

A Bifunctional Ceramic Fuel Cell Energy System (Progress Report 2016-2017)

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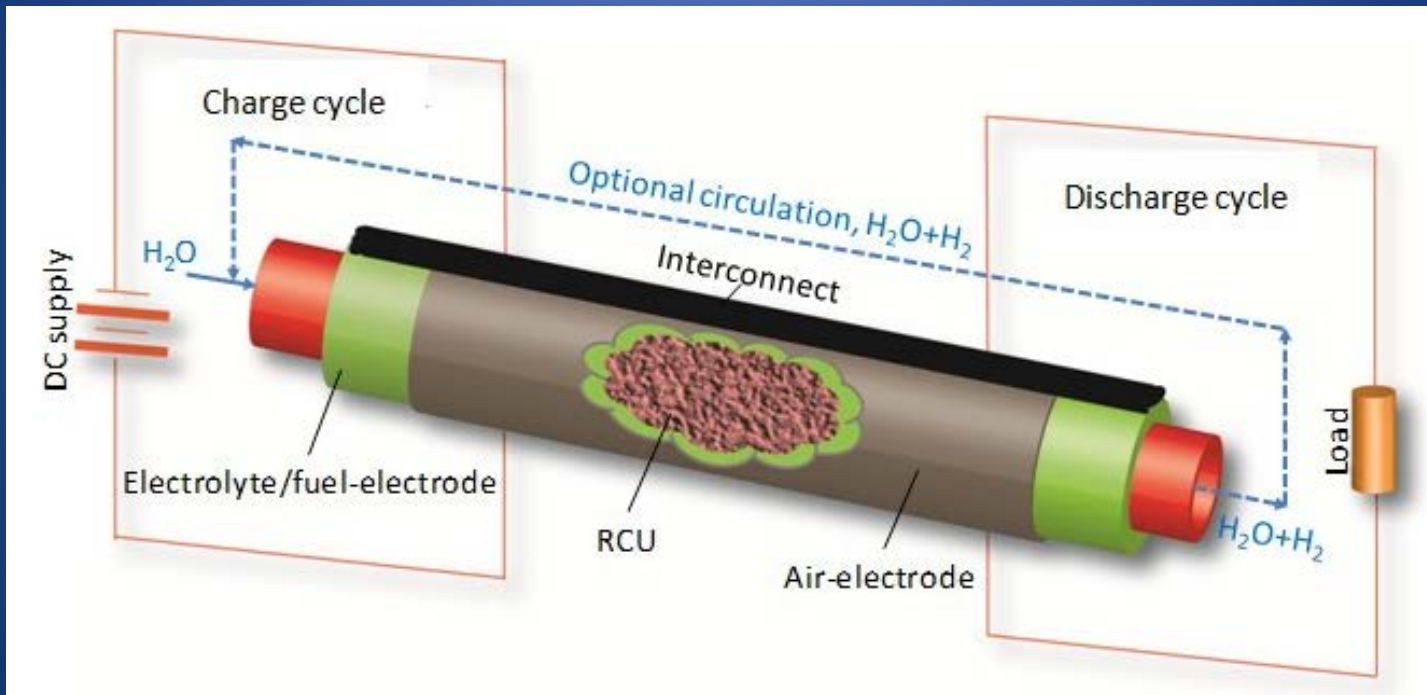
Columbia, SC29201



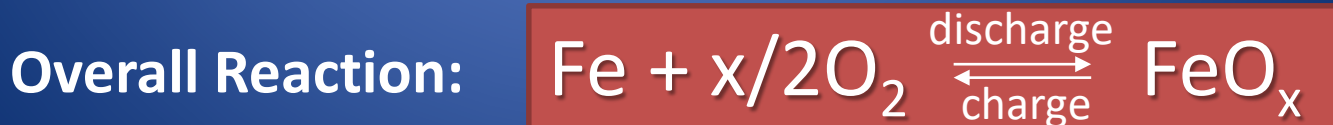
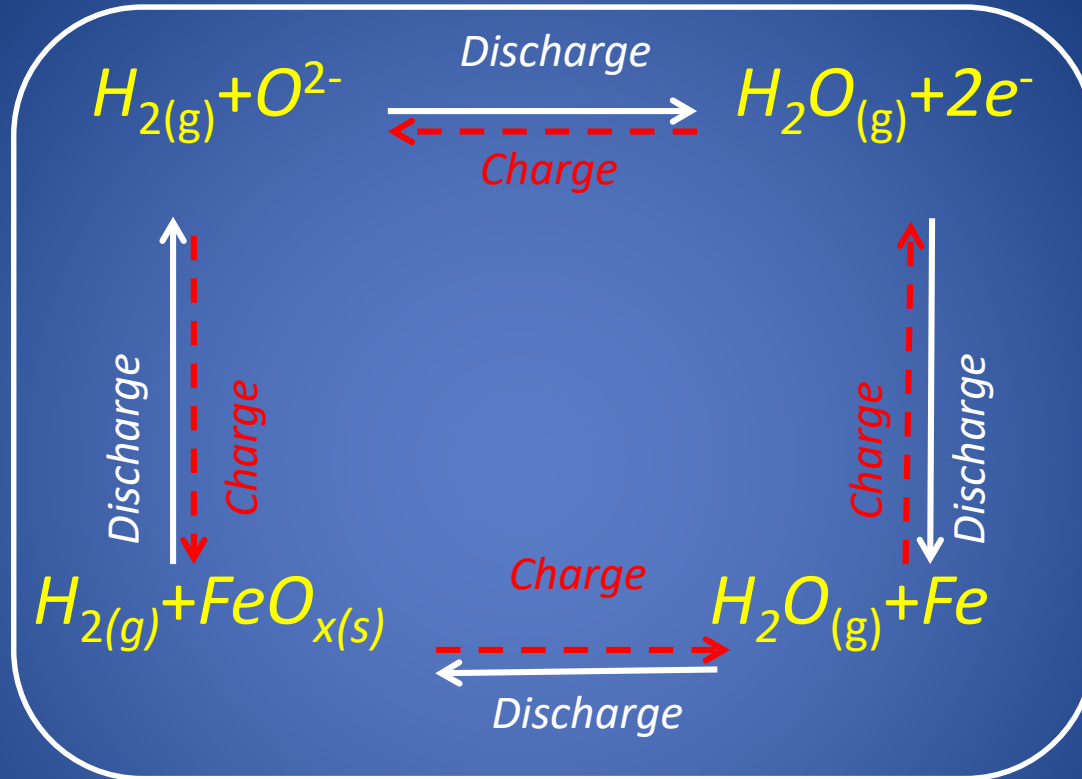
Outline

- The bifunctional ceramic fuel cell system
- Recent progress in IT-SOIARB development
 - Button cell (500°C)
 - Pilot cell (650°C)
- Recent progress in IT-cathode development
- Conclusions
- Acknowledgement

The Bifunctional SOFC

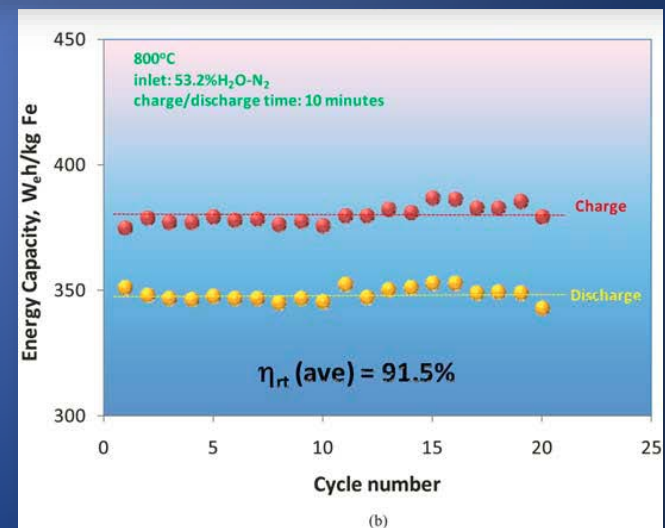
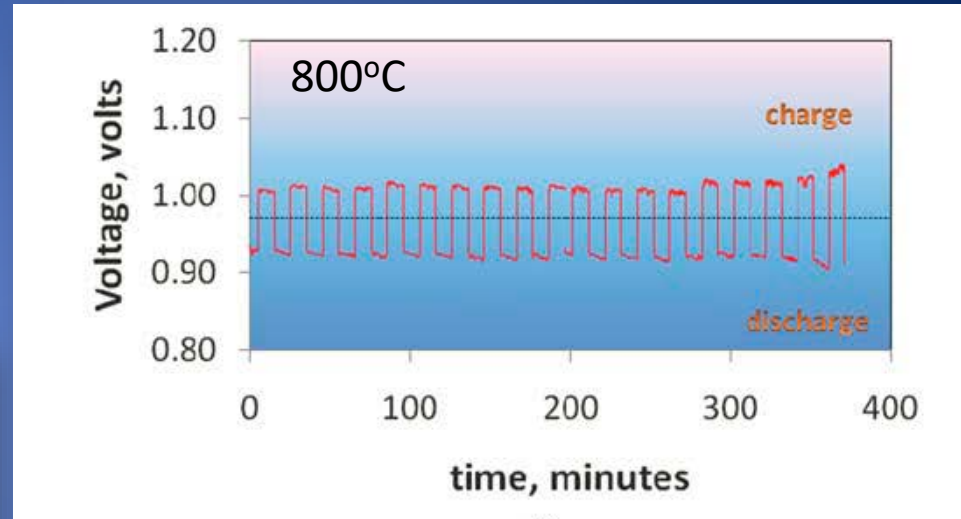
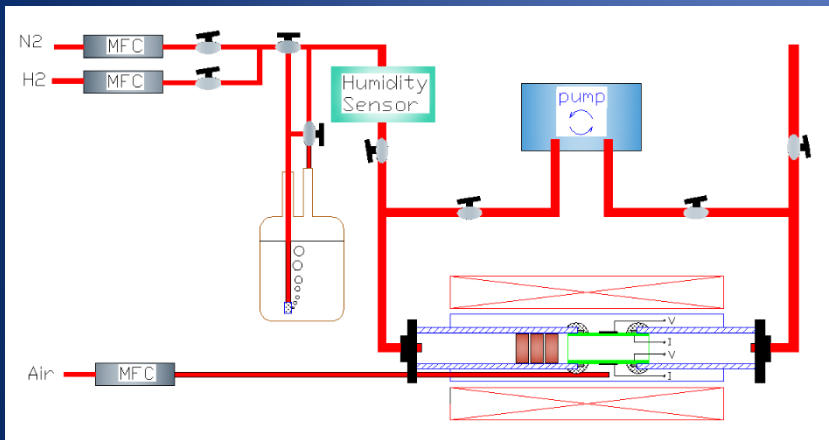


The Chemistry



Solid Oxide Iron Air Redox Battery (SOIARB)

A SOFC with Energy Storage Functionality



Recent Progress in IT-SOIARB Development

Battery Materials for 500°C-SOIARB (Button Cell)

- **RSOFC:**

- Electrolyte: 30 μ m Sc-ZrO₂
- Cathode: 20 μ m LSM+BYC
- Anode: 500 μ m Sc-ZrO₂+Ni

- **Oxygen shuttle gas:**

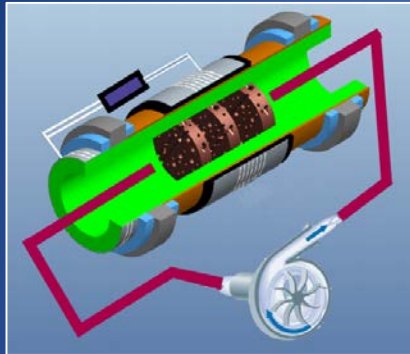
- 80%H₂-20%H₂O for 500°C
- 65%H₂-35%H₂O for 800°C

- **RCU:**

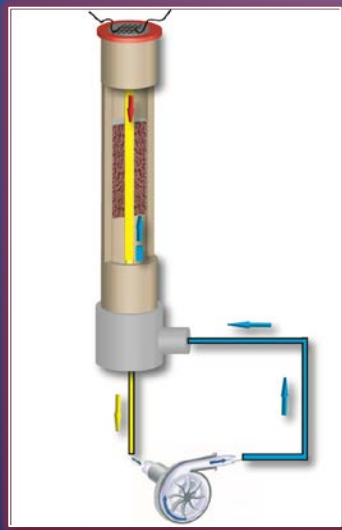
- Fe-Fe₃O₄ for <600 °C
- Fe-FeO for \geq 600 °C

