Solid Oxide Fuel Cells for distributed energy applications

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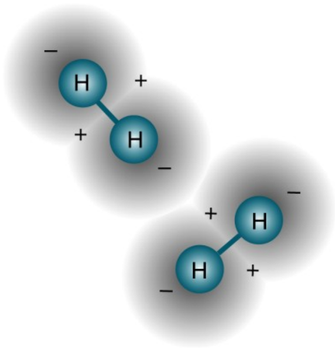
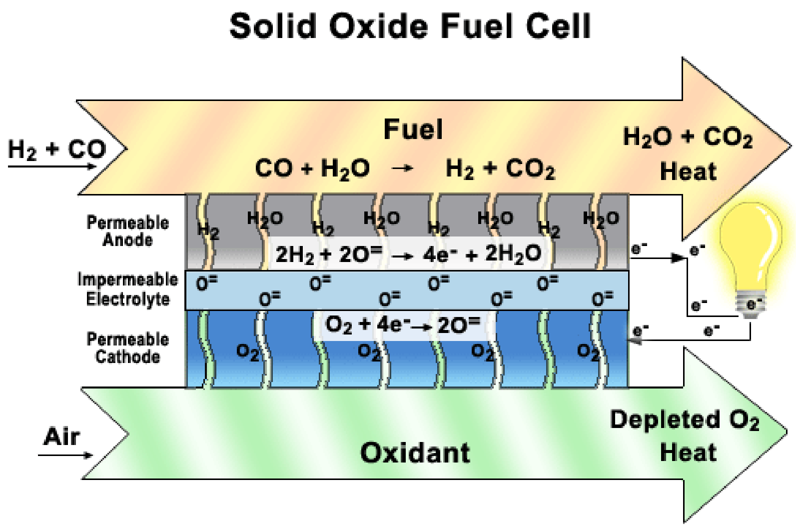
Presentation plan

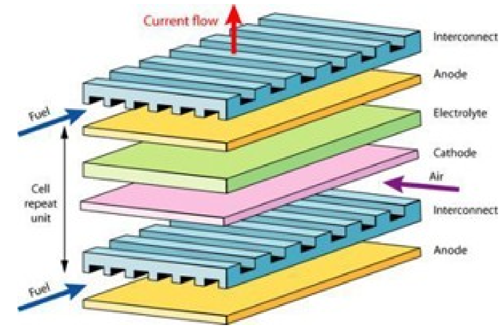
- Introduction to fuel cell technology
- Fuel considerations
- Available systems
- Perspectives
- Summary

