Degradation and Reliability Advancements in Tubular SOFC

DE-FE0026095

June 14th, 2018

Outline

- Background
- Project objectives
- On-cell Getter Cathode Protection
- Dense Electrolyte Development
- Interface Between Ceramic Interconnection and Current Collector
- Current Collector
- Acknowledgement

The Atrex Power System

ARP Series:

- Standard units in 500w, 1000w and 1500w fueled by natural gas or propane
- Outputs from 50w up to 1500w at 5VDC up to 60VDC (AC available as well)
- Automatically adjusts to load needed (automatic load following)
- Rugged for remote, unattended outdoor use in harsh environments
- Easy to install and use
- High fuel efficiency
- Remote monitoring and control
- Minimal emissions = “Green”
- Reliable and quiet
- Scalable
- Low maintenance
- Small footprint
- -40C to +50C
- Thermal cycles: 150+
- Longest running field units: 35,000+ hours

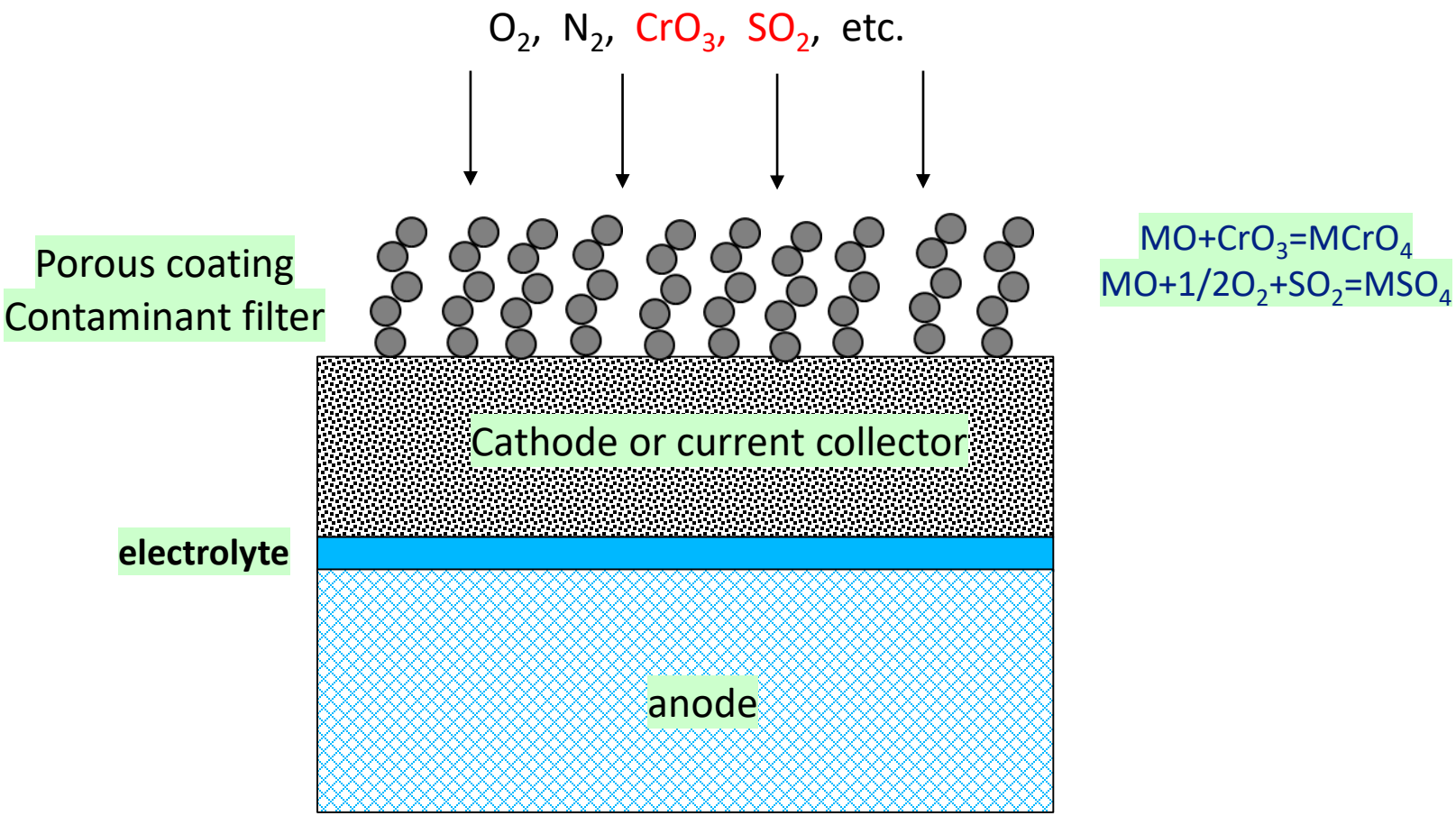
Atrex Energy – Capabilities and Resources

