Development of Low Cost, Robust and Durable Cathode Materials to Support SOFC Commercialization

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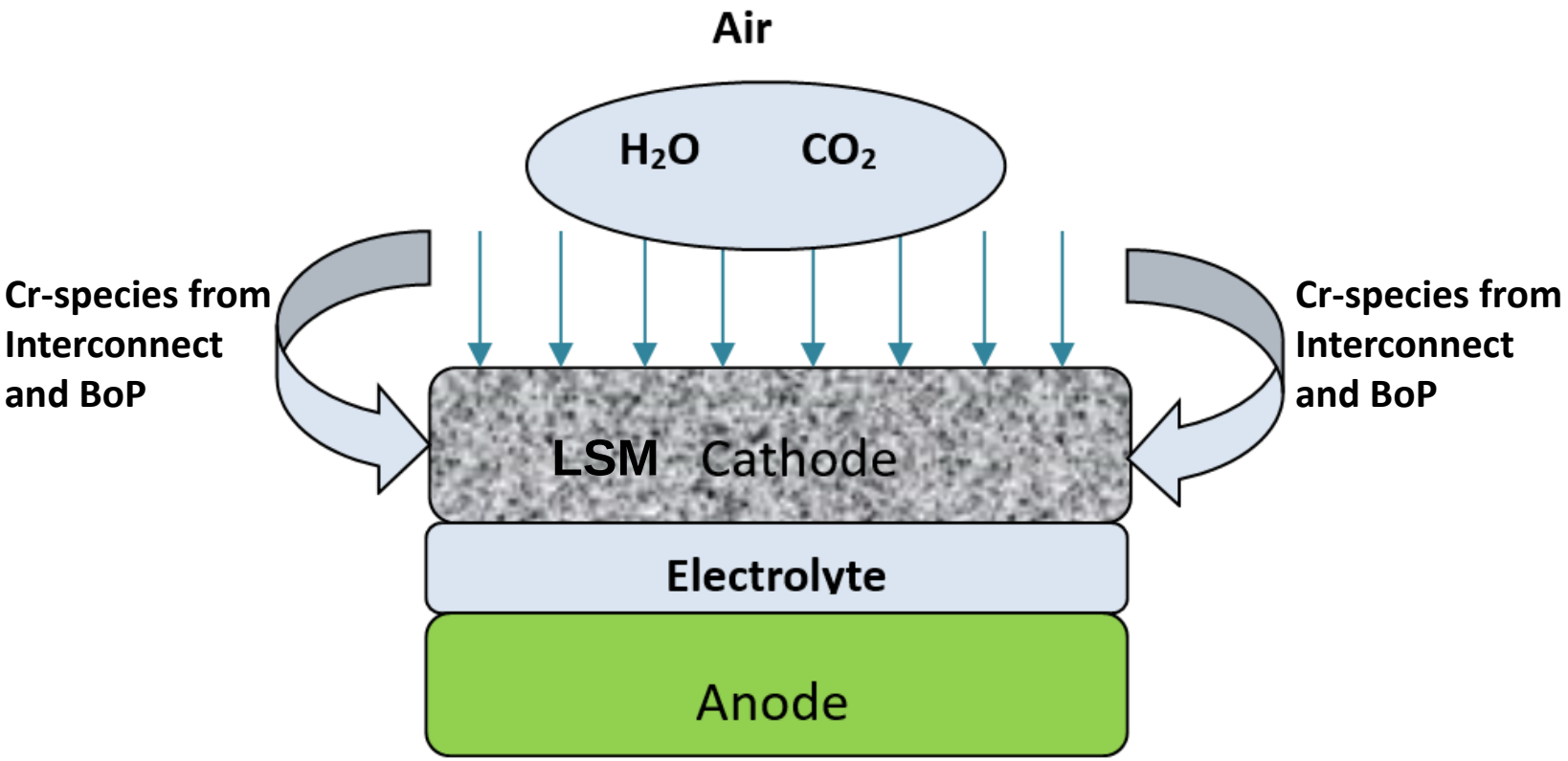
Outline

