Redox REBELS Project: Lower Temperature SOFCs

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

Team & Project

Datacenter/Utility Partners

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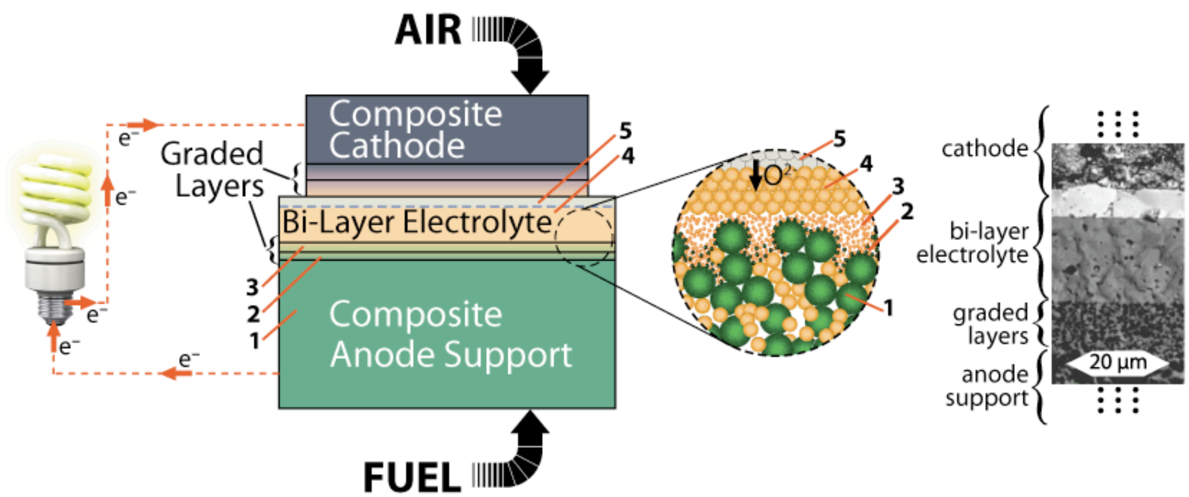
REDOX

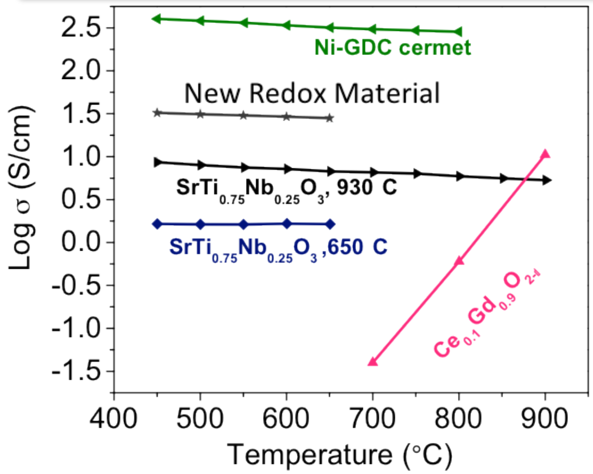
Trans-Tech
Ceramics and Advanced Materials

- 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



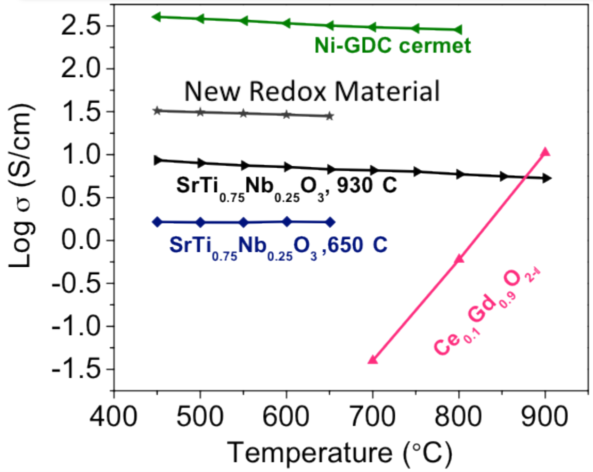
- GDC, leakage current
- Bi_2O_3, high conductivity but unstable in fuel (low PO_2)
- Together form a bilayer with a synergetic performance boost

