An Intermediate Temperature Metal-Supported Proton-Conducting Solid Oxide Fuel Cell Stack

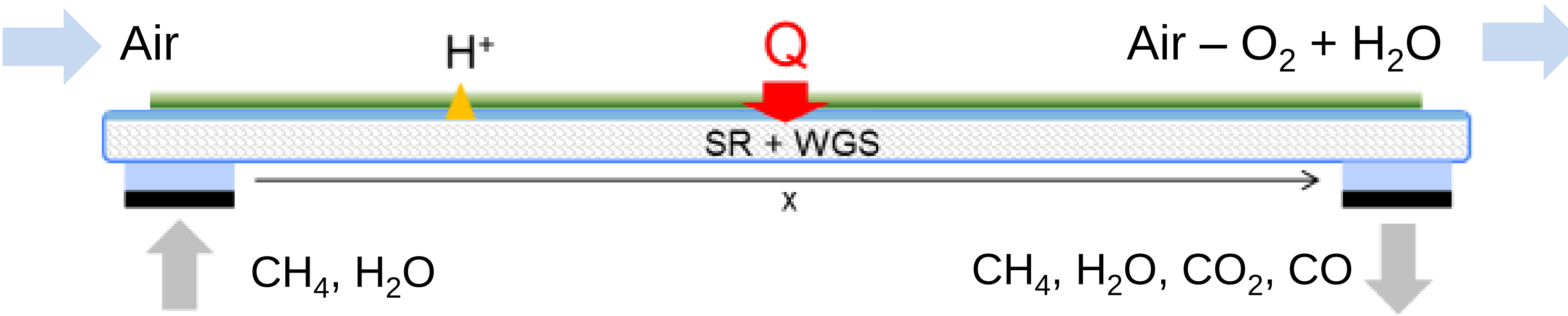
17th Annual SOFC Workshop

July 19, 2016

United Technologies Research Center
Northwestern
University of Maryland
UCONN
ElectroChem Ventures

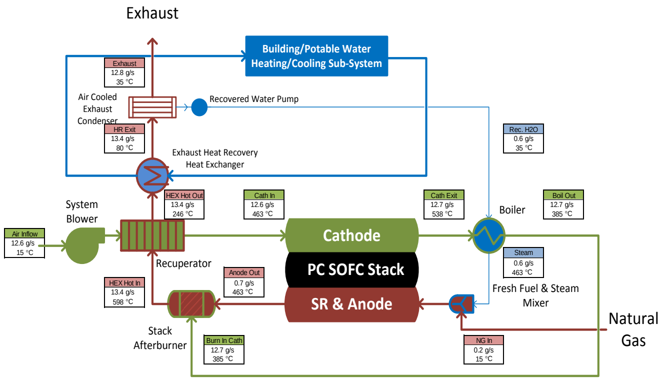
Stack Concept

Metal supported p-SOFC with internal CH_4 reforming

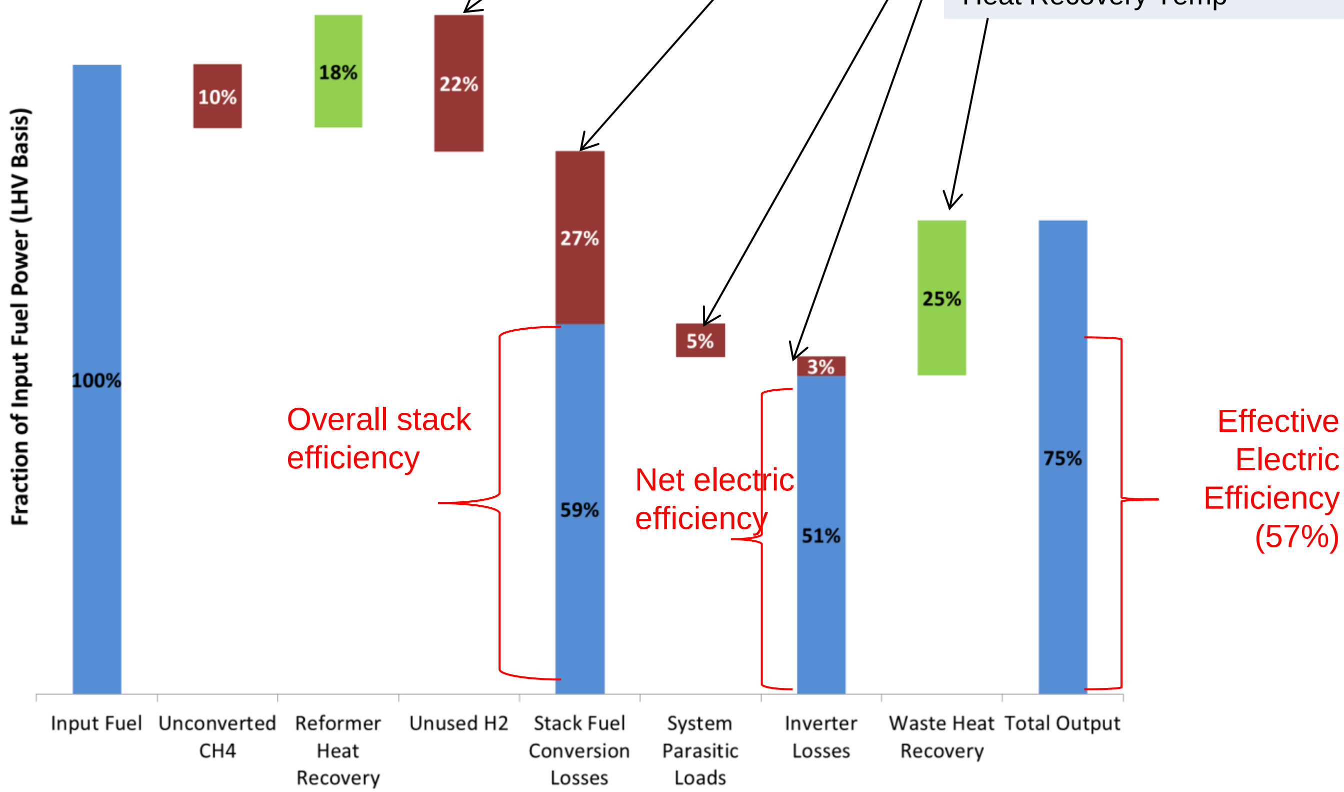


Feature	Lead Organizations
Proton-Conducting Oxide	Northwestern, University of Maryland, UCONN
Metal Support	ElectroChem Ventures, UCONN, United Technologies Research Center
Internal Fuel Reforming	United Technologies Research Center

