ATREX ENERGY

POWERFUL POSSIBILITIES

Progress Update on Matrix Study of Aged SOFC Performance and Materials Degradation

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- **Application of Atrex Energy product**
- **Technical progress**
  - Performance of aged cells
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- **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 **>25,000hrs**
- **PRODUCTS**
  - 250W-10kW products
  - 250-1500 W commercial power products (NG, APG, LPG)
  - 3kW and 10kW development products (biofuel, diesel, JP8) for the US military
- **FUELS and APPLICATIONS**
  - Natural gas, wellhead gas, LPG, JP8, biofuel
  - Critical remote power, cathodic protection
  - Units all utilize remote monitoring for additional reliability

Atrex Energy – Capabilities and Resources

- SOFC - “Powder to Power” all in one 30,000 sq ft facility in Walpole, MA
- Employees include electrical, mechanical, chemical and material, automation, Firmware engineers and manufacturing staff
- Full Scale research, development and testing laboratory
  - Ceramics forming & processing
  - Commercial manufacturing
  - Power electronics
  - Prototype machining
  - Chemical reactor design
  - Thermo-mechanical design and integration
  - Ground up board and firmware development

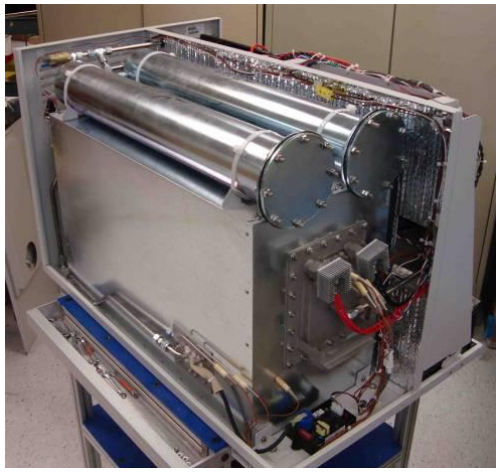
Remote Power Application

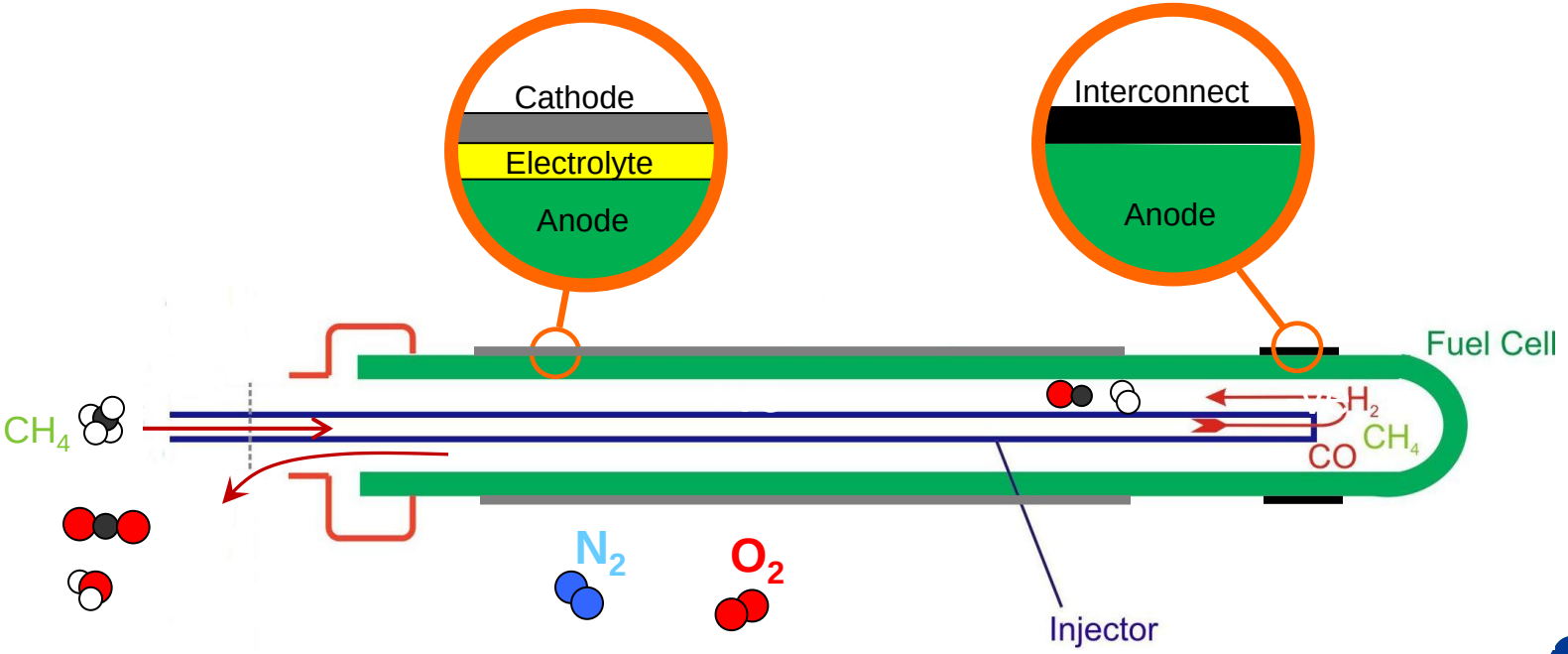
- US Coast Guard Radio Network Towers in Alaska
- LPG flown in by helicopter; fuel efficiency highly desirable