- Solid Oxide Fuel Cell (SOFC) - "Powder to Power" all in one 30,000 sq ft facility in Walpole, MA
- 45 Full and Part-time Staff - electrical, mechanical, chemical and material, automation, firmware , sales/marketing and manufacturing
- 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

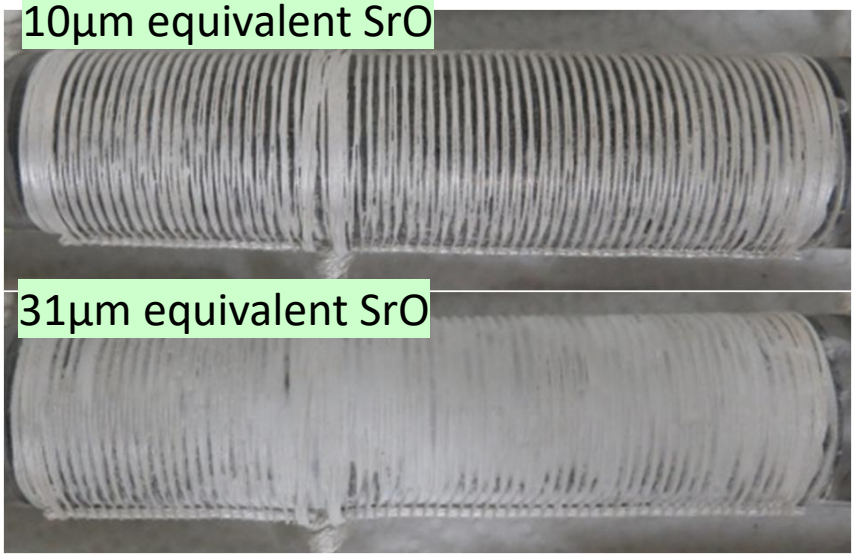
Project Objectives

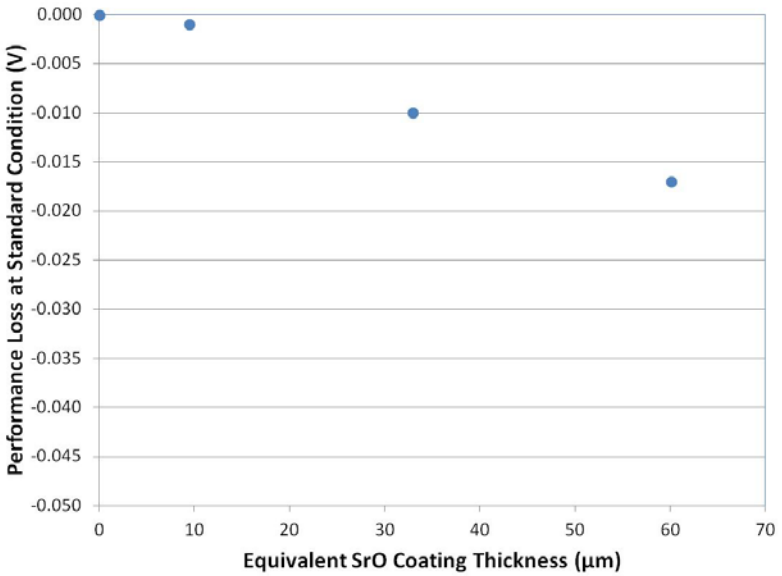
- **Mitigate degradation, enhance the reliability of Atrex Energy's tubular SOFC in major functioning components**
  - **Cathode**: *provide on-cell getter protection*
  - **Ceramic interconnection**: *improve bonding with current collector*
  - **Electrolyte**: *perfect density*
  - **Current collector**: *screen print current collector*
- **Demonstrate low degradation at stack level with developed cell technologies**
- **Implement proven technology in existing production line and future products**

1. On-cell Getter Cathode Protection: concept



On-cell Getter Cathode Protection:





1. Up to 31um equivalent SrO coating on cathode and current collector surface showed no significant impact on fuel cell performance.
2. SrO containing compounds will be further screened for gettering application and evaluated by accelerated tests.
3. Manufacturing process for on-cell getter layer will be developed and optimized.

