Recent Developments for SOFCs as well as News from IEA Annexes 32 and 37

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Why SOFCs?

SOFC has many advantages over conventional techniques:

- High electrical efficiency
  - 60 % possible for systems as small as 1.5 kW
  - 70-75 % possible when combined with steam and gas turbines (triple-system)
- Fuel flexibility [can also be combined with gasification]
- Insignificant NO_X, SO_X and particulate emissions
- Reduced CO_2 emissions

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Why SOFCs?

SOFC has many advantages over conventional techniques:

- Possibility to use a Swedish / European fuel
  - Giant bio-fuel potential from forestry and forest industry
- SOFCs have relatively high pollution tolerance (except for sulfur)
- Silent and vibration free operation [military applications]
- Possibility for dual direction operation in a smart-grid

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Current status SOFC

- Lifetimes over 78,000 hours reached (still running) for stack in laboratory environment (FZ Jülich).
- 9 years old technology [even longer lifetime with technology of today expected]
    - No similar long-time tests being started

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Current status SOFC

- The efficiency and electrochemistry issues of SOFC are essentially solved: the state-of-the-art SOFC shows reasonable efficiencies and stable electrochemical performance.
- Electrical efficiency over 60% (LHV) achieved for residential SOFC in a combined heat and power (CHP) system, as small as 1.5 kW electricity (SolidPower (former CFCL)).
- Durability and cost still remain the major barriers to SOFC systems' commercialization. Complete understanding of all the physical phenomena inside the cell is still lacking. Needs for experimental and modeling development.

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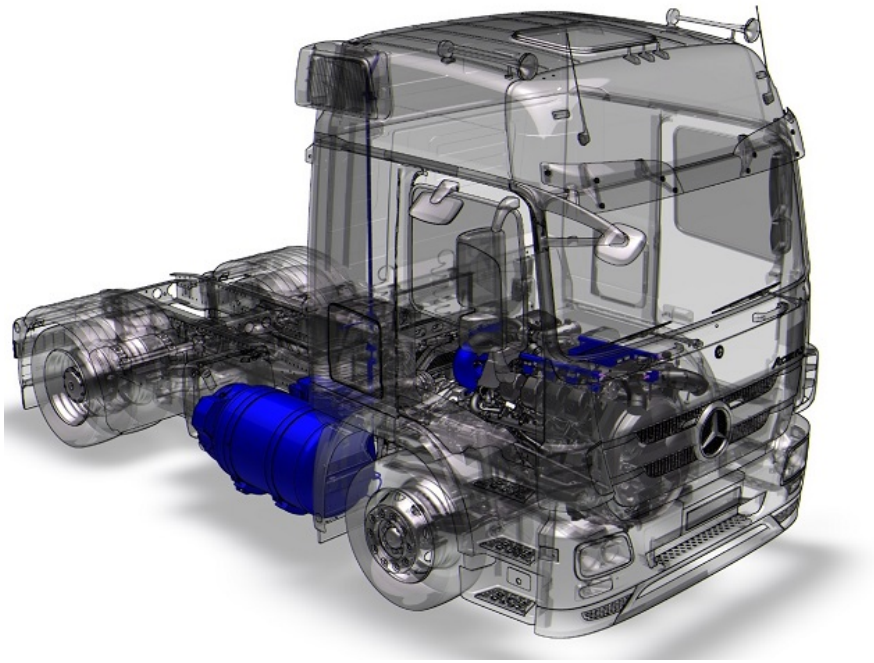
European funding for APU project SAFARI

- SOFC APU For Auxiliary Road-truck Installations
- Partners: Adelan, IREC, ALMUS AG, ZUT and University of Birmingham
- Fuel: LNG (internal reforming)
- Jan 2016 -> 3 years