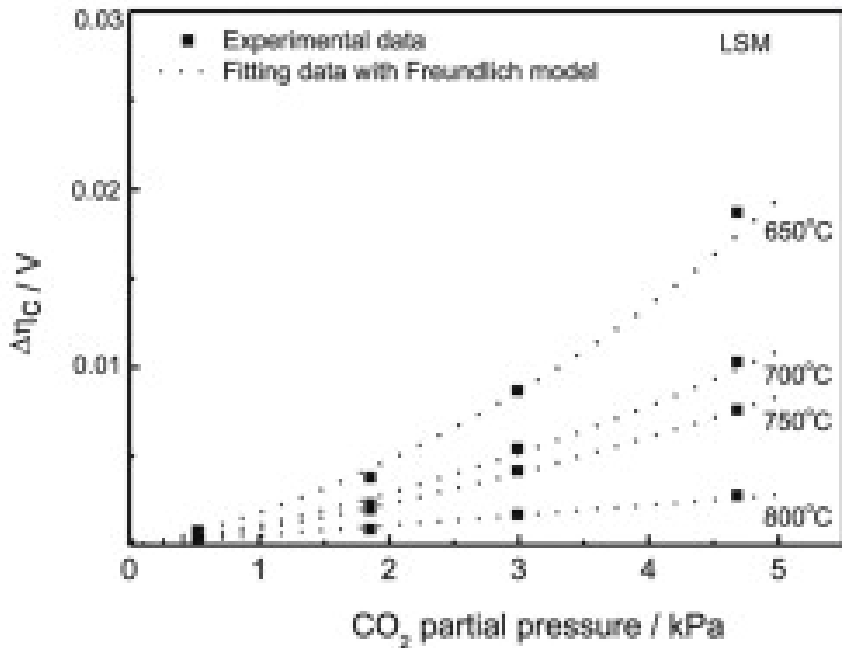
- Background;
- Technical approach;
- Project objective;
- Project structure;
- Project schedule;
- Project budget;
- Project Management Plan, including Risk Management

Background – Cathode Degradation due to the Environment



Schematic illustration of the possible cause of performance degradation of the LSM cathode materials

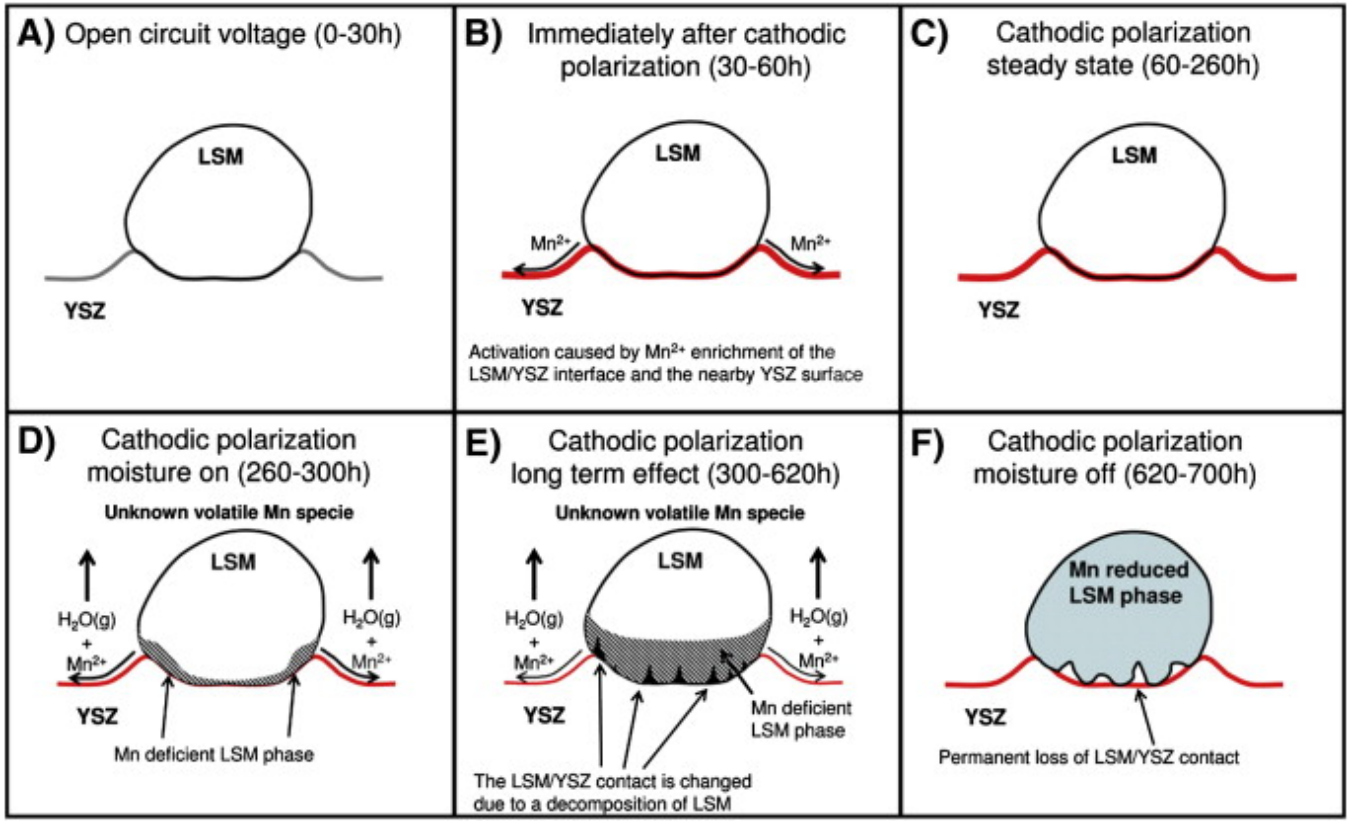
Background –CO_2 Impact on LSM Cathode Durability



