Overview of Large Fuel Cell Applications World Wide

Properties, Development and Application of PEFC, PAFC, MCFC, SOFC for CHP, Prime Power, UPS

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Outline

Overview Fuel Cell Technologies
• Mobile, Portable, Stationary

Small Stationary Fuel Cells

Large Stationary Fuel Cells
• Overview
• PEFC (Ballard, Nedstack)
• PAFC (Doosan, Fuji)
• MCFC (Fuel Cell Energy)
• SOFC (Seca, Bloom Energy, General Electric, Mitsubishi-Hitachi)

Conclusions
# Overview Fuel Cell Technologies

<table>
<thead>
<tr>
<th>Todays Applications</th>
<th>Mobile</th>
<th>Portable</th>
<th>Stationary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forklifts etc.</td>
<td>APU</td>
<td>Micro CHP up</td>
</tr>
<tr>
<td></td>
<td>Cars Busses</td>
<td>Military Battery</td>
<td>Big Power Plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>others</td>
<td>Telecom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Security Supply</td>
</tr>
<tr>
<td>Power (Stack)</td>
<td>1 – 200 kW</td>
<td>5 W 20 kW</td>
<td>1 kW – 400 kW</td>
</tr>
<tr>
<td>FC-Technology</td>
<td>PEFC DMFC (SOFC)</td>
<td>PEFC DMFC (SOFC)</td>
<td>PEFC PAFC MCFC SOFC</td>
</tr>
<tr>
<td>Fuels</td>
<td>H2 Methanol</td>
<td>Methanol H2</td>
<td>Natural Gas Digester Gas Landfill Gas</td>
</tr>
</tbody>
</table>
Overview: Mobile FC-Applications

- Hydrogen Bus Postauto AG
- Forklift from Still
- Mercedes F-Cell and H₂-Filling Station
- Honda FCV
Overview: Portable FC-Applications

- SOFC from Delphi for APU
- „Battery“ Pack DMFC from EFOY
- APU for Camper from Truma (DMFC) launched 2012 - stopped 2014
Overview: Stationary FC-Applications

Tokio Gas 1 kW PEFC

Baxi Innotec 1.5 kW PEFC

Hexis 1 kW SOFC

Fuel Cell Energy 300 kW MCFC

UTC PureCell 400 (12 Units)
Small Stationary Fuel Cells

In **Japan** is far ahead
- To the end of 2014 over **100,000 units** (PEFC, SOFC) were *delivered*
- Similar development program for SOFC as for small PEFC
- Special requirements of Japanese market hindered sales activities in other regions. Collaborations with EU companies

In **Europe** since many years a lot of diff. R&D and P&D, first market ready products
- Lots of **EU-research** programs
- Driver was/is **Germany**; is looking for partners
- Activities in **Denmark**
- New activities in **UK**
- Project **ene.field** target: Installation of **1000 small scale FC**
- Japan will deliver to EU-Market (Viessmann etc)
## Large Stationary Fuel Cells

Today’s Large Fuel Cells: typical 50 – 400 kW up to 3 MW-units

<table>
<thead>
<tr>
<th>FC Typ</th>
<th>Rated Power</th>
<th>Status</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>[AFC Alkaline]</td>
<td>up to MW</td>
<td>F&amp;E, P&amp;D</td>
<td>AFC Energy (GB)</td>
</tr>
<tr>
<td>PEFC Proton Exchange</td>
<td>100 kW - 1 MW</td>
<td>P&amp;D</td>
<td>Ballard (CAN), Nedstack (NL)</td>
</tr>
<tr>
<td>PAFC Phosphoric Acid</td>
<td>200 – 400 kW 50 - 100 kW</td>
<td>commerc.</td>
<td>Doosan Fuel Cell Energy (US) (UTC), Fuji Electric (J)</td>
</tr>
<tr>
<td>MCFC Molten Carbonate</td>
<td>250 kW – 3 MW</td>
<td>commerc.</td>
<td>Fuel Cell Energy (US, GE, KR), Posco (KR), GenCell (US) [MTU (D), Ansaldo (I)]</td>
</tr>
<tr>
<td>SOFC Solid Oxide</td>
<td>100 kW - MW</td>
<td>commerc. R&amp;D, P&amp;D</td>
<td>Bloom Energy (US), SECA-Program (US): Delphi/FCE Versa-Power/UTC, Rolls-Royce ➔ LG, GE, Siemens (US) Wartsila (FIN), Mitsubishi (J)</td>
</tr>
</tbody>
</table>
Large PEFC: Ballard (Canada)

