High Performance Flexible Reversible Solid Oxide Fuel Cell

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DE-FC36-04GO14351 Project ID:PDP34

Overview

Timeline

- Project start date: October 2004
- Project end date: September 2006
- Percent complete: 75%

Barriers

- Barriers addressed
  - K. Electricity Costs
  - G. Capital Costs
  - H. System Efficiency

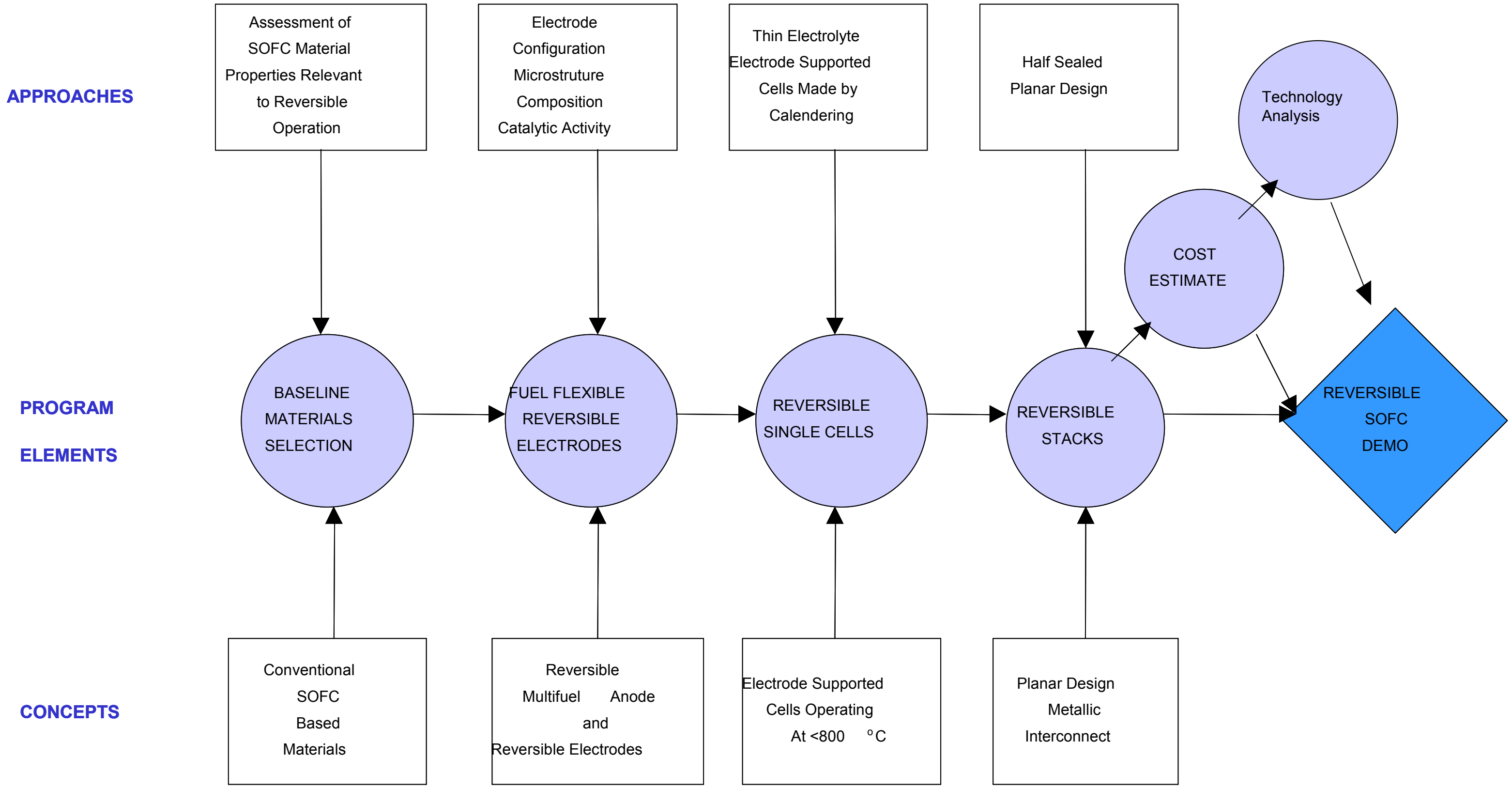
Budget

- Total project funding
  - DOE share: $1,252,683
  - Contractor share: $616,993
- Funding received in FY05: $575,198
- Funding for FY06: $677,485

Objectives

- Demonstrate a single modular stack that can be operated under dual modes
  - Fuel cell mode to generate electricity from a variety of fuels
  - Electrolysis mode to produce hydrogen from steam
- Provide materials set, electrode microstructure, and technology gap assessment for future work

Approaches



Technical focuses:

– Reversible electrode modeling
– Electrode compositions and microstructure engineering

Key challenges:

