Development of High-Performance Metal-Supported SOECs and Innovative Diagnostic Methodologies

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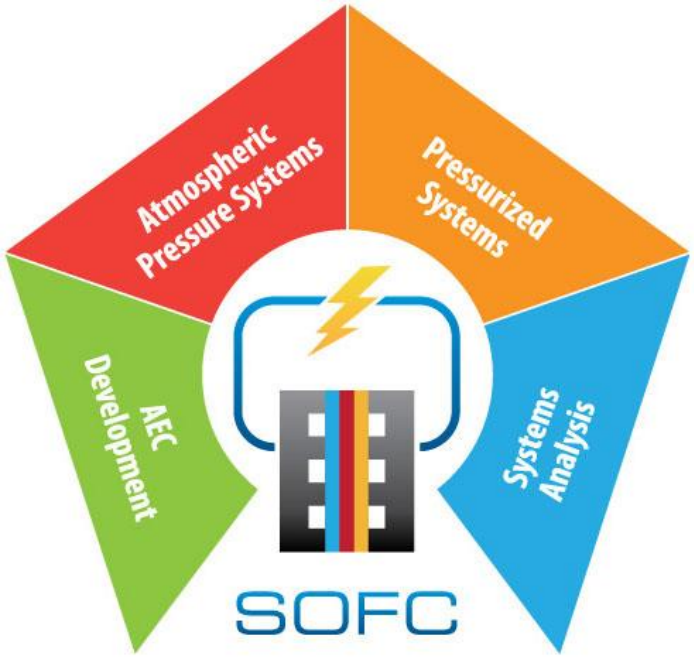


4:00 pm EST on November 18, 2021

DE-FE0032110

Outline

1. **Technical and Scientific Background**
   Necessity and relevance
2. **Project Objectives**
   High performance MS-SOECs and diagnosis
3. **Technical Approaches**
   Experimental and theoretical modeling
4. **Project Budget and Period**
   Cost share, equipment
5. **Project Management Plans**
   Investigators and risk analysis

Hydrogen Production through Solid Oxide Electrolysis Cells (SOECs)

Cost ($/kg):

How to achieve high-performance SOECs?

Durability (A/1000-h or W/1000-h)

What are the factors limiting the performance stability of an SOEC?

Diagnosis

How to develop accelerated test methodologies and quantify the role of electrode microstructures?

Factors Influencing Current Density and Mechanical Strength

$$\boldsymbol{i} = \left(1 - \frac{L}{L - \frac{\boldsymbol{\varepsilon}}{\boldsymbol{\tau}} \frac{p}{RT} \frac{D_{\alpha,\beta} D_{K,\alpha}}{D_{K,\alpha} + D_{\alpha,\beta}} \frac{z_\alpha F}{i_0}}\right) y_{\alpha 0} i_0$$

ε: porosity

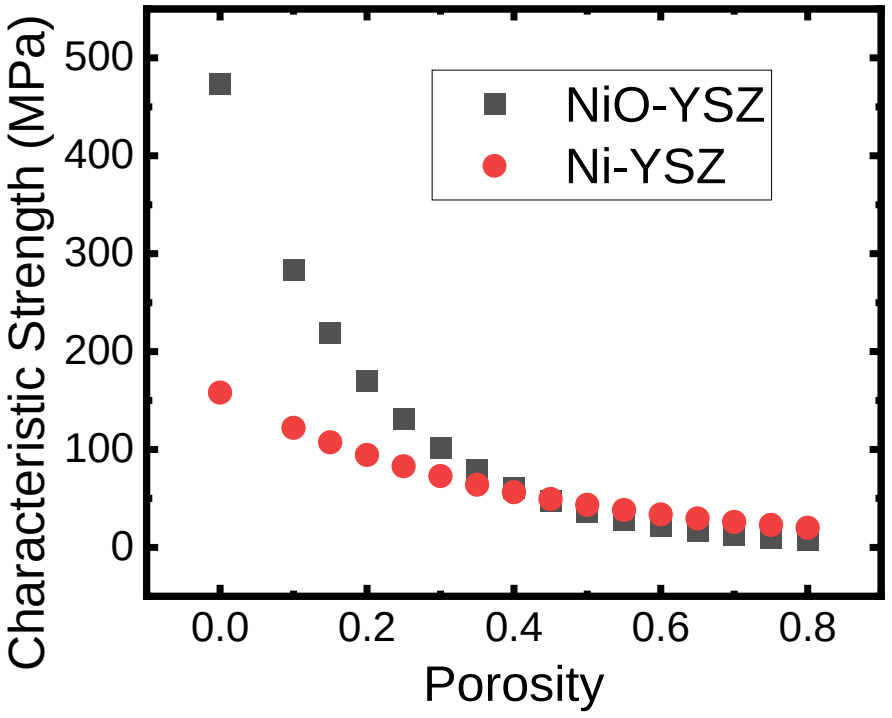
τ: tortuosity

L: diffusion layer thickness

α: molar fraction of species

$y_{\alpha 0}$: molar fraction of species

$D_{\alpha,\beta}$: molecular diffusion coefficient



- A high $\boldsymbol{\varepsilon/\tau}$ value → **high Faradaic current** at the electrolyte/fuel electrode interface.
- Greater porosity ($\boldsymbol{\varepsilon}$) → poor strength of the cell support.

Tasks to Be Performed

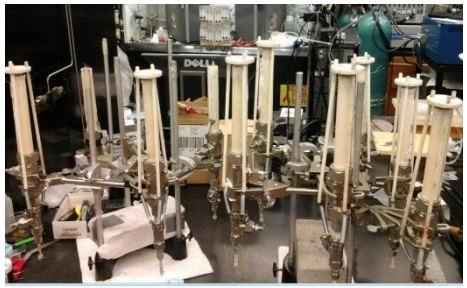
Task 1.1 - Project Management and Planning

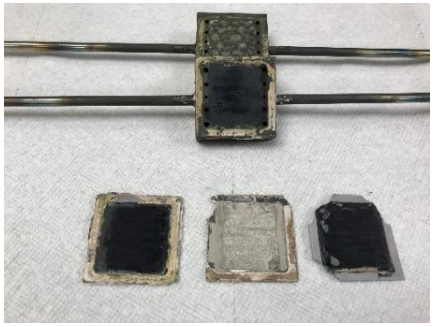
Task 2.0 – Fabrication of Button Cells and Single Cells

