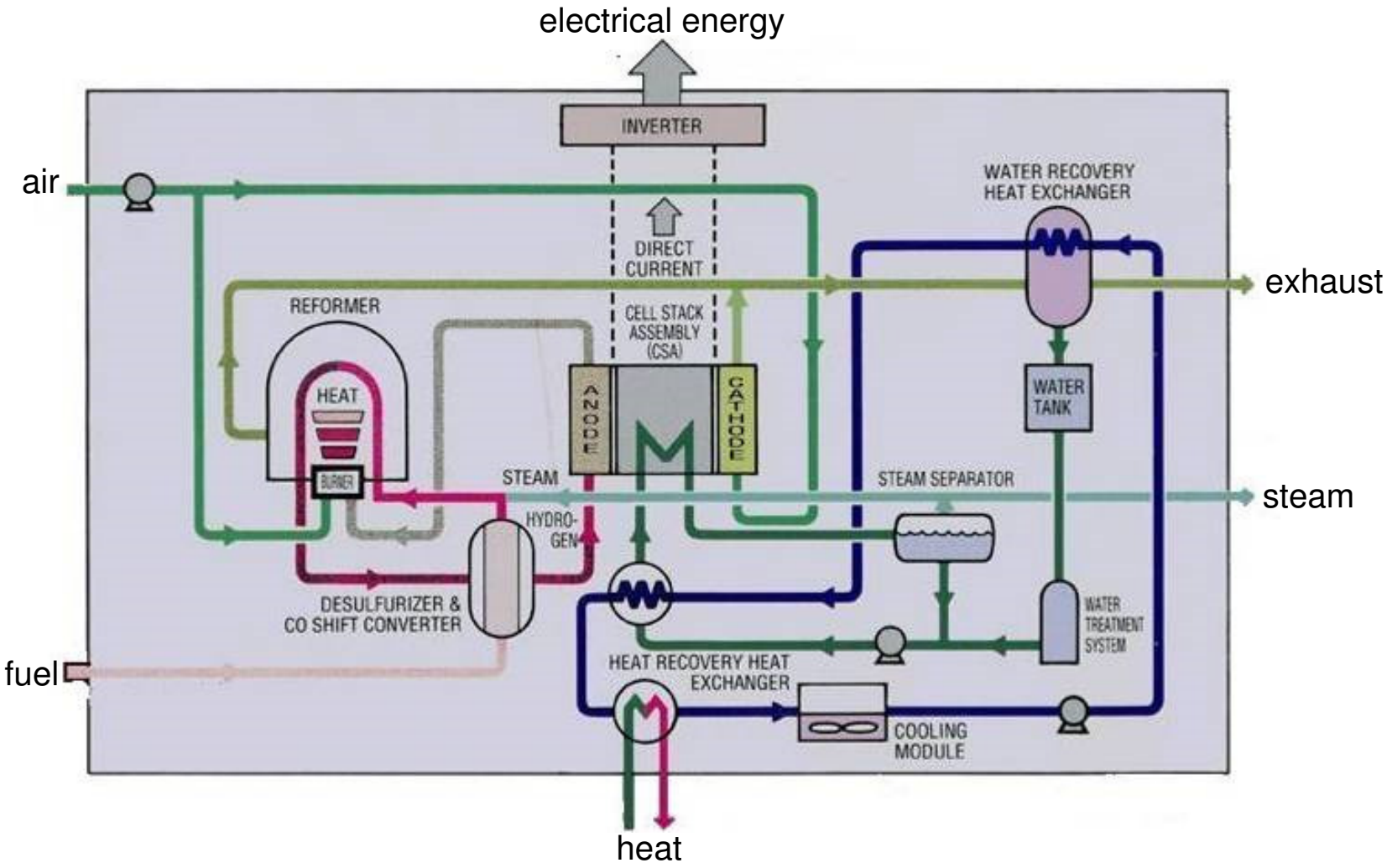
Brennstoffzellensysteme für die dezentrale Energieversorgung
Parallel arbeitende PC25** PAFC-Systeme

US Postal Service Mail Processing Center,
Anchorage, Alaska

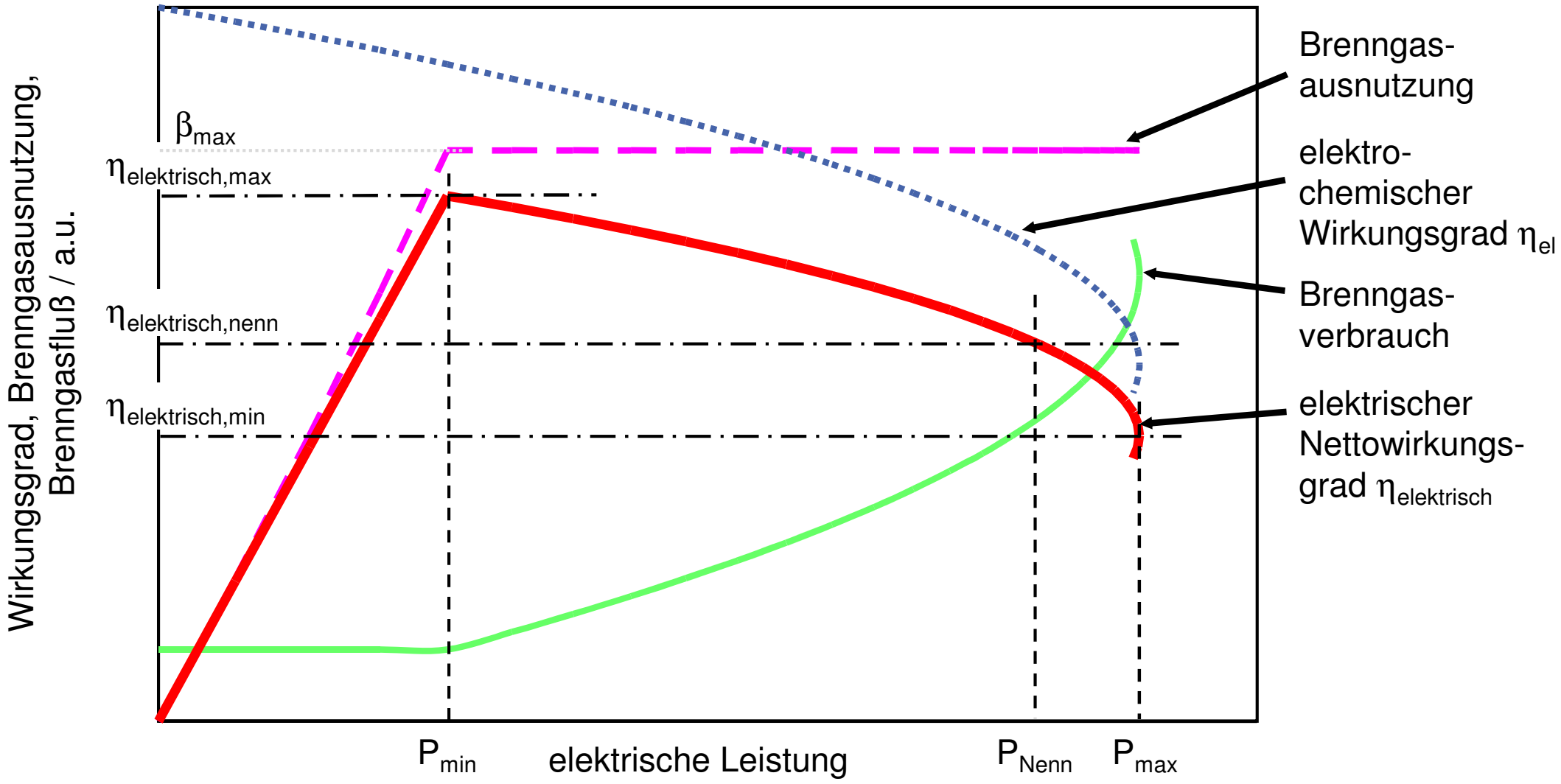
elektrische Leistung:	200 kW
thermische Leistung:	200 kW
Spannung:	450 V @ 50 Hz dreiphasig
el. Nettowirkungsgrad:	40%
Systemwirkungsgrad:	85%
Brennstoff:	Erdgas (u.a.)
Geräuschpegel:	60dB @ 10 m

** mehr als 300 Einzelsysteme weltweit verkauft, nicht mehr verfügbar

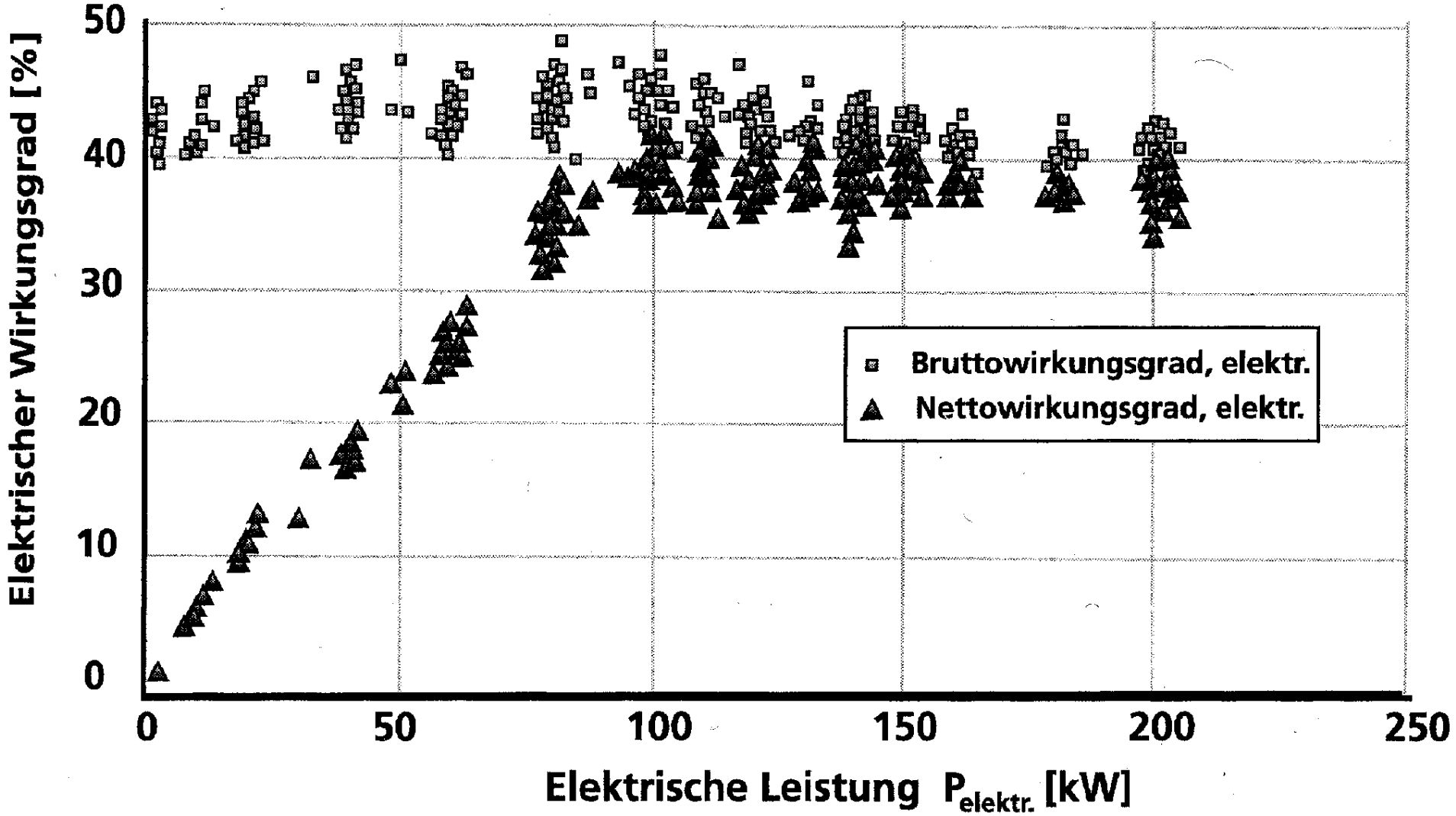
Brennstoffzellensysteme für die dezentrale Energieversorgung
PC25 PAFC-System