- Distributed Generation with PEFC-Technology (several stacks)
- Power: 1 MW el
- electr. eff. 40 %
- Dimensions: 57 000 kg
- Fuel: Hydrogen (NG with reformer)
- End-customer price: 5.2 Mio €
- Stack replacement: 0.850 Mio €
- Latest installation: Toyota

The design of this unit is foreseen for industrial applications, when H$_2$ is available.

Ballard is a pioneer in development and fabrication of PEFC: mobile, portable and stationary

Source: FCH-JU-Report Advancing Europe’s energy systems 2015; Ballard at HFC-Fair 2015
Large PEFC: **Nedstack** (Netherlands)

**Solvay Chlorine Plant near Antwerp**

**Production:**
- 350‘000 tons chlorine/year
- Electrolyser
- 10‘000 tons H₂ as by-product
- Feed in Air Liquide hydrogen pipeline network

**Idea:**
- Use hydrogen with a fuel cell and generate a part of the electricity for the chlorine electrolyser
- Improve efficiency of electrolysis process

Source: picture BRC, Solvay
Large PEFC: Nedstack

- 6 kW-PEFC-stack from Nedstack
- 1MW-Plant with 168 stacks and 12’600 cells
- El. efficiency: 50% ($H_2$)
- Put in operation: 2012
- Investment approx. 5.3 Mio €

Latest news:
Nedstack has sold a 2 MW PEFC to Ynnovate Sanzheng Fine Chemicals Ltd in Yingkou (China) (news 15.4.2015)

Source: BRC, Nedstack
Large PAFC: **Doosan Fuel Cell America** (US, CT) (former UTC)

**History UTC Fuel Cell 200 kW and 400 kW**
- UTC (United Technologies) developed FC for US space program in the 60’s
- Development of PAFC in 80’s; first demo-plants in Europe 1990 onwards: **ONSI PC 25** (200 kW$_{el}$ with reformer for NG)
- Stack lifetime > 40’000 h, el eff. 40%
- Further development until 2010
- 2009 new Model **Pure Cell 400** with stack lifetime 10 years (80’000h) and 42% el.eff.

**Installation in Switzerland 2000 - 2006**
- Connected to district heating
- **Investment** end user: **1.125 Mio €** (complete)
- Efficiency targets achieved (39.4% average)
- Stack lifetime achieved (even more possible)

Source: BRC

Onsi PC 25 used as CHP in Birsfelden/Basel (CH)

Power and voltage over 40’000 hours
Large PAFC: Doosan Fuel Cell America

History UTC Fuel Cell to Doosan Fuel Cell
• UTC decision 2012: sell fuel cell business
• After a intermezzo at Clear Edge, Doosan bought the PAFC department in July 2014 with 30 employees. March 2015: 129 employees, target end of 2015: 300.
• In Europe at Power-Gen Europe June 2015

Markets
• Industry (Samsung, Korea)
• Whole Sale (Shopping Centres)
• Data Centres, Telekom (COX Communication)
• Food Industry (Coca Cola)
• Utilities (NY Power Authority)

Latest News
400 kW Plant sold to B. Becker Investor for its 26 story apartment downtown Hartford US (Jan. 2014)

Source: BRC
Large PAFC: Fuji Electric (Japan)

Fuji Electric PAFC 100
- Similar Technology as PureCell 200
- 40 % el. eff., + 40'000 h
- Market entry started at beginning 2000
- Focus on Asian Market
- Since 2011 sold in Europe N2telligence
- Innovative Application CHP, Tri-, Quattro- generation
- Quattro = Uses exhaust air to reduce $O_2$ in Data centres

Applications in Europe (N$_2$telligence)
- Mercedes-Benz-Niederlassung Hamburg
- Logistikzentrum der Mercedes-AMG GmbH Affalterbach
- Equinix – Rechenzentrum in Frankfurt am Main
- Airbus Deutschland GmbH
- Thyssen Krupp Marine Systems, Blohm & Voss GmbH
- Miniatur Wunderland Hamburg GmbH