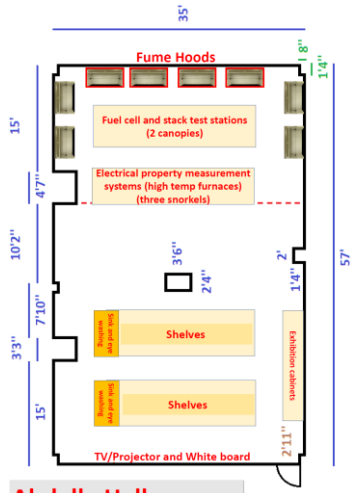
Task 3.0 – Cell Testing and Development of Accelerated Test Protocols
Subtask 3.1 - Cell testing (Pretesting)
Subtask 3.2 – Measurements of baseline cells
Subtask 3.3 – Accelerated test development for SOECs

Task 4 - Theoretical Analysis, Diagnosis, and Post Analysis
Subtask 4.1 - Acquisition of sectional images of SOECs
Subtask 4.2 - Applying machine learning on the analysis of specimens
With a significant number of images.
With a limited number of images.
Subtask 4.3 - Theoretical study

Fuel Cell Testing Lab
(Button Cells and Single Cells)



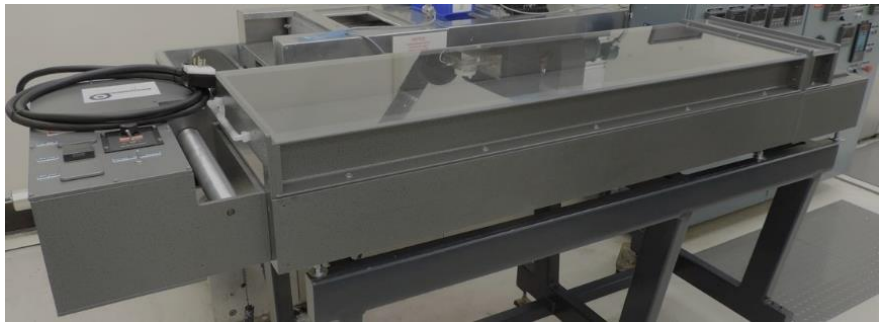


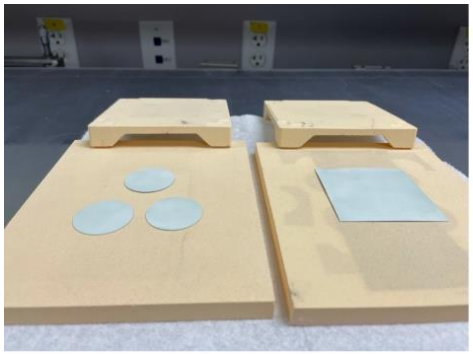


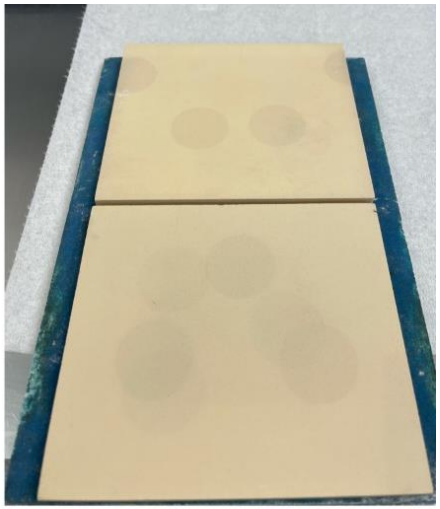
- 2 walk-in fume hoods; 3 bench-top fume hoods
- 26 button cell test stands;
- 6 single cell test stands (5×5 cm^2)
- 32 channels for i-V up to 30 A; 16 EIS channels

