SOFC Development at PNNL

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Pacific Northwest National Laboratory

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Scope of Work

- Core Technology Program: Materials Development
  - Cathode materials and interactions
    - Effects of volatile Cr compounds on cathode performance
      - **Poster: LSM/YSZ Button Cell Tests in Cathode Air with Measured Cr Concentrations (John Hardy)**
    - Improved density of ceria barrier layers
  - Mitigation of Cr poisoning
    - Evaluation of Cr capture materials
      - **Poster: Cr Mitigation by LSCF-based Materials for Solid Oxide Fuel Cells (Matt Chou)**
  - Cathode contact materials
    - Enhancing reliability of cathode/contact materials interfaces
      - **Poster: Composite Approach to Tailoring Thermal Expansion of LSCo-based Ceramic Cathode Contact for Solid Oxide Fuel Cell Applications (Matt Chou)**
  - Interconnects/BOP
    - Reactive air aluminization
      - **Poster: Long Term Stability Tests of Low Temperature and Standard Reactive Air Aluminization Process (Jung-Pyung Choi)**

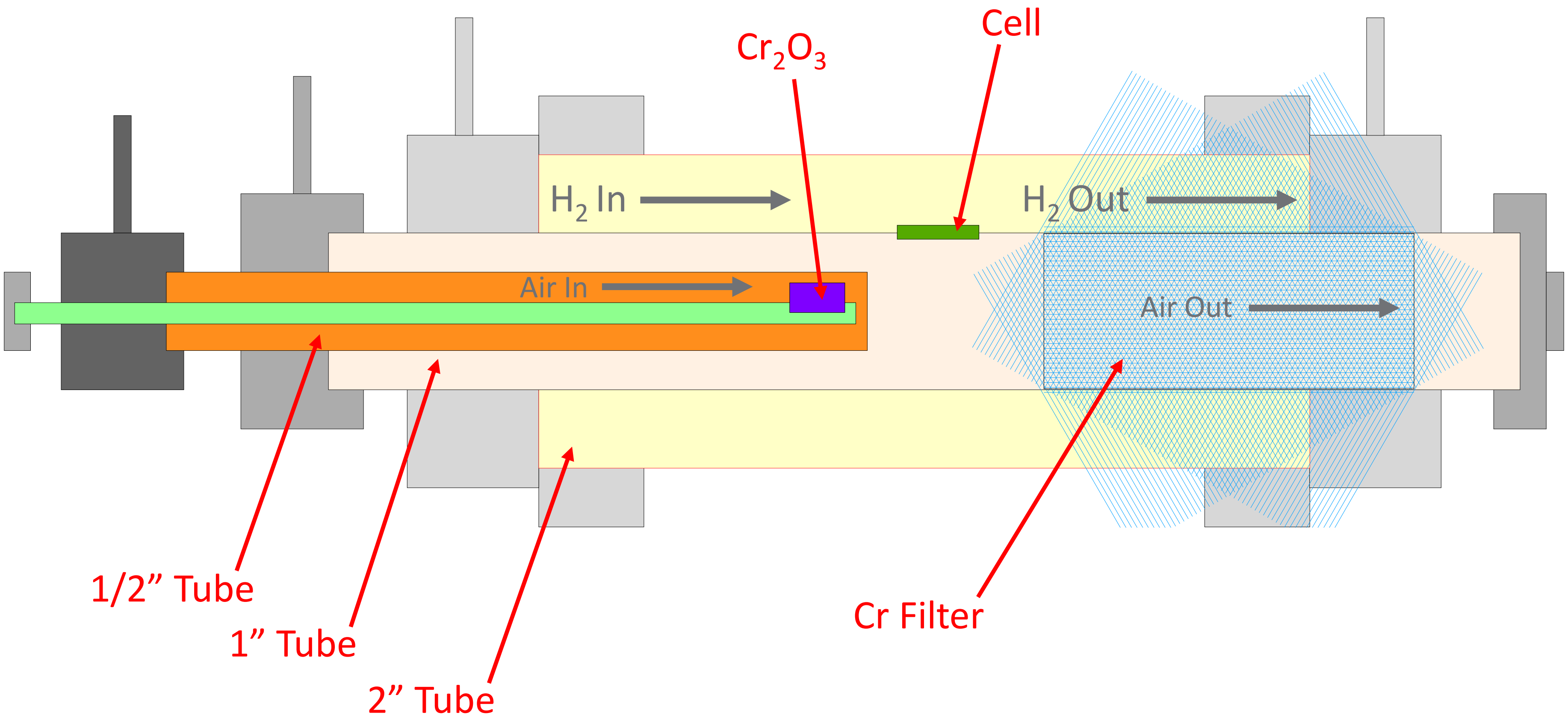
Scope of Work

- Core Technology Program: Modeling/Simulation
  - SOFC Stack and System Modeling Tool Development
    - **Poster: Advanced Reduced Order Model (ROM) Prediction and Error Quantification Framework for SOFC Stacks (Chao Wang)**
  - Modeling of Stack Degradation and Reliability
    - **Poster: Optimal Operating Conditions for Performance and Reliability of Solid Oxide Fuel Cells (Kurt Recknagle)**

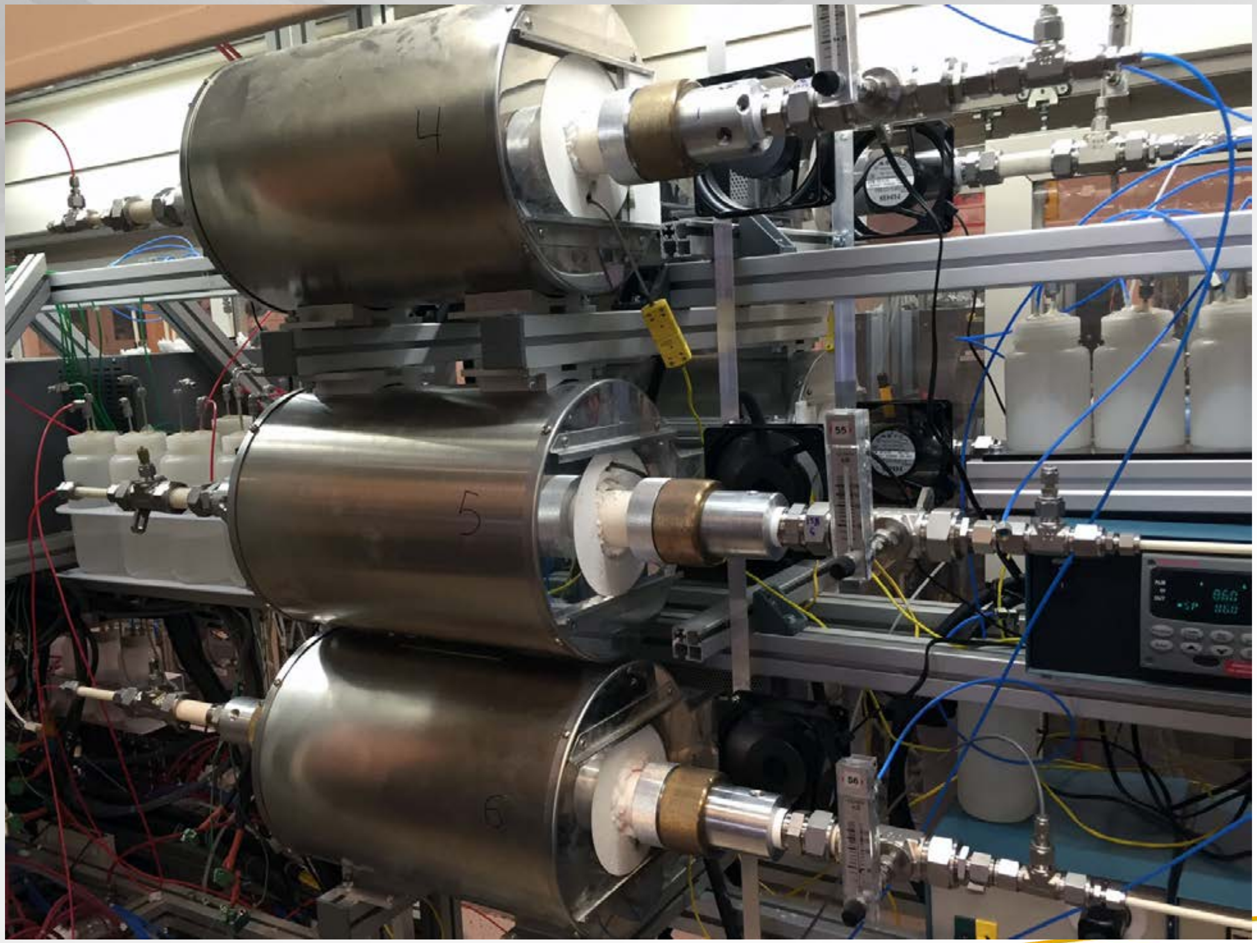
- Small-Scale SOFC Test Platform
  - Design and fabrication of SOFC power system for evaluation of performance and reliability of new stack technologies (1-10 kW)
    - **Poster: Small-Scale Test Platform (SSTP) for SOFC Stacks (Brent Kirby)**

- Industrial Collaborations
  - Cummins/Ceres
    - Effects of Fuel Contaminants on Anode Performance
  - TCF Project: Protective Spinel Coatings
  - TCF Project: Air Braze Optimization
    - **Poster: Air Braze Optimization for Markets Targeted by Aegis Technology, Inc. (John Hardy)**

Cr Poisoning: PNNL Test Fixture Design (Not to scale)

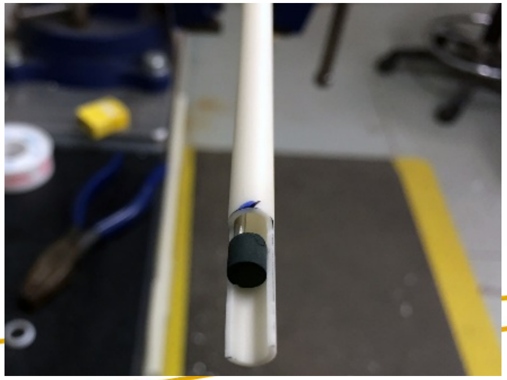


Assembled Cr Test Fixtures



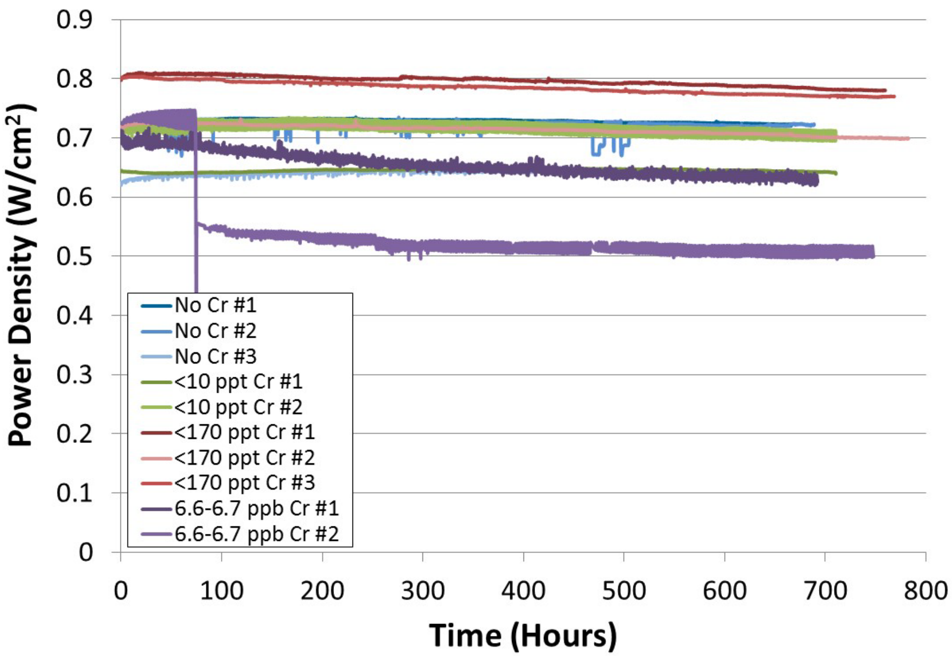
Downstream Filter

Chromia Pellet



Electrochemical Button Cell Tests

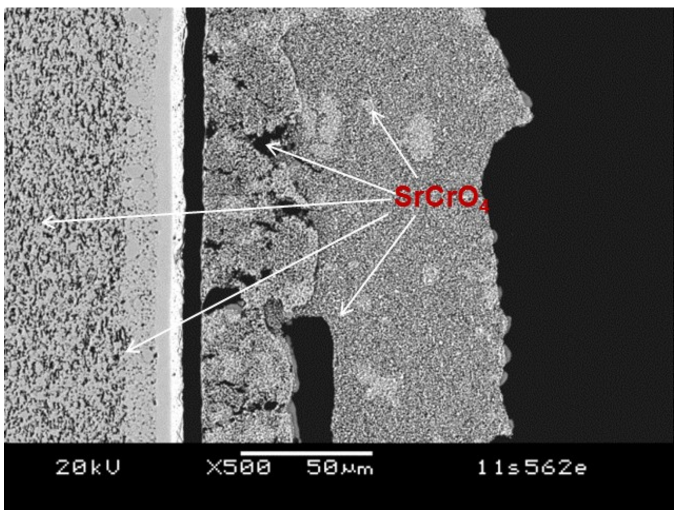
- LSM/YSZ Cathodes
  - LSM-20, A/B = 0.95
- Tested at 850ºC
  - Cr concentration controlled by adjusting Cr_2O_3 source temperature and moisture content of air



Test Condition	# of cells	Ave. Degradation Rate (per kH)
First Round		
No Cr	3	-0.2%
≤10 ppt Cr	2	2.2%
≤170 ppt Cr	3	3.9%
6.6-6.7 ppb Cr	2	13.2%
Second Round		
≤43 ppt Cr	3	-0.8%
≤164 ppt Cr	3	4.9%
≤224 ppt Cr	2	3.9%

Mitigation of Cr Poisoning: LSCF as Cr-gettering Material

- $SrCrO_4$ observed throughout LSCF cathode layer.



