Abstracts for 9th progress in Fuel Cell Systems 31 May & 1 June 2016 - Bruges, Belgium

Organized by:
Title: Smaller and more efficient balance of plant with high speed centrifugal compressors

Presenter: Christof Zwyssig

Organization: Celeroton AG, Switzerland

Abstract:

Volume, weight and efficiency are decisive factors for any fuel cell system whether used in domestic applications, in cars, in the air or in space. Among all components of the Balance of Plant (BoP) of a fuel cell system, the air compressor on cathode side usually consumes the biggest amount of electrical power and accounts for the biggest weight and volume. Furthermore, in some fuel cells systems, especially larger power stacks and/or SOFC systems, a second compressor is employed for the recirculation of the hydrogen on anode side. Therefore, the choice of the compressor technology is important for overall efficiency, size and weight optimization, especially required for mobile but also important for stationary applications. A fuel cell system overview depicting the location of the compressors is shown in Fig. 1.

High-speed centrifugal compressors, also called turbo compressors, achieve the performance levels of conventional scroll or positive displacement compressors but with up to 50 times less volume and weight, and double the efficiency of side channel blowers at up to 10 times less volume and weight. Also on other important factors for fuel cells, such as control response time, pressure fluctuations, noise and vibration generation, centrifugal compressors are superior compared to other compressor technology. Finally, oilfree air supply can be achieved by employing air bearings, also guaranteeing extended lifetime. A more elaborate comparison of compressor technology for fuel cells can be found in [1] and [2].

In this presentation, an overview some key aspects of high-speed centrifugal compressors will be highlighted. First, an overview about achievable specifications such as pressure ratios, mass flow range, inlet temperatures and gas compositions will be given. This includes a discussion of special concepts when exceeding typical centrifugal compressor specification ranges, e.g. stacking of turbo compressor stages to achieve higher pressure ratios or customized thermal concepts for high temperature operation. Secondly, the typical characteristics of a centrifugal compressor, called the compressor map (Fig. 2), will be analyzed with regard to the operation in a fuel cell system. This includes drawbacks and advantages of control schemes (e.g. with or without back pressure valve) and avoidance of operation below the surge line. Finally, the special requirements for a converter driving the compressor in a fuel cell system are discussed.

REFERENCES
Fig. 1. Typical architecture of fuel cell system with compressors for air supply and hydrogen recirculation.

Fig. 2. Compressor map of the CT-17-700 compressor showing the prohibited surge area (red) below the surge line.
Title: Optimized rSOC plant concept and design challenges

Presenter: Matthias Frank

Organization: Forschungszentrum Jülich GmbH, Germany

Abstract:

Renewable energy resources such as wind and solar are by nature intermittent, electrical energy production isn’t, but power must be available at any time. A possible solution, investigated at Forschungszentrum Jülich, to solve this time discrepancy between production and demand are reversible solid oxide cells (rSOC). An rSOC can operate either in electrolysis (SOEC) mode, where electricity is converted into chemical energy (i.e. an easily storage gaseous fuel); or in fuel cell (SOFC) mode where the fuel is used to produce electricity.

The presented rSOC plant concept was developed at Forschungszentrum Jülich. It is based on hydrogen, air and steam; all three are environmentally friendly. An additional requirement is that the plant should be independent from external heat and steam supply. This means that the steam for the SOEC mode is produced by an electrically driven evaporator inside the plant and the energy needed for the steam generation is taken into account in the efficiency calculations. Hydrogen which is produced in SOEC mode is separated from steam and stored in a pressure tank within the rSOC plant.

However, in order to develop an even more efficient system, internal heat recovery was investigated. All high temperature components were grouped into one isolated assembly known as integrated module. Forschungszentrum Jülich had previously developed an integrated module for an SOFC application and the rSOC module was being developed on the same structure.