Button Battery Cell Testing Apparatus

Tubular



Planar

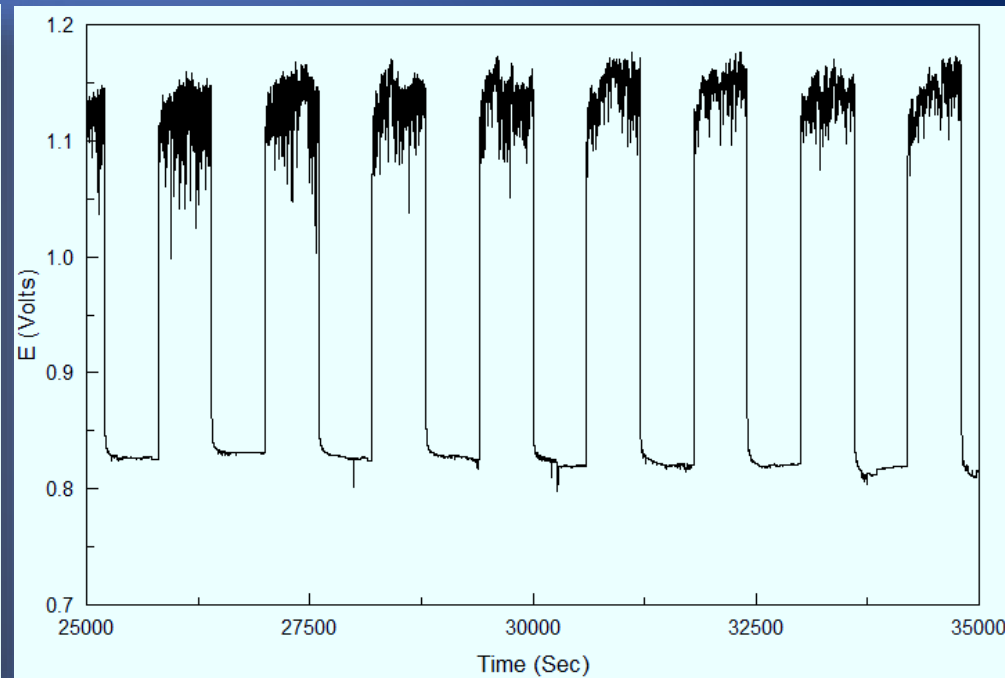
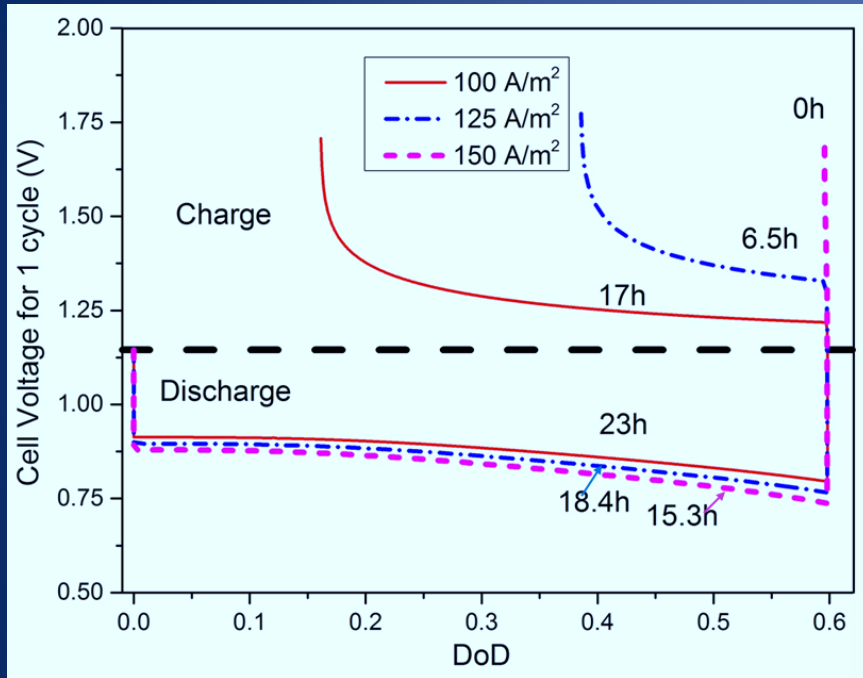


Solartron 1470E 8-channel Potentiostat/Galvanostat



Simplified planar

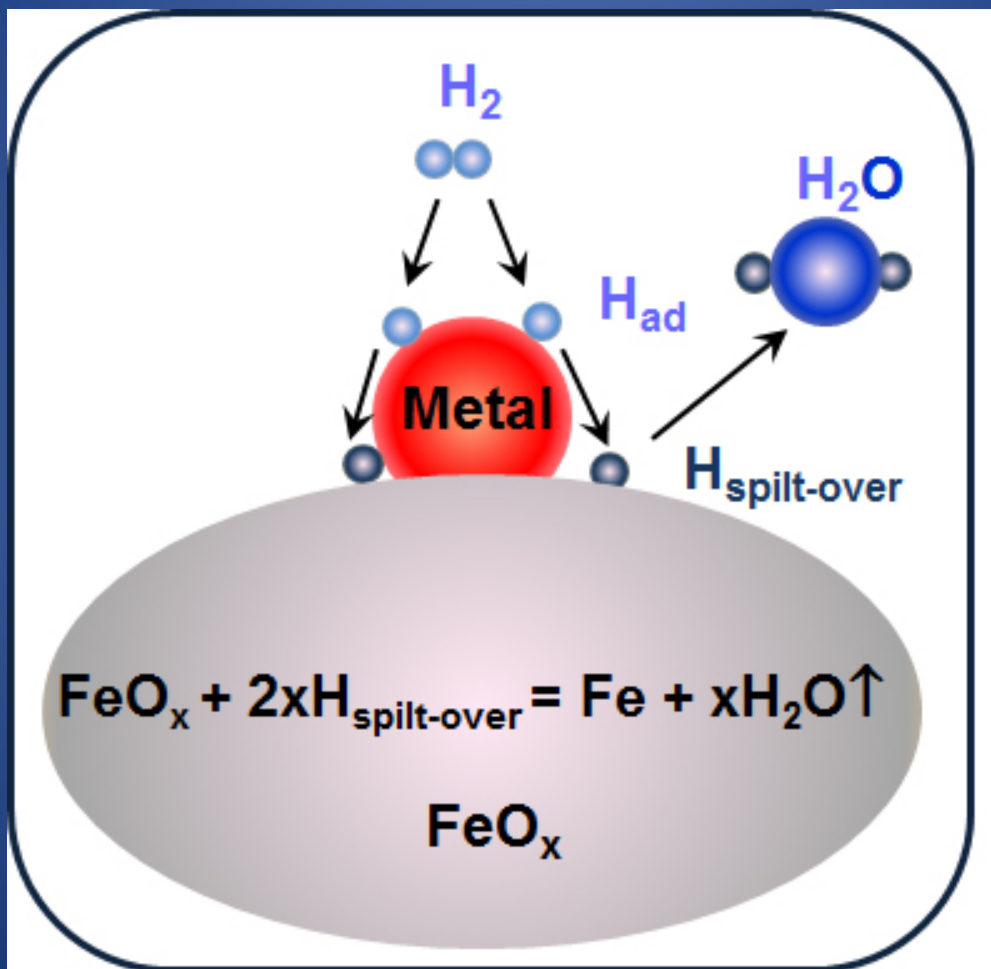
Kinetic Issues at IT Range



Jin and Huang et al, *Journal of Power Sources*, Vol. 280 (2015), 195-204

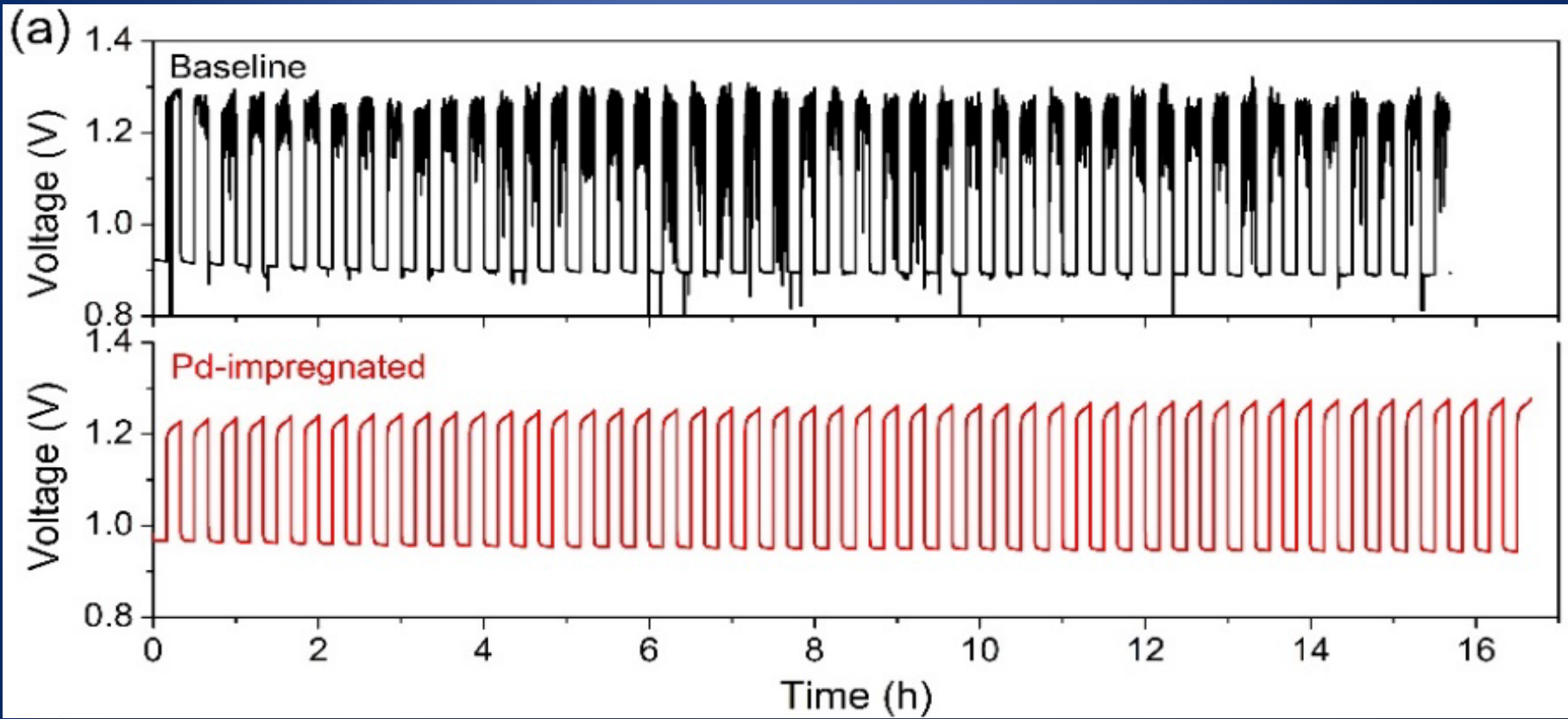
500 °C, $J=10 \text{ mA/cm}^2$, $t=10 \text{ minute}$,
 $C/5.5$, $U_{\text{Fe}}=3.1\%$