The effects of carbon dioxide on oxygen reduction reactions on LSM cathodes: CO_2 inhibits dissociation of adsorbed oxygen molecule or diffusion of O-species on the LSM cathode

Zhao, Z.; Liu, L.; Zhang, X.; Wu, W.; Tu, B.; Ou, D.; Cheng, M., A comparison on effects of CO_2 on $La_{0.8}Sr_{0.2}MnO_{3+\delta}$ and $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ cathodes. J. Power Sources 2013, 222, 542-553

Background –Instability of LSM under Moisture

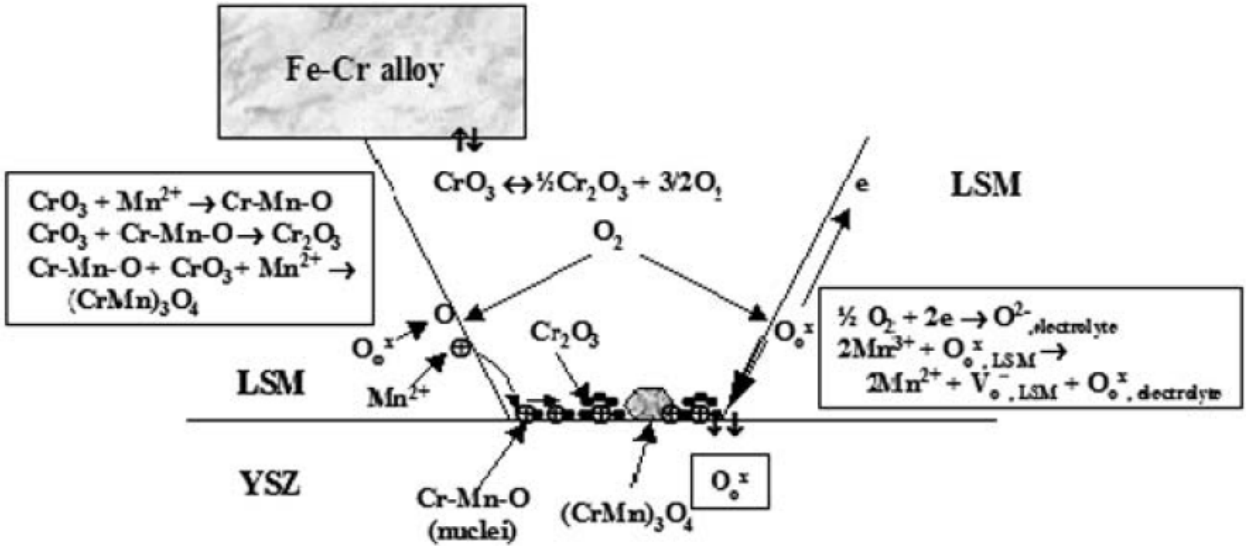


Schematic illustration of the influence of moisture on the performance of LSM/YSZ composite cathode on the YSZ electrolyte

Moisture causes an enhanced removal of manganese from the LSM/YSZ interface and thus eventually a decomposition of LSM

Nielsen, J.; Mogensen, M., SOFC LSM:YSZ cathode degradation induced by moisture: An impedance spectroscopy study. Solid State Ionics 2011, 189 (1), 74-81

