A Transformational Natural Gas Fueled Dynamic SOFC for Critical Datacenter In-Rack Power

(The first 6-month progress report)

DE-FE-0031671

Primary: University of South Carolina
In collaboration with Atrex Energy

2019 Annual SOFC Review Meeting
April 30, 2019

Outline

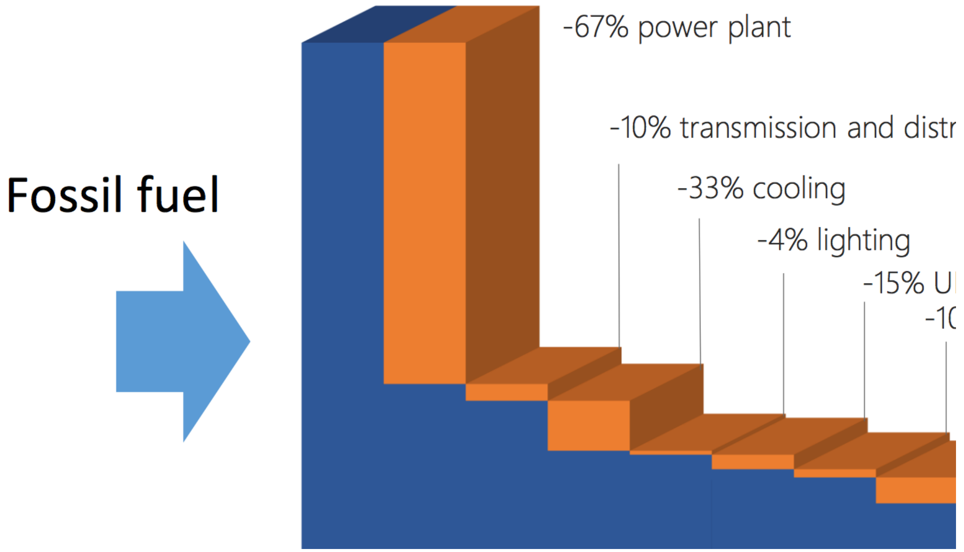
- Datacenter power challenges
- Fe-bed SOFC technology
- Objectives of the project
- Recent results
- Summary
- Acknowledgement

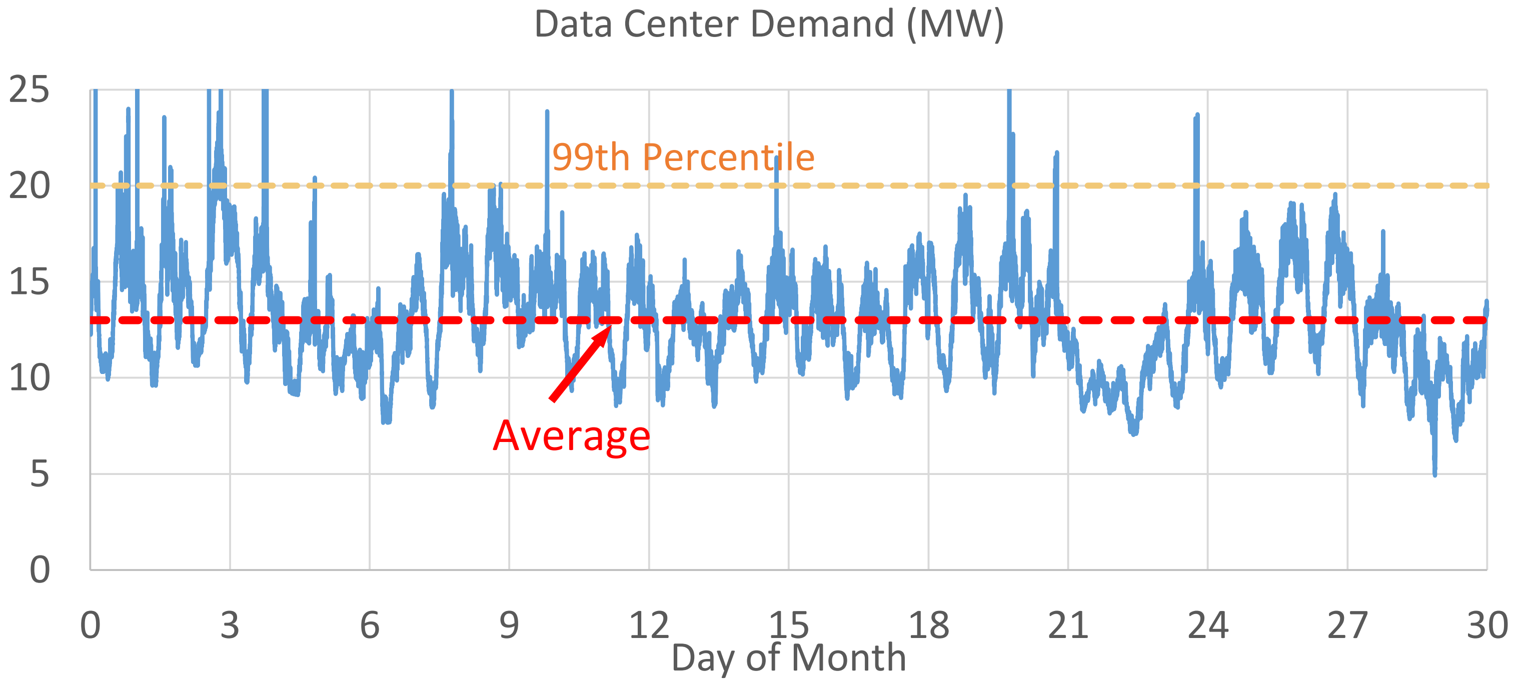
Datacenter Market Size and Key Requirements

- $18.5 billion global market (2018)
- Expected to grow to $32 billion by 2023
- 9.04% compound annual growth rate (CAGR)
- $6 billion market in the US alone
- Representing 2-3% of the total energy consumption in the US and Canada

Keys requirements: reliability, efficiency, cost and load following

The Challenges





100 kW_h fossil to thermal power plant

30 kW_e delivered to the data center

16 kW_e delivered to the server

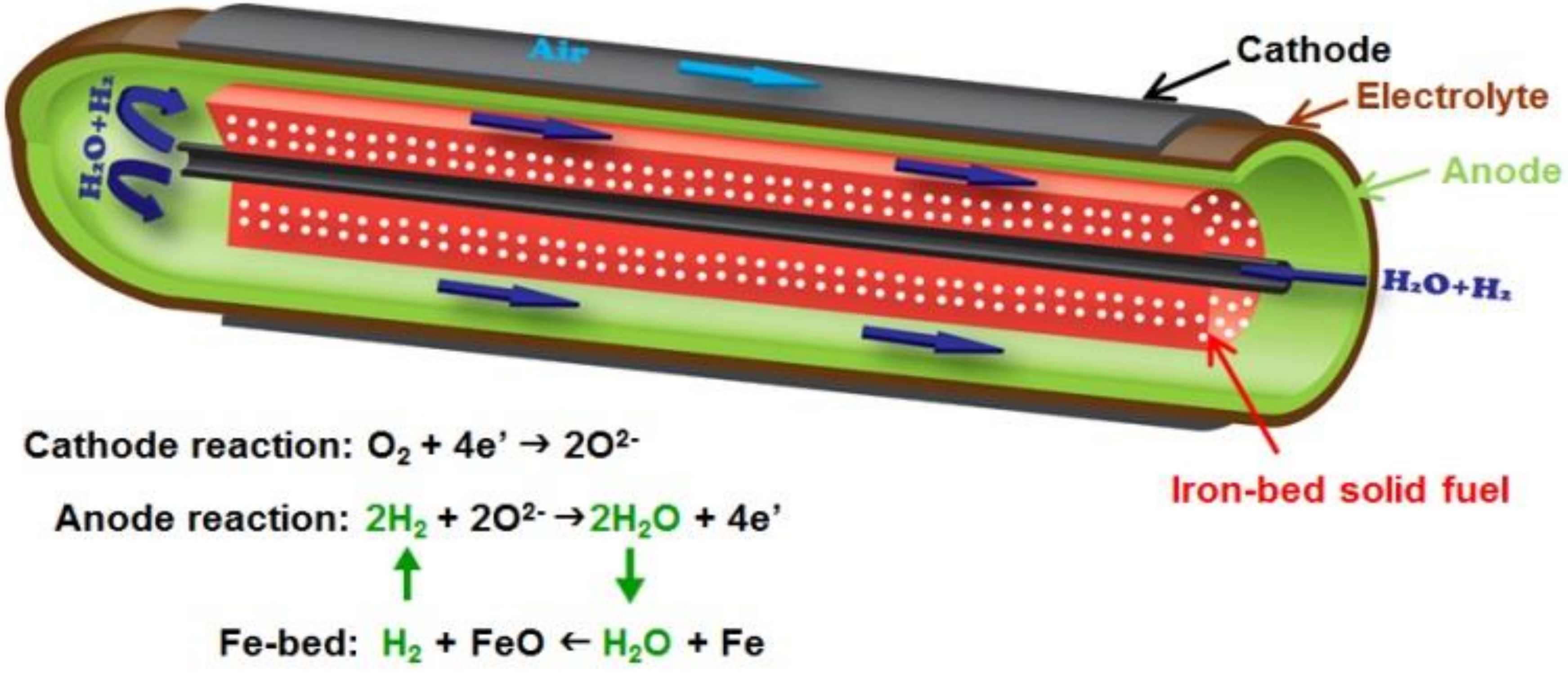
9.5 kW_e delivered to the application

Di Wang, “Co-optimization of data center loads and fuel cell systems”, MSFT-UW Fuel Cell Workshop, January 2017.