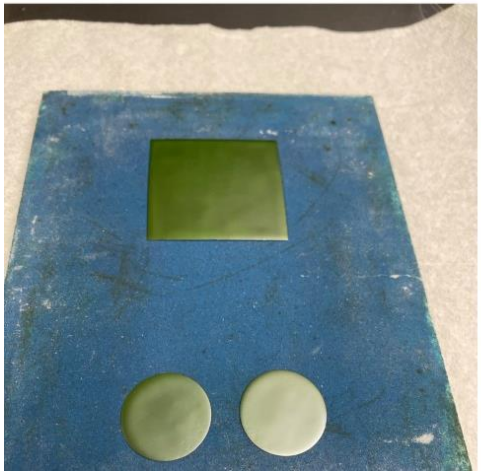
Cell Fabrication

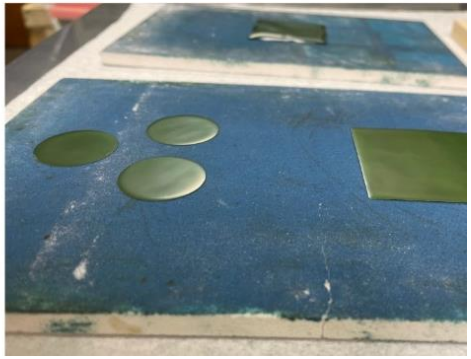
Button Cells and Single Cells

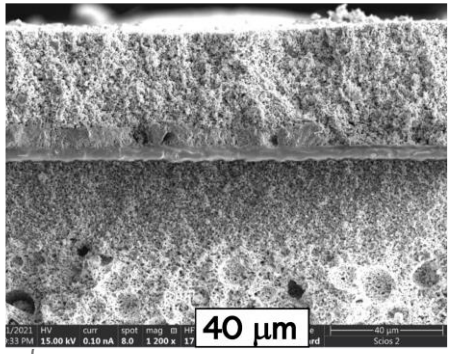


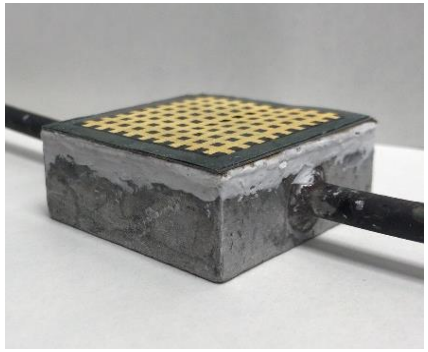




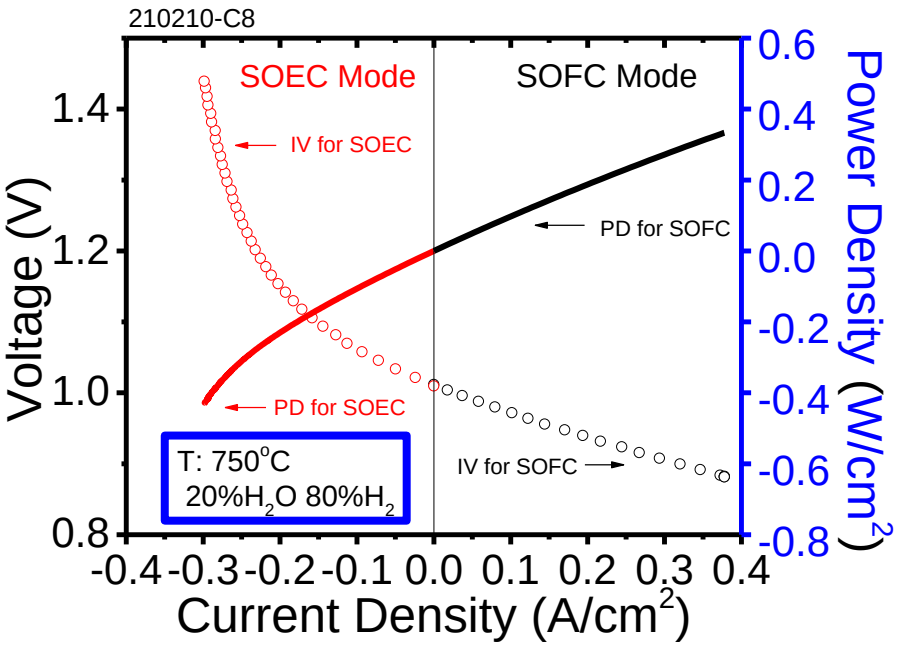


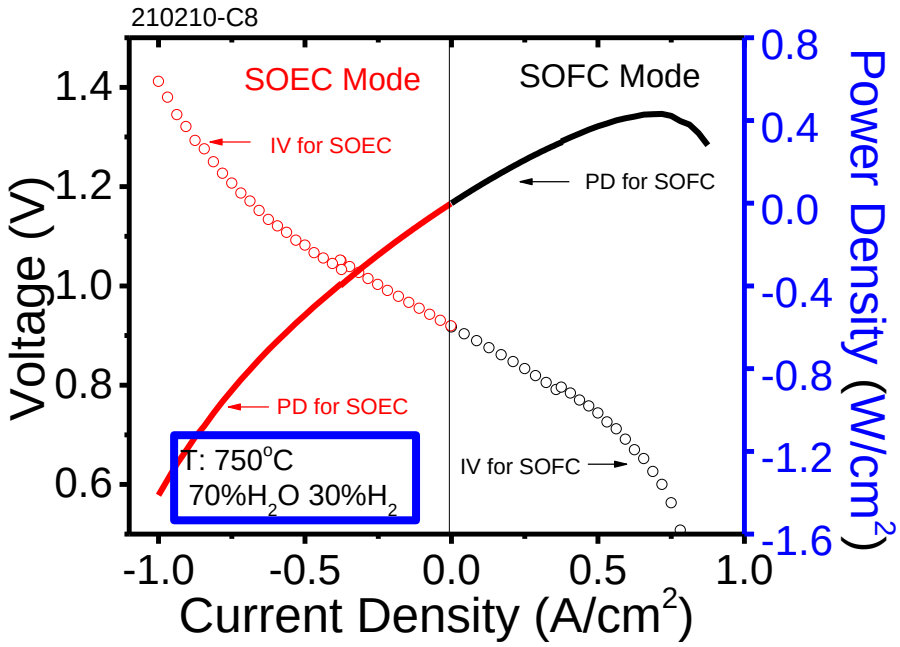






Reversible Cell Performance

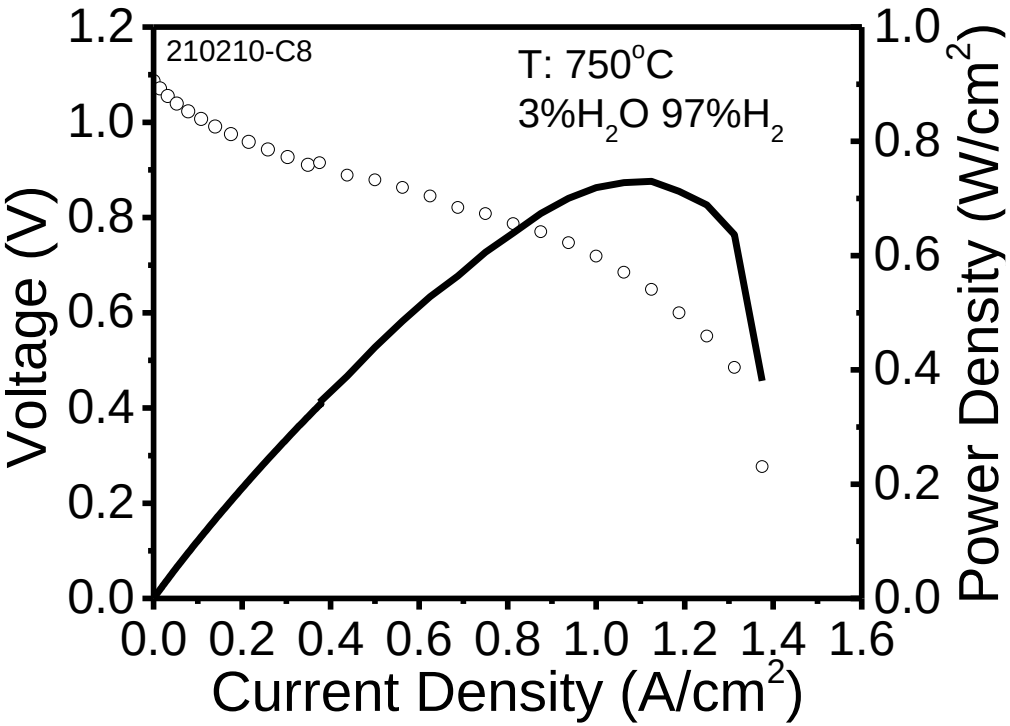


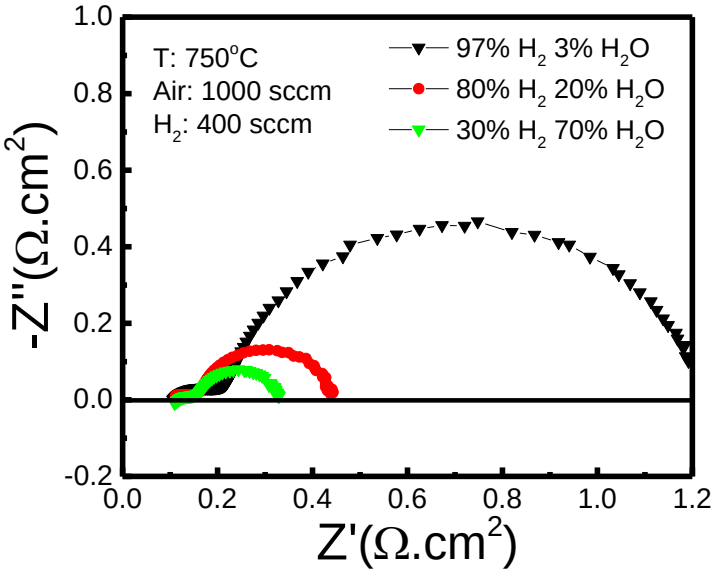


