DEMOSOFC Project:
Results from an Industrial-Size Biogas-Fed Solid Oxide Fuel Cell plant
The DEMOSOFC EU project

POLITECNICO DI TORINO (IT): project coordinator
CONVION (FI): SOFC technology provider
SMAT (IT): WWTP owner / end-user of electricity and thermal energy
VTT (FI): performance evaluation
IMPERIAL COLLEGE (UK): business analysis

Anaerobic digestion for biogas production → Solid Oxide Fuel Cell or Micro Gas Turbine → Heat → Electricity

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 671470. This Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.
• Medium size WWTP
• Entering load: 180'000 P.E.
• # 50 for entering load among all IT WWTPs
• Previous biogas exploitation: boiler for anaerobic digester heating and flare
SOFC: Solid Oxide Fuel Cell

Near-zero emissions to atmosphere (NOx, SOx, PM, VOC)

High electrical efficiency (50-60%)

Modular concept: performance are kept constant from kW to MW size
The DEMOSOFC plant
Plant layout

Waste water (residential and industrial) → Grilling → Primary sedimentation → Biological treatment → Secondary sedimentation → Ultra-filtration → Clean water (sent to the local river Dora Riparia or re-used in an industrial area nearby)

Sludge line → Pre-thickening → Sludge pre-heating → Anaerobic digestion → Sludge drying process → Dried sludge (usually exploited as fertilizers for agriculture)

Biogas → Gas holder → Boiler
Biogas purification system

Required purification level for SOFC
H₂S: 30 ppb
Siloxanes: 10 ppb
Biogas purification system
Plant layout

- Water line: Waste water (residential and industrial) → Grilling → Primary sedimentation → Biological treatment → Secondary sedimentation → Ultra-filtration → Clean water (sent to the local river Dora Riparia or re-used in an industrial area nearby)

- Sludge line: Pre-thickening → Sludge pre-heating → Anaerobic digestion → Sludge drying process → Dried sludge (usually exploited as fertilizers for agriculture)

- Electrical power (174 kWe) 100% self-consumed by the plant

- Thermal power (90 kWth)
The SOFC modules

Inlet flows:
• Biogas @ 4 bar
• Ambient air
• Compressed air (start-up)
• N-H mix purge gas (stand-by)

Outlet flows:
• Electrical power
• Thermal power
• Exhaust gas (CO₂ + H₂O)

• Fuel flexibility (NG+biogas)
• Black box for the end-user, easy to install&operate
Electrical layout: island mode operation
NOMINAL OPERATION

SOFC 1
SOFC 2
SOFC 3
INVERTER
INVERTER
INVERTER
GRID INTERFACE CABINET
SMAT low voltage cabinet
SMAT Collegno WWTP loads
KM1
KM2
Q1.2
Q1.1
Q1.3
Q2.1
Three-phase loads
UPS by-pass G2kVA
UPS main line
Switch cabinet
Socomec switch
Selection cabinet
AUXILIARIES
Q serv
BATTERY

12
**Results**

Fuel in: 67.9 %-CH4, 14 Nm3/h, 98.88 kW (LHV)

Air in: 445 Nm3/h, 1.99 °C

Power output: 60.4 kW-DC Gross, 52.1 kW-AC Net, 52.73 % Eff. EI

HRU water in: 60.50 °C

Hot Exhaust: 425 Nm3/h, 218.1 °C, 22.4 kW, 72.9 %-tot (LHV)

HRU water out: 72.09 °C

Status SOFC:
- RUN ACTIVE
- FAILURE ACTIVE
- HOT STAND-BY ACTIVE
- REMOTE MODE ENABLED

Command to SOFC:
- Run Command
- Stop Command

SOFC Parameters:
- Force Stop SOFC 2
- ON
- OFF

SOFC Modules:
- Biogas
- Crop Air
- Air
- NH mix
- Exhaust

SOFC 2
- Water
- HRU water in temperature: 44.60 °C
- HRU water in temperature: 67.10 °C
- HRU water out temperature: 69.41 °C
- Loading hours: 1486.7
- Stack temperature: 775.68
Biogas quality – online gas analyzer

→ Raw biogas analysis

<table>
<thead>
<tr>
<th>H₂S (ppm)</th>
<th>Si (mgSi/m³)</th>
<th>CH₄ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>31.561</td>
<td>4.065</td>
</tr>
<tr>
<td>Min.</td>
<td>1.833</td>
<td>0.000</td>
</tr>
<tr>
<td>Max.</td>
<td>71.048</td>
<td>9.429</td>
</tr>
</tbody>
</table>

- H₂S (ppm)
- Si (mgSi/m³)
- CH₄ (%)

Average H₂S and Si levels with corresponding CH₄ percentages averaged over different measurement periods.