Background – Cr Poisoning – Chemical Pathway



Scheme of the Cr deposition reaction at LSM cathode and YSZ electrolyte

Mn^{2+} serves as nucleation agent for the formation of Cr_2O_3 from Cr-Mn-O nucleus

$$Cr_2O_3(s) + 3/2O_2 \rightarrow 2CrO_3(g) \quad (1)$$

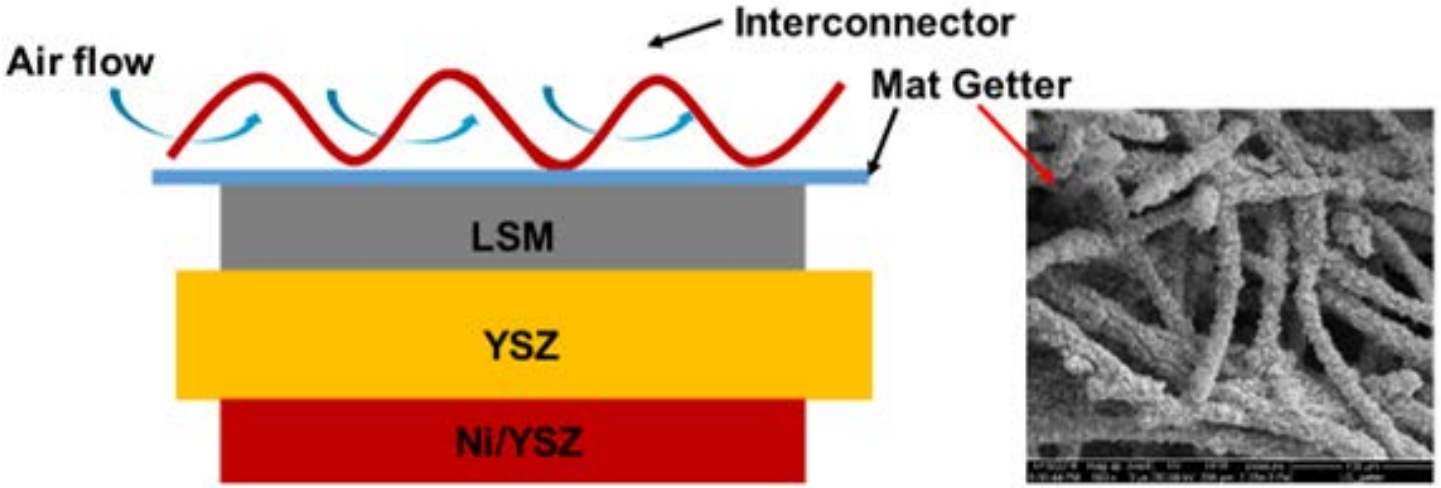
$$Mn^{2+} + CrO_3 \rightarrow Cr–Mn–O_x \text{ (nuclei)} \quad (2)$$

$$Cr–Mn–O_x \text{ (nuclei)} + CrO_3 \rightarrow Cr_2O_3 \quad (3)$$

$$Cr–Mn–O_x \text{ (nuclei)} + CrO_3 + Mn^{2+} \rightarrow (Cr,Mn)_3O_4 \quad (4)$$

Jiang, S. P.; Zhang, S.; Zhen, Y. D., Early interaction between Fe–Cr alloy metallic interconnect and Sr-doped $LaMnO_3$ cathodes of solid oxide fuel cells. J. Mater. Res. 2005, 20 (3), 747-758)

Background – Cr-Getter



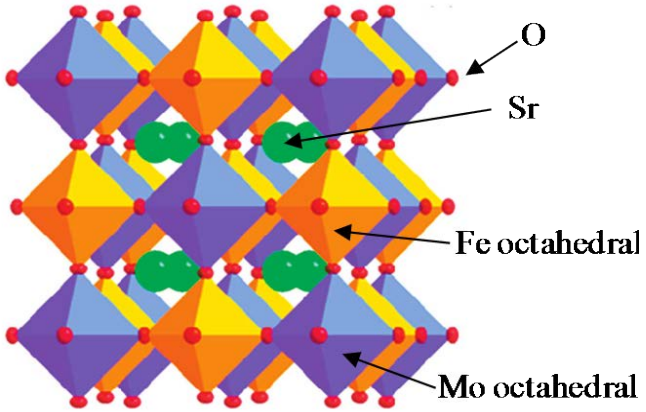
SrO serves as nucleation agent for the formation of $SrCrO_4$

