Advanced Solid Oxide Fuel Cell Stack for Hybrid Power Systems

ARPA-E (INTEGRATE) Project, Award No. DE-AR0000956

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Nexceris, LLC

- Founded in 1994 as NexTech Materials, privately held
- Technology Developer – advanced ceramics, electrochemical devices
- Product Developer – sensors, fuel cells, and catalysts
- Manufacturer/Distributor – sensors, fuel cells, and related products
- ISO 9001:2015 Certified – covers all products and services

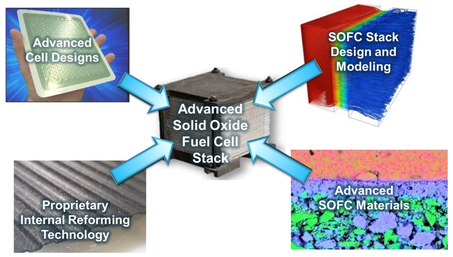
Nexceris History in Solid Oxide Fuel Cell Technology

- **1994:** Company founded, initiated SOFC materials development
- **2000:** Established **fuelcell**materials division, began selling products
- **2004:** Established novel planar cell designs (three patents)
- **2006:** Initiated SOFC stack development for military applications
- **2011:** Developed interconnect coatings to improve SOFC durability
- **2015:** Established high power density SOFC stack design
- **2018:** Initiated ARPA-E project

ARPA-E (INTEGRATE) Project Overview

In this project, Nexceris is developing a compact, ultra-high efficiency 10 kW scale SOFC stack tailored for hybrid power systems. A bank of such stacks will provide 70 to 80 percent of the targeted 100+ kW of the system, with the balance provided by a turbine or reciprocating engine. To meet system cost targets, the stack will be designed for high performance and fuel utilization combined with internal steam reforming. The stack features a novel repeat unit to simplify sealing, enabling pressurized stack operation. Other design features include:

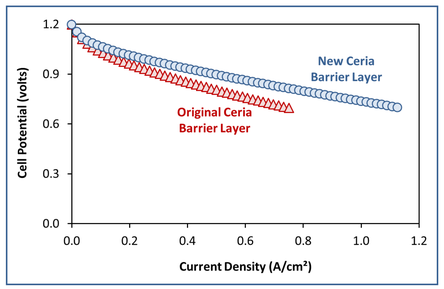
- The stack is being designed for high power density thereby reducing its materials content and cost. Area-specific power density (and efficiency) will be achieved by incorporating advanced electrode materials and architectures.
- The stack is based on a patented planar cell design having the electrochemical performance of anode supported cells and the mechanical robustness and sealability of electrolyte supported cells.
- The stack will be housed in a pressure vessel, with flow-through cathodes with low pressure drop (easing integration with reciprocating or turbine engines).
- The stack will internally reform natural gas using recycled anode exhaust. Novel catalyst technology will be employed to control where reforming occurs, alleviating thermal gradients.

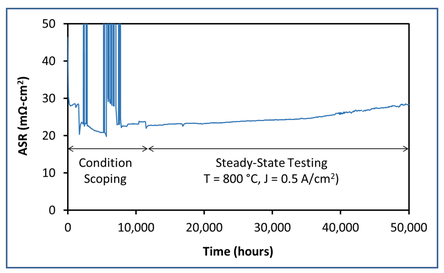


Advanced SOFC Materials and Coatings

Nexceris has demonstrated an approach for greatly improving SOFC performance. The implementation of high performance cathodes, such as $(La,Sr)(Co,Fe)O_3$ (LSCF) requires a ceria barrier layer to prevent formation of a resistive $SrZrO_3$ phase at the cathode/electrolyte interface. Nexceris established an inexpensive spray-based process to apply ceria barrier layer coatings that can be densified with annealing temperatures as low as 1000°C. This is important because higher temperatures lead to a resistive ceria-zirconia interfacial phase, which degrades performance. This ceria barrier layer technology has been used to substantially improve performance of commercial electrolyte-supported cells. Achieving such improvements in SOFC stack performance will be critical when ultra high efficiency is being targeted.

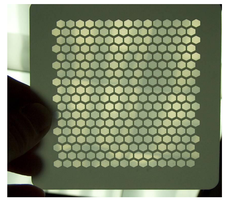
Nexceris has developed a range of protective oxide coatings for metallic stack and balance of plant components. Coating include an electrically conductive manganese cobaltite $(Mn,Co)_3O_4$ (MCO) coating for the air facing, active area of metallic interconnects. Using a cost-effective and scalable aerosol-spray deposition process, a highly protective coating with excellent oxidation and chromium volatility resistance can be achieved. Excellent high temperature stability was demonstrated over 50,000 hours of testing.





