High Temperature Electrochemistry Center

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In collaboration with **Montana State University, University of Florida, and National Energy Technology Laboratory**

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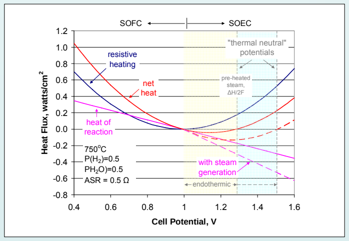
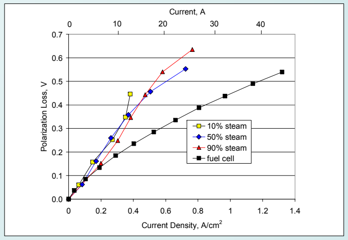
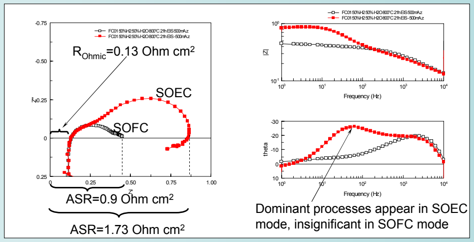
Reversible Fuel Cells provide options for energy storage, producing hydrogen fuel during periods of excess grid capacity, and later convert that fuel to electricity during periods of greater need. The purpose of this research is to examine how electrodic processes and materials stability differ when operated in the electrolysis (SOEC) versus fuel cell modes.



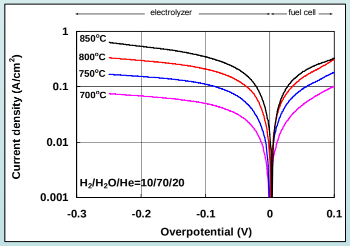
Heat balance in a reversible fuel cell. SOEC operation is exothermic above the thermal neutral potential of ΔH/2F =1.29 V with pre-heated steam and ~1.5 V if steam is produced by resistive heating.



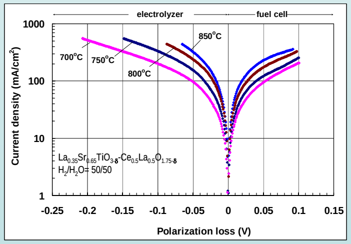
Polarization losses versus current density for an anode-supported reversible fuel cell with a Ni-YSZ fuel electrode, an LSCoF-6428 air electrode, and 7 µm YSZ electrolyte. Area-specific resistances are typically higher in the SOEC direction.



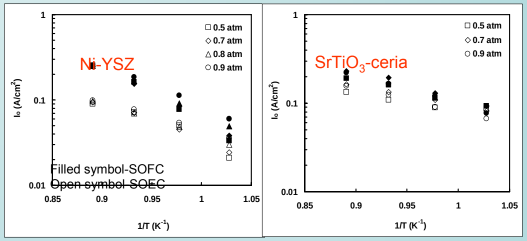
Impedance spectra of a Ni/YSZ-supported cell with LSM positive electrode at 800°C, H2/H2O=50/50, and 0.25 A/cm² (complete cell). Higher losses in the SOEC mode are due to the appearance of additional processes not found in the SOFC mode.



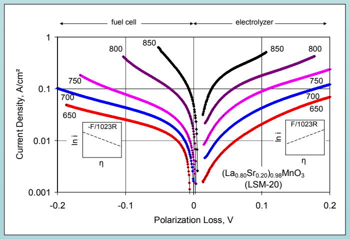
Nickel-based electrodes show similar cathodic and anodic polarization losses at high temperatures, whereas losses are smaller in the fuel cell direction at low temperatures



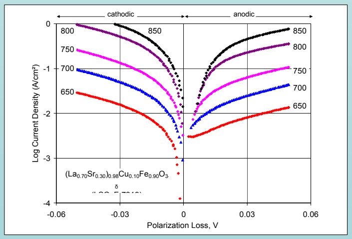
A strontium titanate-ceria composite electrode shows symmetric polarization behavior in cathodic and anodic directions over a range of temperatures



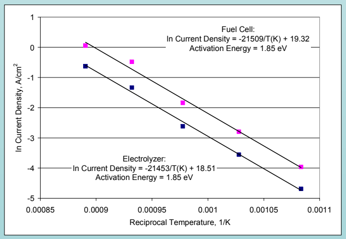
Exchange current density comparison for Ni/YSZ and $SrTiO_3$-ceria composite electrodes. Exchange currents for both electrodes were insensitive to steam concentrations. The ceramic electrode performed similarly in two directions.



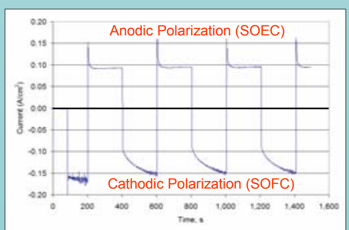
Cathodic and anodic overpotentials versus current density for LSM- 20 on YSZ with a 3 micron-thick SDC interlayer. Higher anodic polarization losses are consistent with expected interfacial oxygen vacancy concentrations.



Cathodic and anodic overpotentials versus current density for LSCuF-7319 on YSZ with a 3 micron-thick SDC interlayer. These active compositions also show higher losses in the anodic than cathodic direction.