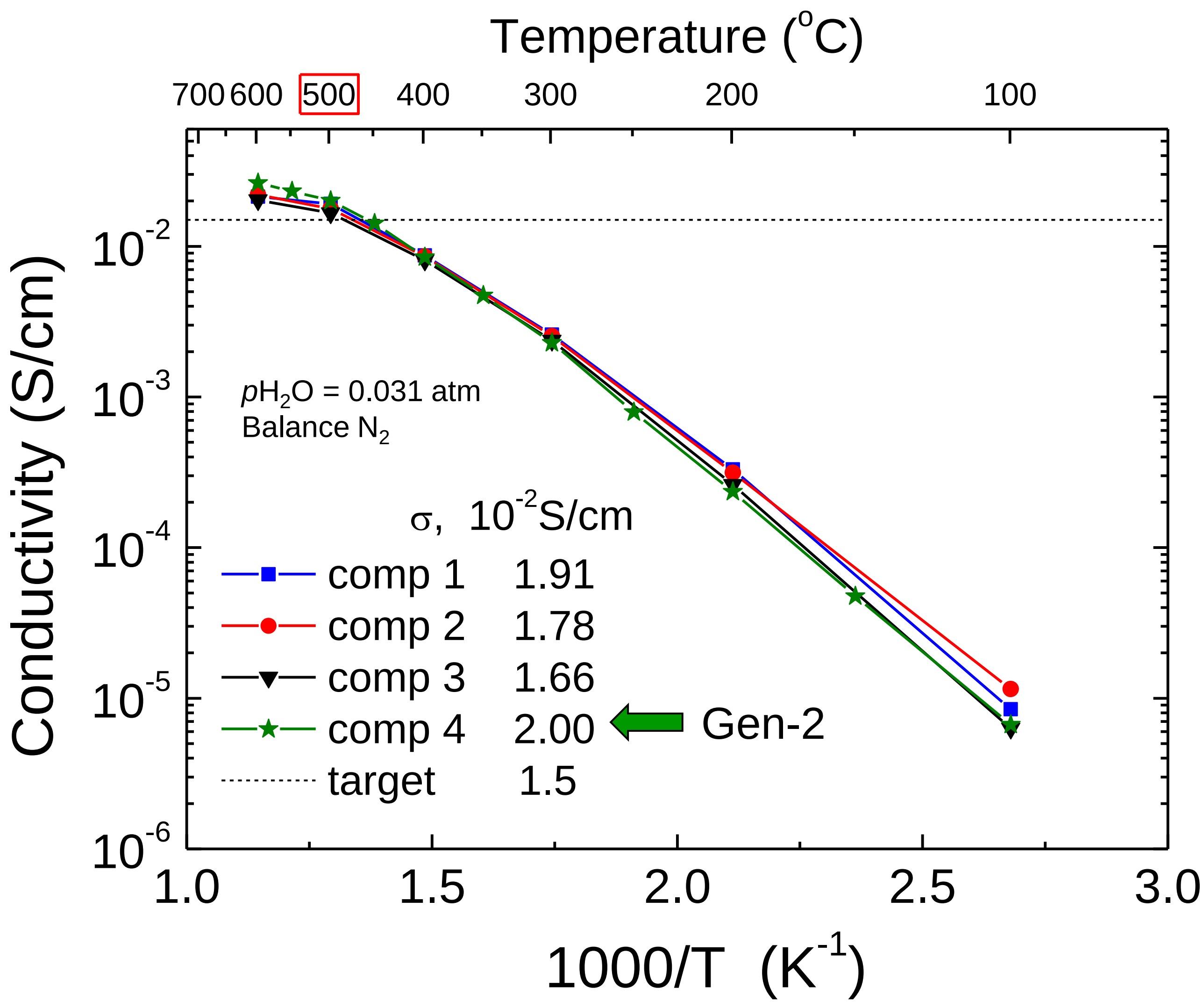
CHP System Concept & Efficiency



Assumptions	
Methane Conversion	90%
H_2 Utilization	80%
OCV (V/Cell)	1.05
ASR (Ωcm^2)	1
Current Density (mA/cm^2)	200
Parasitic Power / Stack Power	9%
Inverter Efficiency	95%
Heat Recovery Temp	75 °C



PCO-Electrolytes: Exceed Target Conductivity



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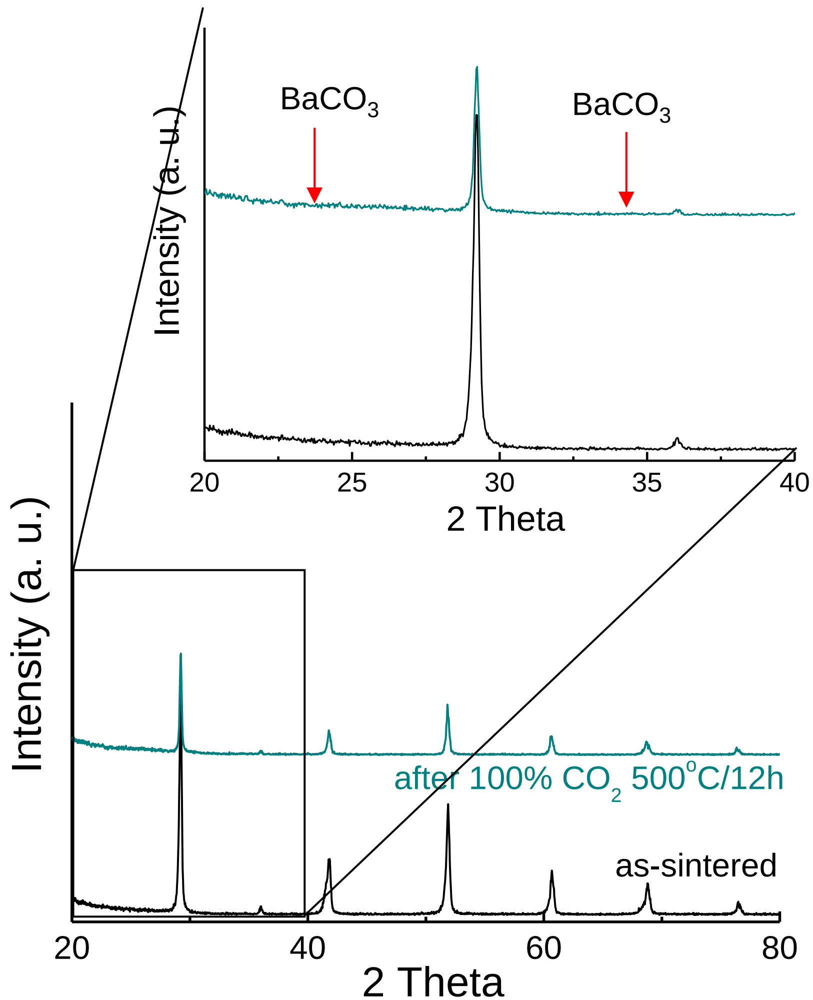
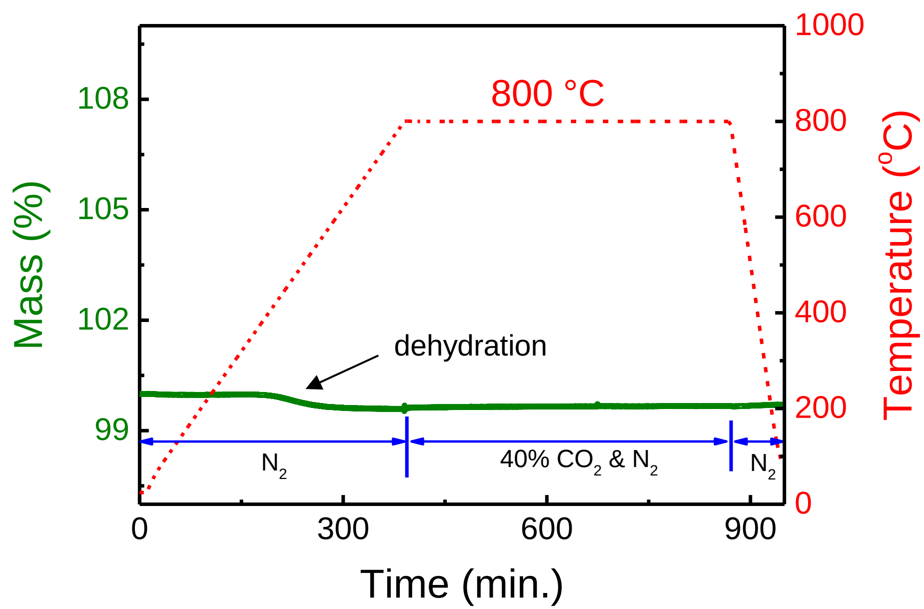
CO_2 stability of Gen-2 Electrolyte





- No carbonate detected by diffraction
- No weight gain under flowing CO_2

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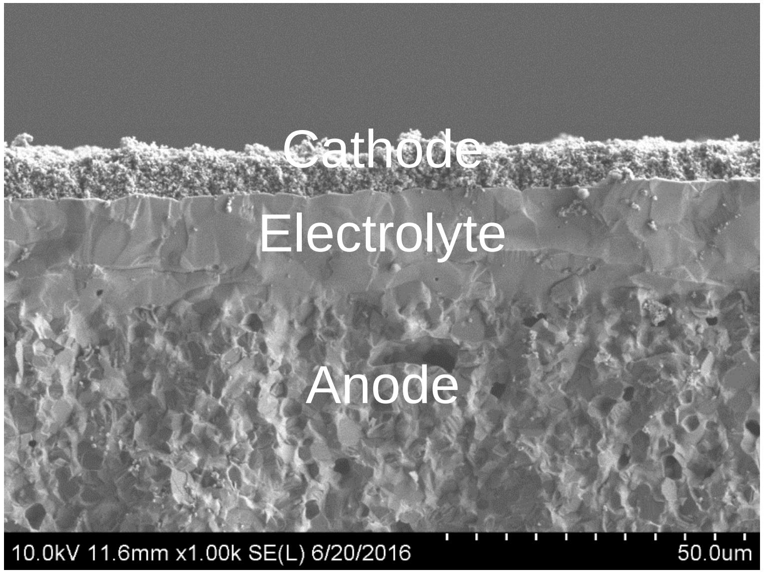
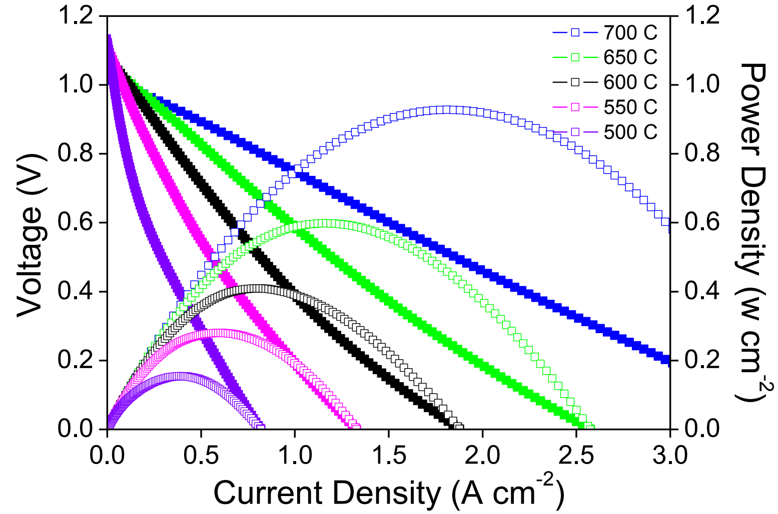
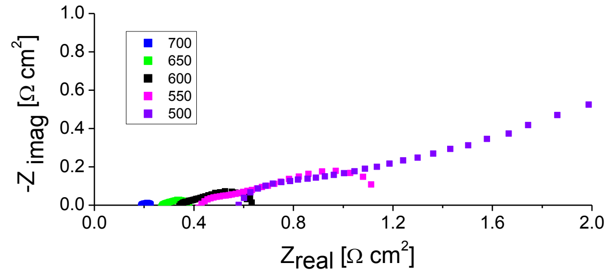
Overall Cell Performance on H_2