Pd as a Catalyst to Boost Rechargeability

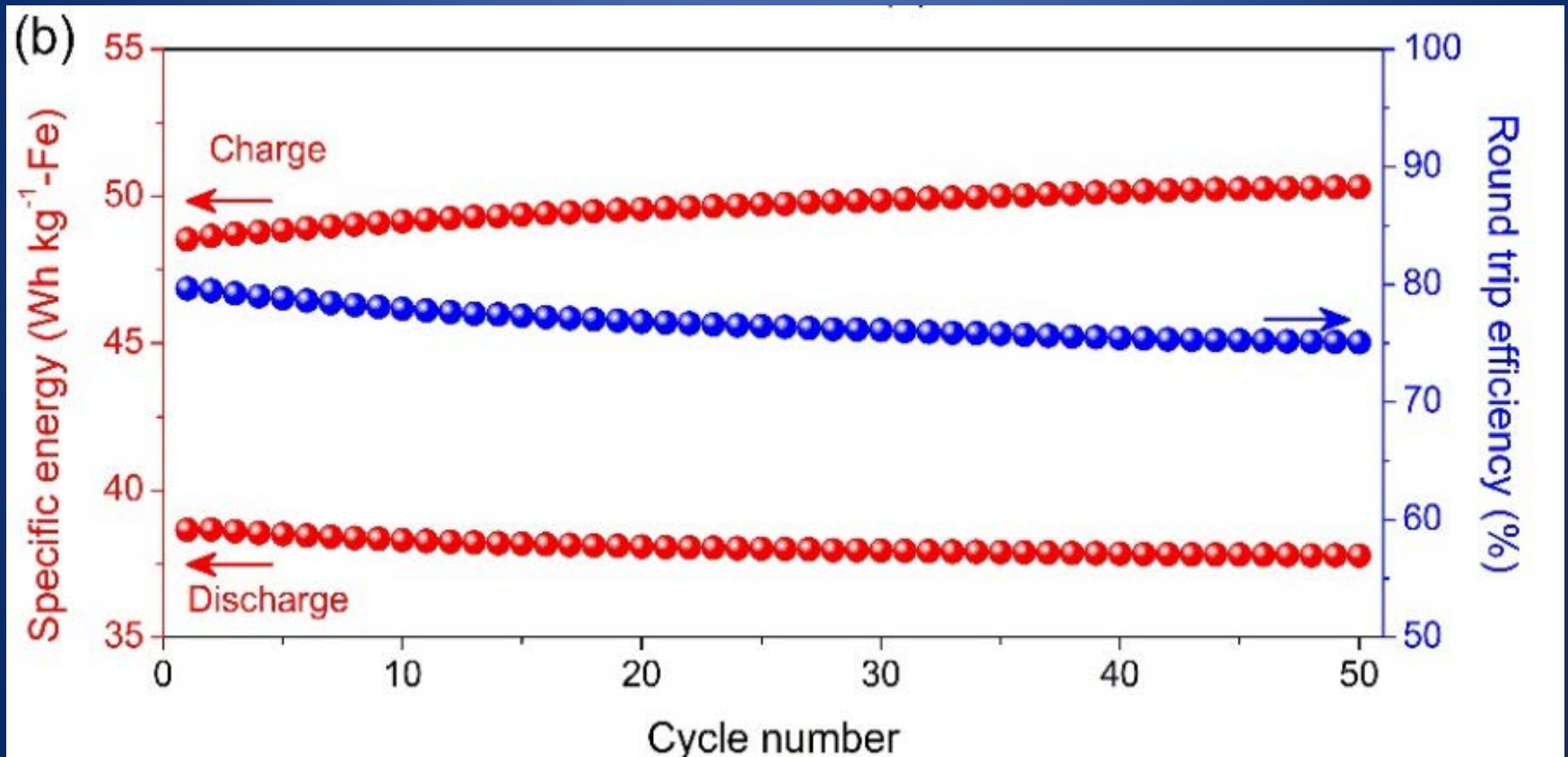


Cycleability Comparison

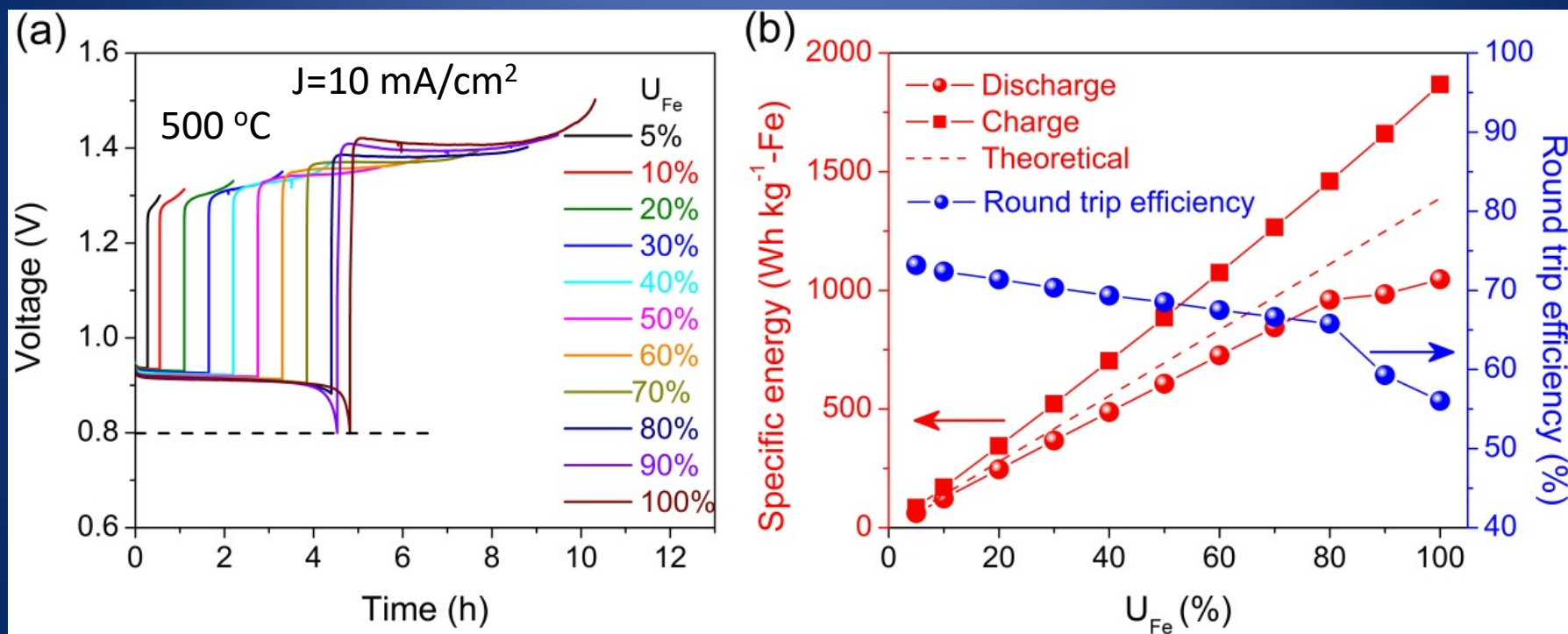
500 °C, $J=10 \text{ mA/cm}^2$, $t=10 \text{ minute}$, $C/5.5$, $U_{\text{Fe}}=3.1\%$