Can Conventional SOFCs Be Applied for Datacenters?

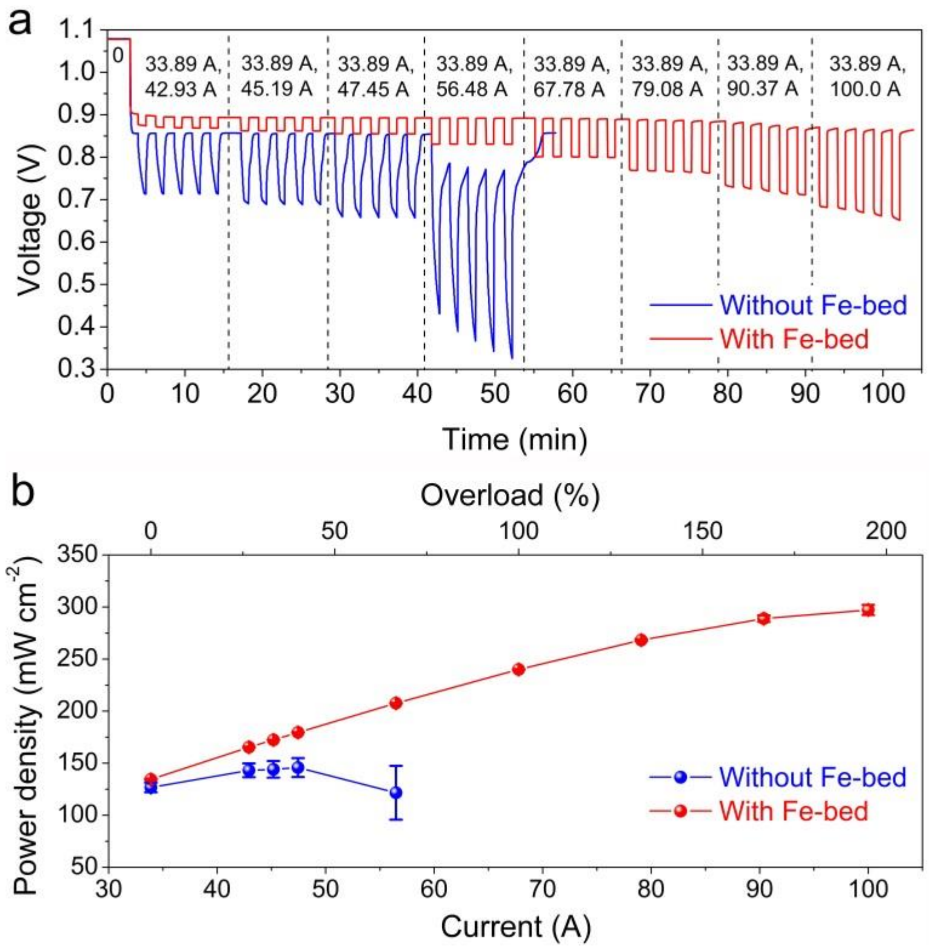
- Designed for baseload power applications at constant fuel and air utilizations
- Poor overload tolerance – causing local fuel starvation, Ni-oxidation and cracks in anode
- Slow fuel supply response system – mass flow controller
- Lack of robust control algorithms