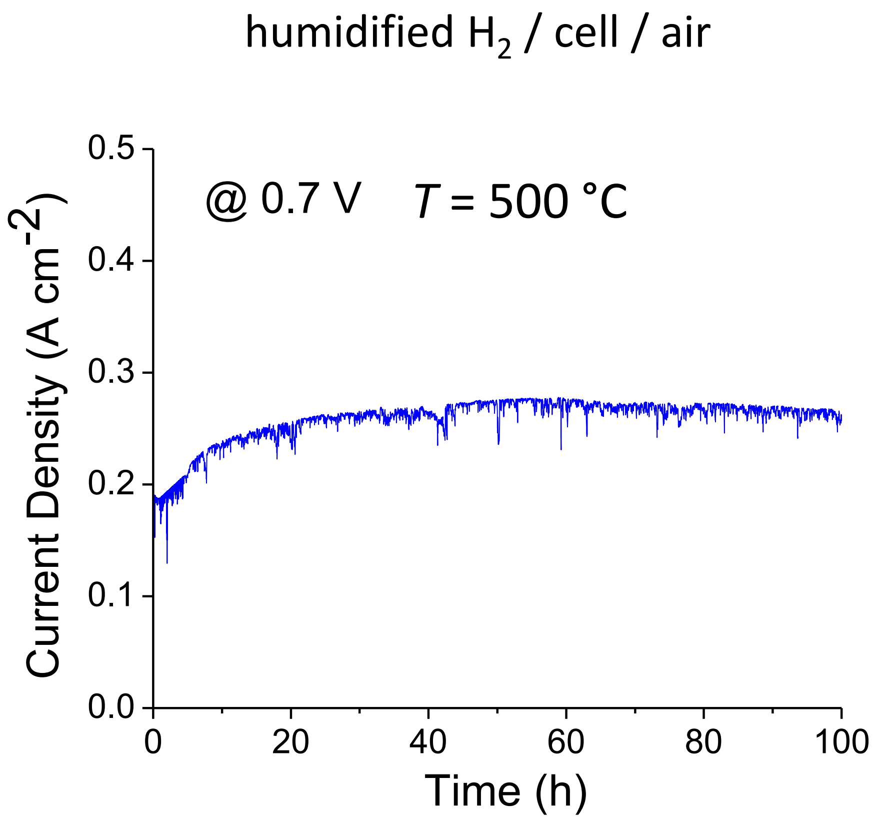


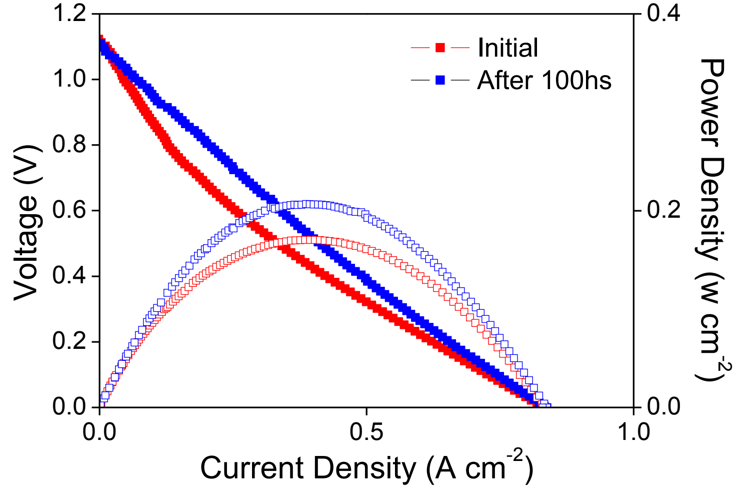


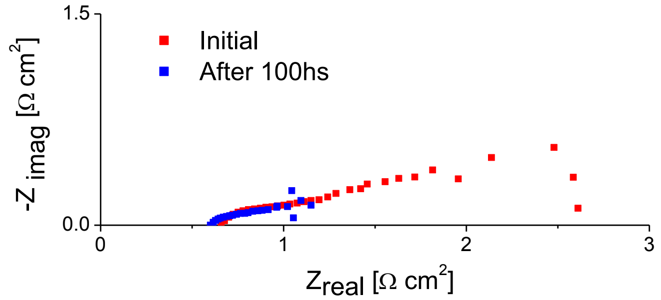


	OCV (V)	Ohmic (Ω cm²) (electrolyte)	Non-ohmic (Ω cm²) (anode + cathode)	Total resistance (Ω cm²)	Maximum power density (W cm⁻²)
600	1.080	0.342	0.285	0.632	0.409
550	1.105	0.418	0.682	1.112	0.280
500	1.126	0.561	2.697	3.277	0.154