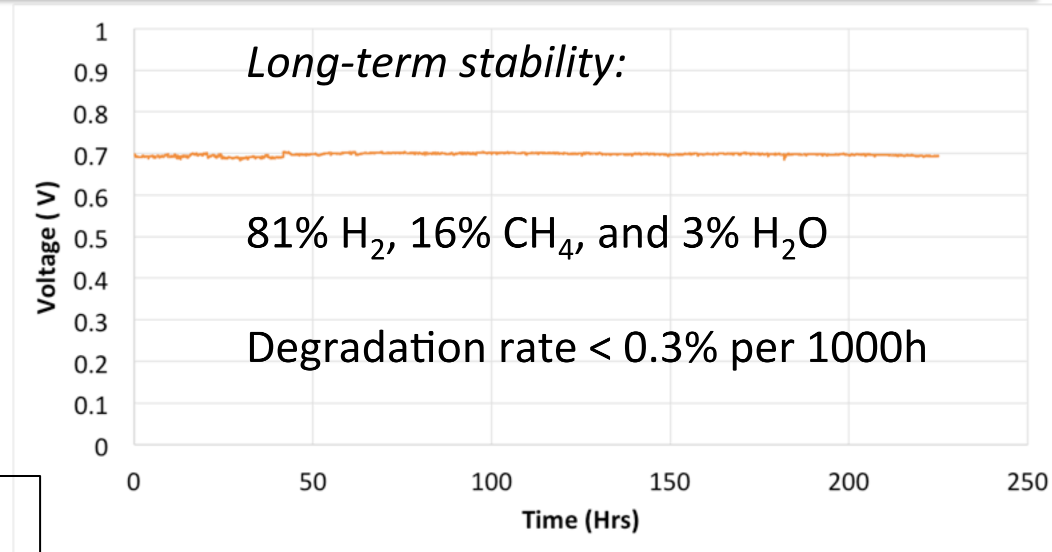
All-Ceramic Anode

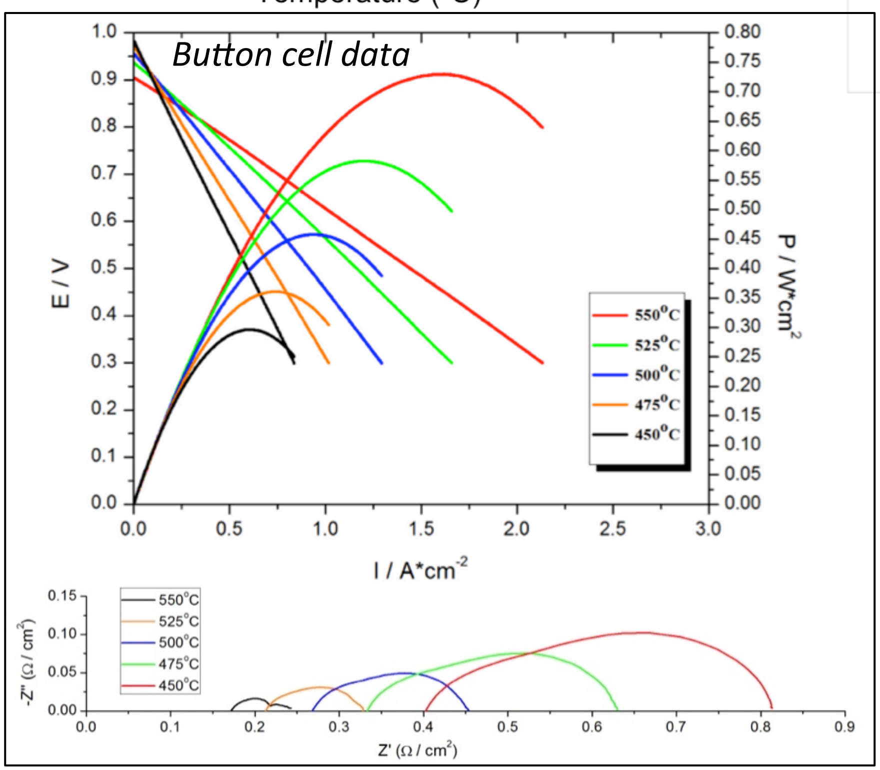


- Ceramic anode material allows for tailoring of electronic conductivity and other properties (e.g., catalytic activity)
- A problem with state-of-art materials (e.g., SNT) is need for high temperature activation in reducing environment
- New Redox Material (orig. developed at Univ. of Md) has higher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

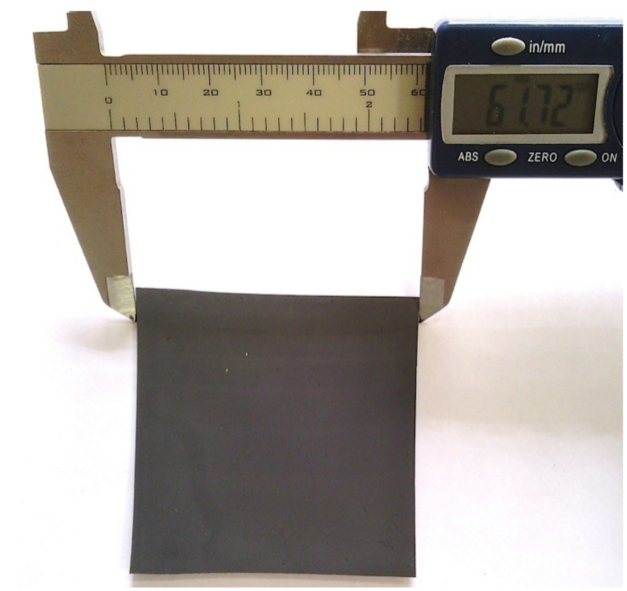
All-Ceramic Anode





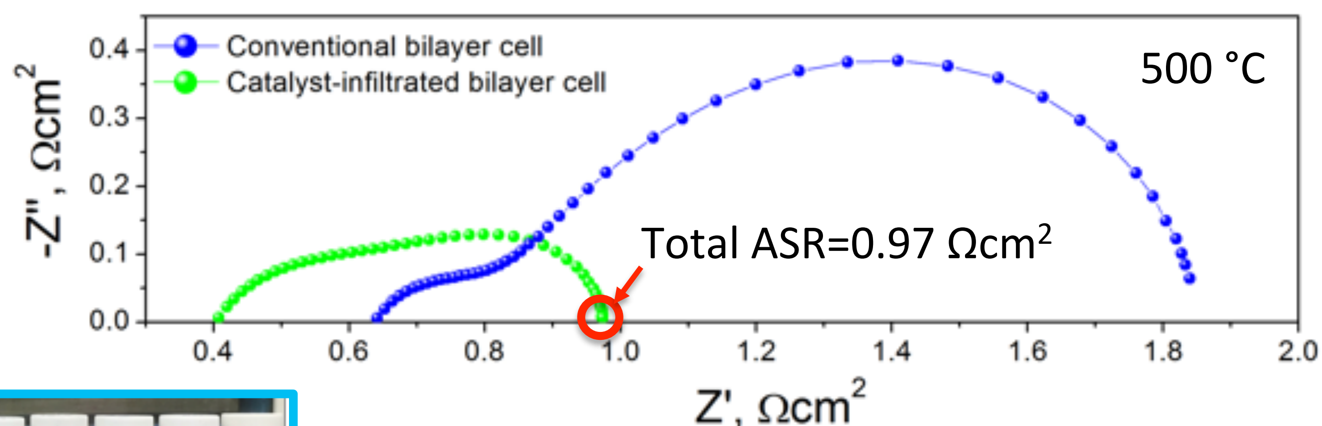


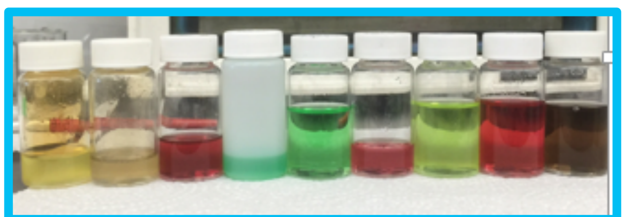
Currently scaling up size to 10 cm by 10 cm size

