



Project Summary on Matrix Study of Aged SOFC Performance and Materials Degradation

Outline

- ❑ **Introduction to Atrex Energy, Inc**
- ❑ **Field observed degradation**
- ❑ **Technical progress**
 - Characterization of aged cells
 - Microstructure observation in aged cells
- ❑ **Acknowledgement**



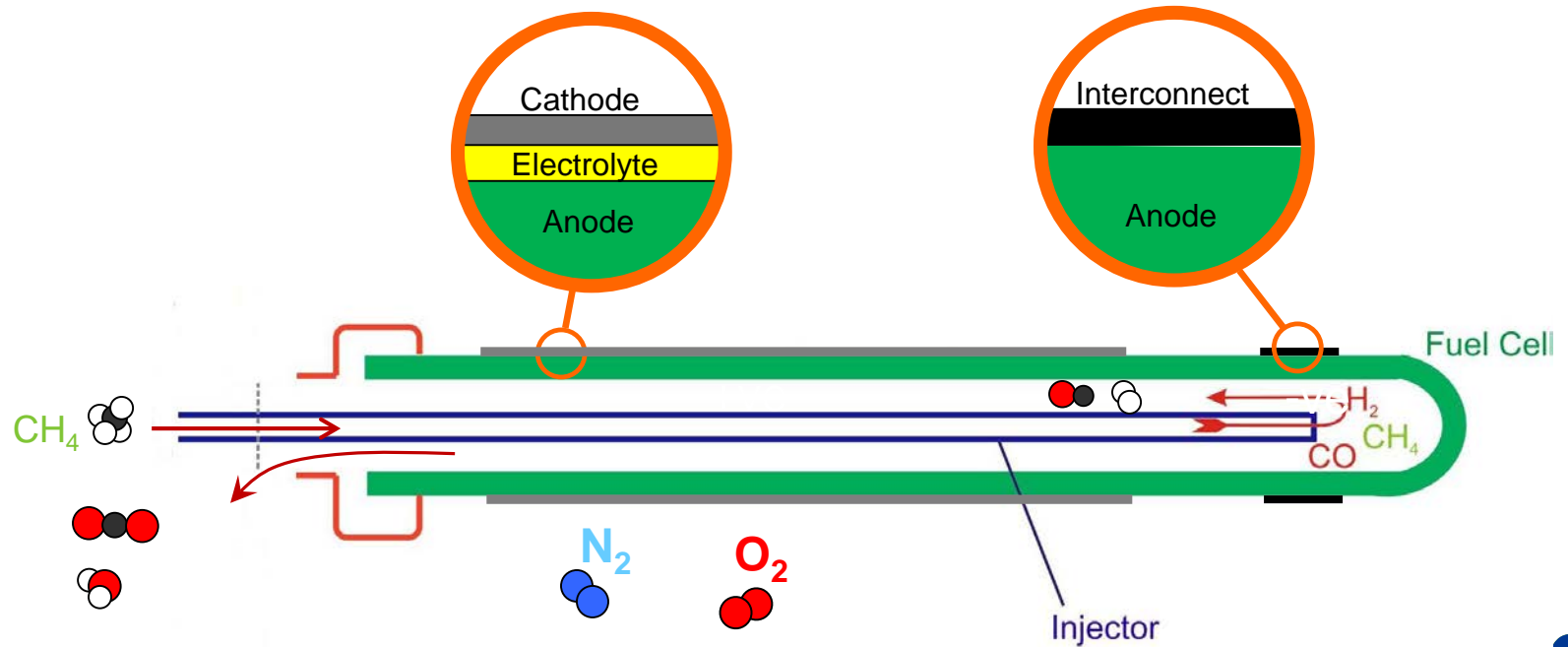
About Atrex Energy

- ❑ **Formerly Acumentrics SOFC division, established in 2000, “Powder to Power” in single facility in MA**
- ❑ **Focus on “rugged” fuel cells, pioneered small tubular SOFC**
 - 30 min startup and shutdown
 - Unattended operation in remote locations with **>35,000hrs**
- ❑ **PRODUCTS**
 - 250-1500 W commercial power products (NG, LPG)
 - 0.5kW to 10kW TRL 6 prototype (biofuel, diesel, JP8) for the US military
- ❑ **FUELS and APPLICATIONS**
 - Natural gas, wellhead gas, LPG, JP8, biofuel
 - Critical remote power, cathodic protection
 - All units utilize remote monitoring for additional reliability