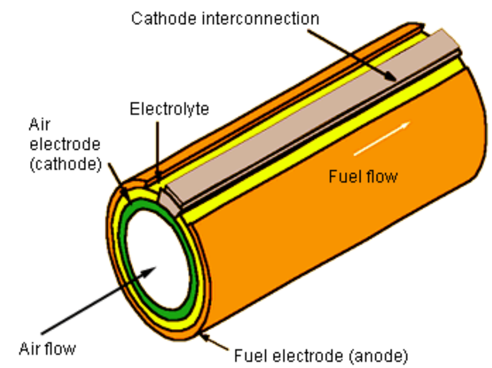


Solid Oxide Fuel Cell

- Fuel cell – ceramic device



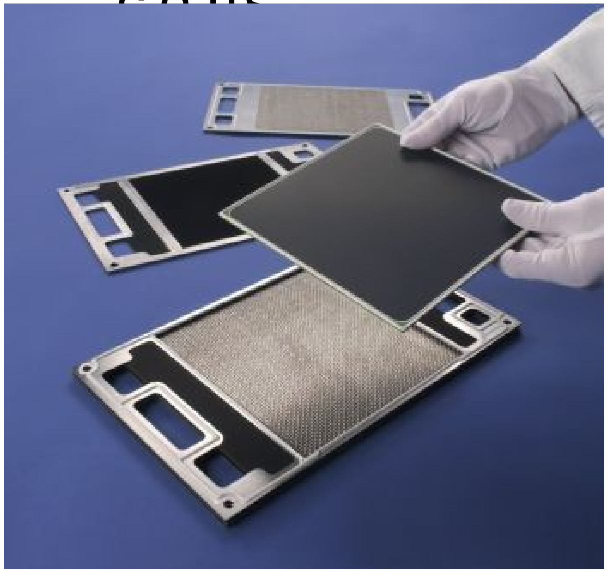




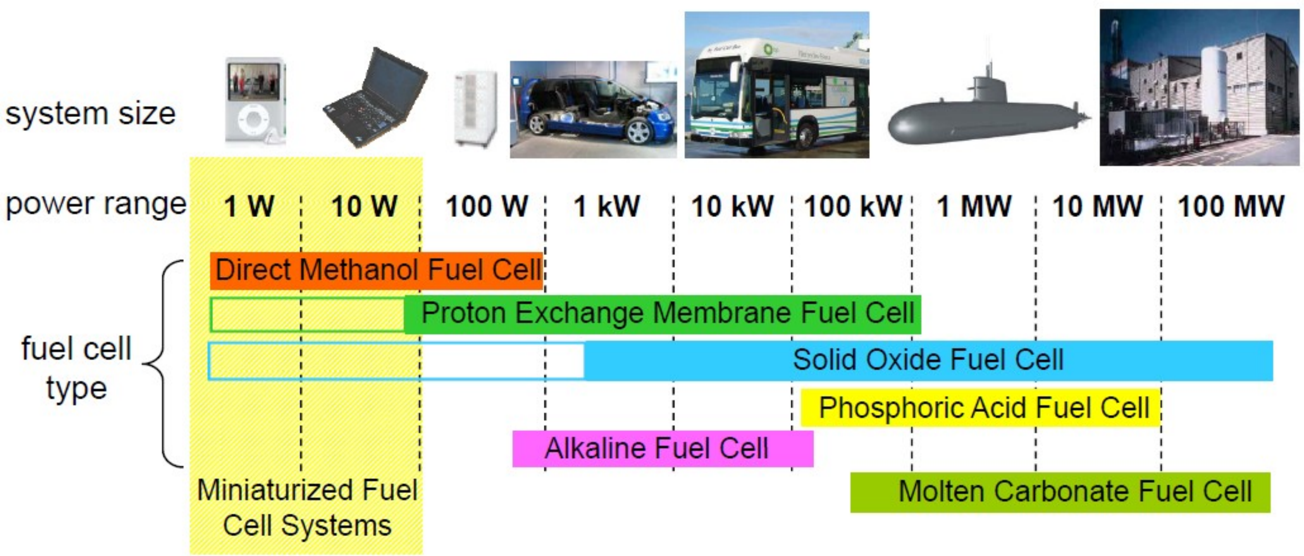
- Working temperature: 600°C –1000°C

Single cell and SOFC stack

- Stack is composed from many cennected cells



Power flexibility

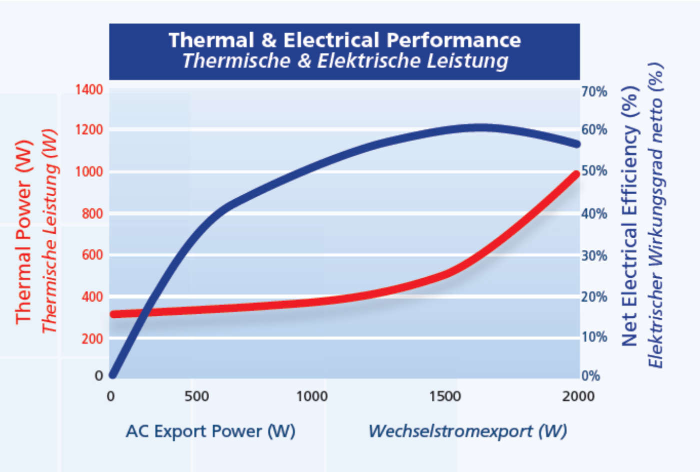


Efficiency issues

Specifications
Model Number: BlueGen
Performance
Electric Output: 0 to 2,000 W Power output modulation from 0 % to 100 %
Max. Electrical Efficiency: 60 % at 1,500 W output (Net AC export LHV)
Note: Thermal output and water recovery only possible with heat recovery system connected
Thermal Output: Approx. 300 W to 1,000 W Depending on electric power output and heat recovery water temperature (exhaust gas cooled to 30 °C)
Total System Efficiency: Up to 85 % (depending on heat and condensate recovered)