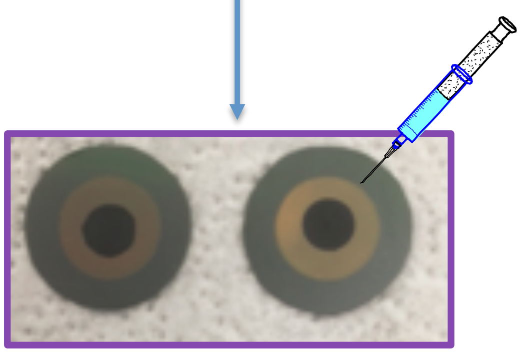


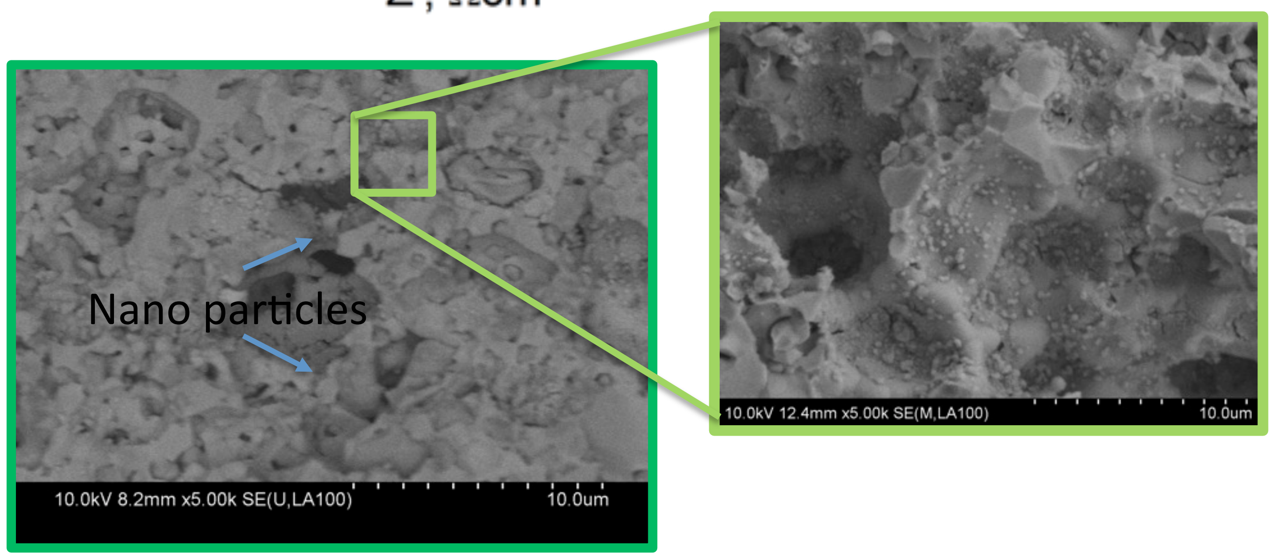
Anode Infiltration Optimization

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

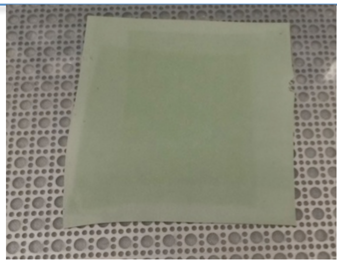




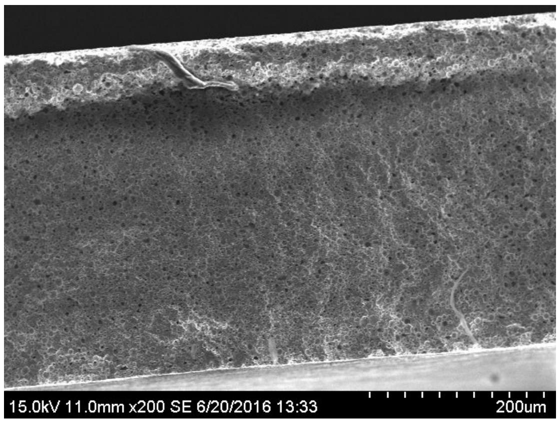


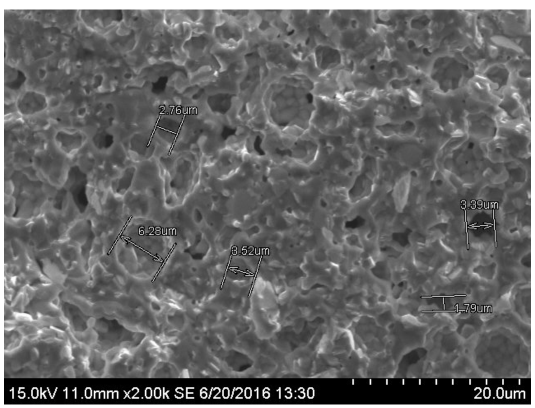


Porous Anode Manufacturing Scale-Up

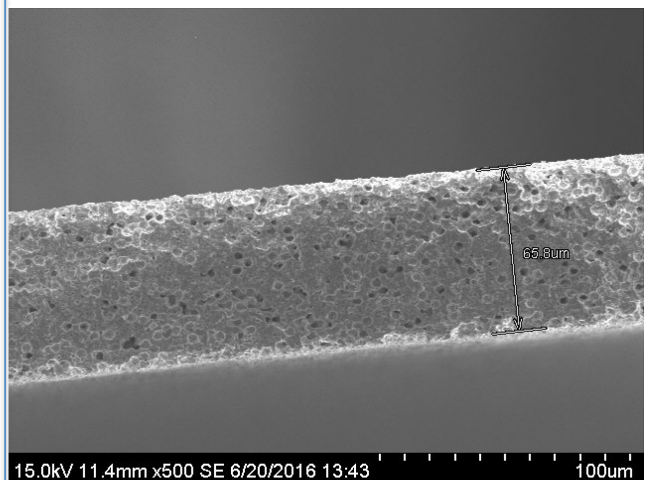


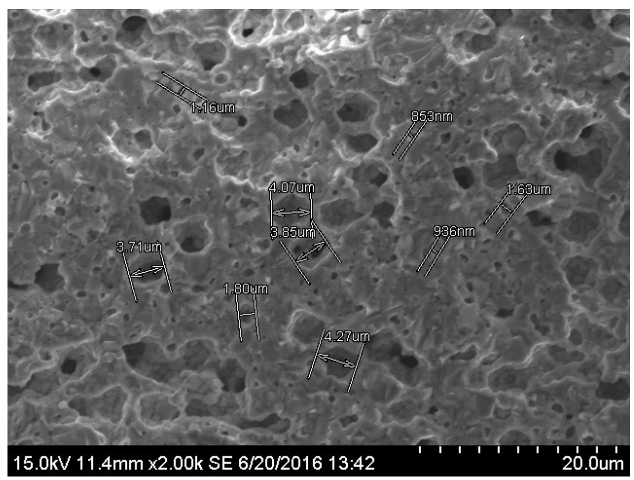
Porous ASL
10x10





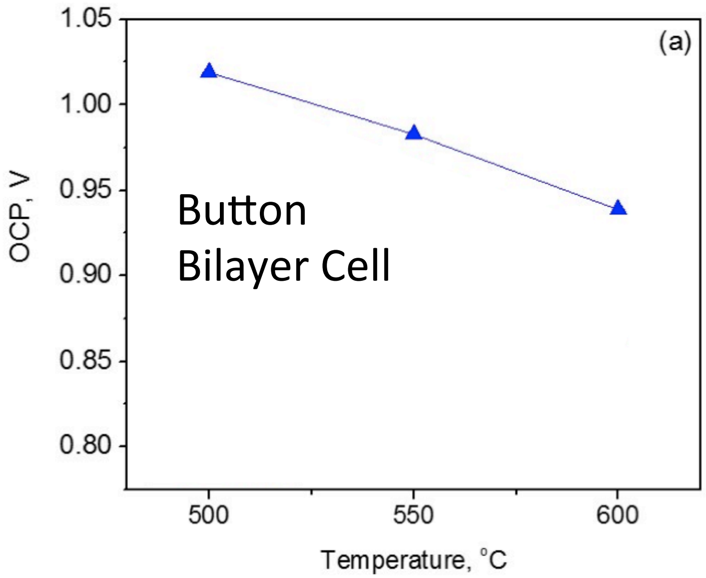
Porous AFL
10x10



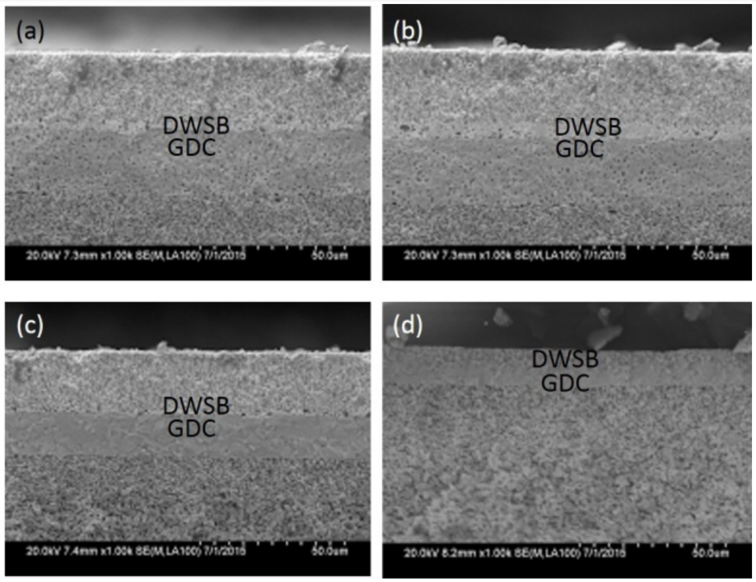