Capacity and Efficiency

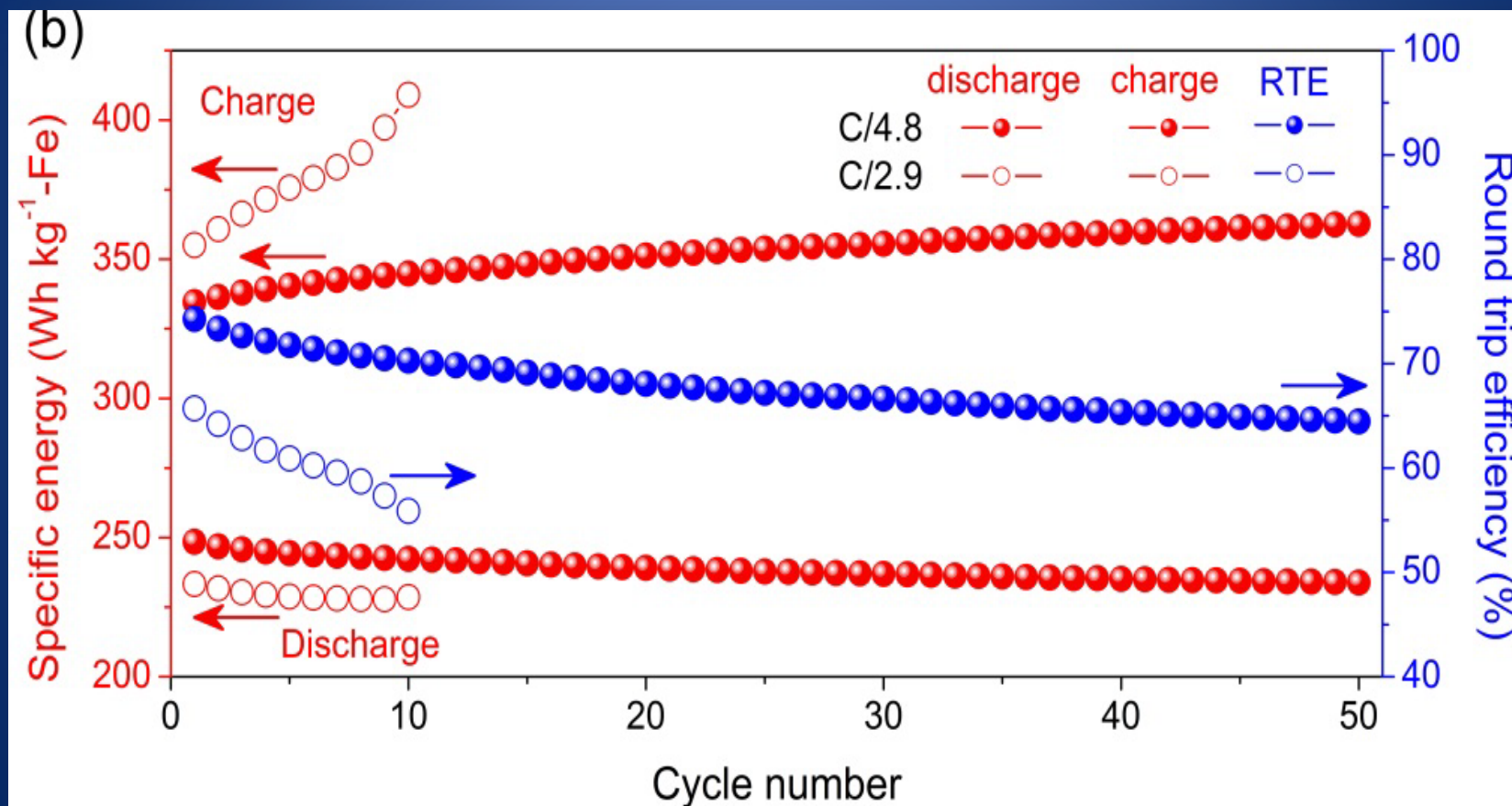


Fe-utilization vs Capacity and Efficiency



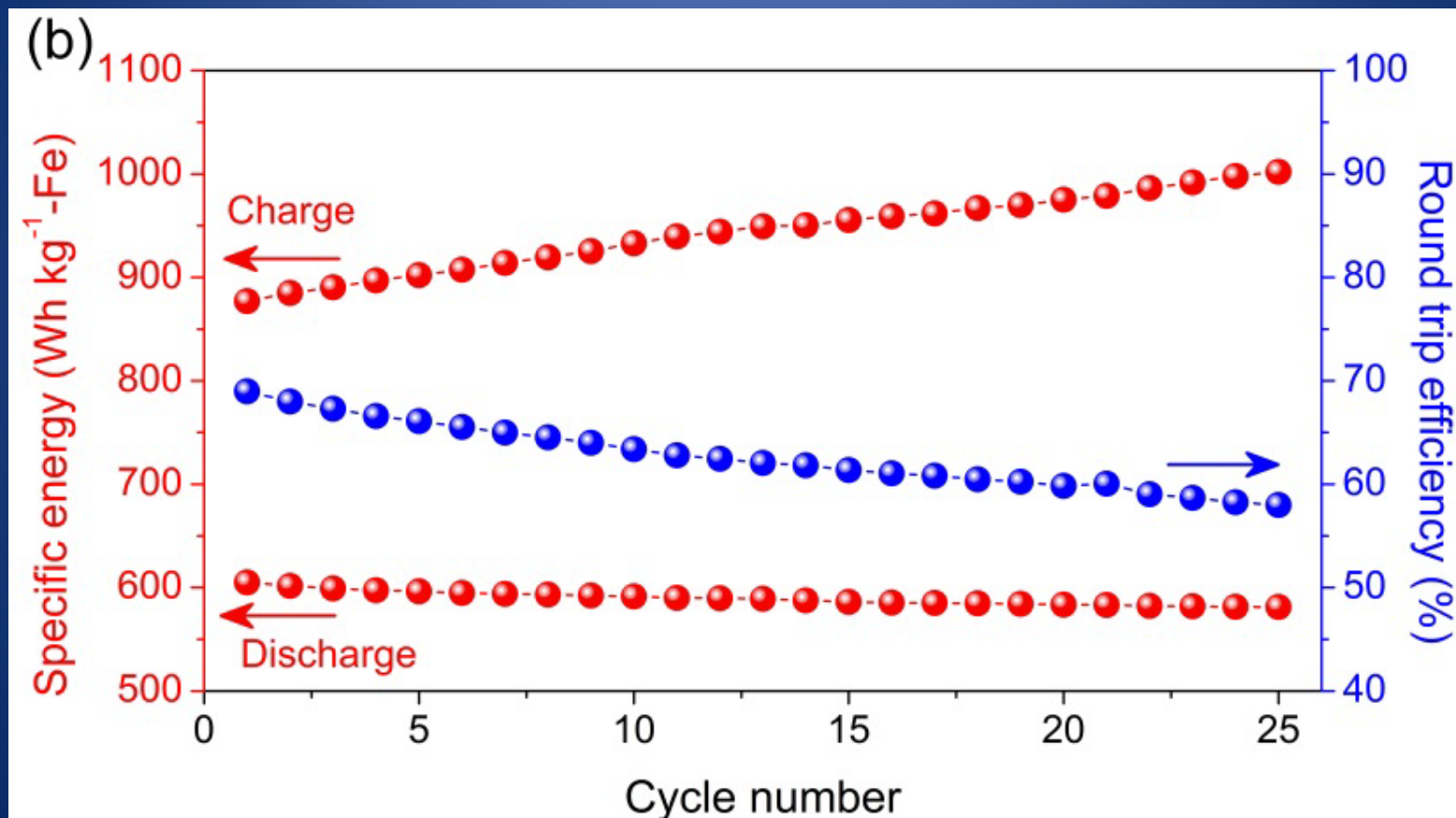
C-rate vs Capacity and Efficiency

500 °C, C/4.8=11 mA/cm² for 1 hr cycle, C/2.9=18.5 mA/cm² for 0.6 h, U_{Fe}=21%



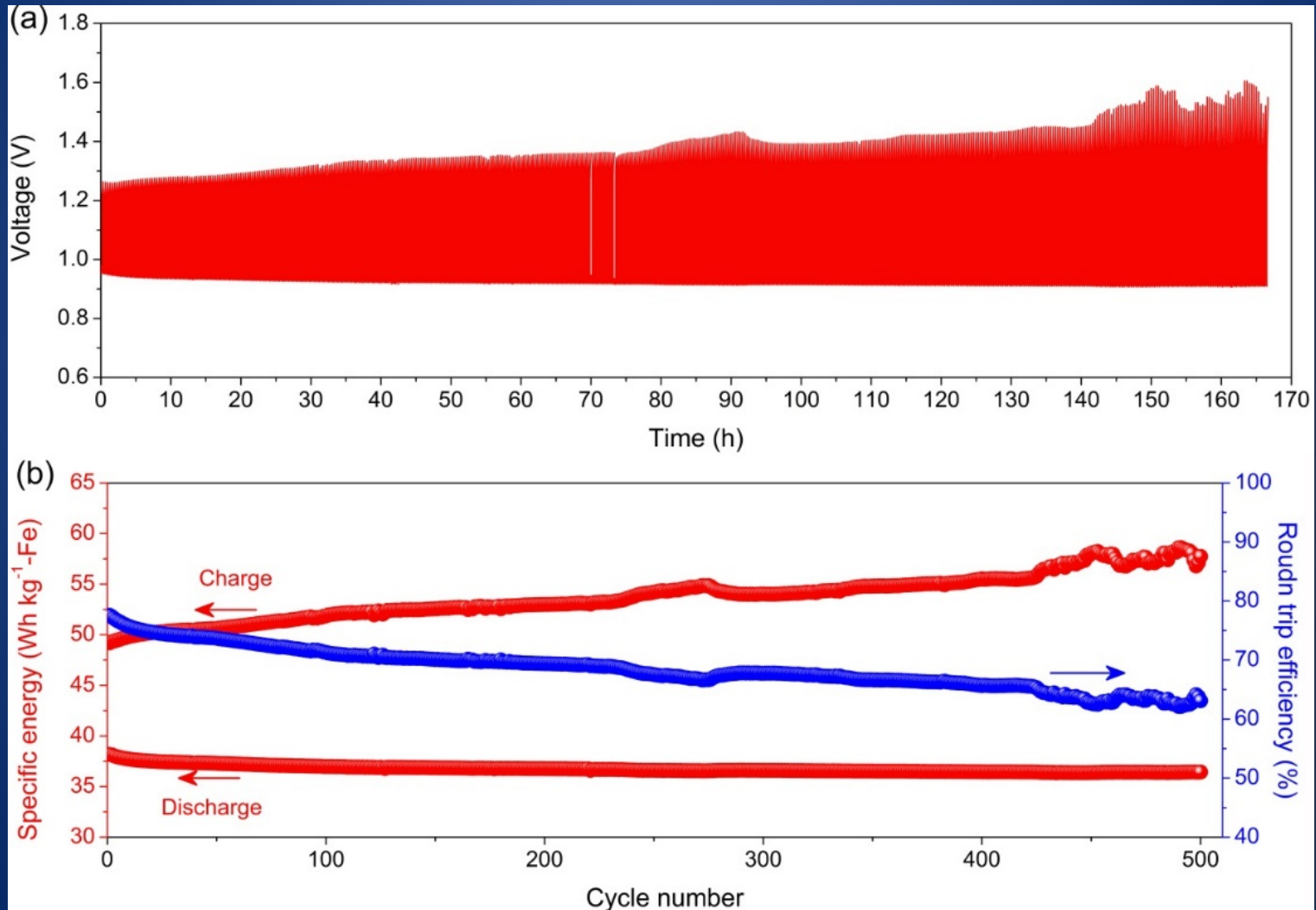
Combined U_{Fe} and C-rate Effect

500 °C, $J=10 \text{ mA/cm}^2$, $t= 2.65 \text{ h}$, $U_{Fe}=50\%$

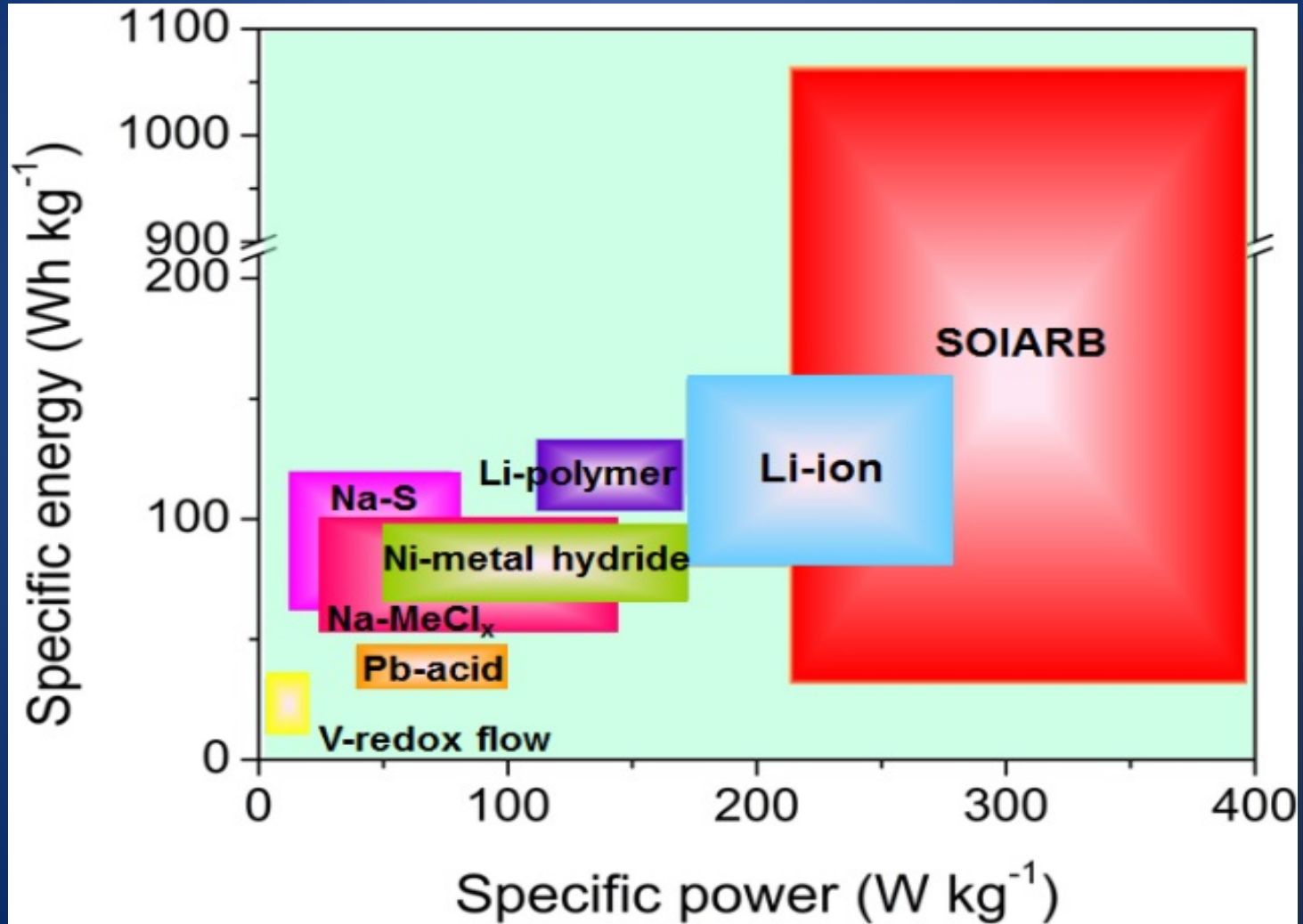


Durability Test

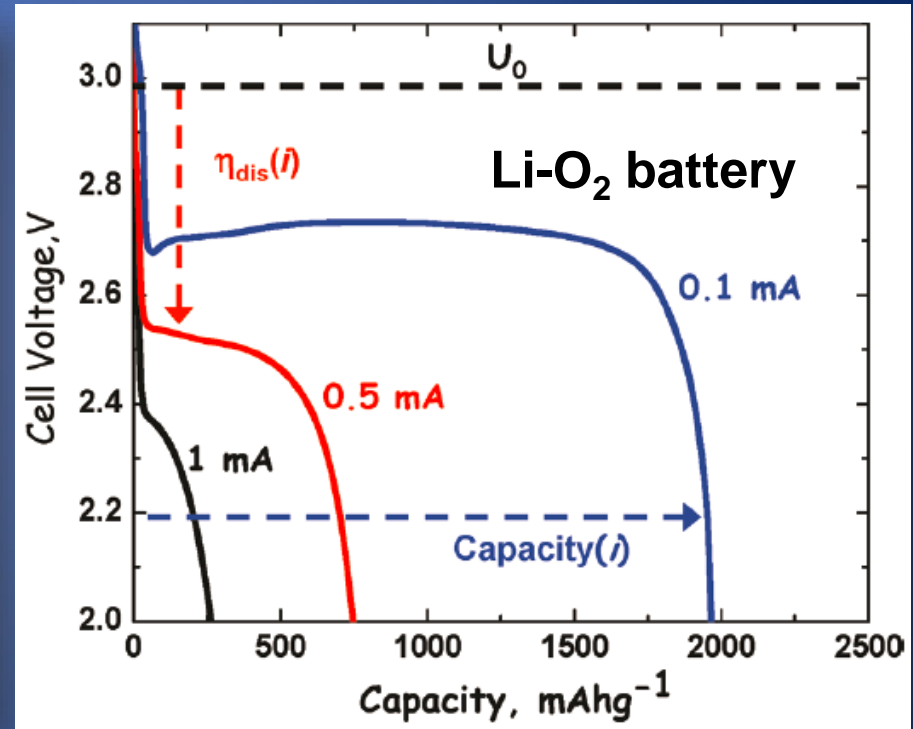
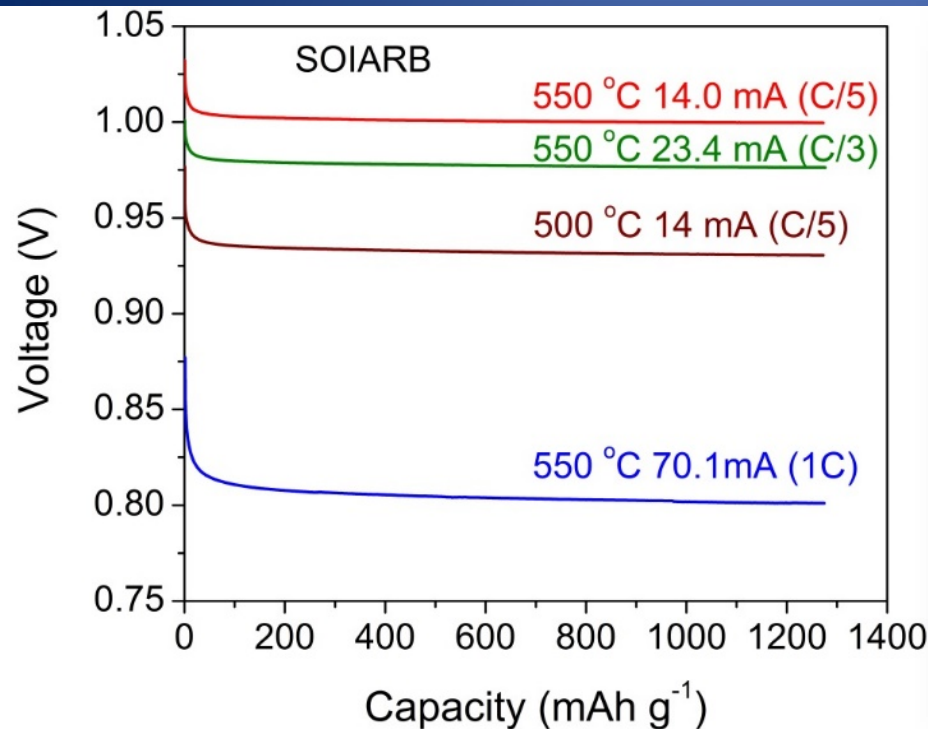
$J=10 \text{ mA/cm}^2$, $C/5.5$, $U_{\text{Fe}}=3.1\%$, 500°C ,