- High electrical efficiency
  - Not limited by the Carnot theorem
- Potential to recirculate anode exhaust gas and use waste heat

Fuel	Electrical Efficiency (%) LHV, net	Total Efficiency (%) (90 °C)
Natural Gas	55	84
Biogas with 50% CO_2	54	80
Methanol	53	85
DME	53	83
Ammonia	55	84
Diesel CPO (5 kW)	41	85



Fuel consideration

- Typical fuel: H_2
- Other fuels: CH_4, CNG, LPG, diesel, ...
  - Possible to use external reforming of hydrocarbon fuels – not efficient !!!
- <u>High working temperature allows internal reforming</u>

$$CH_4 \rightarrow C + 2H_2$$

$$C_nH_{2n+2} \rightarrow nC + (n+1)H_2$$

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$C_nH_{2n+2} + nH_2O \rightarrow nCO + (2n+1)H_2$$

$$H_2 + O^{2-} \rightarrow H_2O + 2e^-$$

$$CO + O^{2-} \rightarrow CO_2 + 2e^-$$

Internal reforming capability

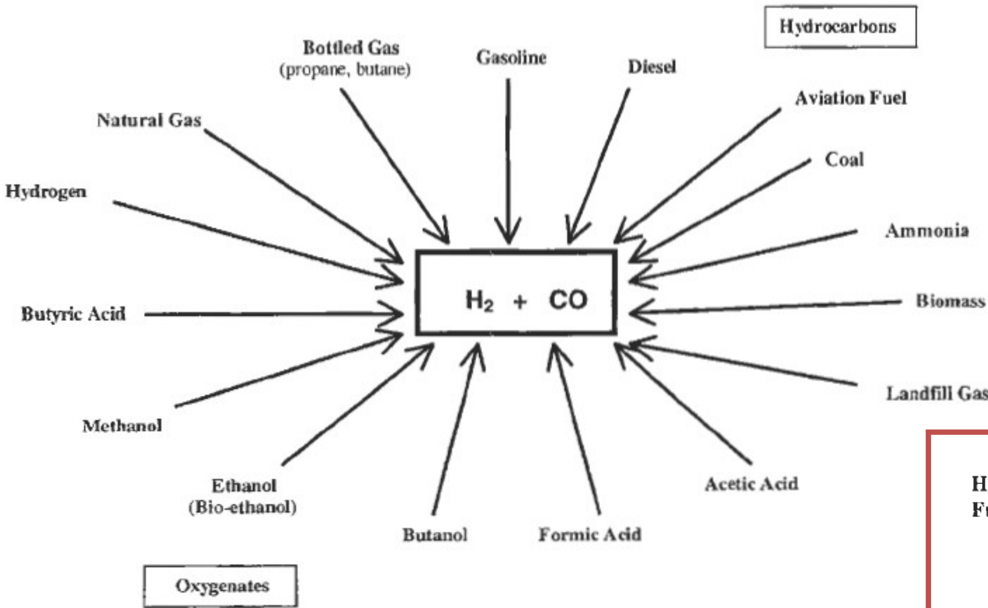


Figure 12.4 Range of potential practical fuels for SOFCs.