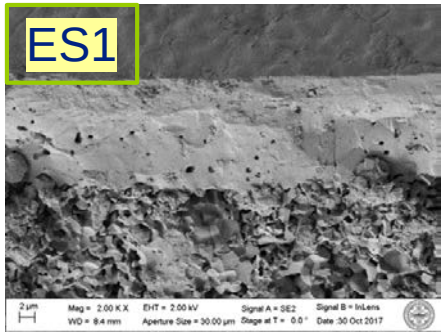
2. Dense Electrolyte Development

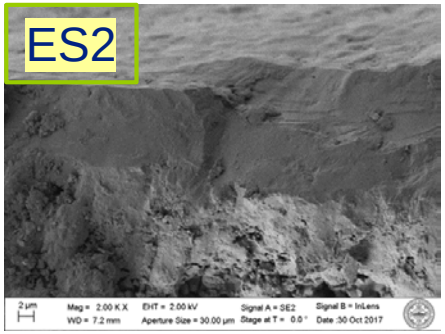
- **Approaches for density improvement**
  - Shrinkage control
  - Sintering aid
  - Bimodal or trimodal particles
- **Electrolyte quality evaluation**
  - Chemical etch based pinhole counting method
  - SEM
  - High temperature high fuel utilization testing
  - $AgNO_3$ induced shorting

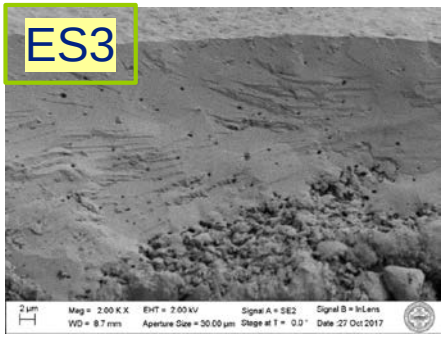
Dense Electrolyte Development: material

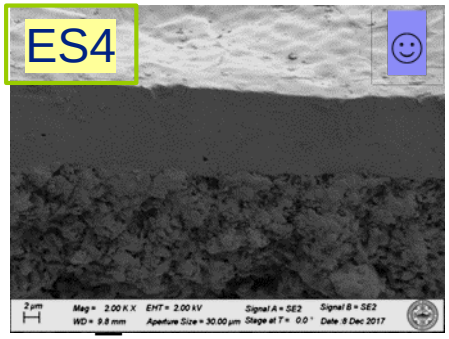
Slurry #	Formulations
Exp Slurry 1 (ES1)	Production powder mixed with smaller particle size powder (same supplier) in 1:1 ratio
Exp Slurry 2 (ES2)	Production powder mixed with Tosoh YSZ powder in 2:1
Exp Slurry 3 (ES3)	Production slurry with 2wt% Al_2O_3
Exp Slurry 4 (ES4)	Production slurry with 1wt% Al_2O_3
Exp Slurry 5 (ES5)	Production slurry with 0.5wt% Al_2O_3
Exp Slurry 6 (ES6)	Production powder mixed smaller particle size powder and Tosoh YSZ powder in 1:1:1 ratio
Exp Slurry 7 (ES7)	Production slurry with 2wt% NiO
Exp Slurry 8 (ES8)	Production slurry with 1wt% NiO
Exp Slurry 9 (ES9)	Slurry with only Tosoh YSZ powder

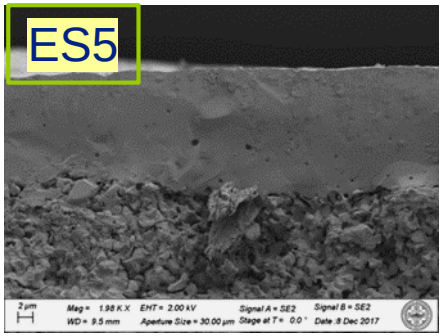
Dense Electrolyte Development: sintered morphology