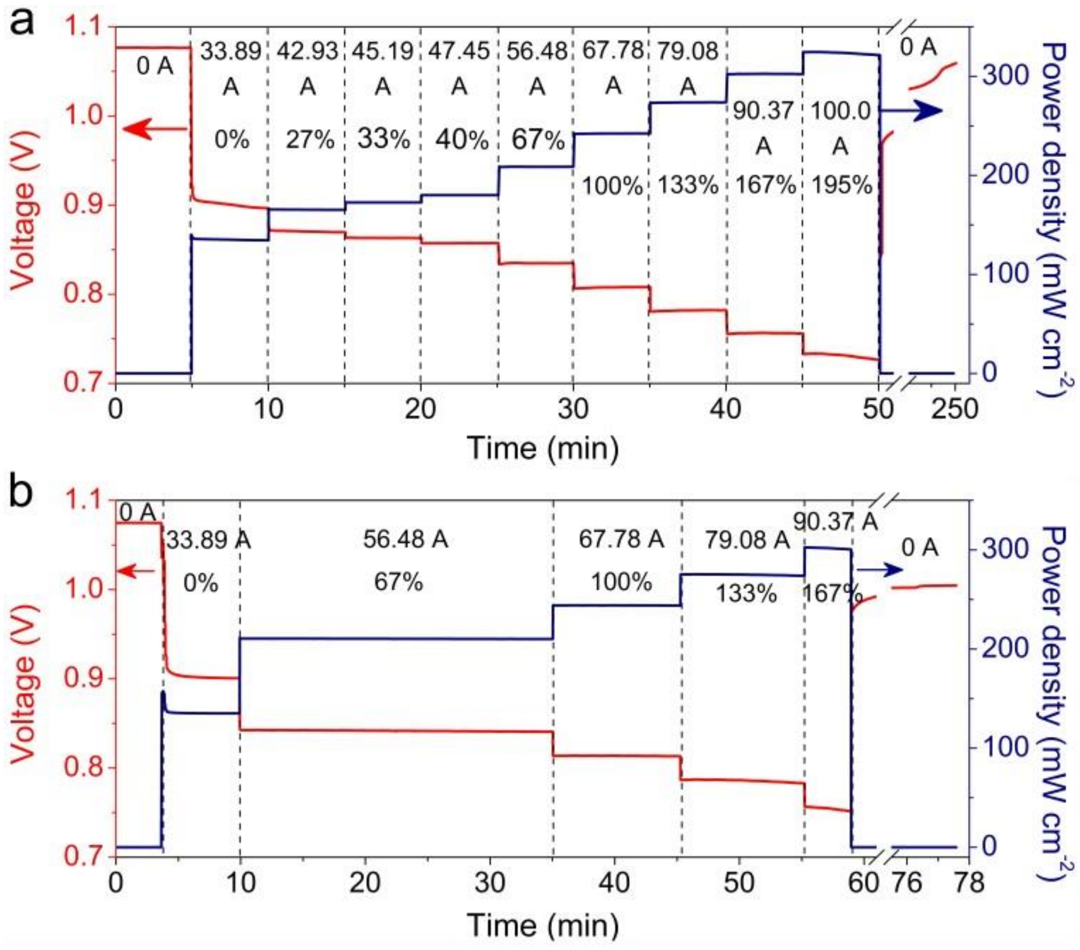
The Fe-Bed SOFC Technology



Energy & Environmental Science*, 4** *(2011), 4942;* ***9 *(2016), 3746 – 3753*

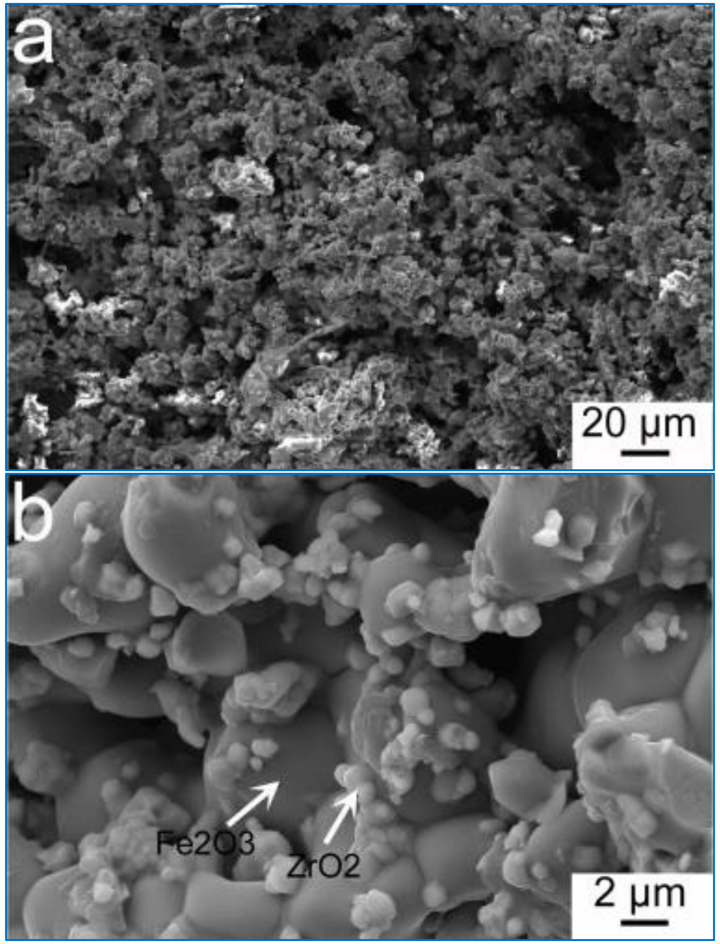
Robust Performance



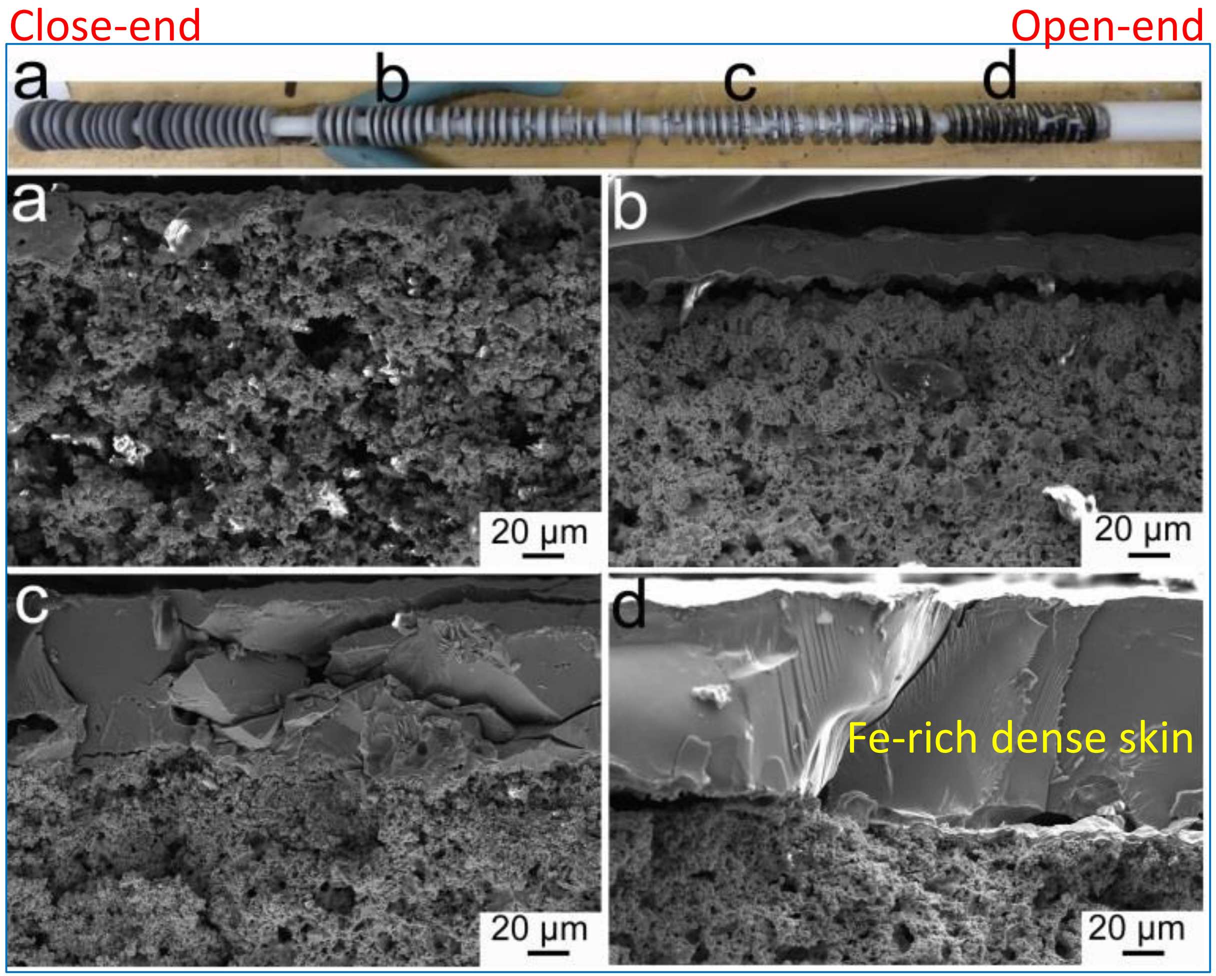


Energy & Environmental Science*, *9 *(2016), 3746 – 3753*

Remaining Issues



Before testing

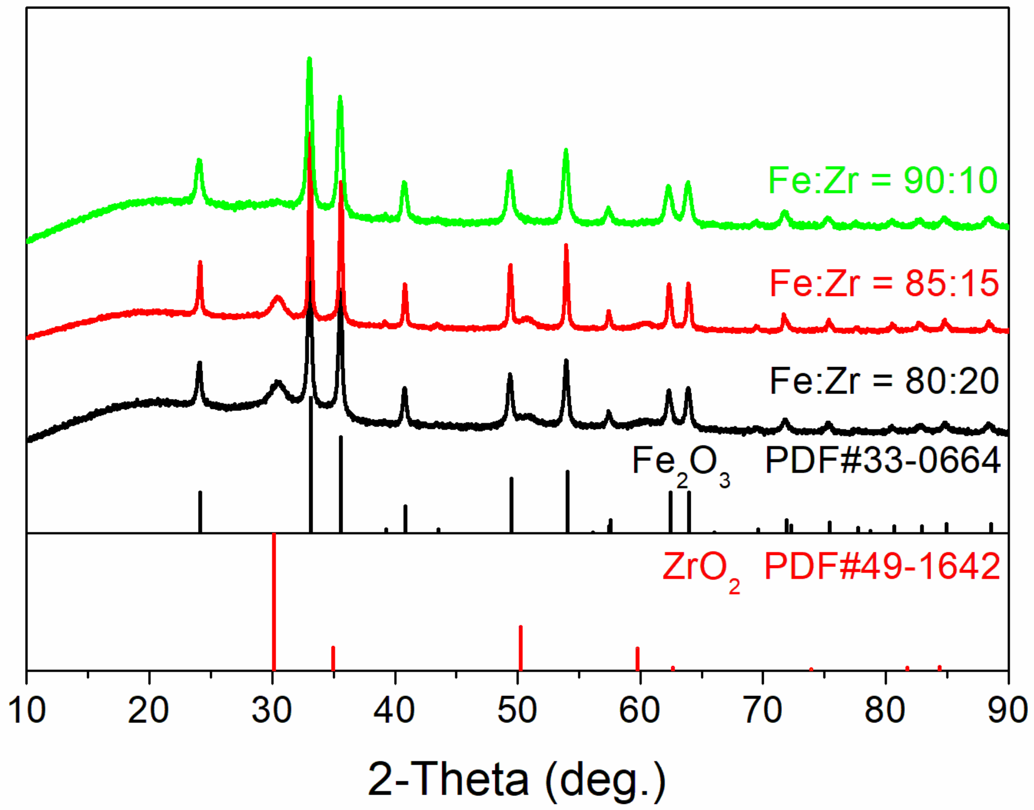


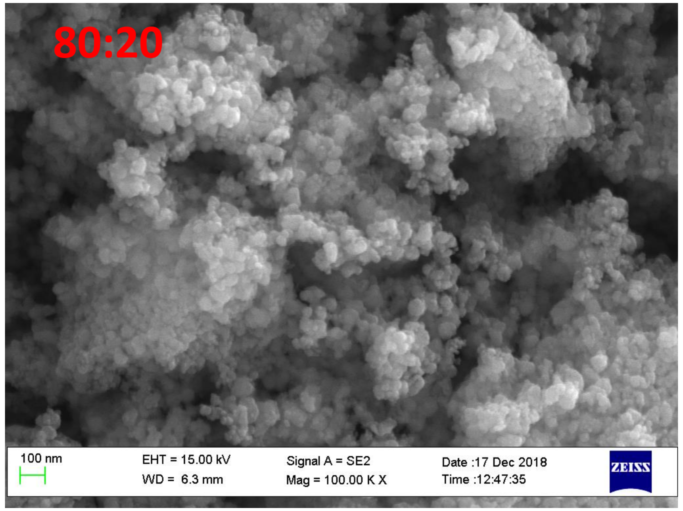
After testing

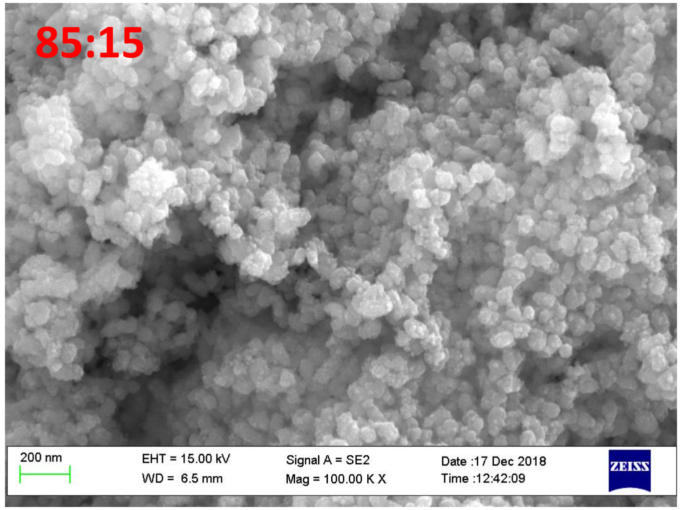
Project Objective(s)