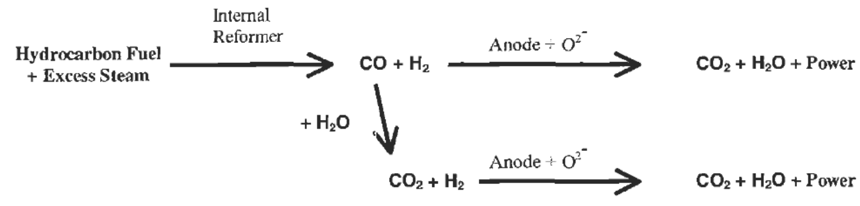


Figure 12.10 Schematic of reaction processes in an SOFC with indirect internal reforming.

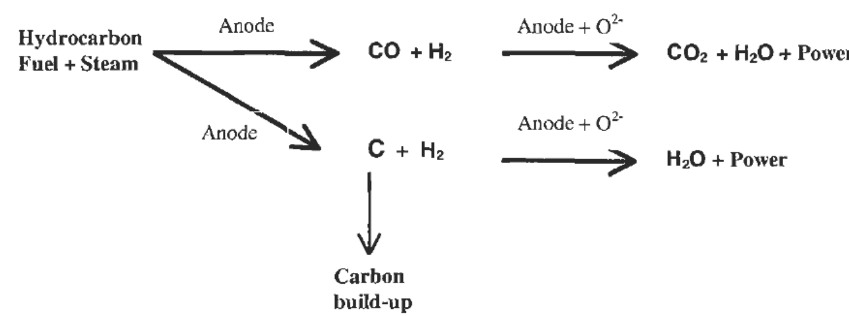
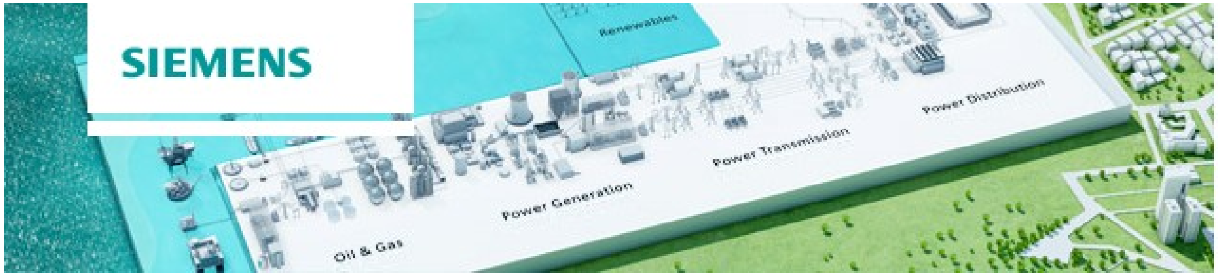


Figure 12.9 Possible reaction pathways in a directly reforming SOFC.



Next Generation SOFC

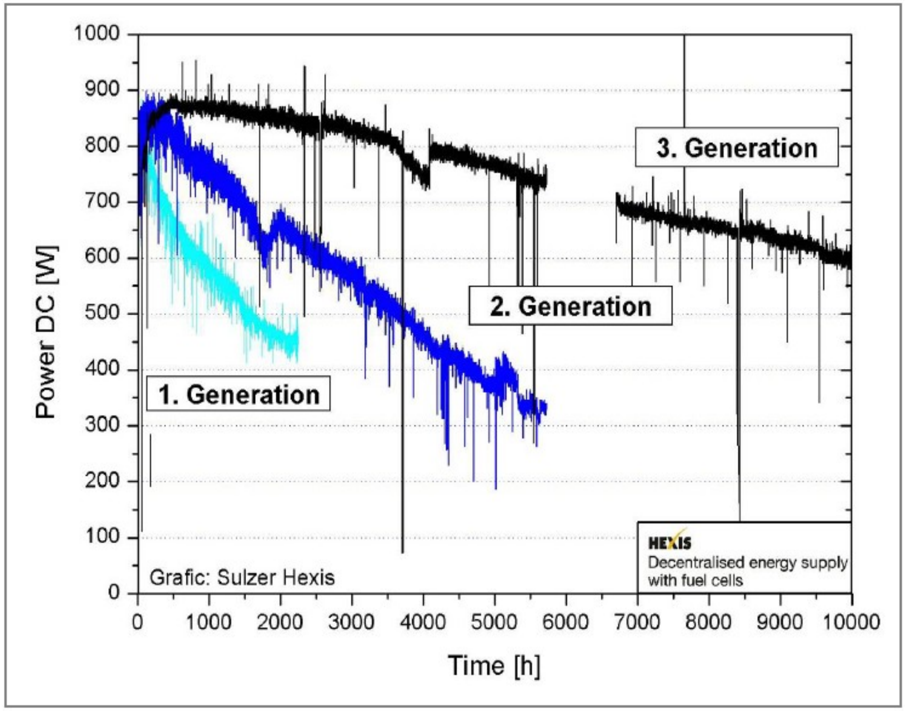
Developed over 25 fully integrated SOFC power generating systems, including the world's first pressurized hybrid demonstration unit

