Efficient, Reliable, and Cost-Effective Reversible Solid Oxide Cell Technology for Hydrogen and Electricity Production

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Project Overview

- Project: Efficient, Reliable, and Cost-Effective Solid Oxide Cell Technology for Hydrogen and Electricity Production (DE-FE0031940)

- Project Objective: Develop and demonstrate reversible solid oxide cell (RSOC) technology with the three main specific objectives
  (i) To validate design, materials and process of technology for both hydrogen and electricity production
  (ii) To demonstrate operation of the technology at relevant conditions with improved performance, reliability and endurance
  (iii) To confirm the cost effectiveness of the technology via a techno-economic assessment of a selected application

- DOE/NETL Project Manager: Ms. Sarah Michalik

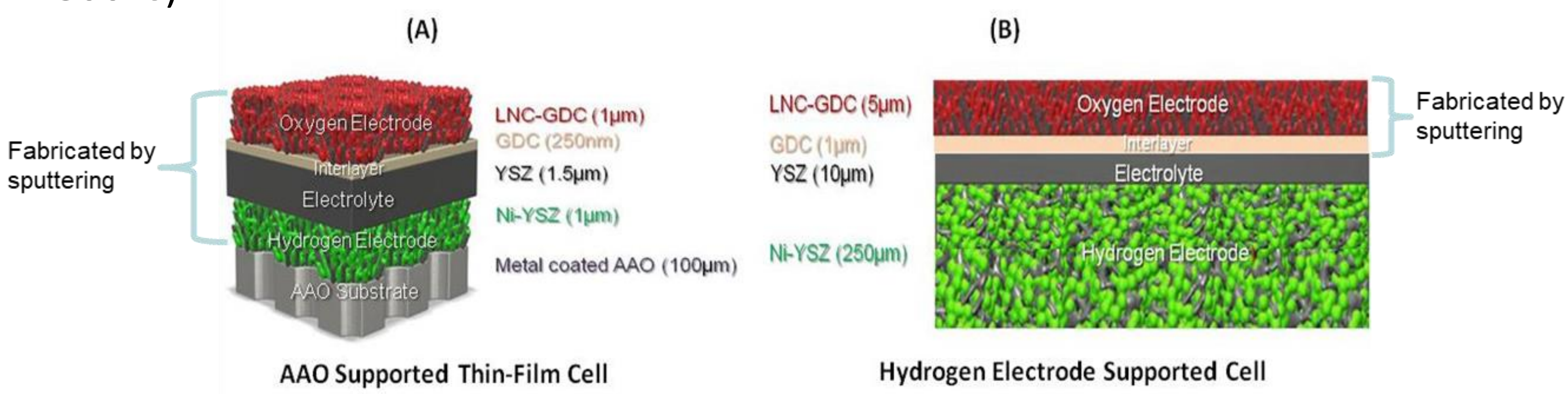
- Project Team:
  - ❑ UCSD
  - ❑ OxEon

RSOC Technology

- RSOC technology evaluated in this project has two key elements
  - A compact, versatile and low-cost stack architecture: arrays of cell modules in electrical parallel and series connection
  - Superior-performance, fuel-flexible reversible cells incorporating components fabricated by sputtering

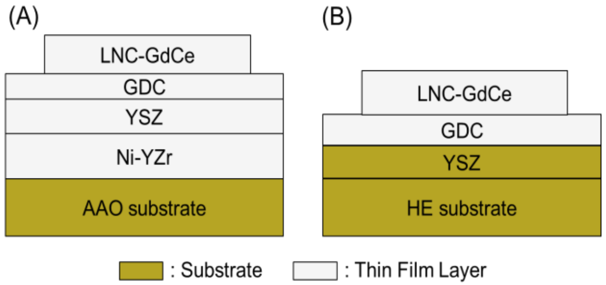
Cell Configurations

- Cell Structure: (A) Substrate supported thin-film (TF) reversible solid oxide cell (RSOC) (500˚-700˚C) and (B) Hydrogen electrode (HE) supported RSOC (700˚-800˚C)



- Cell and substrate materials:
  - Electrolyte : yttria stabilized zirconia (YSZ)
  - Hydrogen electrode: Ni-YSZ
  - Oxygen electrode: lanthanum nickel cobaltite (LNC)-gadolinium doped ceria (GDC)
  - Electrolyte/electrode interlayer: GDC
  - Substrate for TF-RSOCs: Porous ceramic or metal substrates

Cell Designs - Motivation



- Two types of cell configuration
  - Demonstrate the capability of the stack design to ***incorporate different types of cell operating at different temperatures***
  - Use the more advanced ***HE-supported cell as a backup with regards to risk mitigation***
  - Leverage and apply the development of ***sputtered high-performance oxygen electrodes for TF cells to HE-supported cells to improve performance*** as compared with state-of-the-art