In addition, to optimize the process and increase efficiency, an off gas recirculation has been included in the rSOC plant. This means that the stack off-gas (on fuel side) is recycled which allows higher system fuel utilizations in SOFC mode. In SOEC mode hydrogen can be provided by off gas recirculation and needs not to be taken out of the hydrogen tank.

The final rSOC plant concept will be shown and the current design challenges will be discussed. Additionally, simulation results of the entire rSOC plant and the model structure will be presented.
Title: Grid connection of fuel cell systems

Presenter: Juhamatti Korhonen

Organization: Lappeenranta University of Technology, Finland

Abstract:

Connecting a solid oxide fuel cell to a grid conventionally requires two stages of electrical power conversion. Typically the first one is an isolating DC/DC converter. This converter is used to provide isolation and protect the fuel cell from harmful electrical interference. It is also used to boost the voltage from the fuel cell operating voltage to a proper level so that it can be used to feed the grid.

The second stage is the DC/AC converter, called an inverter. This presentation focuses on the different aspects of grid inverters feeding a low voltage grid. A conventional method to implement a grid inverter is a two-level inverter. It is the simplest solution, but increasing the number of voltage levels of the inverter will improve the power quality. When the number of output voltage levels is increased, the number of switches in the inverter is increased accordingly. The benefit of making the inverter and its control more complex is that the efficiency of the inverter is better while gaining improved power quality.

The three-level inverter also allows another approach to limiting electronic interference. The inverter can be controlled so that it does not produce any common-mode voltage. Elimination of common-mode voltage is especially beneficial, as it is harmful for the fuel cell stack. This method may be used to get rid of the isolating transformer of the DC/DC converter.

![Figure 1. Block diagram of an electrical system that is used for connecting a fuel cell to grid.](image1)

![Figure 2. Two-level voltage waveform (blue) and the sinusoidal reference (red).](image2)

![Figure 3. Three-level voltage waveform (blue) and the sinusoidal reference (red).](image3)
Title: Industrial size demonstration of biogas fed SOFC

Presenter: Andrea Lanzini

Organization: Politecnico di Torino, Italy

Abstract:

The DEMOSOFC project aims to demonstrate the technical and economic feasibility of operating a 174 kWe SOFC in a wastewater treatment plant (WWTP).

The fuel for the three SOFC modules (3x58 kWe) is locally available since biogas is produced from the anaerobic digestion of sludge collected from the treated wastewater. Electricity produced from the SOFC is consumed inside the WWTP and will cover about 30% of the overall electricity demand. A heat-recovery loop allows recovering useful thermal energy from the hot SOFC exhaust (90-100 kWth). The heat recovered is transferred through a water loop to the sludge, which must be pre-heated to 40-45 °C prior to feeding the digester. Hence, a full thermal recovery within the WWTP is also achieved. The first SOFC modules will be delivered by the end of 2016, and the demonstration phase will last then 4 years.

The integrated biogas-SOFC plant will includes three main units: 1) the biogas clean-up and compression section; ii) the SOFC power modules; and iii) the heat recovery loop.

The scope of the project is demonstrate the high-efficiency conversion of renewable fuel into electricity and heat. The expected net electric efficiency of the SOFC is in the range 52-55%.

A special focus of the demonstration is also on the deep and reliable removal of contaminants (mostly H2S and siloxanes) found in the raw biogas. In-line and real-time gas analysis will be deployed to monitor the removal efficiency of the adsorbents.

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1 www.demosofc.eu
Title: Car as power plant: Integrated transport and electricity system design for smart cities

Presenter: Vincent Oldenbrook

Organization: Technical University of Delft, The Netherlands

Abstract:

Nowadays Fuel Cell Electric Vehicles (FCEVs) have efficient fuel cells of approximately 100kW. These fuel cells convert hydrogen into electricity when driving, but could also supply electricity when parked when connected to the grid with V2G technology (Vehicle-to-Grid, Figure 1). Cars are parked over 90% of the time. When parked, could FCEVs provide back-up power and energy storage in transport and electricity systems based on intermittent renewable energy. So cars become mobile power plants.