Remote LPG and NG Applications

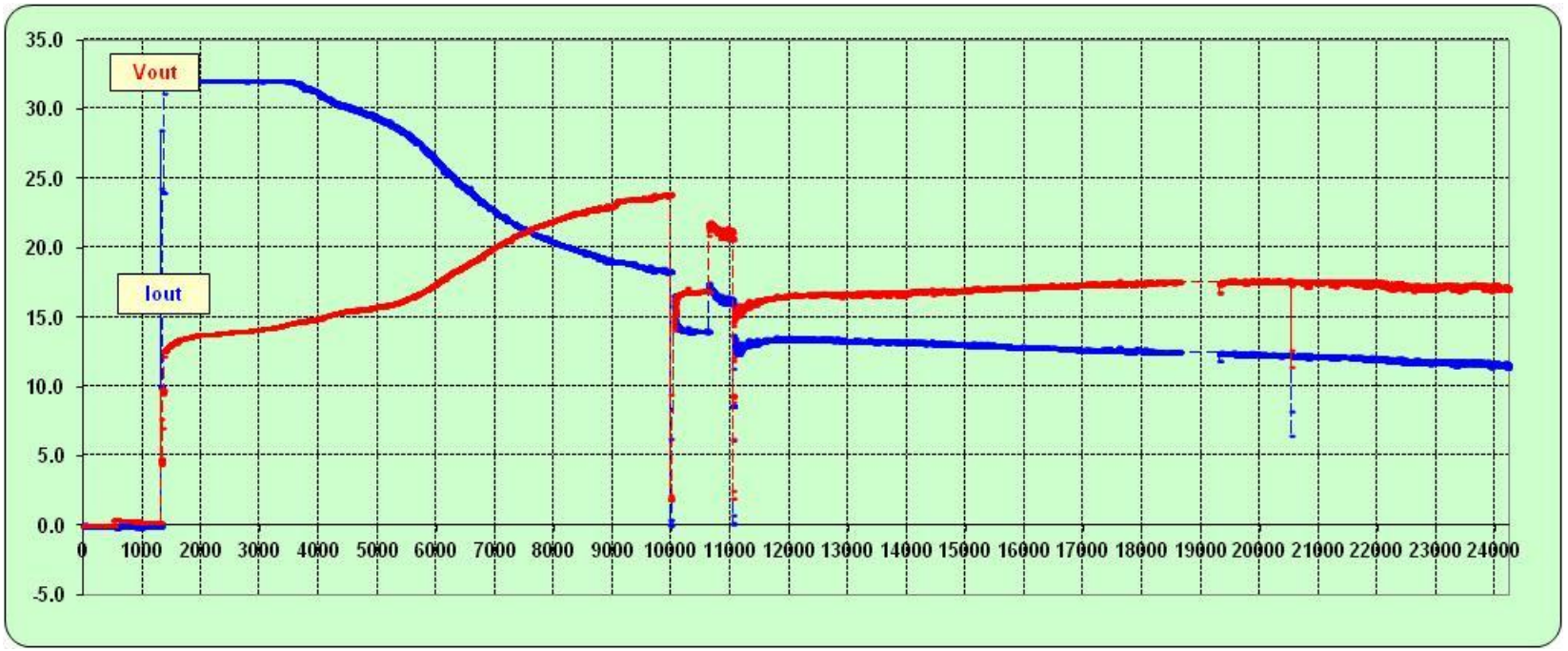
Atrex Energy Tubular Cell Technology

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





Long Term Running 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

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

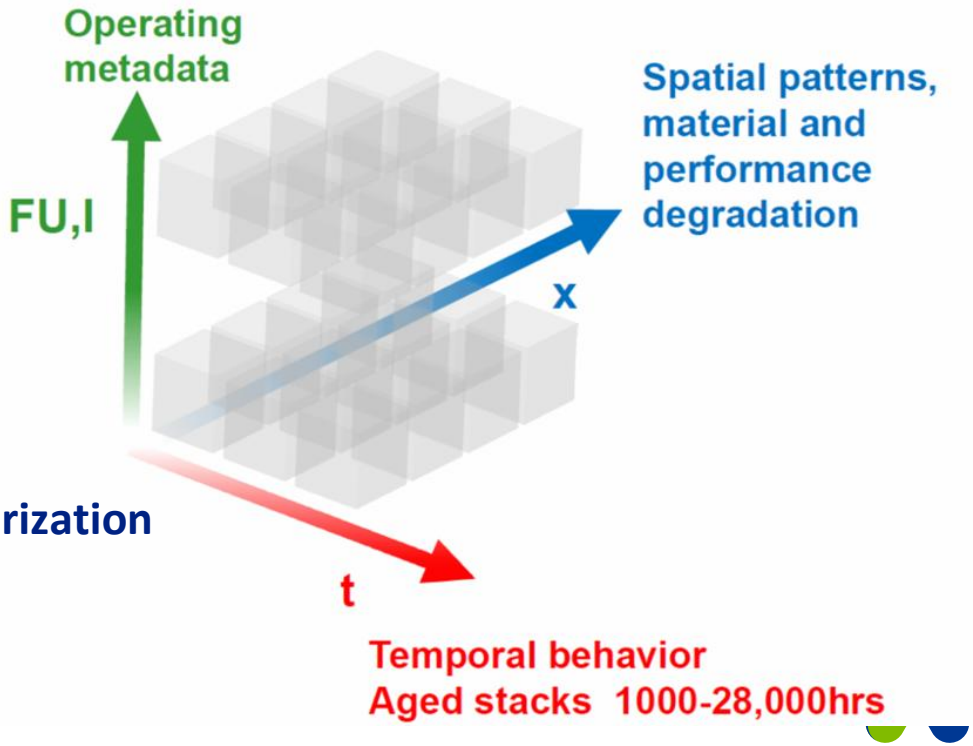