– Performance for cost and efficiency
– Low degradation for reliability

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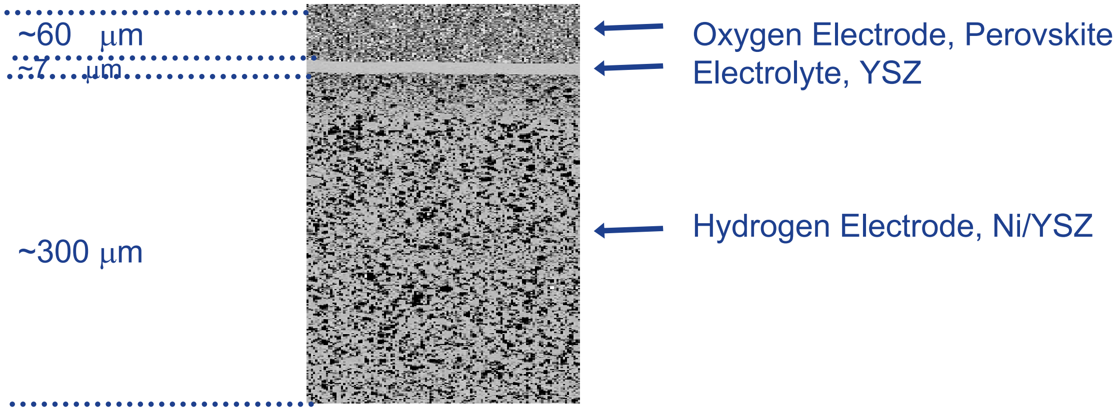
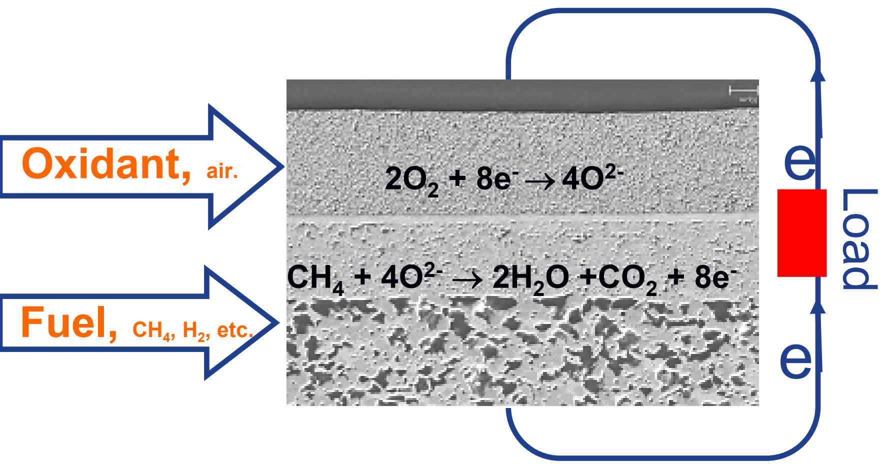
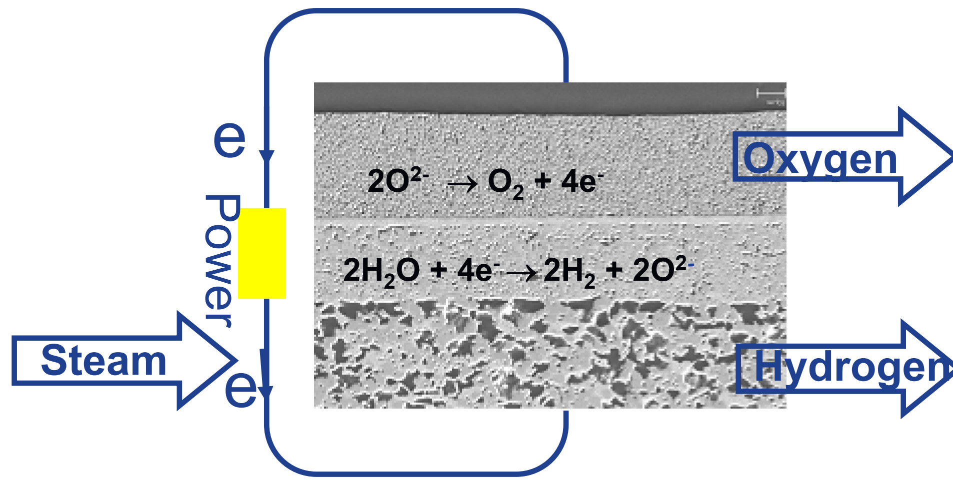
Cell Configuration



Power Generation Mode



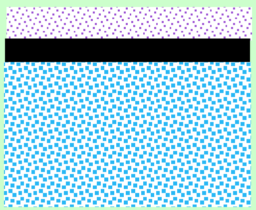
Hydrogen Production Mode



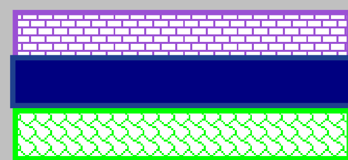
- SOFCs have the flexibility, running under power generation mode and hydrogen production mod
- High temperature solid oxide steam electrolysis can lower the electricity consumption

