Brennstoffzellen-Systeme – von der Forschung zur Kommerzialisierung: Integration – Simulation – Testen

IEA Workshop Brennstoffzellen: Markteinführung, Markthemmnnisse und F&E-Schwerpunkte

27. Februar 2014, Graz

Peter Prenninger

AVL List GmbH
SOFC TECHNOLOGY – EFFICIENCY ENABLER

Efficiency

50 %

30 %

5-10 kW  100-500 kW  1-5 MW

Power Range

SOFC Technology

ICE Technology

SOFC & GT Technology

High efficient fuel gas generation from NG, methanol, Diesel and all Biofuels (80-99%)

High efficient energy conversion in SOFC (>50%)

Best suited for combined SOFC-GT cycles
Challenges in:

• Systems Engineering

• Virtual System Development

• Component Analysis and Optimization

• System Integration

• Validation and Commercialization
Portable power out of diesel fuel without noise and emissions!

Other markets:
- Military
- Marine
- Camping

Design Targets:
- 3kW electrical power
- 10kW thermal power
- el. efficiency ~35%
- Fuel: road diesel (< 15 ppm S)
- 80L, 75kg
- ~ 55dB(A) noise
- 8000h lifetime
- 300/3000 cold/warm cycles
PRODUCT REQUIREMENTS – SIMULATION SUPPORT

Load Cycle - Fuel Cell Power

- Blue line: Load Cycle
- Green line: APU Power
- Red line: SOC

El. Power [kW] vs. Time [h]
CUSTOMER AND MARKET ASPECTS

• Idling Time per Week: 30, 40, 50 & 57.83 h
• Diesel price: 3.9 – 5.0 $/gal (3.9 $/gal = 0.79 €/l)
• Fuel Consumption (Idling):
  o Truck: 0.75 gal/h (2.84 l/h) measured, improved map
  o ICE APU: expected efficiency 2016
  o SOFC APU: 
• Sales price SOFC APU: 12.000 $ (9.230 €)
• Sales price ICE APU: 10.000 $ (7.700 €)
Comparison **Truck Idling vs. SOFC APU**

**Pay back period**

- 3.9 $: 1.62 years
- 4.25 $: 1.50 years
- 4.5 $: 1.41 years
- 5 $: 1.27 years

![Bar chart showing payback periods for different diesel prices]
Challenges in:

• **Systems Engineering**
  - Very mature rivals (costs, reliability…)
  - Extremely high customer expectations
  - Fairly unknown load cycles – no field experience
Challenges in:

• Systems Engineering
• **Virtual System Development**
• Component Analysis and Optimization
• System Integration
• Validation and Commercialization
VIRTUAL SYSTEM LAYOUT

- Air supply and filter
- Vehicle cooling circuit
- Power electronics, Batteries
- ICE…Internal Combustion Engine
- TC…Turbocharger
- Air conditioning circuit
- ICE exhaust from TC
Specifications:
- 3kW electrical power
- 10kW thermal power
- el. efficiency >35%
- Fuel: road Diesel (max 15ppm sulfur)
- 80L/70kg
- < 55dB(A) noise

Technology:
- Solid Oxide Fuel Cell
- metal-supported stacks
- anode recirculation
- auto thermal reforming
- highly efficient radial-blowers for media supply
- system internal regeneration approaches
Challenges in:

• **Virtual System Development**
  ➢ Systems engineering approach needed
  ➢ System integration aspects
  ➢ Model development based on „unknowns“
Challenges in:

- Systems Engineering
- Virtual System Development
- Component Analysis and Optimization
- System Integration
- Validation and Commercialization
Detailed investigation of performance of critical components by means of numerical simulation – boundary condition for linked components (e.g. insulation, air management, control functions …)
Solid oxide fuel cell domains with transport across domain interfaces and reactions

Requested results:

- Electronic ($e^-$) potential in electrodes and interconnect
- Ionic ($O^{2-}$) potential in electrolyte
- Electrochemical reaction rates at TPB, chemical reaction rates in anode domain
- Velocity, pressure and species mass fractions in channels and electrodes
- Temperature in all domains
COMPONENTS & SUB-SYSTEMS