Cell Performance Stability Evaluation @ 500 °C

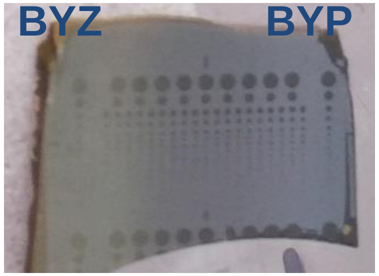


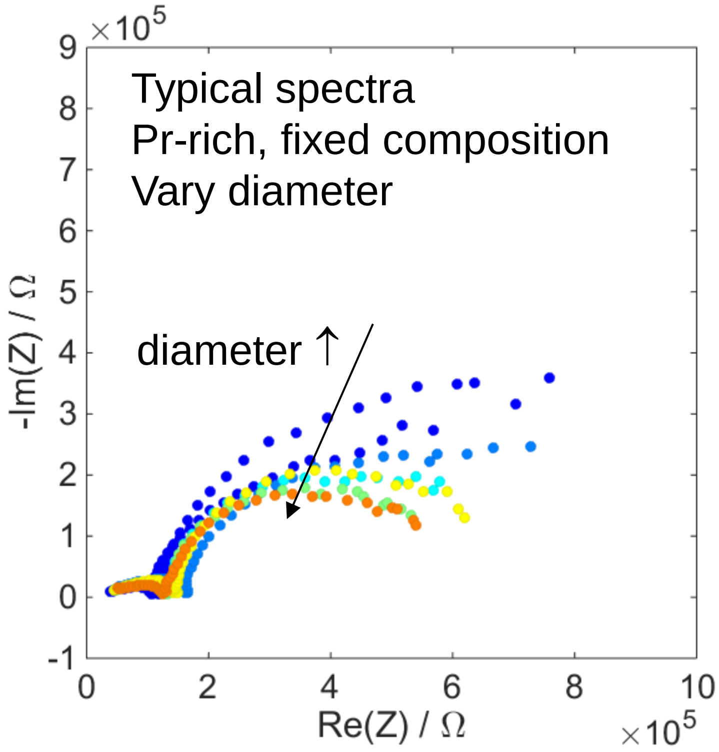


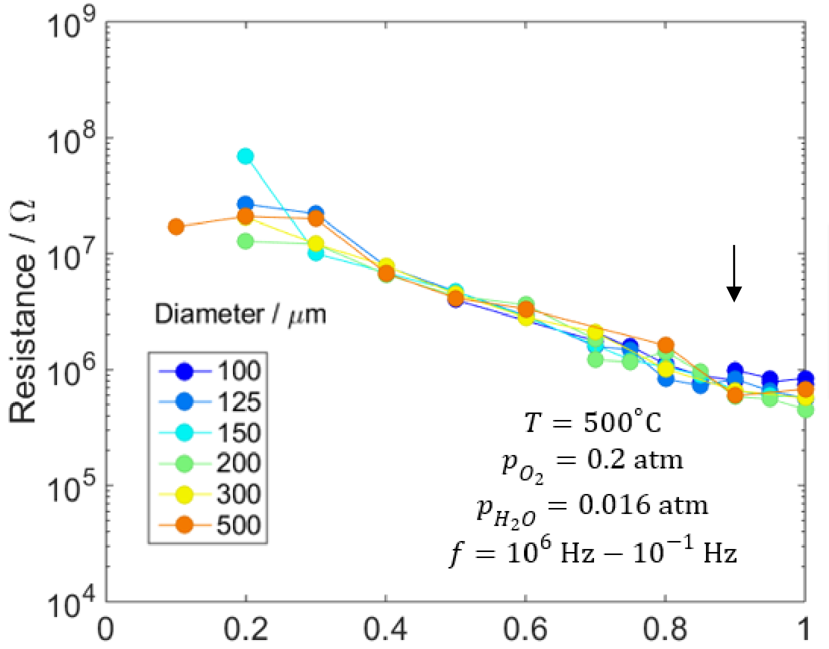


Combinatorial Electrode Development

Cathode: $BaZrYO_3$ - $BaPrYO_3$





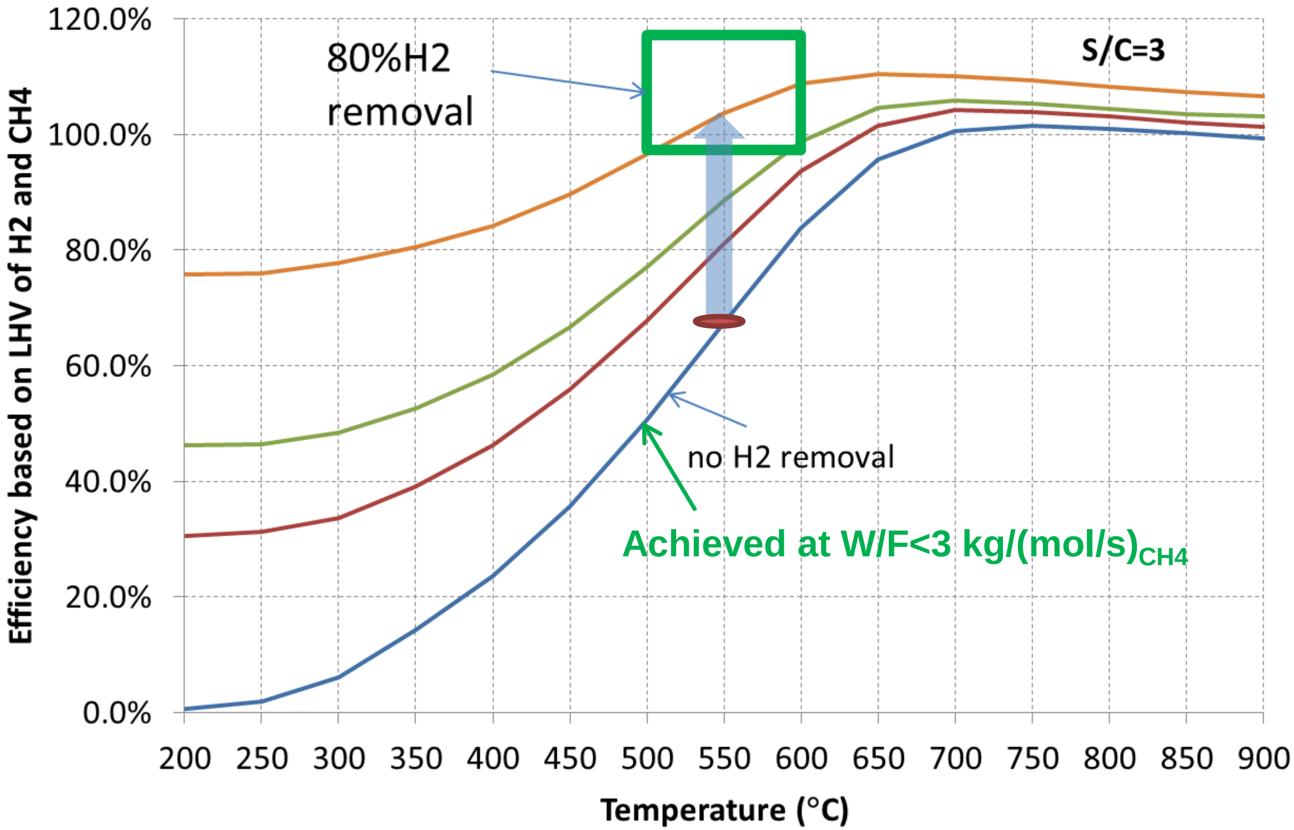


Observation: strong composition dependence, slight diameter dependence

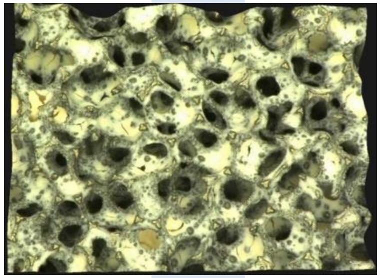
Fuel Processing

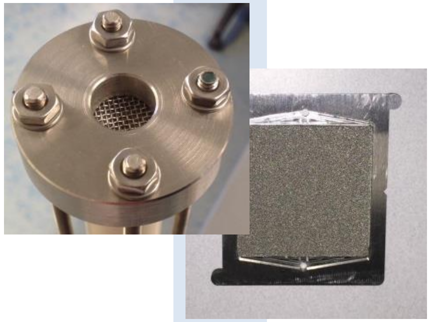
Internal CH_4 steam reforming

<u>*Strategy*</u>



<u>*Dev. Approach*</u>





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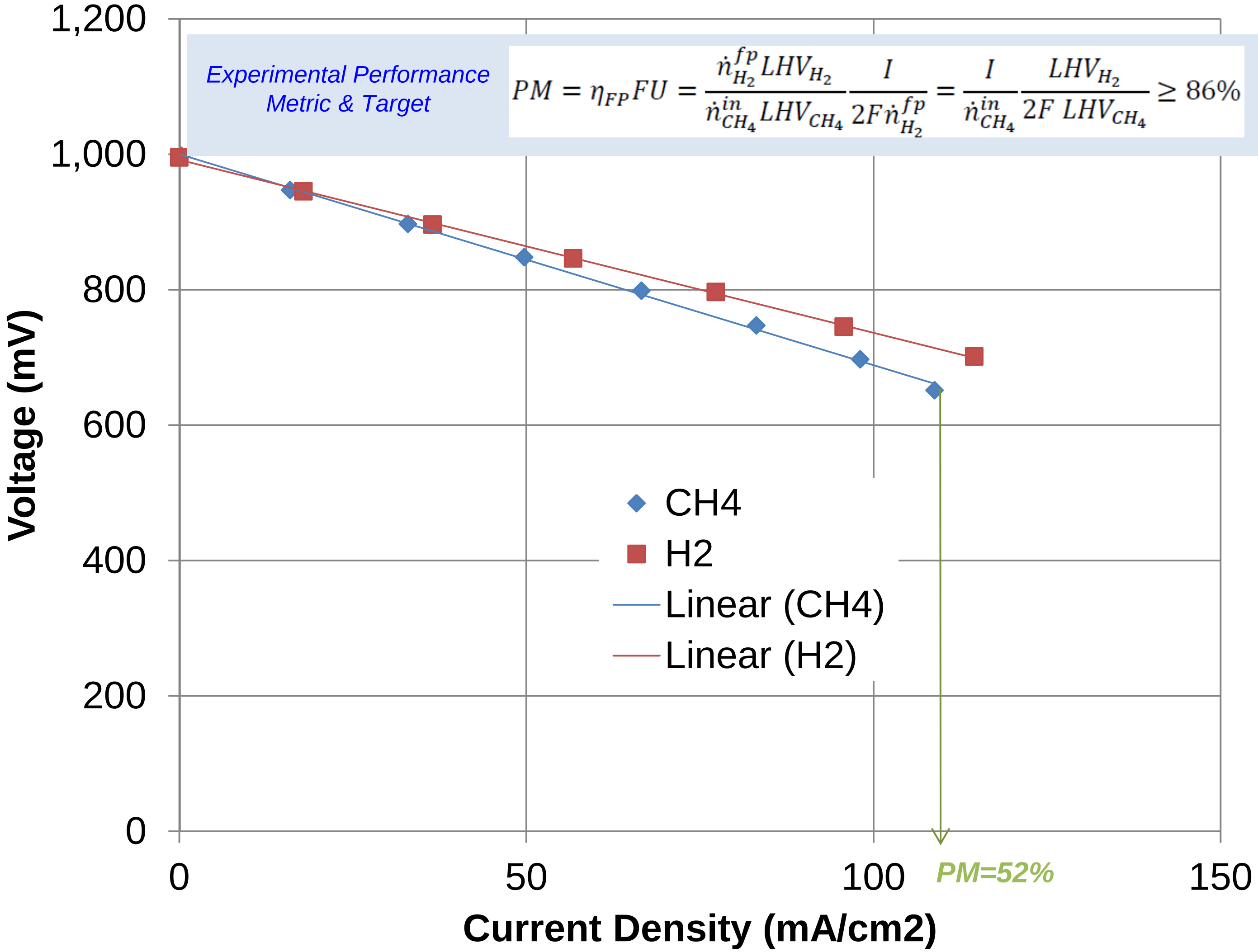
Fuel Processing Test: o-SOFC Cell @ 600 °C