Stack Configuration

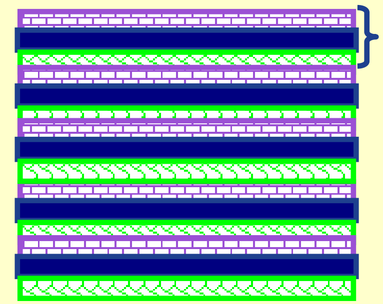
Cell

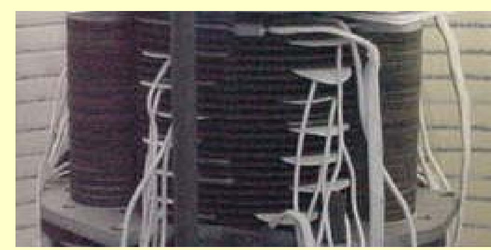


Module

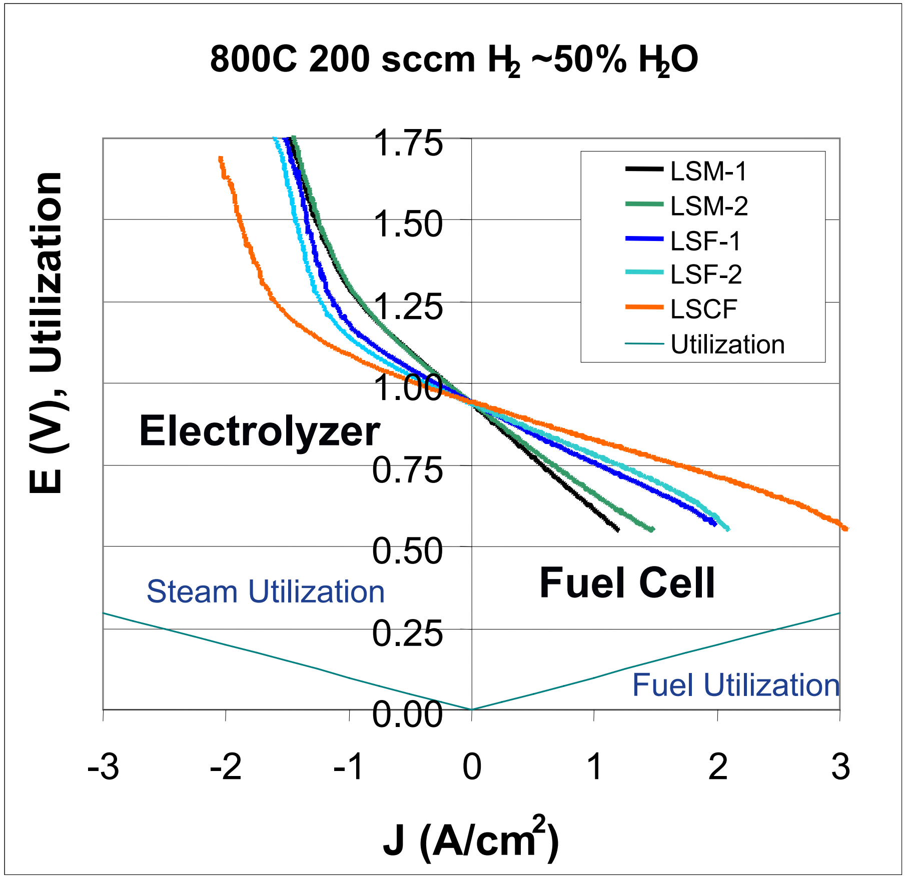


Multi-cell Stack





Oxygen Electrode Performance



- **Screened several lanthanum strontium manganites (LSM), lanthanum strontium ferrites (LSF), and lanthanum strontium cobalt iron oxides (LSCF) as oxygen electrodes**
- **Under both modes, electrode performance increases in the order of LSCF>LSF>LSM/YSZ**