- Potential Advantages
  - Sr segregation from structure
  - High electrical conductivity
  - Chemical compatibility
  - Thermal and phase stability
  - Reasonable mechanical strength
  - Tailorable La/Sr and Co/Fe ratios
    - Control Sr activity
  - Commercially available
- 4 Compositions evaluated
  - $La_{0.8}Sr_{0.2}Co_{0.2}Fe_{0.8}O_3$
  - $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$
  - $La_{0.4}Sr_{0.6}Co_{0.2}Fe_{0.8}O_3$
  - $La_{0.2}Sr_{0.8}Co_{0.2}Fe_{0.8}O_3$

LSCF/Cr_2O_3 Reaction at 800ºC: Normalized Sr % Reacted

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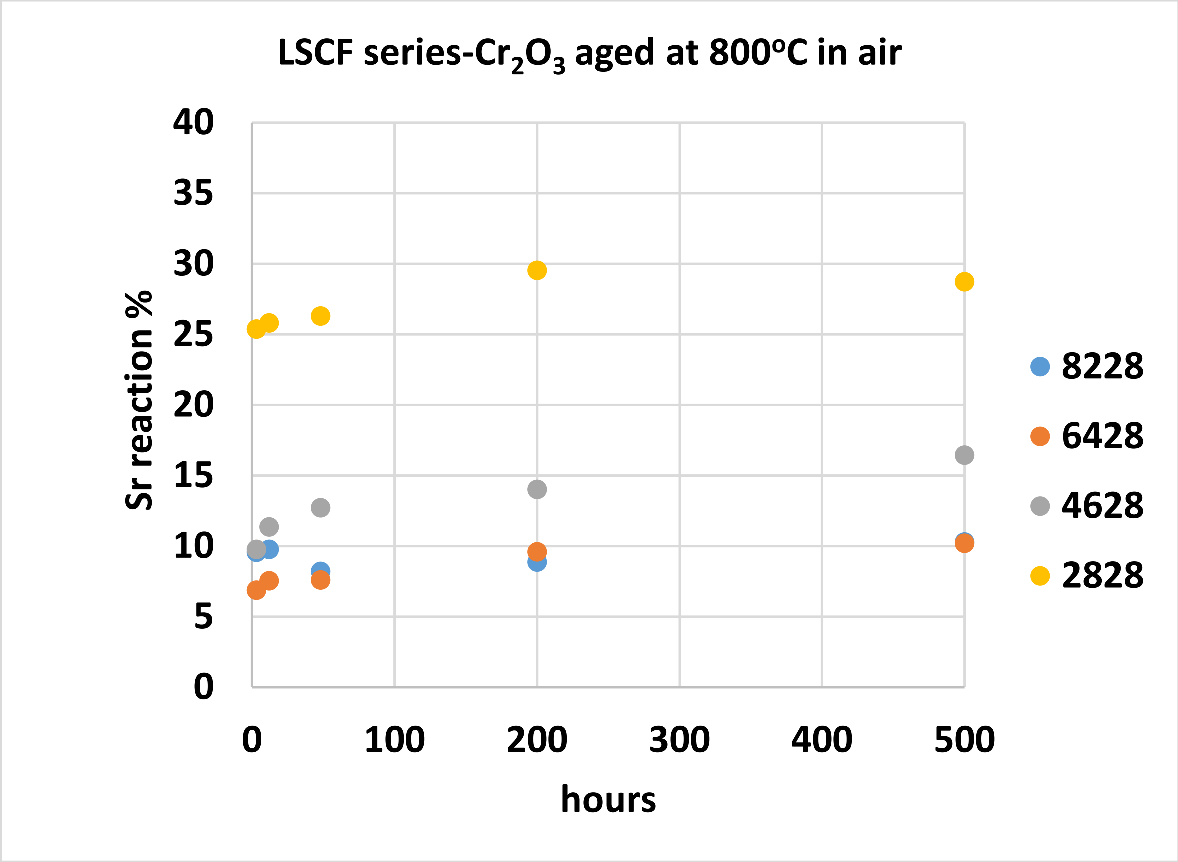
- $SrCrO_4$ wt% converted to Sr wt% then normalized with total Sr wt% in LSCF series as Sr % reacted.



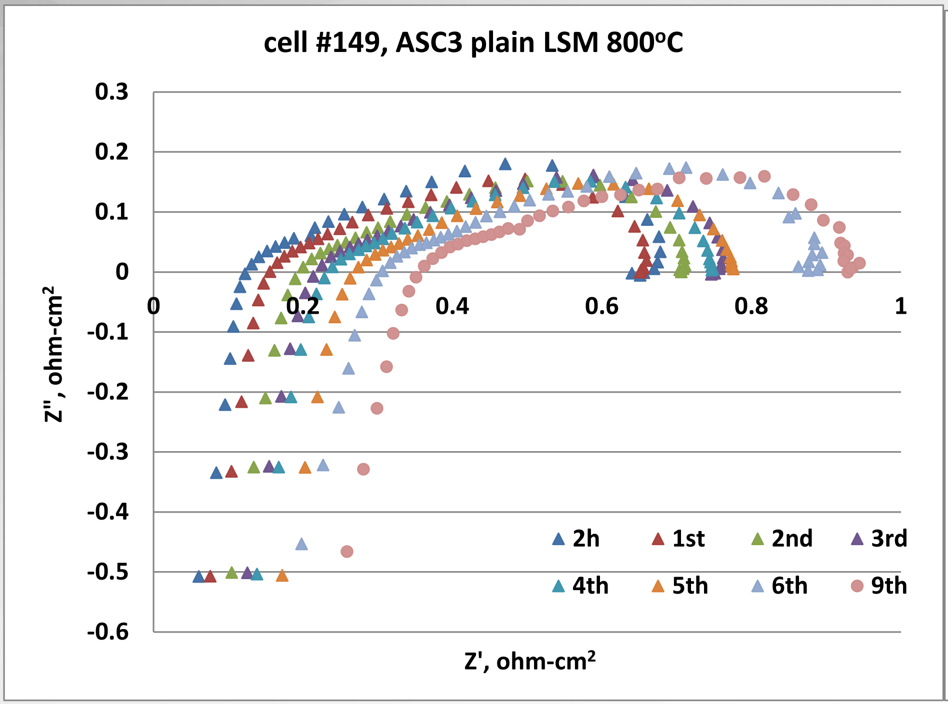
Cathode Contact Development

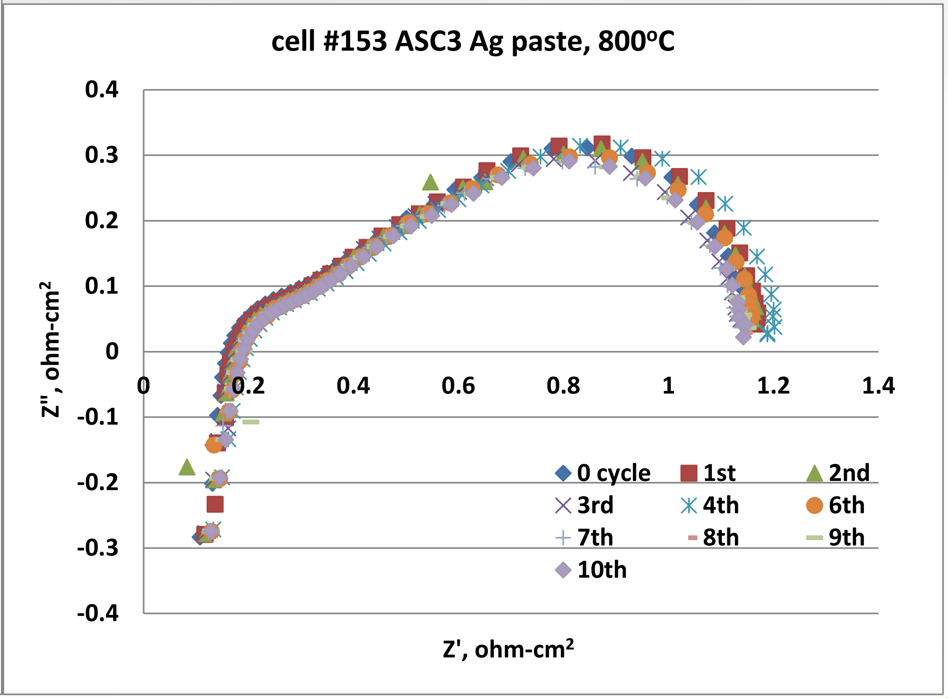
- Approach A: Impregnated Fibrous Substrates
- Approach B: Composite Mixtures to Tailor CTE

$$\sigma = E\,\Delta\alpha\,\Delta T$$

Poor Thermal Cycle Stability of Ceramic Cathode Contact

2”x2” LSM-based cell in stack test fixture during cycling between ~50ºC and 800ºC



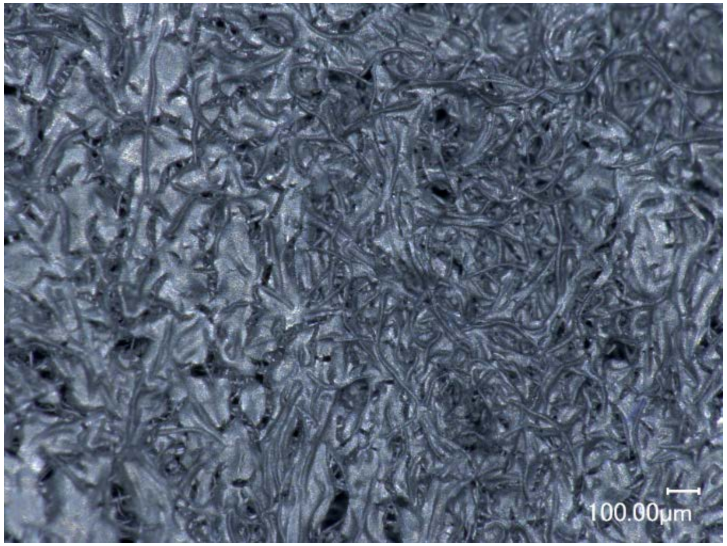


Brittle cathode contact: LSM20

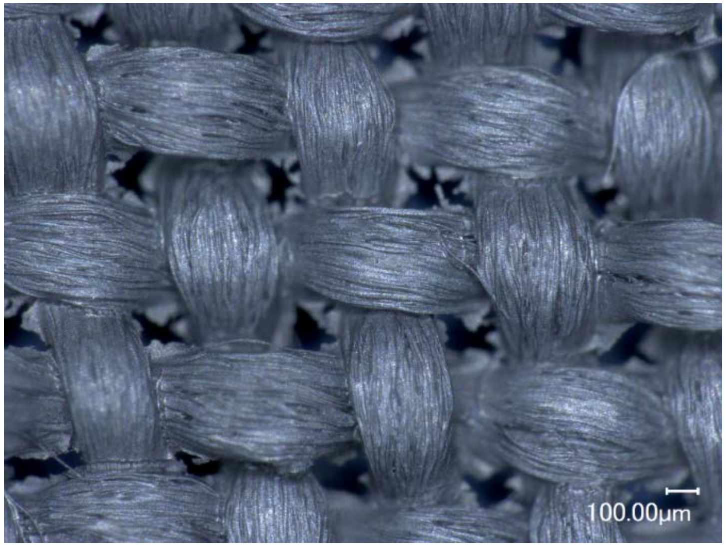
Ductile cathode contact: Ag

Approach A: Impregnated Fibrous Materials

- Inert YSZ fibrous felt/woven cloth substrate
- Impregnate with conducting LSM20 or LSCo phase via dip-coating



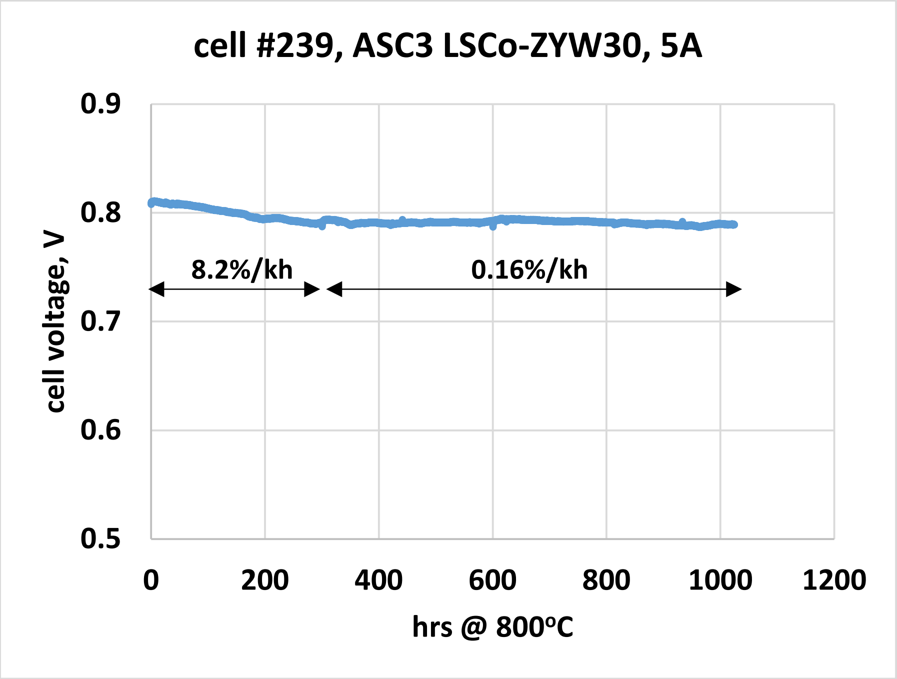
ZYF-50 (Y_2O_3 10 wt% stabilized ZrO_2)
(~0.05” thick, bulk porosity >96%)