Hexis

HEXIS

- Example of continuous development

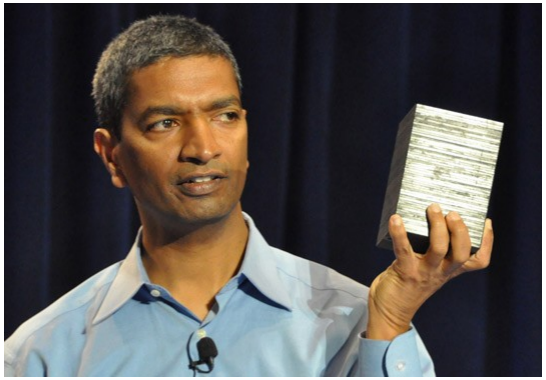
HEXIS: Comparison of Stack Generations



EWR
EWE
EnBW Die Energie-AG
e-on Energie
Thyssengas
Angenehm, Verbundnetz Gas AG
RWE Fuel Cells

Bloomenergy

Bloom Box

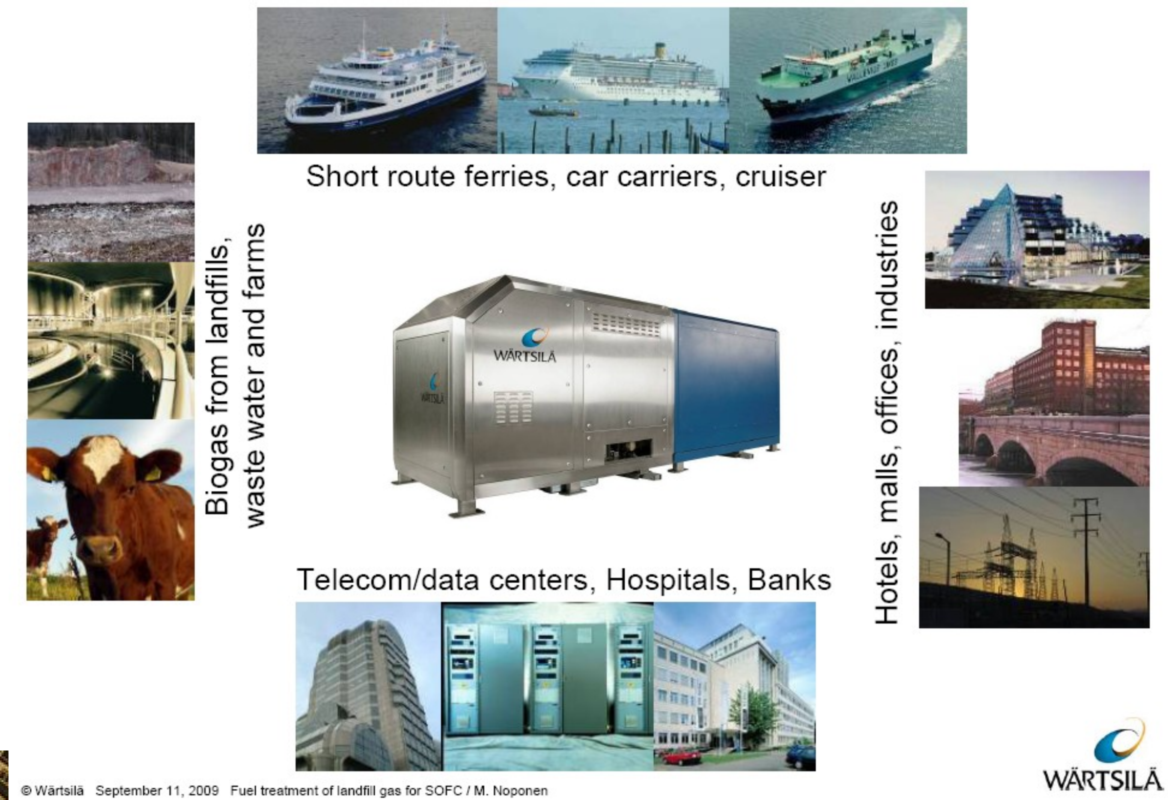


- February 2010
- 100 kWe modules („Energy Savers”)
- 8 years of R&D – 400 mln $

Google
STAPLES