- LNC-GDC oxygen electrode
  - ***A perovskite with high electrical conductivity***
  - LNC ($La_{0.97}Ni_{0.5}Co_{0.5}O_{3-\delta}$) contains ***no strontium, so***
    - ***unwanted Sr segregation***
    - ***unwanted Sr interactions with YSZ to form strontium zirconate***
    - ***interactions with volatile Cr species to form strontium chromium oxides***

    are avoided

Project Activities

- Application Selection and System Design and Analysis
  → completed & reported in the previous meeting

- Techno-Economic Assessment

- RSOC Cell Development

- RSOC Stack development

- Stack Operation Demonstration

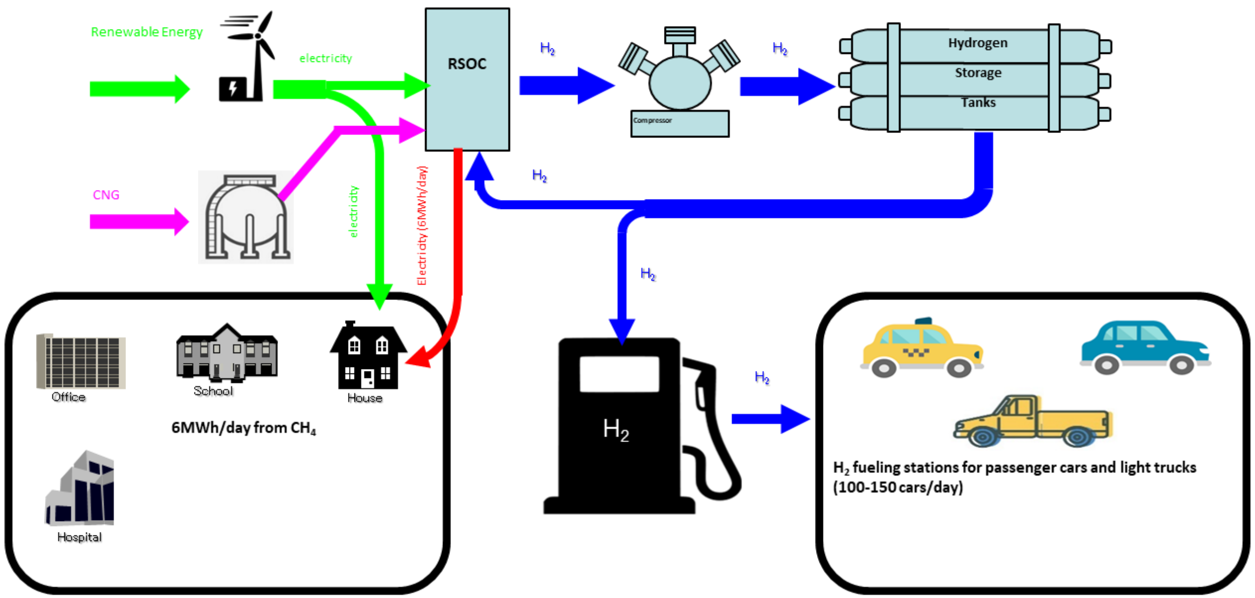
Techno-Economic Assessment - Objective

- Estimate the cost of hydrogen (CoH) for hydrogen production from the system designed for the specific application

- Estimate three key cost elements in the CoH:
  - Capital cost: Stack cost and BOP (balance of plant) cost
  - Feedstock cost: Electricity, steam, heat source for heater and cooling water
  - O&M cost: Fixed cost and stack replacement cost