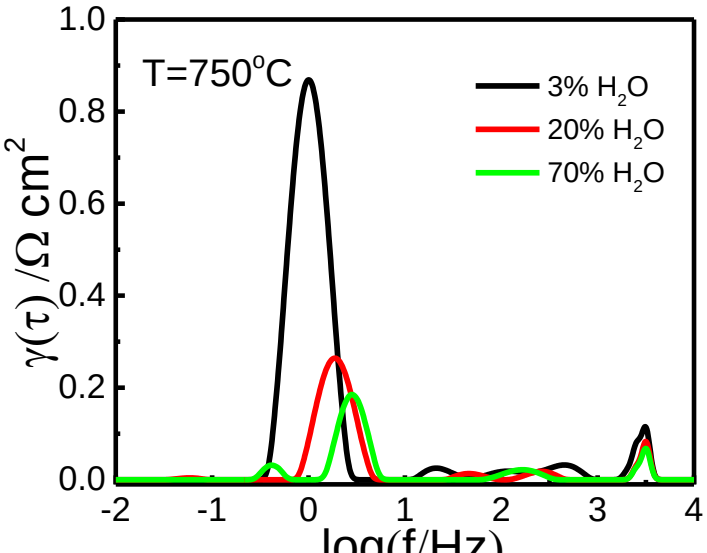
Steam %	OCV theoretical	OCV measured
3	1.118 V	1.087 V
20	1.021 V	1.011V
70	0.920 V	0.917 V

- The good match between **theoretical OCV** and **measured OCV** indicates good sealing performance and the correct steam concentration.
- Performance (**current density**) is highly dependent on operating conditions (H_2O%, temp, and voltage) and cell architectures.