- Similar microstructure as button cells that achieved this milestone early in project
- We will infiltrate same catalysts as button cell work and/or ceramic anode materials
- Current Efforts
  - working to scale the infiltration process
  - 10x10 half cell

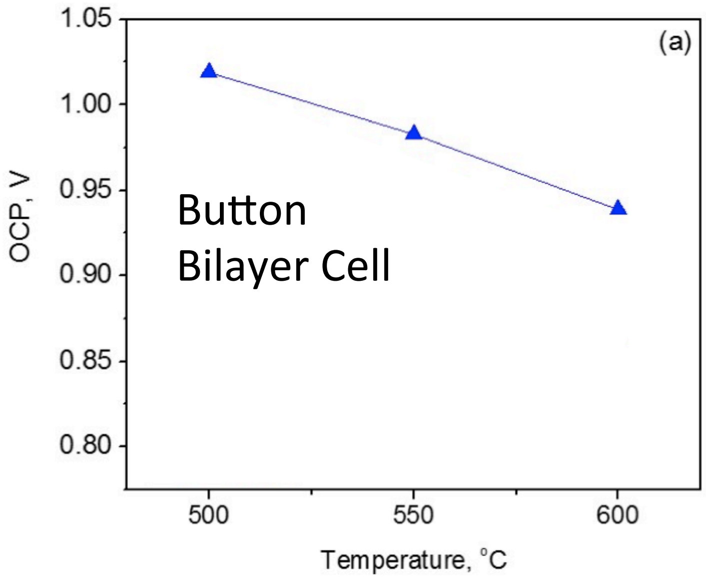
Bilayer Electrolyte



>100 mV OCV increase achieved compared to no bilayer



Bilayer Electrolyte



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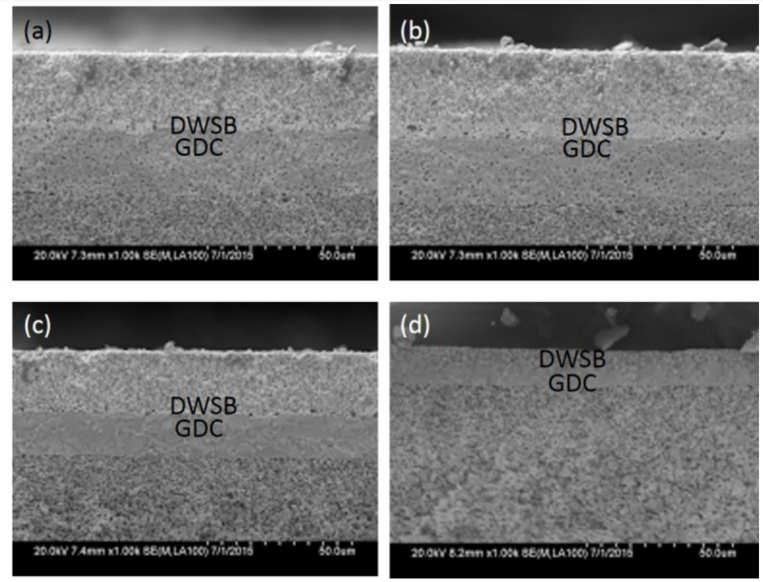
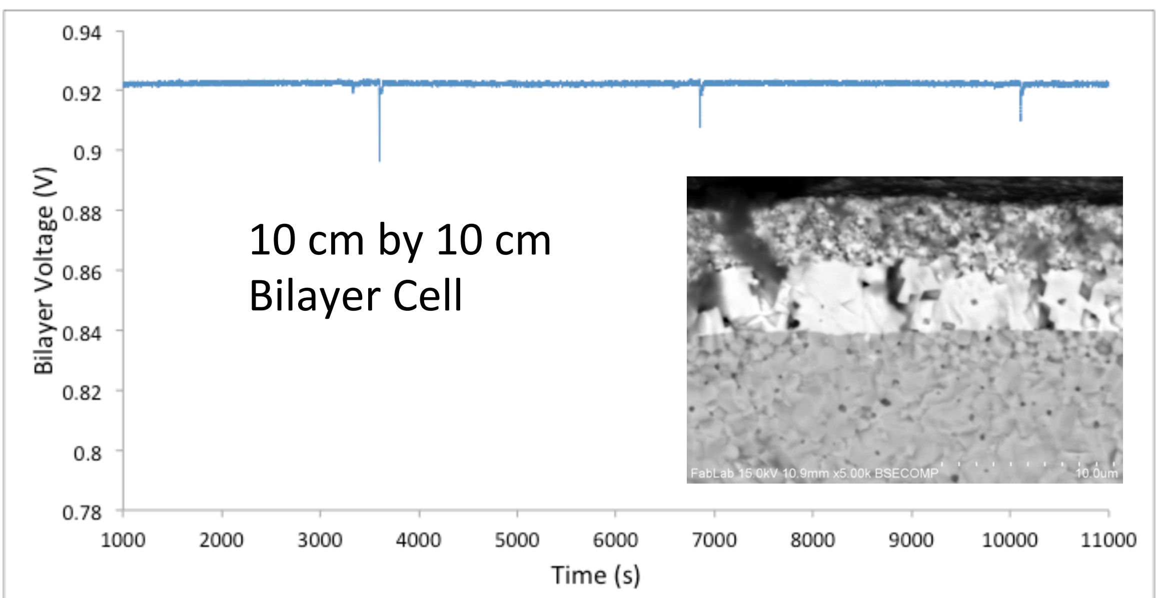
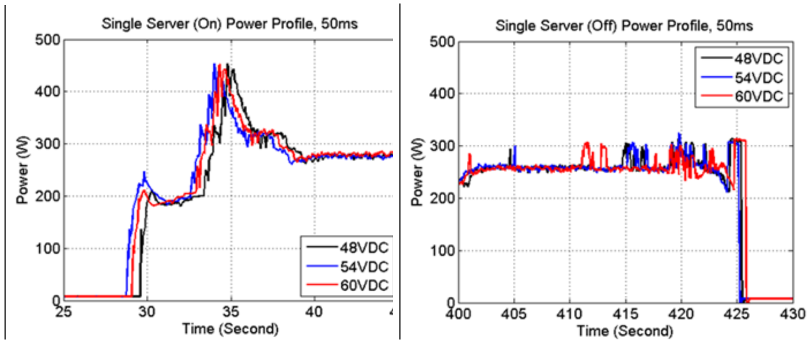