The main research question investigated is: Can solar and wind electricity together with fuel cell electric vehicles and hydrogen as energy carrier, provide a 100% renewable, reliable and cost effective energy system, for power, heat, and mobility for smart cities?

Following approach is taken to answer the research question:

- Design an integrated energy and transport system for smart cities based on EU statistics
- Perform energy and mass balance analysis on an annual and average day basis
- Conduct an economic analysis for system energy and mobility cost
- Scenario analysis: Energy technology and cost development scenarios

A fully renewable integrated transport and energy system is designed, where hydrogen powered fuel cell cars provide all electricity services such as scheduled electricity production, balancing, operating reserve, and emergency power. The future smart city consists of approx. 2000 dwellings with several offices, shops, schools, sport facilities and other buildings (Figure 2). The smart city is a statistical representation of the European Union built environment. All types of vehicles are hydrogen fuel cell powered.

Energy consumption in buildings is all-electric. Heating in buildings is provided through efficient electric driven heat pumps in combination with aquifer thermal energy storage or electric resistance heaters. Solar panels on all rooftops are one of the electricity sources. In case of temporary surplus solar PV electricity, electricity is stored into hydrogen through water electrolysis. The solar panels collect rainwater. After purification via reverse osmosis, rainwater can be used for hydrogen production. Distant on-shore or off-shore wind turbines produce sufficient hydrogen to cover year round energy needs. Hydrogen can be used as fuel for the vehicles in the neighbourhood or as fuel for electricity in case of insufficient electricity supply by the solar PV panels. The FCEVs provide back-up power at night and import energy in the form of hydrogen from the distant wind turbines.
Title: APU system based on HT-PEFC technology and diesel fuel processing

Presenter: Reemzi Can Samsun

Organization: Forschungzentrum Jülich GmbH, Germany

Abstract:

Using new technologies for electrification of on-board consumers in different vehicles in the transportation sector can lead to emissions reduction and fuel savings. High ground emissions of aircraft due to the low efficient operation of the gas turbine based auxiliary power unit (APU) and the idling operation of the long haul sleeper trucks during the night stop can be identified as two possible application areas with a demand on new technologies. Fuel cell based auxiliary power units can offer low fuel consumption and low emissions in both cases. The operation of fuel cells on reformate after proper fuel processing makes it possible to use the available fuel on board, which is kerosene type jet fuel for aircraft and diesel fuel for trucks.

Worldwide, SOFC, PEFC and HT-PEFC technologies are being developed for this purpose. This contribution reports on the development of APU systems based on the HT-PEFC technology at Forschungzentrum Jülich. An integrated fuel cell system was developed using the stack and fuel processing technologies from Jülich on a 5 kW_e power class. The core components of the system are an autothermal diesel reformer, a two-stage water-gas shift reactor, a catalytic burner and two HT-PEFC stacks with 70 cells in total. With the help of the selected system design and operation strategy, it was possible to operate the system at its design point without external heat input for the fuel processor. The 5 kW_e power level was achieved using different fuel qualities including GTL kerosene from Shell, NExBTL diesel from Neste Oil and Ultimate diesel from Aral. System operation was demonstrated for more than 250 hours and many start/stop cycles. Successful test results with the first generation system deliver the proof of concept for the combination of HT-PEFC technology with autothermal reforming on a system level.

