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

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Outline

- Why SOFCs?
- Application areas for SOFCs
- Current status
- APUs
- SOFC projects with vehicle relevance
- IEA Annex 32 (SOFC)
- IEA Annex 37 (Modeling)
- Forecast

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This presentation is mainly based on

- IEA Annex 32 meeting Glasgow, July 2015
- Electrochemical Society conference “SOFC XIV”, Glasgow, July 2015
- IEA Annex 37 meeting Santorini, October 2015
- IEA Annex 37 meeting Jülich, January 2015

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Why SOFCs?

SOFC has many advantages over conventional power trains:

- High efficiency, especially at small scale
- Fuel flexibility
- Insignificant NOx, SOx and particulate emissions
- Reduced CO_2 emissions
- Silent and vibration free operation

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Application areas for SOFCs

- Mobile and military (< 5 kW_e)
- Auxiliary Power Units (APUs) and back-up power (1 - 250 kW_e)
- Residential CHP (1 - 10 kW_e)
- Stationary medium-large scale (20 kW_e - 10 MW_e)

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Current status SOFC

- Life times over 70,000 hours reached (Oct 2015) for stack in laboratory environment (FZ Jülich).

Prof. Ludger Blum (IEK-3), Dr. Norbert H. Menzler (IEK-1), Dr. Jürgen Malzbender (IEK-2), Dr. Bert de Haart (IEK-9) and Nikolaos Margaritis (ZEA-1)

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Current status SOFC

- The efficiency and electrochemistry issues of SOFC are essentially solved: the state-of-the-art SOFC show reasonable efficiencies and stable electrochemical performance.
- Electrical efficiency over 60% (LHV) achieved for residential SOFC in a combined heat and power (CHP) system (CFCL 1.5 kW system (currently owned by Solidpower)).
- Cost still remains as the major barrier to SOFC systems' commercialization.

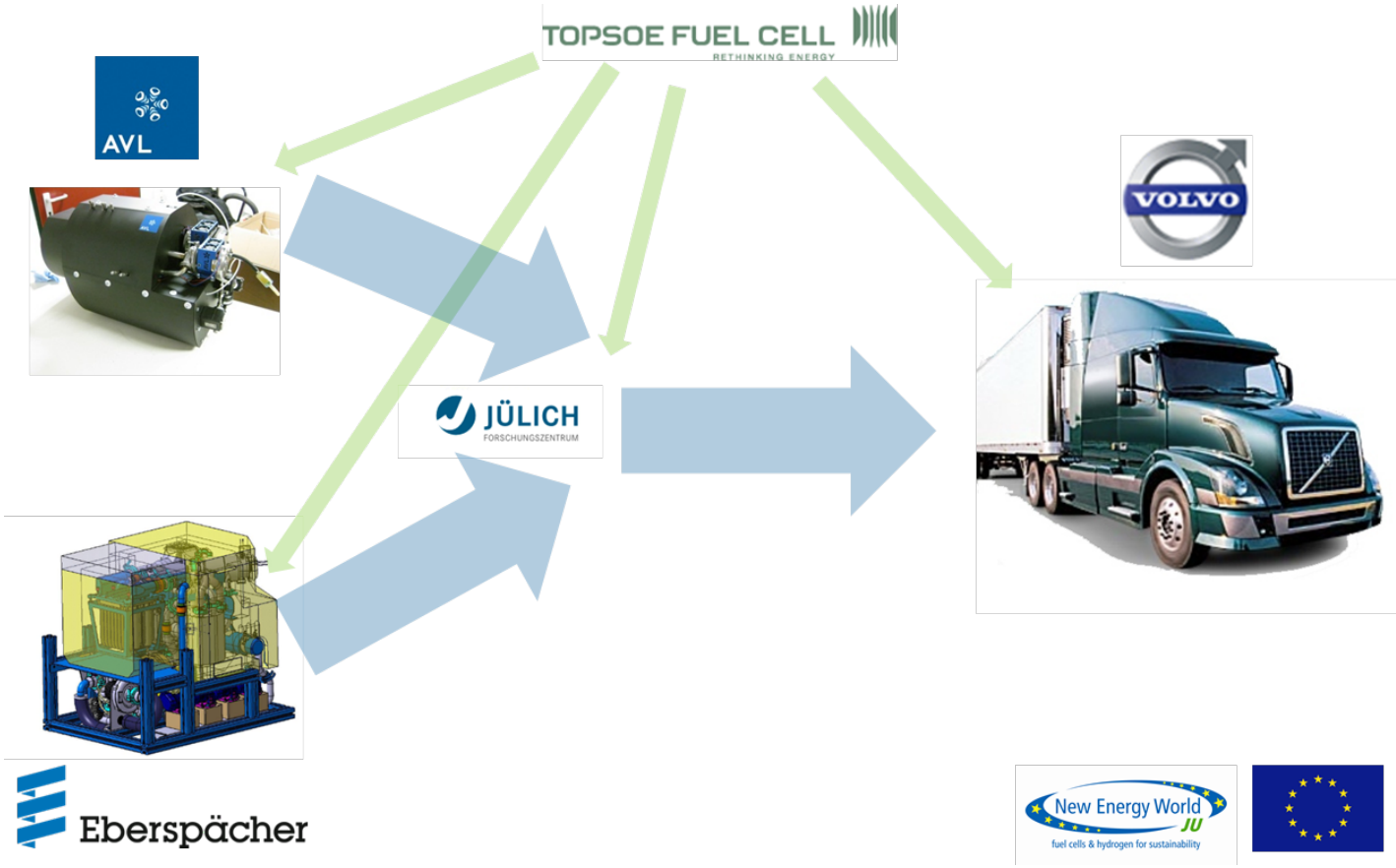
Motivation for APUs in heavy duty trucks