EIS and SOFC Performance

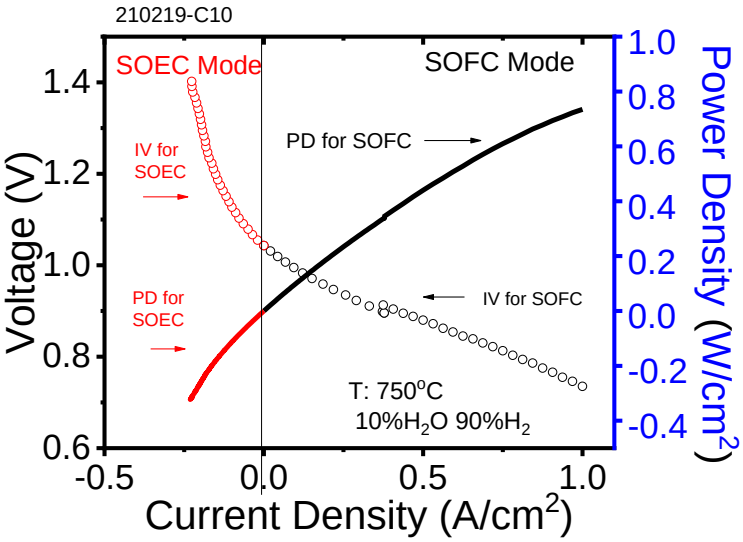


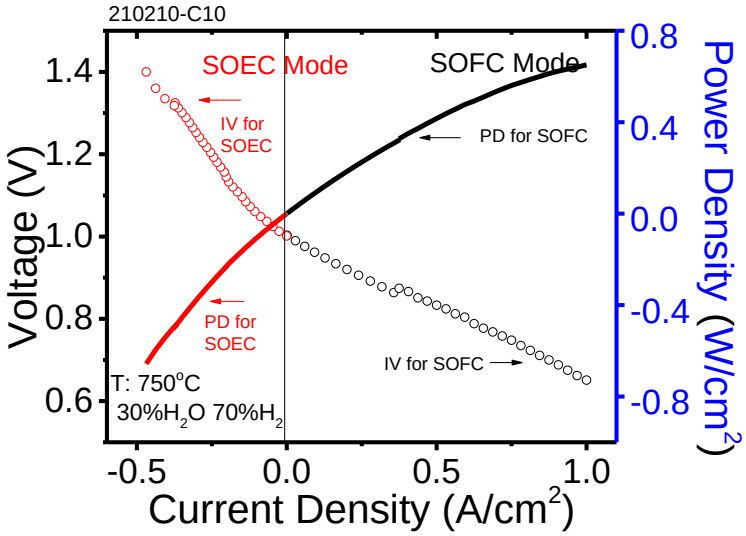


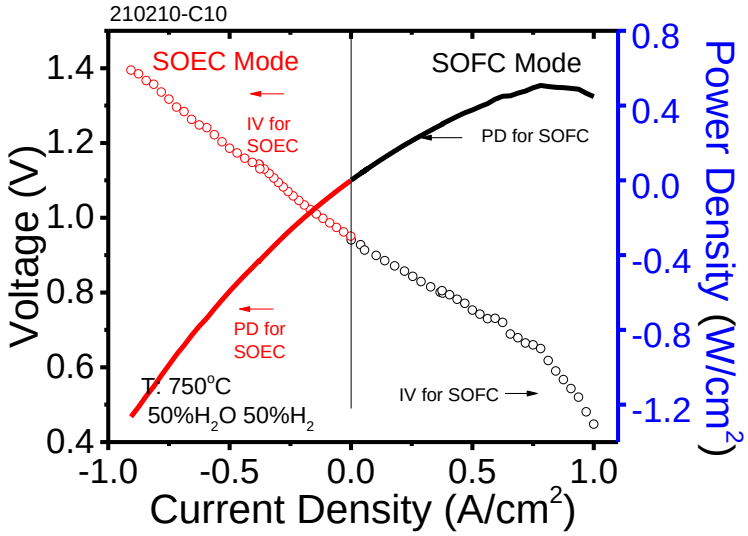


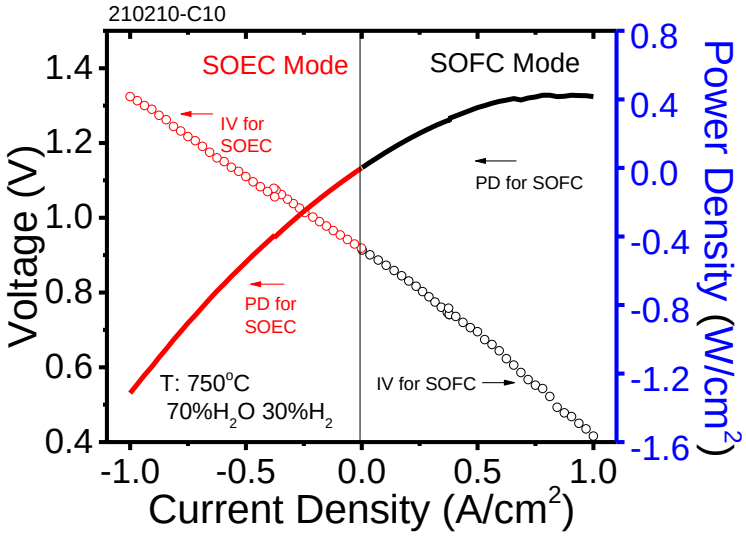
The resistance at low frequencies (about 10 Hz) decreases significantly when more steam is added in the anode.