Project Background

Atrex Energy provides opportunity in degradation study:

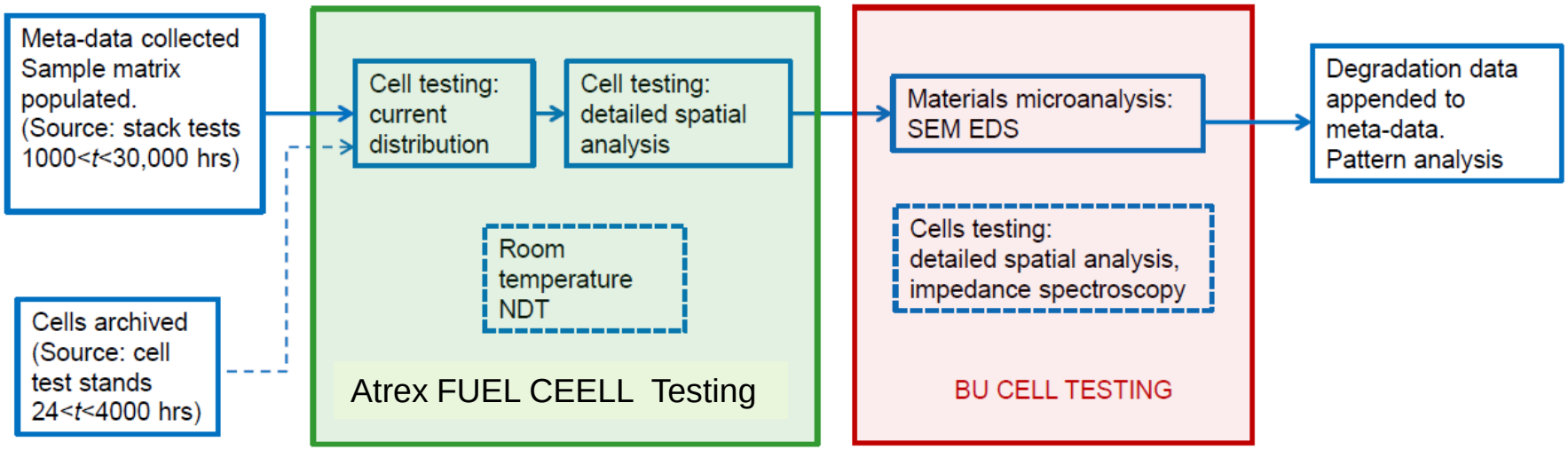
- **Field replaceable bundle**
- **Easy to remove individual cells for post stack testing**
- **Large quantities of units deployed in field**
- **Various running conditions for field units**