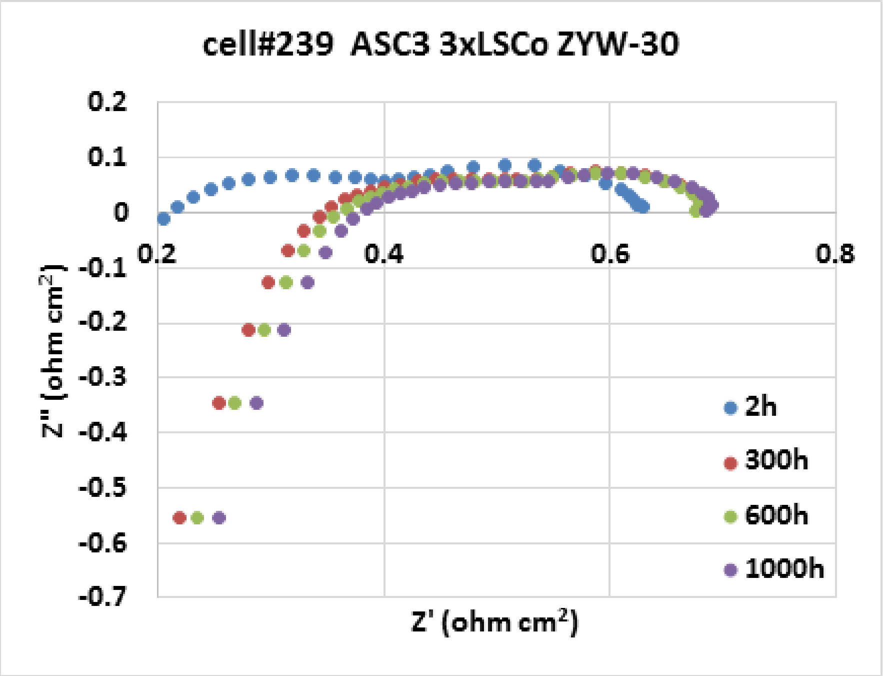


ZYW-15 (Y_2O_3 10 wt% stabilized ZrO_2)
(~0.015” thick, square weave, bulk porosity >96%)

Validation in a Generic Stack Fixture for Thermal Cycle Stability

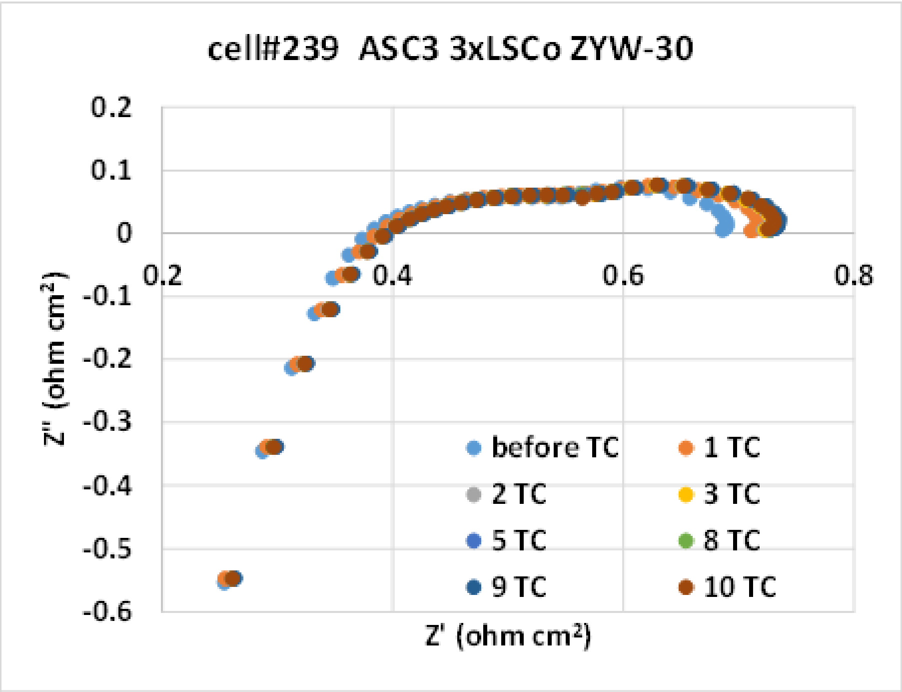
- Standard LSM-based cell (2”x2”) with 3x LSCo impregnated ZYW-30 woven cloth
- First tested at 800°C and constant current for 1000h then thermal cycled for ~10 times between ~50°C and 800°C



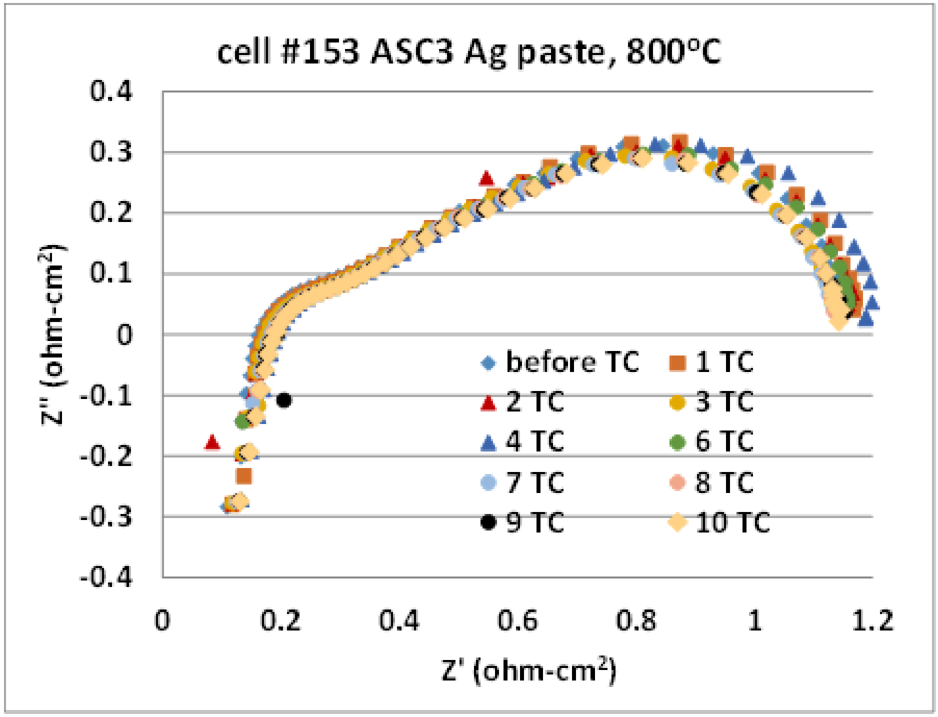


Effect of Thermal Cycling

LSCo-impregnated YSZ cloth



Ag contact



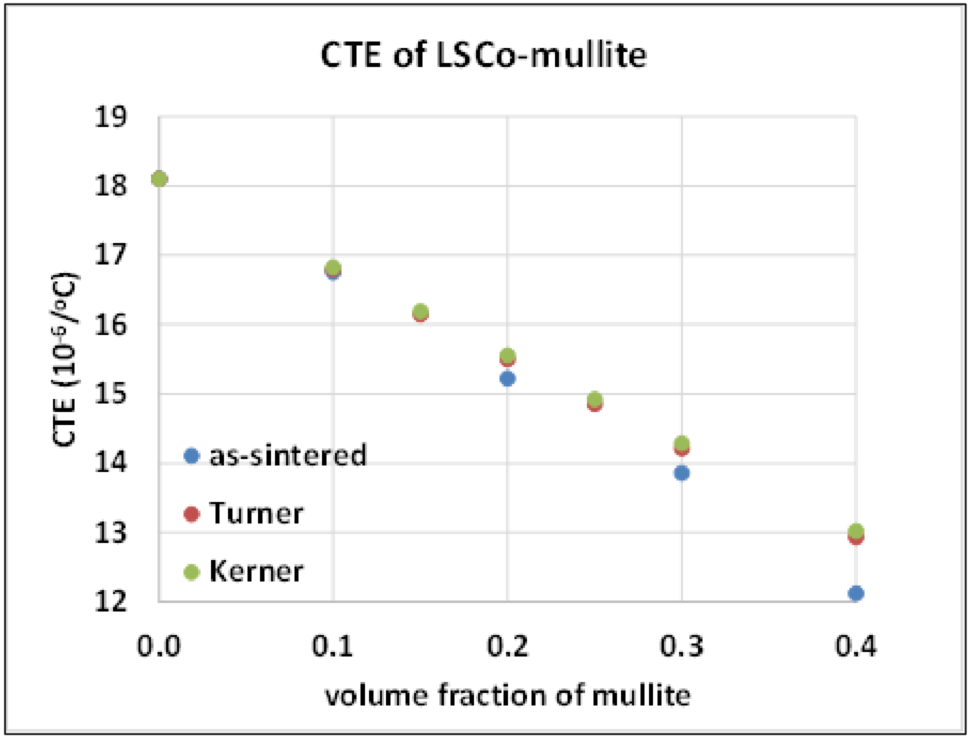
Approach B: Minimize Residual Stresses with Tailored CTE

- LSCo20 perovskite offers high conductivity, but also very high CTE (~18x10^{-6}/^{o}C), while CTE of typical cell and interconnect is 12-13x10^{-6}/^{o}C.
- Composite approach incorporating low CTE mullite ($3Al_2O_3 2SiO_2$ - $2Al_2O_3 SiO_2$): ~5.5x10^{-6}/^{o}C.

Turner's model (considers hydrostatic stress only)
Kerner's Model (hydrostatic + shear stress)

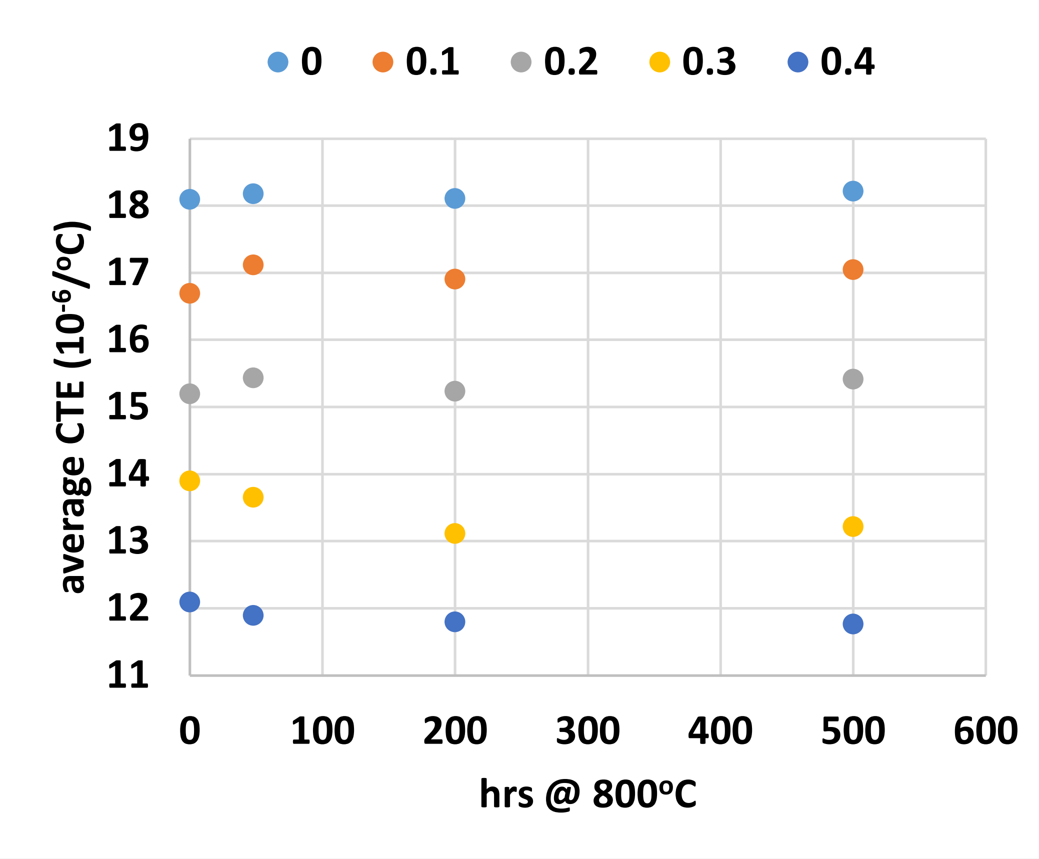
Measured values deviate from prediction at higher vol. fractions

Mullite received contains other phases (sillimanite and kyanite)



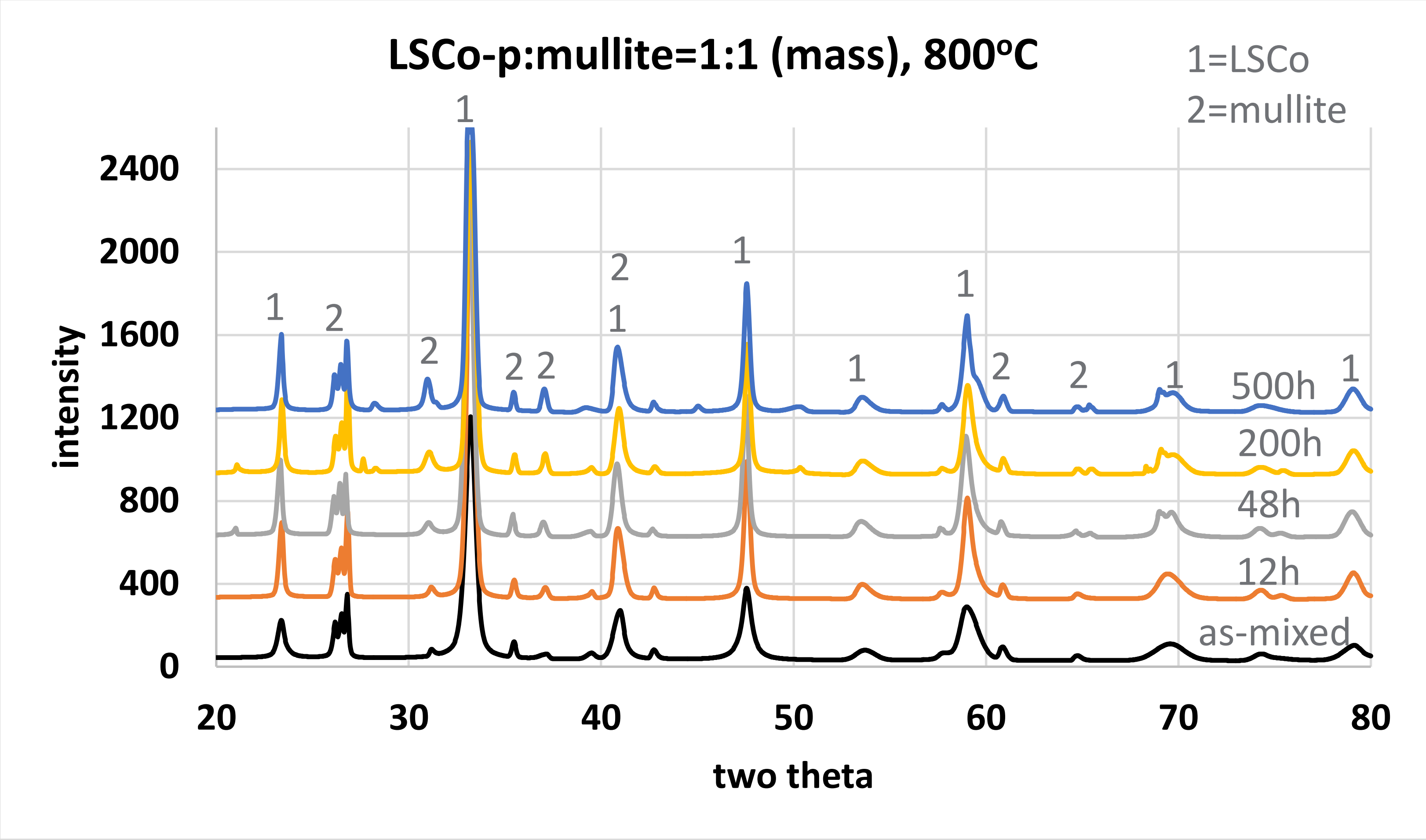
Effect of Isothermal Ageing at 800ºC

- Fairly stable with small changes over 500h ageing
- Indicating thermally stable and likely chemically compatible