210219-C10-Reversible cell performance

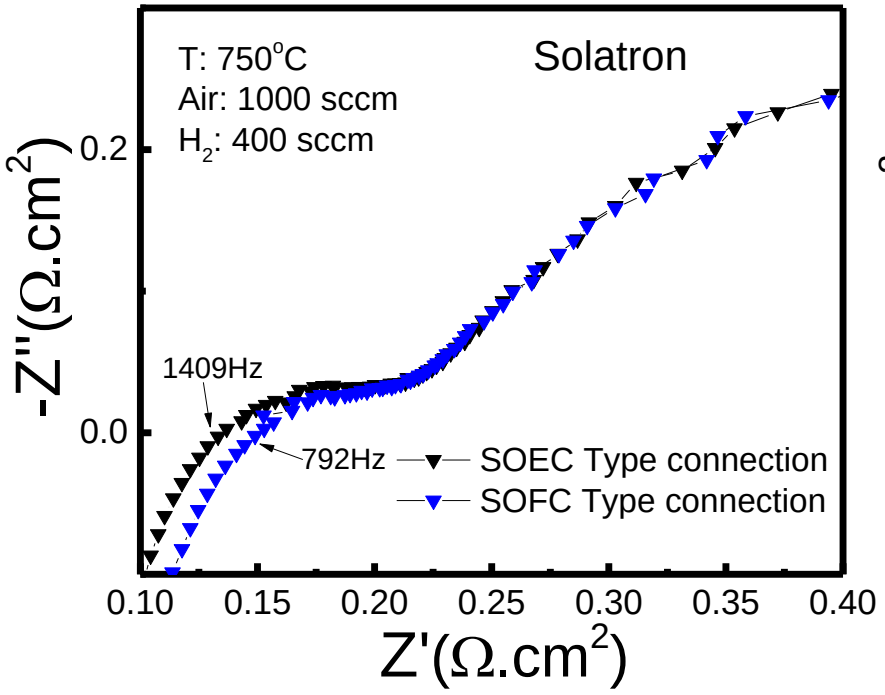


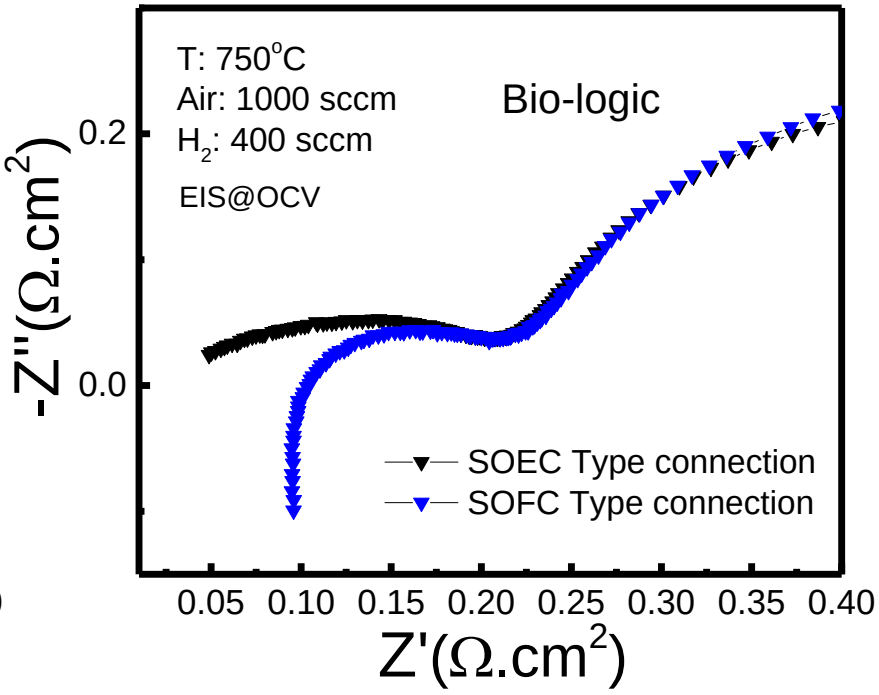




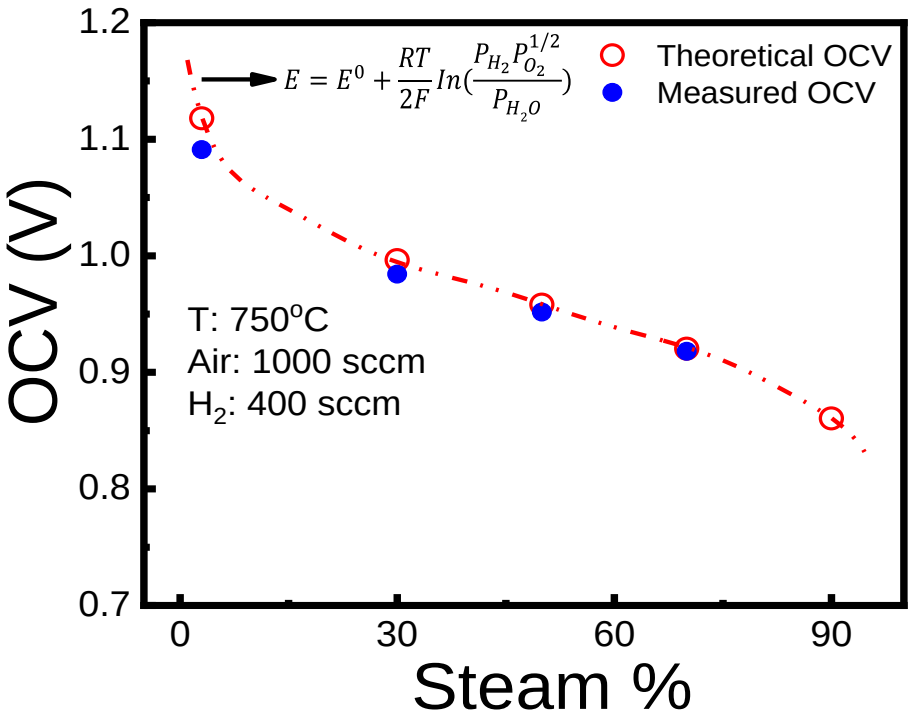


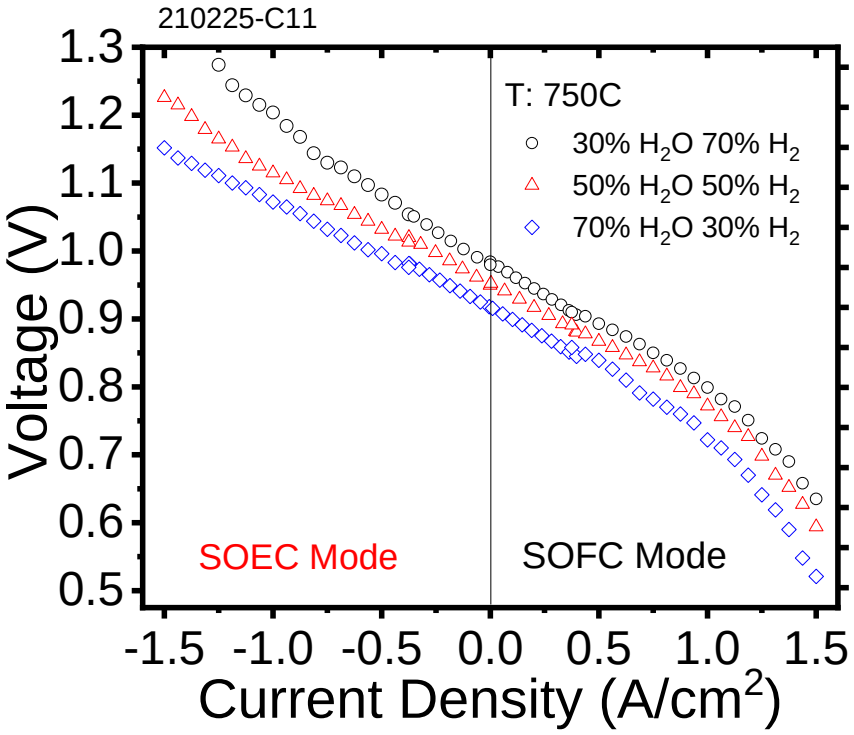
210219-C10-Artefacts at high frequency





Task: High Performance SOEC – Thinner Electrode



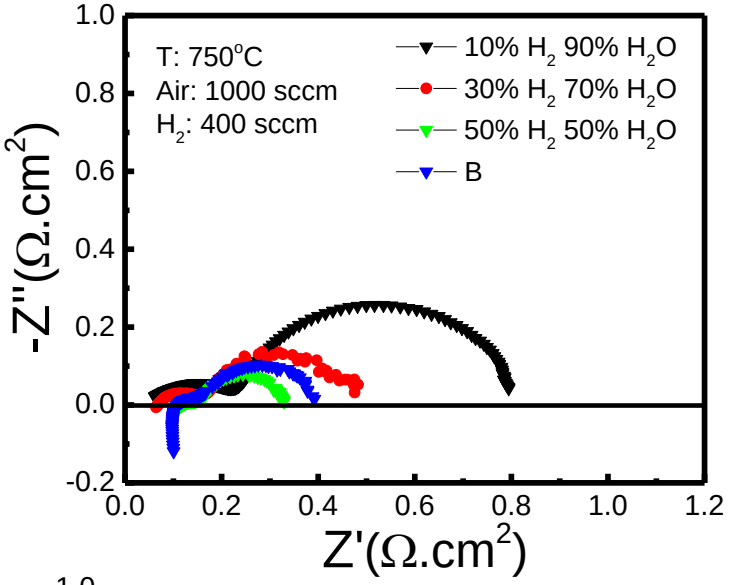


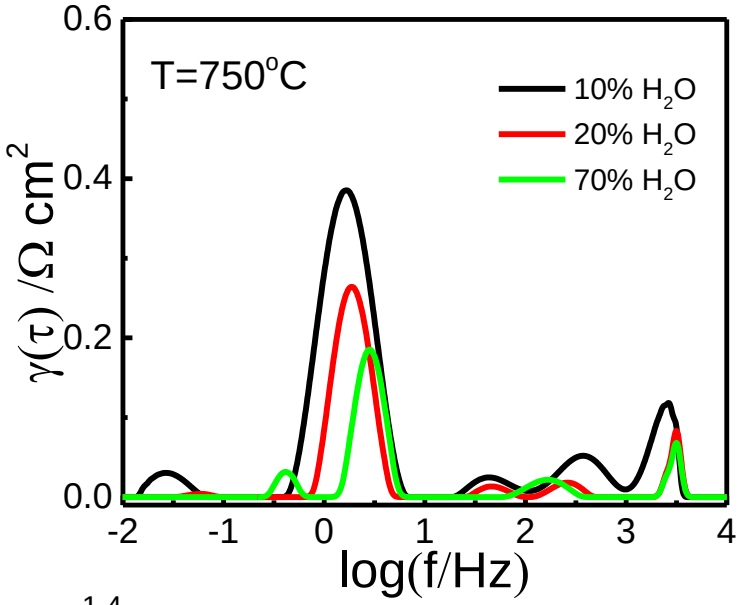
