Scenarios towards the Industrialization of SOFC APUs

A3PS Conference 2013
October 3. – 4., 2013, Vienna

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AVL List GmbH
AVL SOFC APU (Auxiliary Power Unit)

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
Overview 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

first vehicle integration
Achieved Test Results with Gen I

With 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
AVL APU Gen I – 1 Stack System

- with 1 stack system 2.2/1.8kW achieved, ~2.5/2.2kW possible
- AVL APU system designed for 3kW, might reach above 4kW of electr. power
### Status and Outlook

<table>
<thead>
<tr>
<th>Demonstrated</th>
<th>Target</th>
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<tbody>
<tr>
<td></td>
<td>Gen I.I</td>
</tr>
<tr>
<td><strong>Rated el. Power:</strong></td>
<td>2kW</td>
</tr>
<tr>
<td><strong>max. el. Power:</strong></td>
<td>2kW</td>
</tr>
<tr>
<td><strong>Electrical Efficiency¹:</strong></td>
<td>30%</td>
</tr>
<tr>
<td><strong>Thermal Power:</strong></td>
<td>12kW</td>
</tr>
<tr>
<td><strong>Fuel Consumption¹:</strong></td>
<td>0.7l/h</td>
</tr>
<tr>
<td><strong>Packaging Space:</strong></td>
<td>750x420x420mm</td>
</tr>
<tr>
<td><strong>Weight:</strong></td>
<td>90kg</td>
</tr>
<tr>
<td><strong>Noise level:</strong></td>
<td>55dB(A)</td>
</tr>
<tr>
<td><strong>Start up time³:</strong></td>
<td>40min/60min</td>
</tr>
<tr>
<td><strong>Lifetime:</strong></td>
<td>2000h</td>
</tr>
<tr>
<td><strong>Thermal Cycles²:</strong></td>
<td>100/300</td>
</tr>
</tbody>
</table>

1...at rated power
2...cold/warm
3...stack level/system level

**First 2 Gen II are in operation since mid of June 2013!**
BUSINESS CASE:

END USER
(TRUCK OWNER, FLEET OPERATOR)
Assumptions – Reference Scenario
Status April 2013

• 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)
  o ICE APU: measured, improved map
  o SOFC APU: expected efficiency 2016

• Sales price SOFC APU 12.000 $ (9.230 €)
• Sales price ICE APU 10.000 $ (7.700 €)
APU Simulation – Reference Scenario (Batt 280 Ah)
Sensitivity Analyses Fuel Price

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
Sensitivity Analyses Fuel Price

Comparison ICE APU vs. SOFC APU

Pay back period

- 3.9 $: 1.63 years
- 4.25 $: 1.52 years
- 4.5 $: 1.43 years
- 5 $: 1.29 years
Idling Time Variation

58 h

50 h

40 h

30 h

2750 h/a

2400 h/a

1900 h/a

1450 h/a
**Sensitivity Analyses Idling Time**

Comparison **Truck Idling vs. SOFC APU**

**Pay back period:**

- 57.83 h: 1.62 years
- 50 h: 1.86 years
- 40 h: 2.20 years
- 30 h: 2.95 years

![Chart showing idling time and payback period](chart.png)
Sensitivity Analyses Idling Time

Comparison **ICE APU vs. SOFC APU**

**Pay back period:**
- 57.83 h: 1.62 years
- 50 h: 2.01 years
- 40 h: 2.07 years
- 30 h: 2.64 years
Sensitivity Analyses Hotel/Motel

Comparison Hotel/Motel vs. SOFC APU

Pay back period 4 nights:
- 30 $: 2.45 years
- 40 $: 1.72 years
- 50 $: 1.32 years
- 60 $: 1.07 years

Pay back period 5 nights:
- 30 $: 1.87 years
- 40 $: 1.33 years
- 50 $: 1.03 years
- 60 $: 0.84 years
BUSINESS CASE:

APU OEM
(E.G. TIER 1 SUPPLIER)
Assumptions

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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<tbody>
<tr>
<td>1</td>
<td>3.000</td>
<td>5.000</td>
<td>8.000</td>
</tr>
<tr>
<td>2</td>
<td>3.500</td>
<td>7.000</td>
<td>15.000</td>
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<tr>
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<td>11.000</td>
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<td>5</td>
<td>8.500</td>
<td>19.000</td>
<td>22.000</td>
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<tr>
<td>6</td>
<td>10.000</td>
<td>20.000</td>
<td>22.000</td>
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Assumptions

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

3 Scenarios:

<table>
<thead>
<tr>
<th>Year</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>8.190$</td>
<td>9.100$</td>
<td>10.010$</td>
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<tr>
<td>2</td>
<td>7.605$</td>
<td>8.450$</td>
<td>9.295$</td>
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<td>3</td>
<td>7.020$</td>
<td>7.800$</td>
<td>8.580$</td>
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<tr>
<td>4</td>
<td>6.727$</td>
<td>7.475$</td>
<td>8.223$</td>
</tr>
<tr>
<td>5</td>
<td>6.482$</td>
<td>7.202$</td>
<td>7.922$</td>
</tr>
<tr>
<td>6</td>
<td>6.482$</td>
<td>7.202$</td>
<td>7.922$</td>
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</tbody>
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OEM Scenarios

Break Even vs. Production cost / Sales scenarios

![Graph showing Break Even scenarios for Aggressive, Balanced, and Conservative scenarios with Low, Average, and High Production Costs.](image-url)
... some Conclusions:

- Very positive business case, pay back periods between 1-2 years (under certain boundary conditions) for the end-user and the system manufacturer.
- Very big interest from Truck OEMs (especially from 2 US companies), interest from potential system OEMs, but no major (financial) commitment at the moment.
- Major fleet operators will decide about the success of this technology and not the truck OEMs!
- Due to expected EPA ban of idling (5min regulation) an increase of idling equipment market (volume) is expected (extension to class 5-7 vehicles).
- CO₂ credit system is a very important driver for anti-idling technology!
- already today 5min engine shut-down implementation by truck OEM creates CO₂ credits.
- Business case study is without other markets like military and maritime with volumes up to 20,000-40,000 units/a (global).
- Within the last year some interest of European OEMs in APUs primary for „night logistics“
Summary

- Impressive technical progress within the last year (operation on ULSD, 30% efficiency, size, mechanical stability, vehicle integration, system test times, …)

- On the truck side next steps vehicle demonstrations to raise awareness and interest from decision makers in OEMs and big fleet operators.

- Biggest 2 hurdles for faster progress at the moment:
  - Massive supply chain problems
  - High stack costs
Scenarios towards the Industrialization of SOFC APUs

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Acknowledgement:

The results presented are based on research projects funded by the Austrian Ministry of Transport, Innovation and Technology (a3/a3plus-Projects SOFC APU I & II and ASys1) as well as the European Union FP7 (DESTA).