$$CrO_3(g) + Sr_xNi_yO_z \rightarrow SrCrO_4 + NiO + O_2(g) \quad (1)$$

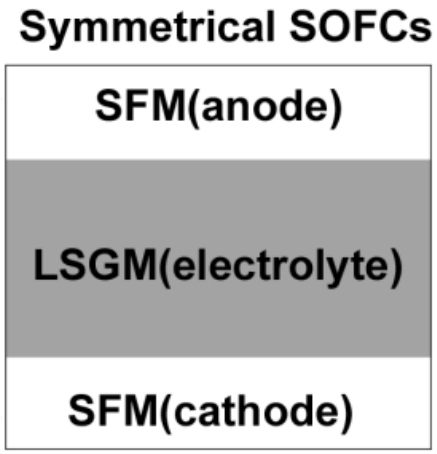
$$CrO_2(OH)_2(g) + Sr_xNi_yO_z + O_2(g) \rightarrow SrCrO_4 + NiO + H_2O\,(g) \quad (2)$$

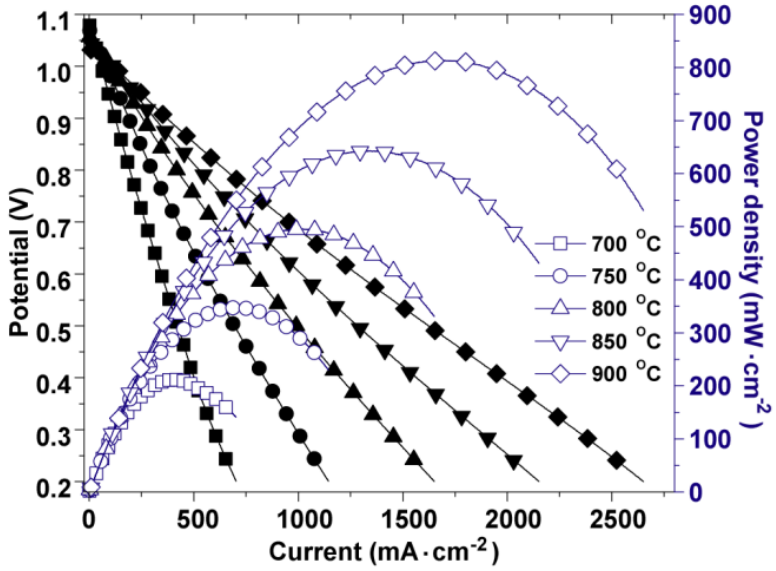
https://www.netl.doe.gov/research/coal/energy-systems/fuel-cells/project-information/proj?k=FE0027894

Technical Approach – Novel Cathode Materials



$Sr_2Fe_{2-x}Mo_xO_{6-\delta}$ (SFM)

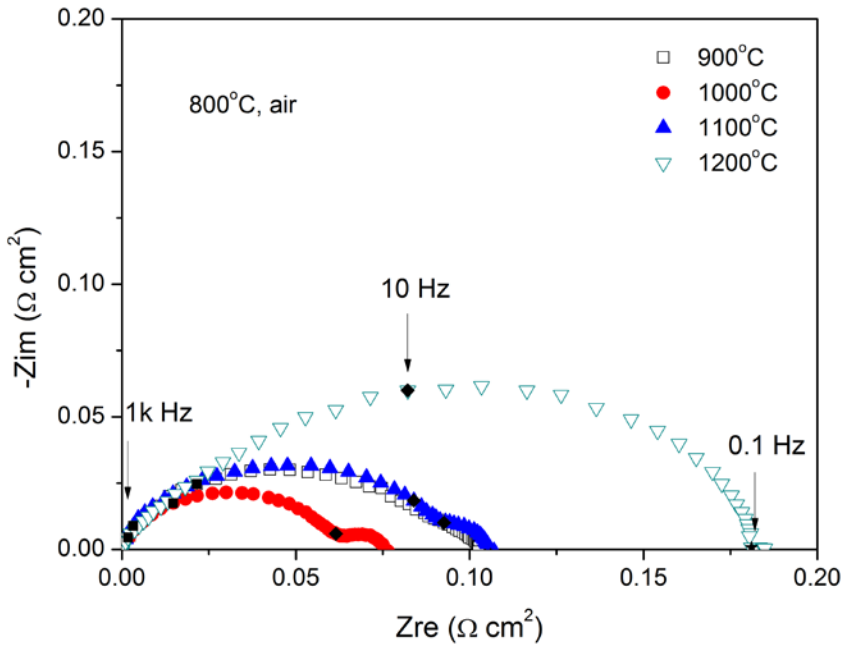




Evaluate new cathode compositions such as SFM that may offer durable cathode performance