$$i = \left(1 - \frac{L}{L - \frac{\varepsilon}{\tau}\frac{p}{RT}\frac{D_{\alpha,\beta}D_{K,\alpha}}{D_{K,\alpha}+D_{\alpha,\beta}}\frac{z_\alpha F}{i_0}}\right) y_{\alpha 0} i_0$$

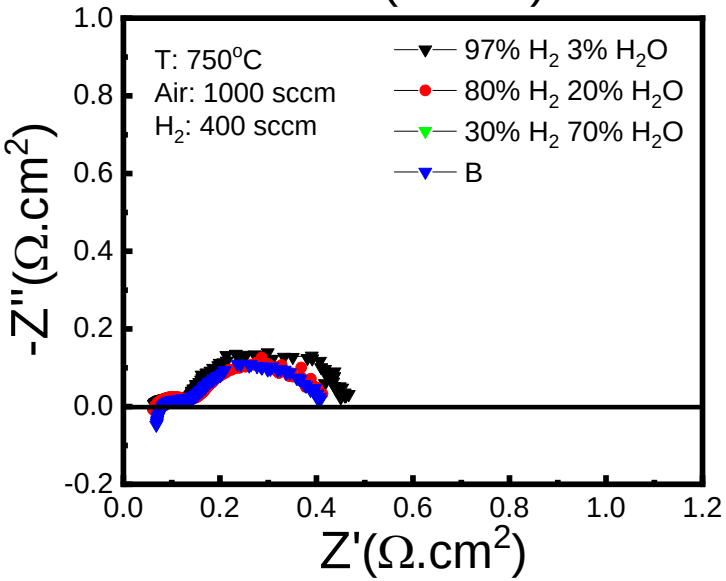
Role of Microstructures: the porosity (ε) and tortuosity (τ).

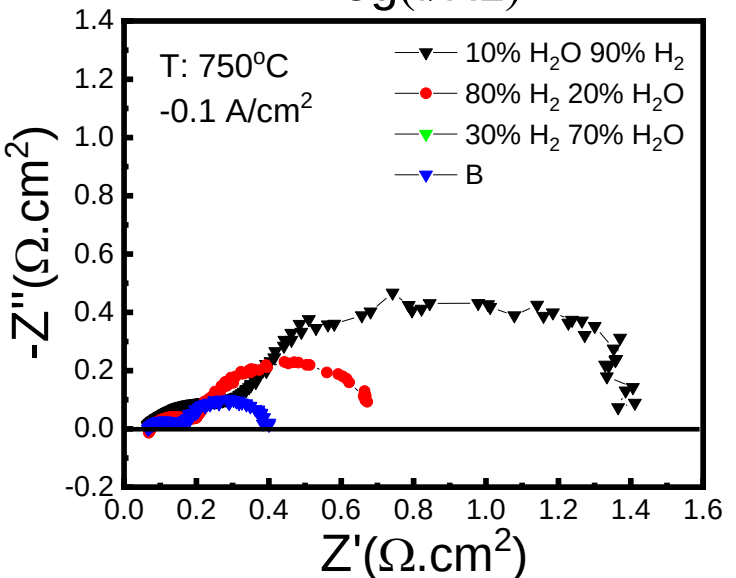
A high ε/τ value will result in a high Faradaic current at the electrolyte/ electrode interface.