- Existing fuel infrastructure
- Legislation (idling, NOx)
- Comfort (vibration, odor)
- Large potential market

European funding for APU project DESTA (finished June 2015)

- Aims for 100% European Value chain for an SOFC APU truck application for the US market

- AVL
- Ebersprächer
- TFC
- Volvo
- FZ Jülich



DESTA

- EU project DESTA (SOFC APU for trucks)
  - 100 % European value chain

Specifically **technical objectives** demonstrated with the DESTA SOFC APU system:

- Maximum electrical power 3kW
- Operation on conventional road diesel fuel
- Expected lifetime verified in long-term tests and with statistical methods to reach >20,000h (20,000h lifetime is equal to ~5,000 APU operating hours in a typical truck operating profile)
- System electrical net efficiency around 35%
- System volume and weight below 150L and 120kg
- CO2 reduction of 75 % compared to engine idling of a heavy-duty truck
  Start-up time of ~30min
- Noise level ~65dB(A)

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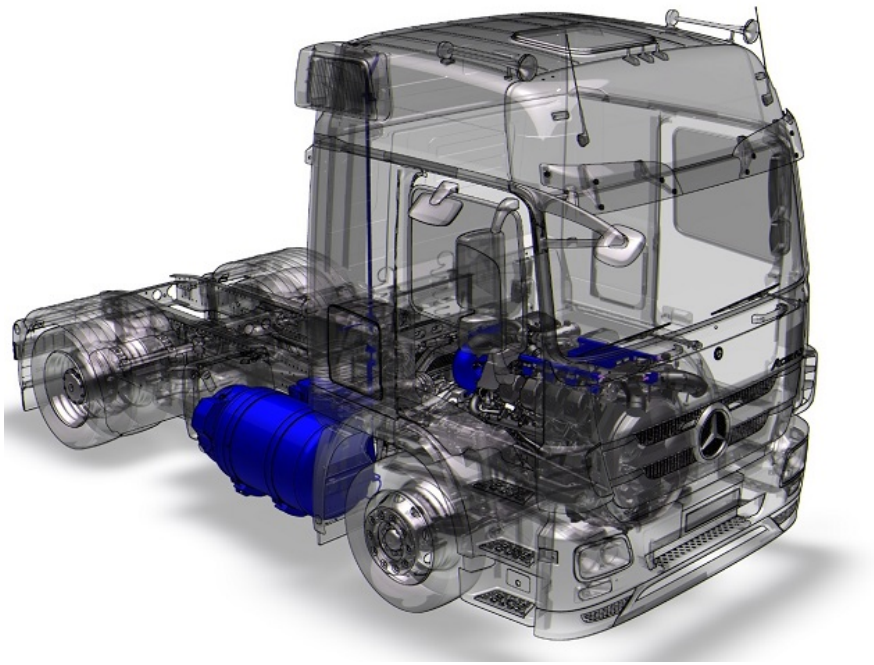
FCH-JU projects – SAFARI (2014-2016)