Source: N$_2$telligence
Large MCFC: **Fuel Cell Energy** (US, CT)

**History Fuel Cell Energy (FCE)**
- FCE develops and manufactures MCFC power plants for natural gas and biogas
- FCE most successful manufacturer of large systems (180 Mio USD of revenues in 2014)
- **Collaboration in EU** with **MTU** until 2010 (HotModul, own technology with FCE-Stack)
- **Fuel Cell Energy Solutions** developer and manufacturer of DFC in Europe (D) and Collaboration with **Fraunhofer IKTS**
- Collaboration with **Posco Energy in South Korea** (starts manufacturing for Asian market 2015)

**Success** (status 2014)
- El. efficiency: 47 %; 400 – 2800 kW plants
- NG, BioGas, SynGas etc.
- 300 MW installed and backlogged
- 110 DFC power plants 50 sites world wide
- 59 MW DFC power park in South Korea

Source: FCE, FCES
Large MCFC: Fuel Cell Energy

Site layout for a Fuel Cell Energy MCFC Plant

Source: FCE, FCES
Large MCFC: Fuel Cell Energy

DFC®-power plants – modular system

DFC®-power plant: based on a modular design: fuel cells, stacks, modules, power plants.

Source: FCE, FCES

Combination of Fuel Cell Energy MCFC Plant

Source: FCE, FCES

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Large MCFC: Fuel Cell Energy

Application in Switzerland: Hot Module in Zurich (from MTU FC, with FCE stack)

- Natural Gas with desulferization
- Rated power: \(230 \text{ kW}_{\text{el}}\) and \(170 \text{ kW}_{\text{th}}\)
- Electric. efficiency 42%
- Total Efficiency (heat + power) 80%
- Continuous operation 8000 h/a

- Put in Operation: October 2010
- Target: 12 years of operation with several stack replacement
- Investment > 4.8 Mio CHF
- Still in operation, 1. stack successful replaced

Source: FCE, FCES
Large SOFC: SECA Program (US)

Focus:
• Near Term: Natural gas distributed generation (DG)
• Long Term: Coal and natural gas central station applications with CCS

Targets:
• System Performance Degradation: 0.2%/1,000 h (Today 1 – 1.5 %)
• Stack Cost: $225/kWe
• Power Block Cost: $900/kWe

Source: NETL, S. Vora
Large SOFC: SECA Program

SOFC compared with other Clean Coal Technologies (NGCC, IGCC)

Cost of Electricity

Power Efficiency

Source: NETL, S. Vora
Large SOFC: **Bloom Energy** (US, CA)

**Bloom’s Energy Server**
- Founded 2001 in Sunnyvale, California, US
- Clean, reliable power on demand
- Fuel: natural gas, biogas
- El. eff. **52 – 60 %**
- No CHP, no use of heat (!)
- Stack with 4000 cells
- Assembling of several stacks for 100 kW, 200 kW
- 200 kW: 8.0 x 2.6 x 2.1 m, 19 t

**New design for Customers such as**
- Apple
- Google
- FedEx
- Ebay
- etc.
Large SOFC: Bloom Energy
130 MW of units installed in U.S (Aug. 2014)