Liu, Q.; Dong, X.; Xiao, G.; Zhao, F.; Chen, F., A Novel Electrode Material for Symmetrical SOFCs. *Adv. Mater.* **2010,** *22* (48), 5478-5482

Technical Approach – SFM Promising ORR Performance

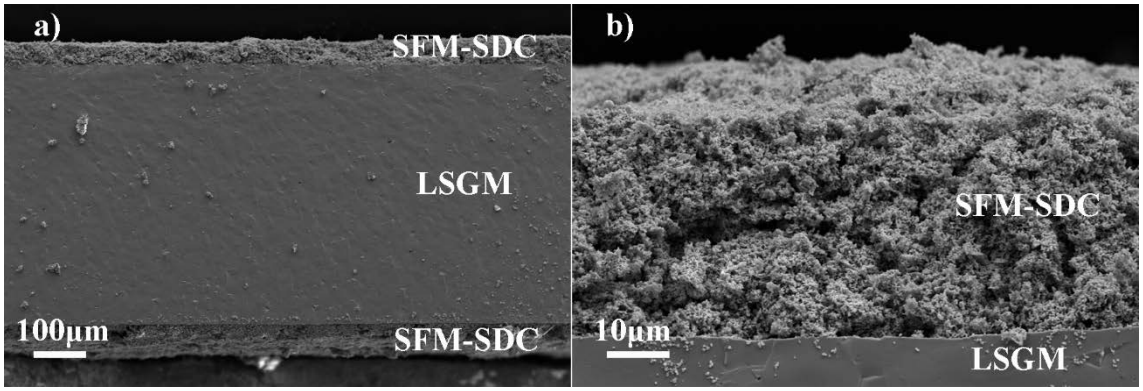


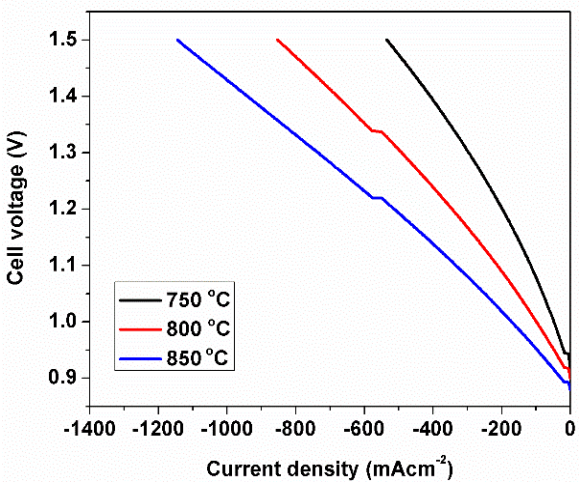
SFM|LSGM|SFM
0.076 Ω cm^2 at 800°C in air
LSC|LSGM|LSC
0.089 Ω cm^2 at 800°C in air

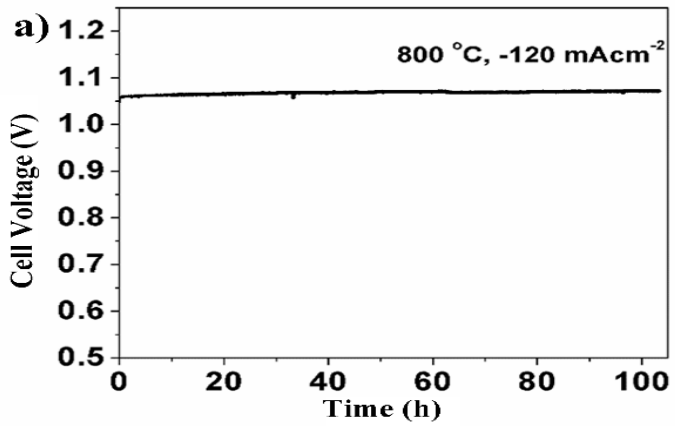
SFM showing low cathode ASR

Xiao, G.; Liu, Q.; Zhao, F.; Zhang, L.; Xia, C.; Chen, F., $Sr_2Fe_{1.5}Mo_{0.5}O_6$ as Cathodes for Intermediate-Temperature Solid Oxide Fuel Cells with $La_{0.8}Sr_{0.2}Ga_{0.87}Mg_{0.13}O_3$ Electrolyte. *J. Electrochem. Soc.* **2011,** *158* (5), B455-B460