Thermal Stability

- LSCo20:mullite at 1:1 ratio aged at 800ºC for 12, 48, 200, and 500h in air

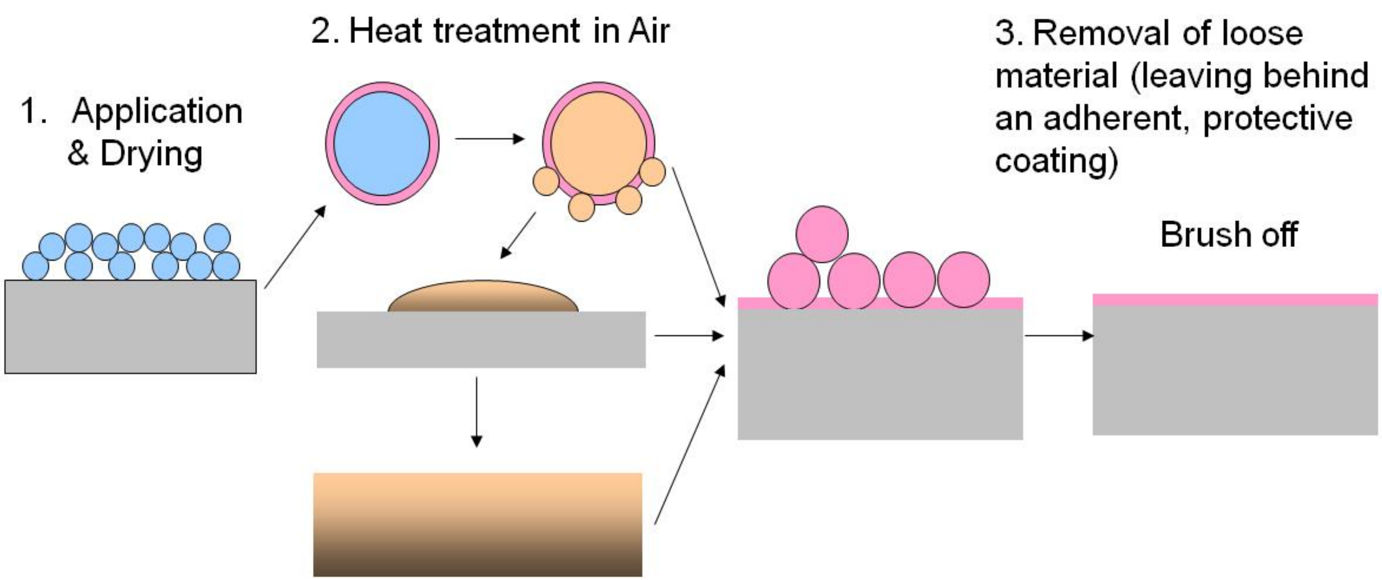


Reactive Air Aluminization (RAA)

•Reaction between alkaline earths in glass seals and Cr in interconnect steel can form high CTE chromate phases (e.g., $SrCrO_4$), which degrade interfacial strength

•Cr volatility from alloys can poison cathodes

•Reactive Air Aluminization (RAA) offers a simple alternative to controlled atmosphere aluminization of interconnects (and BOP components)



Low temperature RAA process

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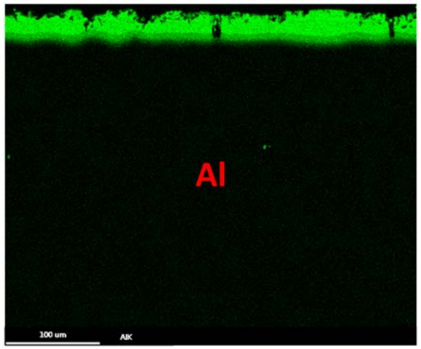
- **Primary challenges to lowering process temperature using our standard slurry are incomplete/nonhomogenous alumina layer formation and excessive reaction/diffusion of Al into substrate**

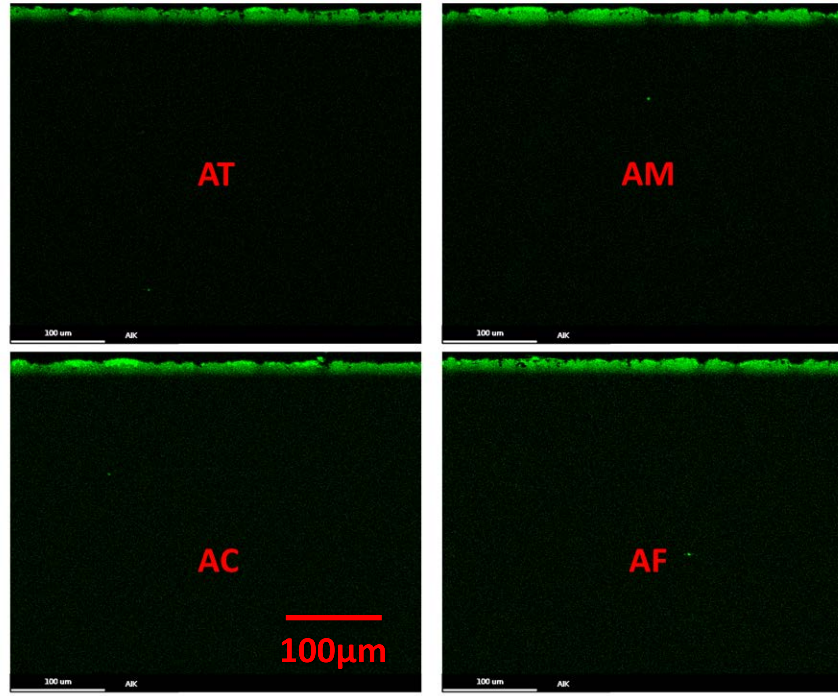
- **Approach: Add additional elements to optimize oxidation kinetics and metal diffusion at lower temperatures (800-900°C) to form protective alpha alumina coating and "right-sized" Al reservoir in substrate to provide CTE gradient (to improve coating bond-strength) and self-healing capability.**

- **Results:**
  - **Seed elements (Mn, Ti, or Fe) enhance formation of cubic gamma phase at lower temperatures, which then accelerates formation of desired alpha phase.**
  - **Formation of thick gamma phase "egg shells" at temperatures below the melting point of the aluminum powder prevents excessive release and diffusion of the molten aluminum into the underlying substrate. During dwell time at temperature (e.g., 900°C), transition from gamma to alpha alumina is completed.**

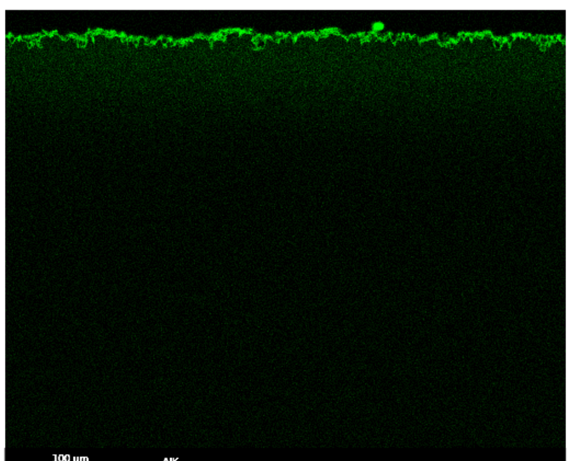
Low temperature RAA process



800°C



Same magnification



Standard RAA at 1000°C

Long term stability test (Standard RAA)

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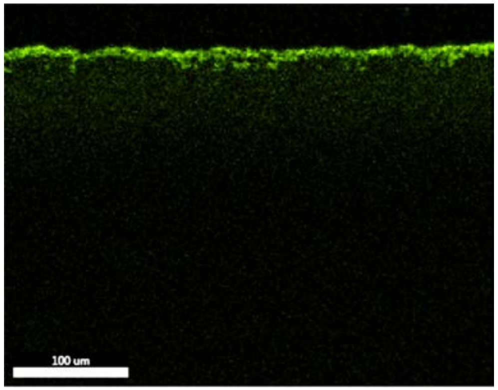
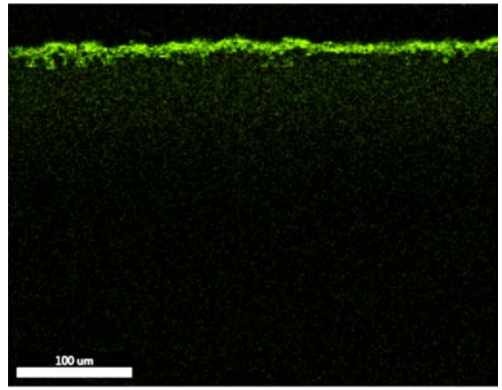
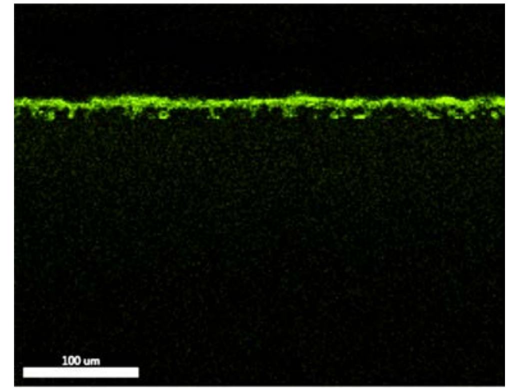
800°C

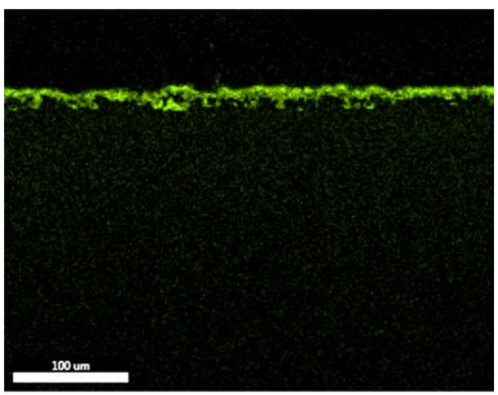


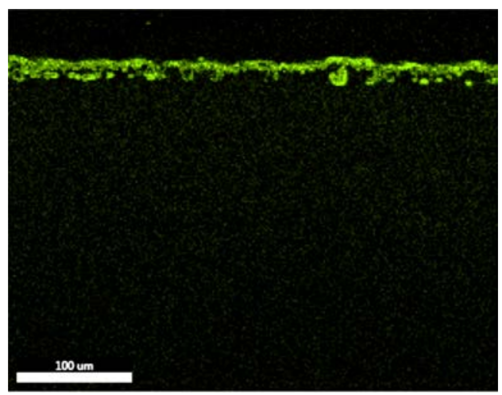


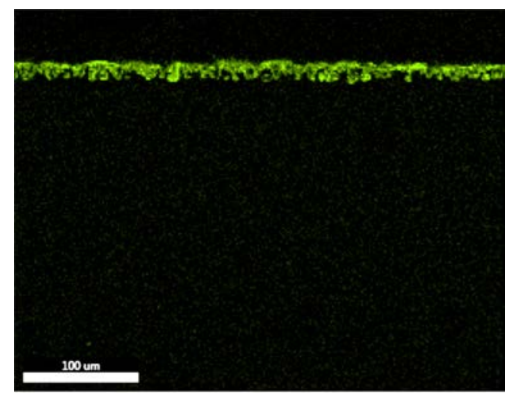


50 cycles | 100 cycles | 300 cycles

900°C







Co-free Electrically Conductive Protective Coatings

- Objective: Develop Co-free, electrically conductive protective coatings for planar SOFC stack interconnects
- Based on previous studies,* selected 3 ternary oxide systems for evaluation
  - Cu-Mn-O
  - Cu-Fe-O
  - Ni-Mn-O
- Approach:
  - Examine powder synthesis options
  - Develop/optimize a cost-effective manufacturing process (aerosol spray)
  - Evaluate long-term and thermal cyclic behavior (in terms of electrical conductivity and surface stability) of these candidate materials on inexpensive ferritic stainless steel substrates

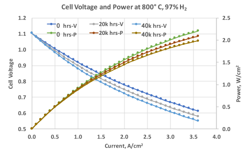
- *A. Petric and H. Ling, J. Am. Ceram. Soc., <u>90</u>, 1515 (2007); S. Hosseini, F. Karimzadeh, M. Enayati, and N. Sammes, Solid State Ionics, <u>289</u>, 95 (2016); N. Hosseini, F. Karimzadeh, M. Abbasi, and G. Choi, Ceramics International, <u>40</u>, 12219 (2014); N. Hosseini, M. Abbasi, F. Karimzadeh, and G. Choi, J. Power Sources, <u>273</u>, 1073 (2015); W. Huang, S. Gopalan, U. Pal, and S. Basu, J. Electrochem. Soc., <u>155</u>, B1161 (2008); Z. Sun, S. Gopalan, U. Pal, and S. Basu, Surface & Coatings Tech., <u>323</u>, 49 (2017); P. Wei, X.Deng, M. Bateni, and A. Petric, Corrosion, 63, 529 (2007); M. Bateni, P. Wei, X. Deng, and A. Petric, Surface & Coatings Tech., <u>201</u>, 4677 (2007)