- Nov-Dec 2017
- Feb-Mar 2018
- Apr-Jun 2018
- Sep-Dec 2018
- Feb 2019 - ongoing

CH₄ (%)

H₂S (ppm), Si (mgSi/m³)
SOFC – Electrical & Total efficiency

- Until May 27th, more than 7500 hours of operation onsite have been reached (+1000h @ Convion facilities)
- Electrical power production: 322'526 kWh$_{el}$
- Thermal recovery for sludge pre-heating: 195’085 kWh$_{th}$
Emissions from SOFC

(onsite analysis done by VTT on Dec 2017)

<table>
<thead>
<tr>
<th>Species</th>
<th>Unit</th>
<th>Measured value</th>
<th>Typical emission limits of gas engines and turbines $^{1,2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
<td>Vol-%</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Vol-%</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>mg/m$^3$</td>
<td>&lt;9</td>
<td>100</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>mg/m$^3$</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>N$_2$O</td>
<td>mg/m$^3$</td>
<td>&lt;8</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>mg/m$^3$</td>
<td>&lt;20</td>
<td></td>
</tr>
<tr>
<td>NO$_x$ (as NO$_2$)</td>
<td>mg/m$^3$</td>
<td>&lt;20</td>
<td>75...200</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>mg/m$^3$</td>
<td>&lt;8</td>
<td>15...60</td>
</tr>
<tr>
<td>C$_2$H$_6$</td>
<td>mg/m$^3$</td>
<td>&lt;14</td>
<td></td>
</tr>
<tr>
<td>HCHO</td>
<td>mg/m$^3$</td>
<td>&lt;7</td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>mg/m$^3$</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>mg/m$^3$</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>SO$_2$</td>
<td>mg/m$^3$</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>Vol-%</td>
<td>18.3</td>
<td></td>
</tr>
</tbody>
</table>
| Particulate   | mg/m$^3$ | 0.01           | Ambient air EU reference values $^3$
|               |         |                | 0.025 (PM2.5), 0.05 (PM10)                                 |

1: Limitation of emissions of certain pollutants into the air from medium combustion plants (MCP-directive), DIRECTIVE (EU) 2015/2193
2: Industrial emissions (integrated pollution prevention and control) (IED-directive), DIRECTIVE 2010/75/EU
Future perspectives & Conclusions
• P.E.: People Equivalent – corresponds to a BOD5 equal to 60 g of oxygen per day

• Number of Active WWTPs in Europe: 23’423 (with loading or capacity data available)

• Minimum entering load suitable for biogas production: 20’000 P.E. (40 kW SOFC) → 19% of total WWTPS
SOFC market potential in Europe

EU potential biogas production
1.86 - 5.44 billion m³/y

EU potential SOFC Power installed
930 - 2550 MWₑₑ

<table>
<thead>
<tr>
<th>Size</th>
<th>Minimum Power</th>
<th>Maximum Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>XS</td>
<td>20,000-60,000 P.E.</td>
<td>25 – 80 kW</td>
</tr>
<tr>
<td>S</td>
<td>60,001-150,000 P.E.</td>
<td>80 – 200 kW</td>
</tr>
<tr>
<td>M</td>
<td>150,001-350,000 P.E.</td>
<td>200 – 500 kW</td>
</tr>
<tr>
<td>L</td>
<td>350,001-750,000 P.E.</td>
<td>500 - 1000 kW</td>
</tr>
<tr>
<td>XL</td>
<td>&gt;750,000</td>
<td>1000 - 1500 kW</td>
</tr>
</tbody>
</table>
Which could be the price of an SOFC system?

SOFC-CHP system investment cost to have the same Cost of Electricity of the ICE case study
Conclusions

→ The DEMOSOFC plant has demonstrated the advantages of the waste-to-energy process by coupling sewage biogas and SOFCs.

→ SOFCs could become a best practice for electricity production from biogas:
  • Higher electrical and lower thermal production (usually unexploited);
  • Zero pollutants to atmosphere (important especially in urban areas).

→ Small-medium size plants are a niche starting market for the technology because of the higher benefits compared to ICEs and biomethane. The replication potential is huge.

→ Because of their modulation capability, SOFC could work in grid balancing and in micro-grids, together with renewables.
Thank you

Come and visit us the DEMOSOFC site!

www.demosofc.eu
https://demosofc.wordpress.com

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