Experimental Performance Metric & Target

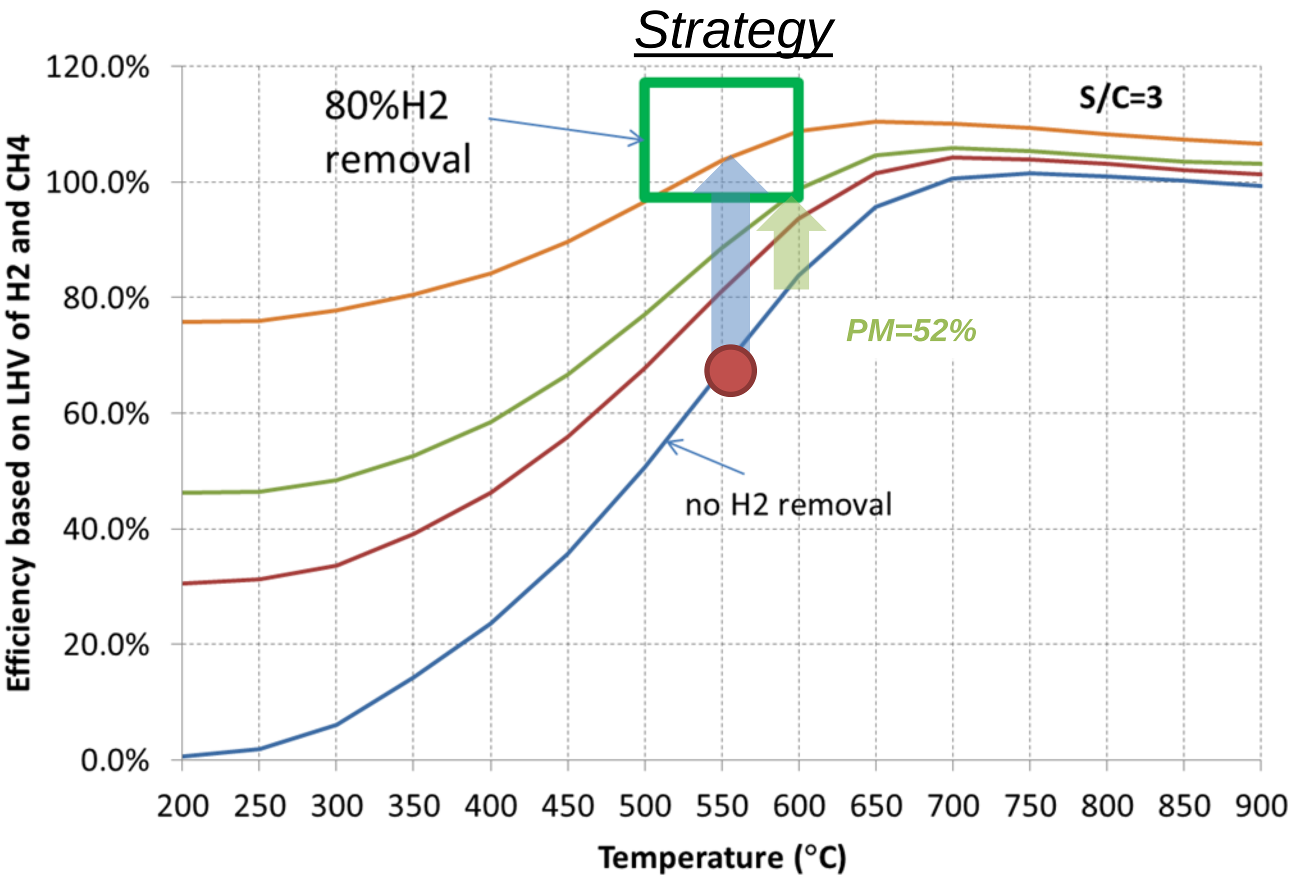
$$PM = \eta_{FP} FU = \frac{\dot{n}_{H_2}^{fp} LHV_{H_2}}{\dot{n}_{CH_4}^{in} LHV_{CH_4}} \frac{I}{2F\dot{n}_{H_2}^{fp}} = \frac{I}{\dot{n}_{CH_4}^{in}} \frac{LHV_{H_2}}{2F\ LHV_{CH_4}} \geq 86\%$$

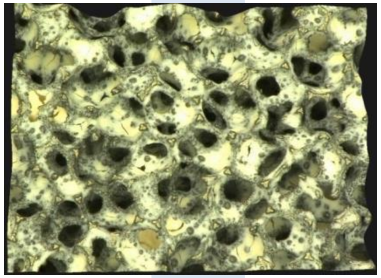


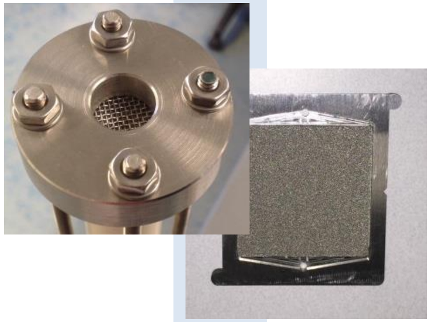
Fuel Processing

Internal CH_4 steam reforming

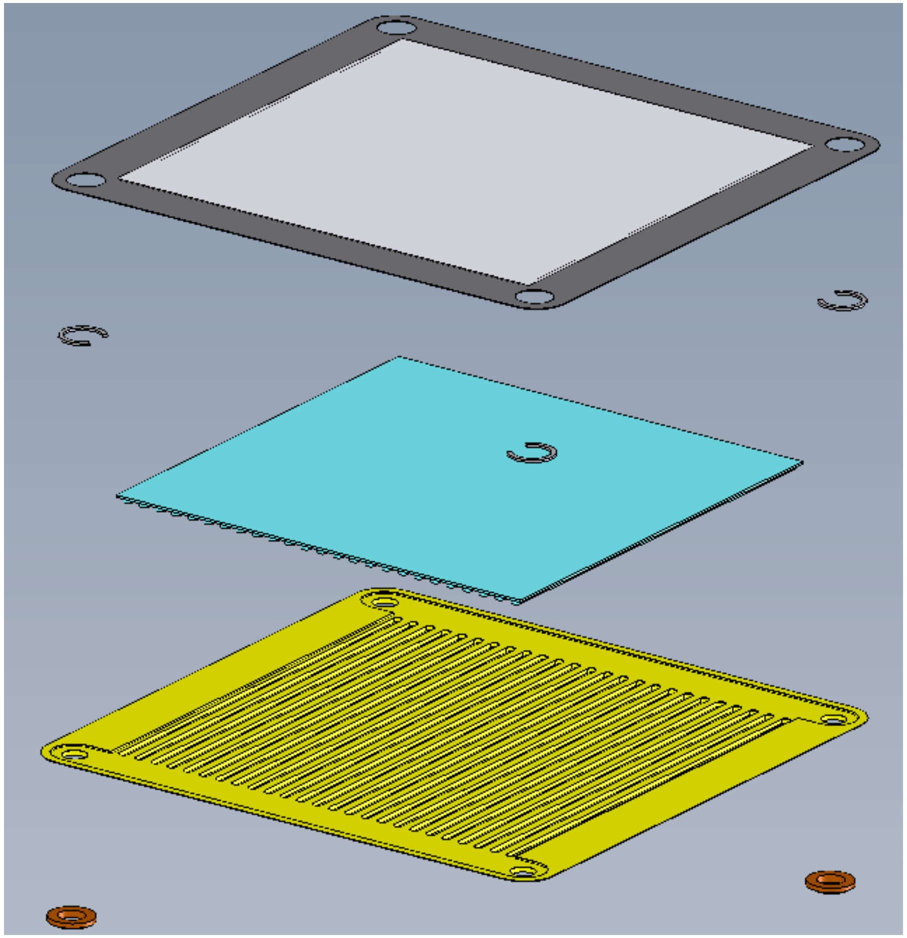
Dev. Approach







Metal Support Design



(1) Metal Porous Sheet
(substrate for p-SOFC trilayer)

(2) Metal C-Ring Inserts/Orifices
(3 out of 4 visible)

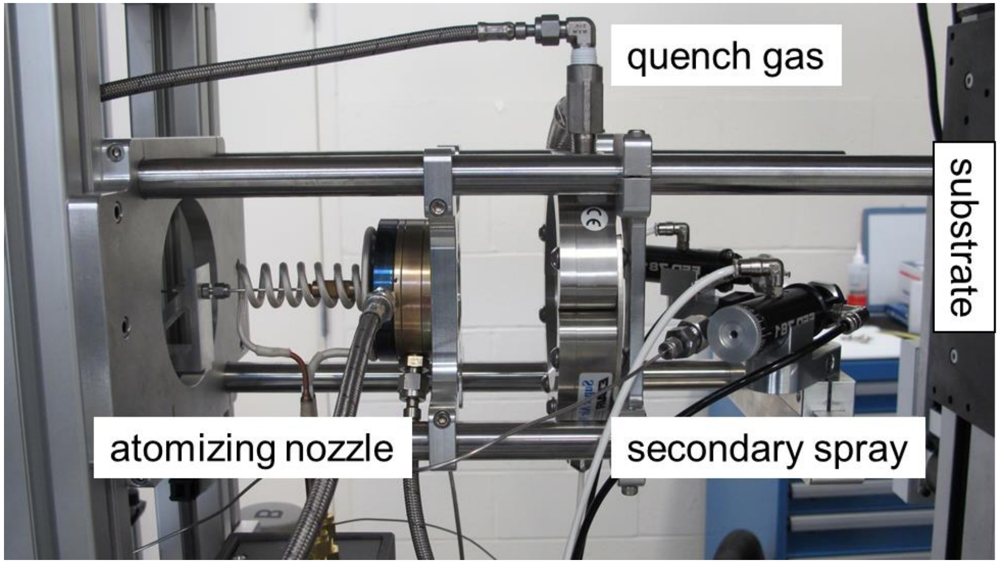
(3) Metal Foam
(substrate for reforming catalyst)