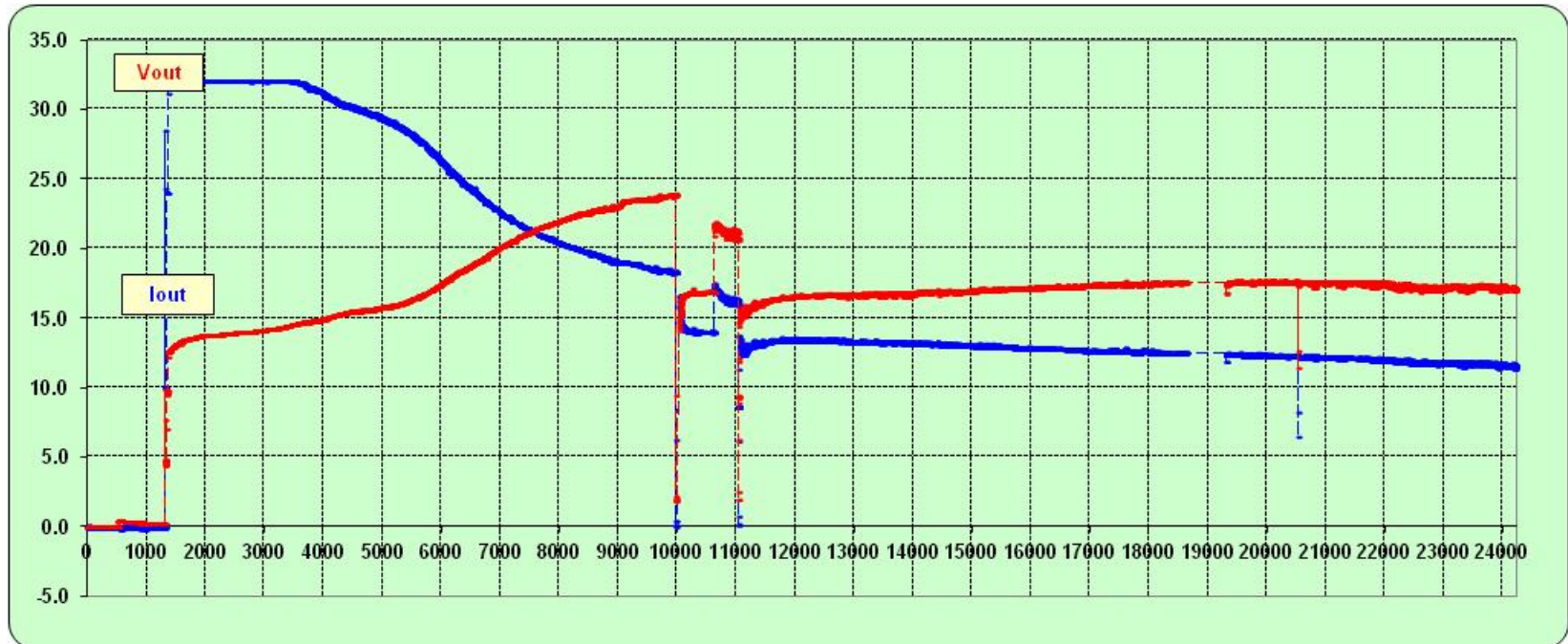


Atrex Energy Tubular Cell Technology

Layer	Materials
Anode	Ni/YSZ
Electrolyte	YSZ
Barrier	Doped Ceria
Cathode	LSCF
Interconnect	LaCrO3



Long Term Operation Example



Hourly averaged data of the voltage and current output from a field unit.



Examples of Degradation

Stack No.	Tmax /°C	Tmin /°C	Degradation /%/1000hr	Degradation Interval/hrs	Total life time /hrs
1	789	724	0.3%	19425	19429
2	799	771	1.5%	14020	25106
3	769	738	0.4%	22877	29031
4	822	778	0.2%	10270	19506
5	785	765	0.7%	15063	25282
6	792	761	1.6%	18481	21913
7	784	740	1.1%	14375	14411
8	782	737	0.6%	20170	20181
9	802	713	1.3%	16690	30035

Those cells offer opportunities to examine field cells in real applications, in the aspects of cell performance and microstructure change.



Project Background

Atrex Energy 's unique product design benefits:

- **Field replaceable bundle**
- **Easy to remove individual cells for post stack testing**
- **Large quantities of units deployed in field**
- **Various running conditions for field units**

Investigation Method:

- **Microscopic analysis**
- **Electrochemical characterization**
- **Impedance spectroscopy characterization**

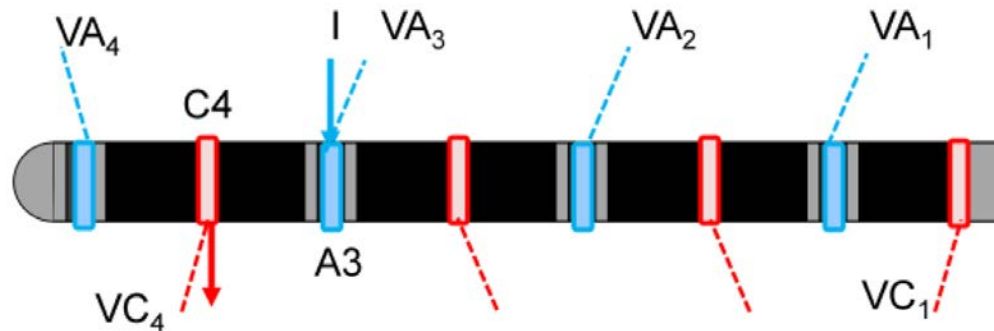
Project Goal:

- **Correlate the relationship between degradation with time, operating metadata**
- **Identify the spatial pattern and microscopic origin**