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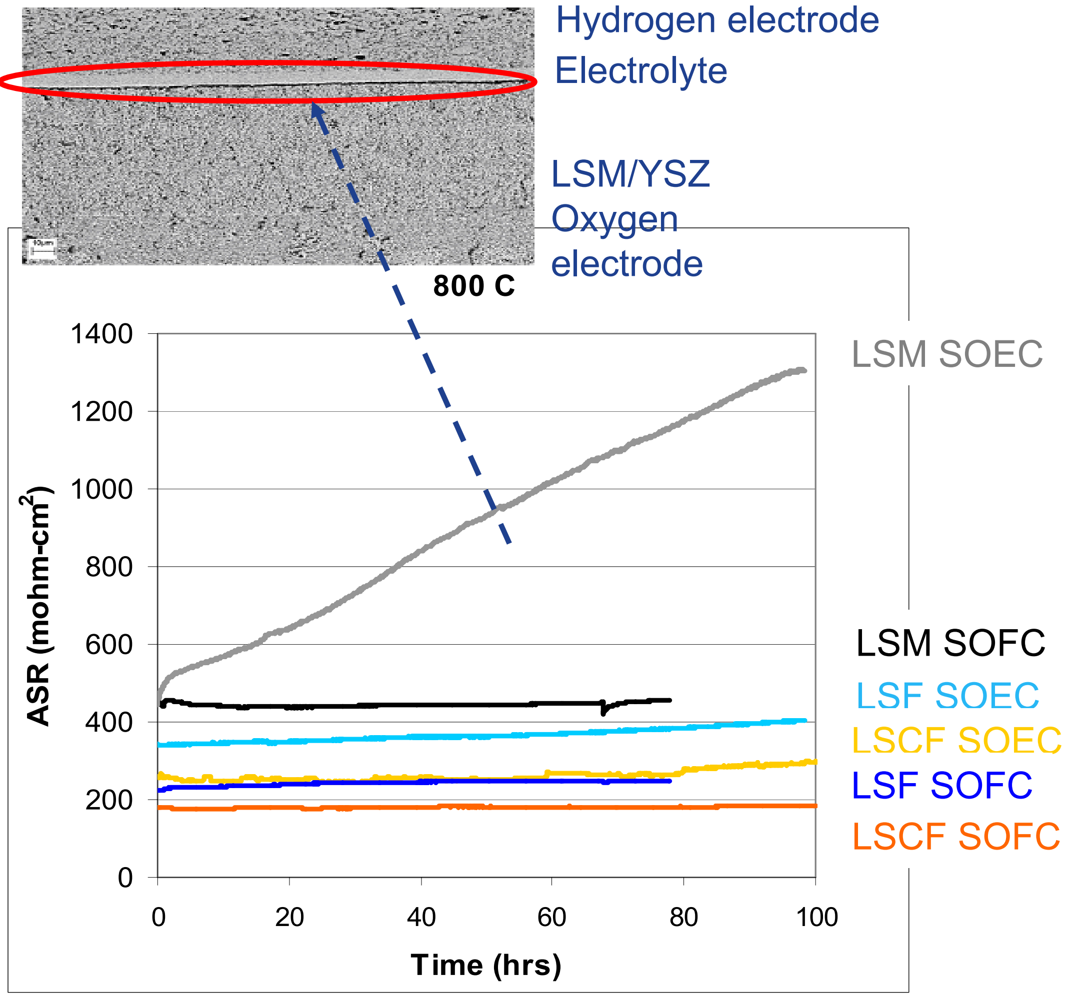
Oxygen Electrode Performance Stability



- **Excess performance degradation was observed with LSM/YSZ as the oxygen electrode in electrolysis mode (SOEC) mainly due to electrode delamination**
- **LSCF and LSF showed better performance stability in electrolysis mode than LSM/YSZ electrode**

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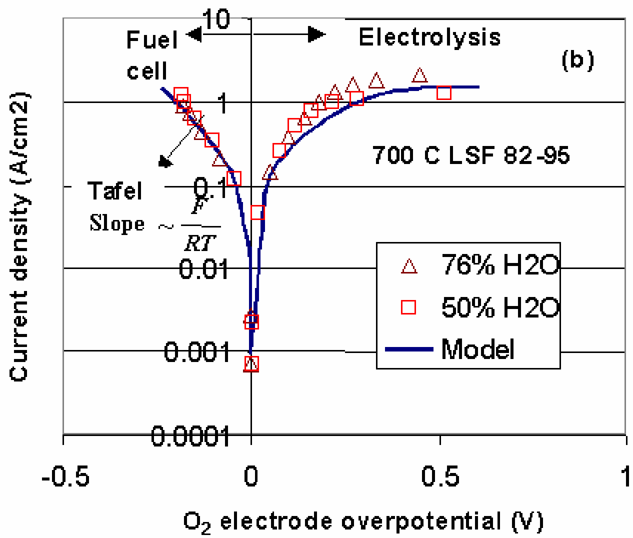
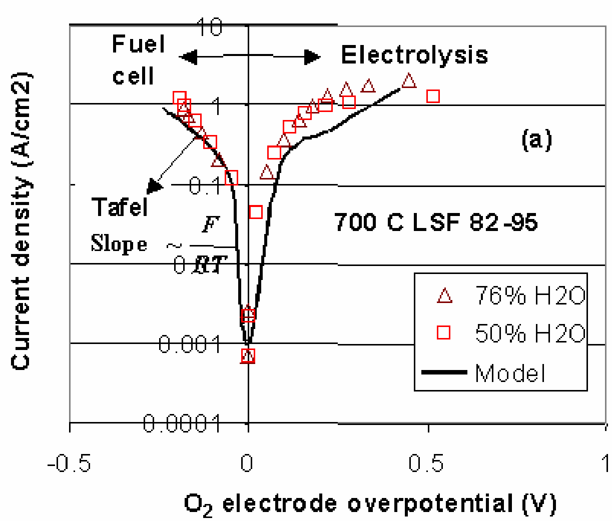
Oxygen Electrode Reversibility