(4) Metal Stamped Dish

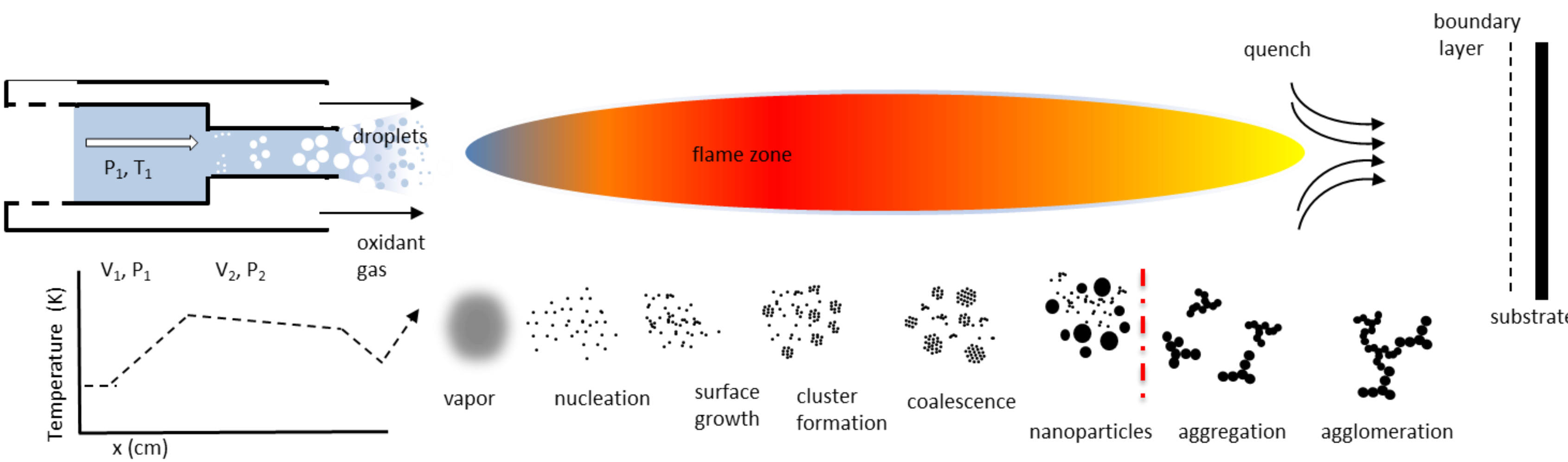
(5) Insulator Couplings
(2 out of 4 visible)

Enabling Fabrication Approach: Reactive Spray Deposition Technology (RSDT)

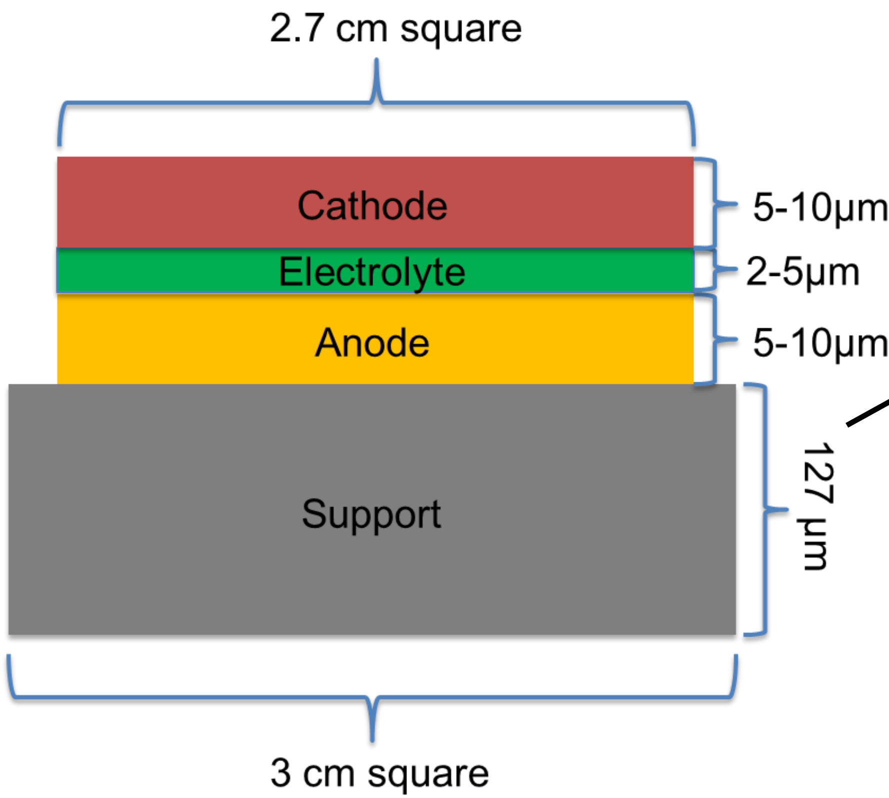
Cell Manufacturing Process: RSDT



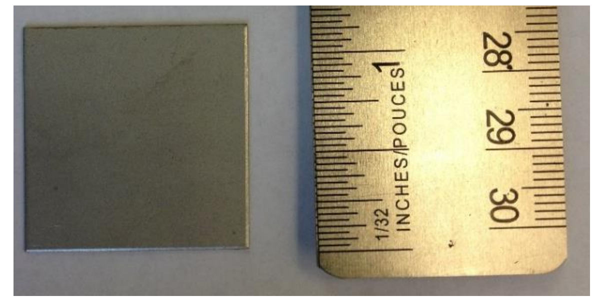
- Flame-based deposition process
- Direct deposition of trilayer cell onto metal support
- Elimination of sintering steps