ebay
Walmart
COX ENTERPRISES
FedEx Express
Bank of America
The Coca-Cola Company
The University of Tennessee SimCenter

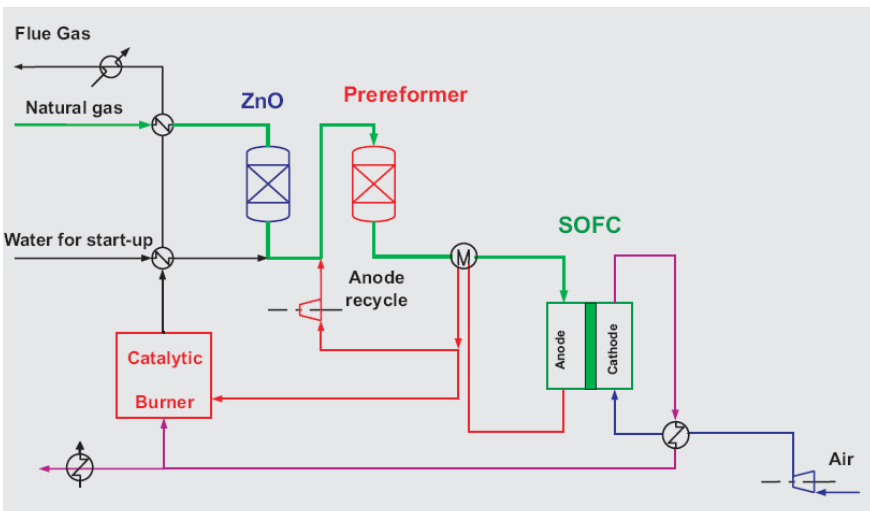
Wartsila SOFC unit

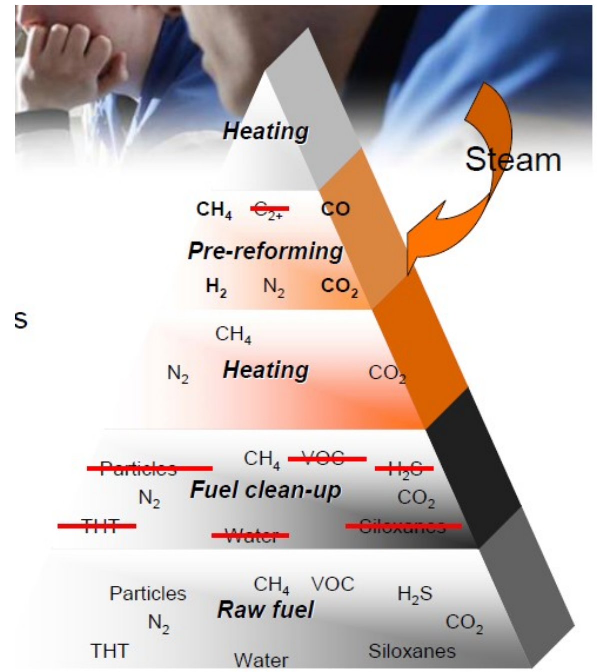
Target of the Wärtsilä fuel cell R&D program is to develop and commercialize SOFC based power units for distributed power generation and for marine auxiliary power