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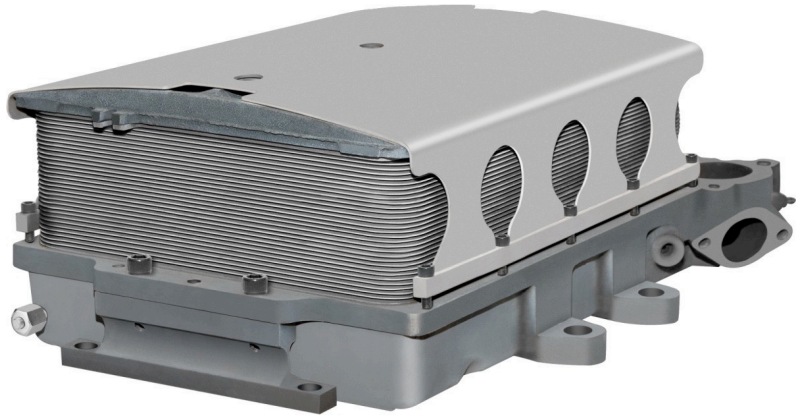
Example Delphi (SOFC APU)

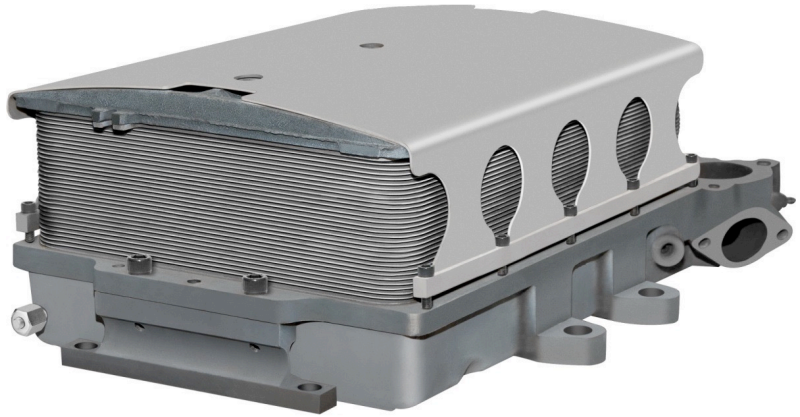
- Worked with SOFCs since 1998
- Research supported by US DOE
- Fuel flexibility (natural gas, diesel, bio-diesel, propane, gasoline)
- 2014-2018 NHTSA/EPA (US National Highway Traffic Safety Administration/US Environmental Protection Agency) Fuel Economy Standards does not mandate an APU, but requires the main engine to be shut off.



Delphi generation 4 stack

Example Delphi (SOFC APU)

- 9 kW system (110 / 12 V)
- Advantages in terms of low noise, high electrical efficiency (40-50 %)
- Main challenges relates to desulfurizer



Delphi generation 4 stack

Additional SOFC APU manufactures

- **Elcogen (Finland/Estonia)**
  - Developing SOFCs since 2001
  - Low operating temperature
  - Cooperation with VTT, Chalmers, Sandvik
- **Protonex (USA)**
  - Acquired SOFC technology in 2007 from Mesoscopic Devices LLC
  - Tubular SOFC technology
- **Ultra Electronics AMI**
  - Acquired SOFC technology in 2011 from Adaptive Materials
  - Aiming for military and civilian market

Japan - AISIN SEIKI

- Coupling between mCHP and vehicle industry (APU)
  - Subcontractor for vehicle industry (part of Aisin group)
  - However, also developed SOFC mCHP system to the Japanese ENE-FARM program.
  - Toyota Motor Corporation is the biggest shareholder
  - Cooperates with Bosch in the European EneField program (mCHP)
    - More challenging gas mixture in Europe
  - In ENE-FARM program, the PEFC development is approximately 5 years ahead of the SOFC development