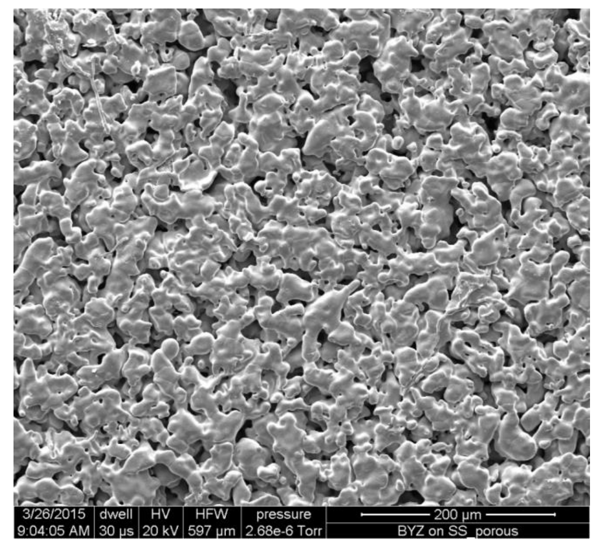


RSDT Deposition Targets



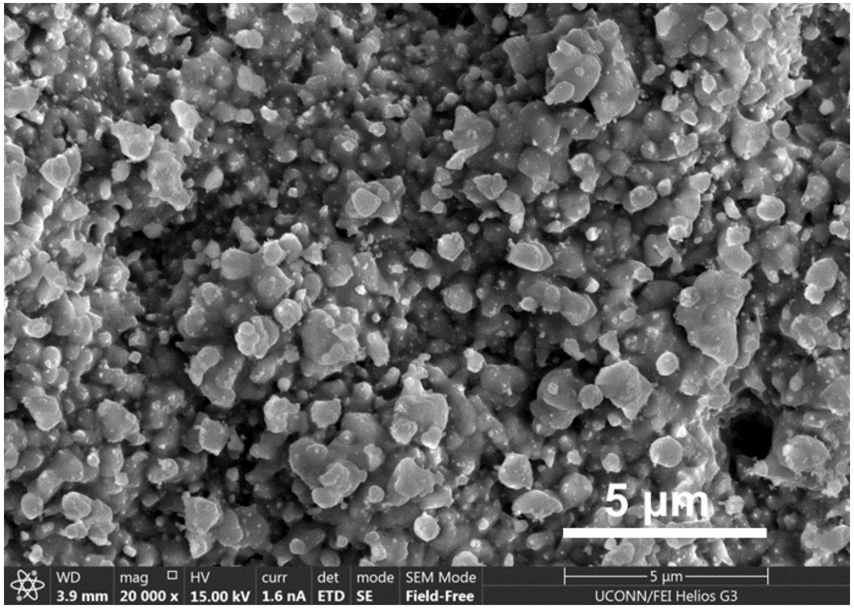
Porous metal support

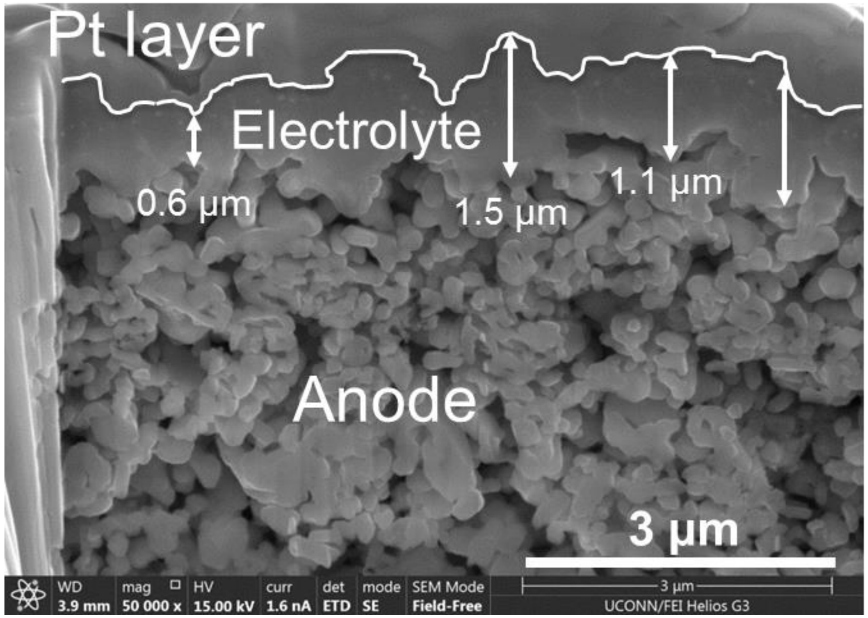




Gen 1 Half Cell by RSDT Process

Achieved dense electrolyte

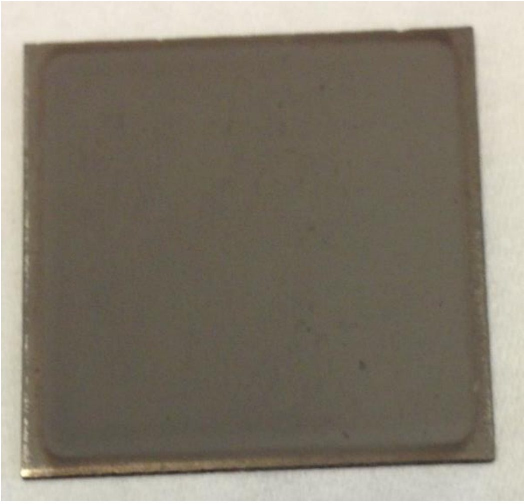




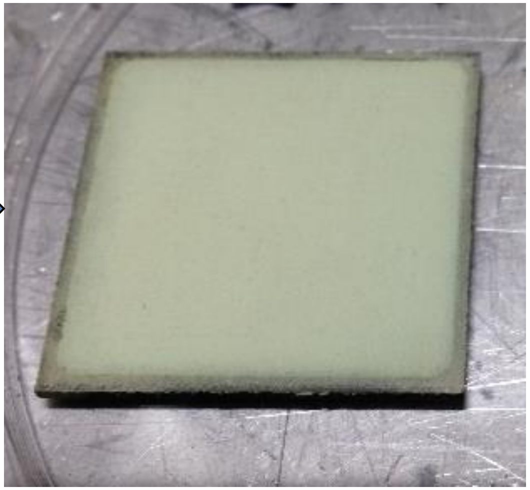
FIB cross section performed using FEI Helios G3

RSDT Full Cell Deposition

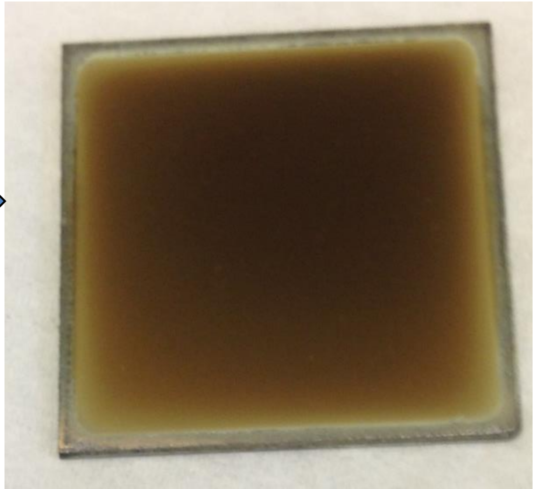
Anode

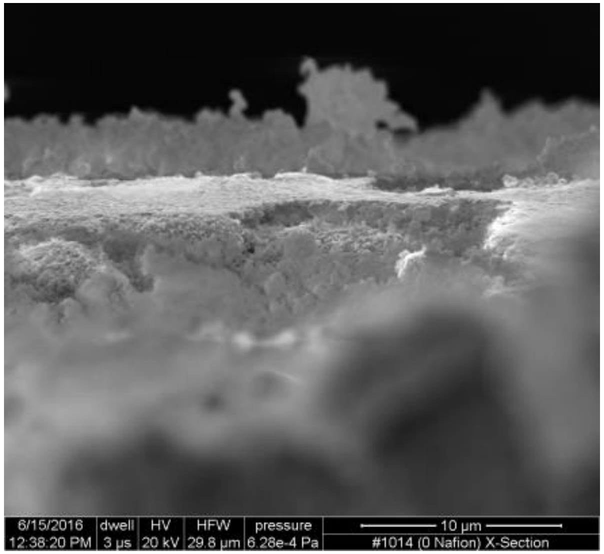


Anode-Electrolyte



Anode-Electrolyte-Cathode

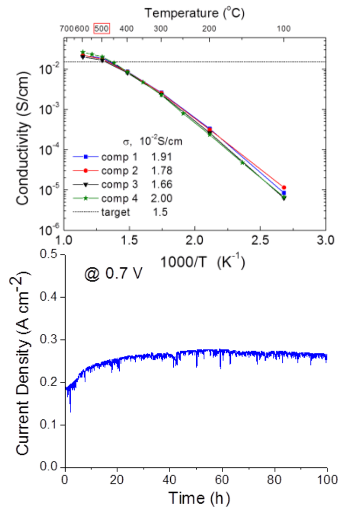


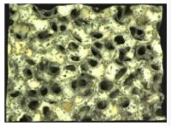


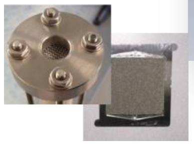
Electrolyte on anode
no electric shorts

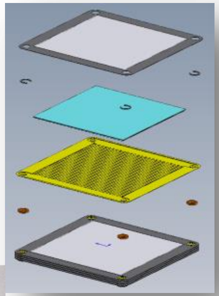
Summary

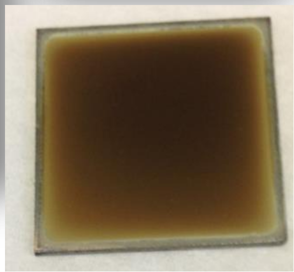
- Progress
  - Cell materials
  - Internal fuel processing
  - Stack design
  - RSDT fabrication process











- Next Steps (Major upcoming milestones)
  - Fuel cell fabrication by RSDT and performance verification
  - 100 W Stack fabrication and testing

Acknowledgements

The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000498.

Organization	Team Members
Northwestern	Sossina Haile, Sihyuk Choi, Chris Kucharczyk, Daekwang Lim
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University of Maryland	Ichiro Takeuchi, Xiaohang Zhang, Yangang Liang
United Technologies Research Center	Tianli Zhu, David Tew, Justin Hawkes