Stack Capital Cost Estimation

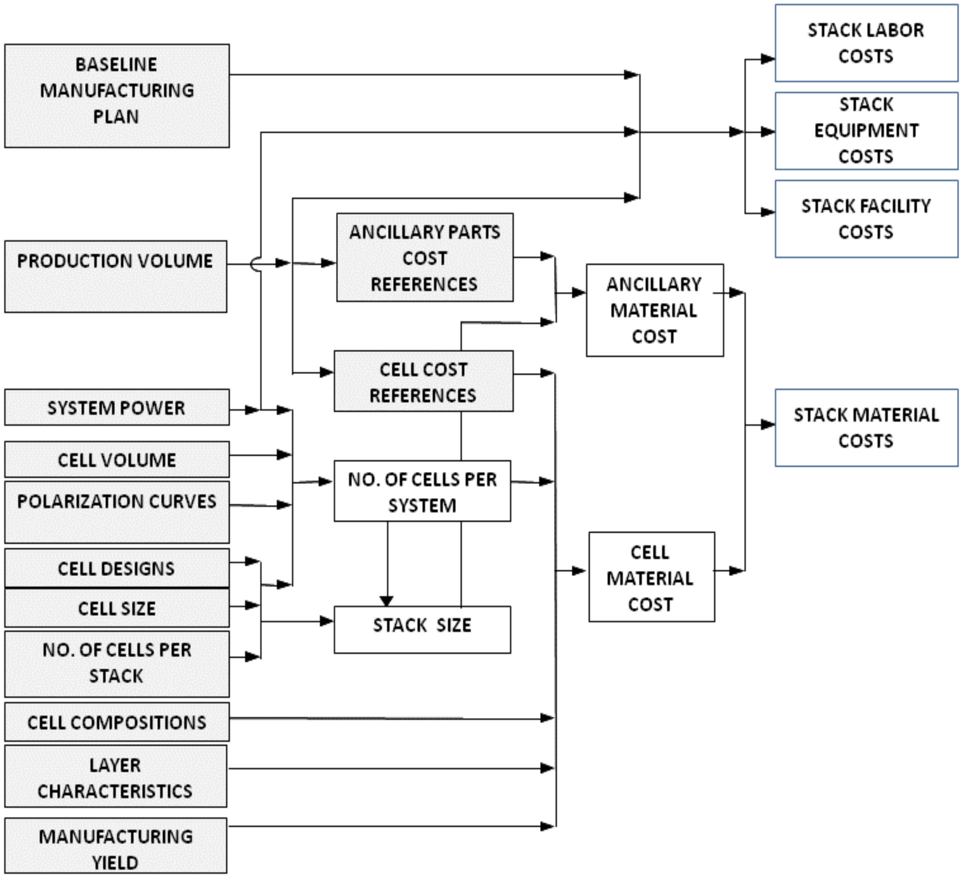
Application Assumptions



	Gas station	Replace by 10%		
		RSOC system	H_2 production	Number of RSOC cell
Gas fueling stations (convenience store) in U.S.	150,000 (127,588) (1)	15,000 units	8.2 million tons/year	7.8 million cells/year(2)

(1) https://www.api.org/oil-and-natural-gas/consumer-information/consumer-resources/service-station-faqs#:~:text=The%20NACS%2C%20the%20association%20for,are%20convenience%20stores%20selling%20fuel.
(2) Lifetime of RSOC system is 10 years and cell size is 15cm x 15cm

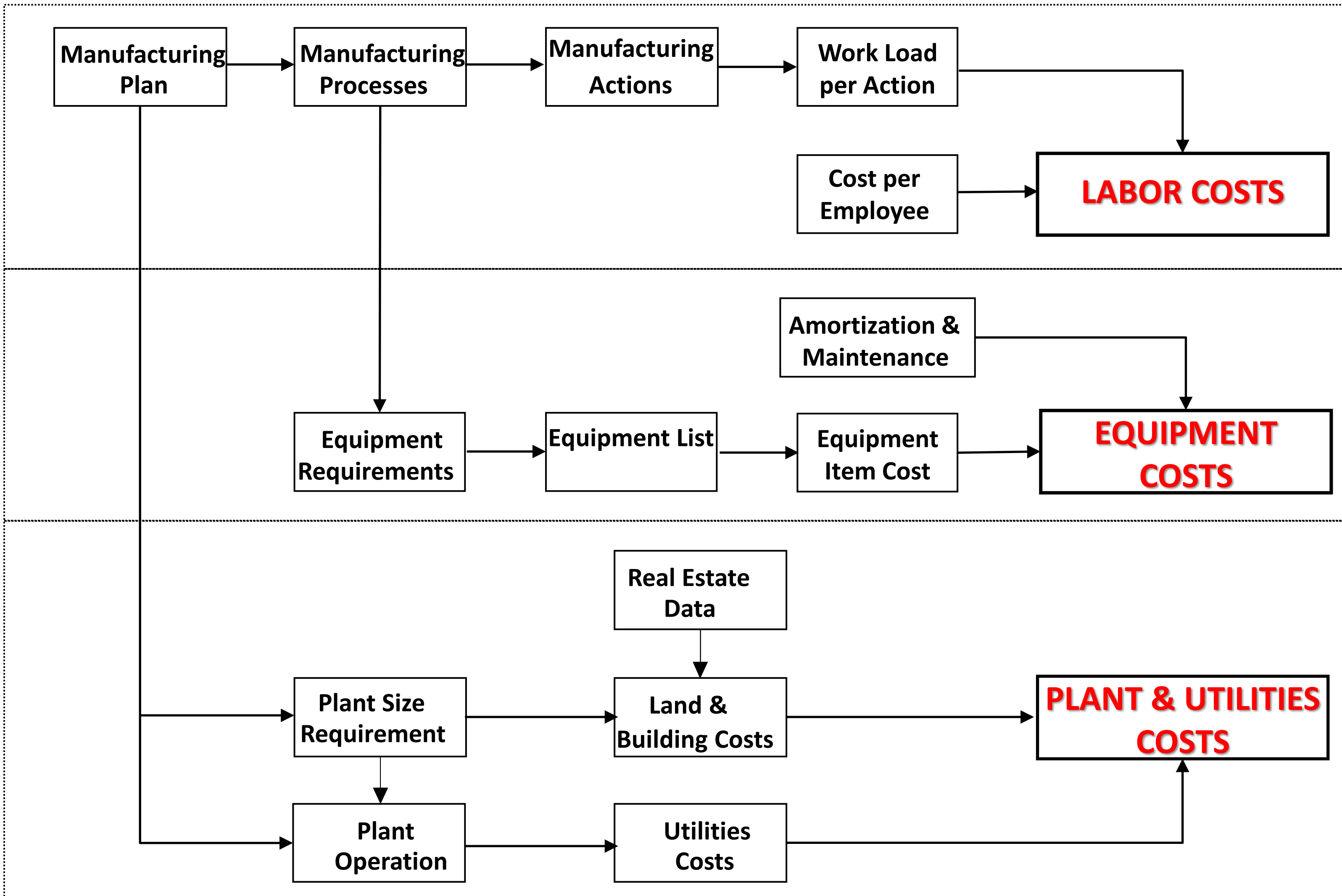
Stack Cost Estimation Process



Key assumptions in stack cost estimation:

- Thin-film cells made by sputtering with anodic aluminum oxide (AAO) substrates
- UCSD stack design
- Thin-film cells manufactured in plant, other stack components procured from outside vendors/suppliers

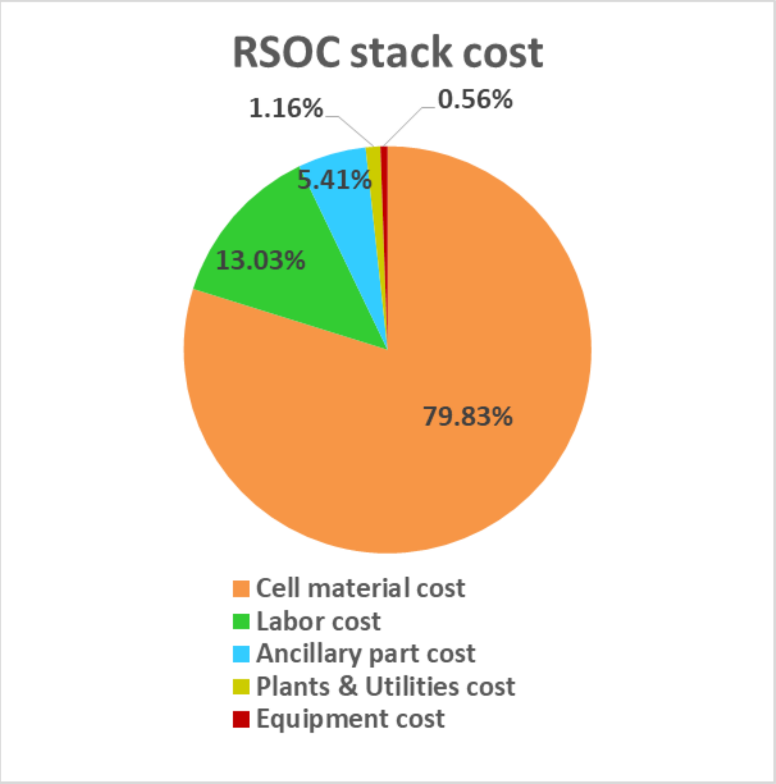
Estimation Process for Other Stack Costs