Redox multiphysics model showed that closed & open pores can reduce OCV due to ineffective TBP and decreased conductivity (leakage current in GDC)

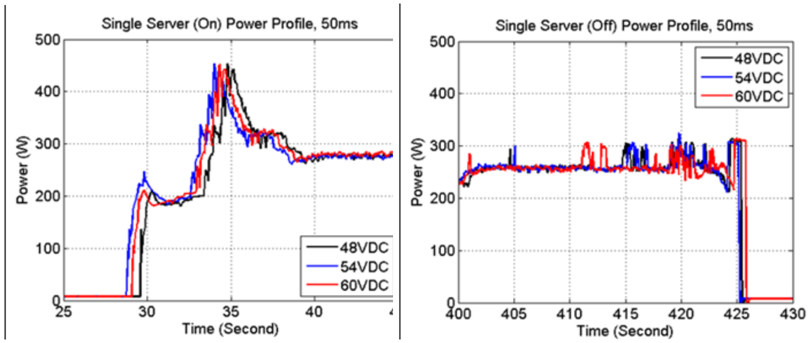
Extreme Load Following

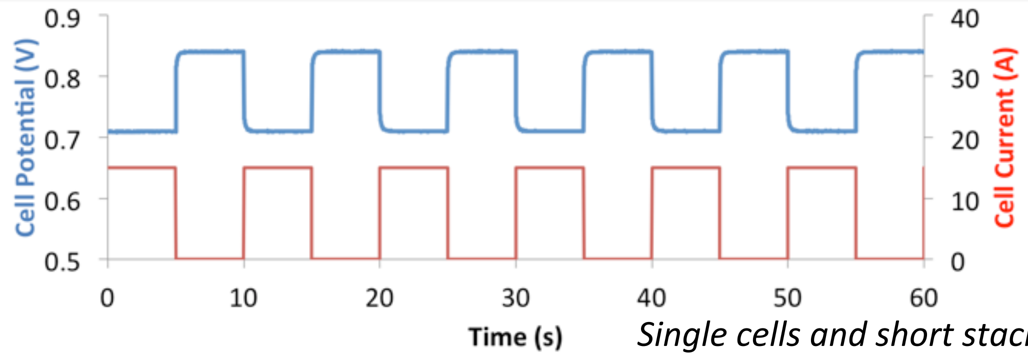


Datacenter load profiles have very fast transients (sub-second)

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





Single cells and short stacks (H_2 and reformate)

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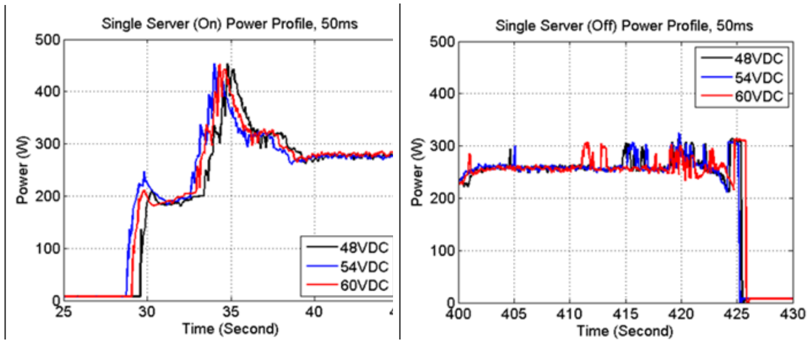
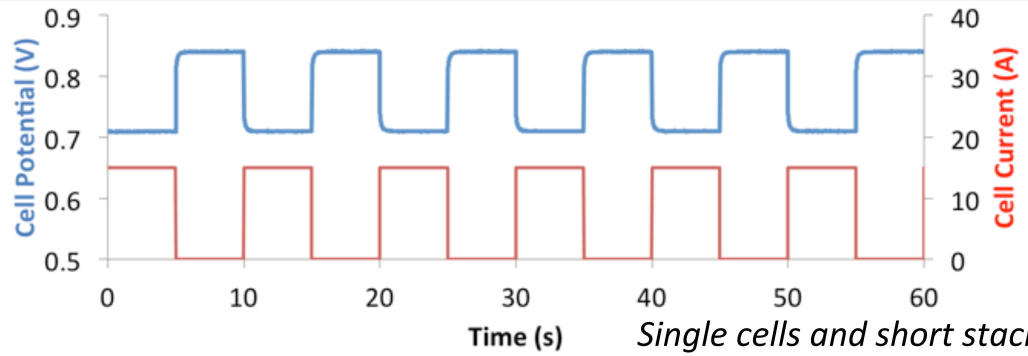
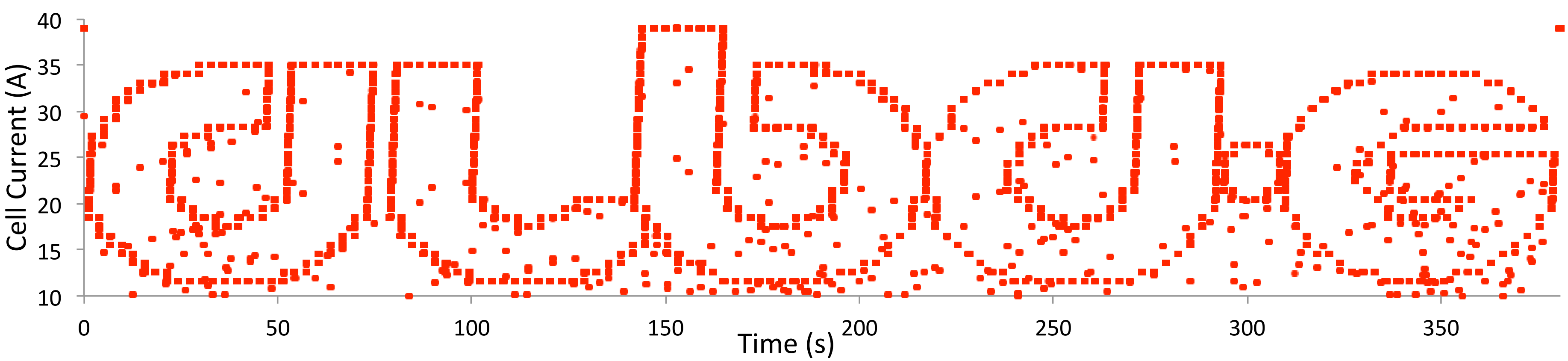