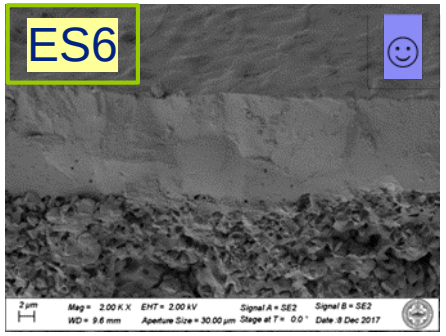


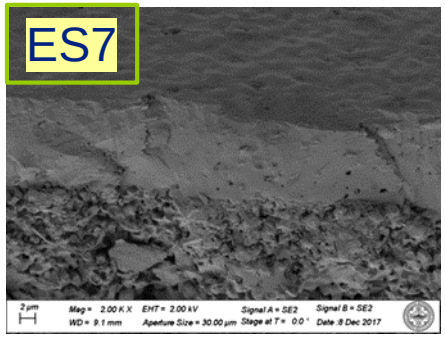


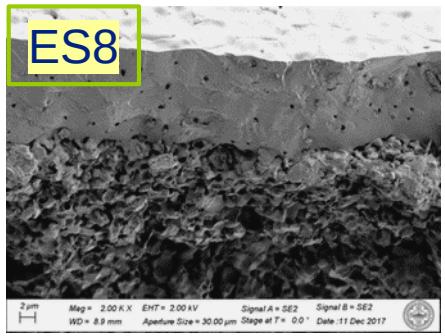






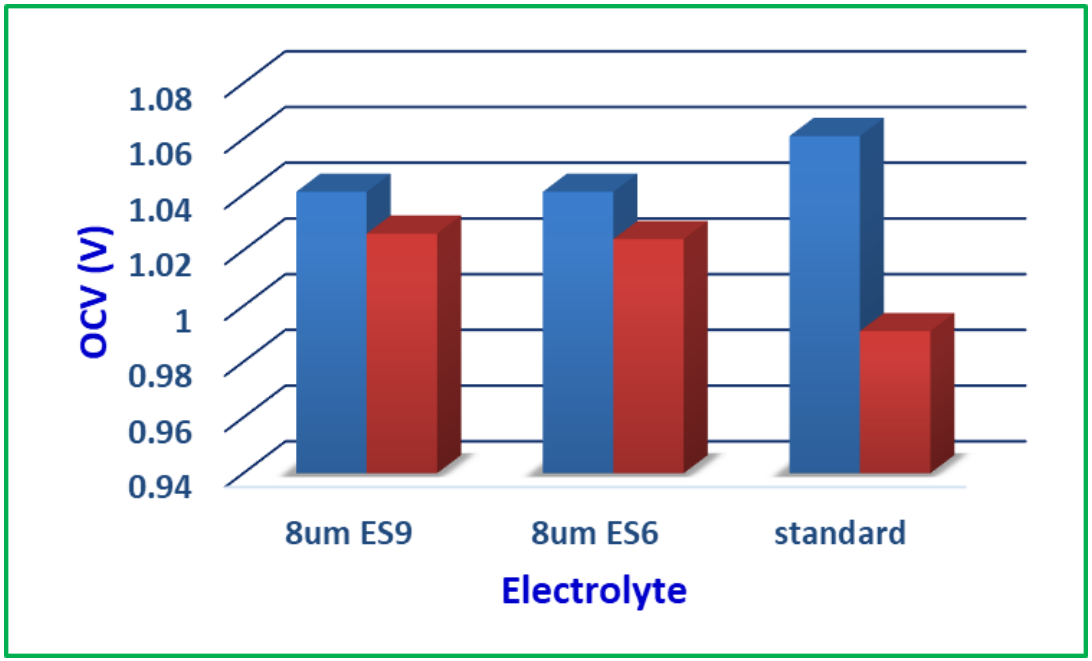






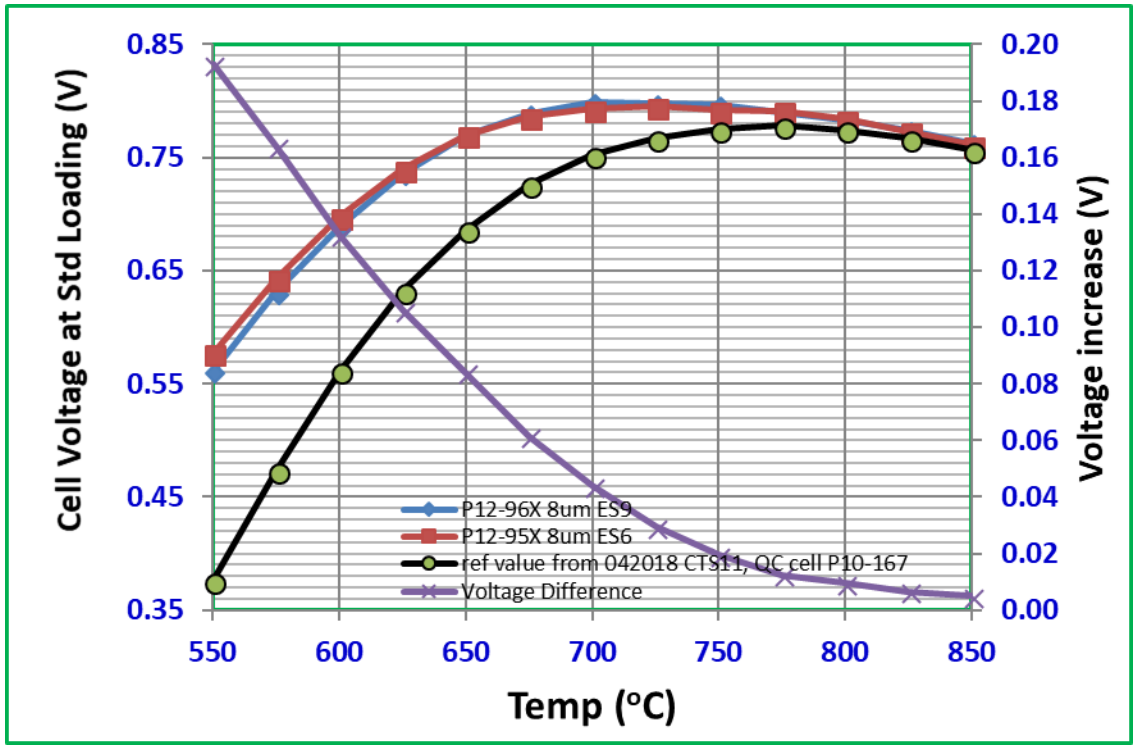
Dense Electrolyte Development

Accelerated test using $AgNO_3$ infiltration