Techno-Economic Assessment

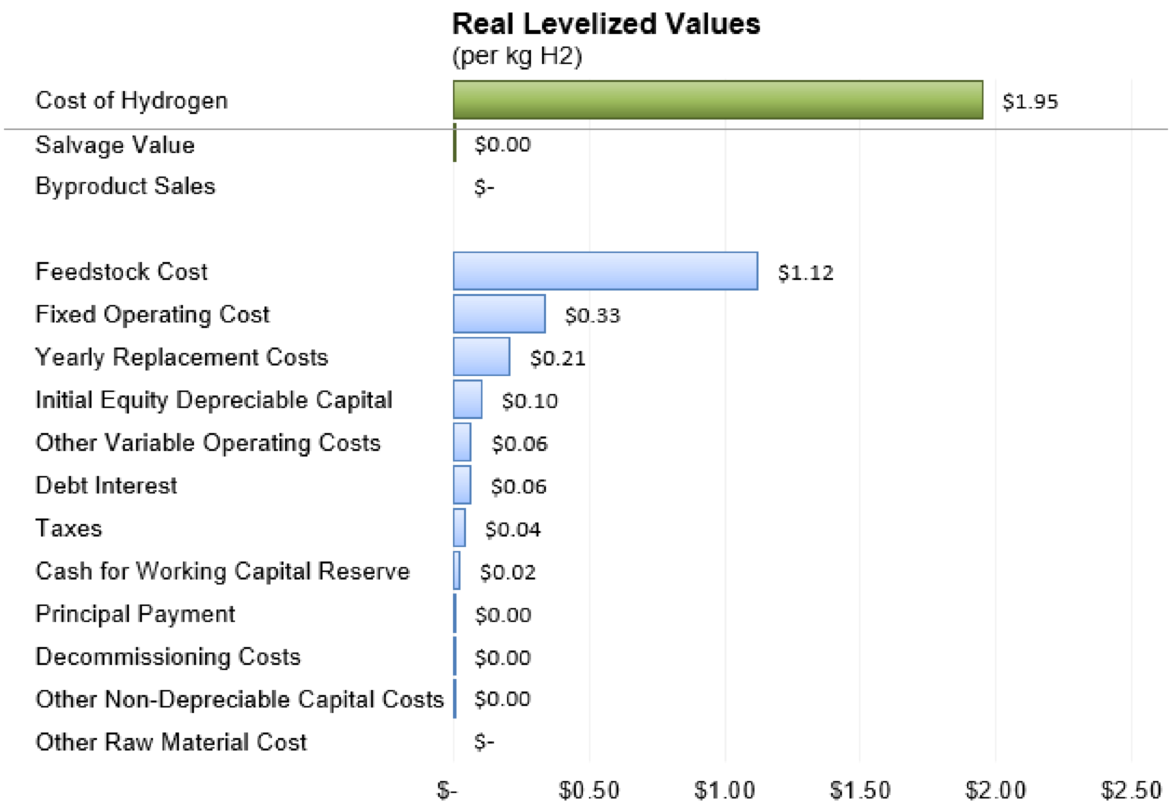
Total Stack Cost Breakdown

	Cost ($/kW)	
Cell material cost	150.16	79.83%
Labor cost	24.51	13.03%
Ancillary part cost	10.18	5.41%
Plants & Utilities cost	2.18	1.16%
Equipment cost	1.06	0.56%
Total	**188.09**	



Estimated Cost of Hydrogen (CoH)

using DOE H2A cost analysis tool

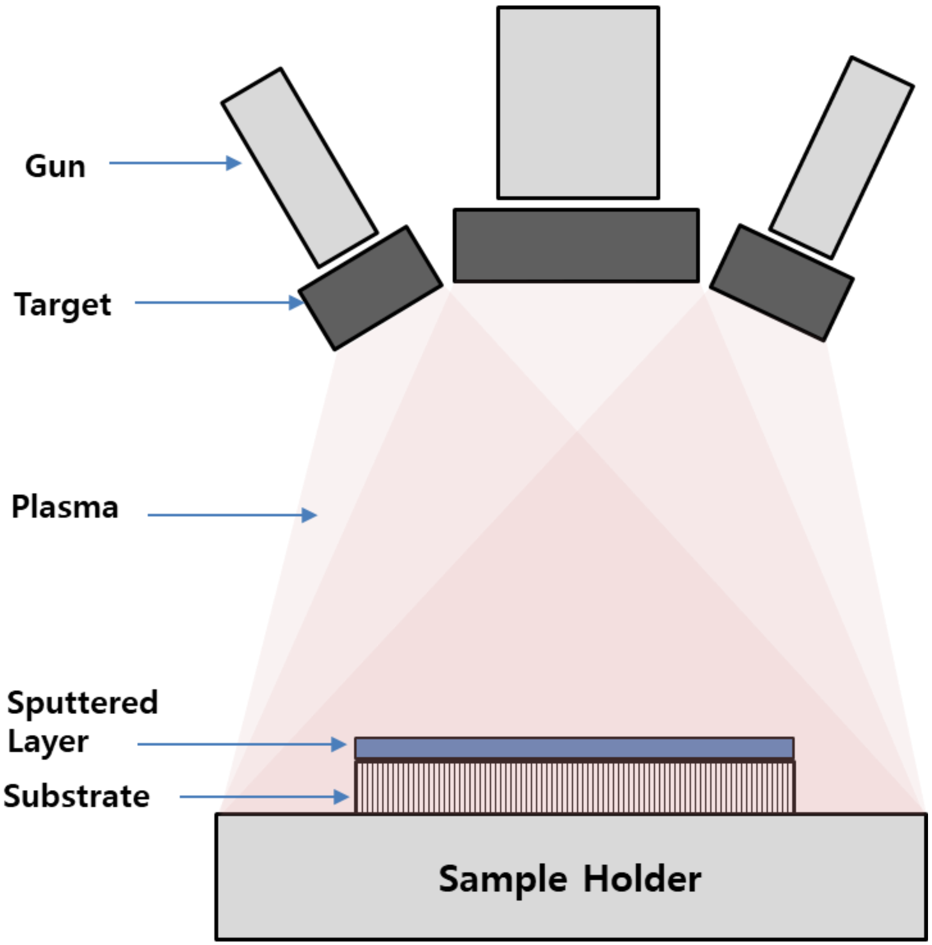


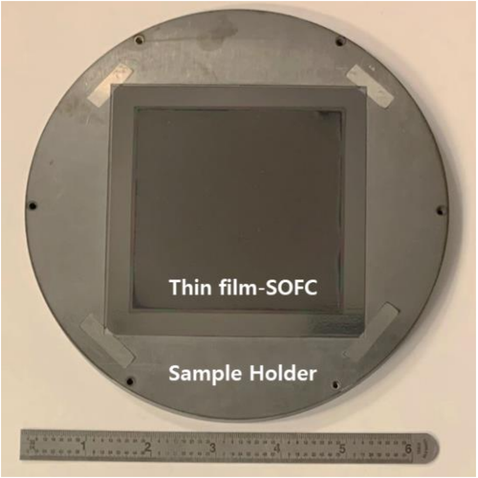
RSOC Cell Development - Key Activities

- Sputtering process scale-up studies
  - Demonstrate sputtering process scalability, especially for the GDC interlayer and LNC-GDC oxygen electrode, up to 15cm x 15cm
  - Improve film uniformity