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



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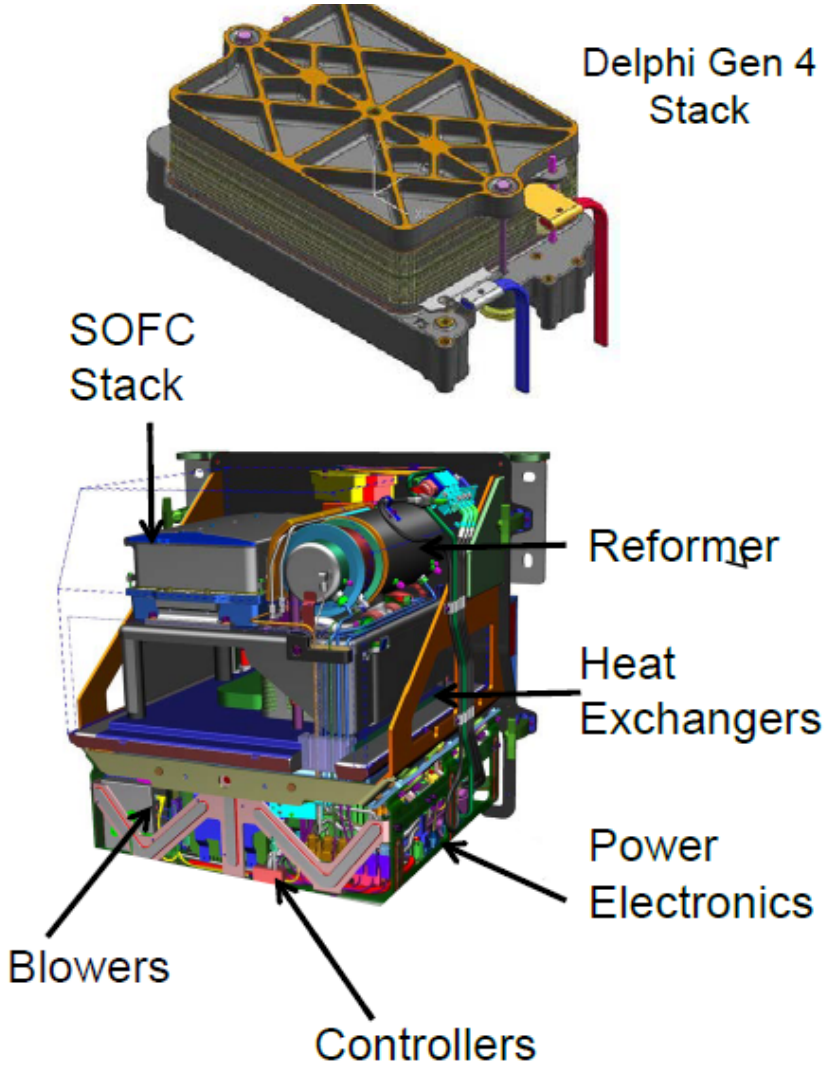
Example Delphi (SOFC APU)

- Research supported by US DOE
- Current NHTSA/EPA Fuel Economy Standards does not mandate an APU, but requires the main engine to be shut off.
- Advantages in terms of low noise, high electrical efficiency
- Main problems relate to desulfurizer (removed from test system)
- Some federal funded projects recently finished, but it is unclear what is the next step (larger scale demonstration or more research)



Additional SOFC APU manufacturers

- **Elcogen (Finland/Estonia)**
  - Low operating temperature
  - Cooperation with VTT
- **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

Still only minor players

FCH-JU projects – SUAV (finished 2014)

Microtubular SOFC Power System into a Mini-UAV, with:

- 100-200W mSOFC stack
- A fuel processor converting propane into suitable SOFC fuel
- Integrated into a mini Unmanned Aerial Vehicle platform