Technical Approach – SFM Stability in Moisture and CO_2



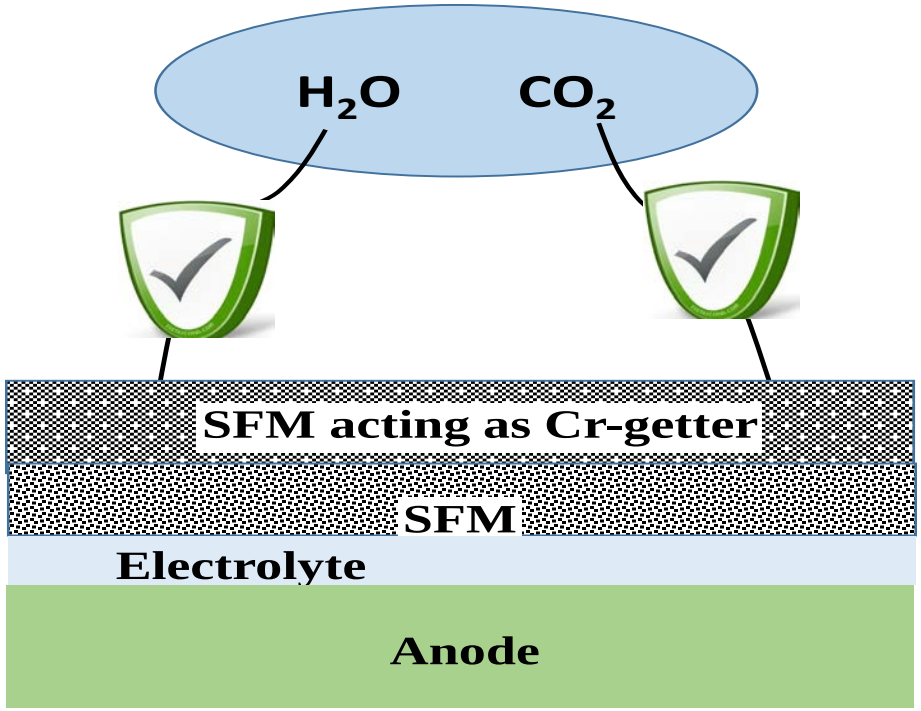




Stable cell performance of symmetrical cell SFM-SDC/LSGM/SFM-SDC under co-electrolysis operation (water vapor flow of 8 sccm, CO_2 flow of 8 sccm, H_2 flow of 10 sccm and N_2 flow of 24 sccm).

Wang, Y.; Liu, T.; Fang, S.; Chen, F., Syngas production on a symmetrical solid oxide H_2O/CO_2 co-electrolysis cell with $Sr_2Fe_{1.5}Mo_{0.5}O_6$–$Sm_{0.2}Ce_{0.8}O_{1.9}$ electrodes. *J. Power Sources* **2016,** *305*, 240-248)

Project Objective – Cr-tolerant Cathode



- Evaluate cathode materials such as SFM ($Sr_2Fe_{2-x}Mo_xO_{6-\delta}$) that have recently been developed as low cost, robust and durable cathode to support SOFC commercialization.
- Study the performance and durability of these cathode materials under relevant contaminants in the practical operating conditions.

