Fuel cells and biogas

Fredrikstad 26th April 2018
Bengt Ridell  Sweco Energuide
Fuel Cells

- High efficiency also for small power units
- Fuel flexibility Hydrogen, natural gas, biogas etc
- Low emissions, only water
- Low noise level

- PAFC 200°C
- PEM, PEFC, 80°C
- HT-PEFC 120°C – 200°C
- MCFC 650°C
- SOFC 700°C – 1000°C
Different applications for fuel cells
The fuel cell market

Asia: **Cars** Toyota, Hyundai and Honda and Japan **stationary** fuel cells. Panasonic, Toshiba and AISIN

North America: **Large fuel cells** Bloom Energy SOFC, Doosan PAFC, Fuel Cell Energy MCFC and Ballard Canada PEFC
Status of the Ene-Farm in Japan

The home FC system, Ene-Farm, have been sold since 2009.
About 47,000 units were installed in 2016.
Over 200,000 units have been installed in Japan.

PEFC systems
Tokyo Gas with Panasonic

SOFC systems
Osaka Gas with Aisin

Advanced cogeneration and energy utilization center JAPAN

https://panasonic.biz/ appliance/FC/
http://www.aisin.co.jp/cogene/enefarm.html

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Toshiba Hydrogen FC System

- Developing High Efficiency H2 Fueled FC System in Toshiba Gr.
  - Electrical Efficiency 55%, Total Efficiency 95%
  - PEFC based on ENE-FARM Technology

- 700W Residential
- 3.5kW Multi kW Model
- 100kW PJ of Ministry of the Environment

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$H_2$ One™ system was installed in “Kawasaki Marien”.

In case of disaster, the $H_2$ One™ can supply the electricity for 300 people during 1 week.

撮影協力：川崎マリエン

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Industry Orders for Fuel Cells on the Rise

Over 15,000 fuel cell forklifts deployed or on order

Approx. 6 million hydrogen refuelings to date
• Heavy Class-8 trucks are on the road
• The air quality in ports is important
• The military is a strong driver for the development of fuel cells
• Fork-lifts and back-up power large growing markets
Microsoft’s headquarters in Seattle, in one of their huge data centers, ten fuel cell generators are currently being installed to provide electricity.
<table>
<thead>
<tr>
<th>Dachs InnoGen</th>
<th>Cerapower FC10 Logapower FC10</th>
<th>PEMmCHP G5</th>
<th>Elcore 2400</th>
<th>Galileo 1000 N</th>
<th>Inhouse 5000+</th>
<th>ENGEN 2500</th>
<th>BLUEGEN</th>
<th>Vaillant G5+</th>
<th>Vitovalor</th>
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</thead>
<tbody>
<tr>
<td>LT PEM 700W</td>
<td>SOFC 700W</td>
<td>LT PEM 2kW</td>
<td>HT PEM 300W</td>
<td>SOFC 1kW</td>
<td>LT PEM 5kW</td>
<td>SOFC 2.5kW</td>
<td>SOFC 2kW</td>
<td>SOFC 1kW</td>
<td>PEM 700W</td>
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<td>Natural Gas</td>
<td>Natural Gas, Gas</td>
<td>Natural Gas</td>
<td>Natural Gas</td>
<td>Natural gas</td>
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<tr>
<td>Floor</td>
<td>Floor Bosch Thermotechnik</td>
<td>Floor Dantherm Power</td>
<td>Wall Elcore</td>
<td>Floor Hexis</td>
<td>Floor RBZ</td>
<td>Floor Solid power</td>
<td>Floor Vaillant</td>
<td>Floor Viessmann</td>
<td></td>
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</table>
PACE at a glance
Promoting a successful transition to the large scale uptake of Fuel Cell micro-Cogeneration across Europe

8 Partners
> 2,500 Fuel Cell micro-Cogeneration units
> 500 Systems per manufacturer
10 Countries
4 Countries
€90m Total budget

Representing manufacturers, utilities & research community
To be deployed across Europe between 2016-2021
Established production capacity per manufacturer
Where the units will be installed
Selected for policy & market development (Belgium, Italy, Netherlands and UK)
Including €33.9m Horizon 2020 funding via FCH JU