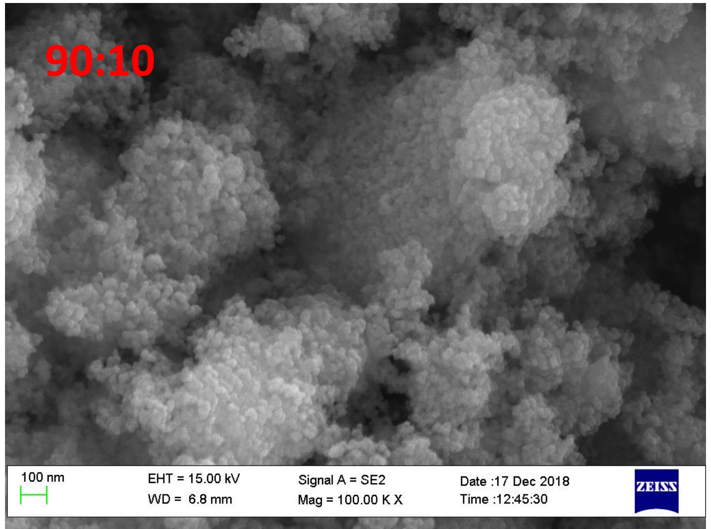
- Overarching objective: to develop a new generation of dynamic SOFC system operated on NG for datacenter applications
  - ✓ Primary objective -1: to develop robust metal-bed design and compositions
  - ✓ Primary objective -2: to demonstrate the new cell technology at pilot-scale