Project Structure

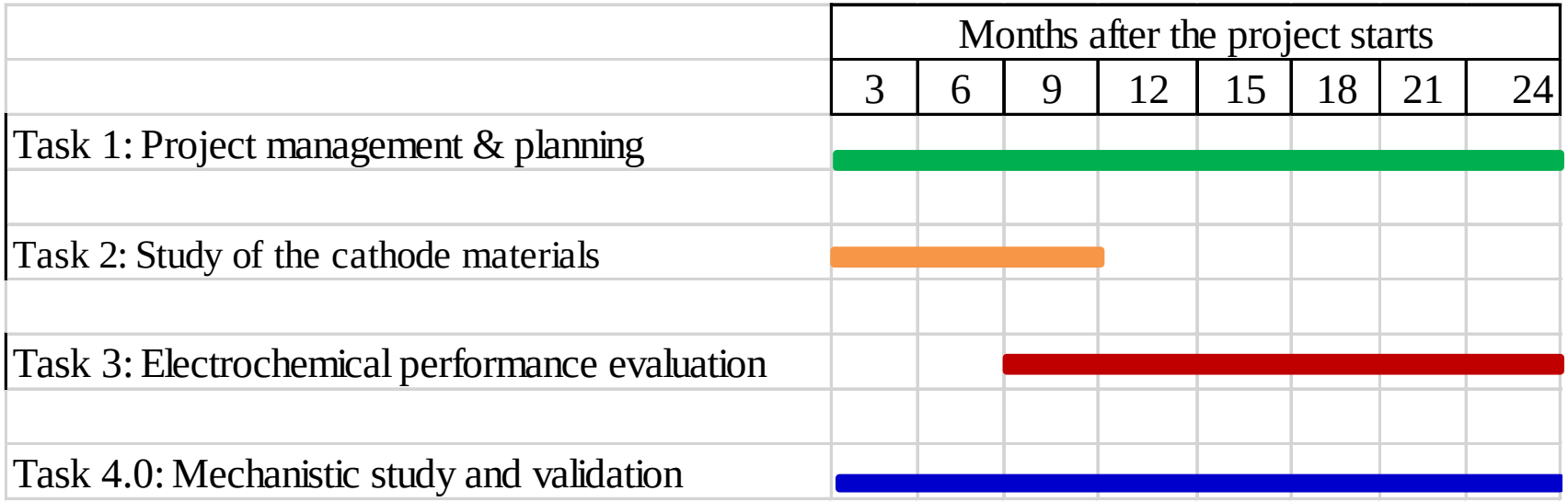
Dr. Fanglin (Frank) Chen, PI
Department of Mechanical Engineering
University of South Carolina

Graduate Student A → Experimental studies

Dr. Kevin Huang, Co-PI
Department of Mechanical Engineering
University of South Carolina

Graduate Student B → Modeling and mechanistic investigation

Project Schedule --Gantt Chart



Project Budget

Month	Federal (DoE) Fund	Non-federal Cost Share
October-17	$12,500	$3,125
November-17	$12,500	$3,125
December-17	$12,500	$3,125
January-18	$12,500	$3,125
February-18	$12,500	$3,125
March-18	$12,500	$3,125
April-18	$12,500	$3,125
May-18	$12,500	$3,125
June-18	$12,500	$3,125
July-18	$12,500	$3,125
August-18	$12,500	$3,125
September-18	$12,500	$3,125
October-18	$12,500	$3,125
November-18	$12,500	$3,125
December-18	$12,500	$3,125
January-19	$12,500	$3,125
February-19	$12,500	$3,125
March-19	$12,500	$3,125
April-19	$12,500	$3,125
May-19	$12,500	$3,125
June-19	$12,500	$3,125
July-19	$12,500	$3,125
August-19	$12,500	$3,125
September-19	$12,500	$3,125
Project Total	**$300,000**	**$75,000**

Project Management Plan – Milestones for the Project

Milestone ID	Deliverables and milestones	(Months after start)
1	Thermodynamic evaluation of the reactivity of the cathode with different Cr-species	3
2	Experimental assessment of chemical compatibility of the cathode with Cr-species	6
3	Half-cell evaluation of pristine cathode performance	9
4	Half-cell evaluation of cathode performance with Cr-contaminants	12
5	Cr-gettering evaluation of the cathode material	15
6	Button-cell testing of Cr-mitigation for the cathode	18
7	Electrochemical cell performance model development of cells using the new cathode	21
8	Demonstration of Cr-tolerance and mitigation of the new cathode in operating cells	24

Project Management Plan – Risk Management

Risks	Risk Mitigation Activity
Chemical compatibility of the cathode with the electrolyte	Evaluate the chemical compatibility of the cathode with the state-of-the-art electrolyte, especially the widely applied YSZ electrolyte. If the cathode and YSZ are not chemically compatible, then a buffer layer between the new cathode and YSZ electrolyte will be be used.
Cathode tolerance to Cr-species	If the new cathode reacts with Cr-species, efforts will be then devoted to apply the cathode as potential Cr-getter in the cathode.
Long-term stability of the cathode	Evaluate different compositions to optimize the long-term cathode performance and durability.

Acknowledgements

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- Special thanks to the DOE project manager, Dr. Arun Bose, and the entire SOFC program management team for guidance.