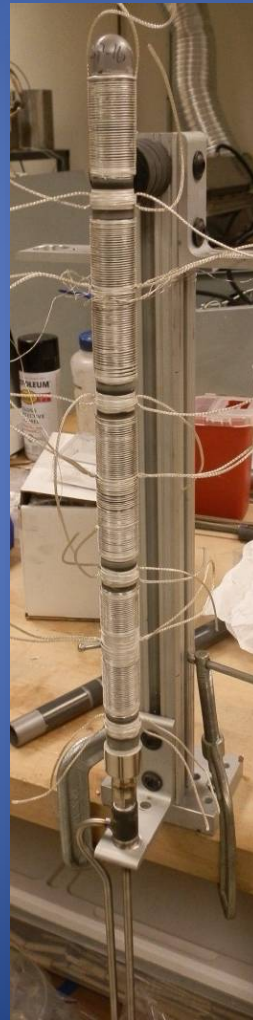
Ragone Plot



Comparison with Other Metal-Air Batteries



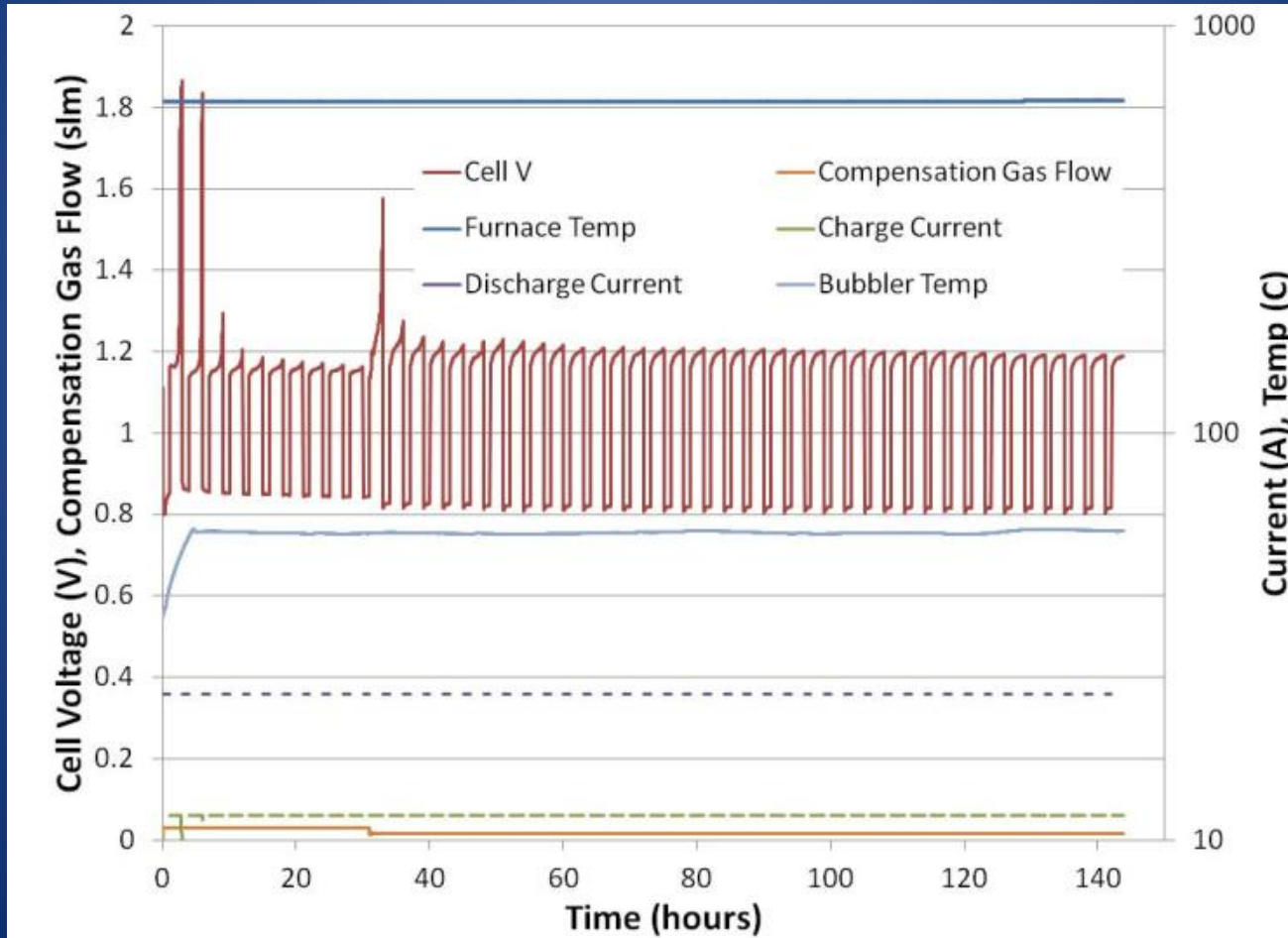
Pilot Scale Battery Testing at Atrex



Atrex Anode Supported
Tubular SOFC

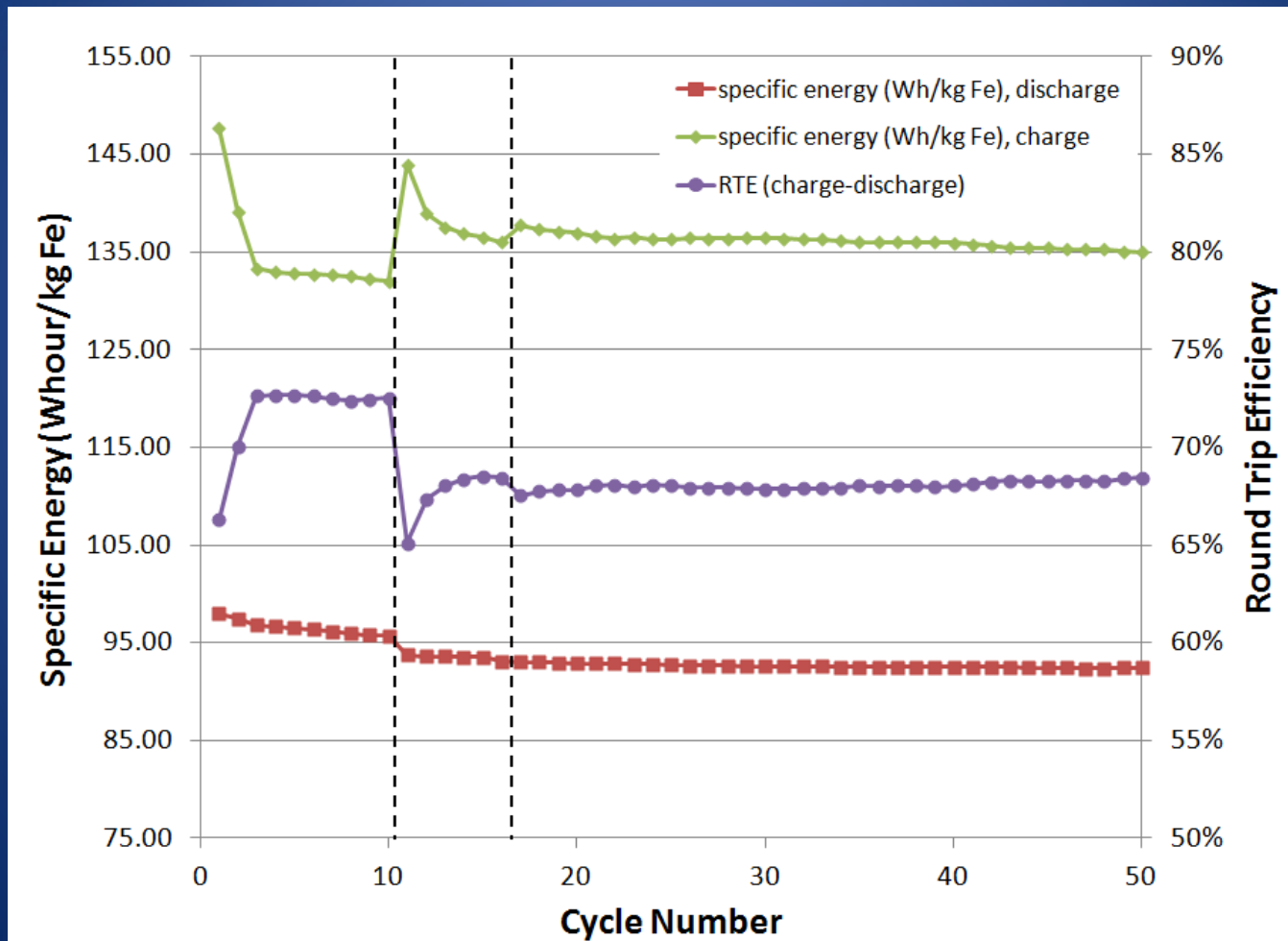
Pilot Battery Cycleability Testing

Discharge current: 23A (100 mA/cm²); charge current: 11.5A, Fe utilization: 12%; C/8