Investigation Method:

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

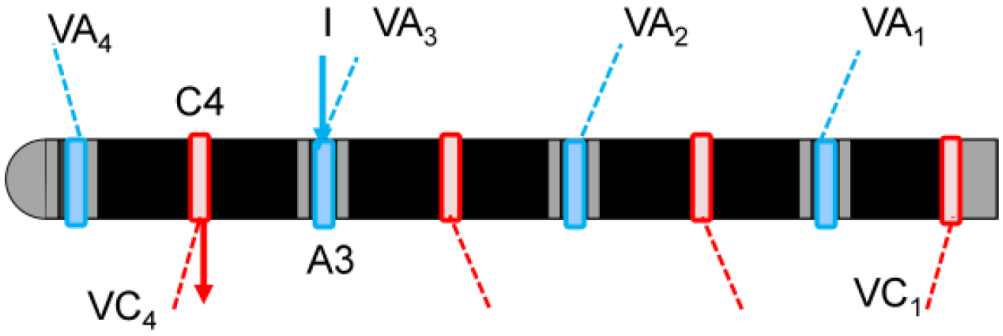


Project Overflow

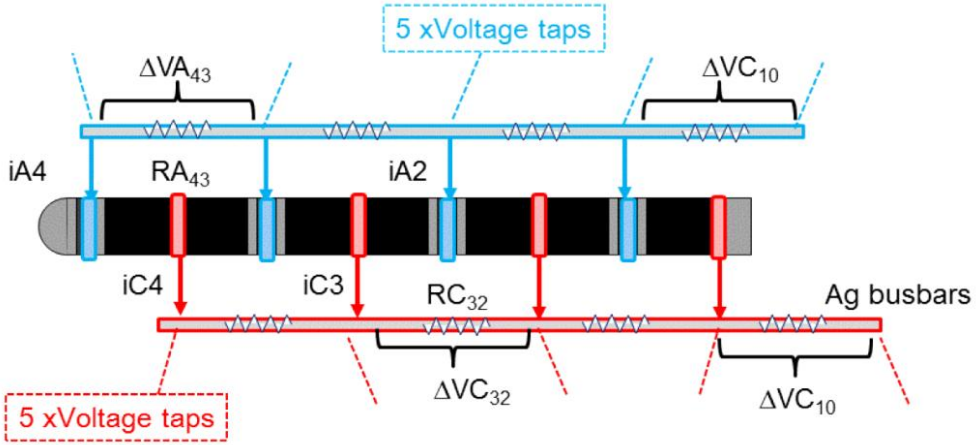


Electrochemical Characterization of Aged Cell Setup and Technique

❑ Detailed individual cell study

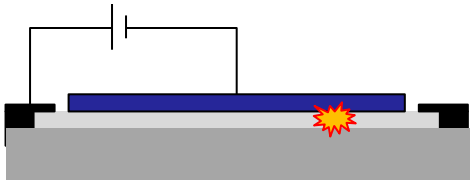


❑ Current distribution study/Regular test



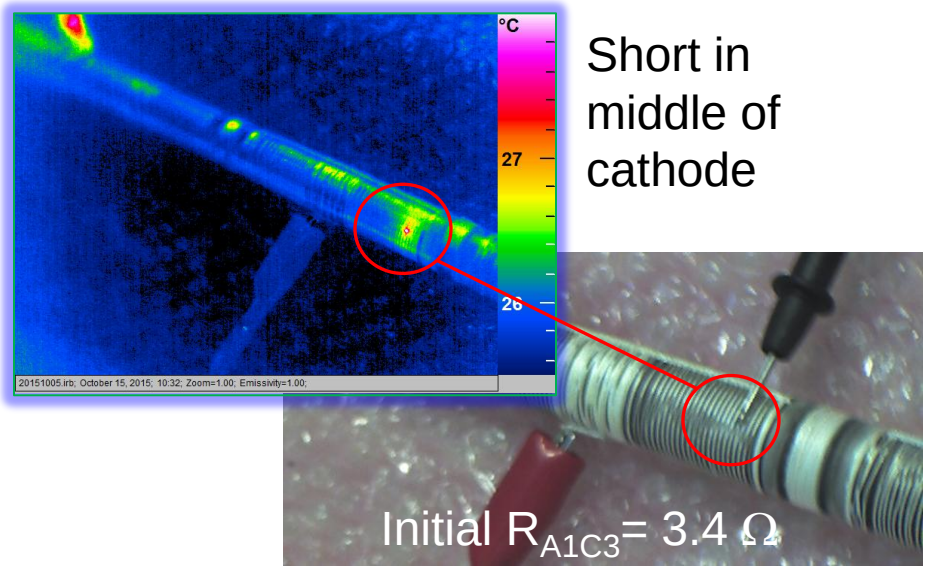
Imaging of Electric Shorts

Heat signature of joule heating from an electric short can be easily picked up by a thermal camera (~0.1W)