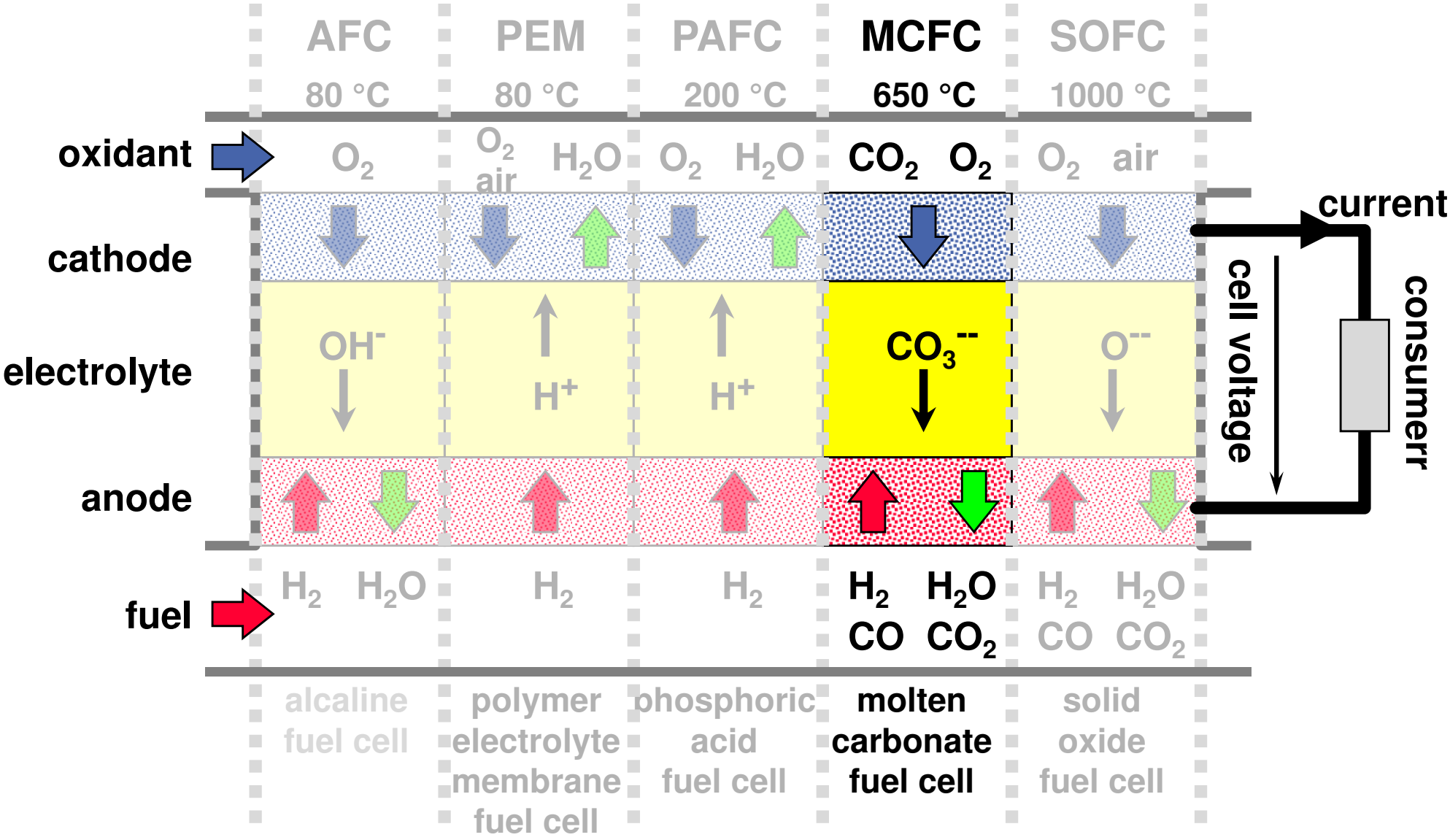
Elektrischer Nettowirkungsgrad als Funktion der Leistung



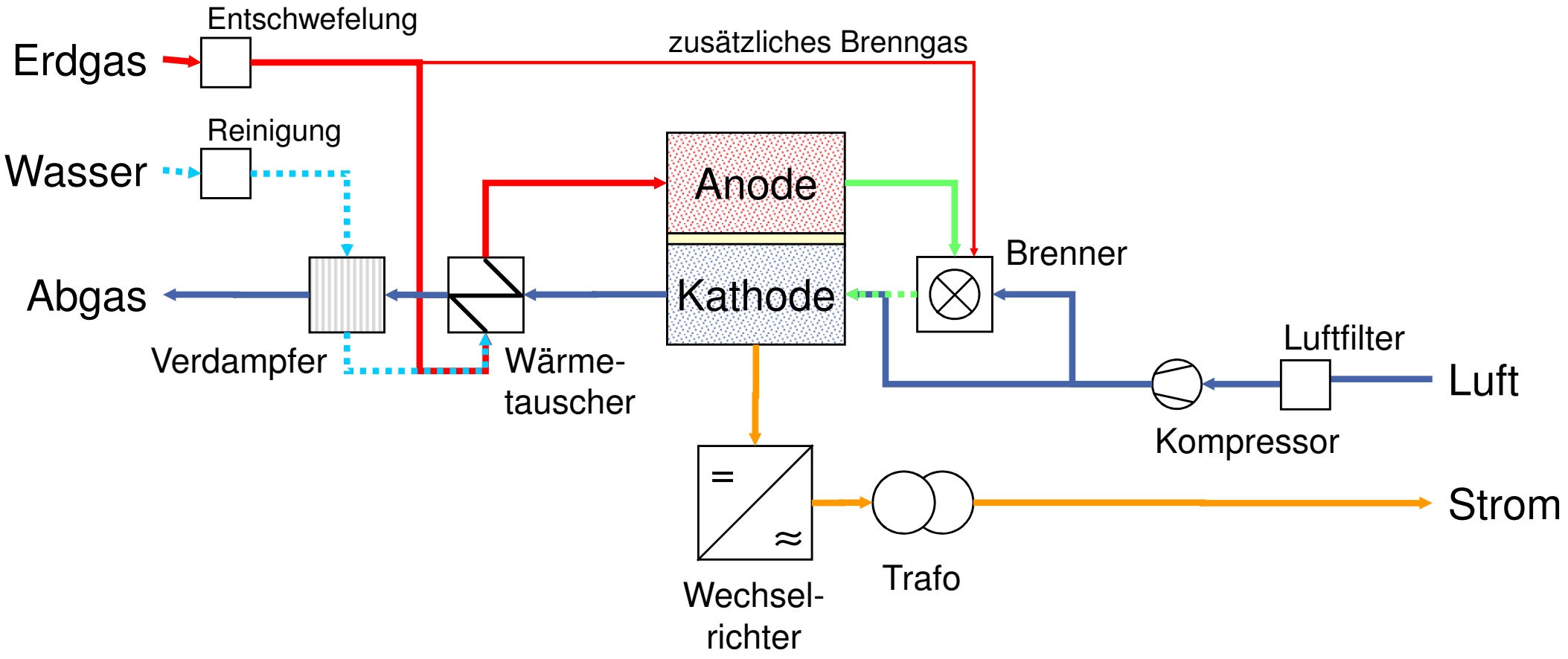
Brennstoffzellensysteme für die dezentrale Energieversorgung
PC25TM PAFC-System Wirkungsgrad als Funktion der Leistung



Types of Fuel Cells

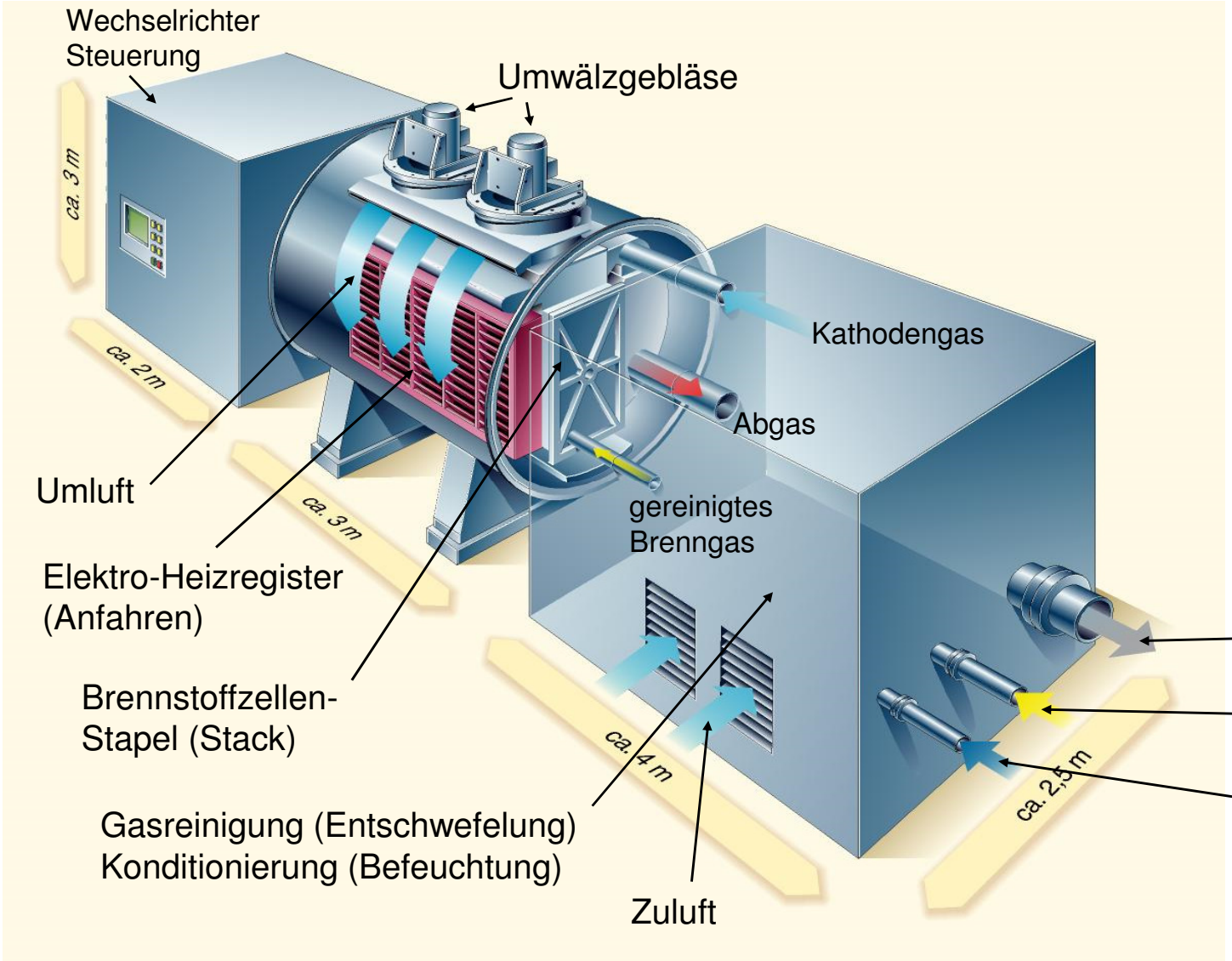


Brennstoffzellensysteme für die dezentrale Energieversorgung
Molten Carbonate Fuel Cell (MCFC)