Task: High Performance SOEC – Thinner Electrode

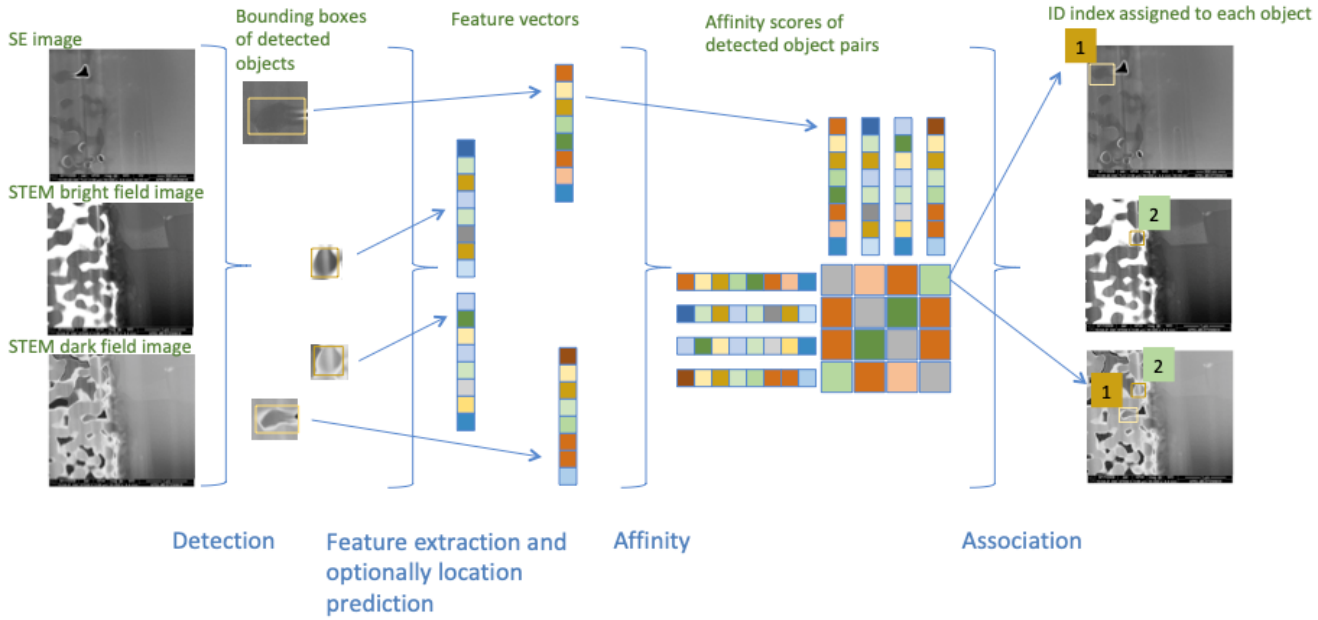








Proposed Steps of the Algorithm for Image Analysis

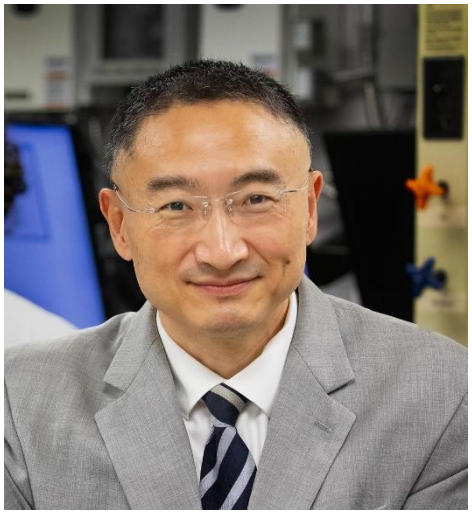


1. **Detection stage:** an object detection algorithm analyzes each input frame to identify objects belonging to the target classes (such as pores or grains) using bounding boxes;
   - the output of Stage 1 is a list of bounding boxes for each of two (or more) neighboring frames; each box corresponds to an object;
2. **Feature extraction stage:** one or more feature extraction algorithms analyze the detections from Stage (1) to extract shape information;
   - the output of Stage 2 is, for each bounding box from Stage 1, a feature vector;
3. **Location prediction stage:** predict the next position of each tracked object; this stage is optional for when we match across image modalities;
   - the output of Stage 3 is, for each feature vector, an appendix that contains the predicted location in the next frame;
4. **Affinity stage:** the feature and location predictions are used to compute a similarity/distance score between pairs of detections;
   - the output of Stage 4 is a matrix which has as elements the score between a pair of detections;
5. **Association stage:** the scores from Stage 4 are used to associate detections belonging to the same target.

Milestone Log

	WBS	Title	FY2022				FY2023			
			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	1	Task 1. Project Management, Planning and Reporting								
2	2	Task 2. Fabrication of button cells and single cells								
3	M2.1	Achieving metal supported SOECs single cells (5x5 cm^2)			◆ 01/30					
5	3	Task 3. Cell Testsing and Develop Accelerated Test Protocols								
6	M3.1	Achieving reliable baselines				◆ 06/30				
7	M3.2	Achieving accelerated test protocols for SOECs								09/30 ◆
8	4	Task 4. Theoretical Analysis, Diagnosis, and Post Analysis								
9	M4.1	Successful acquisition of sectional images of SOECs					03/01 ◆			
10	M4.2	Establish quantitative relation between performance and microstructure details through machine learning							09/01 ◆	

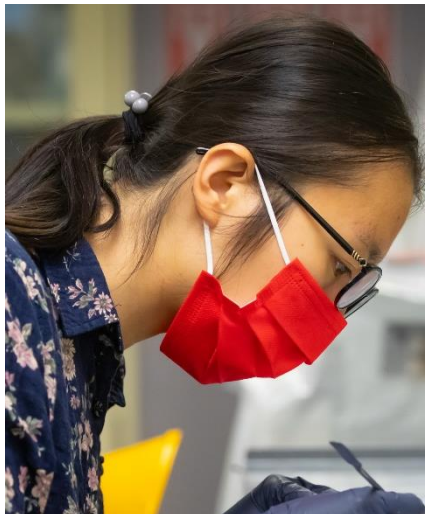
Investigators and Team Members



Xiao-Dong Zhou, PI

Henry Chu, Co-PI

Tom Pesacreta, co-PI



Yanhua Sun, Postdoc

Yudong Wang
Graduate Student

Alex Tucker
Under/graduate Student

Noah Richard
Undergrad Student

Austin Schilling
Undergrad Student

Jacob C Hoffpauir
Undergrad Student

Project Budget and Period

	Type	Budget	Activities	Period
DOE	Cash	$1,000,000	Cell fabrications	09/10/21 – 09/09/23
UL Cost Share	Cash at UL	$172,414	1. Postdoc fellow 2. Materials	09/10/21 – 09/09/23
	In-kind at UL	$77,586	1. Indirect cost of cash cost share	09/10/21 – 09/09/23
Total	$1,250,000; Cost share percentage: 20% (cash% = 13.8%)			

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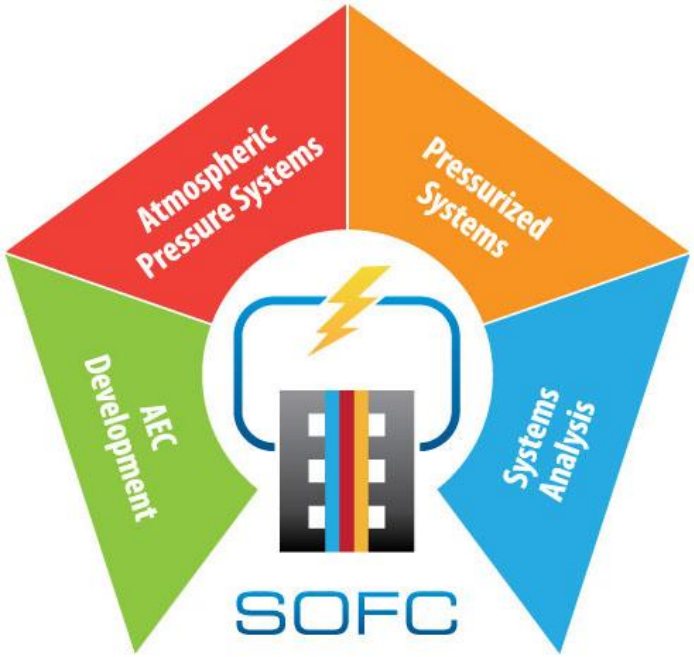

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