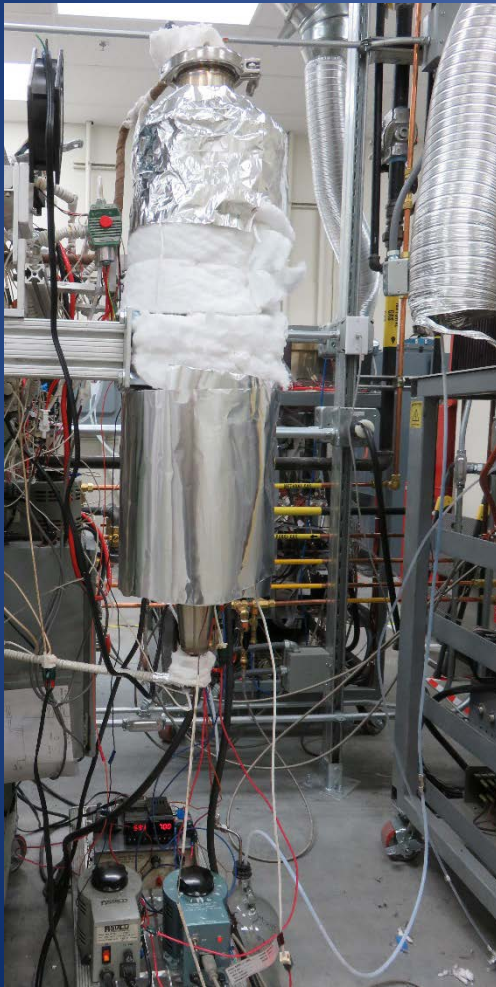


Pilot Battery Capacity and Efficiency

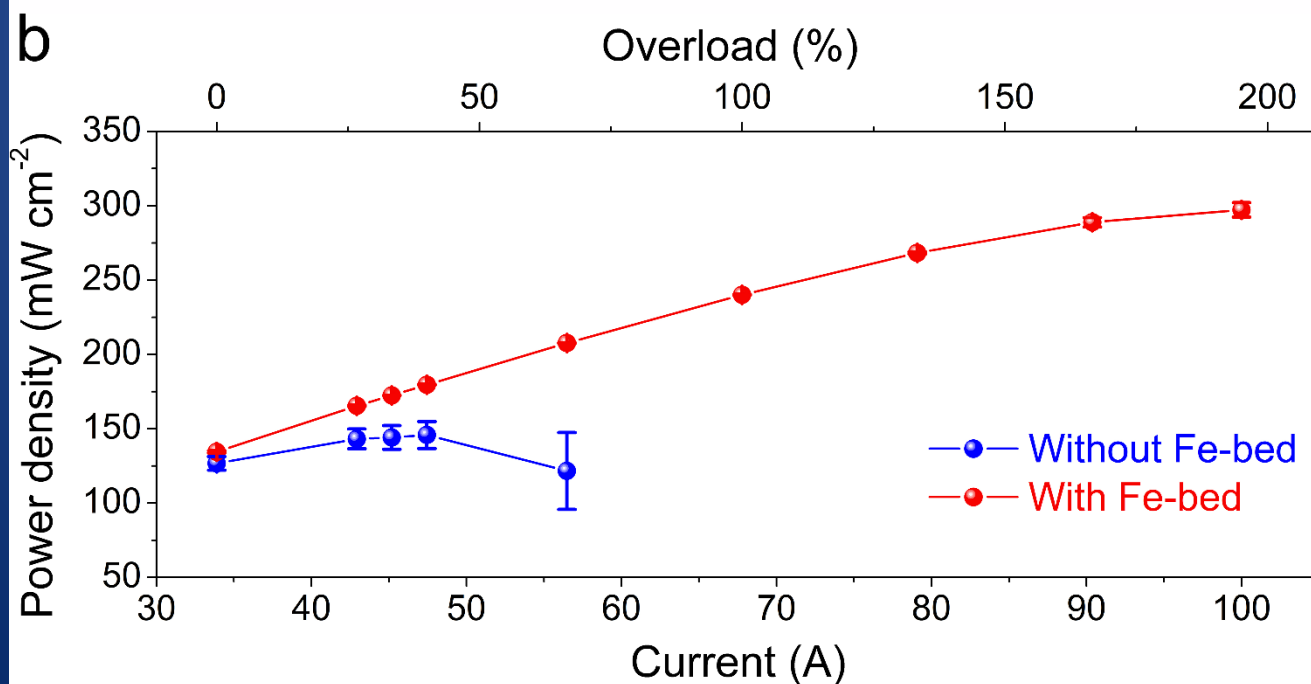
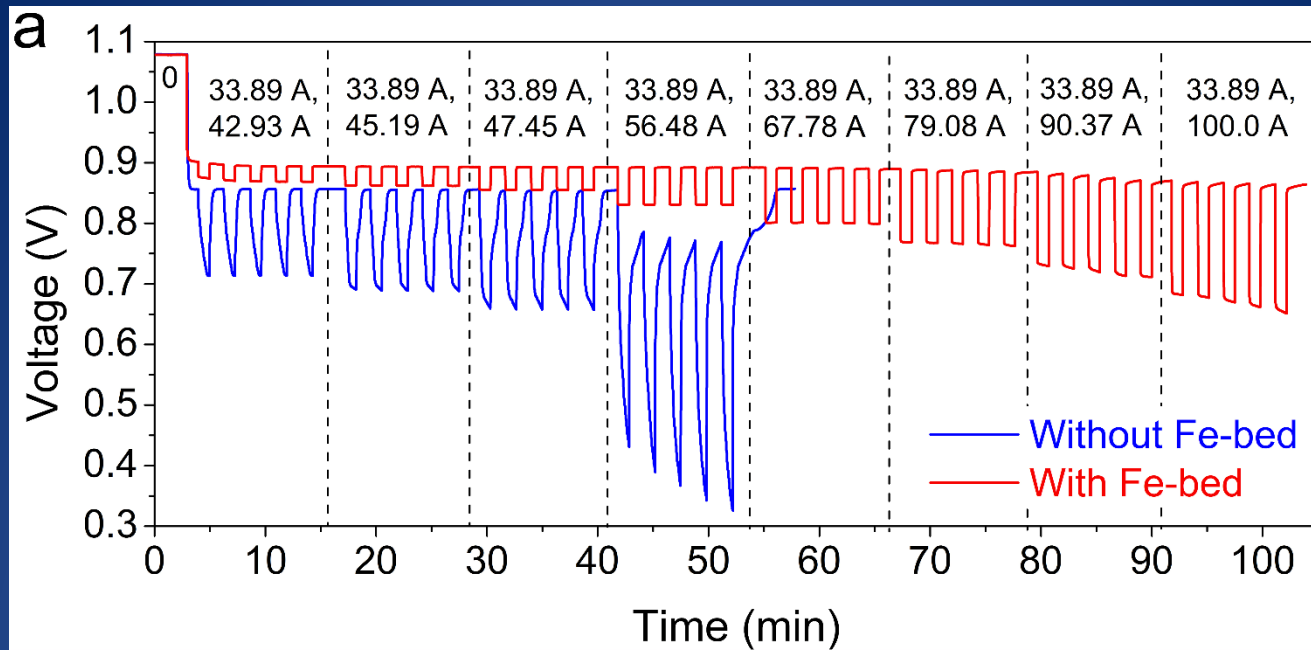
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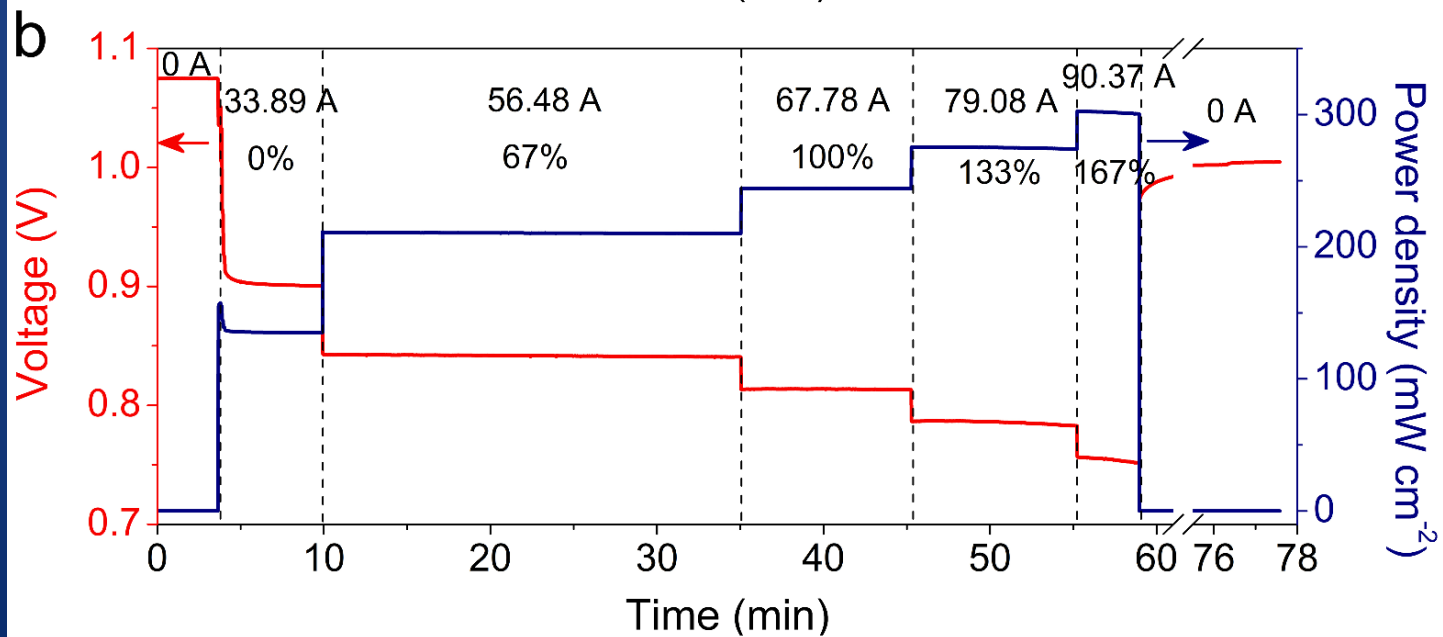
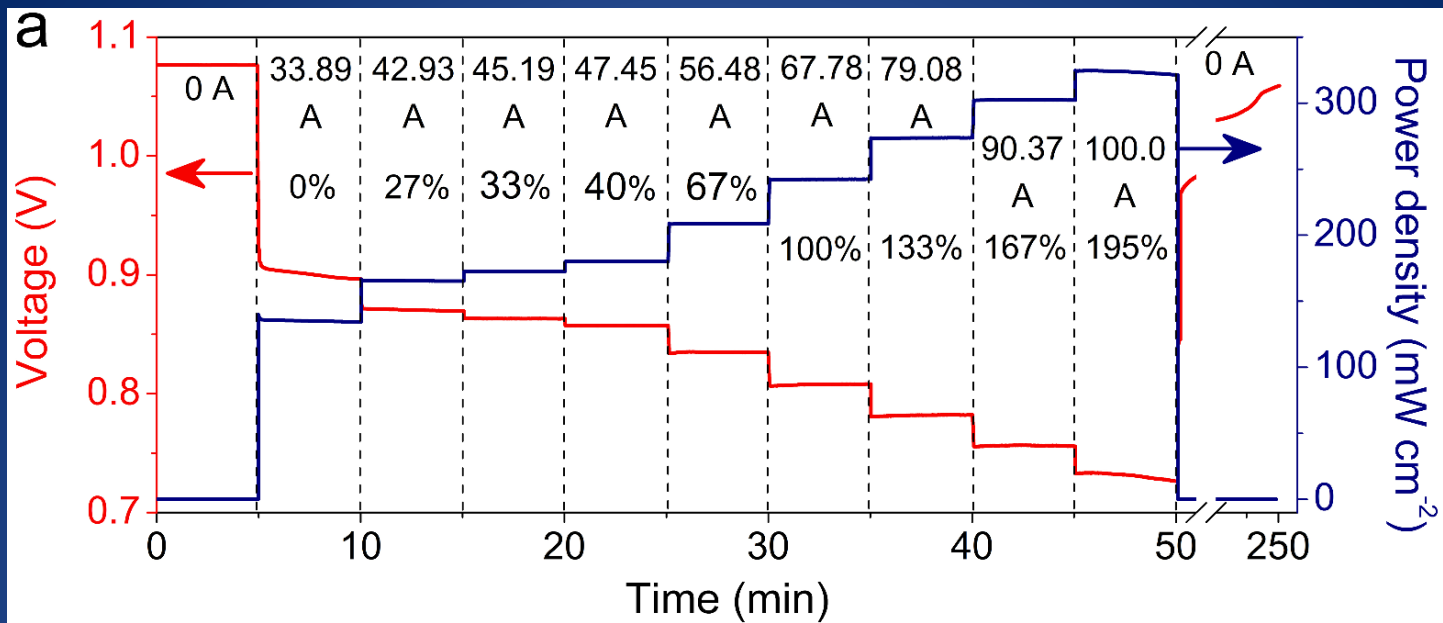