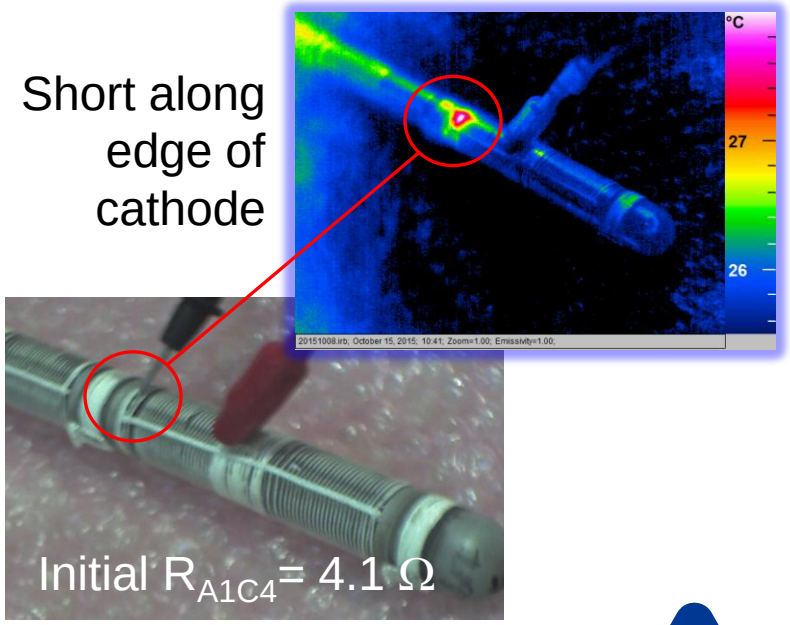
Have not found any examples of electrical shorts in production; have found a few examples in old stacks. Useful technique for investigating degradation phenomena