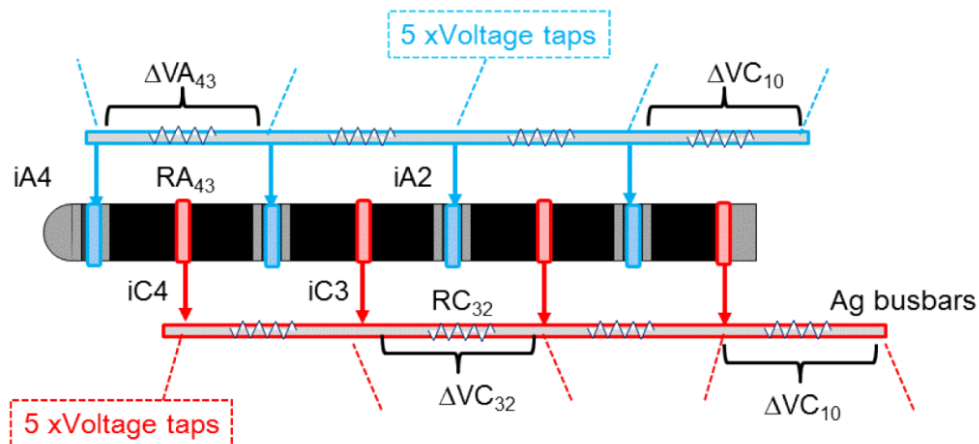


Electrochemical Characterization of Aged Cell Setup and Technique

□ Detailed individual cell study

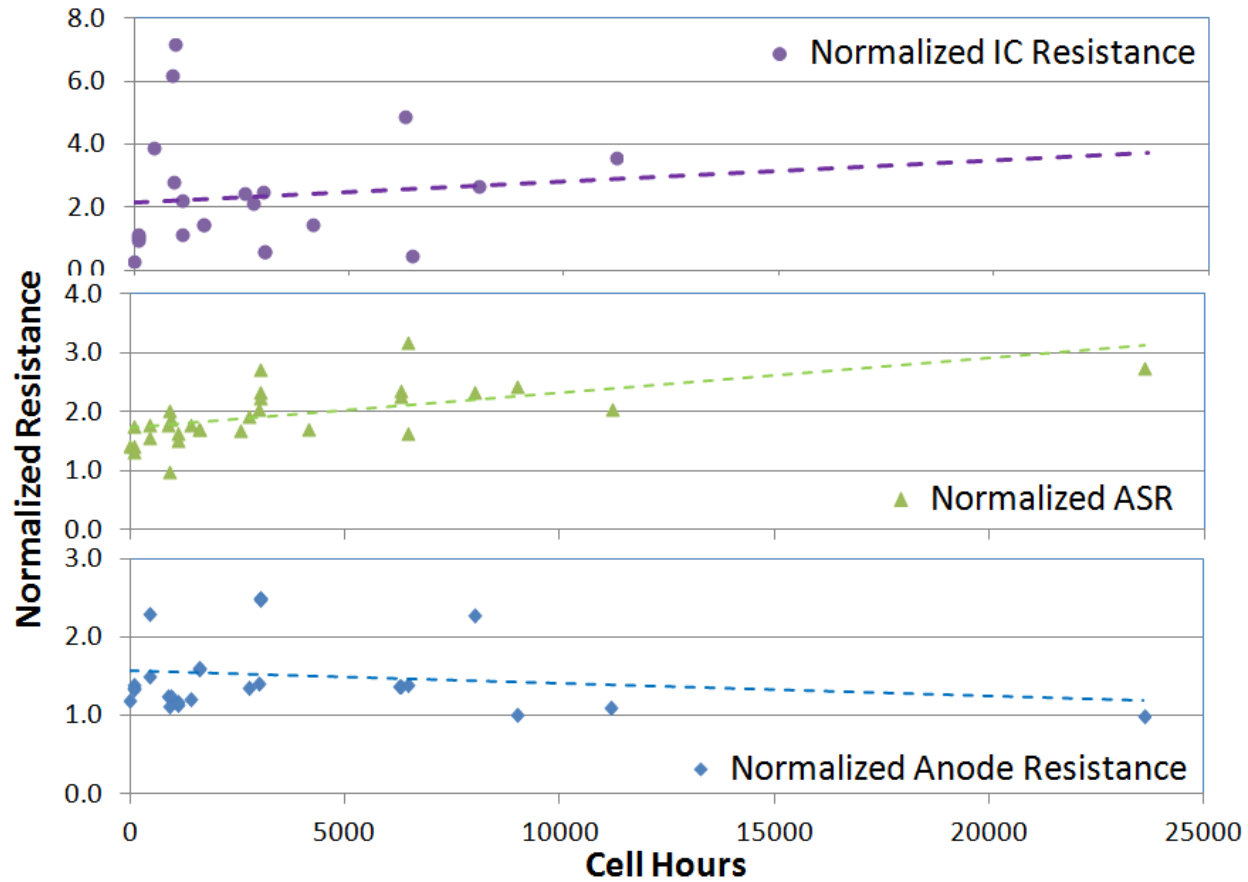


□ Current distribution study/Regular test