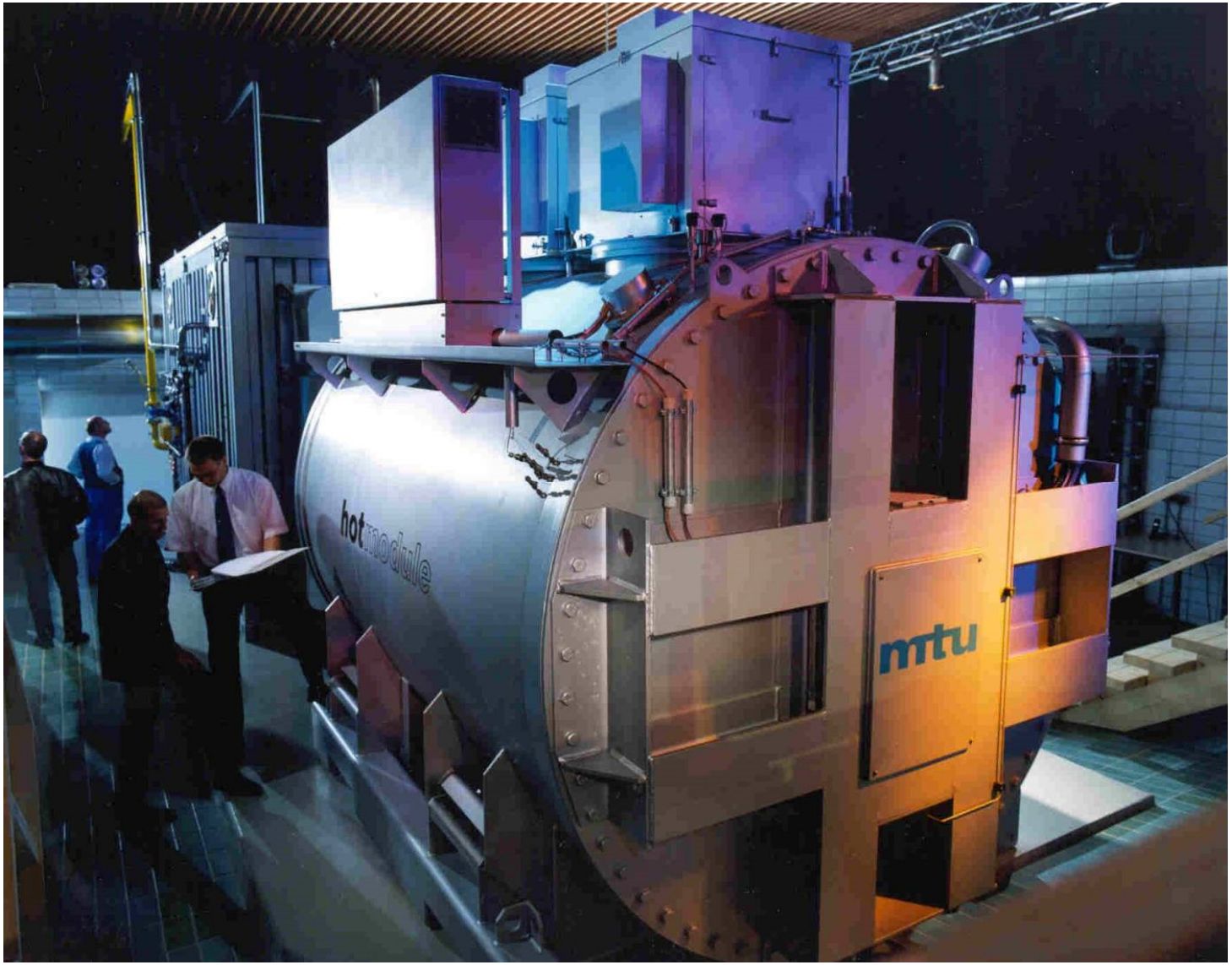
Brennstoffzellensysteme für die dezentrale Energieversorgung
2 MW MCFC-Kraftwerk in Santa Clara (USA)

Brennstoffzellensysteme für die dezentrale Energieversorgung
MCFC Systemtechnik - Hot Module



Kooperation von Fuel Cell Energy und MTU

Brennstoffzellensysteme für die dezentrale Energieversorgung
MCFC Systemtechnik - Hot Module



Brennstoffzellensysteme für die dezentrale Energieversorgung
Fuel Cell Energy Solutions (MCFC-Systeme)

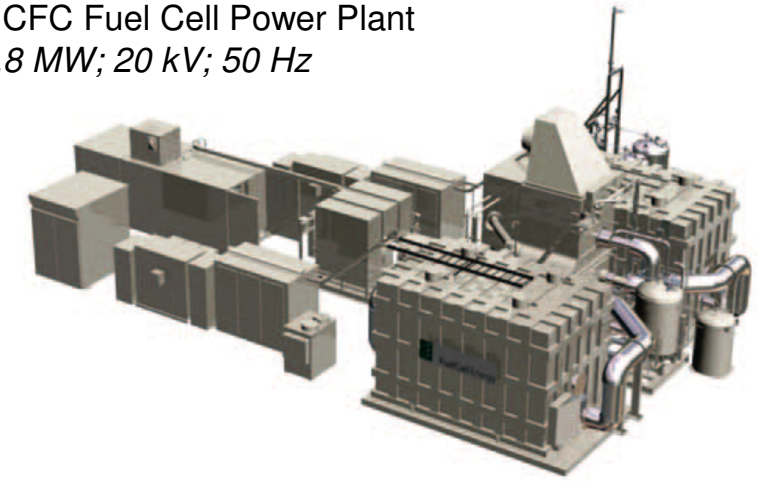
DFC®250 EU
MCFC-Fuel Cell Power Plant
250 kW; 400 V; 50 Hz

DFC®1500 EU
MCFC-Fuel Cell Power Plant
1,4 MW; 20 kV; 50 Hz

DFC®300 EU
MCFC-Fuel Cell Power Plant
300 kW; 400 V; 50 Hz

DFC®400 EU
MCFC-Fuel Cell Power Plant
400 kW; 400 V; 50 Hz

DFC®3000 EU
MCFC Fuel Cell Power Plant
2,8 MW; 20 kV; 50 Hz



Brennstoffzellensysteme für die dezentrale Energieversorgung
Fuel Cell Energy Solutions (MCFC-Systeme)

- **59 MW fuel cell park**
  - Construction period only about one year
  - 21 power plants: 2.8 MW DFC3000®
- **Ownership**
  - 49% by electric utility KHNP
  - 21% by financial investors
  - 15% by gas company Samchully
  - 15% by POSCO Energy

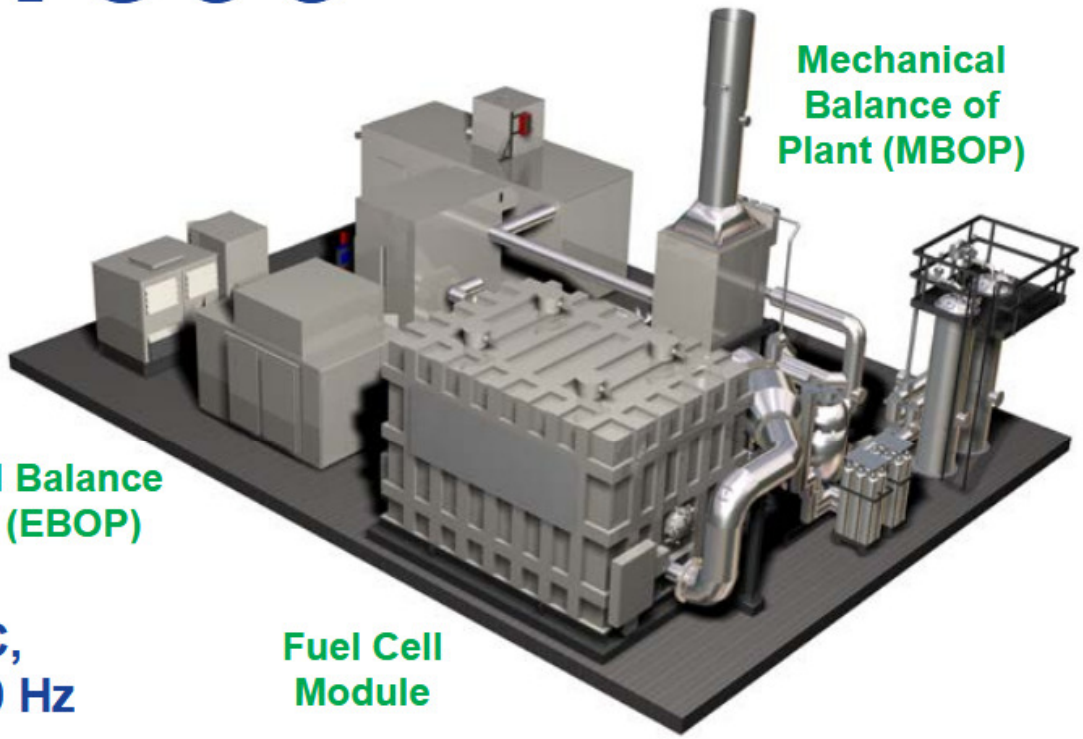
fuelcellenergy

SureSource 1500

1.4 MEGAWATTS

KEY FEATURES

- Continuous Power
- Highly Efficient
- Fuel Flexible
- Ultra-Clean
- Scalable
- Modest Footprint
- Quiet Operation



1.4 MW, 480 VAC,
1,550 kVA, 50 or 60 Hz

APPLICATIONS

Featuring ultra-low emissions, quiet operation and minimal space requirements (about the size of a tennis court), the SureSource 1500 is suitable for locations where combustion-based traditional power generation technologies are not feasible or desirable such as next to buildings or in space-constrained urban locations. This solution is ideal for on-site power generation for large installations requiring continuous power and value high-quality steam for facility heating and/or absorption chilling; including industrial facilities, hospitals, universities and wastewater treatment plants.

SureSource 1500

PERFORMANCE

Gross Power Output

Power @ Plant Rating	1,400 kW
Standard Output AC voltage	480 V
Standard Frequency	60 Hz
Optional Output AC Voltages	By Request
Optional Output Frequency	50 Hz

Efficiency

LHV	47 +/- 2 %

Available Heat

Exhaust Temperature	700 +/- 50 ºF
Exhaust Flow	18,300 lb/h
Allowable Backpressure	5 iwc

Heat Energy Available for Recovery

(to 250 ºF)	2,216,000 Btu/h
(to 120 ºF)	3,730,000 Btu/h

Fuel Consumption

Natural gas (at 930 Btu/ft3)	181 scfm
Heat rate, LHV	7,260 Btu/kWh

Water Consumption

Average	4.5 gpm
Peak during WTS backflush	15 gpm

Water Discharge

Average	2.25 gpm
Peak during WTS backflush	15 gpm

Pollutant Emissions

NOx	0.01 lb/MWh
SOx	0.0001 lb/MWh
PM10	0.00002 lb/MWh

Greenhouse Gas Emissions

CO2	980 lb/MWh
CO2 (with waste heat recovery)	520-680 lb/MWh

Sound Level

Standard	72 dB(A) at 10 feet

lb (pound) = 0.454 kg
g (gallon) = 3.785 L
1 Btu = 0.293 Wh

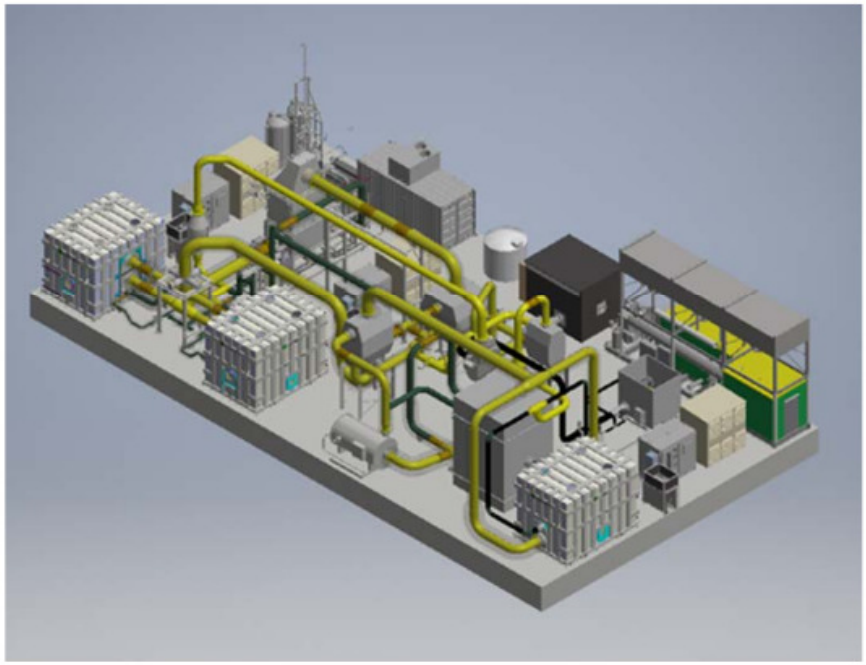
SureSource 4000

3.7 MEGAWATTS

KEY FEATURES

- Continuous Power
- High Electrical and Total Efficiency
- Fuel Flexible
- Ultra-Clean
- Scalable
- Modest Footprint
- Quiet Operation

3.7 MW, 13,800 VAC,
50 or 60 Hz



APPLICATIONS

The SureSource 4000 is the largest in the SureSource power plant fleet and utilizes a third fuel cell module to generate 3.7 megawatts (MW) of ultra-clean power with an industry-leading electrical efficiency of approximately 60%. Scalable to more than 100 MW, this enhanced-efficiency fuel cell system is designed for utilities, large industrial users, data centers, and other customers focused on clean and affordable power driven by the benefits and economics of high system electrical efficiency.