Model validation
Comparison to experimental results
CFD mesh: 1.3 mio. cells
Active area: 127 cm²
COMPONENTS & SUB-SYSTEMS

Model validation

Test cell: voltage and power density vs. current density, fitted result

COMPONENTS & SUB-SYSTEMS

Model validation
Temperature (K) of cathode interconnect

Var.2 ($\lambda = 1.25$)  Ref. ($\lambda = 1.333$)  Var.1 ($\lambda = 1.667$)
COMPONENTS & SUB-SYSTEMS

Very focused development of particular „key enabling“ technologies & components ➔ Air and Gas Management

AVL Schrick FC Blowers

Ultra Low Sulfur Diesel

Anode Blower

Reformer

Burner

SOFC - STACK

Cathode

Air Compressor

P_{EL}
• 1 kW SOFC APU Proof-of-concept
• SOFC stack from research partner
• High dynamics in „self-sustained“ mode
• Control concept for transient mode incl. AVL stack-monitoring technique „AVL-THDA“
• System efficiency > 35%
• Successful full hot box system integration
Challenges in:

- **Component Analysis and Optimization**
  - Availability of high quality tools
  - Non-existing development environment
  - Very little know how on supplier level
  - Premature components & subsystems
Challenges in:

- Systems Engineering
- Virtual System Development
- Component Analysis and Optimization
- **System Integration**
- Validation and Commercialization
TEST ENVIRONMENT FOR SYSTEM INTEGRATION
TEST ENVIRONMENT FOR SYSTEM INTEGRATION

- Test of single components, subsystems, stacks at operating temperature and complete systems on 1D & 2D vibration test rigs
- Random noise tests
- Frequency sweep tests
- Test of bad-road truck vibration profiles

Christoph Kügele, Tomas Dehne
Experimental results 1 stack systems:

- ~2.2kW gross power output
- ~1.8kW net power output
- 29% electrical efficiency
- start up time ~1h
- operation completely without lab infrastructure (inert gas,…)
- very reasonable degradation
- ~2000h of operation with Gen 0 (stopped) and with Gen I
- 50 cold starts / 100 warm starts
- <55dB(A) noise level
CONTINUOUS SYSTEM IMPROVEMENT

AVL APU Generations

Gen. 1.0
Sep. 2011
first AVL System with full functionality

Gen. 1.1
first vehicle integration

Gen. 2
May 2013
2 stack design -25% in size

nominated for Austrian national prize 2013
Challenges in:

• **System Integration**
  
  - Simultaneous establishment of test infrastructure
  
  - Parallel basic research and continuous improvement
  
  - System development based on premature components
Challenges in:

• Systems Engineering
• Virtual System Development
• Component Analysis and Optimization
• System Integration

• Validation and Commercialization
ADDITIONAL MARKET OPPORTUNITIES

Synergies SOFC CHP System (Components, Control ...)

Front

![Diagram of SOFC CHP System with dimensions: 1930 x 600 x 900]

BoP
SUPPORT OF COMMERCIALIZATION

Assumptions for System OEM/Tier 1

Invest:

- Series development, validation, certification: 15.6 Mio $
- Build up manufacturing line: 2.6 Mio $
- Sales Price: 12,000 $
- Sales Volume (3 Scenarios):

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SUPPORT OF COMMERCIALIZATION

Assumptions

Production Cost incl. licence fee, sales & admin. overhead

3 Scenarios:

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![Diagram showing Production Cost over years for low, average, and high scenarios]
SUPPORT OF COMMERCIALIZATION

OEM/Tier 1 Scenarios

Break Even vs. Production cost / Sales scenarios
Challenges in:

• **Validation and Commercialization**
  
  ➢ High market inertia – low early market volume
  
  ➢ High dependence on „outer boundary conditions“ (legislation, energy prize, …)
  
  ➢ OEM expectation: „mature“ prototypes – RoI as „conventional“ products
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