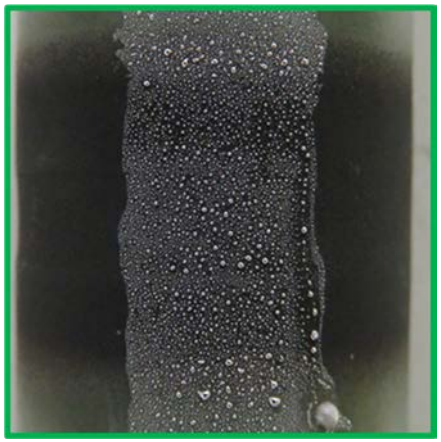


Dense Electrolyte Development

Table. VJ slopes at 650°C and 750°C for cell with 50% electrolyte thickness and reference



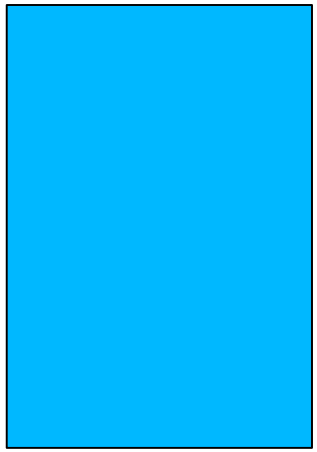
3. Interface Between Ceramic Interconnection and Current Collector: wetting