Single cells and short stacks (H_2 and reformate)



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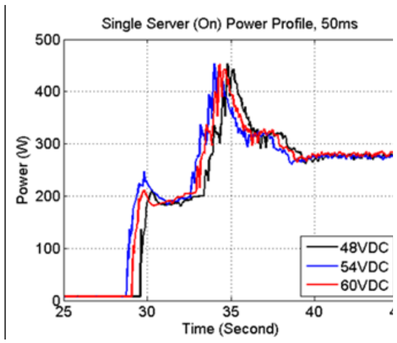

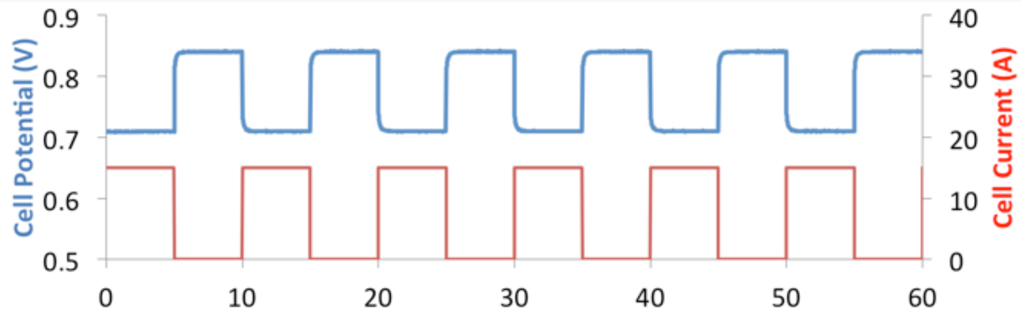

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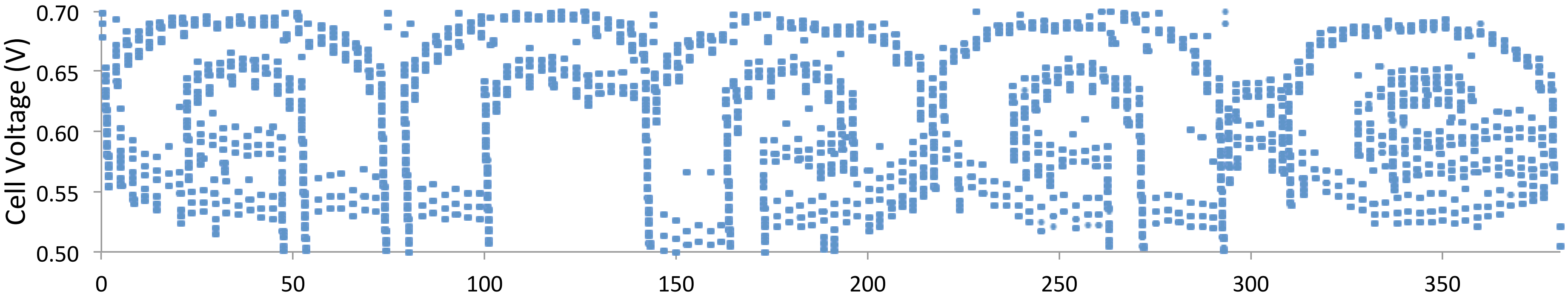
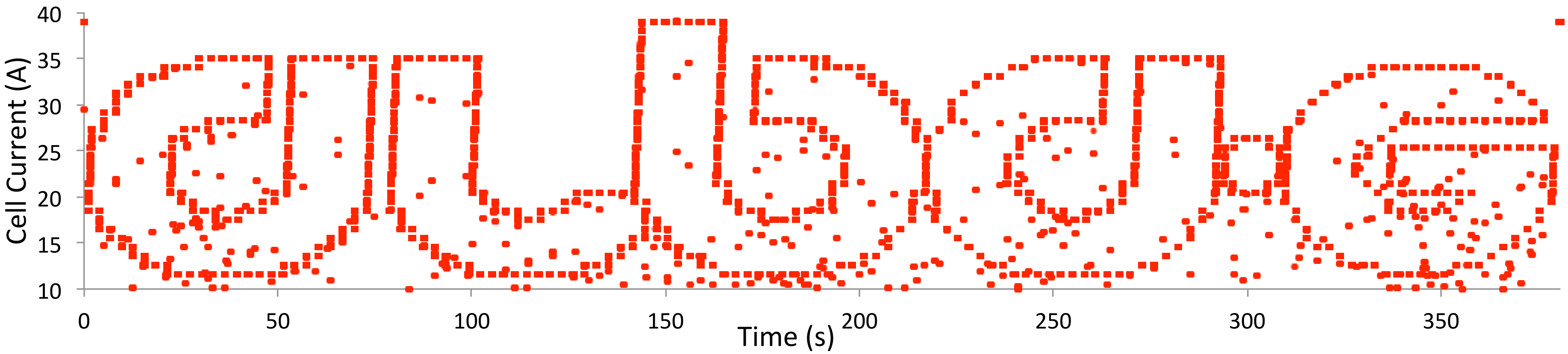
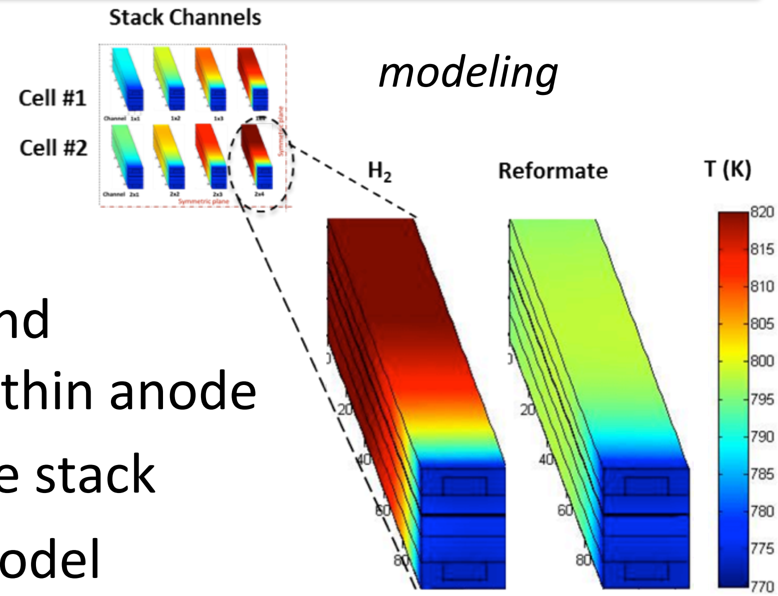