Optimizing Fe/ZrO_2 Ratio

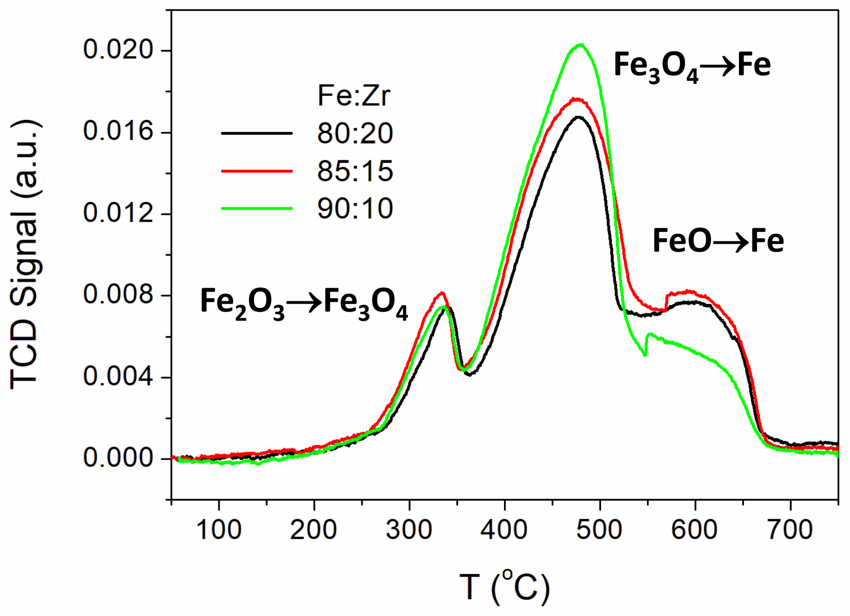


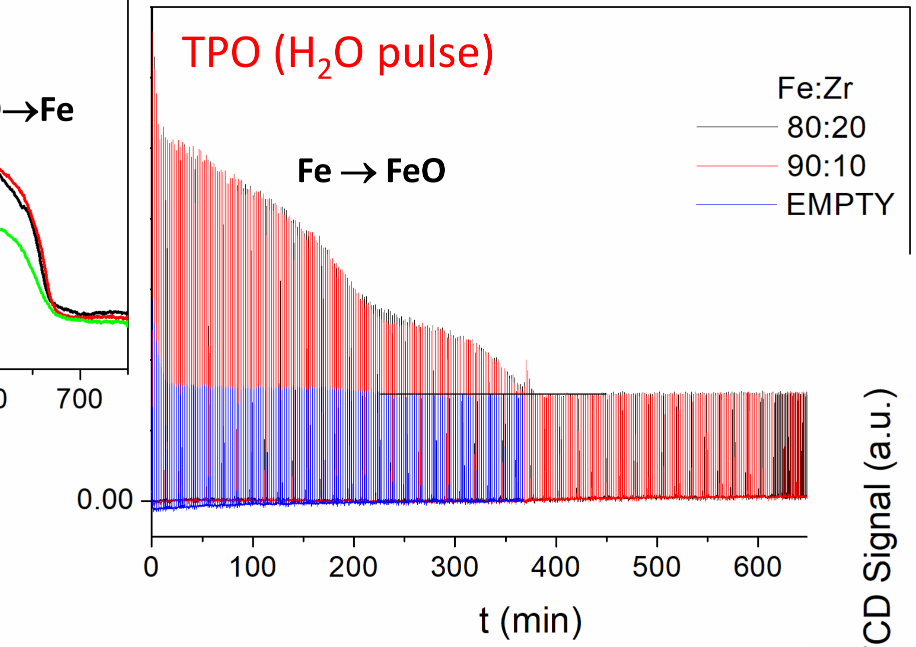


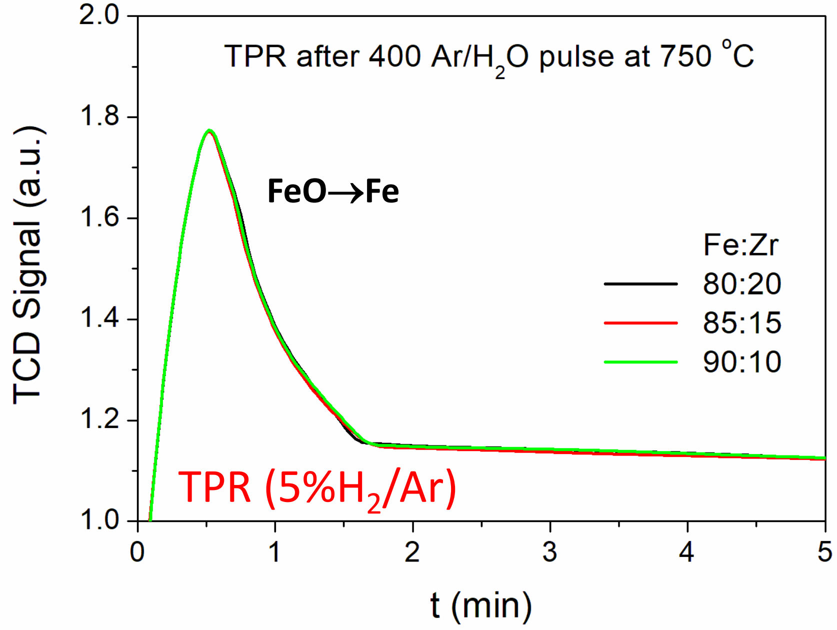




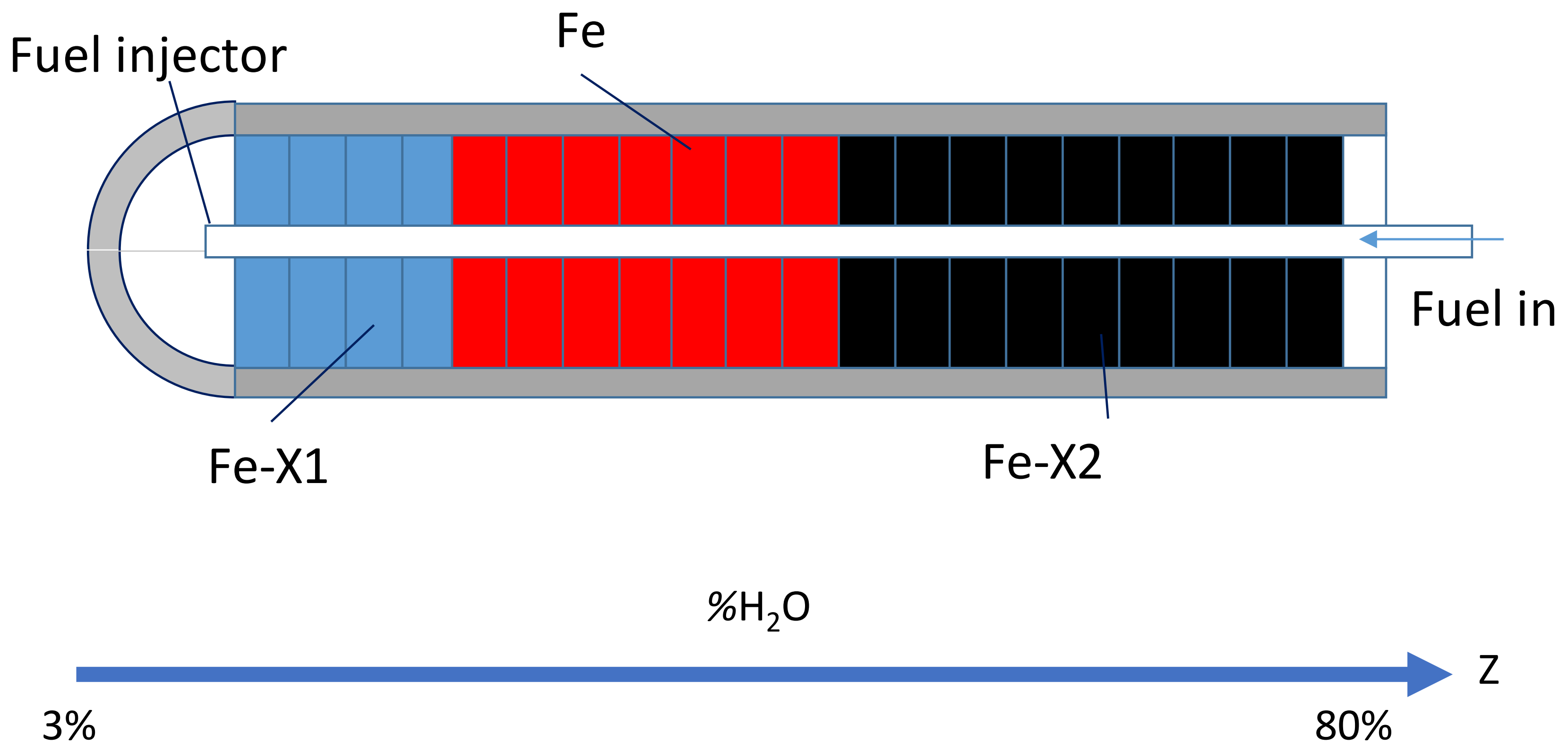
TPR/TPO Study



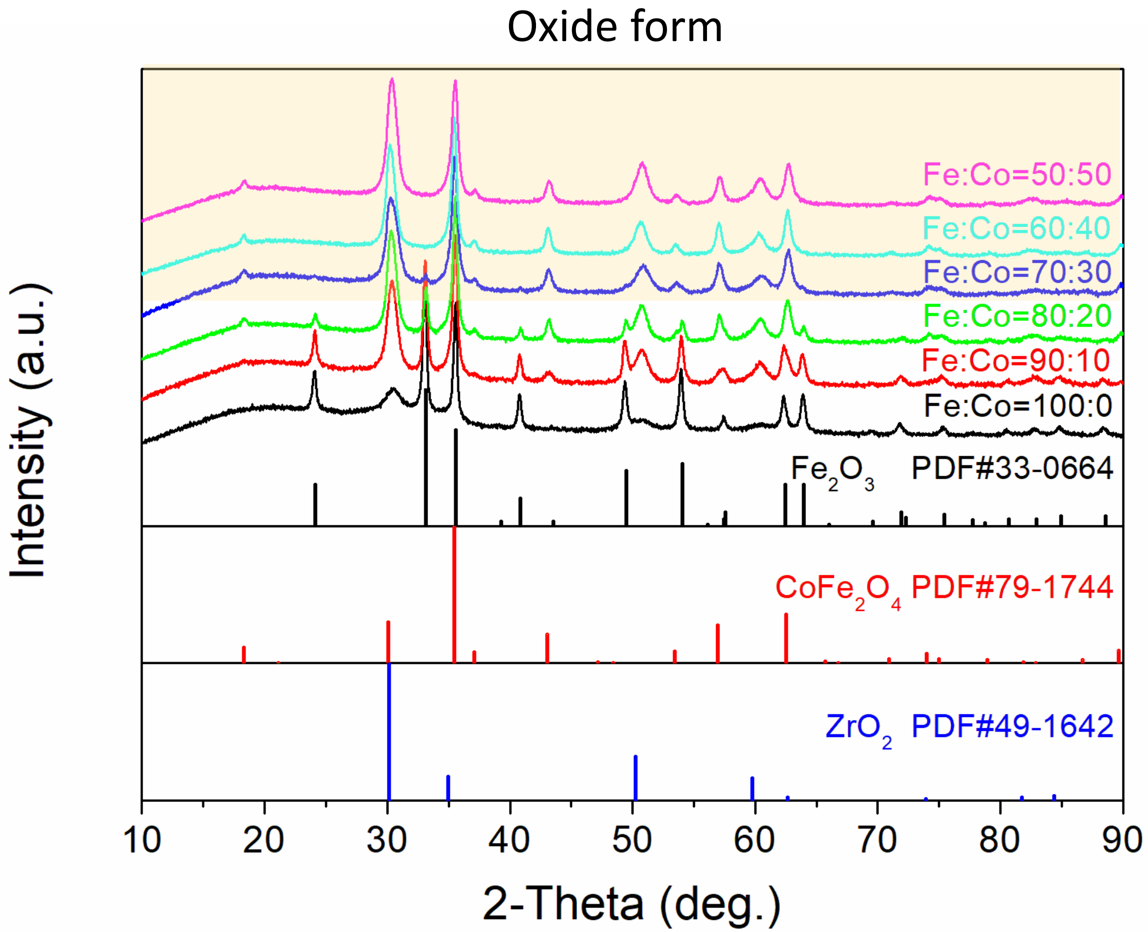


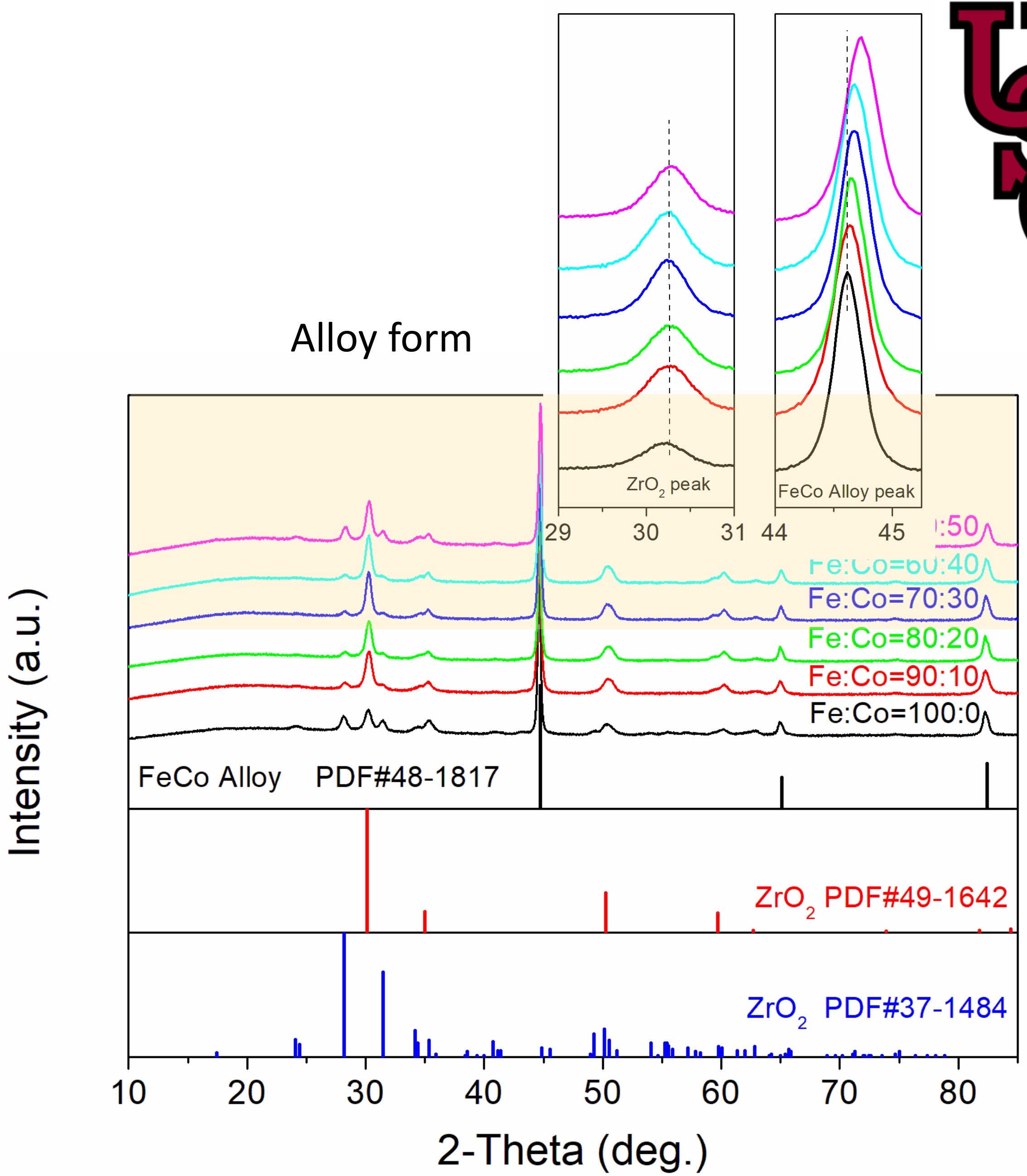