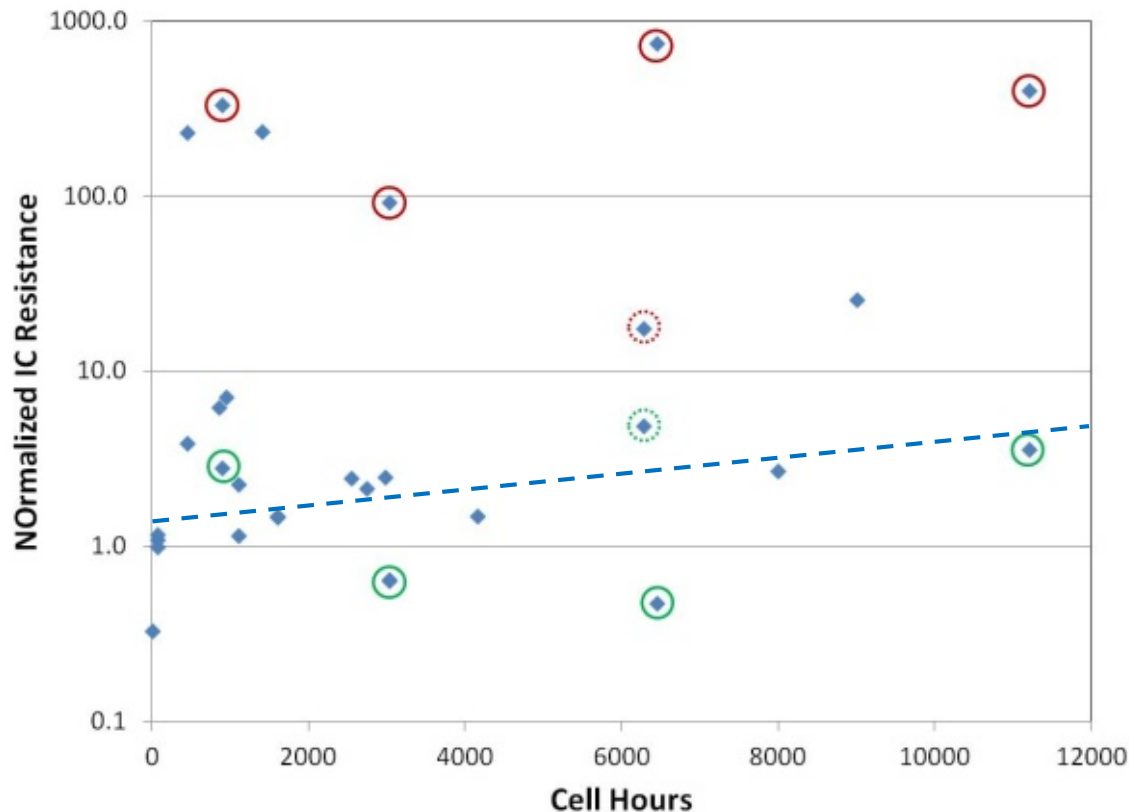


Performance Degradation Factor Analysis

Major degradation factors are cathode, and interconnection.



Interconnection Degradation Analysis

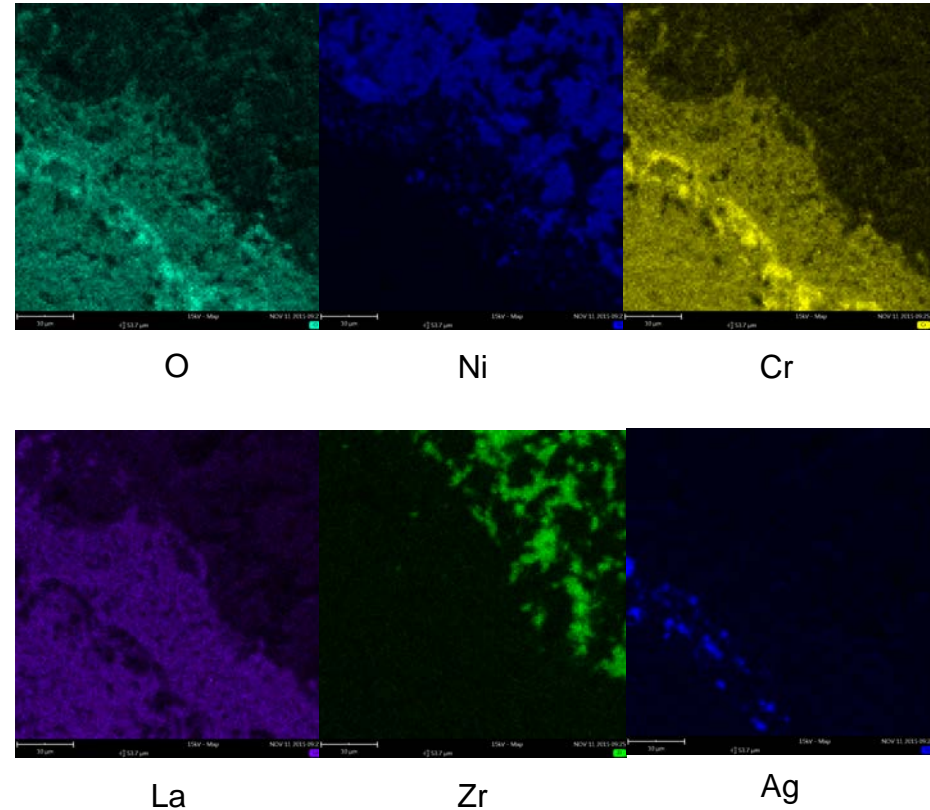
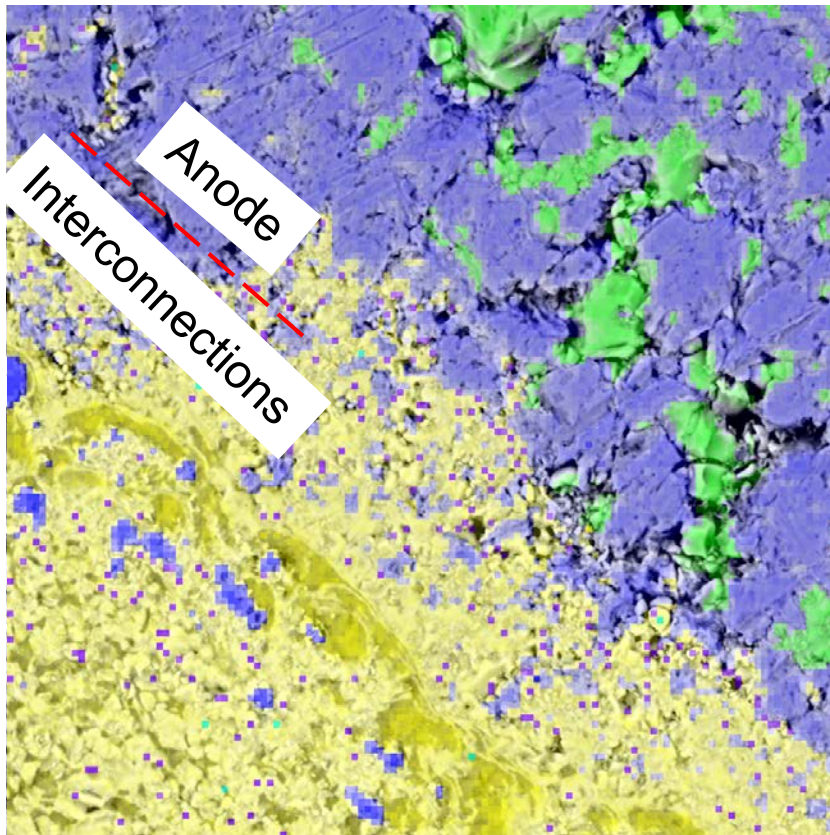