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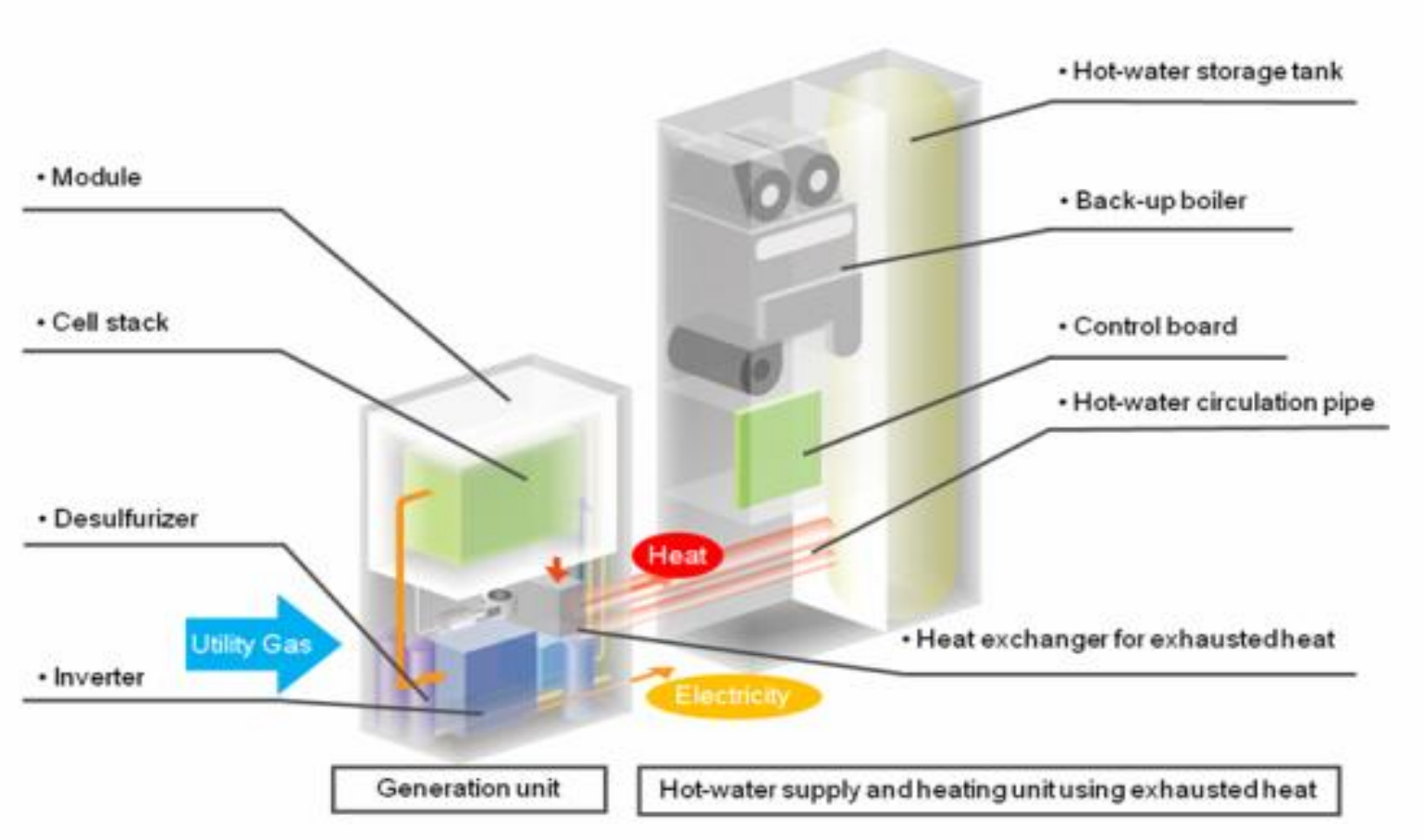
AISIN SEIKI – ENE-FARM - type S



Courtesy of AISIN

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IEA Annex 32 (SOFC)