Segmented Bed Design

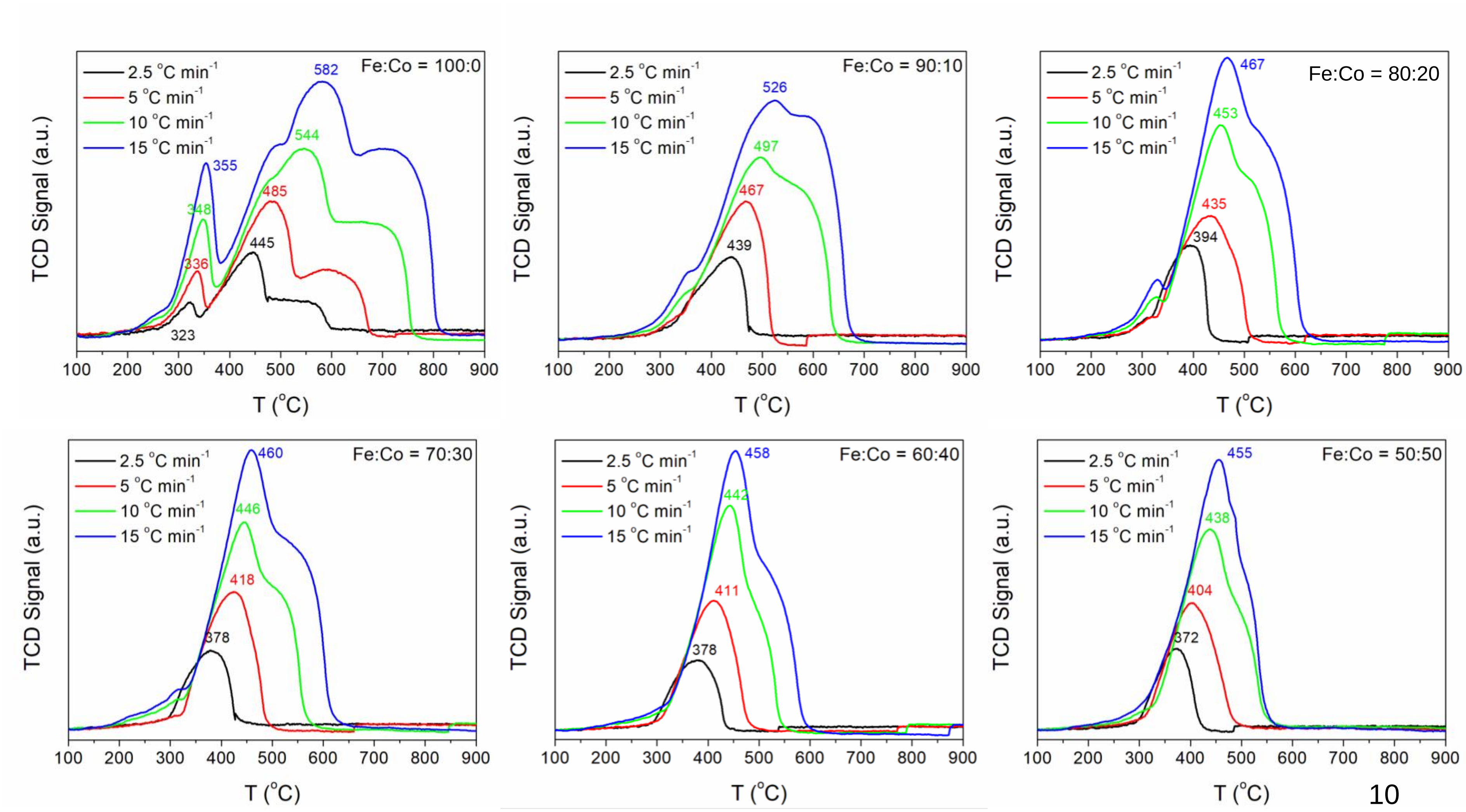


$FeCoO_x$-ZrO_2 Phases





TPR @ Different Ramping Rates



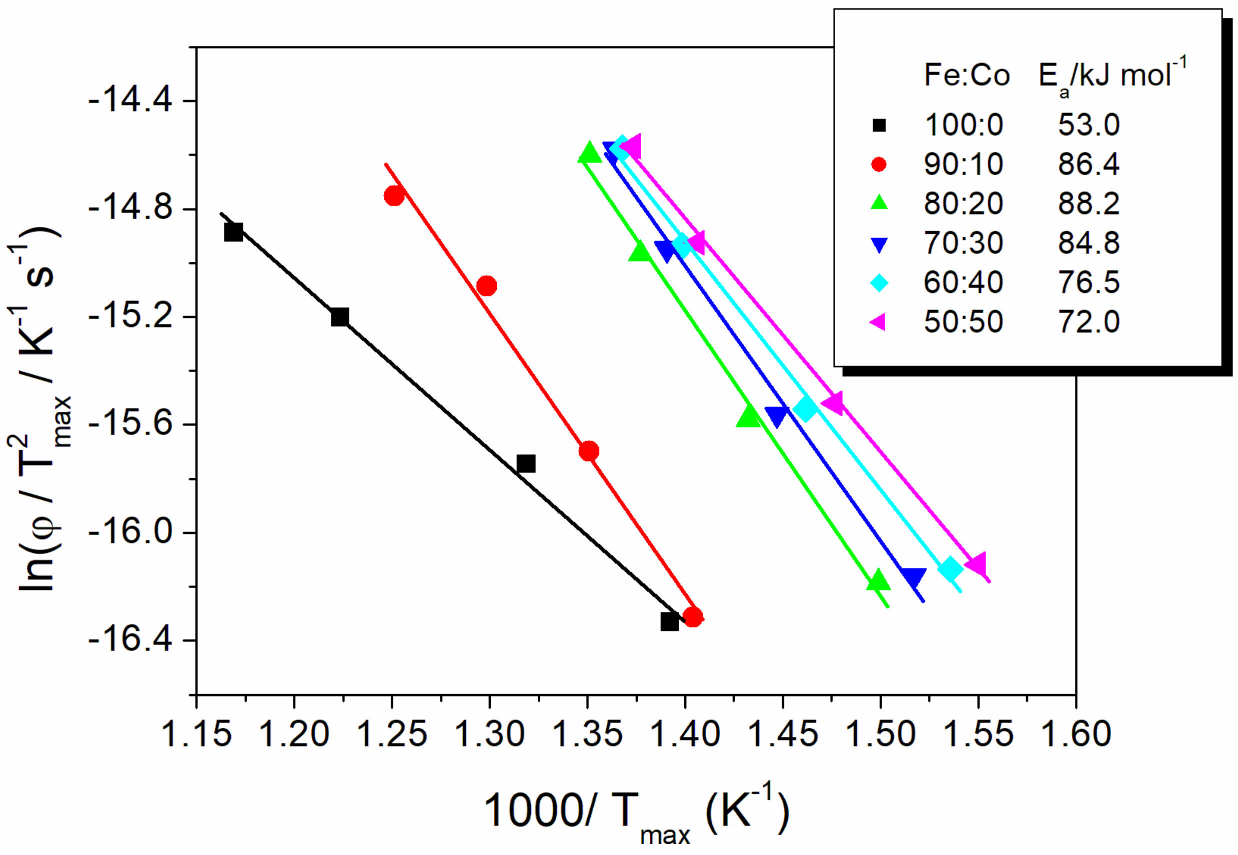
Studying $FeCoO_x$ Reduction Kinetics by TPR

$$\ln\left(\frac{\varphi}{T_m^2}\right) = -\frac{E}{RT_m} - \ln\left(\frac{E}{AR}\right) + C$$