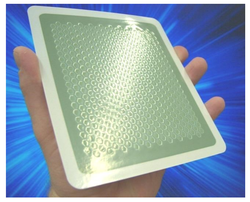
Innovative Planar Cell Designs

The core to Nexceris' SOFC stack technology are two planar cell designs, which offer enabling attributes. The FlexCell is an electrolyte supported planar cell based on a thin electrolyte membrane layer (50-60 µm) that is mechanically supported by a relatively thick (150-200 µm) electrolyte mesh. The Hybrid Cell is similar to the FlexCell, except that a thin porous anode layer (30-40 microns) is incorporated between the support and electrolyte membrane layers. The thinner electrolyte membrane of the Hybrid Cell increases electrochemical performance. A dense electrolyte periphery is common to both cell designs, which greatly reduces sealing challenges.



FlexCell

U.S. Patent No. 8,192,888

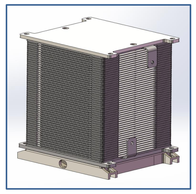


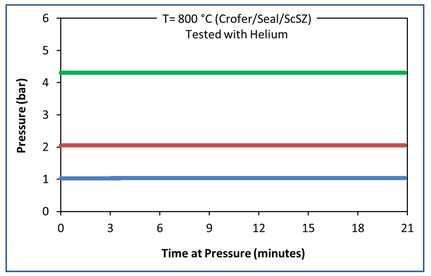
Hybrid Cell

U.S. Patent No. 7,736,787

SOFC Stack Design

With Nexceris' existing military-purpose SOFC stack design as a starting point, a design concept was established for a pressure tolerant, 10-kW scale stack. The stack design retains the external air and internal fuel manifolding features of the starting point stack design. A cell-in-frame approach is being implemented to enable like-to-like sealing at the stack periphery. Work also has been ongoing to develop and implement improved seals that are essential for the stack to be robust to relatively high pressure differentials and perturbations common to hybrid systems. As shown at the right, Nexceris' newly developed thermal-expansion matched seal gaskets are robust to 4 bars of pressure differential.





Seal gasket testing results obtained under ARPA-E Award No. DE-AR0000959 (project led by Stony Brook University)

Internal Reforming Modeling

Nexceris is targeting an SOFC stack that operates via internal reforming of methane at relatively high temperatures. A key challenge of high temperature internal reforming is that nickel based anodes (and current collection components) catalyze reforming of methane immediately as it enters the stack. The endothermic reaction absorbs heat, creating sharp thermal gradients that can cause cell (and stack) failure. For this reason, internal reforming SOFCs usually operate at temperatures below 700 °C, where area-specific SOFC power density is relatively low (which increases stack size and cost). Nexceris' approach is to spatially control the internal reforming process with catalytic coatings, thereby reducing thermal gradients and enabling higher temperature SOFC operation. Also, the use of recycled anode exhaust for internal reforming reduces the extent of reforming, leading to less intense thermal gradients.

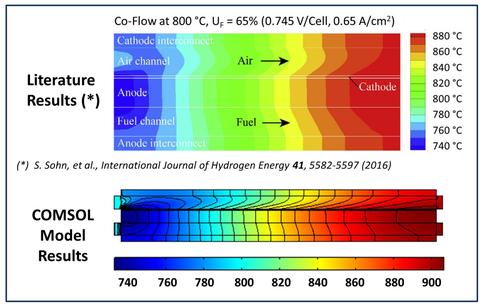
A multi-physics (COMSOL) model was built to guide design of internal reforming catalysts. The model was derived from a literature model of internal reforming in a stack of anode supported cells (ASCs) by making three assumptions:

(1) The anode support in ASCs corresponds to nickel foam current collectors in Nexceris' stack design;

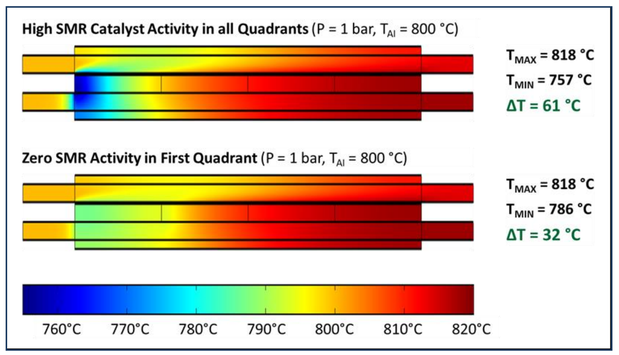
(2) The anode functional layer in ASCs corresponds to the anode in Nexceris' electrolyte supported cells;

(3) Catalyst activity (percent of equilibrium) is assigned to each "anode layer".

The COMSOL model replicated the thermal gradient predicted for a co-flow manifolded stack operating via internal methane reforming (S/C = 3, U_F = 65%). The COMSOL model predicted a thermal gradient of 160 °C, compared to 140 °C for the literature model.



To assess the impact of spatially controlling catalyst activity of anode current collectors, a comparison between current collector having 100 percent catalyst activity (as a percentage of equilibrium) over its entire length and a current collector having zero catalytic activity over the first 25 percent of its length and 100 percent activity over the remainder. As shown at the right, turning off catalytic activity in the first quadrant of the current collector reduced the thermal gradient from 61 to 32 °C (anode inlet temperature of 800 °C). The model also has been exercised to explore the impacts of operating pressure and pressure.



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