Building up on the experience with this system, the next generation of the APU system is currently being developed in Jülich. The second generation system is planned as a self-sustaining system, therefore, the hybridization of the system with batteries is essential to deliver the energy demand during system start. In addition, all balance of plant components must be included in the system. The target power density corresponds to 40 W_e/l which is US DOE’s target for 1-10 kW_e fuel cell auxiliary power units for 2020. This results in an ambitious volume target of 125 l for the 5 kW_e power class. On the complete system side, further heat integration concepts are necessary to achieve a compact system. In addition, new stack concepts with metallic bipolar plates are under development. This measure includes an enormous potential to improve the power density (W_e/l) and specific power (W_e/kg) of the complete system.
Title: Gas processors for LT-PEM, HT-PEM and SOFC systems

Presenter: Hans-Peter Schmid

Organization: WS Reformer GmbH, Germany

Abstract:

Introduction
In stationary applications, efficient, smart and small-scale reformers play an integral role for most FC systems. WS Reformer GmbH has addressed these challenges and presents technology platforms and products for all FC technologies. The presentation intends to initiate an open discussion about concepts, their benefits and drawbacks as well as commercialisation aspects.

Small scale LT-PEM Systems
Steam reforming is the accepted technology, life time of stacks and reformers are proven and the CO fine cleaning problem has been solved, preferably cost-effective by selective methanation (SelMeth). Technical economical potential for electric system efficiency seems to be 40%, while reforming efficiency (based on LHV) meets 82%. Compared to the numerous components the catalyst on the stack does not play a dominant role for overall cost. As an example, the features of the FLOX micropower system are highlighted and scaling options of the reformer are discussed.

Questions: Although materials and components are standard and cost effective, the complexity puts some burdens on the bill of materials. Do we meet target cost at reasonable production quantities and what are the parts and subsystems, which could be engineered out from the current state-of-the-art?

The HT-PEM Option
HT-PEM systems promise a less complex system design and knock at the door of the market (elcore, Truma). Steam reforming also sets the scene, reformers are available and just miss the CO fine cleaning step. Open issues seem to be the life-time and degradation of the MEA, particularly for CHP applications. The efficiency drawback, respectively reduced power density compared to LT-PEM stacks can be compensated by smart thermal integration of reformer and stack. A drastically simplified system design, revealing minimum number of BOP components has been demonstrated and will be presented.

Questions: Obviously, PBI-based MEA designs are more complex than the LT-PEM version. Can this be compensated by the reduced system complexity and is the small HT-PEM community able to follow the LTPEM train, driven by the automotive industry?

SOFC Gasprocessors
There are no doubts, that SOFC systems reveal the highest electric efficiency. Almost 60% have been demonstrated – but only if steam reforming is the choice. Anode or electrolyte supported designs, including operation temperatures are in competition. Another open issue is the share of internal (within stack) versus external reformation. Both have got a strong influence on the heat management of cathode and anode gases and thus the gas processor design. However, all concepts need cost-effective and robust heat exchangers for very high temperatures. The presentation reveals the latest development of WS, including a compact and scalable gas processor design for pre-reforming and anode-recycle options in the 10 kW category.

Questions: Gas processing is strongly linked to the current status and choice of the stack technology. A standard solution is therefore not at the horizon. Will there be any in the future? What is the better solution for the scaling of stack power: Cell area, cell number or modularization?

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Title: Theoretical analysis of SOC reactors in highly efficient PtX and PtP systems

Presenter: Srikanth Santhanam

Organization: DLR Stuttgart, Germany

Abstract:

Solid oxide cell reactors are attractive for hydrogen and hydrocarbon generation due to their superior electrical efficiency and fuel flexibility. In a Power to X (PtX) system where X stands for final form of end product such as gaseous fuel or liquid fuel enables storage of electricity in chemical form. In reversible mode SOC are also discussed as an interesting option for electric energy storage as a Power to X to Power (PtP), X is the intermediate form of energy storage either has Hydrogen or hydrocarbons in gaseous or liquid form.