Two contributing factors:

1. Ag/ceramic contact degradation, which is also the major degradation issue for IC and the cell
2. Intrinsic interconnection ceramic degradation



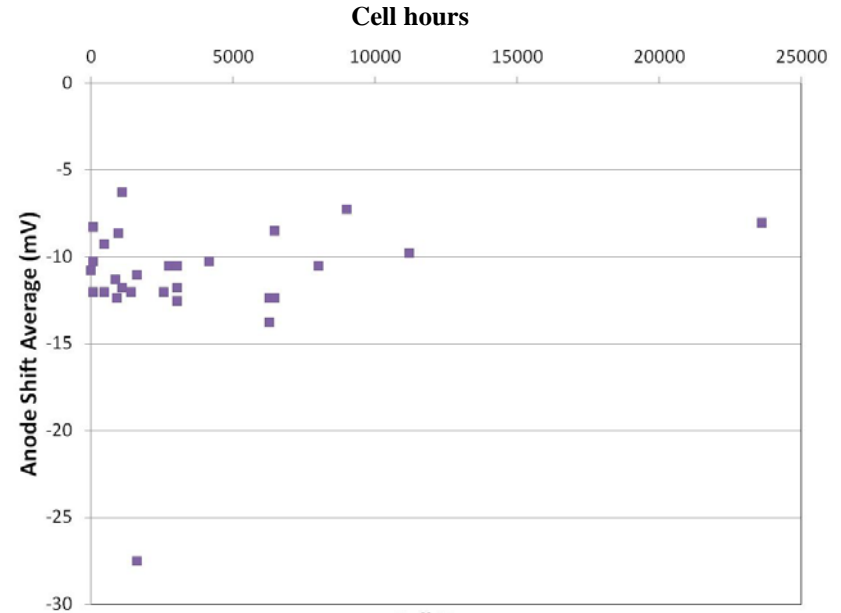
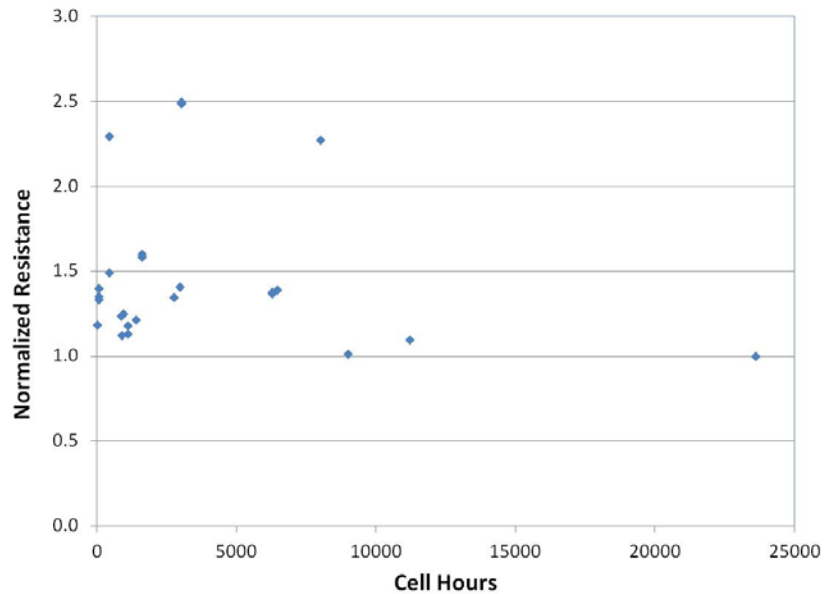
Observation in Aged Cell Inter Connections Compound Decomposition