- Cell performance characterization
  - Electrochemical performance testing and performance mapping
  - Durability and long-term operation evaluation

Sputtering Process

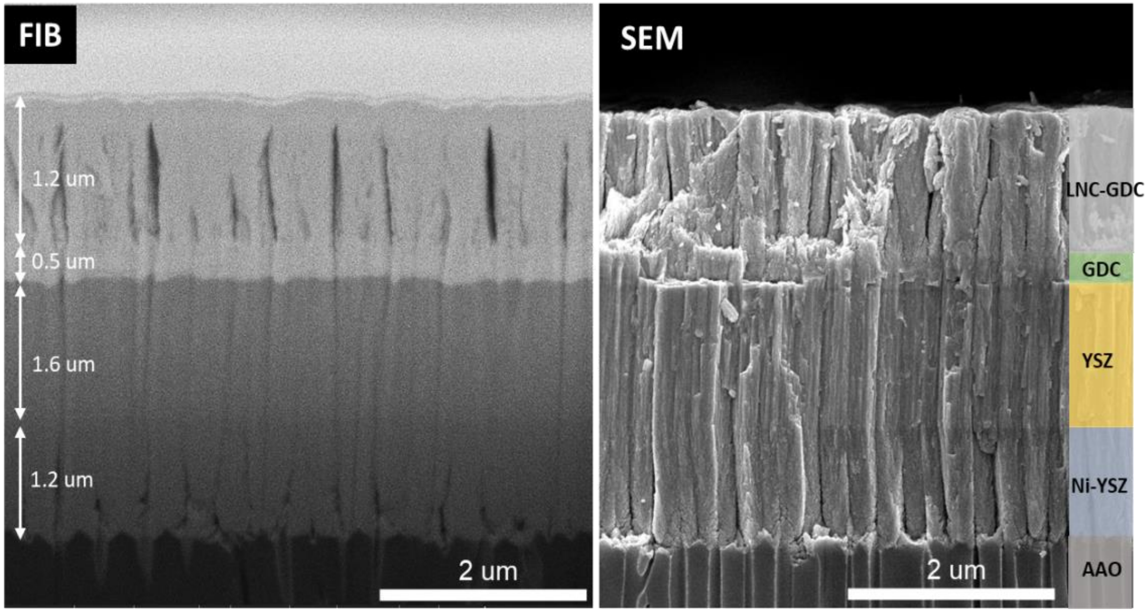




Sputtering Process Parameters

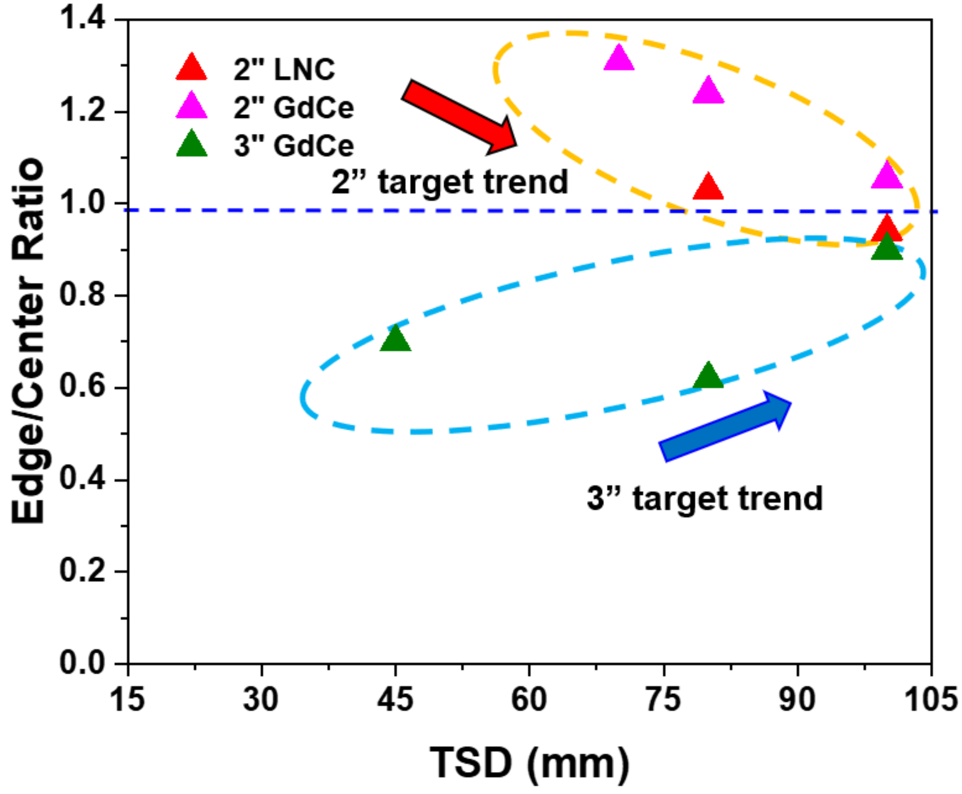
Key process parameters:

- Chamber pressure
- Target to substrate distance (TSD)
- Power
- Atmosphere



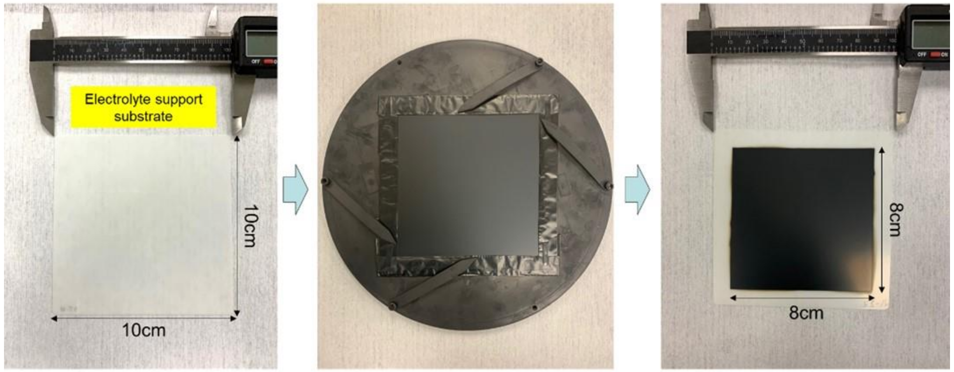
Sputtered Layer Thickness Uniformity

Deposited with Different TDS and Target Size



RSOC Cell Development

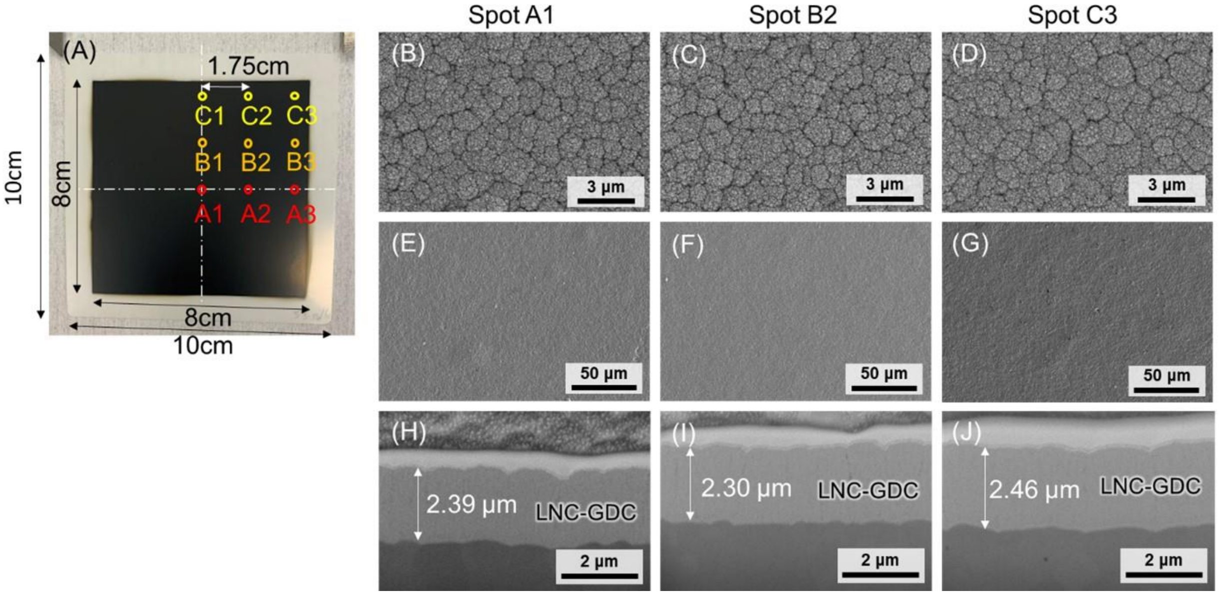
Fabrication Scaleup – LNC-GDC



10cm×10cm
Electrolyte support substrate

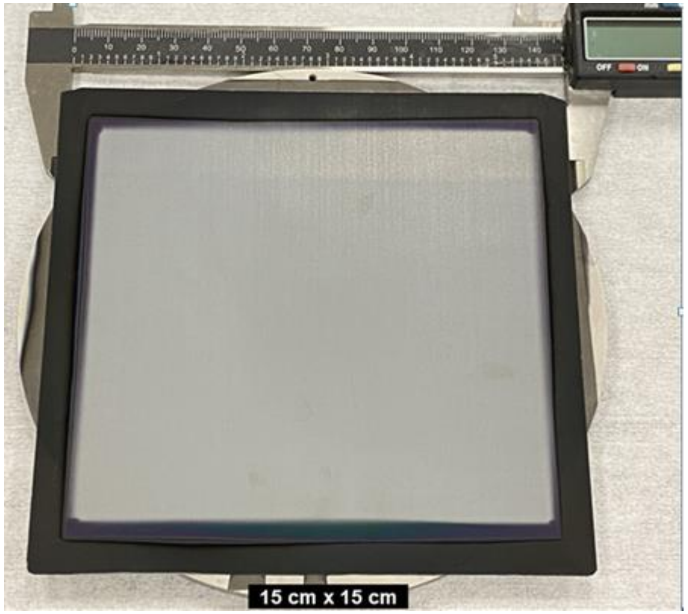