A theoretical study is performed to highlight interesting aspect of endothermic operation of a SOC reactor during electrolysis mode and how it can be achieved. An analysis of simple PtP systems is presented for energy storage. Efficiency of the system is quantified as a function of system operating parameters such as Temperature, Pressure, Current Density, extent of reaction etc. The analysis presents the maximum efficiencies of such PtP systems that can be realised with current SOC reactors and possible future state of art SOC reactors.
Title: Integrated air pre-heater and anode off gas oxidizer

Presenter: Yves De Vos

Organization: Bosal ECS NV, Belgium

Abstract:

The performance of a cathode air preheater with internal off-gas oxidation is presented. This component is a plate heat exchanger, handling both injection and oxidation of depleted anode gas in the hot cathode flow. The gas mixture oxidizes in the heat exchanger, and the reaction heat is used to preheat cathode air.

An initial integration effort using two separate components is reported. The system consists of close coupled injector and a downstream plate heat exchanger, which was catalytically coated. The performance was constrained by reaction kinetics: the off-gas and cathode mixture typically ignites within 5 – 10 ms at mixture temperatures above 750°C.

CFD on this system show that part of the mixture takes more than 15 ms before reaching the inlet port of the heat exchanger, leading to early ignition. Both CFD and SEM analysis showed that the walls of the heat exchanger overheat to 1000 – 1100 °C. The SEM analysis reveals the effect of this overheating on scale growth and evaporation of Cr VI in the heat exchanger, and its subsequent condensation on the cool, catalytically coated walls.

The integrated HEX and oxidizer consists of an internal injector, which delivers the anode gas to each cathode flow path between pairs of heat exchanging plates. The injection occurs adjacent to a catalytically coated zone in the heat exchanger. The CFD effort covers the combined effects of injection, mixing, generation of reaction heat and heat exchange. The results show that the injection and subsequent mixing is uniform. The mixture reaches the cooled sections of the heat exchanger within 3 ms, and thus below the auto ignition time. These calculations are in line with experimental performance data on the integrated component.

![Fig. 1 Flow lines of the injected anode off-gas, colored by elapsed time since injection.](image)
Title: SOFC-Generator fleet in field testing

Presenter: Matthias Boltze

Organization: New Enerday GmbH, Germany

Abstract:

Increasingly unreliable power grids, exploding energy prices and increased environmental awareness require alternative solutions for the power supply. There is a demand for reliable, energy-efficient and environmentally friendly energy generators. The new enerday GmbH is a young company developing and producing compact and highly efficient SOFC systems for off-grid and back-up power solutions on the basis of logistic and worldwide available fuels. With 10 years’ experience from a former SOFC development program at a leading automotive supplier in Germany, the team at new enerday continued with a focused product development in the new company founded end of 2010. The compact and energy efficient SOFC-modules by new enerday can be used for different off-grid and back-up power solutions, for example in order to protect critical infrastructures against longer lasting blackouts or for the autonomous power supply at off-grid locations in combination with or as a supplement to photovoltaic or wind-power systems.

Some key figures of the SOFC-modules are:

- Use of logistic fuels like propane/butane (LPG) as well as natural gas
- Scalable power range of 200 – 650 W DC
- No internal or external handling of liquid water for reliability and freezing conditions
- Dry CPOX (catalytic partial oxidation) reformer concept
- Designed life time of more than 5,000 hours and more than 150 start-up cycles
- Robust mechanical design for mobile applications
- Wide temperature range of -25 … + 50 °C for indoor and outdoor applications
- Net electric efficiencies of more than 32% over a wide power range

In the last three years a number of system generations were built and tested at new enerday and in customer applications. Relevant system components were successfully tested for more than 10,000 hours. Complete fully integrated systems showed stable system operation for more than 5,000 hours and more than 100 system cycles with power degradation rates below 5 %. For a number of target markets, these results are sufficient for a market entry.

Facing a growing customer interest in complete energy solutions for off-grid AC power as a substitute for diesel gen-sets, new enerday developed and tested such a solution called PowerTrailer or PowerBox. A fleet of 15 generators is operated by new enerday on a rental basis in real world customer operations. This expanded field test is carried out at different European locations.

Latest development results for the SOFC Modules and internal components as well as first field trial results of the generator fleet will be presented and discussed during the Workshop.