Silver does NOT wet $LaCrO_3$ well

Gold wets $LaCrO_3$

Silver-palladium wets $LaCrO_3$



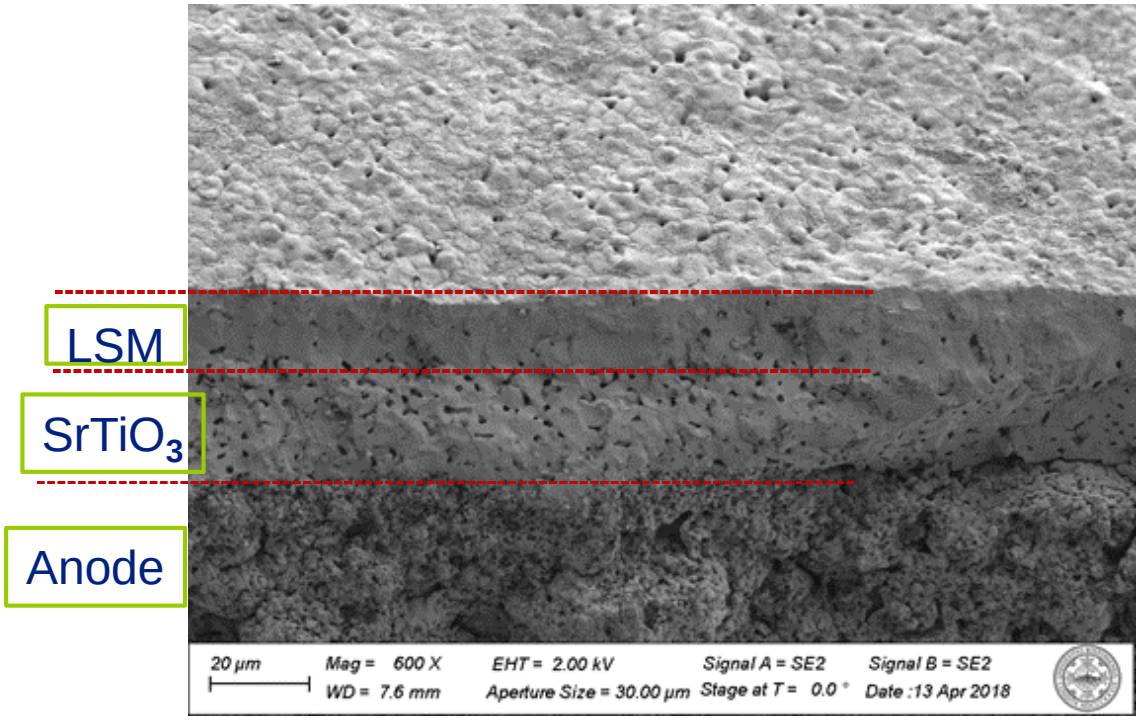
Silver wets LSCF

Bonding between Anode Interconnection and Current Collector

	$LaCrO_3$/Ag	$LaCrO_3$ /Au/Ag	$LaCrO_3$ /LSCF/Ag
As-tested			
Wire bundle peeled off			

Gold bonding layer showed good adhesion. However, the high cost make it unfeasible for production.
LSCF showed moderate adhesion and further materials development is needed.