Participants: HyGear Fuel Cell Systems, Adelan, Catator (SE), CNR-ITAE, EADS, Efceco, University of Birmingham, Survey Copter, ZUT

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Dutch project – The Green Village

Announced 2012, building phase since 2013

Car Park demonstration unit being built at Delft with significant industrial participation

- SOFC as a reformer for hydrogen production
- FCEVs for power production in a centralized system: 40-60% electrical efficiencies

- Products: Electricity, District heating, Water, Hydrogen (Mobility)

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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, S. Korea, Russia, Sweden,

IEA Annex 32 (SOFC)

- Yearly meetings in connection to global fuel cell conferences
  - Proving a good overview of the status 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

(previous annex 24 = current annex 32)

New issue with more shared participation planned for July 2016 (press conference planned at SOFC Forum in Luzern)

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Annex 37 (FC modeling)

openFuelCell

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The Project

The openFuelCell project is a forum to develop open source computational fluid dynamics (CFD) software to model fuel cells. Fuel cells http://en.wikipedia.org/wiki/Fuel_cell are devices that convert hydrogen and oxygen to water and electricity, and are promising renewable energy conversion devices. Computational fluid dynamics tools are used to size and rate fuel cell systems. OpenFoam is an open source CFD toolbox, available for downloading at http://www.openfoam.com/, written in C++ and conforming to the object-oriented paradigm.

Members

The project is open to anybody who wishes to apply or produce open source fuel cell models. The founding members of the openFuelCell project are (in alphabetical order) Forschungszentrum Jülich, National Research Council Canada, Queen's University/Royal Military College Fuel Cell Research Centre, and Wikki Ltd.

Models

There are various types of fuel cells under development; at the present time the openFuelCell project is centred on solid oxide fuel cells (SOFCs). The first model to be released is a model of a single-cell SOFC operated in co-flow, counter-flow, or cross-flow with hydrogen and water on the fuel side, and dry air as the oxidant. It is envisaged that modules of polymer electrolyte membrane fuel cells (PEMFCs) and other fuel cell designs will be added, in time. These could include stack level models (multiple fuel cells connected in series), micro-scale models for computing effective property values, and models where the full ionic and electronic electric potential fields are considered.

Annex 37 (FC modeling)

Swedish participants: Martin Andersson and Bengt Sundén.

Chaired by: FZ Jülich (Germany)

4 meetings this year:

January (start-up in Jülich)
April – Grenoble
September – Greece
December – Italy

Current active members: Croatia, Denmark, France, Germany, Italy, Netherlands, S. Korea, Sweden, USA.

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Annex 37 (FC modeling)

Subtask 1: Code development. Open Source.

Subtask 2: Experimental validation, SOFCs and PEMFCs.

Subtask 3: Model equations – best practices.

Examples of activities of members in Annex 37

Germany (FZJ):	Open Foam PEFC modeling including parallelization
Sweden (LU):	Open Foam PEFC modeling with focus on two-phase flow
EC (JRC)	PEFC modeling benchmark data base
Croatia (U Zagreb)	Open Foam code development
USA (Berkeley)	PEFC modeling review
Denmark (DTU)	Connections to EU FCH-JU PROSOFC project
France (CEA)	Open Foam PEFC modeling
Italy (ENEA)	Standarization of SOFC test procedures

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Summary and Conclusions

- Several different companies (AVL, Delphi, Adelan etc.) developed SOFC based APU systems, which have been tested within public funded programs
  - Public funded big scale (at least 1000 units) demonstration program needed before commercialization can take place

- Life time of 70,000 hours achieved for stationary SOFC at FZJ in Germany

- Electrical efficiencies above 60 % (LHV) for a 1.5 kW system archived by CFCL (currently owned by Solidpower)

Forecast

- Expected new FC markets (not necessary SOFCs):
  - Buses (replacing the main engine)
  - Refrigeration (on-board vehicles)
  - Range extenders (on-board vehicles)
  - Media, i.e., sending TV from remote locations.
  - Harbors and Airports (legislations considering CO_2, NO_X, noise, etc)
  - APUs (hotel load) for aircrafts. Both Boeing and Airbus have demonstration programs.

Thanks for your attention