PERFORMANCE

Gross Power Output	
Power @ Plant Rating	3,700 kW
Standard Output AC voltage	13,800 V
Standard Frequency	60 Hz
Optional Output AC Voltages	12,700 V 4,160 V
Optional Output Frequency	50 Hz

Electrical Efficiency	
LHV	60%

Available Heat from Exhaust	
Exhaust Temperature	325ºF
Exhaust Flow	38,000 lb/h
Allowable Backpressure	5 inches

Heat Energy Available for Recovery	
(to 250 ºF)	734,000 Btu/h
(to 120 ºF)	2,000,000 Btu/h

Additional Hot Water Capability	
Water up to 120 ºF	2,500,000 Btu/h

Fuel Consumption	
Natural gas (at 930 Btu/ft3)	383 scfm
Heat rate, LHV	5,785 Btu/kWh

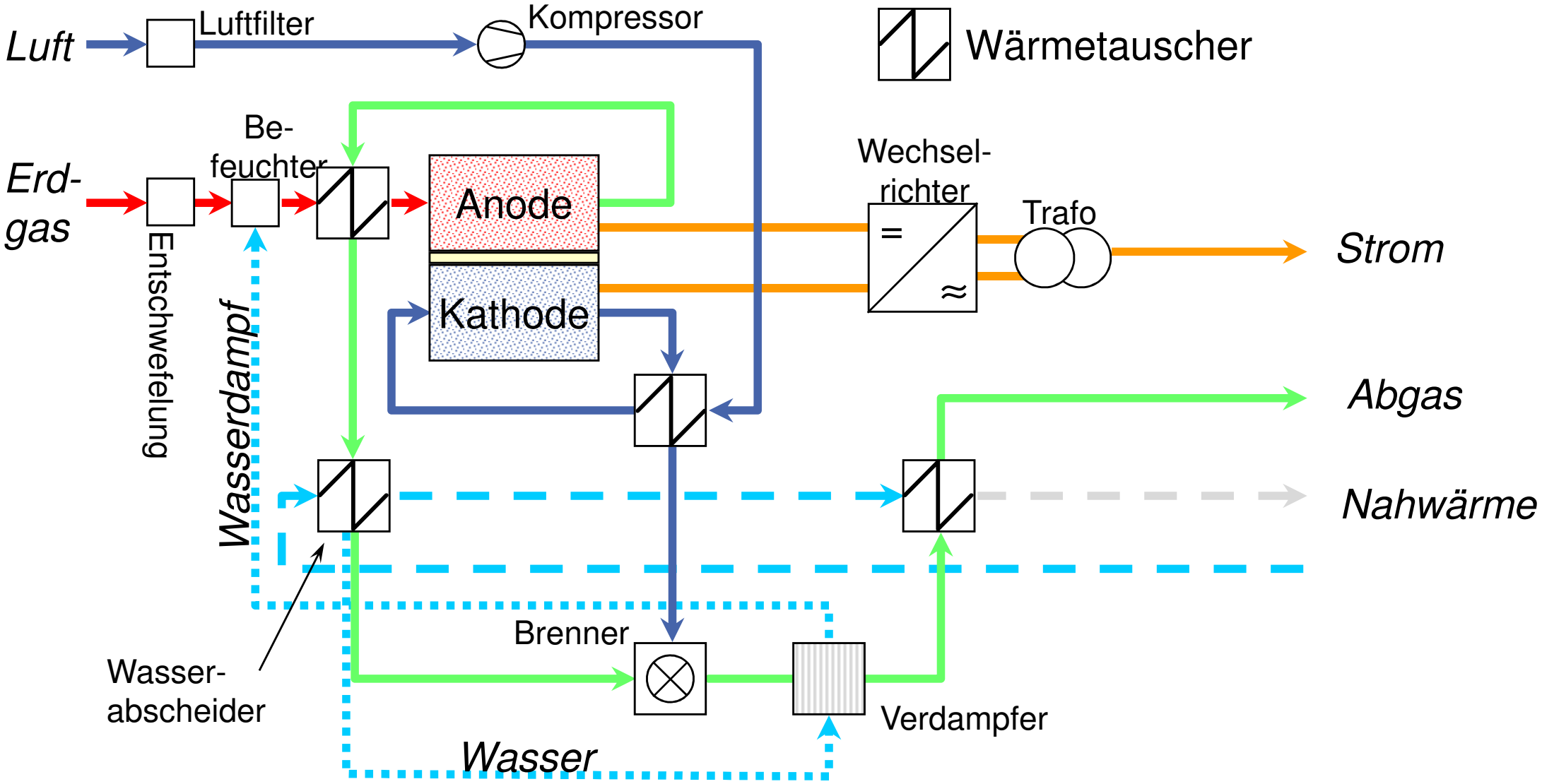
Water Consumption	
Above 2.2 MW power output	0 gpm
Below 2.2 MW power output	< 1 gpm

Emissions	
NOx	0.01 lb/MWh
SOx	0.0001 lb/MWh
PM10	0.00002 lb/MWh
CO_2	725 lb/MWh
CO_2 (with waste heat recovery)	550-680 lb/MWh

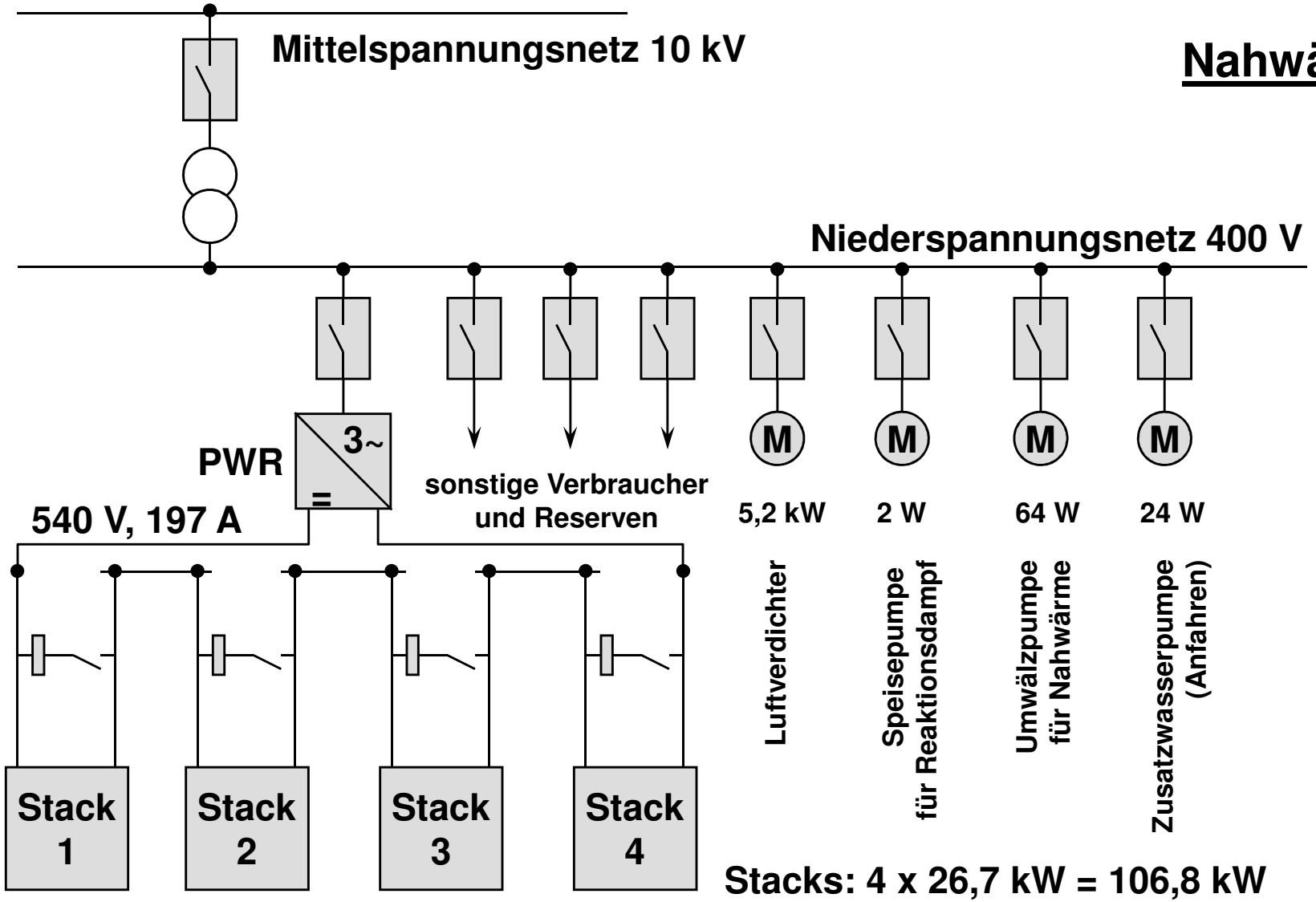
Sound Level	
Standard	72 dB(A) at 10 feet

lb (pound) = 0.454 kg
g (gallon) = 3.785 L
1 Btu = 0.293 Wh

Brennstoffzellensysteme für die dezentrale Energieversorgung
Systemkonzept 100 kW-SOFC-BHKW-Anlage

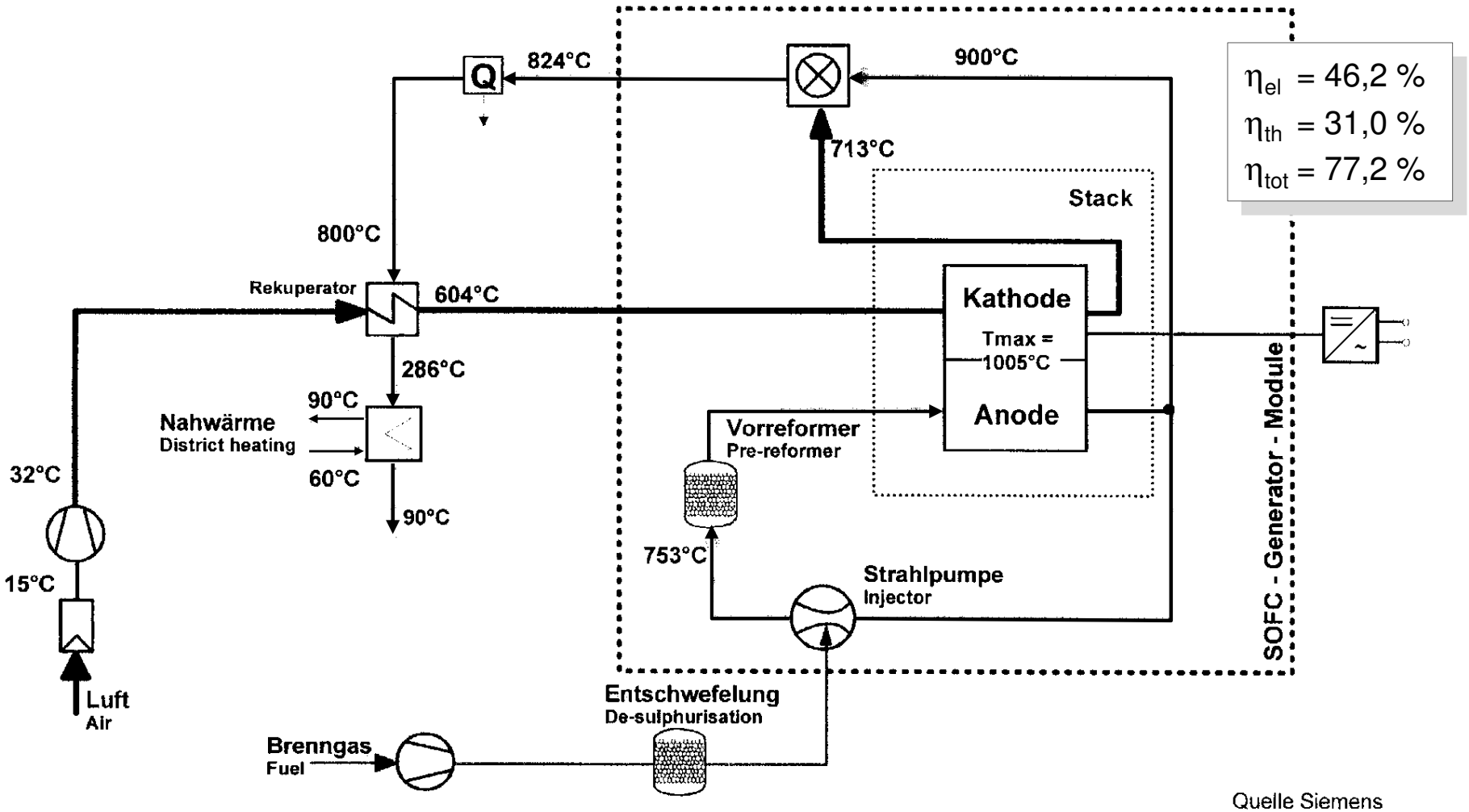


Systemkonzept 100 kW - SOFC - BHKW - Anlage
E-Schaltanlagenkonzeption mit netzgeführtem Wechselrichter