Non-symmetrical vacancy model

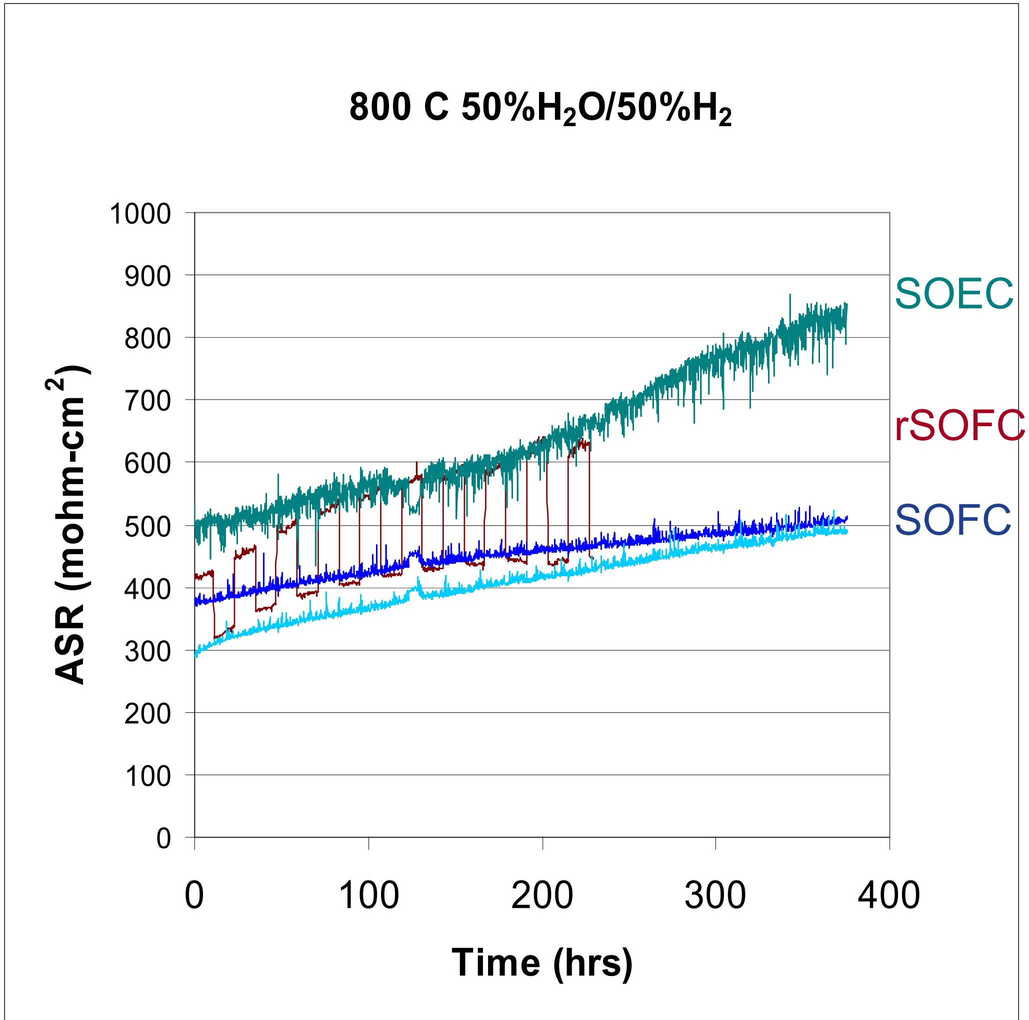


Non-symmetrical vacancy model



- **Vacancy diffusion and activation at the oxygen electrode/electrolyte interface are different for fuel cell mode and electrolysis mode**
- **Higher current densities can lead to depletion of vacancies at the interface in electrolysis mode**
- **Experimental data matched well with non-symmetrical vacancy model**

Operation Mode Cyclic Ability



- **Evaluated cell performance for fuel cell mode alone, electrolysis mode lone, and fuel cell/electrolysis cyclic mode**
- **Similar degradation in fuel cell (SOFC), electrolysis (SOEC) and cyclic modes (rSOFC) – perhaps enhanced electrolysis degradation**