e.g. cell tested in field for 9000 hrs



Short in middle of cathode

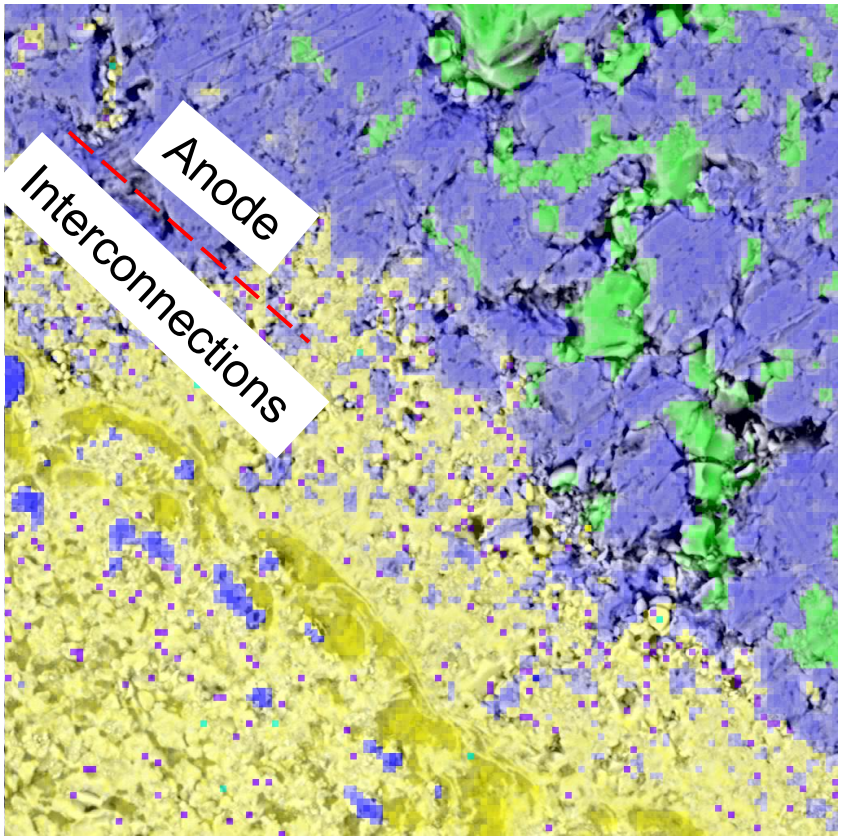
Short along edge of cathode

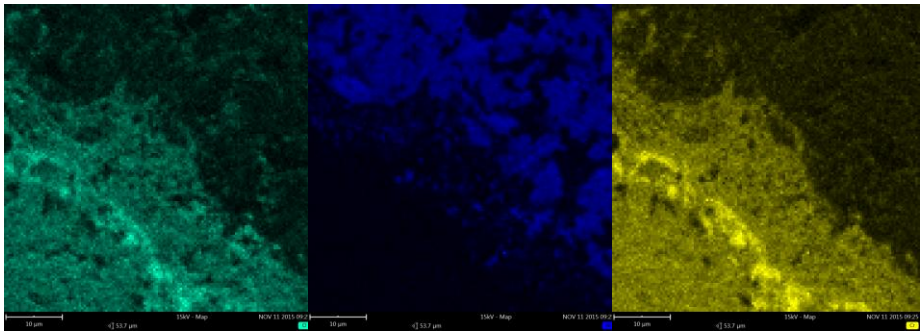


Expected Results from Electrochemical Characterization (Upcoming)

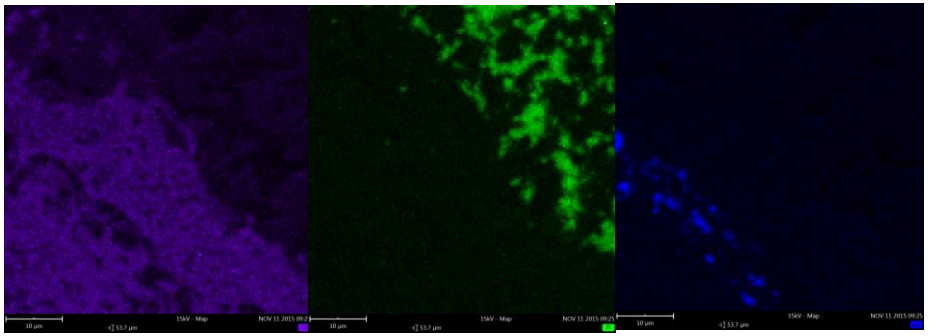
- **Comparison between low running hours vs. high running hours**
- **Comparison between low running current vs. high running current**
- **Comparison between low running temperature vs. high running temperature**