Source: Bloom Energy

Apple, Google, Walmart, AT&T, eBay, Staples, NSA
Large SOFC: **Bloom Energy**

**Bloom’s Energy Server Customer**

<table>
<thead>
<tr>
<th>Customer</th>
<th>City</th>
<th>State</th>
<th>Size (kW)</th>
<th>Facility Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahold / Stop &amp; Shop</td>
<td>Mt. Vernon</td>
<td>NY</td>
<td>250</td>
<td>Shopping Center</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>Hayward</td>
<td>CA</td>
<td>1000</td>
<td>Data Center</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>Sherman Oaks</td>
<td>CA</td>
<td>1000</td>
<td>Telecommunications</td>
</tr>
<tr>
<td>eBay Inc.</td>
<td>South Jordan</td>
<td>UT</td>
<td>6000</td>
<td>Data Center</td>
</tr>
<tr>
<td>Johnson &amp; Johnson / Advanced Sterilization Products</td>
<td>Irvine</td>
<td>CA</td>
<td>500</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Keio University</td>
<td>Fujisawa-sha</td>
<td>Kanagawa Prefecture</td>
<td>200</td>
<td>University</td>
</tr>
<tr>
<td>Life Technologies / Thermo Fisher Scientific</td>
<td>Carlsbad</td>
<td>CA</td>
<td>1000</td>
<td>Biotech</td>
</tr>
<tr>
<td>Life Technologies / Thermo Fisher Scientific</td>
<td>Pleasanton</td>
<td>CA</td>
<td>1000</td>
<td>Biotech</td>
</tr>
<tr>
<td>Macy’s</td>
<td>Cheshire</td>
<td>CT</td>
<td>600</td>
<td>Fulfillment Center</td>
</tr>
<tr>
<td>Morgan Stanley</td>
<td>Purchase</td>
<td>NY</td>
<td>250</td>
<td>Office Building</td>
</tr>
<tr>
<td>NSA / U.S. DoD</td>
<td>Fort Meade</td>
<td>MD</td>
<td>1600</td>
<td>Campus</td>
</tr>
<tr>
<td>Osaka Prefectural Central Wholesale Market</td>
<td>Osaka</td>
<td>Fukushima Ward</td>
<td>1200</td>
<td>Market</td>
</tr>
<tr>
<td>Owens Corning</td>
<td>Compton</td>
<td>CA</td>
<td>400</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Prime Healthcare</td>
<td>Inglewood</td>
<td>CA</td>
<td>250</td>
<td>Medical Center</td>
</tr>
<tr>
<td>Roll Global</td>
<td>Los Angeles</td>
<td>CA</td>
<td>250</td>
<td>Office Building</td>
</tr>
<tr>
<td>Savvis / CenturyLink</td>
<td>Irvine</td>
<td>CA</td>
<td>500</td>
<td>Data Center</td>
</tr>
<tr>
<td>SoftBank</td>
<td>Fukuoka</td>
<td>Fukuoka Prefecture</td>
<td>200</td>
<td>Office Building</td>
</tr>
<tr>
<td>SoftBank</td>
<td>Minato-Ku</td>
<td>Tokyo</td>
<td>200</td>
<td>Office Building</td>
</tr>
<tr>
<td>Walmart</td>
<td>Carlsbad</td>
<td>CA</td>
<td>300</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Walmart</td>
<td>Waterford</td>
<td>CT</td>
<td>250</td>
<td>Shopping Center</td>
</tr>
<tr>
<td>Walmart</td>
<td>New Haven</td>
<td>CT</td>
<td>400</td>
<td>Shopping Center</td>
</tr>
</tbody>
</table>

Source: Bloom Energy
Large SOFC: Mitsubishi Hitatchi Power Systems (J)

Mitsubishi targeting highest efficiency
• Own development of SOFC-Technology
• SOFC-MGT System for efficiency > 60%
• First Demoplant at Kyushu University ((J)
• Pressurised 250 kW hybrid power generation system with solid oxide fuel cell stack and micro gas turbine (MGT)

Source: Mitsubishi
Large SOFC: General Electric (US)

GE’s vision: SOFC + Jenbacher

• GE re-entered SOFC development improved technology
• Tubular Cell Design with new production process (spray techn.)
• Target 65 %+ el. eff.
• Combination of SOFC an ICE (Jenbacher)
• Plant design 1-10 MW
• GE Built new development/manufacturing center in US