Alternative Anode Interconnection: non $LaCrO_3$



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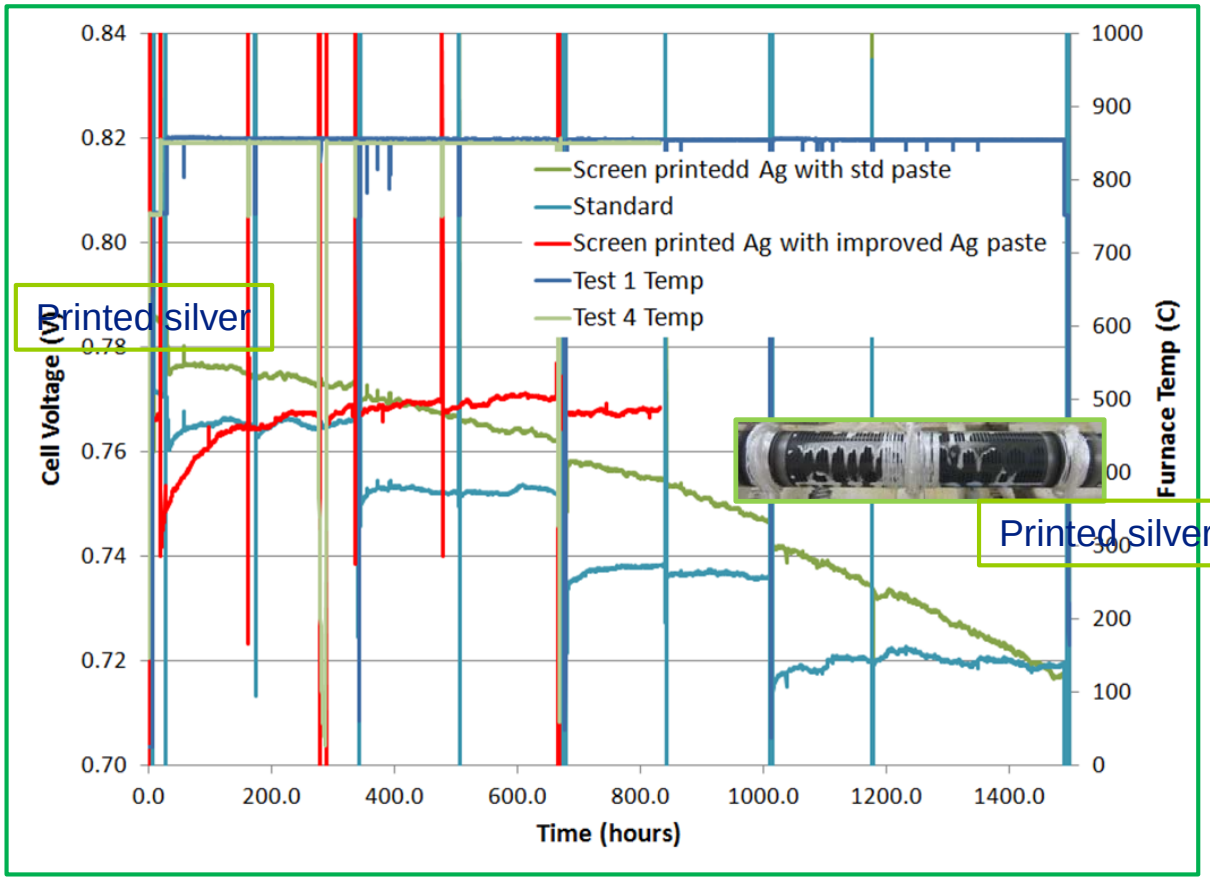
2) Yanjie Xu, Shaorong Wang, Renzhu Liu, Tinglian Wen, Zhaoyin Wen, Journal of Power Sources 196 (2011) 1338–1341
3). Beom-Kyeong Park, Jong-Won Lee, Seung-Bok Lee, Tak-Hyoung Lim, Seok-Joo Park, Rak-Hyun Song, Dong-Ryul Shin, Journal of Power Sources, 213 (2012) 218-222
4) Mi Young Yoon, Byung-Hyun Choi, Rak Hyun Song, Hae Jin Hwang Ceramics International, 38 (2012) 6843–6847
5) Heechul Yoon, Taewook Kim, Sungtae Park, Nigel Mark Sammes, Jong-Shik Chung, International Journal of Hydrogen Energy, 43 (2018) 363-372

4. Current Collector: degradation origin

Screen printed Ag ID	Condition
Ag layer from production paste	Standard production Ag paste was used for the print. This will serve as the reference.
Ag layer from improved paste	High Ag loading paste which will yield 3X thickness of current production paste.

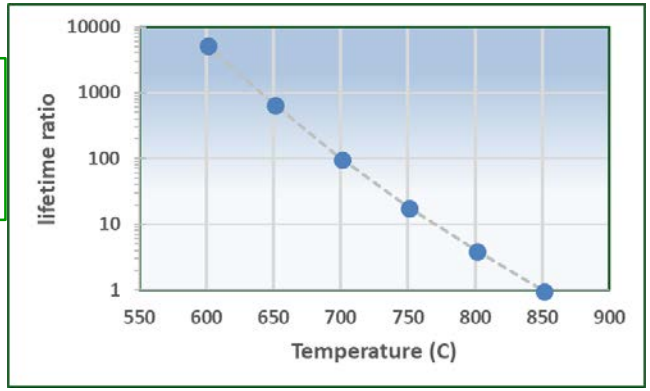


Accelerated test traces at 850oC for various current collector configurations

Current collector lifetime

Silver vapor pressure vs. temperature:

log (P/Pa) = 14.133 - 14999 / (T/K) - 0.7845 *log* (T/K)