Comparison of current densities for a LSCuF-7319 air electrode at a constant polarization loss of 35 mV. Current densities in the cathodic direction are consistently higher, while apparent activation energies remained unchanged



Hysteresis in performance of LSM-20 electrode at 800°C at constant overpotential. Cathodic polarization leads to initially higher anodic performance.

Future Directions:

Reversible fuel cells: Investigate mechanisms of degradation, including operation in high steam concentrations and repeated cycling between SOFC and SOEC modes.

Fuel electrode interactions with coal gas contaminants: Coal gas can contain multiple compounds that can deactivate the fuel electrode.

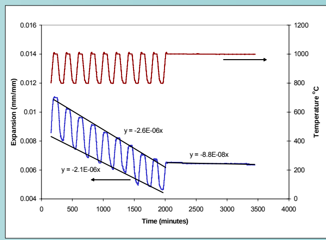
Contact paste development: New contact paste materials are being investigated that show good conductivity, good CTE match to 430SS, and form a strong bond to SS at ~900°C.

High temperature electrochemical capacitors: Investigate charge and energy storage phenomena in composite electrodes. Up to 20 F/g and 15 J/g have been obtained to date.

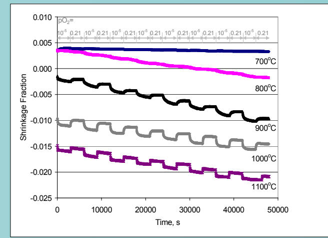
Low-temperature cathodes: Evaluate rare earth nickelate materials as possible cathode materials. These form Ruddleson-Popper structures with high mixed conductivity.

High temperature thermoelectric materials: Enhance thermoelectric yield through optimization of composition and structure of both *p*- and *n*-type oxides.

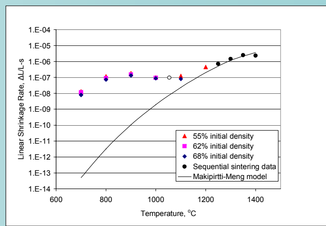
Enhanced Sintering of LSM at Low Temperature: $La(Sr)MnO_{3+\delta}$ previously shown to densify at low temperature when thermally cycled, an effect which can be suppressed through A- and B-site substitutions. The purpose of this research is to investigate possible mechanisms by which LSM may be densified under conditions relevant to SOFC operation.



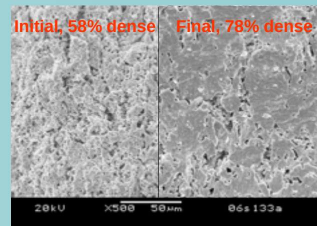
Densification of LSM-10 (62% initial density) is enhanced when thermally cycled between 800 and 1000°C. The shrinkage rate slows when thermal cycling is halted.



Cycling between air and 10 ppm at a constant temperature also leads to densification. Reversible expansion/shrinkage is due to oxygen equilibration.

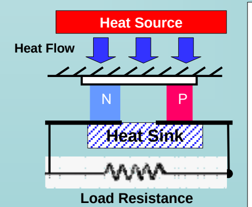


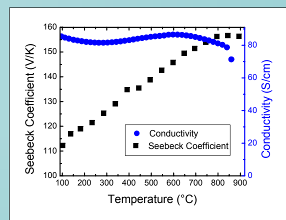
Shrinkage rates are enhanced by orders of magnitude by cycling the oxygen partial pressure below ~1100°C compared to rates expected from high temperature behavior.

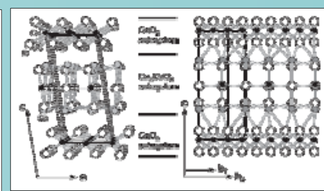


Microstructure of LSM-10 before and after exposure to 300 air-10 ppm O_2 cycles at 800°C (cycle time = 2 hours).

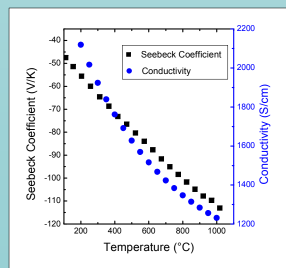
Thermal to Electrical Energy Conversion with High Temperature Thermoelectric Materials: Thermoelectric devices offer one way to recover waste heat from SOFCs and other fossil energy conversion systems. Current research is aimed at developing suitable compositions and forms that are compatible with high temperatures present in fuel cells and other fossil energy conversion systems.

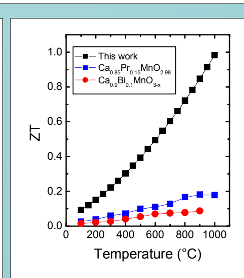




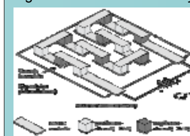


P-type calcium cobaltite ($Ca_3Co_4O_9$) exhibits a layered structure, with high Seebeck yields and good electrical conductivity

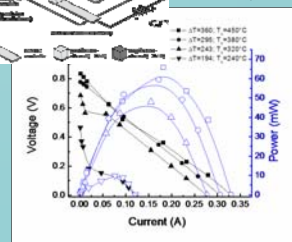




A new n-type indium oxide-based composition has been developed with thermoelectric yields considerably higher than the best known n-type oxides



Power output of device with 11 p and 11 n legs



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