Source: GE Global Research
## Large Fuel Cells: Installations in Grocery Markets

<table>
<thead>
<tr>
<th>Customer</th>
<th>Type</th>
<th>Location</th>
<th>Status</th>
<th>Fuel Cell Manuf.</th>
<th>Fuel Cell</th>
<th>Configuration</th>
<th>Benefits</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Chopper</td>
<td>Grocery store</td>
<td>Middletown, CT</td>
<td>Planned</td>
<td>UTC Power</td>
<td>PureCell® Model 400 PAFC (400 kW)</td>
<td>The fuel cell system is set up to send excess electricity production back to the grid.</td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Safeway</td>
<td>Grocery store</td>
<td>Santa Cruz, CA</td>
<td>2009-present</td>
<td>Bloom Energy</td>
<td>Bloom Energy Server SOFC (200 kW)</td>
<td>Power—serves 20% of the building's energy load.</td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Staples</td>
<td>Retail distribution center</td>
<td>Ontario, CA</td>
<td>2008-present</td>
<td>Bloom Energy</td>
<td>Bloom Energy Server SOFC (300 kW)</td>
<td>Power - delivers electricity to the store (no further details available).</td>
<td>In the first year, the fuel cell generated over 2 million kWh of power, which resulted in a reduction of 2.5 million pounds of CO₂. Fuel cell availability has been above 99%.</td>
<td></td>
</tr>
<tr>
<td>Star Market</td>
<td>Grocery store</td>
<td>Chestnut Hill, MA</td>
<td>2009-present</td>
<td>UTC Power</td>
<td>PureCell® Model 400 PAFC (400 kW)</td>
<td>CHP - provides electricity and thermal energy in the form of chilled water and hot water. The chilled water supplies refrigeration system sub-coolers, predominately for space conditioning and cold storage areas. The hot water produced is used for space conditioning, desiccant regeneration, and for making domestic hot water.</td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Stop &amp; Shop</td>
<td>Grocery store</td>
<td>East Torrington, CT</td>
<td>2010-present</td>
<td>UTC Power</td>
<td>PureCell® Model 400 PAFC (400 kW)</td>
<td>CHP - generates 95% of the store's total electric energy requirement, uses thermal energy for heating and cooling.</td>
<td>From Jun 2010-Jan 2011 the fuel cell produced over 1.7 million kWh of electricity and reduced the total electric and natural gas utility bills by roughly 50%.</td>
<td></td>
</tr>
<tr>
<td>Wal-Mart</td>
<td>Retail store</td>
<td>Lancaster, CA</td>
<td>2009-present</td>
<td>Bloom Energy</td>
<td>Bloom Energy Server SOFC (400 kW)</td>
<td>Power - delivers electricity to the store (no further details available).</td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Wal-Mart</td>
<td>Retail store</td>
<td>Hemet, CA</td>
<td>2010-present</td>
<td>Bloom Energy</td>
<td>Bloom Energy Server SOFC (400 kW)</td>
<td>Power - delivers electricity to the store (no further details available).</td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Wal-Mart</td>
<td>Retail stores</td>
<td>17 sites in California</td>
<td></td>
<td>Bloom Energy</td>
<td>N/a</td>
<td></td>
<td>N/a</td>
<td></td>
</tr>
<tr>
<td>Whole Foods Market</td>
<td>First grocery store to deploy a fuel cell</td>
<td>Glastonbury, CT</td>
<td>2008-present</td>
<td>UTC Power</td>
<td>PureCell® Model 200 PAFC (200 kW)</td>
<td>CHP - generates 50% of store's electricity and nearly 100% of store's hot water, configured for grid-independent operation if the power fails.</td>
<td>Total electrical and heat energy costs were 30% lower after the first year than a comparable, conventionally powered store in West Hartford, CT.</td>
<td></td>
</tr>
<tr>
<td>Whole Foods Market</td>
<td>Grocery store</td>
<td>Dedham, MA</td>
<td>2009-present</td>
<td>UTC Power</td>
<td>PureCell® Model 400 PAFC (400 kW)</td>
<td>CHP - generates approximately 90% of electricity and nearly 100 percent of store's hot water.</td>
<td>N/a</td>
<td></td>
</tr>
</tbody>
</table>

Source: Fuel Cells 2000 (fuelcells.org)
Conclusion

Different Concepts
- Assembling of 100 of small stacks (PEFC, SOFC)
- Big stacks (100 - 400 kW) and installation of MW-Power Plants (PEFC, PAFC, MCFC, SOFC)

Different Success
- PEFC special (niche applications with pure hydrogen; power to gas in the future?)
- PAFC: First in the market (90's) but still no «break through»
- MCFC from Fuel Cell Energy most successful
- SOFC: an up and down, companies appear and disappear; a few remain (FCE, LG)
- SOFC: design, marketing, high efficient technology help to be successful: Bloom

Target Markets and Requirements
- Reliable power supply: Data centre in the US!
- Whole Sale, Shopping Centres, Industry with continous demand of electricity
- Clean air: Fuel Cell have very low $\text{No}_x$-emissions
200 kW PAFC Installation in Switzerland 2000 - 2006

22.04.2015

Thank you for your attention!

Questions?