Field trial + installer training + targeted market & policy development activities
Field trial + local installer training

Coordination & Dissemination Partner
Manufacturers
Viessmann
Bosch
BDR Thermea Group

Research Partners
Element Energy
DTU

Utility
EWE

> 10,000 FC micro-cogeneration units/year post 2020
- Viessmann - Panasonic PEFC Japan
- Bosch - AISIN Seiki SOFC Japan
- BDR Therma - Toshiba Japan
- SOLID Power - SOFC Italy (CFCL Australian technology)
FC tolerance to contaminants

<table>
<thead>
<tr>
<th>Main compounds (%)</th>
<th>CH₄</th>
<th>40 - 70 %</th>
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<tbody>
<tr>
<td></td>
<td>CO₂</td>
<td>30 - 50 %</td>
</tr>
<tr>
<td></td>
<td>N₂</td>
<td>0 - 20 %</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>0 - 5 %</td>
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<table>
<thead>
<tr>
<th>main contaminations (ppm)</th>
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<tbody>
<tr>
<td>H₂S</td>
</tr>
<tr>
<td>Mercaptanes</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Traces contaminations (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siloxanes</td>
</tr>
<tr>
<td>Halogenated HC</td>
</tr>
</tbody>
</table>

Biogas composition and contaminants

<table>
<thead>
<tr>
<th>FC-Typ</th>
<th>PEFC</th>
<th>AFC</th>
<th>PAFC</th>
<th>MCFC</th>
<th>SOFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas comp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>CH₄, CₙHₘ</td>
<td>IG</td>
<td>poison</td>
<td>IG</td>
<td>IG/F</td>
<td>F</td>
</tr>
<tr>
<td>CO₂</td>
<td>IG</td>
<td>poison</td>
<td>IG</td>
<td>React.</td>
<td>IG</td>
</tr>
<tr>
<td>CO</td>
<td>poison (&lt;50ppm)</td>
<td>poison (≤500ppm)</td>
<td>poison (≤500ppm)</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>H₂S, COS</td>
<td>nd</td>
<td>poison (≤50ppm)</td>
<td>poison (≤0.5ppm)</td>
<td>poison</td>
<td>poison</td>
</tr>
<tr>
<td>NH₃</td>
<td>poison</td>
<td>F</td>
<td>poison</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Siloxanes</td>
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<td>poison</td>
<td>poison</td>
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<td>poison</td>
</tr>
</tbody>
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Fuel cells in the food and agriculture industry
MCFC Anaerobic digester plants
ADP in USA and Germany

Santa Barbara
WWP

Los Angeles
San Pedro
WWP

Tognum
Ottobrunn

München

Mossburg
Data center T-Mobile i München

A biogas driven MCFC Fuel Cell of 250 KWe supplies electricity to a T-mobile data centre in Munich, Germany. The waste heat from the Fuel Cell in the form of Exhaust gas at 380 deg C is directly fed to a Thermax Absorption chiller to deliver 150 kW of cooling.

Data centres require round the year, 24/7 supply of electricity and cooling. T-mobile has chosen the this system for their high reliability and availability
Affordable efficient hydrogen, heat and power systems
Ready for follow-on demonstrations and deployment
Distributed Hydrogen Production

Industrial Hydrogen Use
Existing market

Vehicle Fueling
Emerging market

Demonstration Projects:
- Orange County Sanitation District, CA – Hydrogen from wastewater treatment digester gas for vehicle fueling
- Village Farms, Vancouver Canada - Hydrogen from landfill gas for vehicle fueling
- Torrington DFC Manufacturing Plant – Hydrogen for industrial heat treating

Orange County Sanitation District
Renewable Hydrogen for Vehicle fueling

Zero or low-carbon $H_2$ economically produced near end users
Cold Weather Operation
PureCell® Model 400 Capability

1,000 kW natural gas

120° C
230 kW high-grade heat

500 kW total heat

270 kW low-grade heat
70° C

400-kW electricity

175-kW cooling

Grid connect / Grid independent power

Space heat

Refrigeration sub-cooling

Domestic water / space heat

UTC Power

A United Technologies Company

SWECO

DOOSAN

DID YOU KNOW? These fuel cells reduce energy consumption by 30% in this help!
Fleet Experience PAFC