FY18 Modeling Focus

- Recent modeling task activity continued to focus on ***linking model results across length scales***
  - Utilize the ***Reduced Order Model (ROM)*** approach to improve the accuracy of power system models

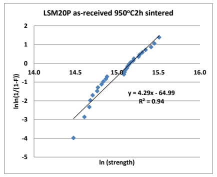
Micro/Meso-Scale Models

I-V Performance

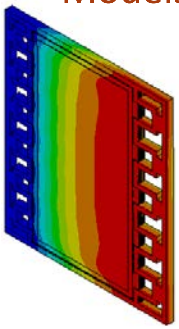


Cell Material Testing

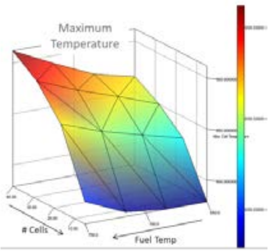
Property Data



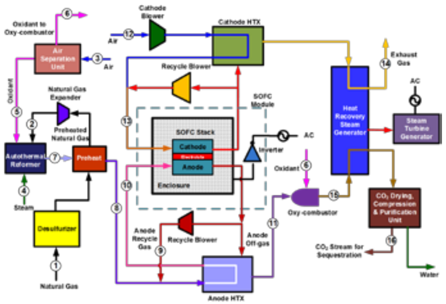
Cell/Stack Models



Response Surface Analysis



System Models



Performance: Electrical Thermal Mechanical

Reduced Order Model (ROM)

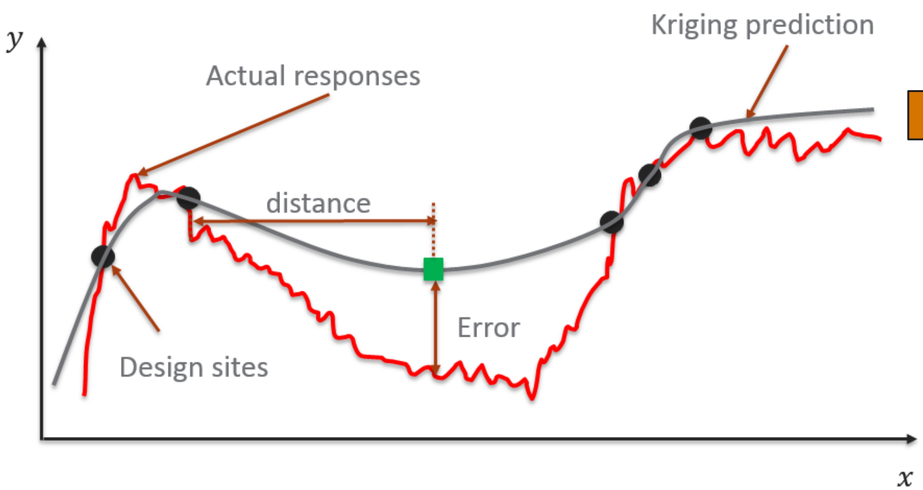
Modeling Presentation Topic Summary

- SOFC ***Modeling Tool Development***
  1. Response surface regression and error quantification
  2. ROM tool for SOFC stacks
  3. ROMs generated for NETL system analysis

- Modeling of ***Stack Degradation and Reliability***
  4. Short-term and long-term mechanical reliability
  5. Optimal conditions for short-term reliability

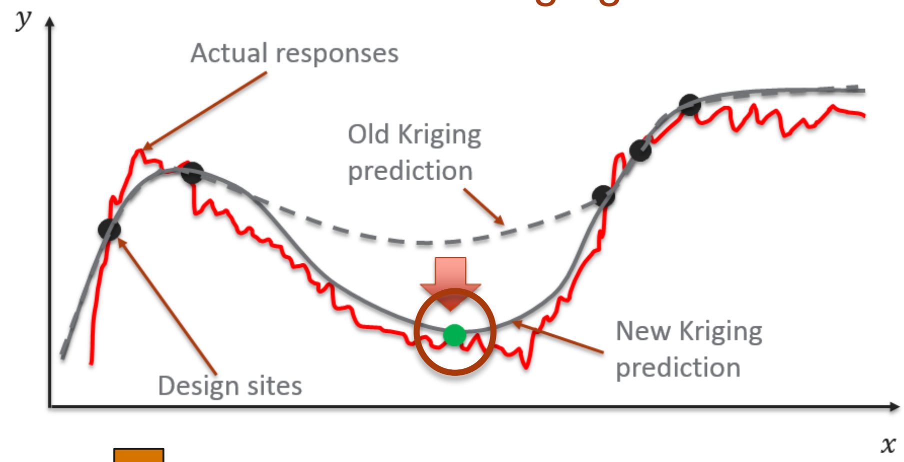
Introduction of ROM Framework

Initial Kriging regression

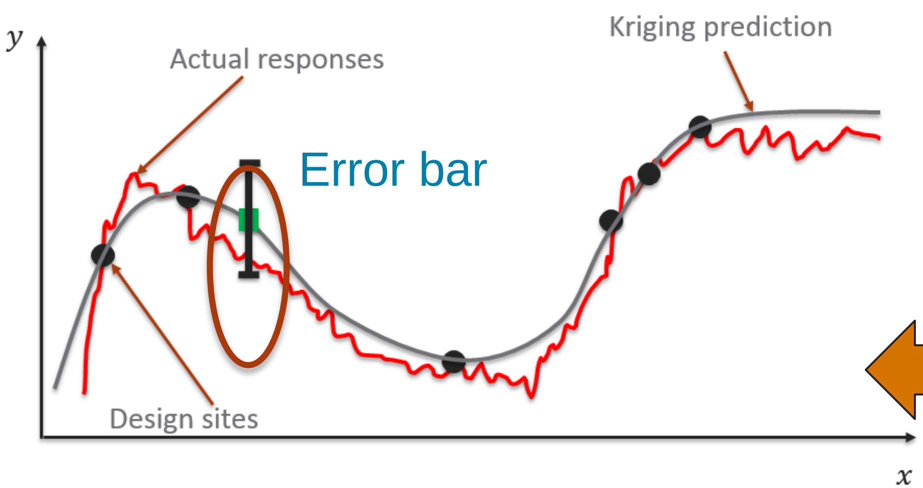


- *But how to select the best location to add additional design sites?*
  - *Need smart sampling*

Smartly add sampling points to reduce Kriging MSE



Quantify the error of Kriging prediction



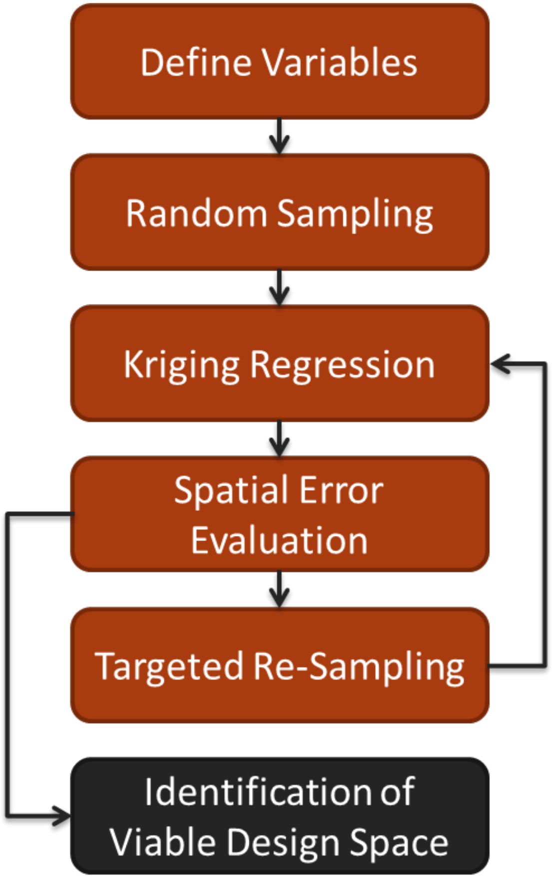
- *But how accurate is the prediction?*
  - *Need error bar*

Framework to Minimize Regression Error

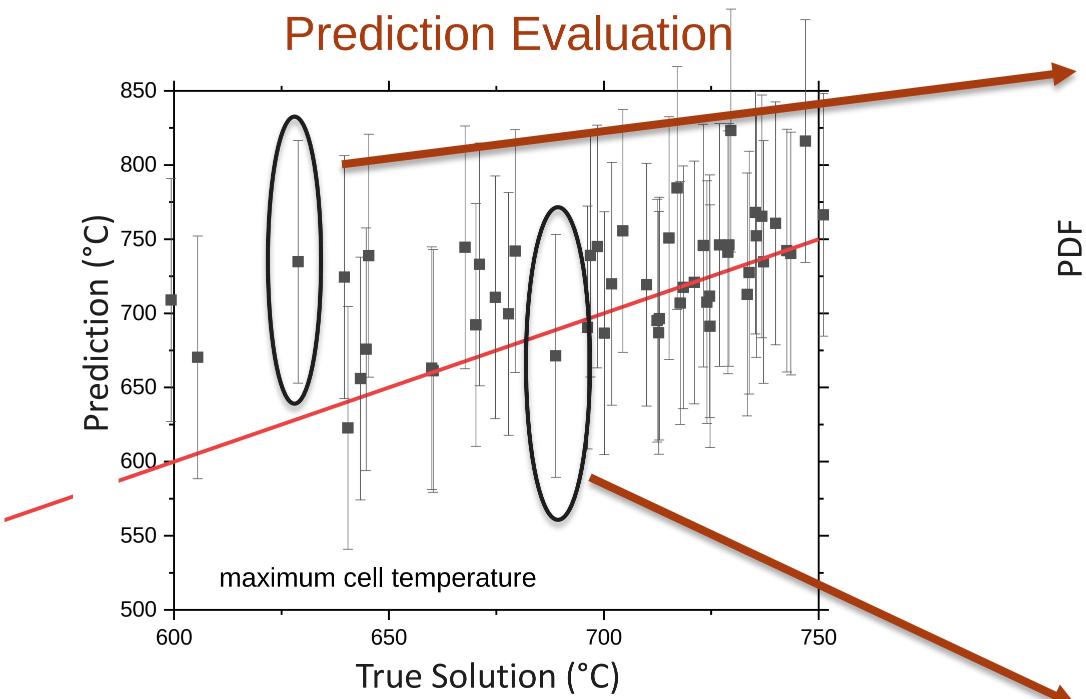
- Demonstrate advantage of ***adaptive smart sampling*** versus traditional sampling using ***NGFC stack model***
- Traditional sampling:
  - 11k random samples
  - Additional 1k samples for validation cases
  - Max voltage mean square error (MSE) of 3.0e-4
- Adaptive smart sampling:
  - 2k initial samples followed by MSE evaluation
  - Additional 2k targeted samples
  - Repeat iteration until desired MSE is reached
- ***Same error*** achieved with ***~30% less samples*** (<8k)

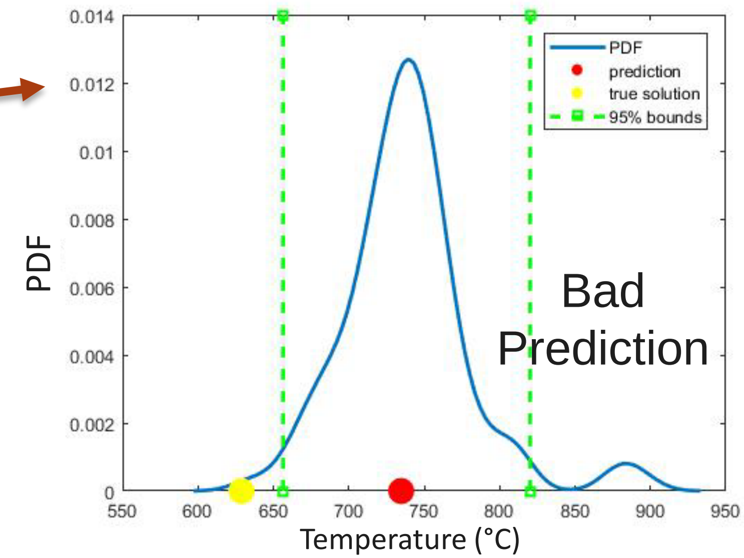
Number of Samples	Maximum MSE	MSE Ratio
2000	1.5e-3	487%
4000	4.2e-4	141%
6000	3.8e-4	126%
8000	**2.9e-4**	**96%**