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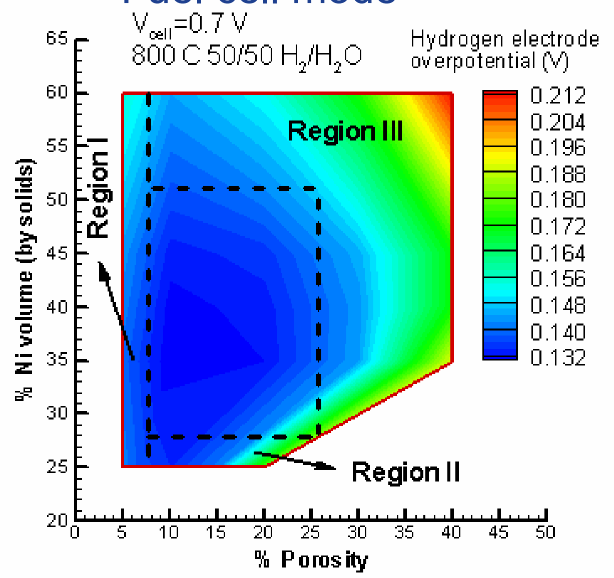
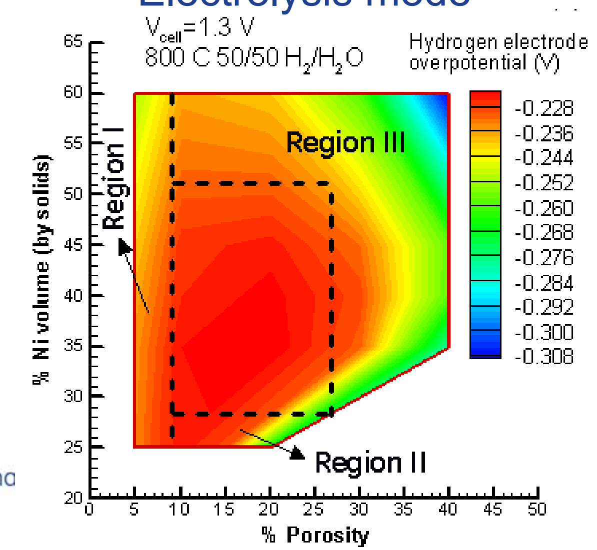
Hydrogen Electrode Performance

Fuel cell mode



Electrolysis mode

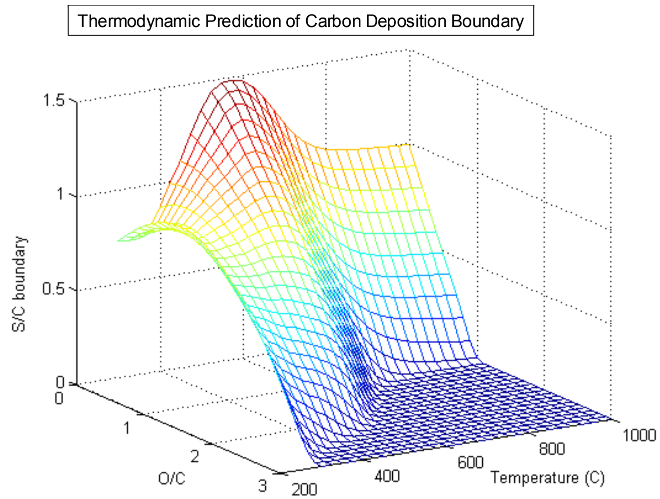


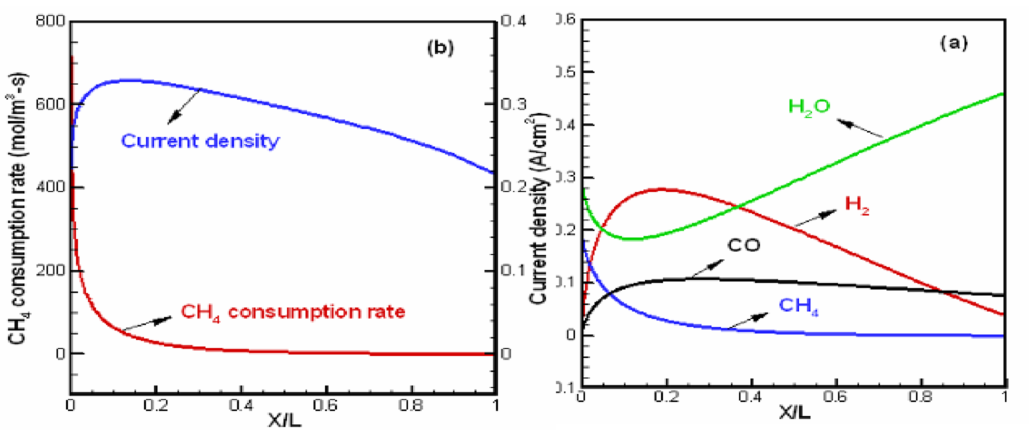
- **Higher polarization losses predicted under electrolysis mode mainly due to difference of diffusion**
- **Thinner electrode and smaller particles preferred**

Conditions:
T = 800 C
Fuel = 50/50 H_2/H_2O
Active layer thickness= 16 μm
Active layer particle size=0.8 μm

Region I – H_2/H_2O diffusion and reaction limited
Region II – Reaction limited
Region III – Ion conduction and reaction limited

Hydrogen Electrode Internal Reforming





X is the distance from the fuel inlet along the channel and L is the total channel length

- **At 800°C, internal reforming kinetic was fast**
- **CH_4 conversion measured (gas chromatography) > 98%, agrees well with thermodynamic prediction**
- **Thermodynamic calculations defined carbon deposition boundary**