Units with 8600 hours operation in field



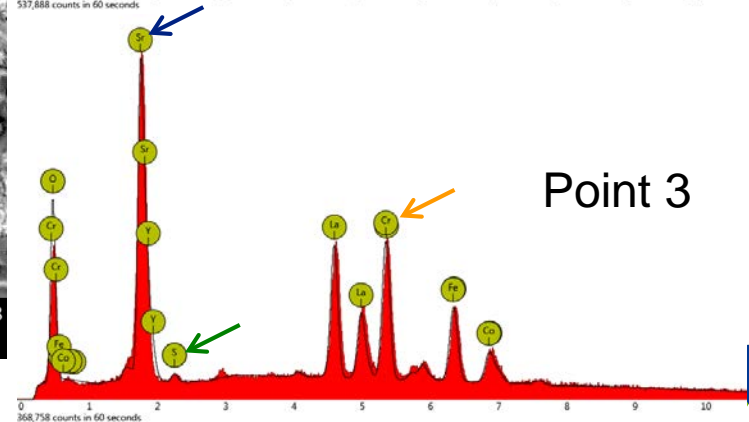
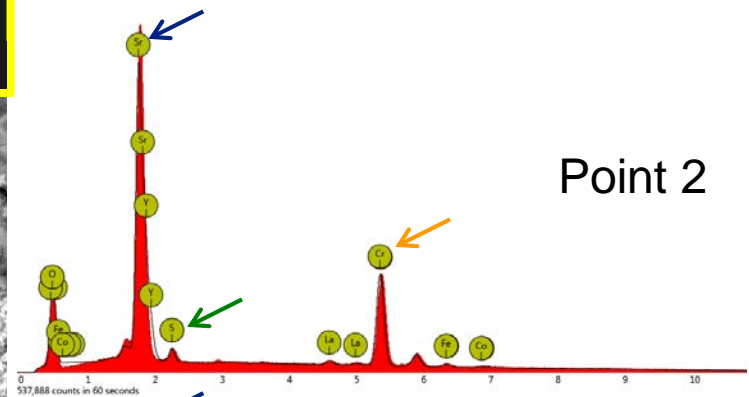
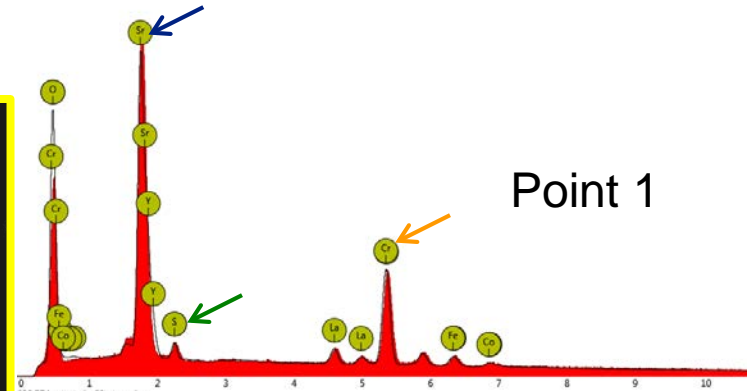
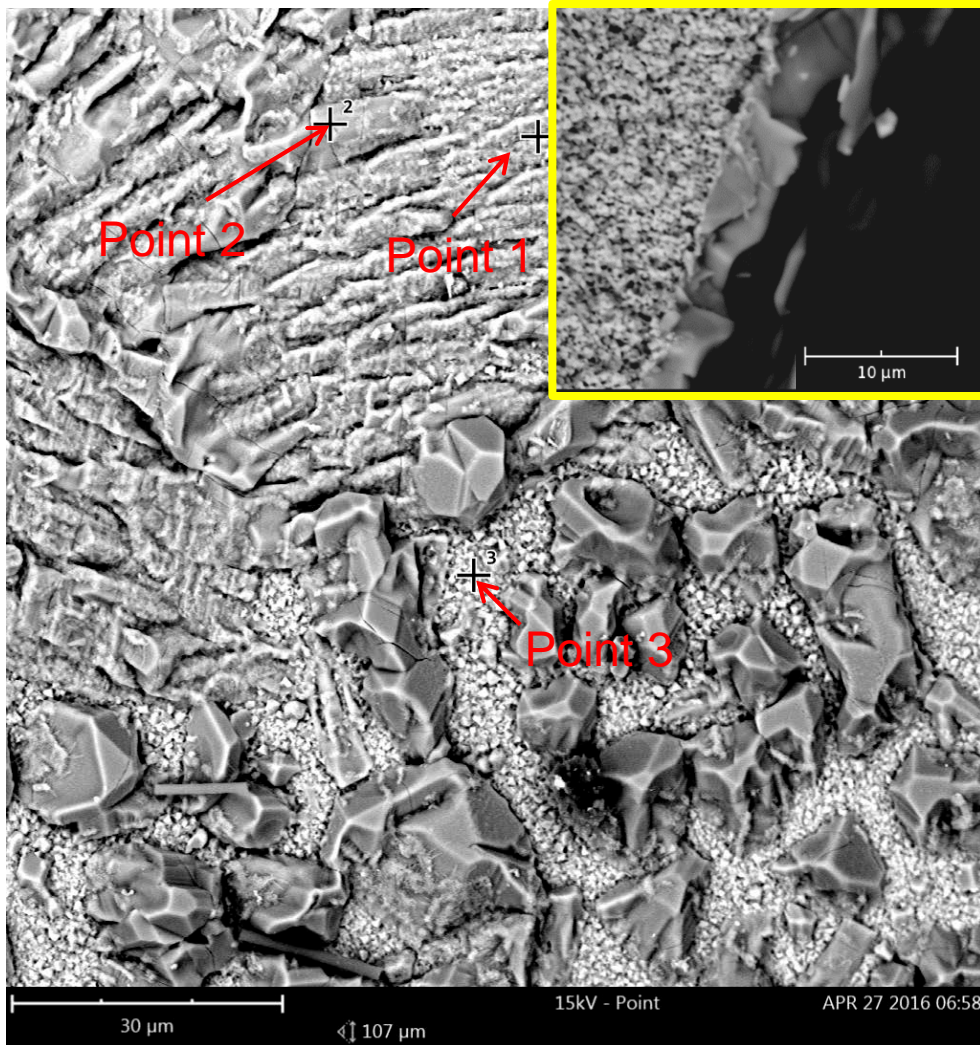
Anode Degradation Analysis



1. The anode resistance doesn't show significant trend with cell operation time.
2. The fuel dilution test indicates that the anode porosity and polarization doesn't change significantly with cell operation time as well.