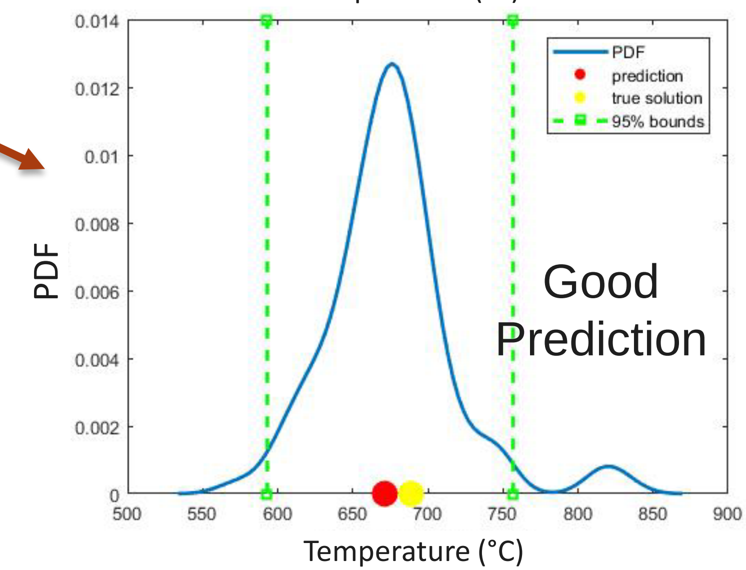
Iterative Sampling Approach



ROM Error Quantification



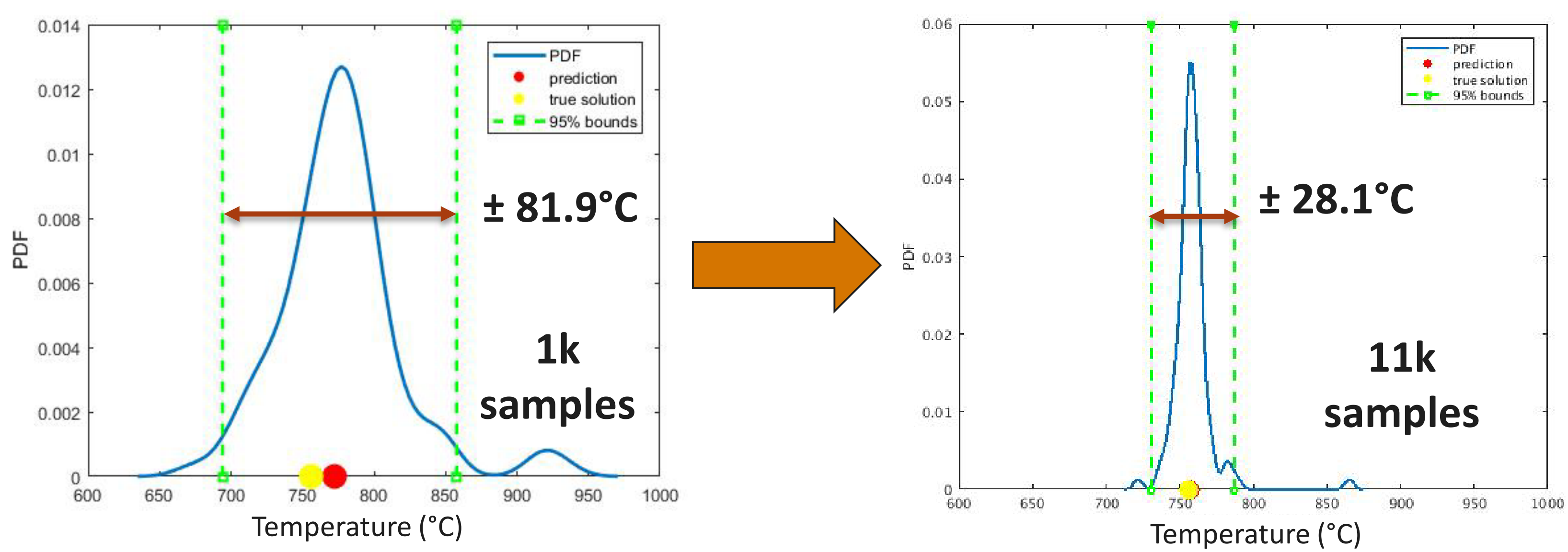




- Prediction (black square) and 95% confidence interval (error bar) are shown
- Error bar crossing red line (100% match) indicates good prediction
- 48 out of total 50 predictions are good: 96%≈95% ***validates the quantified error***

ROM Error Quantification (cont'd)

- Error quantification permits user to ***obtain the required ROM accuracy***
- Evaluated the impact of sample size on ***95% confidence interval*** (CI)
  - Increase number of samples and perform cross-validation on maximum cell temperature
- Results:
  - Increased number of sample size by 11X, 95% CI range is reduced by 3X
  - Prediction is more accurate and closer to true solution
  - Allows user to choose desired range of 95% CI
- ***Incorporating the error quantification framework in the ROM generation tool***



ROM Generation Tool

- ***User interface*** for stack simulations and ROM generation on ***high performance computer*** (HPC)

After creating all the simulations cases, use "Simulations on HPC" tab to run the simulations on Linux HPC clusters

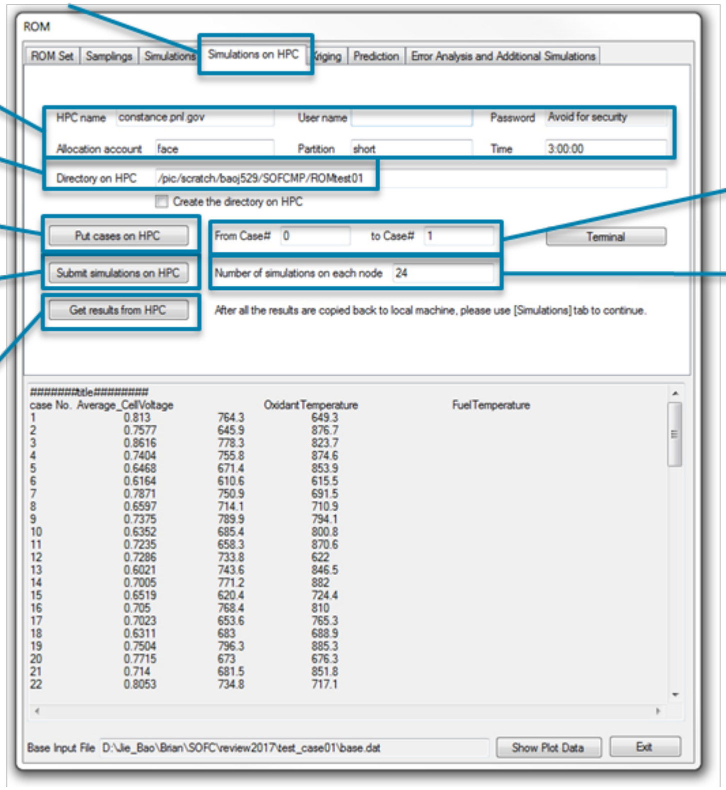
1. Account setup on HPC

2. Working direction on HPC

3. Copy data to HPC

4. Submit simulation jobs into queue on HPC. No need to keep connecting to HPC after submitting the jobs

5. Gather simulation results from HPC to local PC. List the cases without simulation results for tracking and/or rerun



Specify the case/s run on HPC clusters for resume or rerun incomplete cases

SOFC-MP is a serial code. For fully use the capacity of compute node on HPC, specify the number of cases that can run simultaneously on each HPC node

ROM Parameter Sensitivity Analysis

- ***Sensitivity scores***
  - Deviation between ROM predictions and SOFC-MP simulation results after removing each input parameter
  - The parameter that induces the largest deviation after removing it from the ROM prediction has the highest sensitivity score (scaled to 100)

NG Inlet Temperature has little influence on most outputs.

Required Heat Exchanger Effectiveness depends strongly on amount of on-cell reforming.

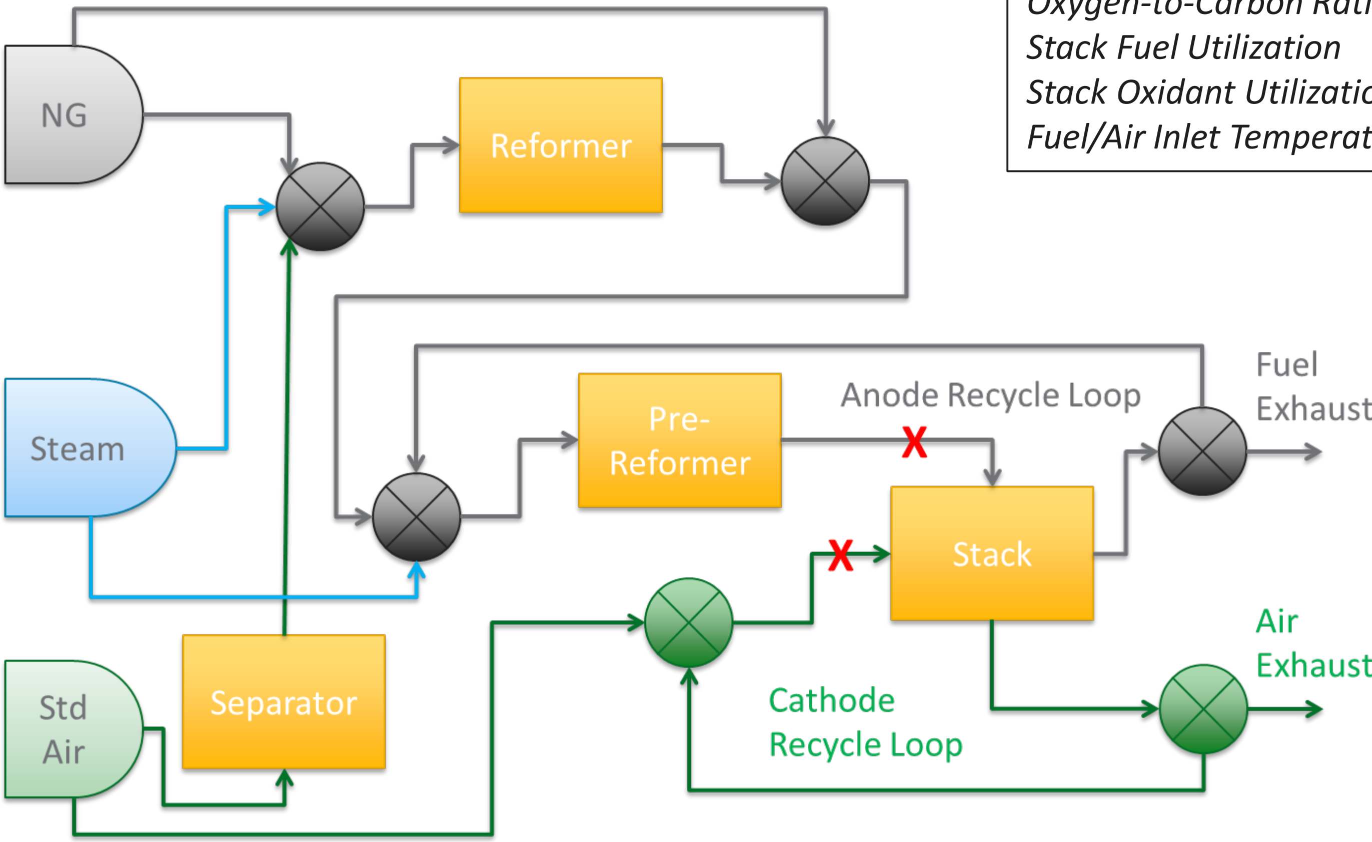
Output Parameters

Input Parameters

	Stack Voltage	Avg cell voltage	Max current density	Min current density	Avg Cell Temperature	Max Cell Temperature	Min Cell Temperature	Delta Cell Temperature	Outlet Fuel Temperature	Delta Fuel Temperature	Outlet Air Temperature	Delta Air Temperature	Air Heat Exchanger Effectiveness	Fuel Utilization	Outlet Fuel Flowrate	Outlet Fuel H2	Outlet Fuel H2O	Outlet Fuel CO	Outlet Fuel CO2	Outlet Fuel CH4	Outlet Fuel N2	Outlet Air Flowrate	Total Power	Air Enthalpy Change	Fuel Enthalpy Change	Electrical Efficiency	Stack Efficiency	FSI Temperature	FSI Flowrate	FSI H2 MF	FSI H2O MF	FSI CO MF	FSI CO2 MF	FSI CH4 MF	FSI N2 MF	Fuel Temperature after Mix	Fuel Temperature before Gibbs Reactor	Fuel Heat Exchanger Effectiveness
Average Current Density	74	74	49	100	17	20	20	55	0	0	15	13	19	0	62	0	0	0	0	42	0	53	100	71	100	32	18	0	61	0	0	0	0	0	0	0	0	0
Fuel NG Temperature	0	0	11	0	11	10	5	13	0	10	12	14	20	0	0	0	0	0	0	0	0	0	0	21	5	26	5	23	6	11	5	18	9	13	7	100	44	100
Internal Reforming	54	54	79	40	46	54	31	70	32	63	62	68	100	48	78	30	57	43	43	100	100	0	15	100	39	100	35	100	76	100	46	100	100	100	100	100	49	85
Oxidant Temperature	81	81	74	24	62	63	71	20	60	100	68	12	46	0	0	7	7	53	36	100	15	0	15	43	15	53	20	62	5	39	26	63	35	50	32	63	65	76
Oxidant Recirculation	89	89	100	30	77	78	100	82	78	73	80	81	57	0	4	12	9	31	22	39	0	100	17	18	7	30	8	66	6	17	10	42	23	27	21	38	79	36
Oxygen To Carbon Ratio	38	38	64	51	15	15	15	31	4	29	28	33	33	38	100	0	0	0	0	25	0	0	8	29	18	40	49	34	100	73	100	79	65	79	52	82	40	69
Stack Fuel Utilization	100	100	87	72	36	44	25	62	19	63	54	60	86	100	100	100	100	100	100	79	9	0	20	86	29	84	100	44	100	33	21	49	30	39	26	33	32	66
Stack Oxidant Utilization	89	89	100	30	100	100	100	100	100	85	100	100	74	0	4	12	14	36	28	32	0	100	17	17	8	28	18	66	8	23	13	54	27	35	24	43	100	100

ROMs for NETL System Analysis: NGFC Material Flowchart

- Baseline model is natural gas fuel cell (***NGFC***) system
  - 93% CH_4 requires external reformer



ROM Input Parameters

Average Current Density	2000-6000 A/m^2
Internal Reforming	0-100%
Oxidant Recirculation	0-80%
Oxygen-to-Carbon Ratio	1.5-3.0
Stack Fuel Utilization	40-95%
Stack Oxidant Utilization	12.5-83.3%
Fuel/Air Inlet Temperature	550-800°C