Observation in Aged Cell
Inter Connections Compound Decomposition





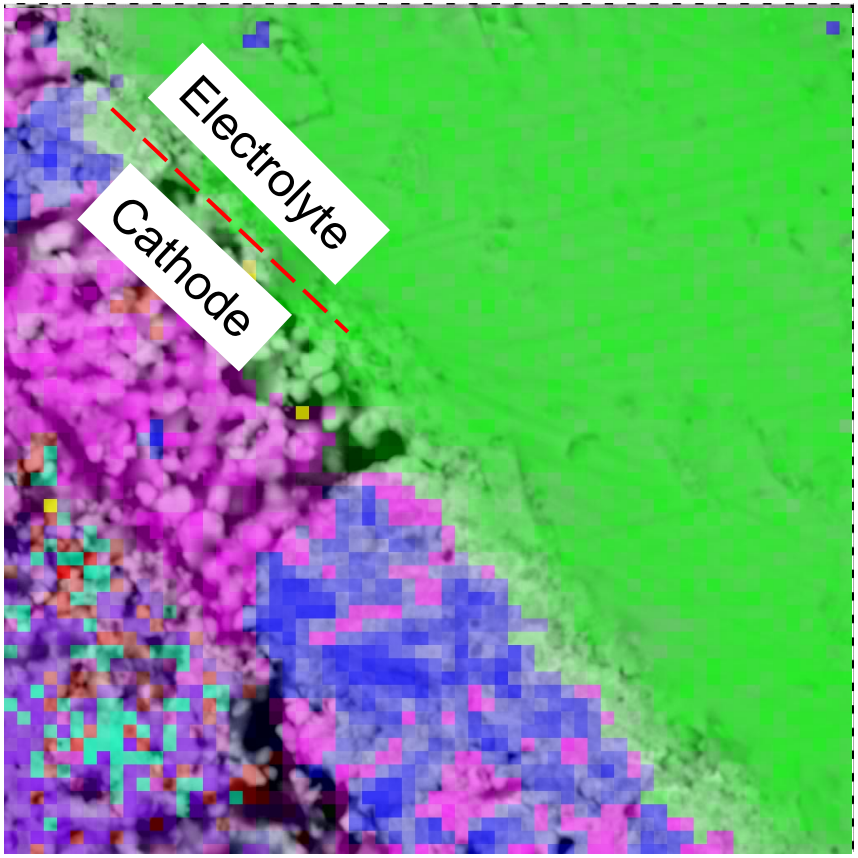
O Ni Cr

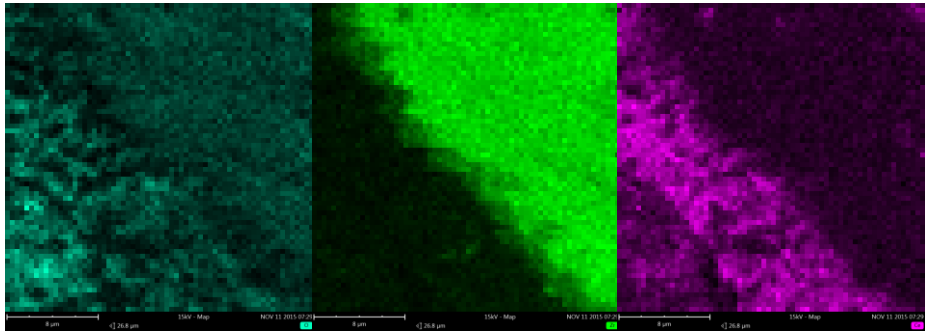


La Zr Ag

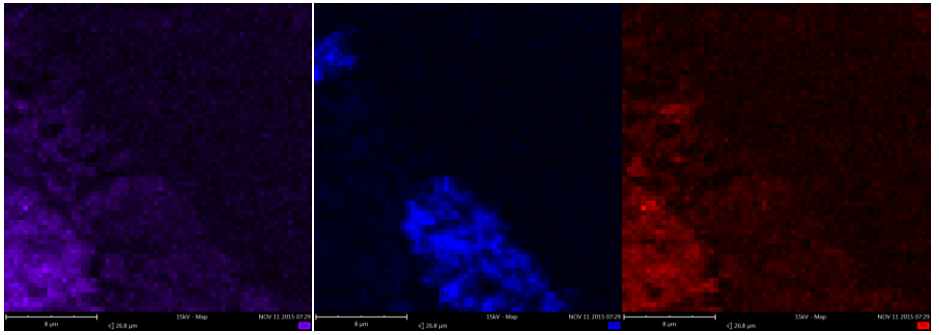
Cell with 8600 hours running from field

Observation in Aged Cell
Ag Migration





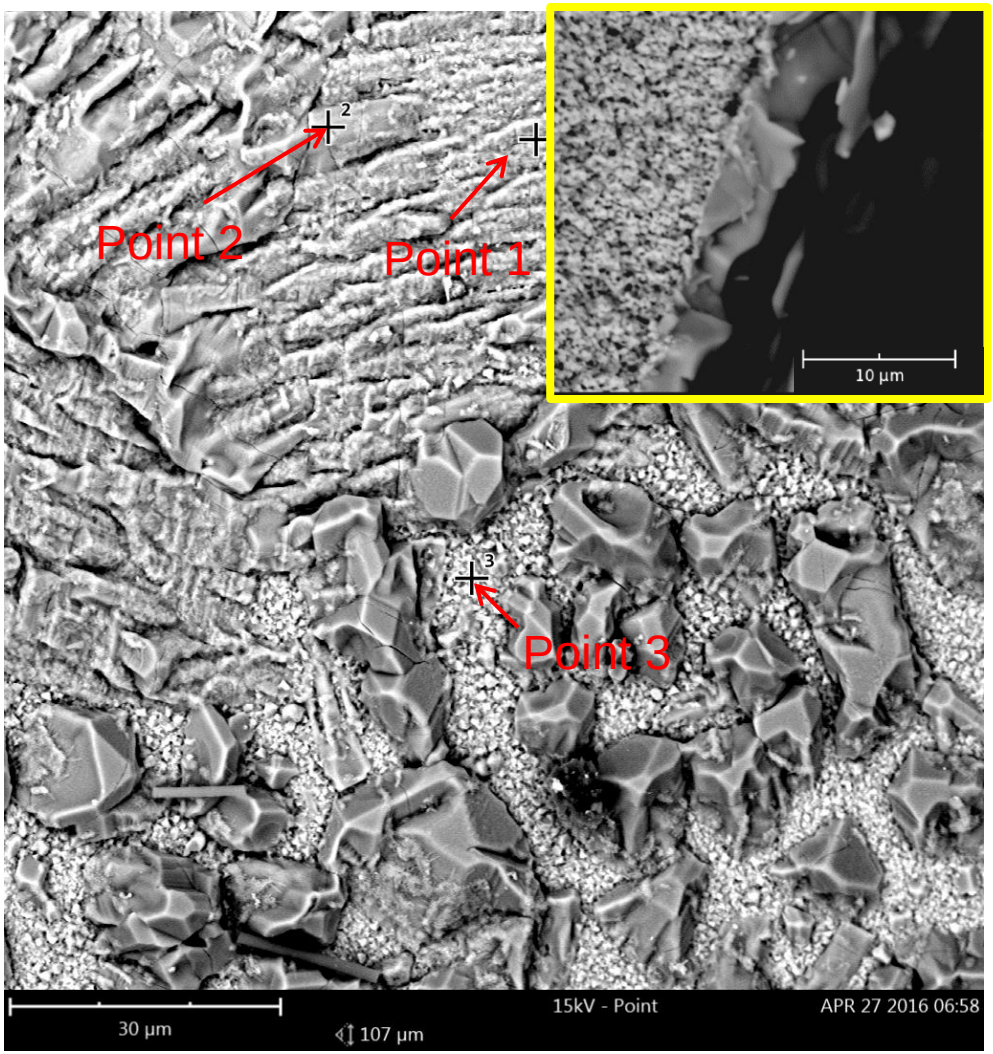
O Zr Ce

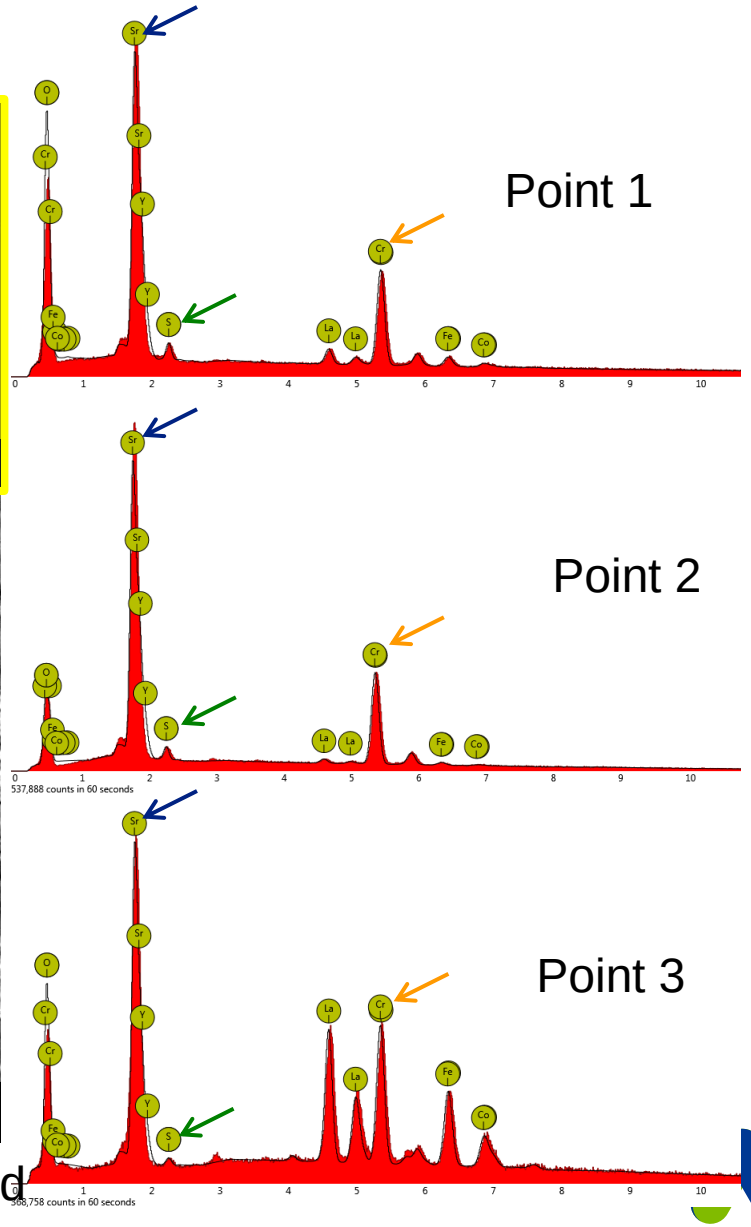


La Ag Fe

Cell with 8600 hours running from field

Observation in Aged Cell Cathode Decomposition





Atrex Energy Cell with 7000 hours running from field

Future Work

- **Complete the electrochemical characterization of several cells**
- **Build correlation between impedance spectroscopy and aging behavior**
- **Investigate the cell microstructure in more thorough details like 3D reconstruction**
- **By end of the project period, gain more understanding of degradation for tubular cell and find mitigation solutions.**

Acknowledgement

- **Project manager: Joe Stoffa**
- **Harry Abernathy for discussion and guidance for cell degradation**
- **Collaborators**
  - Boston University: Prof. Srikanth Gopalan and his team
- **Atrex Energy**
  - Manufacturing team
  - Cell engineering Team
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