Brennstoffzellensysteme für die dezentrale Energieversorgung
250 kW BHKW (CHP)

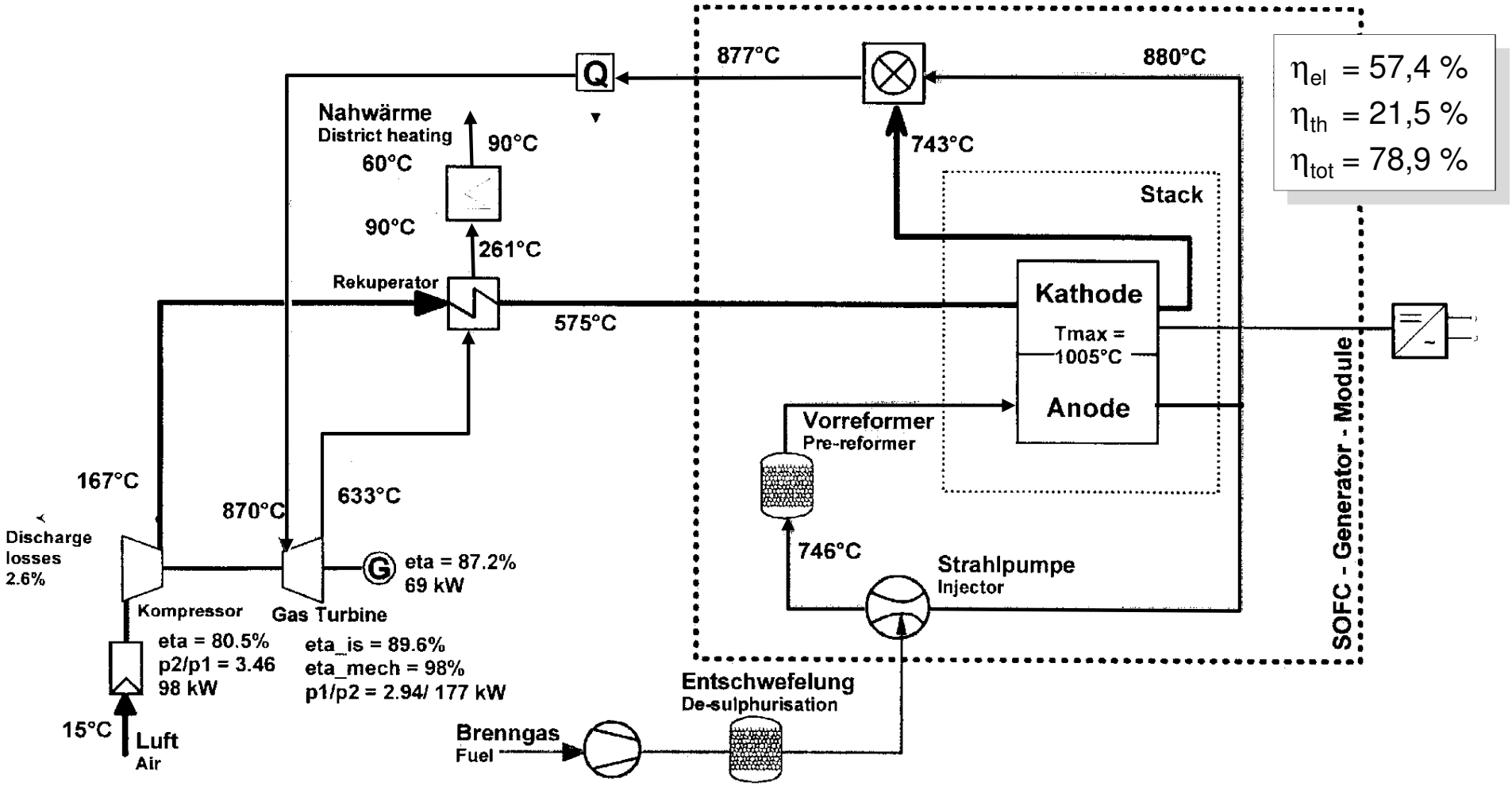
(Brenngasnutzung 84%, Zellspannung 0,65 V)



Quelle Siemens

Brennstoffzellensysteme für die dezentrale Energieversorgung
320 kW Druck-Hybrid-Anlage

(Brenngasnutzung 84%, Zellspannung 0,63 V)

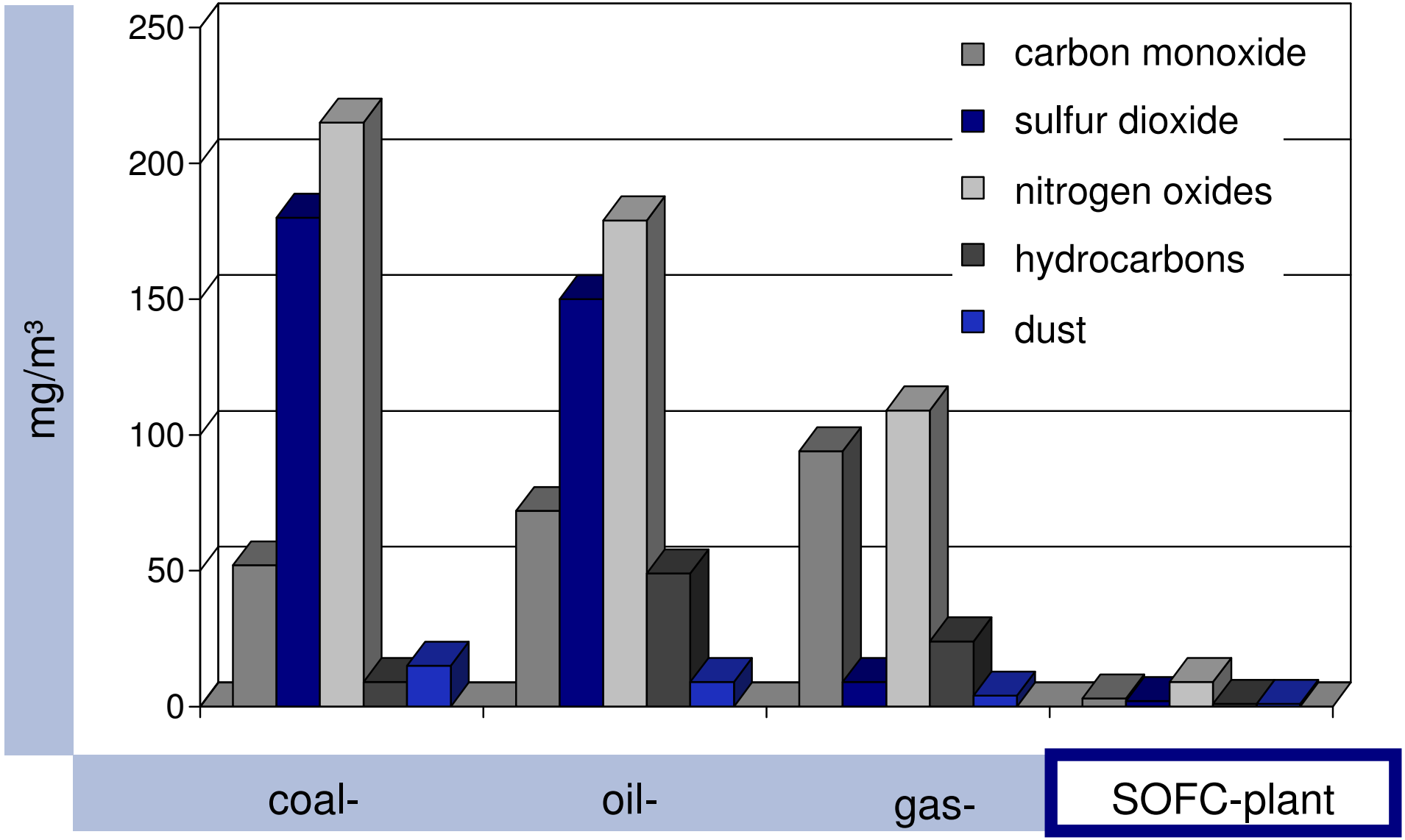


Quelle Siemens

Brennstoffzellensysteme für die dezentrale Energieversorgung
Siemens Westinghouse 100 kW SOFC-BHKW

P_{el}: 100 kW_{el}
P_{th}: 65 kW_{th}
Brennstoff: Erdgas
$\eta_{elektrisch}$: 46 %
$\eta_{thermisch}$: 29 %
η_{gesamt}: 75 %

Pollutant emissions of different generators



Brennstoffzellensysteme für die dezentrale Energieversorgung
Siemens Westinghouse 220 kW SOFC-Hybridsystem

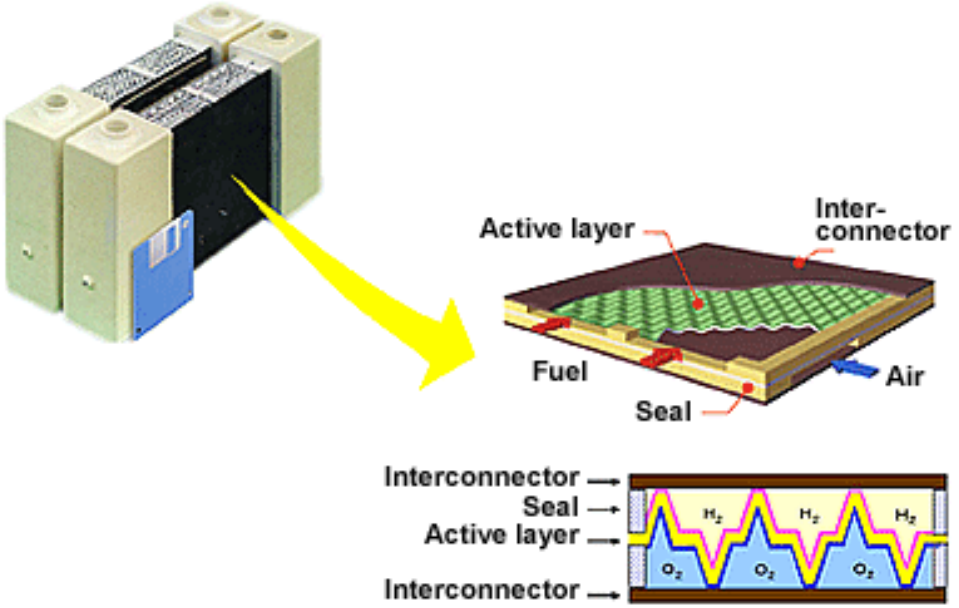
Siemens Westinghouse

Brennstoffzellen-Typ	SOFC
Betriebstemperatur	1000°C
Leistung BSZ	173 kW_{el}
Leistung Mikroturbine	47 kW_{el}
thermische Leistung	65 kW_{th}
Brennstoff	Erdgas
el. Nettowirkungsgrad	55%

Betrieb durch Southern California Edison Co. an der University of California, Irvine.