NG Composition

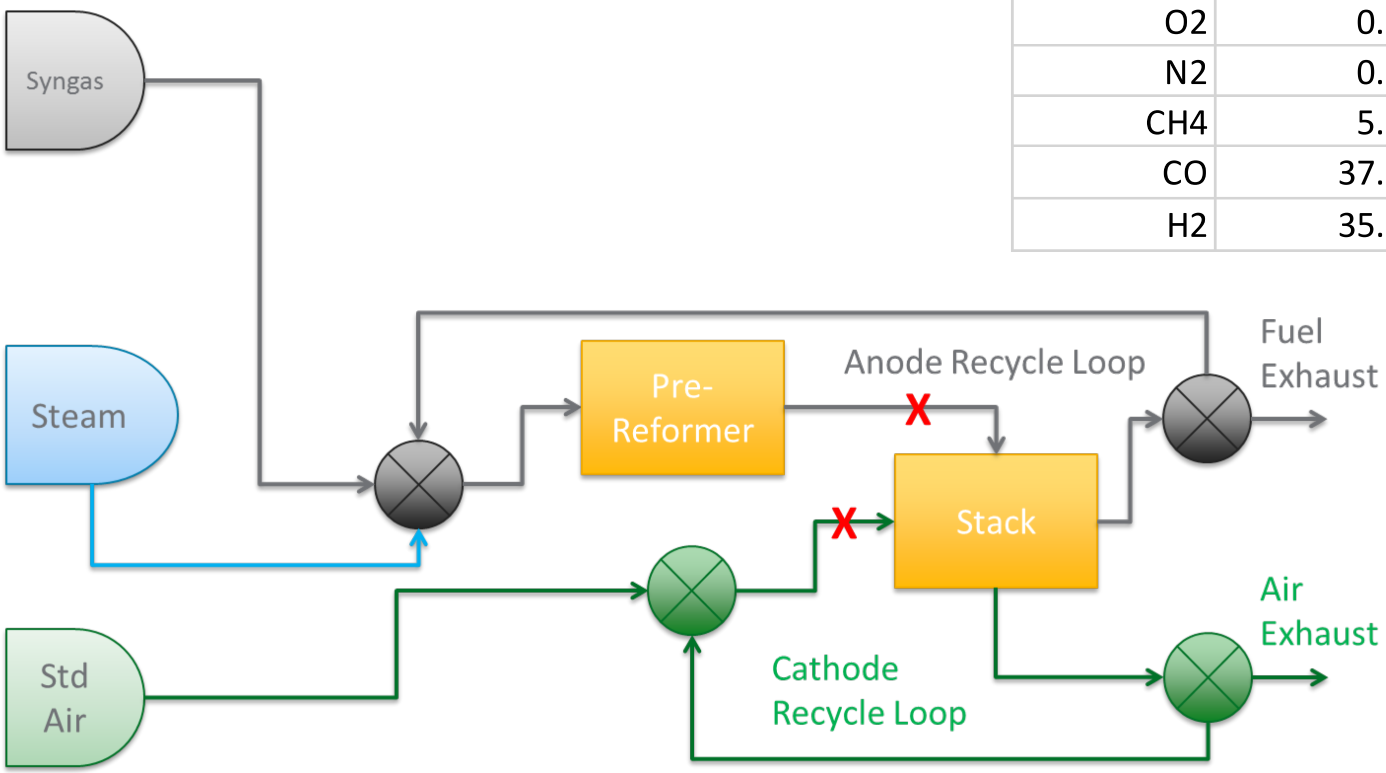
H2O	0.0%
Ar	0.0%
CO2	1.0%
O2	0.0%
N2	1.6%
CH4	93.1%
CO	0.0%
H2	0.0%
C2H6	3.2%
C3H8	0.7%
C4H10	0.4%

ROMs for NETL System Analysis: IGFC Material Flowchart

- Reduced CH_4 composition of integrated gasification fuel cell (***IGFC***) syngas (6-32%) does not require the external reformer

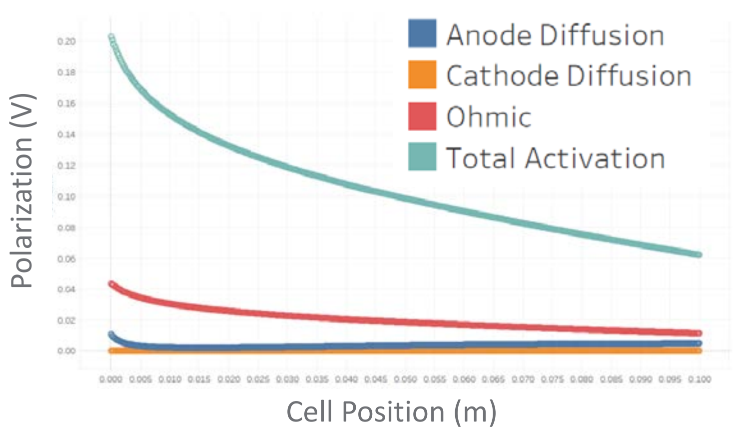
Syngas Fuel Compositions

	Conventional	Enhanced	Catalytic
H2O	0.1%	0.1%	0.0%
Ar	0.1%	0.1%	0.0%
CO2	20.4%	24.2%	34.7%
O2	0.0%	0.0%	0.0%
N2	0.6%	0.6%	0.7%
CH4	5.8%	10.2%	31.6%
CO	37.7%	34.1%	9.1%
H2	35.2%	30.6%	23.9%

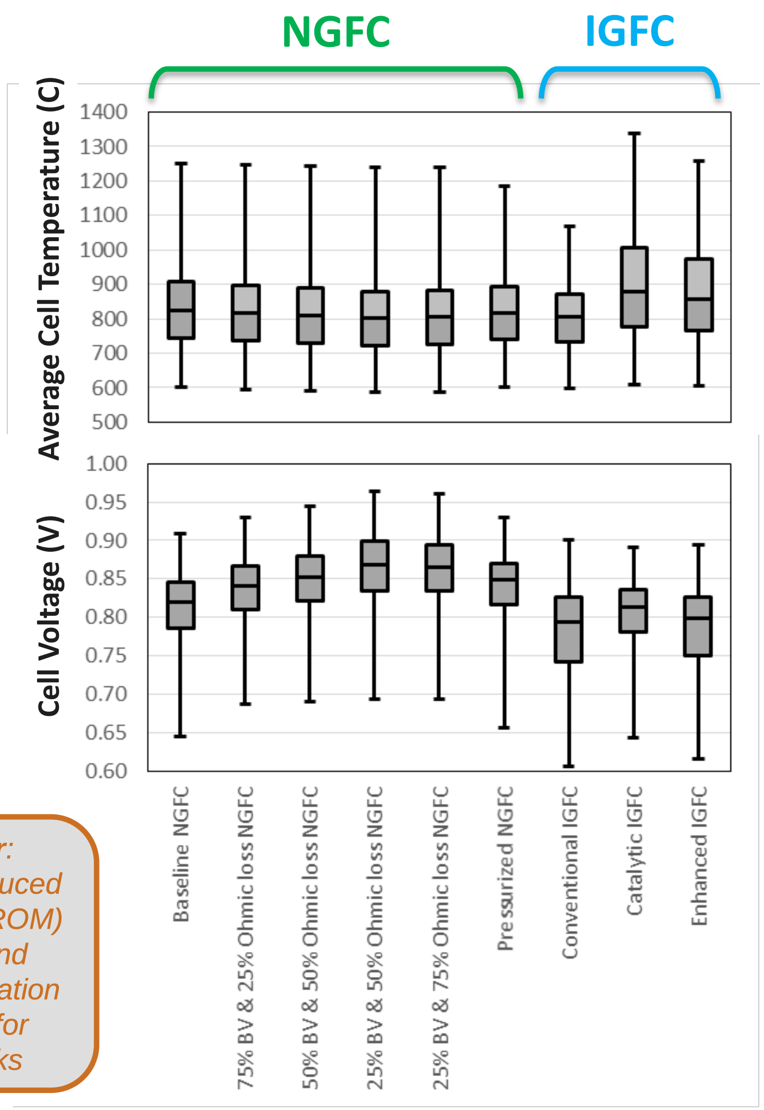


ROM Usage for Power System Analysis

- ***Collaborating with NETL*** on ROMs for different stack operating performance levels and systems
  - SOA atmospheric NGFC
  - Future performance NGFC with reduced activation/ohmic losses
    - 25%-75% reduction combinations
  - Pressurized NGFC
  - IGFCs



***See Poster**: Advanced Reduced Order Model (ROM) Prediction and Error Quantification Framework for SOFC Stacks*



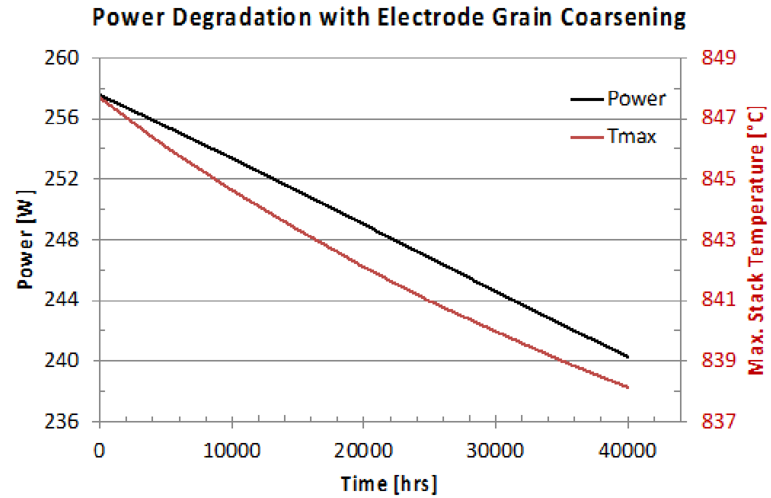
Long-Term Stack Reliability: Degradation by Grain Coarsening

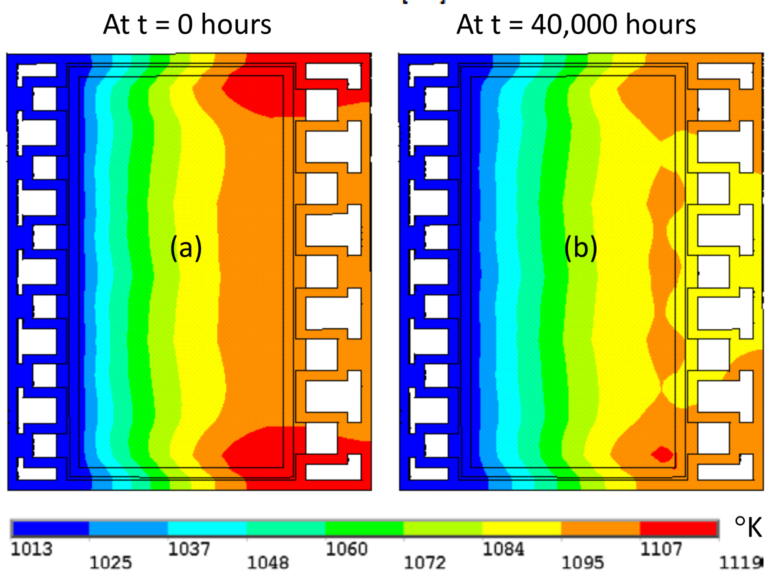
- Baseline 3D model for ***single-cell, co-flow*** cell operating at 750°C average temperature.
- Reliability evaluated at the beginning and end of operating life w/ ***grain coarsening***.
- ***Structural reliability increase*** is predicted after long-term degradation due to ***reduction in the stack peak temperatures and thermal gradients*** at end-of-life conditions.

Initial and Degraded stack component reliability

Stack Component	Initial (t = 0 hrs)		Degraded (t = 40,000 hrs)	
	Max. Stress [Pa]	Prob. Of Failure, P_f (%)	Max. Stress [Pa]	Prob. Of Failure, P_f (%)
Air Seal	4.70E+06	0	4.82E+06	0
Fuel Seal	6.00E+06	0	6.05E+06	0
PEN Seal	3.92E+06	0	3.90E+06	0
Electrolyte	7.20E+07	3*	7.14E+07	2*
Anode	8.10E+06	0	8.10E+06	0
Cathode	9.71E+06	0	7.67E+06	0
Cathode Contact	1.95E+06	10	1.09E+06	2
Stack Overall P_f	12%		4%	

NOTES: *Localized risk of rupture at corners observed



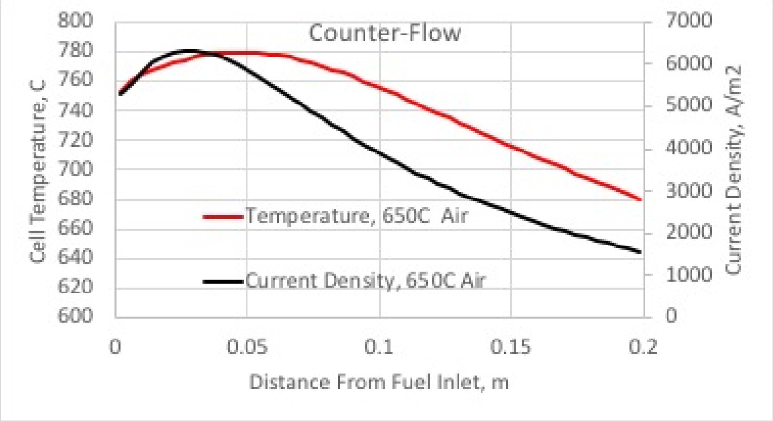


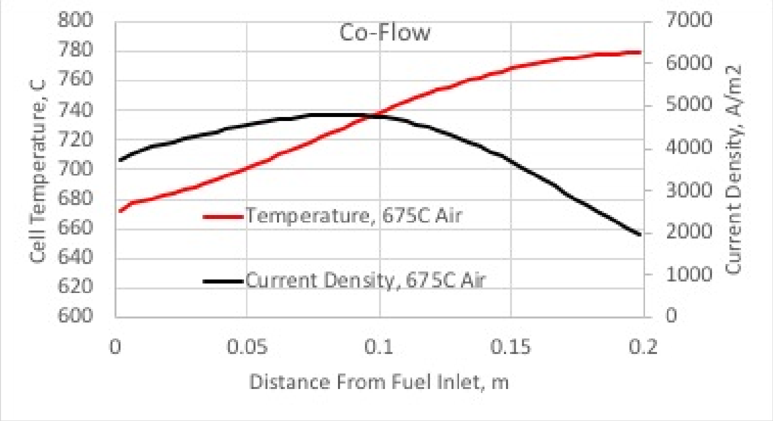
Short-Term Reliability Study: Scoping Simulations w/ 2D Model

Pacific Northwest

- Parameter ranges selected to focus structural simulation cases near ***likely operating points*** from the NGFC pathway evaluations
  - ***Targeted 750°C average and 800°C maximum temperatures*** at 400 mA/cm^2
  - SOA and future NGFC operations (100% IR)
- Outputs of 2-D simulation sets show cathode inlet air temperature ranges can be focused down to a 50°C range
  - Use full range of fuel and air utilizations
  - Use three NG fuel compositions

Set #1 Case Results





Input Parameters for 3D Model Cases

	Counter-flow		Co-flow	
	Minimum	Maximum	Minimum	Maximum
Tair, °C	650	700	675	725
UA(stack), %	13.0	16.1	13.0	16.1
UF(stack), %	68.8	84.4	68.8	84.4
Fuel Composition	All	All	All	All