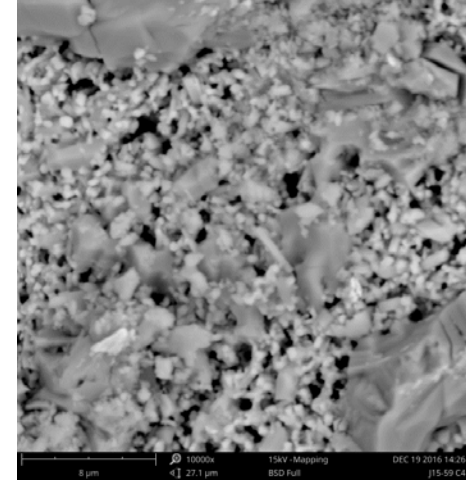
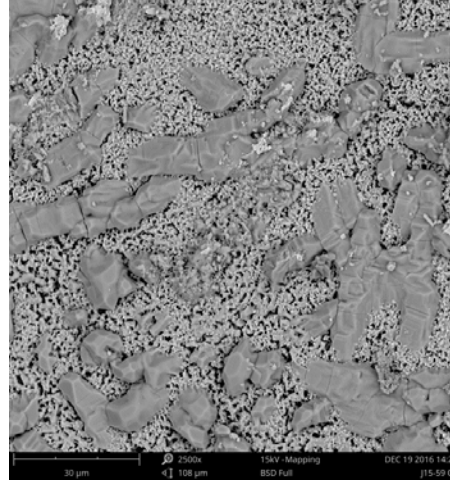


Cathode Degradation, SrO Segregation and S and Cr Contamination

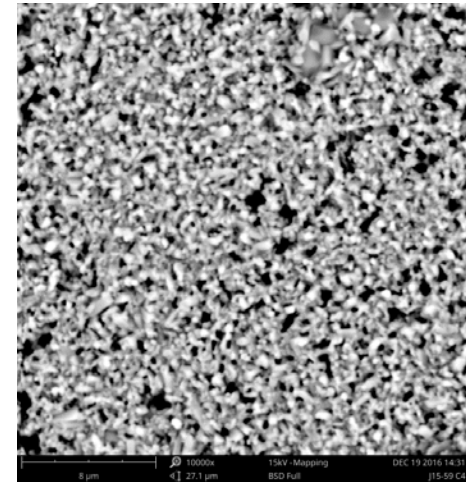
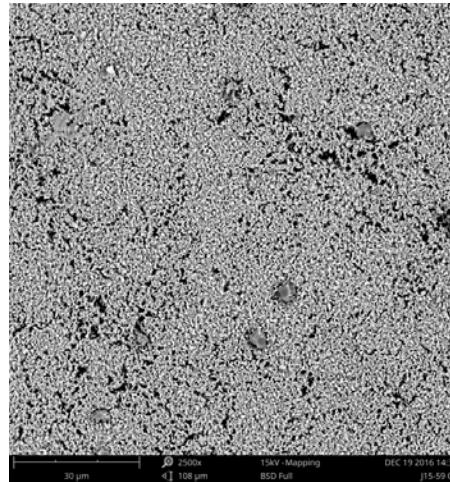
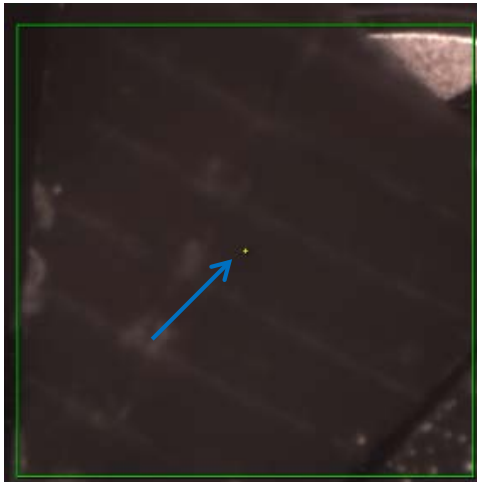