Worldwide Fuel Cell Deployment and Experience*

* Based on the Model 200 fuel cell

• 280 systems delivered to 19 countries on 5 continents
• More than > 8.7 million hours of operation
• More than 1.3 billion kWh of electricity generation

- 59,456 hrs
  Hospital
  Bocholt, Germany

- 58,307 hrs
  Casino
  Uncasville, CT

- 56,630 hrs
  District Heating works
  Halle, Germany

- 54,694 hrs
  Huis Ten Bosch
  Sasebo, Japan

- 62,165 hrs
  Central Park Police Station
  New York City, NY

- 65,615 hrs
  Fleet Leader
  Toshiba
  Houston, TX
KOREA PURECELL FLEET

In operation: 62.44 MW (143 units)
Under construction: 38.28 MW (87 units)

U.S. PURECELL FLEET

Installed Capacity: 33 MW

PRODUCT PORTFOLIO

<table>
<thead>
<tr>
<th>NG/Bio-gas Model</th>
<th>Availability</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>• Current</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrogen Model</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ from electrolysis</td>
<td>• 2018</td>
</tr>
<tr>
<td>By-product H₂ from O&amp;Gs</td>
<td>• 2018</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>LPG Model</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote area / Islands</td>
<td>• 2018</td>
</tr>
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<table>
<thead>
<tr>
<th>Tri-Gen Model</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicle &amp; Fuel cell vehicle charging station</td>
<td>• 2020</td>
</tr>
</tbody>
</table>

DOOSAN
Technological Idea “Manure-to-electricity”

Questions of scale, cost, technological readiness, and dynamic response:
- Manure resource size/type relevant for Switzerland
- Anaerobic digester techno-economic feasibility at small scale (2 – 75 kWₑ)
- Choice of gas cleaning material
- Appropriateness of SOFC for electricity conversion vs. ICE
- Need for storage or transport of manure/digestate/biogas
DEMO SOFC

- Demonstration of 175 kW_e SOFC power plant using biogas from waste water treatment plant (Turin, Italy)
- Power plant consists of three ~ 60 kW_e units: installations starts 2017
- Polito (Coordinator), Convion (SOFC units), SMAT (WWTP), VTT (Verification), Imperial College (Techno-economic studies)

- Convion SOFC produces 30% of electrical power and 100% of normal heat loads of the plant process needs.
In the joint industry project, FellowSHIP, a 330 kW fuel cell was successfully installed, and demonstrated smooth operation for more than 7000 hours on board the offshore supply vessel Viking Lady using LNG as fuel.
Biogas for fuel cells


Fuel Cell cars at the Oscar Academy Award

Ford FCV 333 km/h Utah
Thanks for listening!

SWECO

bengt.ridell@sweco.se
Track Records in Korea

Commercial operation ~150 MW in 20 places

Boil Off Gas (BOG) - KOGAS (300kW)

Large Scale Power Generation (Grid Support) - Gyeonggi Green Energy (58.8MW)

Bio Gas (blended ADG) - Busan Wastewater Treatment Center (1.2MW)
Stationary fuel cells

- Biogas is a common fuel for fuel cells more than 100 MWe is produced from biogas in fuel cells
- The main difficulty for biogas is impurities
- The stationary fuel cells heavily rely on subsidies
- North America and Asia in the lead
- Europe is still in R&D and demonstration phase
- Japan Ene-Farm now over 220,000 fuel cells systems installed
- Doosan starts to deliver the 400 kWe PAFC again in large quantities about 100 MWe installed
- Telecom back up and remote power competitive market more than 10,000 systems delivered
Heavy Class 8 trucks with fuel cells

- Four Class 8 fuel cell hybrid electric trucks based on pre-commercial model Tyrano
- Specifications
  - 320 kW electric motor
  - Direct drive w/ two-speed rear end
  - Parallel hybrid system with 33 kW PEM fuel cell
  - 130 kWh battery pack (Lithium Iron Phosphate)
  - 20kg hydrogen storage
  - Level 2 Charger (8 hrs)
- Performance
  - 60 mph top speed (65,000 lbs)
  - Extended range: 200 miles
  - Refuel time: 10-15 min. H₂ @ 6,250 psi