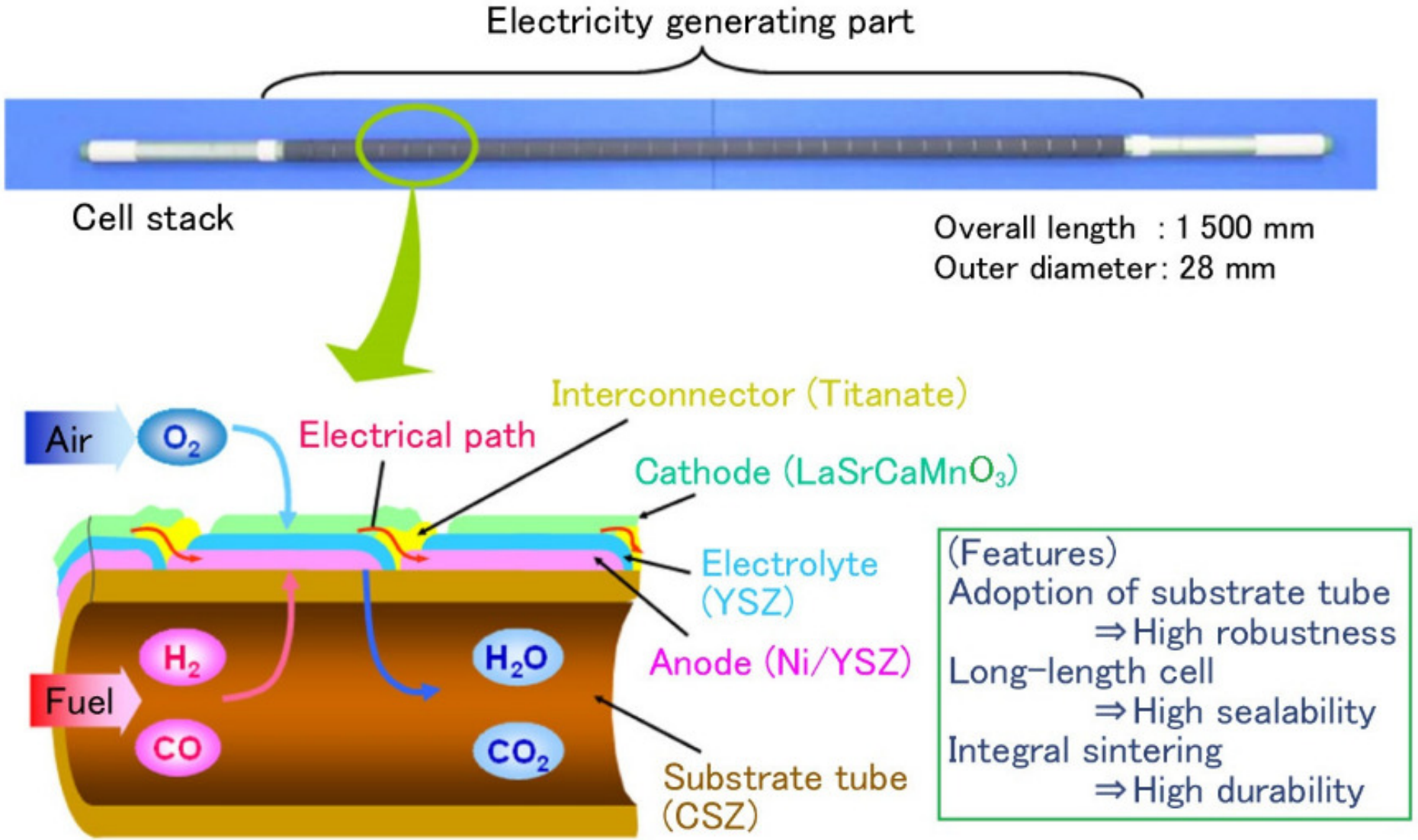
Brennstoffzellensysteme für die dezentrale Energieversorgung
Mitsubishi Heavy Industries - MOLB-Type

- several systems (1 kW ... 1 Stack unit .... 50 kW) under operation/construction
- 10 kW_{el} system operated from July 2000 to Oct. 2001 (total 7500h, 2437h with direct internal reforming), 0,24 W/cm², max power 15 kW_{el}, stack consisting of 10 cells (20x20cm², 1 kWel / Stack), operating temp. 950°C (up to1000°C)
- thermal and load cycling is no problem
- several kW systems operated on desulfurized NG (3-4 ppm), complete internal reforming realized by fuel circulation
- planned multi 10 kW system (3x3x6m³)

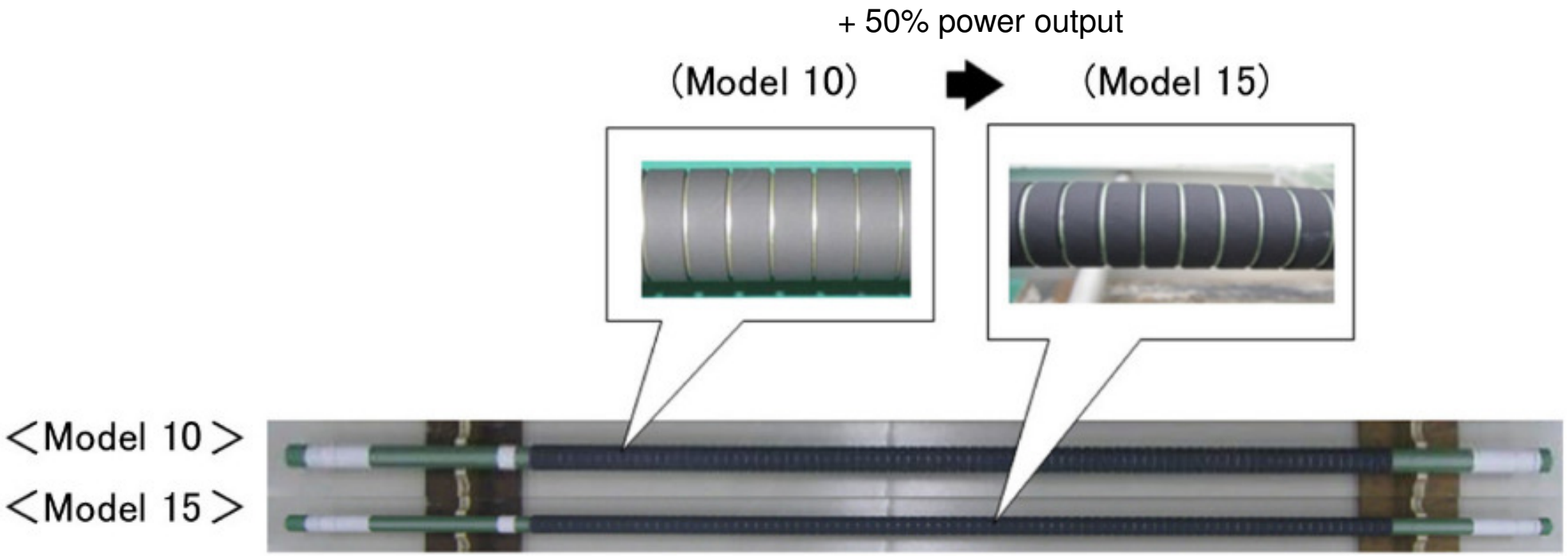


Brennstoffzellensysteme für die dezentrale Energieversorgung
Mitsubishi Heavy Industries - 30 kW Molb-Type SOFC System

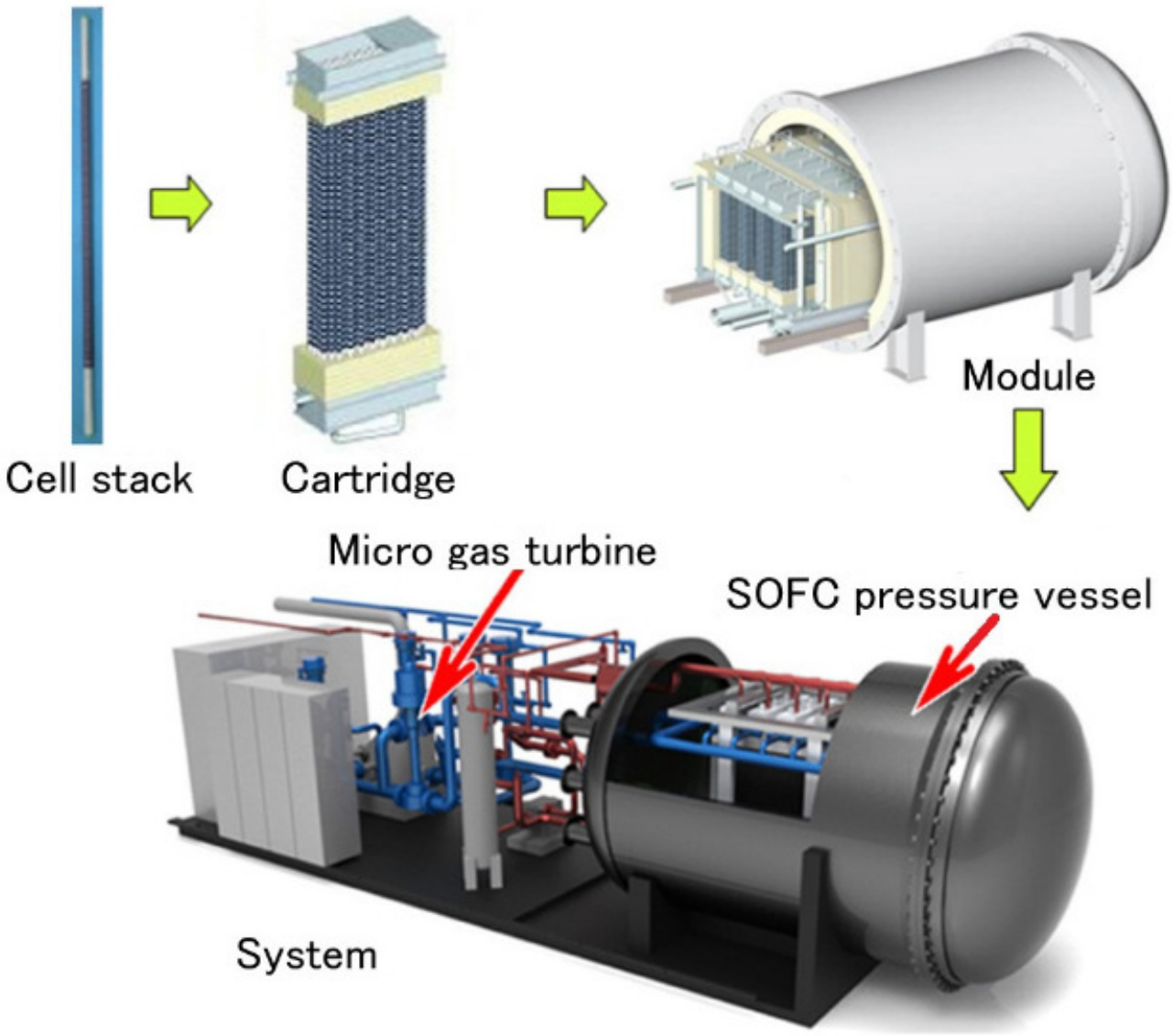
Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC



Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC



Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC

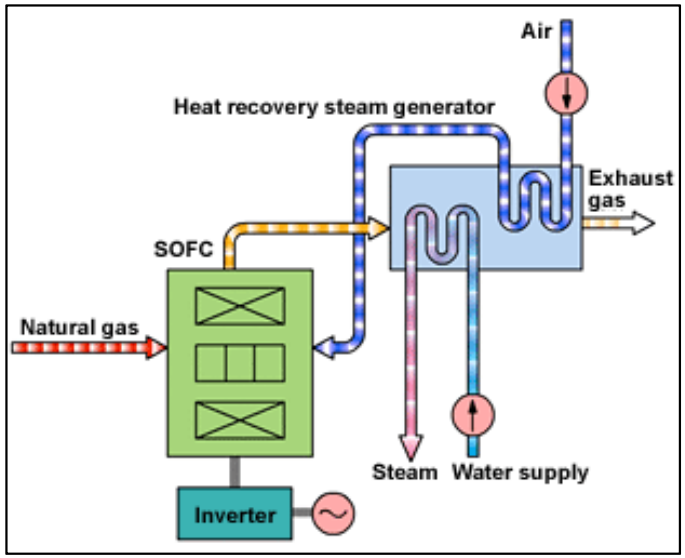


Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC

MHI

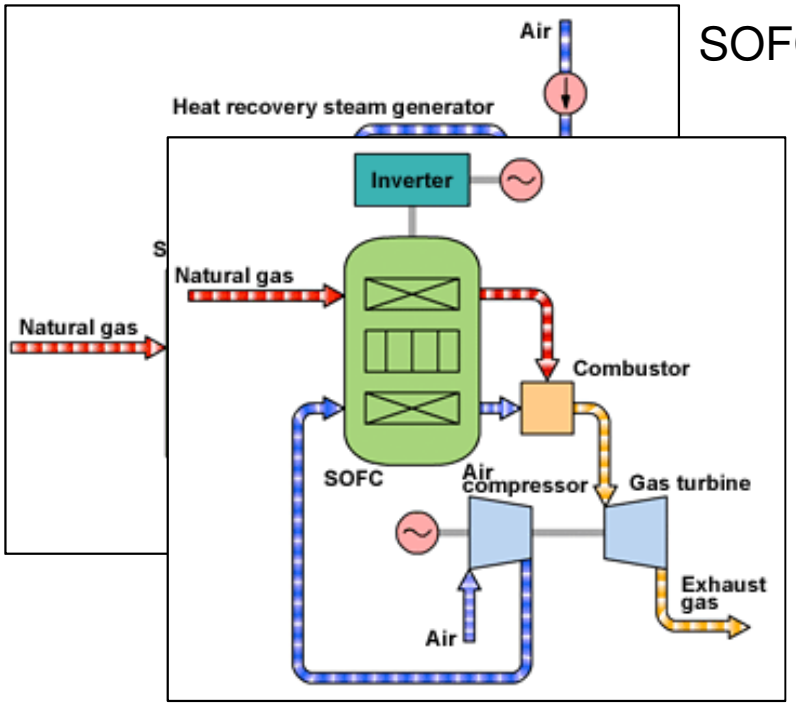
Brennstoffzellen-Typ	SOFC
Betriebstemperatur	>900°C
Leistung	229 kW_{el}
Brennstoff	Erdgas
el. Nettowirkungsgrad	52 %

Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC



SOFC-CHP

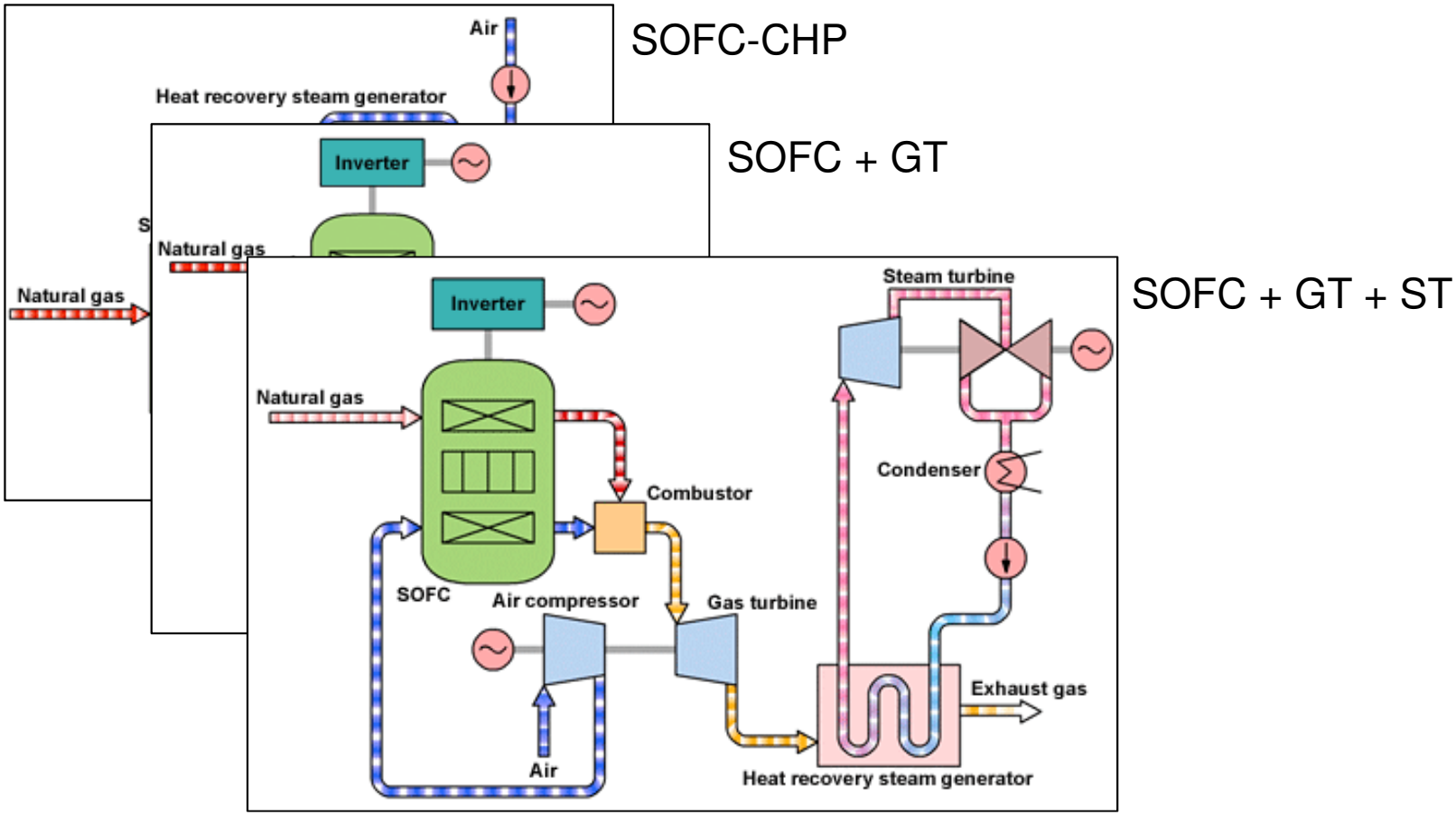
Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC



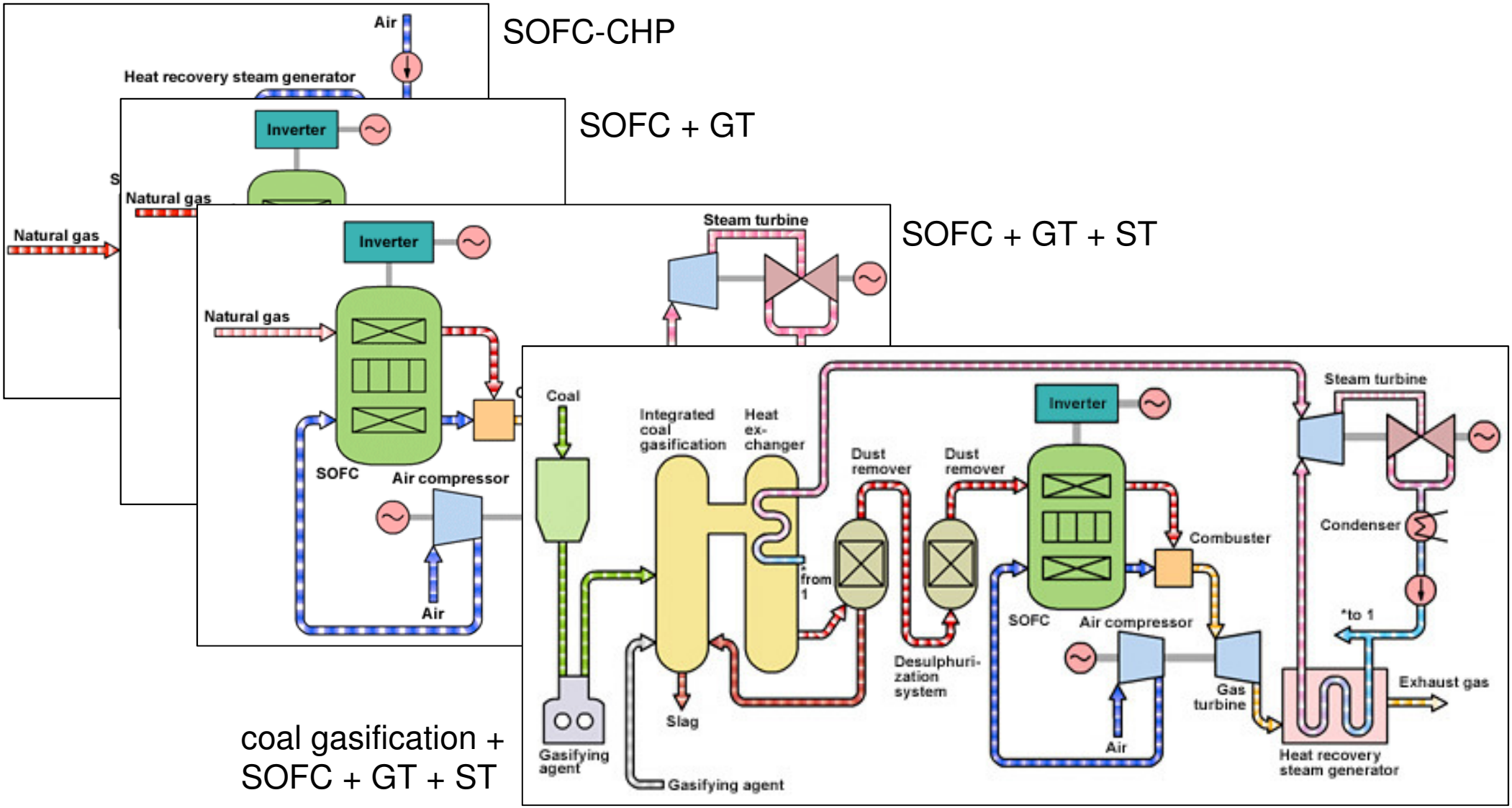
SOFC-CHP

SOFC + GT

Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC



Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries - Tubulare SOFC

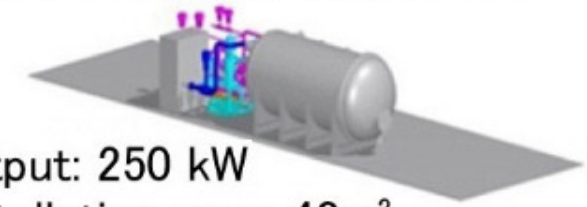


Brennstoffzellensysteme für die stationäre Energieversorgung
Mitsubishi Heavy Industries – aktuelle Systeme

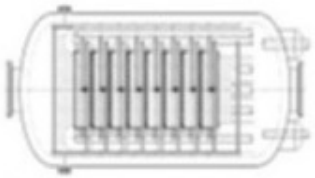
【Module】

【Cartridge /Solidia®】

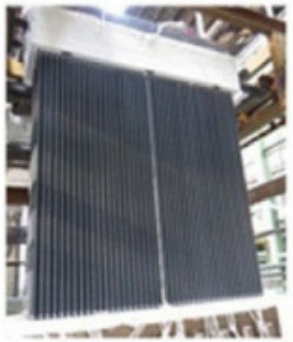
Kyushu University (Model 15)



Output: 250 kW
Installation area: 40m²

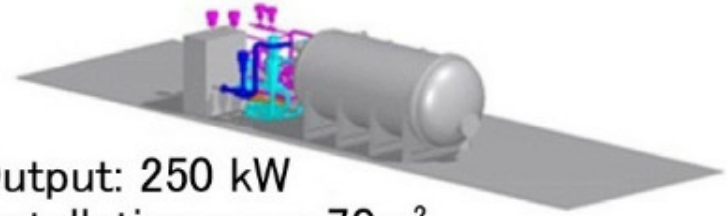


ϕ 2.9m × L 5.0m

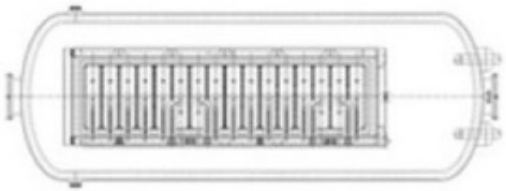


High packing density type
1,800 pcs./m²

Tokyo Gas Co., Ltd. (Model 10)