arpa·e CHANGING WHAT'S POSSIBLE

Grigorii Soloveichik, Scott Litzelman, John Tuttle, John Lemmon

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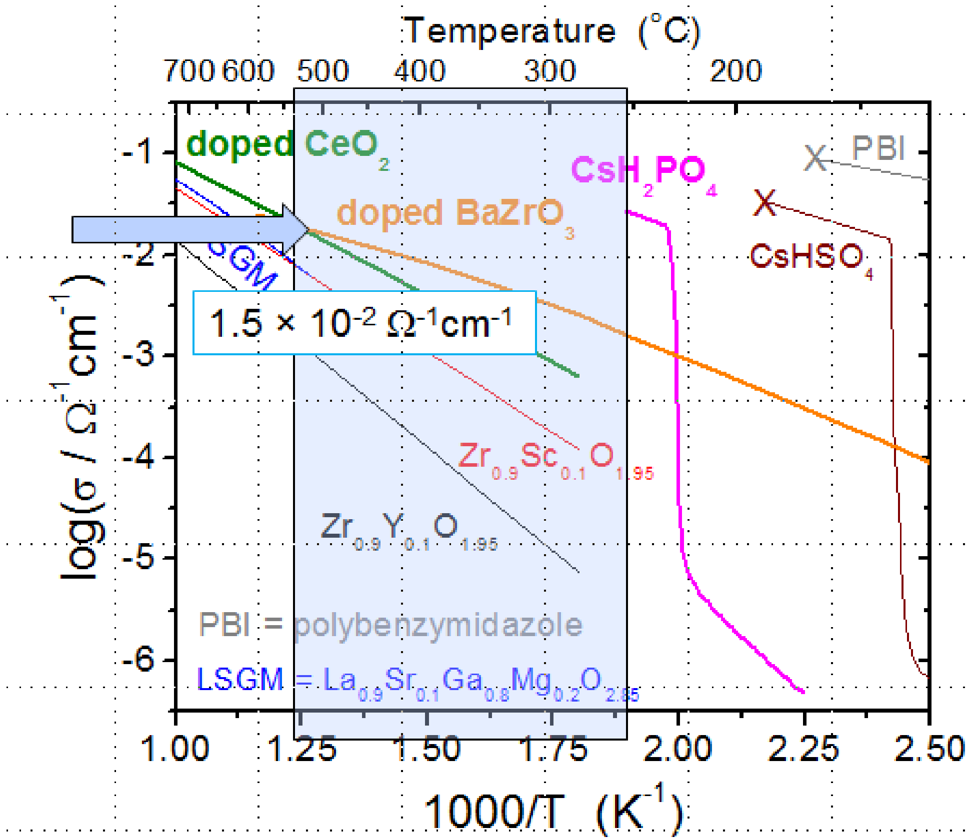
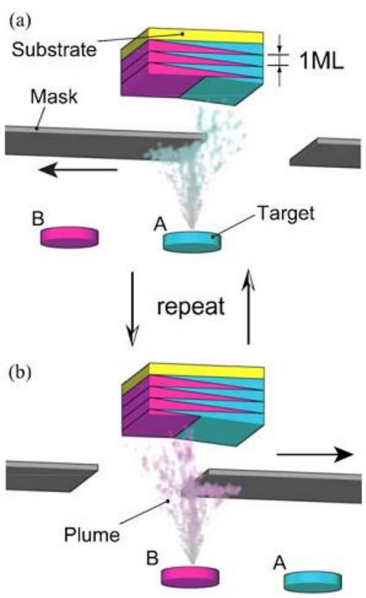
Back Up

Proton Conducting Oxide

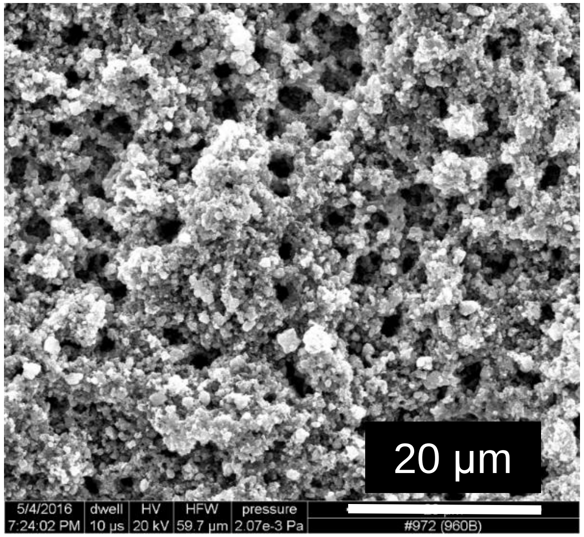
High-Throughput Material Evaluation Approach



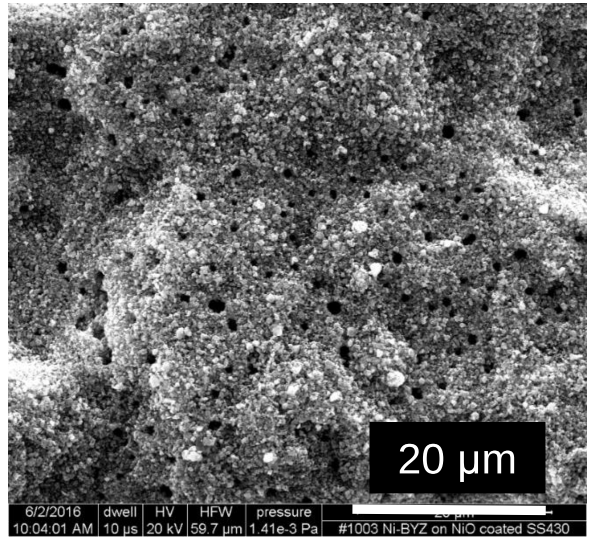


RSDT Anode Microstructure Refinement

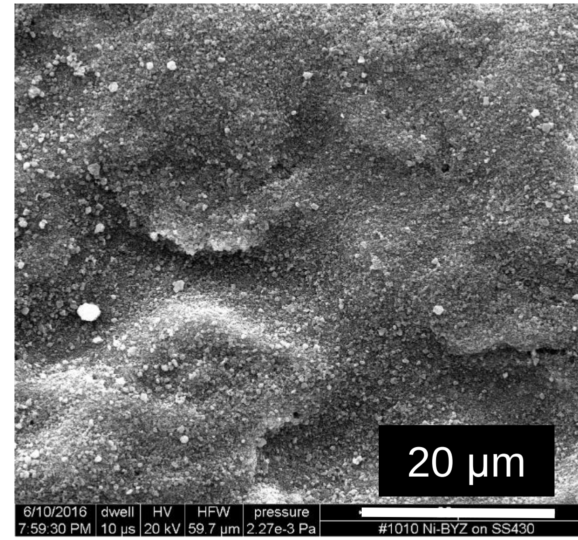
Effect of Binder on Porosity and Microstructure



30 wt% Nafion : NiO
Porosity: 26%



7.5 wt% Nafion : NiO
Porosity: 10%



0 wt% Nafion : NiO
Porosity: 1%

Porosity based on stereology, MIP in progress

Decreasing Binder Concentration

Decreasing Porosity

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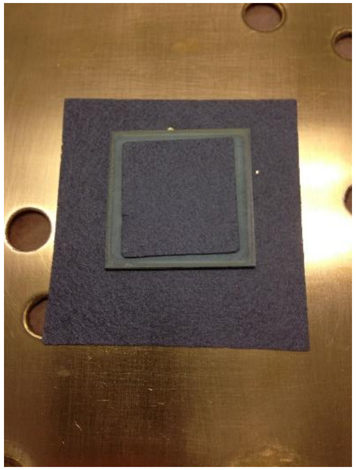
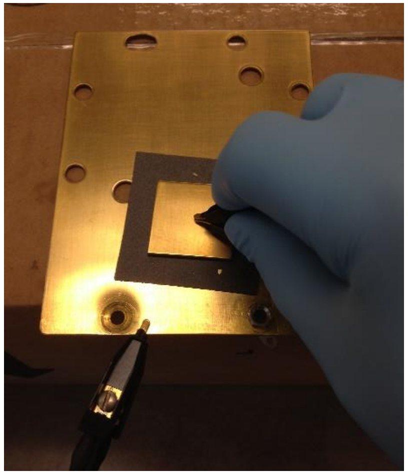
M4.2.1.1 RSDT Anode Microstructure Refinement

- Deposited electrolytes onto 0% and 7.5% anodes and performed resistance check
  - Check performed with Agilent 43388 milliohmmeter
  - Stack gold plate/carbon fiber mat/sample/carbon fiber mat ($6\ cm^2$) /gold plate

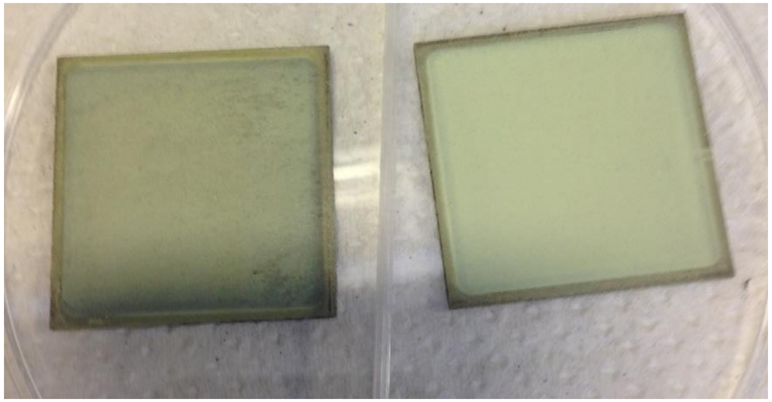
Sample	Resistivity (Ω-cm)
Base	1
Doctor bladed SS430	300
Anode (30 wt% Nafion)	144000
Half cell	$>10^8$





Half Cell

0% binder 7.5% binder



System Concept

5 kW Residential CHP System

Performance Summary	
Net DC Power (W)=	5000
Net AC Power / Methane LHV=	51%
Recovered Heat /Methane LHV=	25%
Effective Electric Efficiency=	57%