Wartsila SOFC unit

Wärtsilä to deliver the world's first SOFC fuel cell power plant using landfill gas to the Vaasa Housing Fair site





Sulphide poisoning

- Most important issue is posioning by H_2S compounds, levels of ~1 ppm can degrade fuel cell performance rapidly… (but often reversibly)

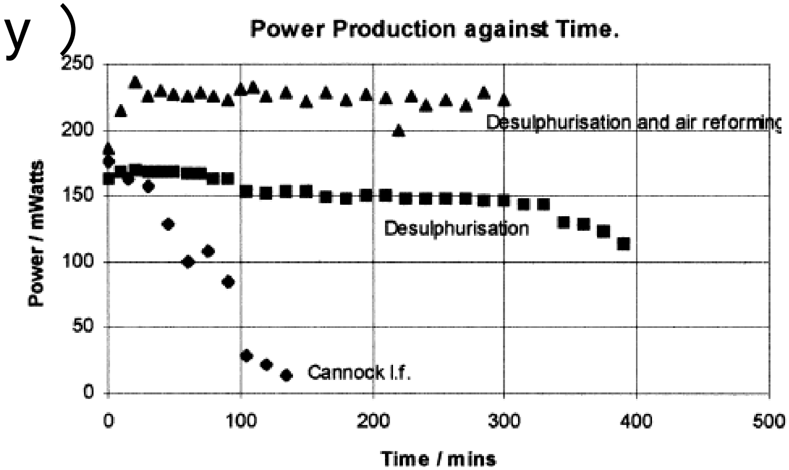
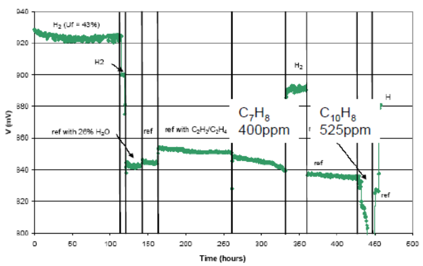


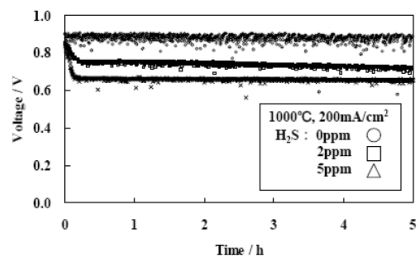
Fig. 4. Desulphurisation and air reforming of Cannock landfill gas.

Nitrogen	18%
Methane	56%
Carbon dioxide	26%
Hydrogen sulphide	< 1%

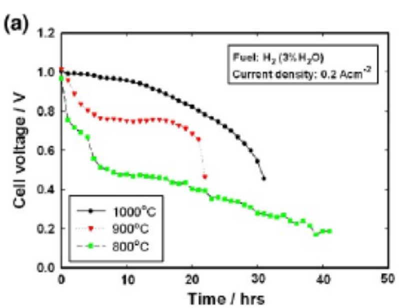
Wartsila SOFC unit



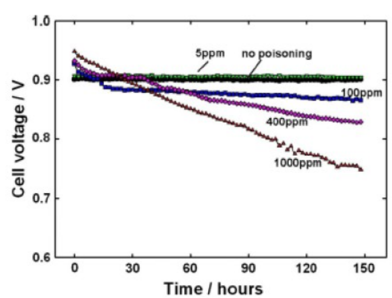
Effect of VOC on SOFC performance (750 °C)



Effect of H_2S on SOFC performance (800 °C)



Effect of siloxane D5 (10 ppm) on SOFC performance



Effect of Cl_2 on SOFC performance (800 °C)