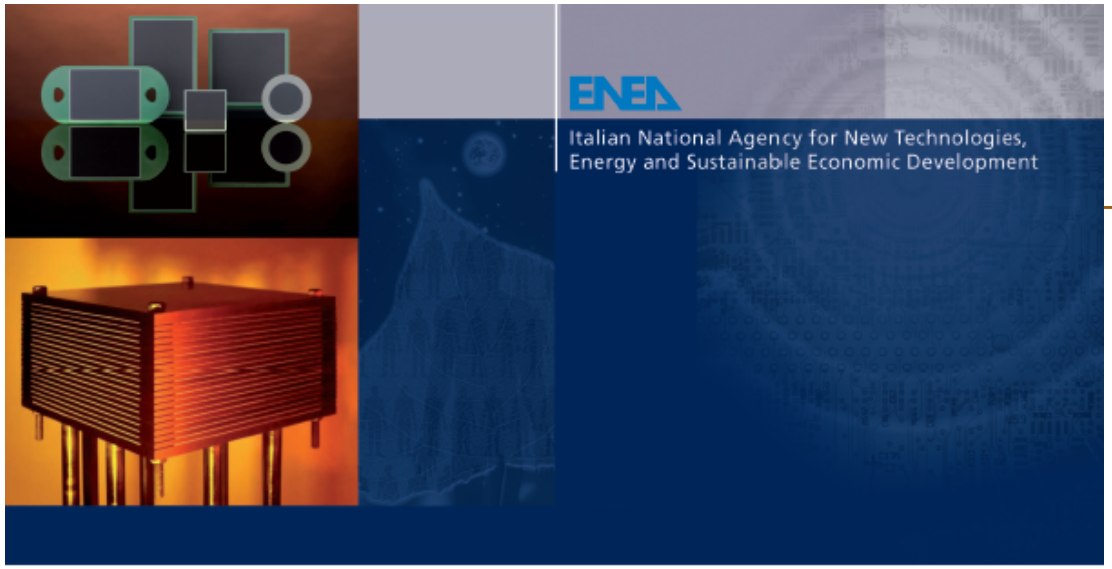
Swedish participants: Bengt Sundén and Martin Andersson.

Chaired by VTT (Finland)

- The aim is the continuation and intensification of the open information exchange to accelerate the development of SOFC towards commercialization.
- Members: Denmark, Finland, France, Germany, Italy, Japan, Korea, Netherlands, Russia, Sweden, Switzerland and USA

IEA Annex 32 (SOFC)

- Yearly meetings in connection to global fuel cell conferences
  - Proving a good overview of the state-of-the-art of development and commercialization activities
  - Networking



DOSSIER

THE YELLOW PAGES OF SOFC TECHNOLOGY

International Status of SOFC deployment
2012-2013

Stephen J. McPhail, Luigi Leto, Carlos Boigues-Muñoz

IEA
Implementing Agreement *Advanced Fuel Cells*
Annex 24 – SOFC

Outcome Annex 24 (currently annex 32)

Updated version expected to be published in January 2017. Presents SOFC companies working at stack and system scale.

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Annex 37 (FC modeling)

The modeling annex aims at developing, maintaining, and applying a suite(s) of open source computational fluid dynamics (CFD) software for application to FCs, electrolysers and other electrochemical applications (hydrogen storage, batteries, etc.) including validation and verification by comparison with other CFD codes, physical experiments and development of "benchmark problems"

Challenges: No joint research funding, i.e., all participants have different aims and priorities, but annex 37 is very good for networking, research discussions, state-of-the-art information.

Annex 37 (FC modeling)

Swedish participants: Martin Andersson and Bengt Sundén.

Chaired by: FZ Jülich (Germany)

2 meetings 2016 (3 meetings 2015, the startup year):

June – Grenoble, France

November – Beijing, China

Members: Canada, China, Croatia, Denmark, France, Germany, Italy, Japan, United States, South Korea and Sweden.

Forecast

- Commercialized FC markets (not necessary SOFCs):
  - Small scale CHP (Japan)
    - Expensive electricity (post-Fukushima)
    - The amount of installations in Germany is increasing (but from low levels)
  - Forklifts (USA)
    - Increased efficiency compared to battery driven forklifts
  - Back-up power (USA, India, China)
    - Needed when grid is not that good.
  - Computer centers (USA)
    - Environmental image and cheap natural gas
  - MW-scale power generation (South Korea)

Forecast

- Expected new FC markets (not necessary SOFCs):
  - UAVs (Unmanned aerial vehicle) - Significant US activities
    - Main advantage is increased mission length (time)
    - Also submarine activities (mainly US)
  - Buses (replacing the main engine) [European demonstration program]
  - APUs (hotel load) for aircrafts. Both Boeing and Airbus have demonstration programs.
  - Very big systems – Mitsubishi aims for 1200-1400 MW triple (SOFC + GT + ST) pressurized systems (in 10-20 years) with 70-75 % electrical efficiency

Thanks for your attention