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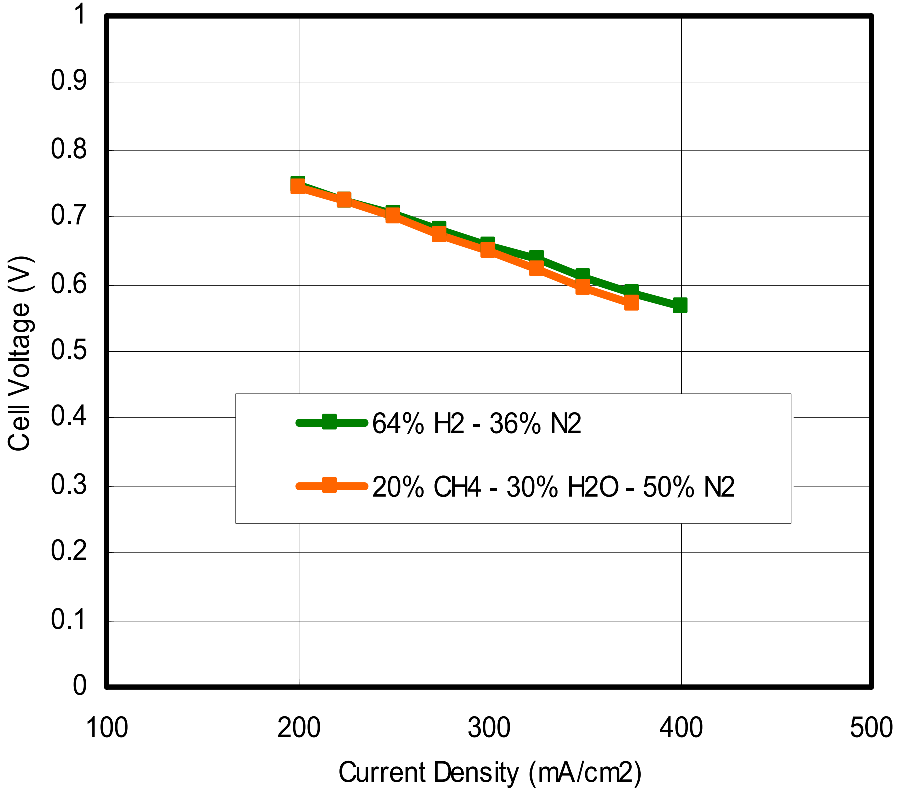
Performance with Internal Reforming



- **Performance (I-V curve) with internal reforming similar to that with 64% H_2/36%N_2 fuel**
- **Improved cells efficiency and potential system simplification with internal reforming**

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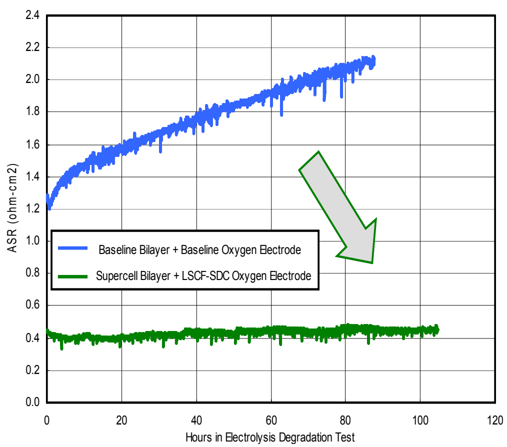
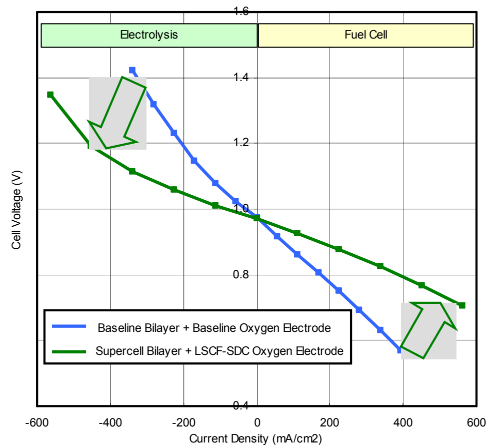
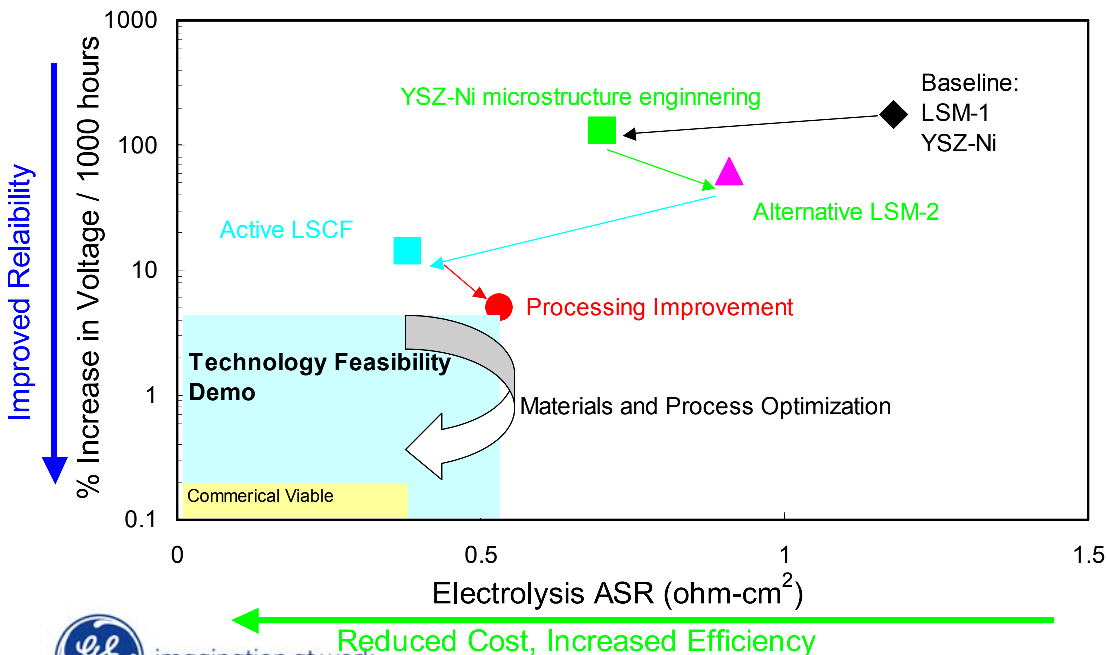
Module Performance Improvement







