Redox REBELS Project: Lower Temperature SOFCs

Bryan Blackburn

NETL SOFC Project Review Meeting
Pittsburgh, PA
07/19/2016
Team & Project

Datacenter/Utility
Partners
Team & Project

Datacenter/Utility Partners

• Approach
  – Lower temperature electrolytes and cathodes
  – New low temp anodes
  – New stack architectures and coatings
  – Scale materials and cells as we go
  – Design with system in mind

- [Diagram]

• GDC, leakage current
• Bi$_2$O$_3$, high conductivity but unstable in fuel (low PO$_2$)
• Together form a bilayer with a synergetic performance boost
All-Ceramic Anode

- Ceramic anode material allows for tailoring of electronic conductivity and other properties (e.g., catalytic activity)
- A problem with state-of-art materials (e.g., SNT) is need for high temperature activation in reducing environment
- New Redox Material (orig. developed at Univ. of Md) has higher conductivity and activation can happen below 650 °C
  - Little difference in conductivity when activated at even lower temperatures
All-Ceramic Anode

Long-term stability:

- 81% H₂, 16% CH₄, and 3% H₂O
- Degradation rate < 0.3% per 1000h

Currently scaling up size to 10 cm by 10 cm size
Anode Infiltration Optimization

- Conventional anode optimization (below)
- Same process will be used on ceramic anode

![Graph showing impedance spectra for conventional bilayer cell and catalyst-infiltrated bilayer cell.](attachment:image1.png)

**500 °C**

**Total ASR=0.97 Ωcm²**

![Image showing nano particles in anode cross-section.](attachment:image2.png)
**Porous Anode Manufacturing Scale-Up**

- Similar microstructure as button cells that achieved this milestone early in project
- We will infiltrate same catalysts as button cell work and/or ceramic anode materials
- Current Efforts
  - working to scale the infiltration process
  - 10x10 half cell
Bilayer Electrolyte

>100 mV OCV increase achieved compared to no bilayer
Bilayer Electrolyte

>100 mV OCV increase achieved compared to no bilayer

Redox multiphysics model showed that closed & open pores can reduce OCV due to ineffective TBP and decreased conductivity (leakage current in GDC)
Datacenter load profiles have very fast transients (sub-second)

Q: Can lower temperature operation enable new load following applications, given reduced TEC mismatch stresses, or will a datacenter system require a lot of energy storage?
**Extreme Load Following**

Q: Can lower temperature operation enable new load following applications, given reduced TEC mismatch stresses, or will a datacenter system require a lot of energy storage?
Extreme Load Following

Single cells and short stacks (H₂ and reformate)
Extreme Load Following

Single cells and short stacks (H₂ and reformate)
Low Temp Stack Designs

• **Model Capabilities**
  – Thermochemical and physical properties of materials
  – Captures kinetics of electrochemical and heterogeneous reforming reactions within anode
  – Scaled-up from single channel to entire stack
  – Added bilayer electrolyte physics to model

• **Low Temp Parametric Studies**
  – Flow field optimization
  – Stack component geometry

• **Stack Sealing**
  – Low temperature gasket configurations
  – 75% lower total leak rate
**Low Temperature Stack Coatings & Contacts**

- Developed electrical contact coatings compatible with Bi$_2$O$_3$ electrolyte
- Developed stack coatings compatible with low temp operation
- Performance Summary (Contact + Stack Coating)
  - For Bi$_2$O$_3$ based cells: ASR = 0.081 Ω-cm$^2$
  - For alternative configurations: ASR = 0.034 Ω-cm$^2$
Independent Stack Testing

• Independent testing to begin in August/September 2016 with the National Fuel Cell Research Center

• Shipping stacks and ensuring they survive transport

• Aggressive test protocols with datacenter application load profile focus
Additional REBELS Related Efforts

- Testing the limits of reformers
  - Tube-in-shell and plate reformers
  - Best reformer operating temperatures in light of low-temperature stack
  - Impact of operating temperature on response time
  - Controls implications and capabilities

- Studying the impact of lower operating temperatures on system design and capability
  - Size/cost of balance of plant components
  - Tradeoff studies: Efficiency vs Transients vs CAPEX
Redox Scale-Up Efforts

- Raw Oxide Powders
- Specialized manufacturing, custom components
- ~100W Bilayer SOFC Cells
- 1 to 10 kW_e SOFC Stacks
- Balance Of Plant
- 25 kW_e Cube System

Materials within REBELS program have been successfully scaled to several kg, meeting or beating powder specs and cost objectives
Proof of Concept R2R

- Proof of concept roll-to-roll (R2R) lamination demonstrated using commercial equipment
- Option to dramatically reduce costs of current cell fabrication process for lamination and casting steps
- Cost comparison with current process being conducted with Strategic Analysis
Techno-Economic Analysis Modeling

- **Cell model**
  - 100% updated
  - Redox Updates to SA model
    - Materials & supplier costs
    - Specific manufacturing process

- **Stack model**
  - 75% complete
  - Redox Updates to SA model
    - Stamped ICs
    - IC coatings
    - Assembly
    - Hotbox insulation

- **System model**
  - will begin once Redox system studies for lower temperature stack operation are complete
  - Estimated completion mid 2017
Summary of REBELS Efforts

• High performance, low temperature ceramic anode
  – Degradation of only ~0.3% per 1000h in reformate (500°C)
  – Scale-up to 10cm by 10 cm in progress

• Rapid load following focus with sub-second response times
  – Beginning independent tests in August/September

• Key technical challenges remaining
  – Match performance of bilayer button cells at the 10 cm by 10 cm cell size and ultimately stack
    • microstructural optimization
  – Scale-up size of all-ceramic anode support while meeting target cell specifications
    • reduce camber with modification to shrinkage and firing steps
  – Improve catalytic activity of all-ceramic anode
    • Optimize catalyst dispersion and look at alternative infiltrants
Acknowledgments

• ARPA-E Team
  – Paul Albertus (and formerly John Lemmon)
  – Scott Litzelman
  – John Tuttle and Ryan Umstattd

• University of Maryland
  – Energy Research Center (fundamental R&D) – Prof. Wachsman
  – mTech Incubator (business advice)

• Trans-Tech Inc. (materials scale-up/cell manufacturing)

• Strategic Analysis (TEA Modeling) – Brian James and Jennie Huya-Kouadio