Sr Segregation with Current Distribution

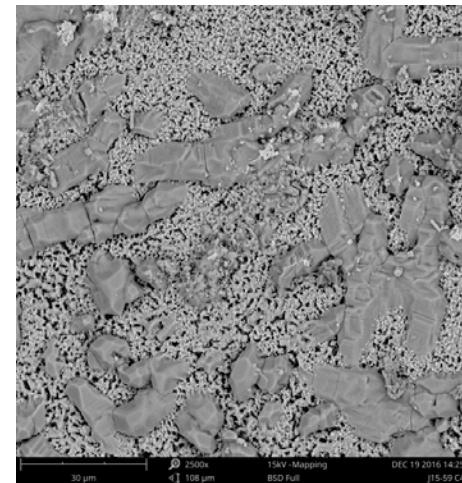
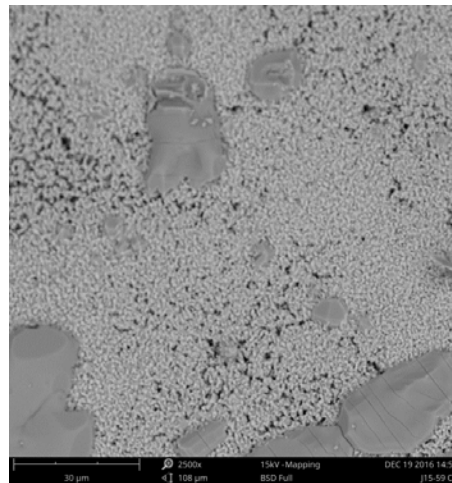
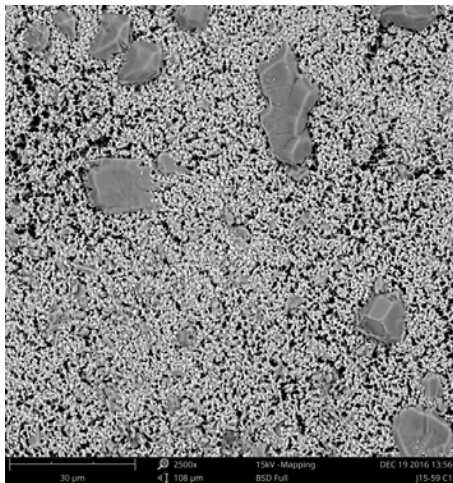
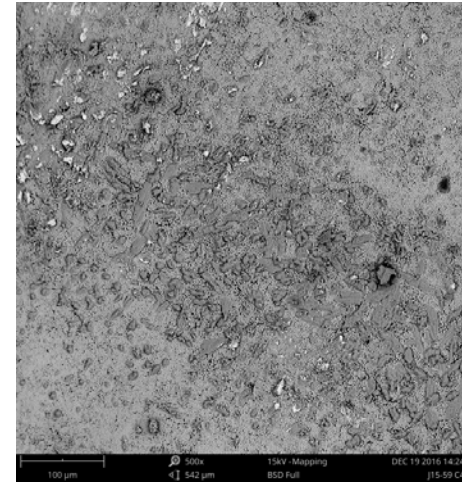
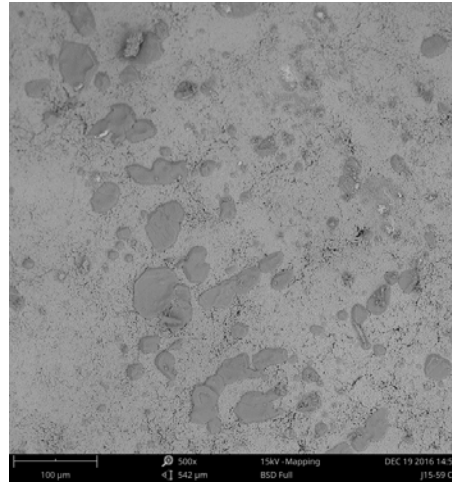
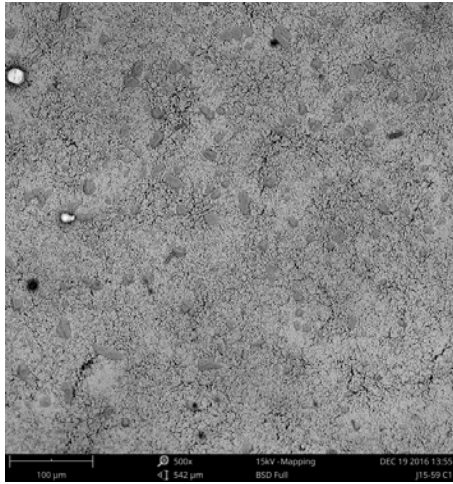
High Current Density



Low Current Density



Sr Segregation, Location Dependence



Fuel lean region

Middle region

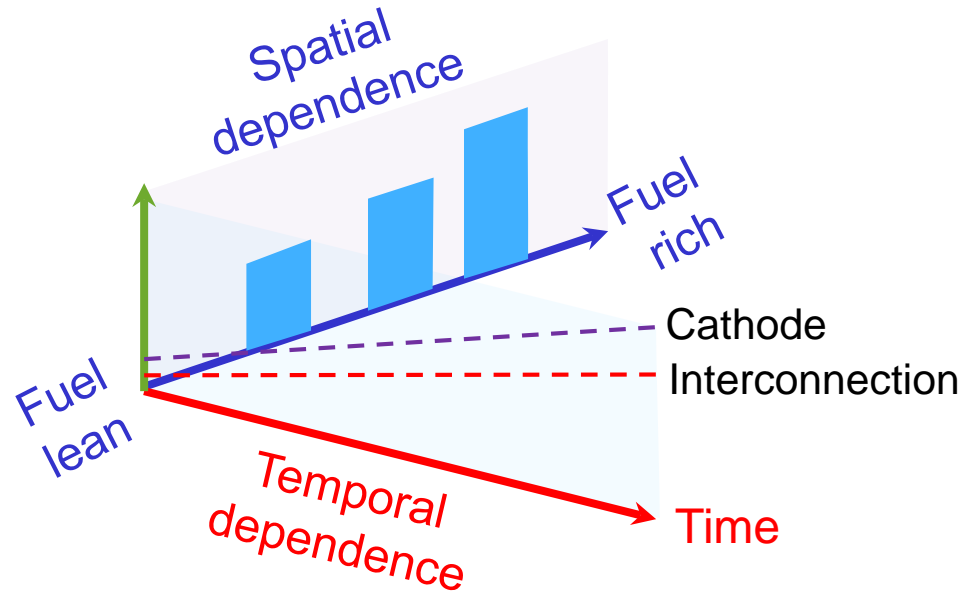
Fuel rich region



Summary

❑ Major degradation sources for anode supported tubular cell were identified

- Interconnection
- Cathode



❑ Materials degradation responsible for cell degradation were identified

- contact between interconnection ceramic with current collector
- Intrinsic interconnection ceramic decomposition
- Cathode degradation by contamination and SrO segregation



Future Work to Enhance Reliability and Longevity

❑ Interconnection improvement

- Improve bonding between current collector and ceramic interconnection

❑ Cathode enhancement

- Cr and S contamination protection
- SrO segregation prevention
- Improve current collector

❑ **With above proposed work, the stack life is expected to reach 50000 hours with degradation rate approaching 0.2%/khr.**



Acknowledgement

- **DOE project management: Joe Stoffa, Shailesh Vora**
- **Collaborators**
 - Boston University: Prof. Srikanth Gopalan and his team
- **Atrex Energy**
 - Manufacturing team
 - Cell engineering Team
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