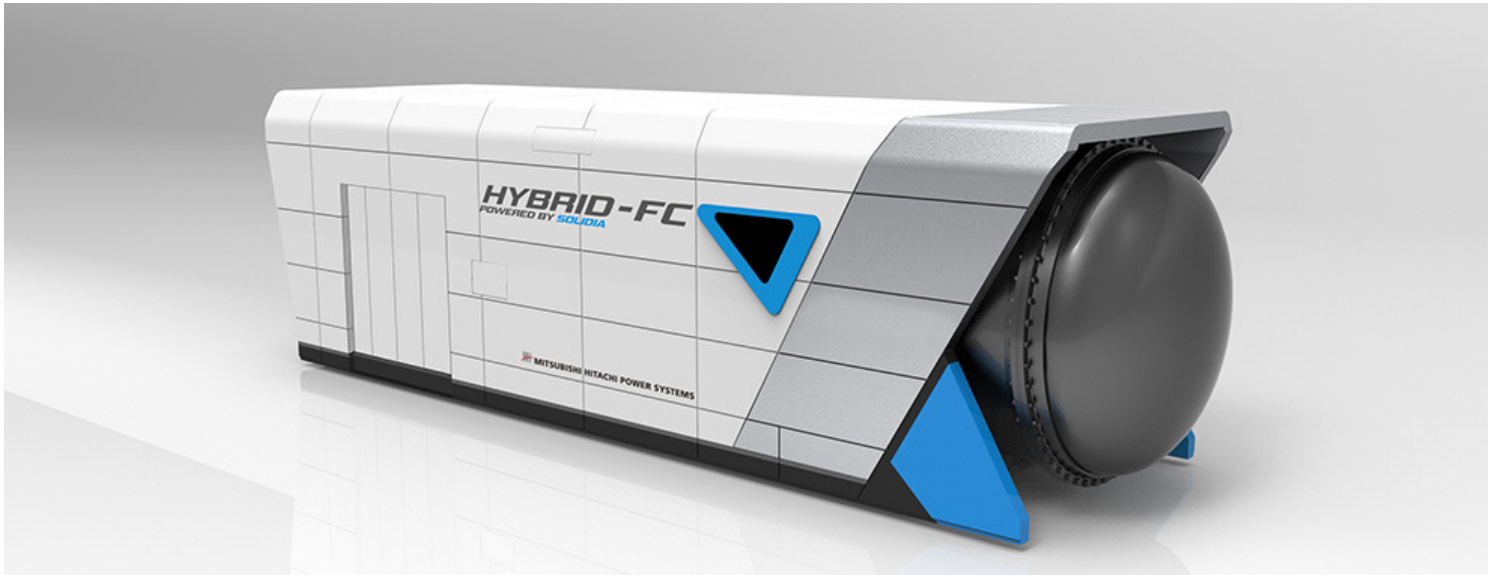
Output: 250 kW
Installation area: 70m²



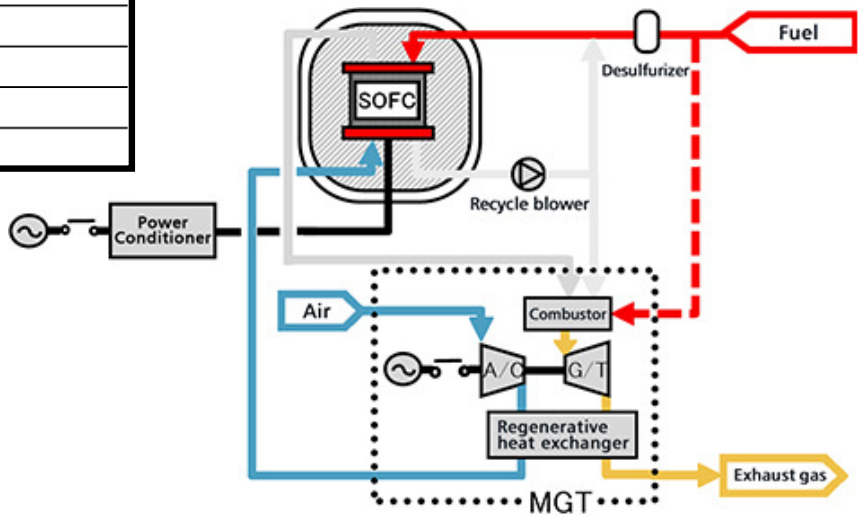
ϕ 2.9m × L 8.0m

Conventional type
800 pcs./m²

Mitsubishi Hitachi Power Systems Hybrid-FC

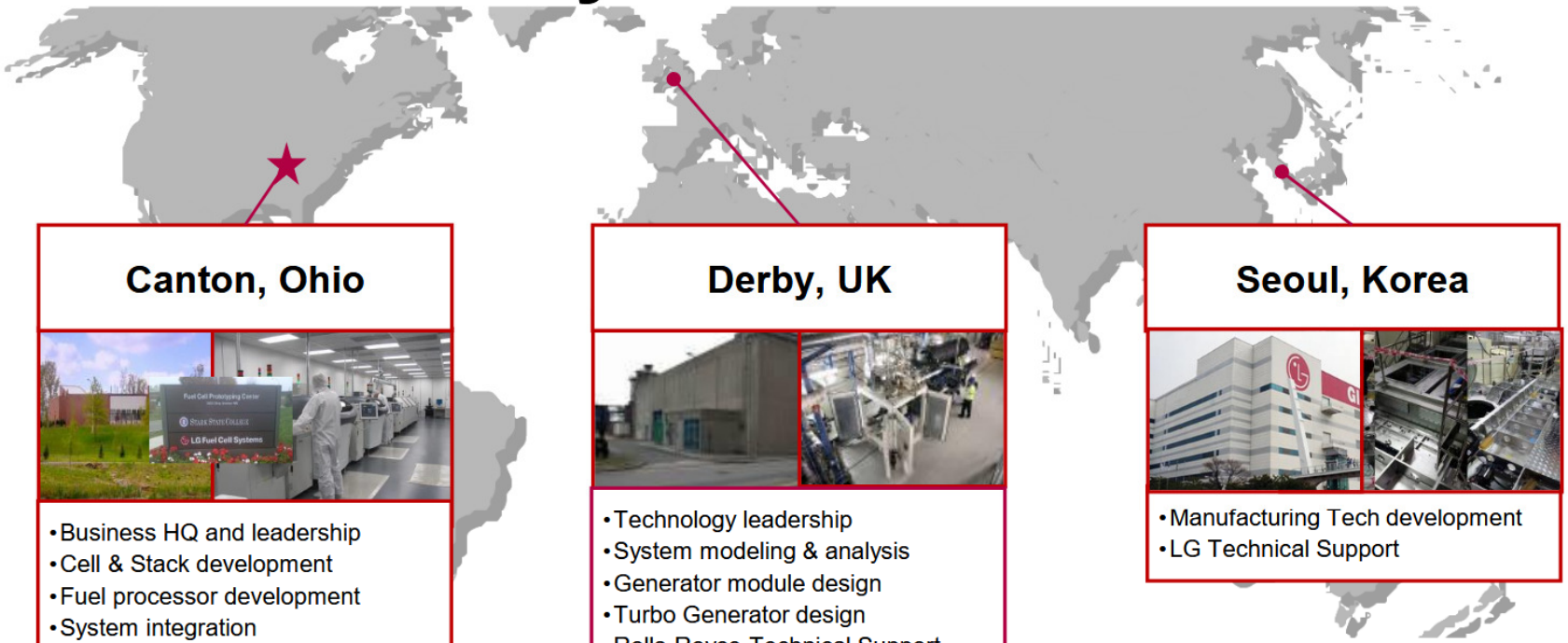


Rated output	(kW)	250
Net efficiency	(%-LHV)	55
Total heat efficiency	(%-LHV)	73 (hot water), 65 (steam)
Dimensions of the unit	(m)	12.0 x 3.2 x 3.2
Operation		For cogeneration



Rolls Royce Fuel Cells Systems

LG Fuel Cell Systems



Canton, Ohio

- Business HQ and leadership
- Cell & Stack development
- Fuel processor development
- System integration
- Control software development
- Prototype Manufacturing & Testing

Derby, UK

- Technology leadership
- System modeling & analysis
- Generator module design
- Turbo Generator design
- Rolls-Royce Technical Support

Seoul, Korea

- Manufacturing Tech development
- LG Technical Support

Foundational Value of LG and Rolls-Royce Joint Venture

Rolls-Royce Fuel Cells
- FC Technology
- Fuel Processing
- System Engineering
- Design & Modeling
- Scaled Testing
- Years of know-how

Rolls-Royce Group
- Turbine & compressor
- Aero-thermal expertise
- High-temp Materials
- Power Electronics
- System Integration

LG Group
- Process Development
- Volume Manufacturing
- Design for Manufacturing
- Supply-Chain Development
- Electronics and Controls

Targeting 1MW Power System

- Nominal 1MW SOFC System scalable from 250 kW to >20 MW
- High availability for base load operation on natural gas

Bloom Energy

	ES-5700	ES-5710
Outputs		
Nameplate power output (net AC)	210 kW	262.5 kW
Base load output (net AC)	200 kW	250 kW
Electrical connection	480 V, 3-phase, 60 Hz	480 V, 3-phase, 60 Hz
Inputs		
Fuels	Natural gas, directed biogas	Natural gas, directed biogas
Input fuel pressure	15 psig	15 psig
Water	None during normal operation	None during normal operation
Efficiency		
Cumulative electrical efficiency (LHV net AC)	52-60%	52-60%
Heat rate (HHV)	6,295-7,264 Btu/kWh	6,295-7,264 Btu/kWh
Emissions		
NOx	< 0.01 lbs/MWh	< 0.01 lbs/MWh
SOx	Negligible	Negligible
CO	< 0.10 lbs/MWh	< 0.10 lbs/MWh
VOCs	< 0.02 lbs/MWh	< 0.02 lbs/MWh
CO2 @ stated efficiency	735-849 lbs/MWh on natural gas; carbon neutral on directed biogas	735-849 lbs/MWh on natural gas; carbon neutral on directed biogas
Physical Attributes and Environment		
Weight	19.4 tons	19.4 tons
Dimensions	26' 5" x 8' 7" x 6' 9"	26' 5" x 8' 7" x 6' 9"
Temperature range	-20° to 45° C	-20° to 45° C
Humidity	0% - 100%	0% - 100%
Seismic vibration	IBC site class D	IBC site class D
Location	Outdoor	
Noise	< 70 dBA @ 6 feet	< 70 dBA @ 6 feet
Codes and Standards		
Complies with Rule 21 interconnection and IEEE1547 standards		
Exempt from CA Air District permitting; meets stringent CARB 2007 emissions standards		
Product listed by Underwriters Laboratories Inc. (UL) to ANSI/CSA America FC 1-2004		
Additional Notes		
Access to a secure website to monitor system performance & environmental benefits		
Remotely managed and monitored by Bloom Energy		
Capable of emergency stop based on input from the site		

Bloom Energy
Update - Technical Data

	Technical Highlights (ES5-FABAAN)	Technical Highlights (ES5-EA2AAN)	Technical Highlights (ES5-YA8AAN)
Outputs			
Nameplate power output (net AC)	200 kW	250 kW	300 kW
Load output (net AC)	200 kW	250 kW	300 kW
Electrical connection	480V, 3-phase, 60 Hz	480V, 3-phase, 60 Hz	480V, 3-phase, 60 Hz
Inputs			
Fuels	Natural gas, directed biogas	Natural gas, directed biogas	Natural gas, directed biogas
Input fuel pressure	10-18 psig (15 psig nominal)	10-18 psig (15 psig nominal)	10-18 psig (15 psig nominal)
Water	None during normal operation	None during normal operation	None during normal operation
Efficiency			
Cumulative electrical efficiency (LHV net AC)[1]	65-53%	65-53%	65-53%
Heat rate (HHV)	5,811-7,127 Btu/kWh	5,811-7,127 Btu/kWh	5,811-7,127 Btu/kWh
Emissions[2]			
NOx	0.0017 lbs/MWh	0.0017 lbs/MWh	0.0017 lbs/MWh
SOx	Negligible	Negligible	Negligible
CO	0.034 lbs/MWh	0.034 lbs/MWh	0.034 lbs/MWh
VOCs	0.0159 lbs/MWh	0.0159 lbs/MWh	0.0159 lbs/MWh
CO_2 @ stated efficiency	679-833 lbs/MWh on natural gas; carbon neutral on directed biogas	679-833 lbs/MWh on natural gas; carbon neutral on directed biogas	679-833 lbs/MWh on natural gas; carbon neutral on directed biogas
Physical Attributes and Environment			
Weight	12.6 tons	13.6 tons	15.8 tons
Dimensions (variable layouts)	14'9" x 8'8" x 7'0" or 25'9" x 4'5" x 7'5"	14'9" x 8'8" x 7'0" or 29'4" x 4'5" x 7'5"	17'11" x 8'8" x 6'9" or 32'3" x 4'4" x 7'2"
Temperature range	-20° to 45° C	-20° to 45° C	-20° to 45° C
Humidity	0% - 100%	0% - 100%	0% - 100%
Seismic vibration	IBC site class D	IBC site class D	IBC site class D
Location	Outdoor	Outdoor	Outdoor
Noise	< 70 dBA @ 6 feet	< 70 dBA @ 6 feet	< 70 dBA @ 6 feet

Bloom Energy

- kleinflächige Zellen, elektrolytgestützt (~ 10 x 10 cm²)
- Stack mit metallischem Interkonnektor
- Verschaltung vieler Stacks im Modul
- Energy Server als kleinste eigenständig funktionierende Einheit
- kundenspezifische Energiesysteme bestehend aus mehreren Energy Servern

Ausblick

- BSZ-Systeme
  - µCHP-Systeme
    - PEMFC
    - SOFC
  - mobile Anwendungen
    - mobile Stromversorgung
    - Auxiliary Power Units
  - Brennstoffzellen in der Elektromobilität