Separate Fe-bed Design at Atrex

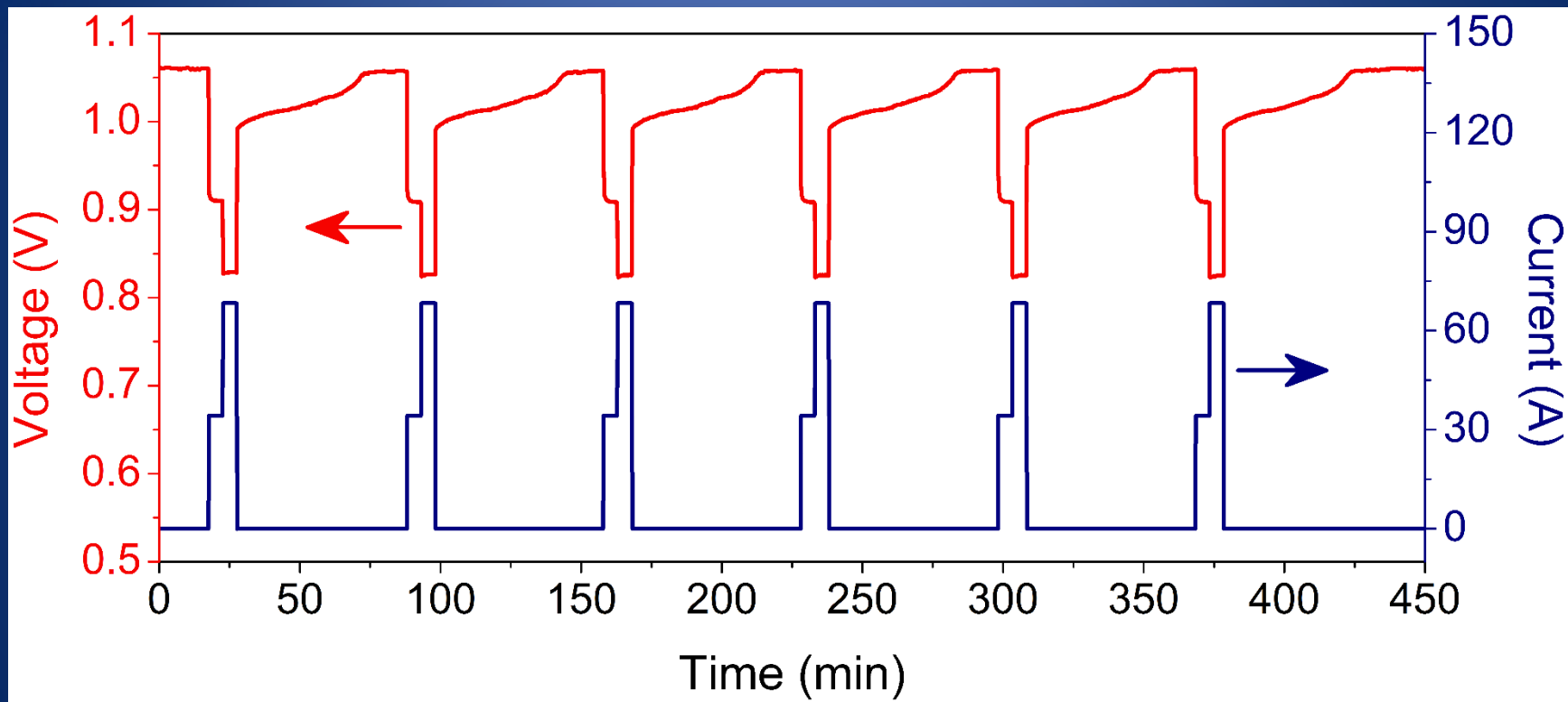


- A vertical Fe-bed design
- A total of 2,590g Fe-bed
- The capacity: 1,353Ah for Fe/FeO and 2,141Ah for Fe/Fe₃O₄.
- Operating current 11.5A
- C-rate of 1/10
- Fe-utilization of 20%