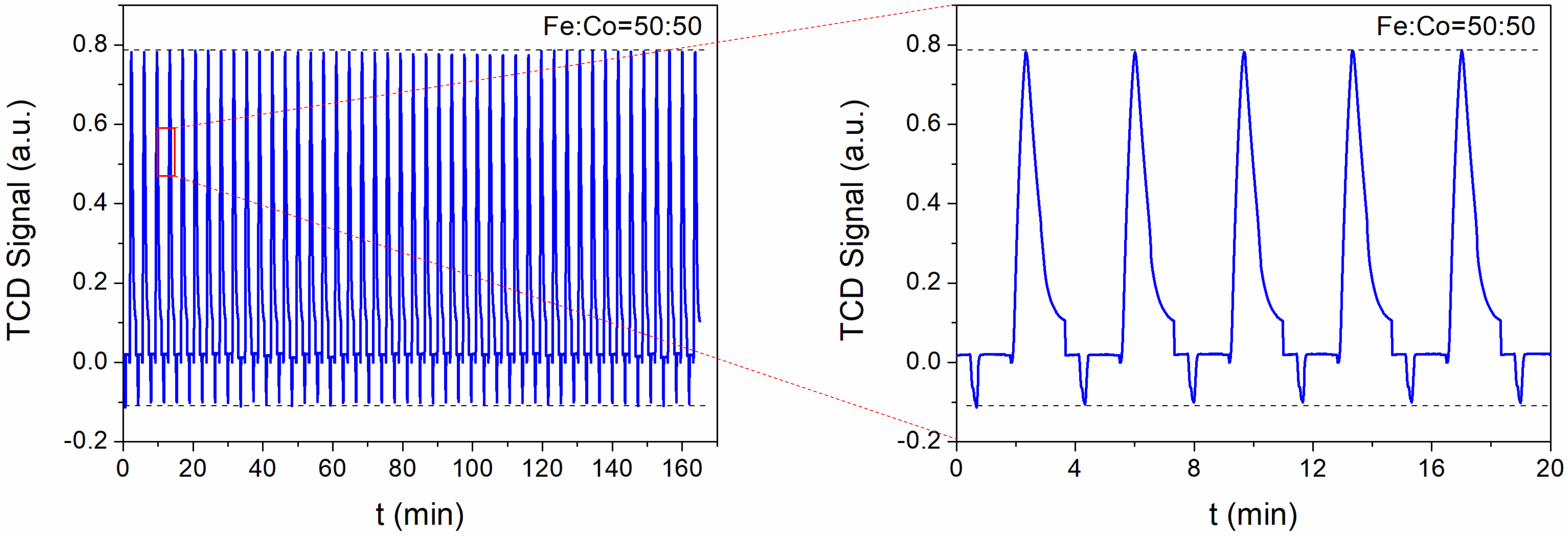
$$A = \frac{-E}{RT_m^2} \times \frac{\varphi e^{E/RT_m}}{d\left(\frac{df(\alpha)}{d\alpha}\right)_{T=T_m}}$$

$$f(\alpha) = k(T)t = [1-(1-\alpha)^{1/3}]^2$$

$$k(T) = Ae^{-E/RT}$$



TPO/TPR Alternate 50 Cycles



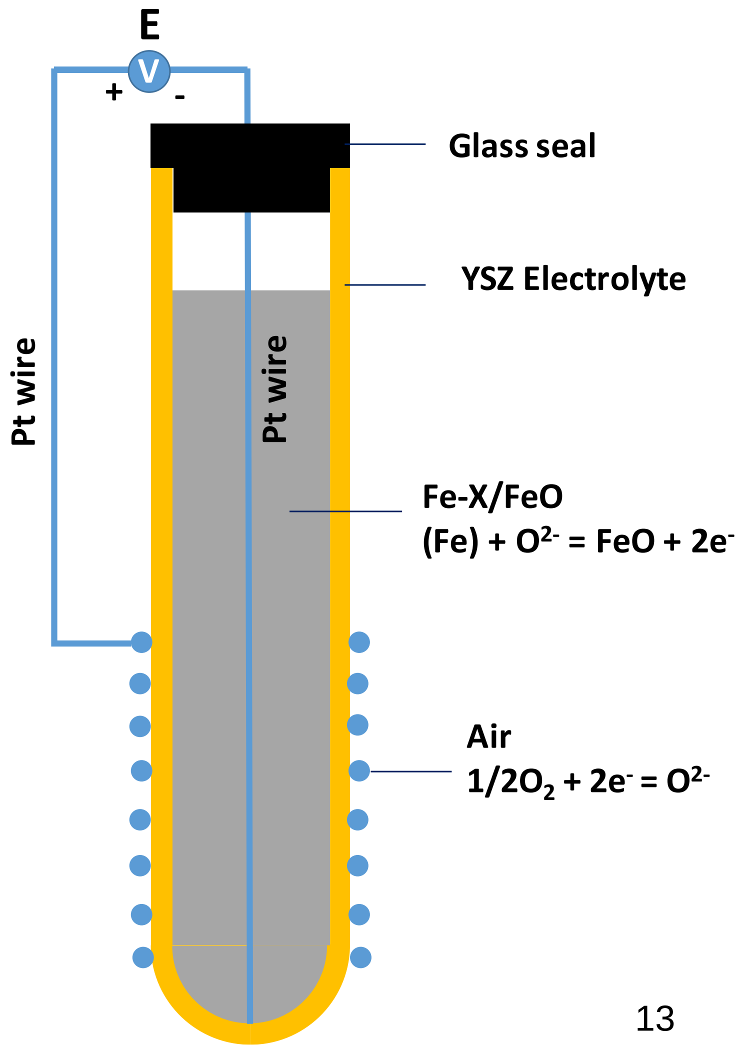
Oxygen Concentration Cells: Measuring a_{Fe}

$$(Fe) + \frac{1}{2}O_2 = FeO$$

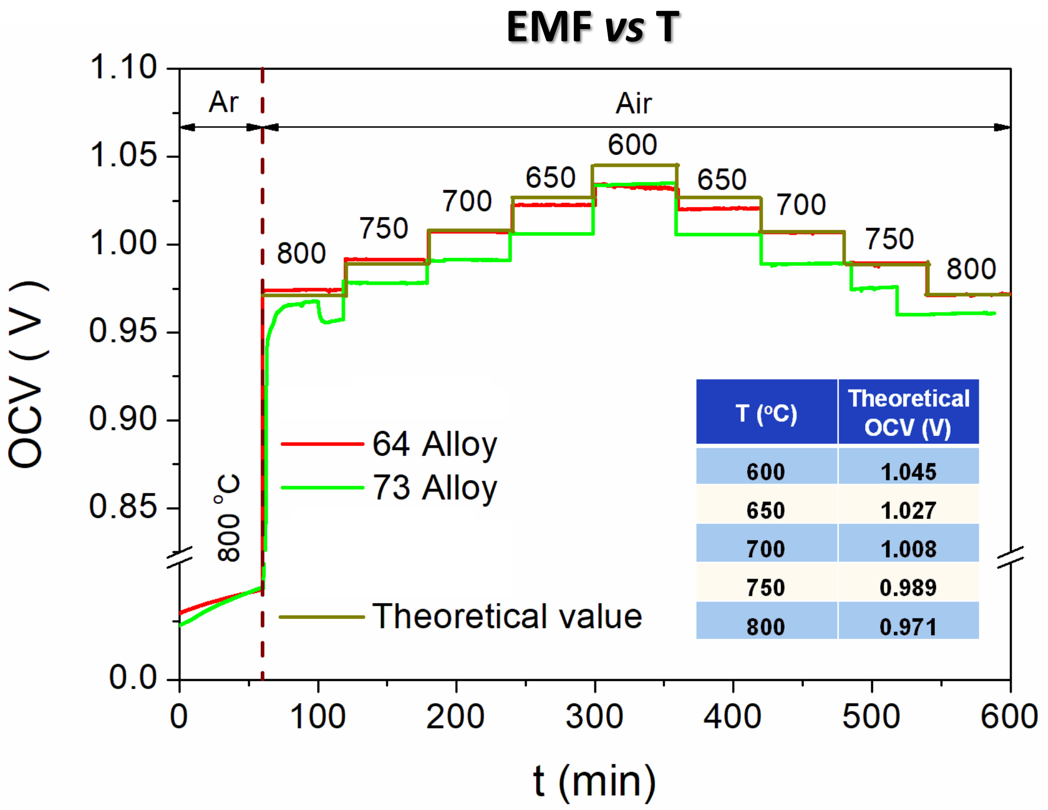
$$P_{O_2} = 0.21exp\left(-\frac{4EF}{RT}\right)$$