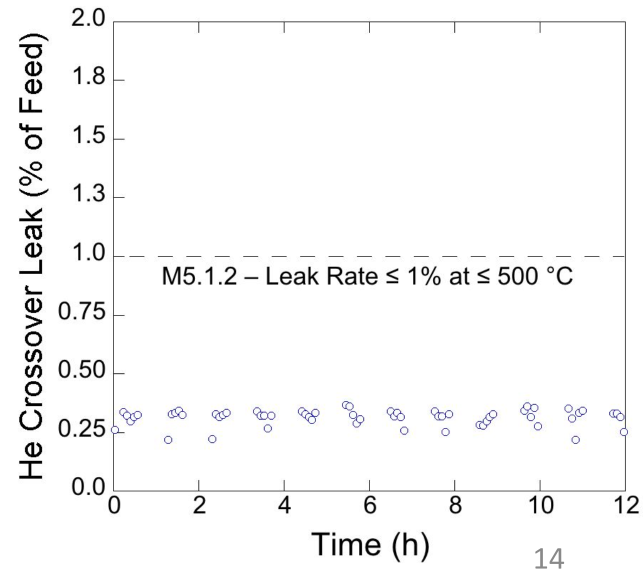
Low Temp Stack Designs

- 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

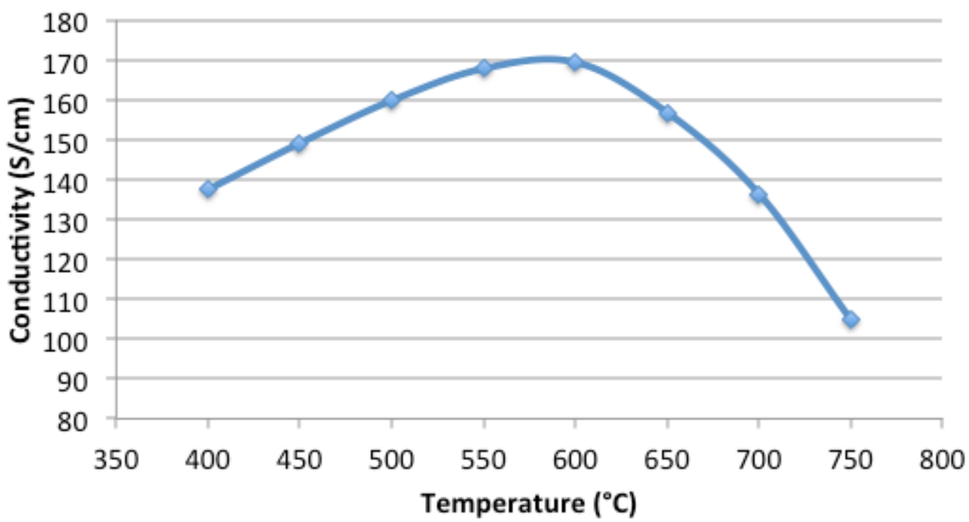


- Low Temp Parametric Studies
  - Flow field optimization
  - Stack component geometry
- Stack Sealing
  - Low temperature gasket configurations
  - 75% lower total leak rate

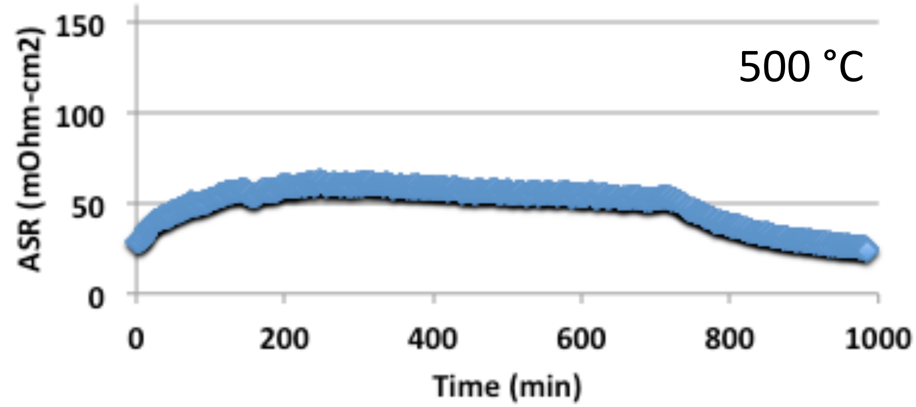
New Gasket Configuration



Low Temperature Stack Coatings & Contacts



New Electrical Contact Coatings



New Stack Coatings

- Developed electrical contact coatings compatible with Bi_2O_3 electrolyte
- Developed stack coatings compatible with low temp operation
- Performance Summary (Contact + Stack Coating)
  - For Bi_2O_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