Regenerability

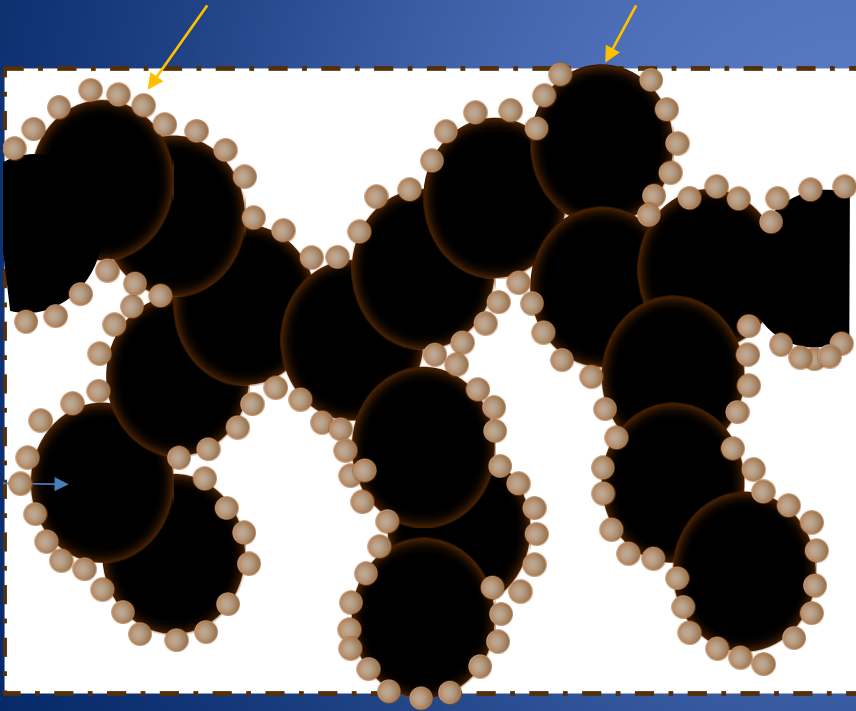


Recent Progress in IT-Cathode Development

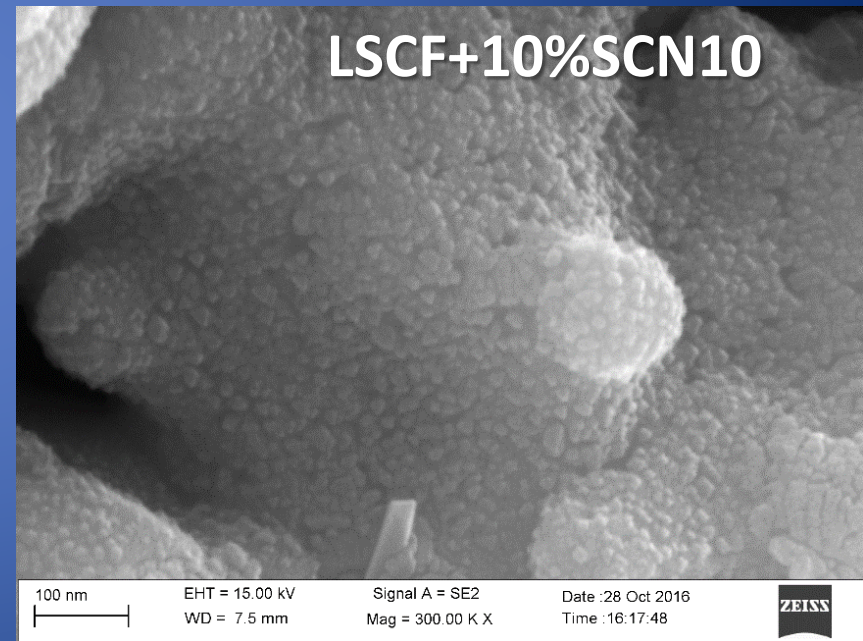
The Approach: ORR Catalyst on LSCF

ORR Catalyst

LSCF skeleton

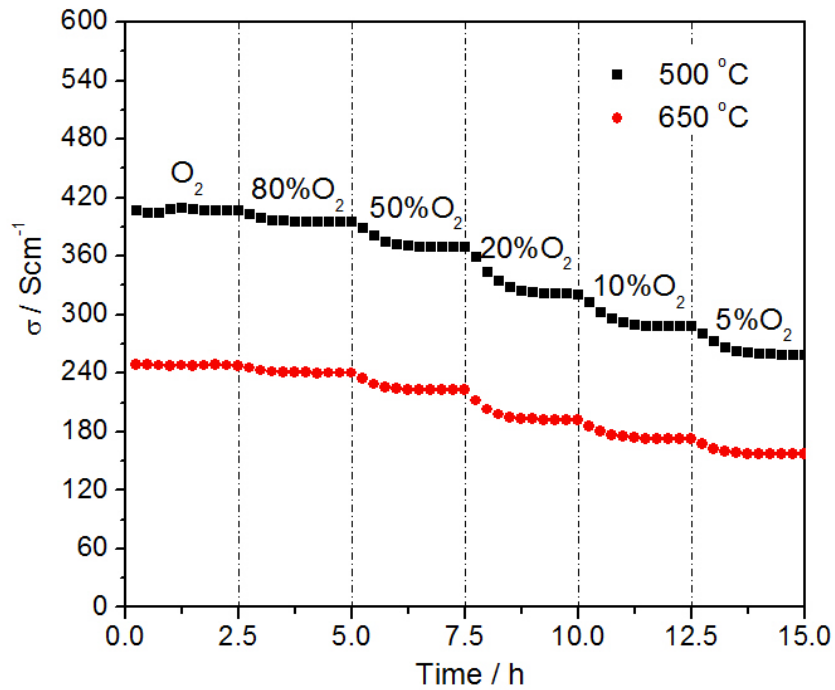


SCN10: $\text{SrCo}_{0.9}\text{Nb}_{0.1}\text{O}_{3-\delta}$

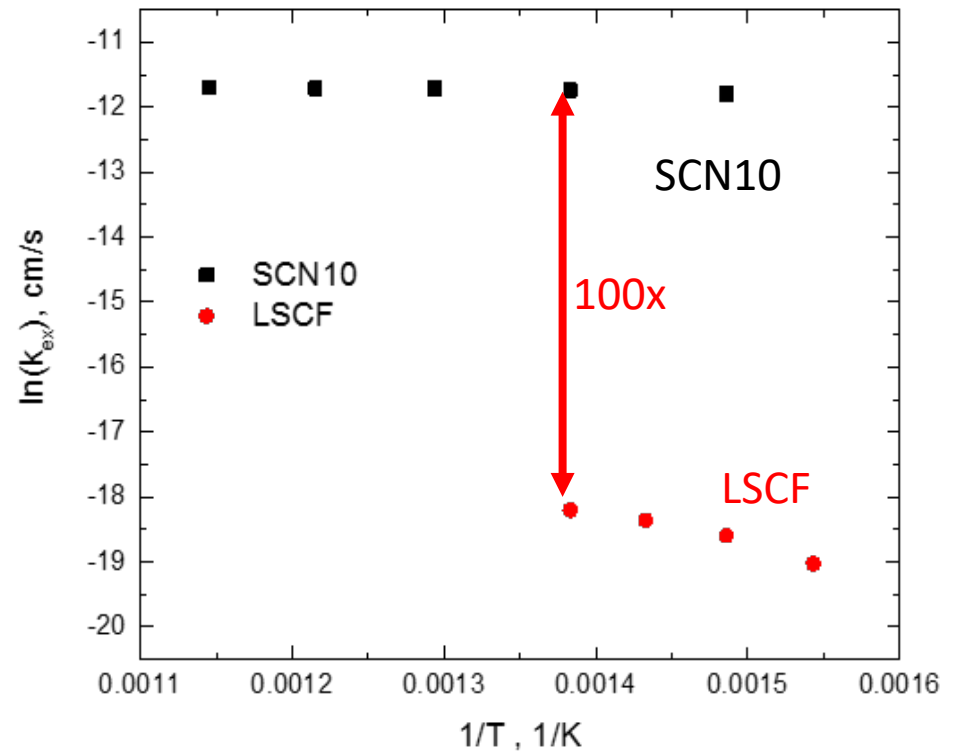


SCN10: $\text{SrCo}_{0.9}\text{Nb}_{0.1}\text{O}_{3-\delta}$

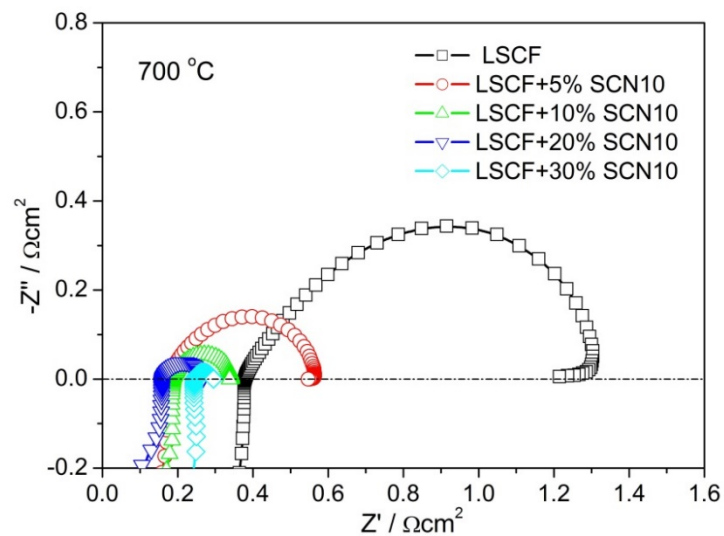
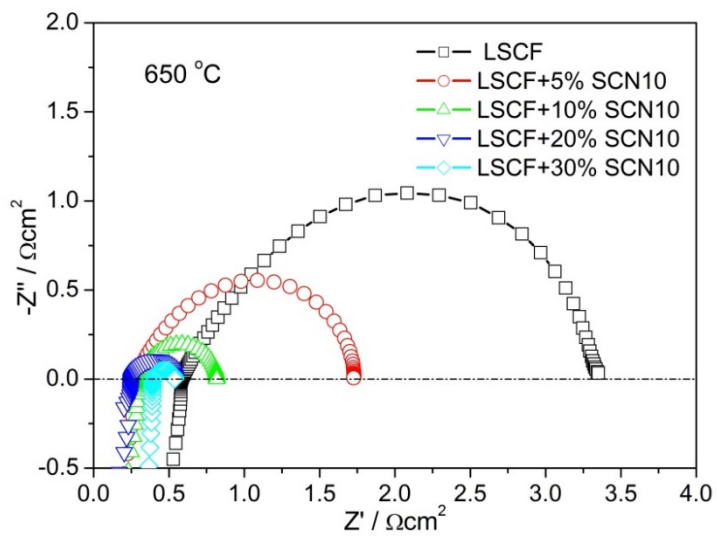
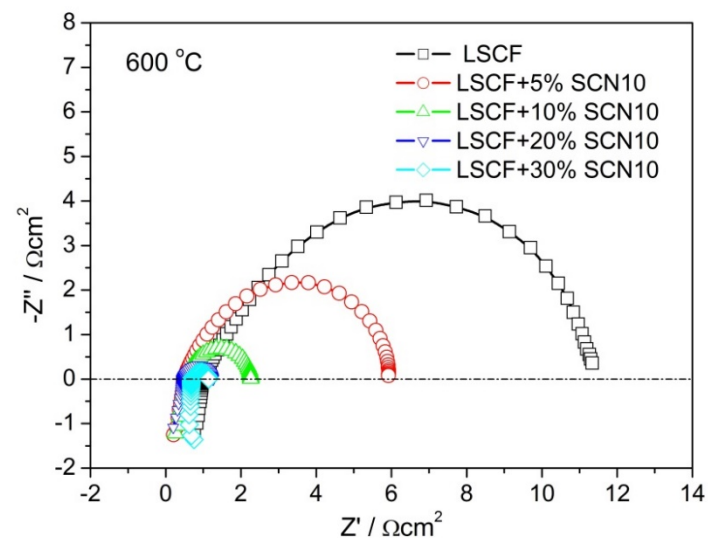
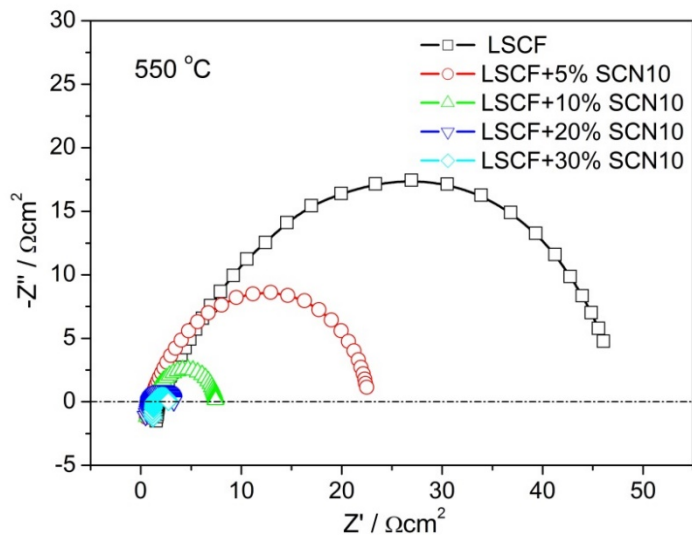
Conductivity

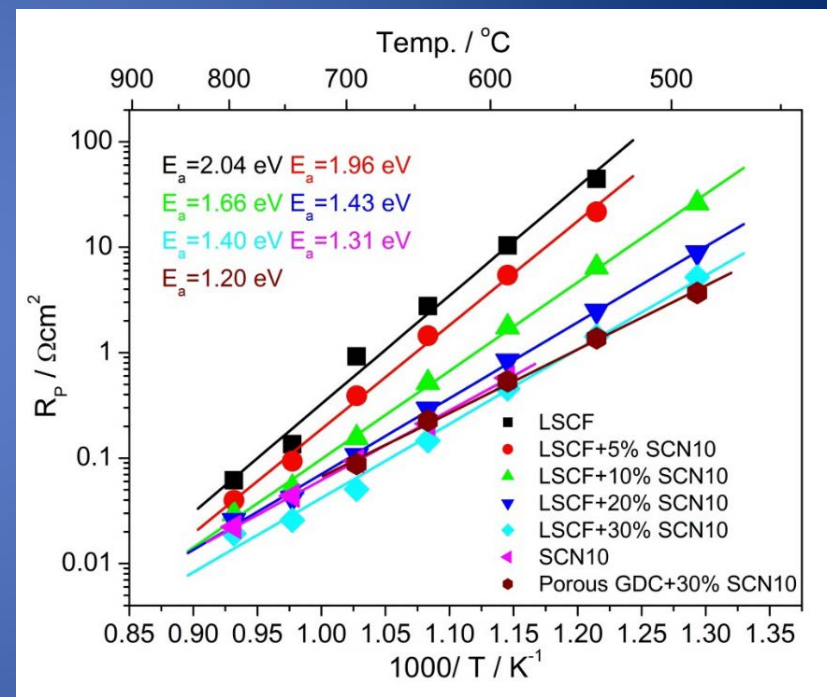
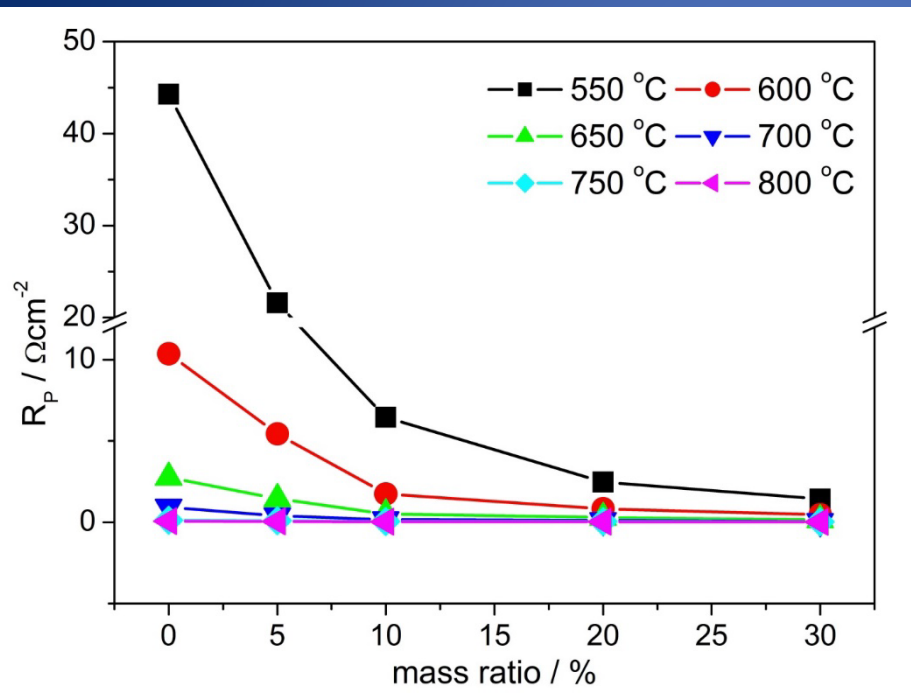


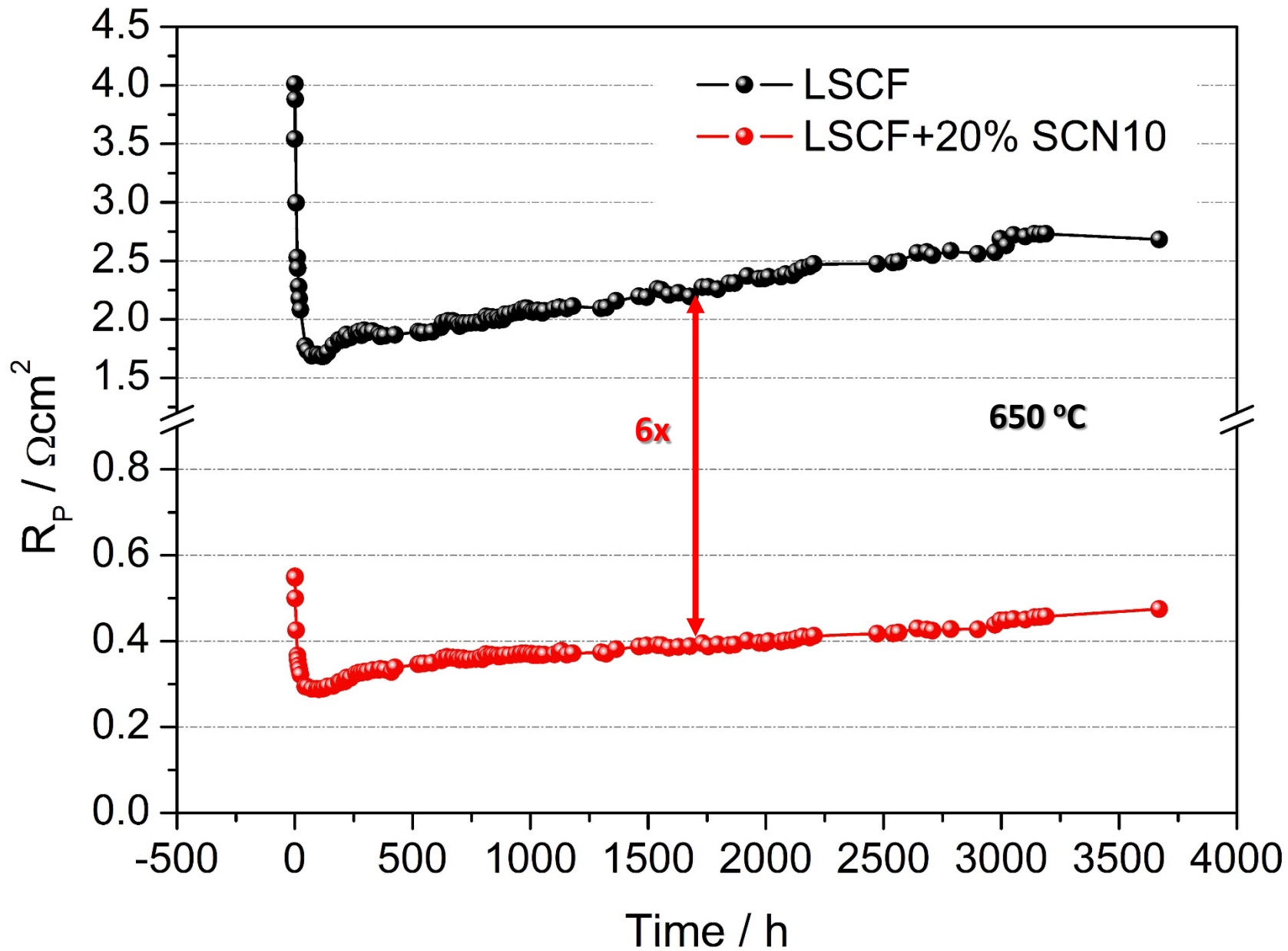
Surface oxygen exchange rate



UMD results







Summary

- The 500°C-SOIARB needs Pd as a catalyst to boost the kinetics of Fe_3O_4 -reduction
- Cycleability of pilot scale Atrex battery cell has been successfully demonstrated at 650°C
- Fe-bed SOFC has potential applications in data center overload protection and fast ramping power for grid management
- SCN10-modified LSCF cathode shows low R_p and durable performance at IT range

Acknowledgement

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