$$a_{Fe} = \frac{1}{KP_{O_2}^{1/2}}$$

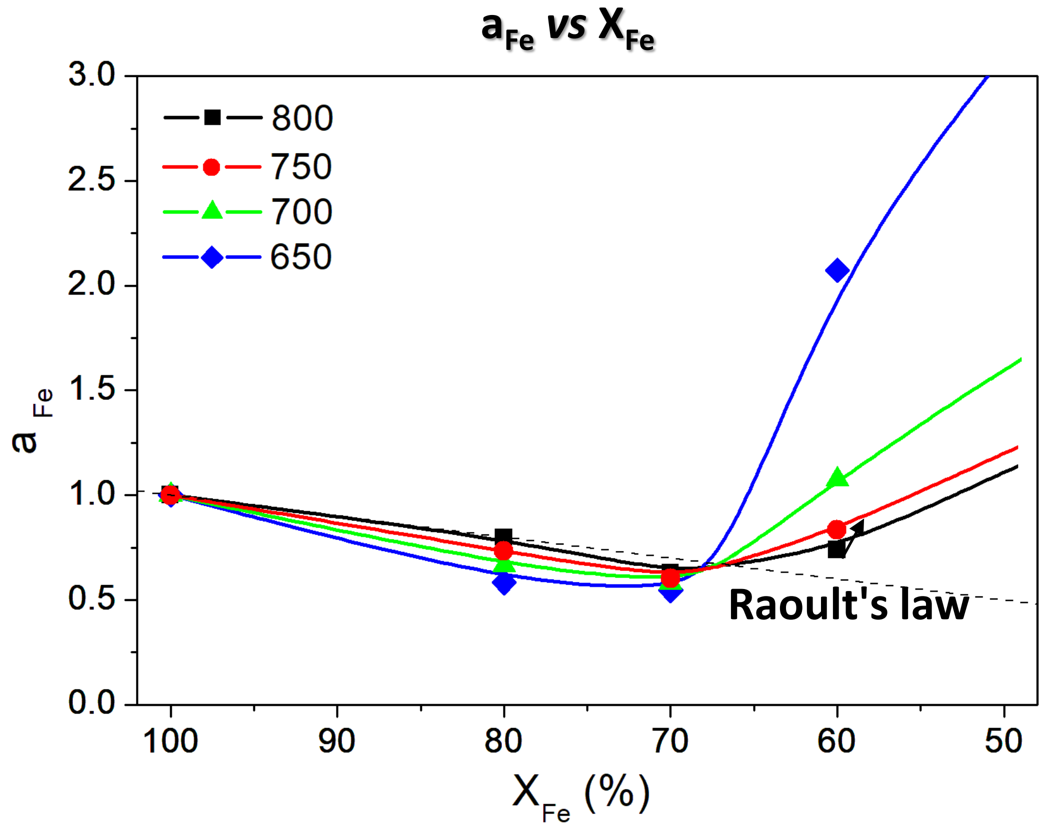
$$-RTlnK = \Delta G^0$$



Fe-Activity in Fe-Co Alloys



T (°C)	Theoretical OCV (V)
600	1.045
650	1.027
700	1.008
750	0.989
800	0.971



Conclusions

- Fe_2O_3:ZrO_2 molar ratio can be increased to 9:1
- Adding Co into Fe makes Fe(Co)O_x reduction easier
- It is also confirmed for Fe-Co alloys that $a_{Fe} < 1$ at $X_{Co} < 0.4$, above which $a_{Fe} > 1$ below 700 ^oC

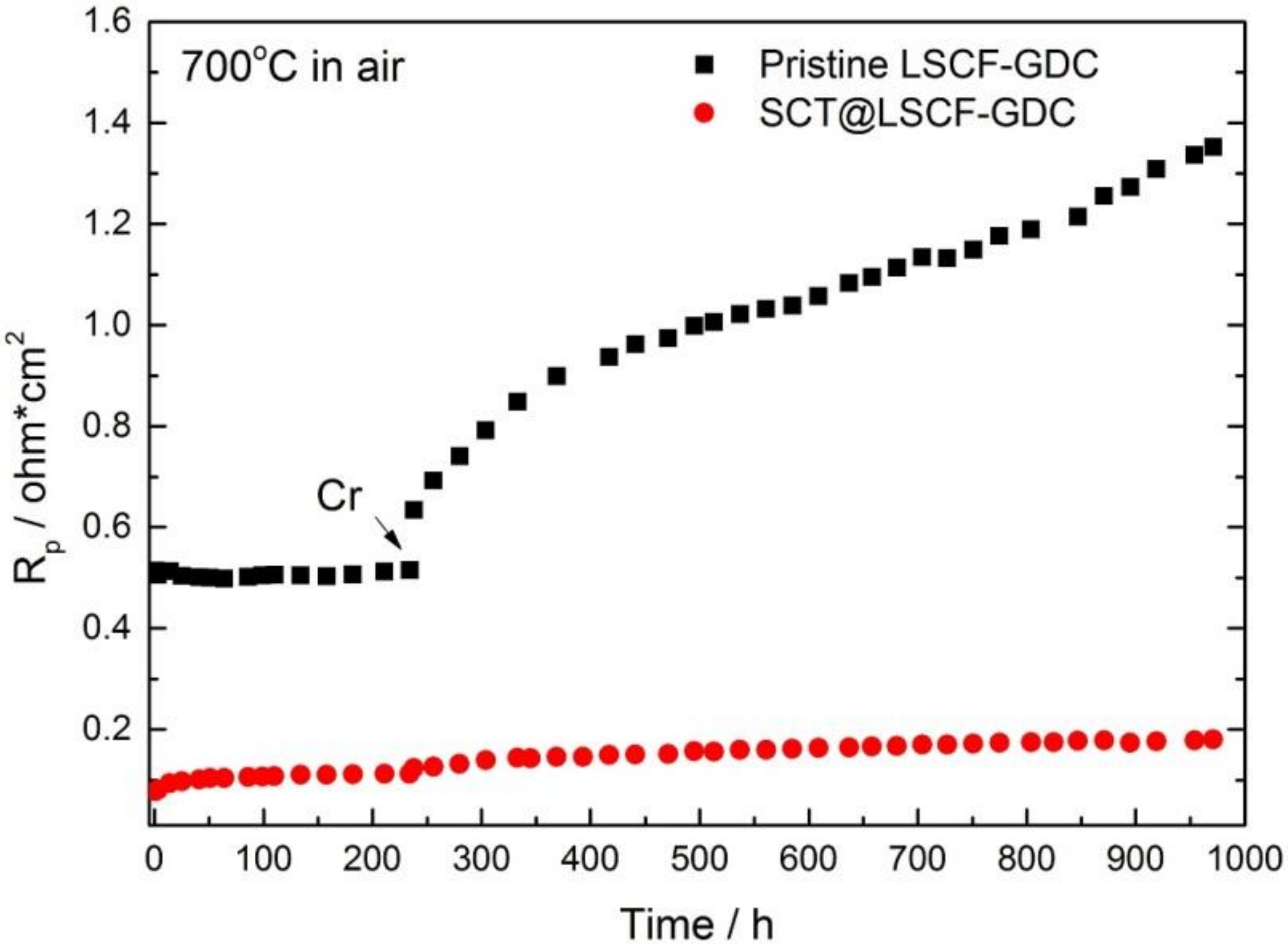
Next Steps

- Finishing EMF study for all Fe-Co alloys
- Expanding EMF study to Fe-Ni alloys
- Down selecting Fe-X compositions for pilot-scale testing at Atrex

Acknowledgement

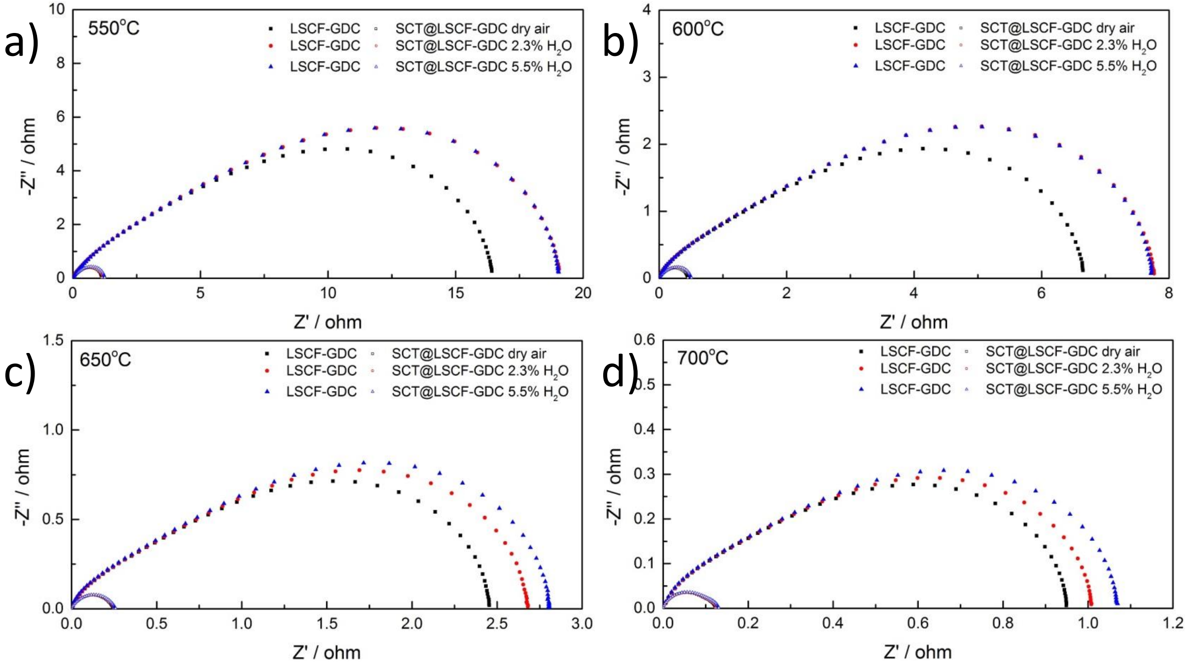
- DOE NETL for supporting this work under award DE-FE-0031671
- Dr. Diane Madden is the project manager and Dr. Shailesh Vora is the program director

A New Isostructural Bilayer Cathode Tolerant to Cr



A New Isostructural Bilayer Cathode Tolerant to H_2O and CO_2

H_2O Effect



CO_2 Effect