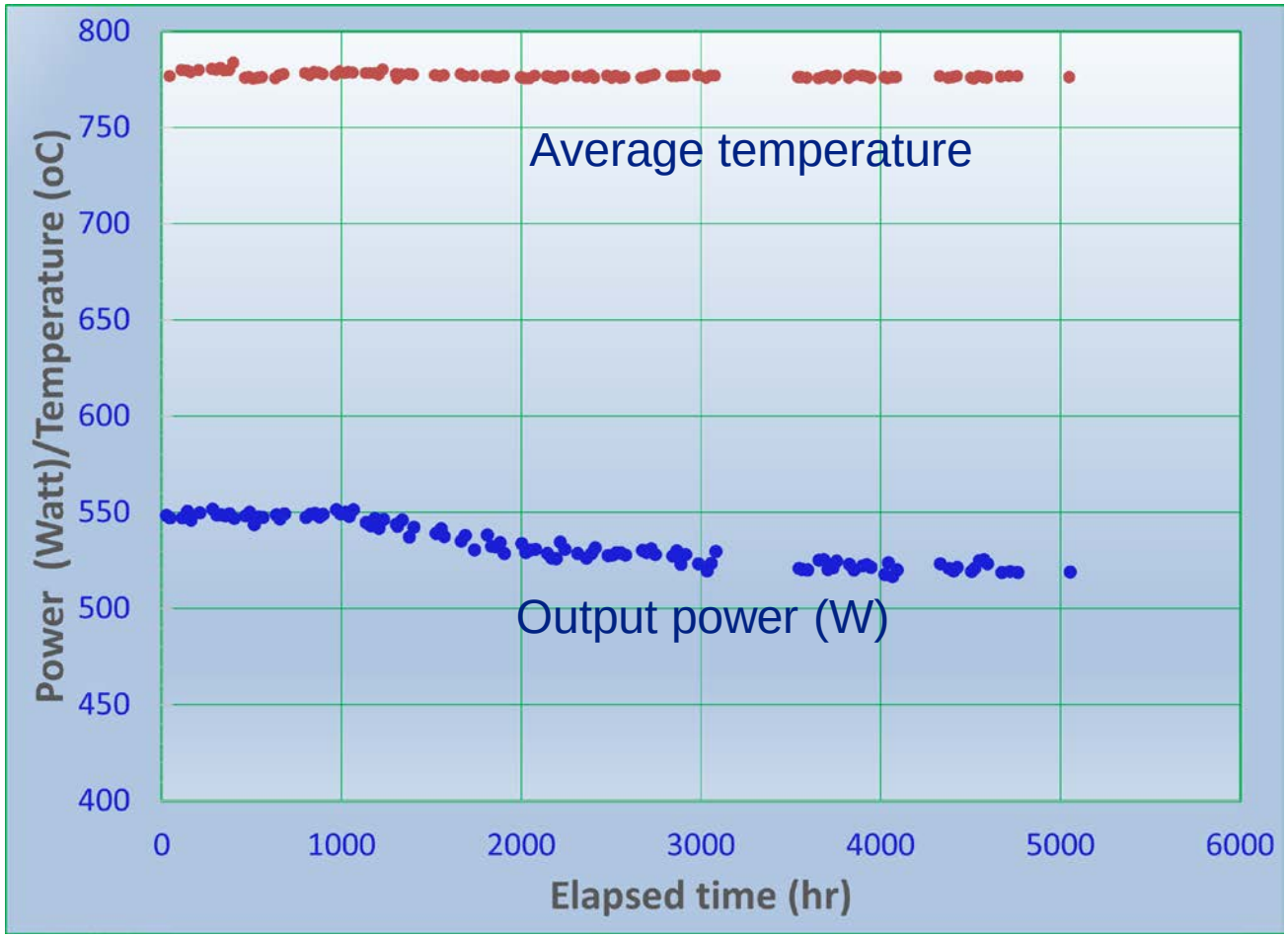


Lifetime ratio to that of 850C

Screen printed Ag cathode current collection outlive wire current collection, >35,000h lifetime expected

Projected degradation behaviors of Ag current collector at 750ºC

Printed Ag Current Collection – Stack Performance



Life chart of baseline stack

Acknowledgement

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