Impurities after cleaning

Components	Landfill gas	After cleaning (new)
Siloxanes TMS MOH L2 L3 L4 D3 D4 D5	~150 ppm	Below detection limit < 1 ppm
VOC Benzene Toluene Ethylbezene Xylene	~100 ppm	~0.1 ppm
Sulfur H_2S DMS Ethyl mercaptan	~20 ppm	Below detection limit < 1 ppm
Halogen hydrocarbons R11 R12 Chlorine/Fluorine-compounds	~100 ppb	Below detection limit < 10 ppb
Particles Na Al Si K Ca Mg Fe Cl Au S Cr…	< ppb	<< ppb
Oxygen	~ 0.1 %	~ 0.1 %

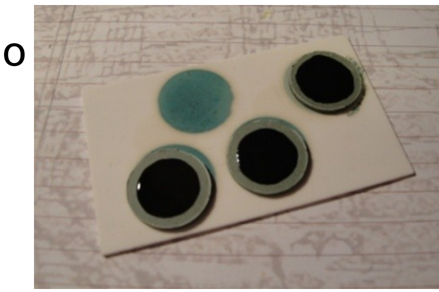
Perspectives

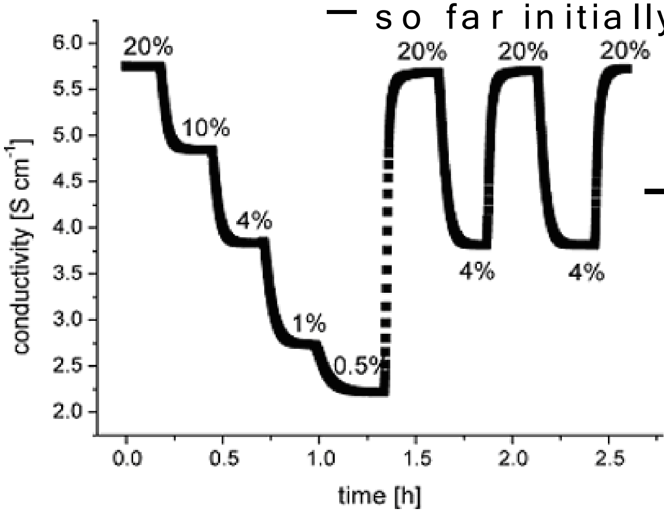
- Wartsila claims this technology will become viable at the end of the decade…
- Potentialy many more producers will advance
- Potential of materials breakthrough

- Profits:
  - Higher efficiencies, more electricity

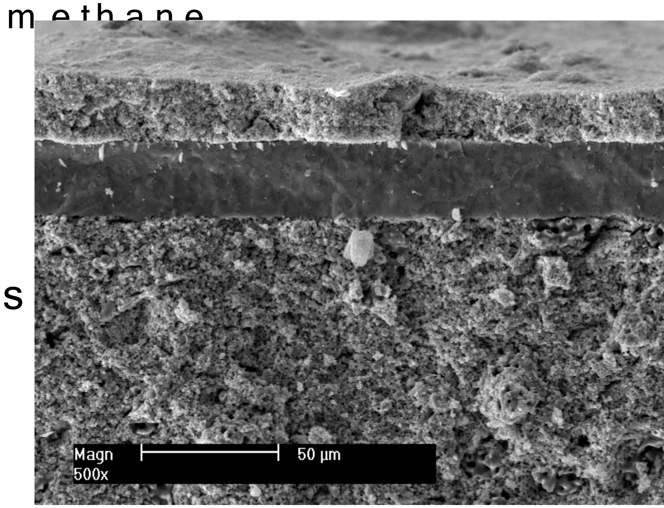
Our research

- Ceramic processing methods
  - Fuel cells R&D
    - Materials development and characterizatio
    - SOFC cells construction
      - Fabrication of H_2 fuelled SOFC
      - so far initially tested cells fuelled by methane





  - Gas sensors
    - Oxygen sensors
    - NOx sensors



The End...

- **Any questions??**

- Contact:

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