- **LSCF performed better than LSM/YSZ electrode**
- **Substantial degradation rate reduction achieved with LSCF oxygen electrode in electrolysis mode**
- **Improved performance with electrode material selection and process engineering**

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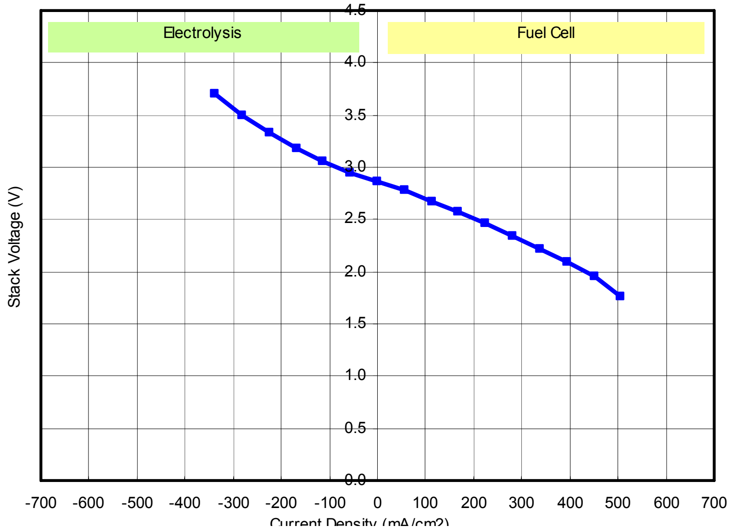
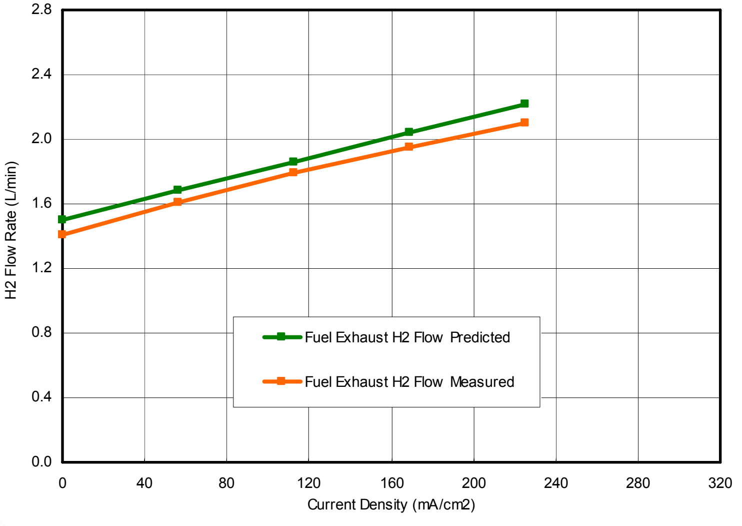
Multi-cell Stack Performance





- **Built and tested 3-cell stacks under power generation and electrolysis mode for more than 1000 hrs**
- **Hydrogen production measured and the measured value close to the predicted**
- **Cell-cell performance variation needs to be addressed**

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Future Works

- Demonstrated multi-cell stack operation and assess performance under reversible operating conditions
- Estimate hydrogen production cost ($/kg H_2)
- Conduct technology assessment and gap analysis

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Summary

- **Oxygen electrode development**
  - Performance: LSCF>LSF>LSM
  - "Irreversibility" of oxygen electrode observed, associated with differences in vacancy diffusion and activation at electrode/electrolyte interface
- **Hydrogen electrode development**
  - Internal reforming with Ni-YSZ modeled and demonstrated
  - Higher polarization loss under electrolysis mode expected, mainly due to difference of H_2 and H_2O diffusion
- **Module and stack development**
  - Module and stack performance improved by electrode engineering
  - Initial multi-cell stacks tested and hydrogen generation demonstrated

Acknowledgement

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