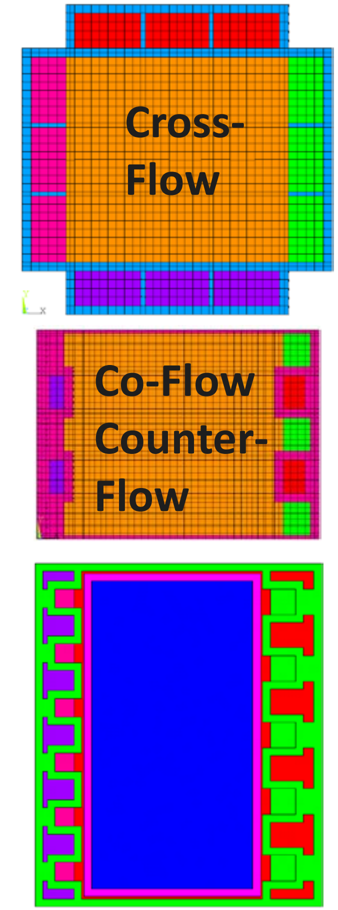
***See Poster**: Optimal Operating Conditions for Performance and Reliability of Solid Oxide Fuel Cells*

Design of Experiments (DOE) Approach: Effect of Fuel Compositions & Geometry

Fuel Compositions and Flow Rates
(20% Pre-Reformed with Anode Recycle)

Species %	Fuel species entering the stack (high UF)		
	Composition #1	Composition #2	Composition #3
	60% IR, 2.1 OCR	60% IR, 2.6 OCR	100% IR, 2.1 OCR
H_2O	32.65	41.44	36.25
Ar	0.02557	0.0243	0
CO_2	15.65	19.22	22.79
O_2	0	0	0
N2	0.5620	0.5356	0.6514
CH_4	9.165	6.393	12.37
CO	10.77	8.304	7.259
H_2	31.18	24.09	20.67
C_2H_6	0	0	0
C_3H_8	0	0	0
C_4H_{10}	0	0	0
	Fuel flow rate, mol/s-cell (20x20 cm^2 cell)		
High UF	1.250E-03	1.792E-03	1.362E-03
Low UF	1.557E-03	2.447E-03	1.956E-03

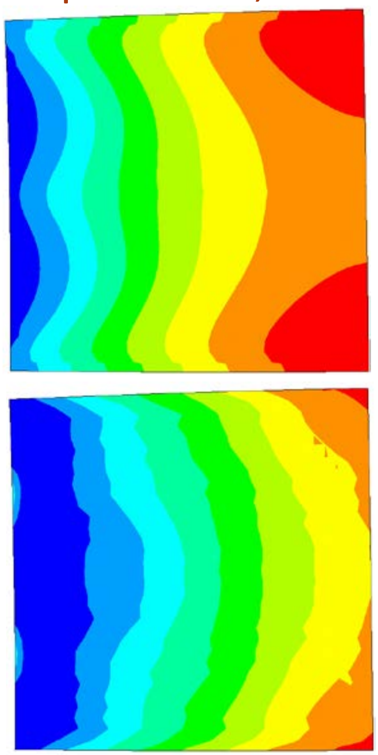
Cell Geometry



Effect of Composition on Reliability

- ***Significant variation in cell reliability*** for ***similar power output*** under varying combination of air temperature and fuel/air flow rates
- Higher OCR fuel (with higher flow rates) increased reliability
- Fuel with 100% internal reforming significantly increased reliability

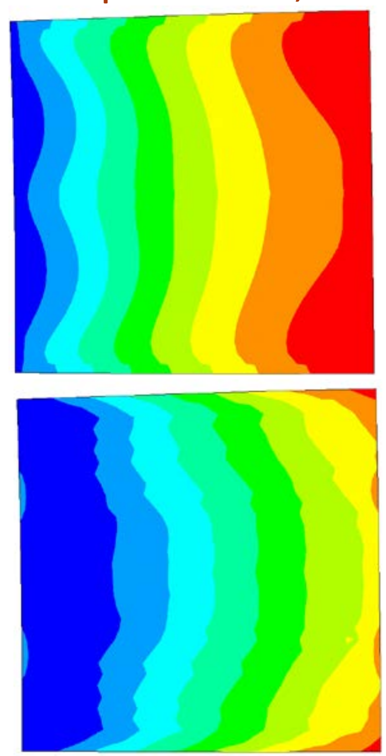
Comp1: 60%IR, 2.1 OCR



T_{avg} = 789°C

P_f = 11.5%
54 MPa

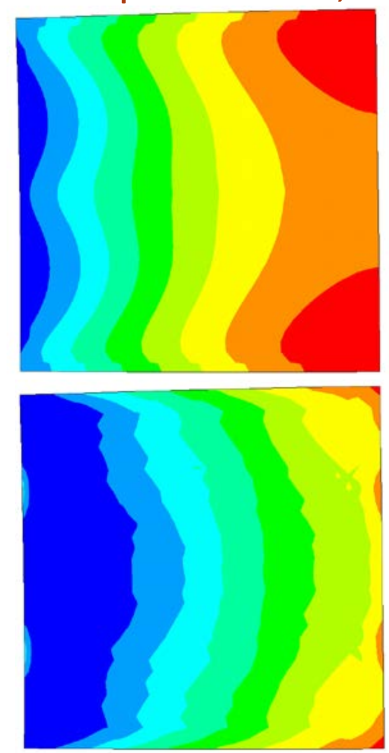
Comp2: 60%IR, 2.6 OCR



T_{avg} = 782°C

P_f = 5%
51.2 MPa

Comp3: 100%IR, 2.1 OCR



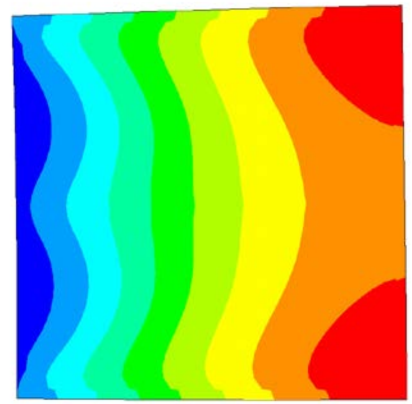
T_{avg} = 763°C

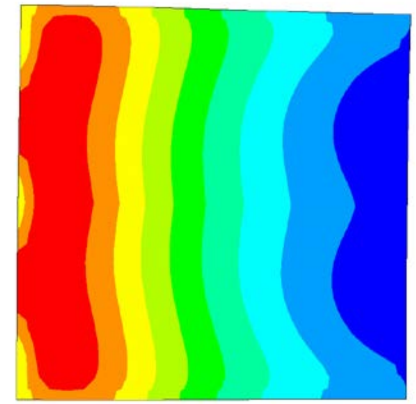
P_f = 0.1%
34 MPa

Effect of Flow Configuration on Reliability

- Evaluated Composition 1 (60% IR, 2.1 OCR) for co- and counter-flow geometry
- ***Similar power output could be produced in counter flow configuration with lower air temperatures***
- When same conditions of air temperature, air and fuel flow rates are maintained, the counter flow configuration produced ***lower T_{avg} but higher P_f because of increased temperature gradient*** across the cell.

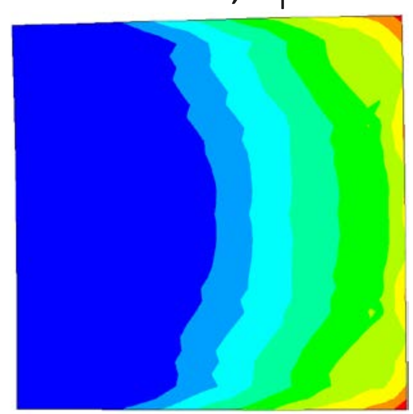
Co-flow	Counter-flow
P = 132W	P = 133W
T_{avg} = 737°C	T_{avg} = 732°C
ΔT = 112°C	ΔT = 123°C

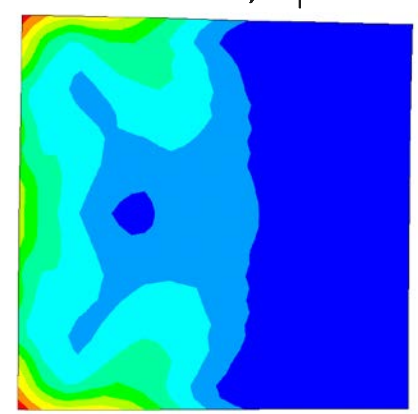




44 MPa max, P_f = 0.2%

59 MPa max, P_f = 1.1%



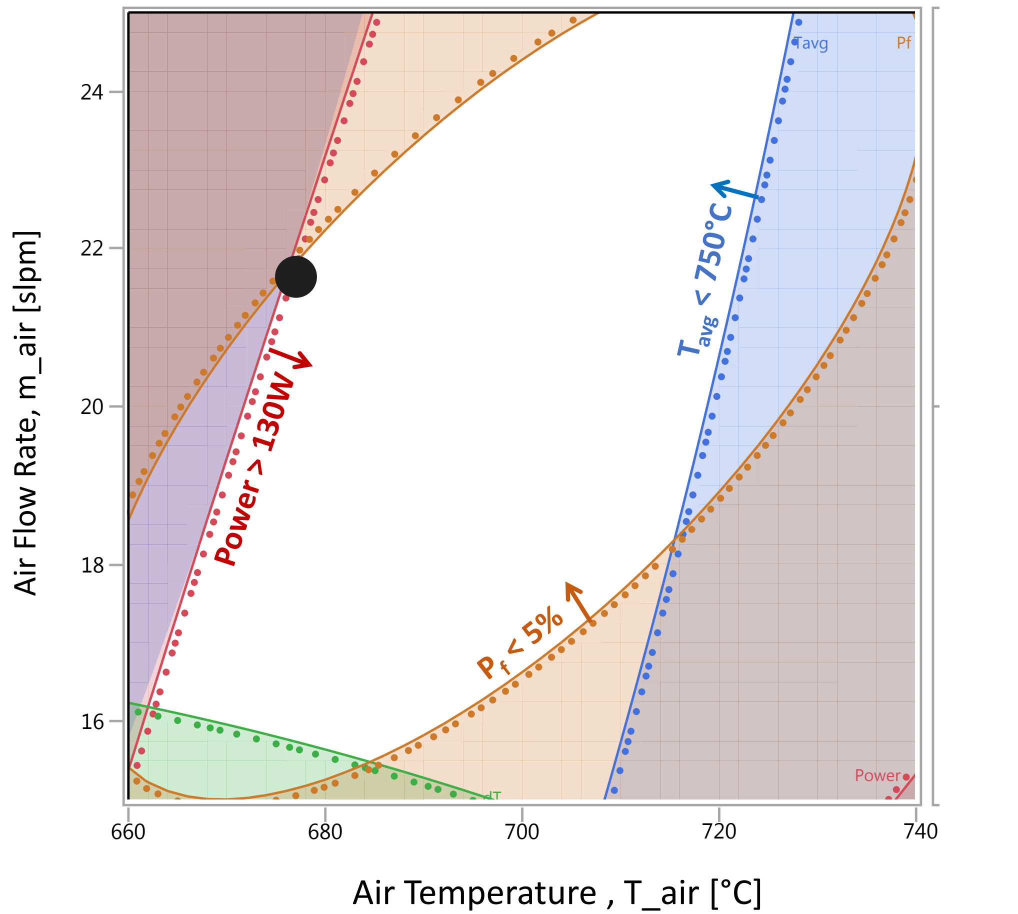


Domain for Co-flow Design (Composition 1)

Pacific Northwest

- ***Desirability function approach*** to find optimal solution
- Optimization Constraints:
  - Power > 130 W
  - P_f < 5%
  - T_{avg} < 750°C
  - ΔT not constrained
- ***Optimal solution*** of D=0.87
- Required Input:
  - T_{air} = 675°C
  - m_{air} = 21.26 slpm (AU≈15%)
  - m_{fuel} = 2.8 slpm (FU≈77%)
- Optimal Output:
  - P = 133.5W
  - P_f = 4%
  - T_{avg} = 729°C

Response	Contour	Current Y	Lo Limit	Hi Limit
Power	133.35	130.26248	133.35	140
dT	125	86.593723	75	125
Tavg	775	702.19036	728.7	775
Pf	0.05	0.5046274	-1	0.05



FY18 Modeling Summary: Accomplishments and Next Steps

- **Accomplishments**
  - Developed ***adaptive sampling*** approach to improve response surfaces
  - Used cross-validation technique to quantify the ***error distribution*** and generate ***point and interval estimates***
  - ***Developed tools and user interface*** for ***high performance computing*** for stack simulations and ROM generation
  - ***Provided ROMs to NETL*** for system design and COE analyses
    - SOA and future performance for different system configurations
  - Evaluated ***effects of operating conditions and flow geometry*** on electrical and structural performance
    - Identified ***local optimal condition*** for the cell based on ***mechanical reliability***
- **Next Steps**
  - Continue to ***work with NETL*** staff to use the modeling tools to help ***identify target performance goals*** for SOFC power systems.
  - ***Complete ROM tool GUI*** with error quantification this year
  - Incorporate ***structural reliability performance*** in the ROM tool

Summary

- PNNL is using experimental and computational capabilities to accelerate the commercialization of SOFC power systems.

- Posters
  - LSM/YSZ Button Cell Tests in Cathode Air with Measured Cr Concentrations (John Hardy)
  - Cr Mitigation by LSCF-based Materials for Solid Oxide Fuel Cells (Matt Chou)
  - Composite Approach to Tailoring Thermal Expansion of LSCo-based Ceramic Cathode Contact for Solid Oxide Fuel Cell Applications (Matt Chou)
  - Long Term Stability Tests of Low Temperature and Standard Reactive Air Aluminization (Jung-Pyung Choi)
  - Advanced Reduced Order Model (ROM) Prediction and Error Quantification Framework for SOFC Stacks (Chao Wang)
  - Optimal Operating Conditions for Performance and Reliability of Solid Oxide Fuel Cells (Kurt Recknagle)
  - Small-Scale Test Platform (SSTP) for SOFC Stacks (Brent Kirby)
  - Air Braze Optimization for Markets Targeted by Aegis Technology, Inc. (John Hardy)

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