Stack Shipments

Commercial Test Stand at NFCRC

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

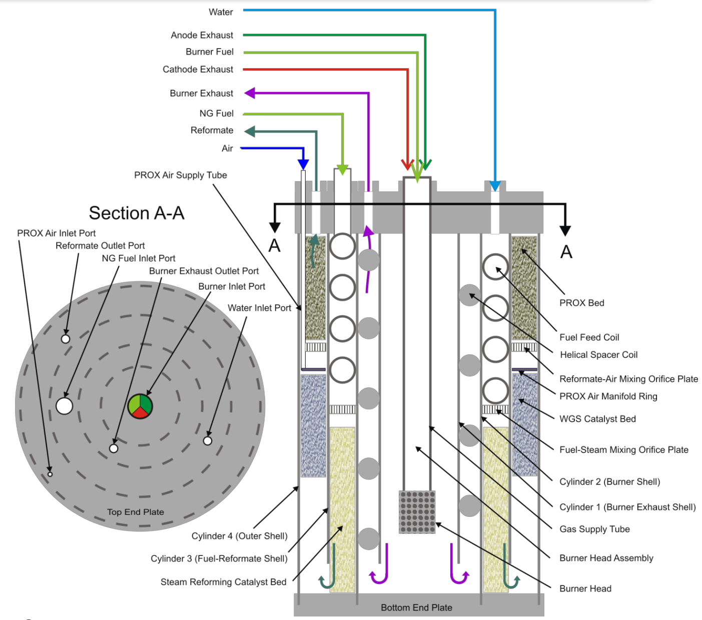


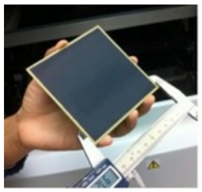
Figure 15: Reactor Diagram

Manufacturing Cost Analysis of Stationary Fuel Cell Systems, SA, 2012

- 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

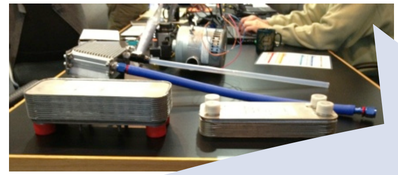
Redox Scale-Up Efforts

Raw Oxide Powders



~100W Bilayer SOFC Cells

1 to 10 kW_e SOFC Stacks



Balance Of Plant

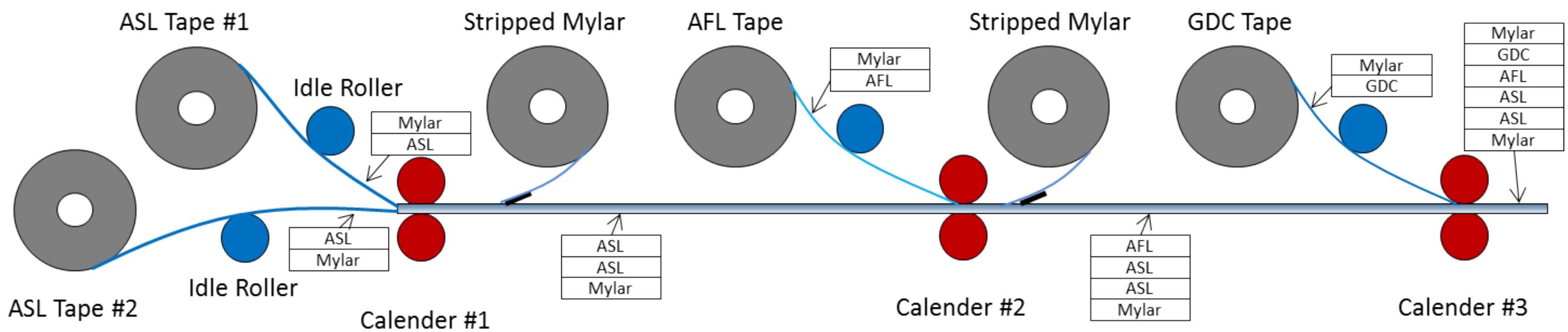
25 kW_e Cube System

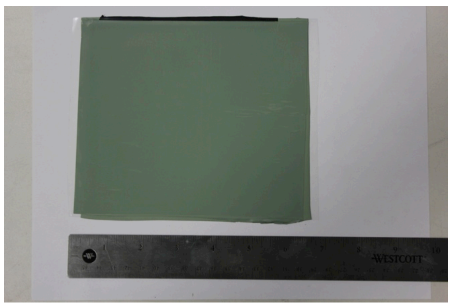
Specialized manufacturing, custom components

Common high volume appliance and electronics manufacturing, COTs components

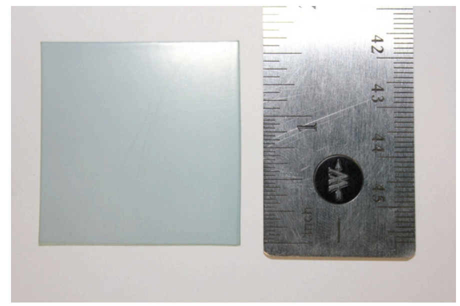
Materials within REBELS program have been successfully scaled to several kg, meeting or beating powder specs and cost objectives

Proof of Concept R2R





6.5” wide, 3 Layer Test Laminate

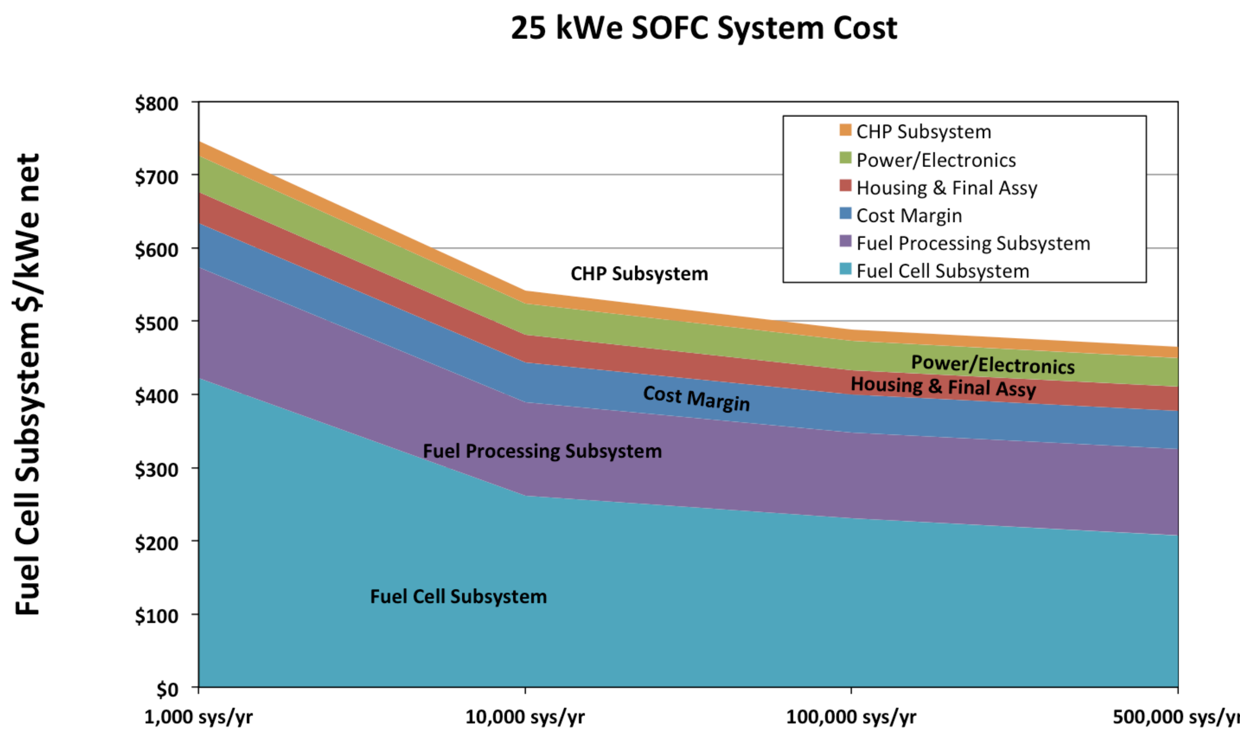


1.6” wide, 3 Layer Fired Test Laminate

- 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



Cell update results (2015 version)

- 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
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  - mTech Incubator (business advice)
- Trans-Tech Inc. (materials scale-up/cell manufacturing)
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