8cm×8cm LNC-GDC
deposition with mask

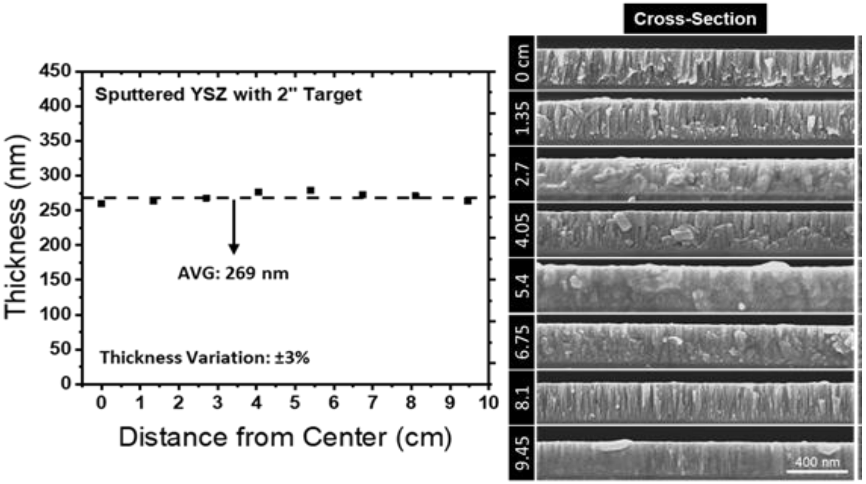
After 8cm×8cm
LNC-GDC deposition



RSOC Cell Development

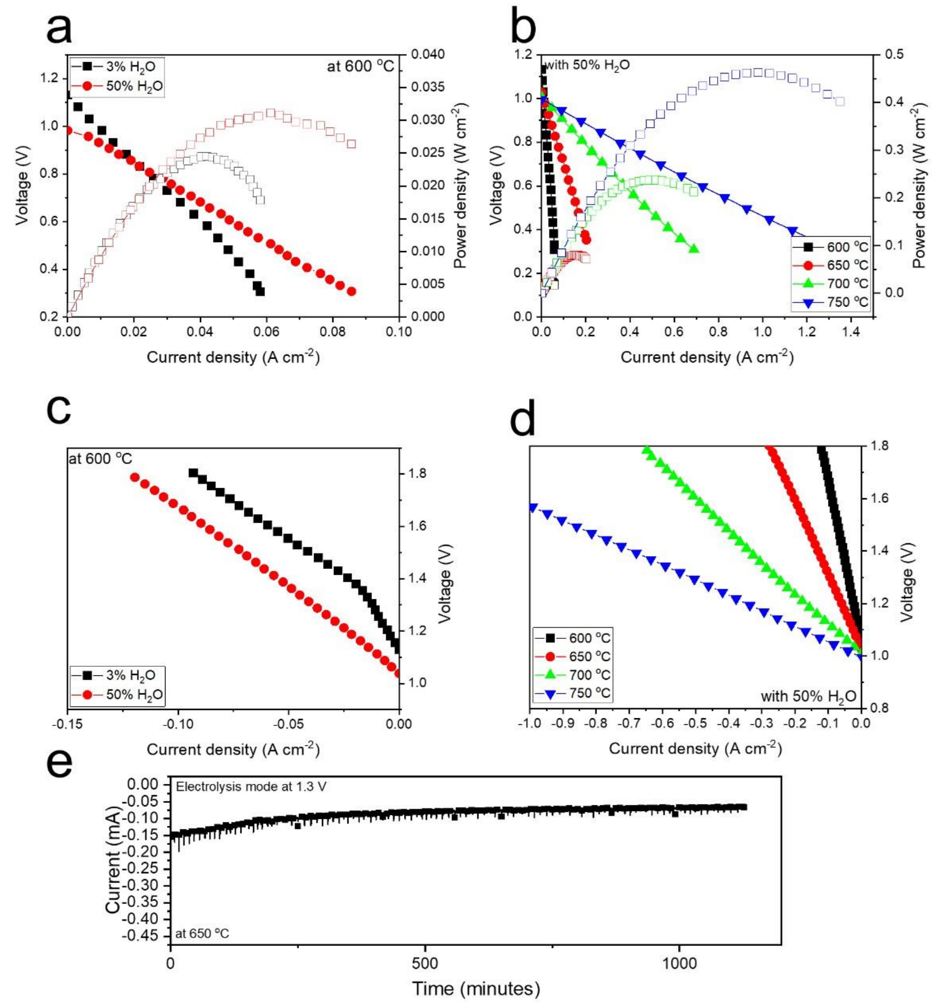
Sputtered Cell Scaleup – YSZ





Evaluation of LNC-GDC Oxygen Electrode

- LNC-GDC electrode reversibility
- Performance better than conventional LSC-GDC electrode
- Short-term stability

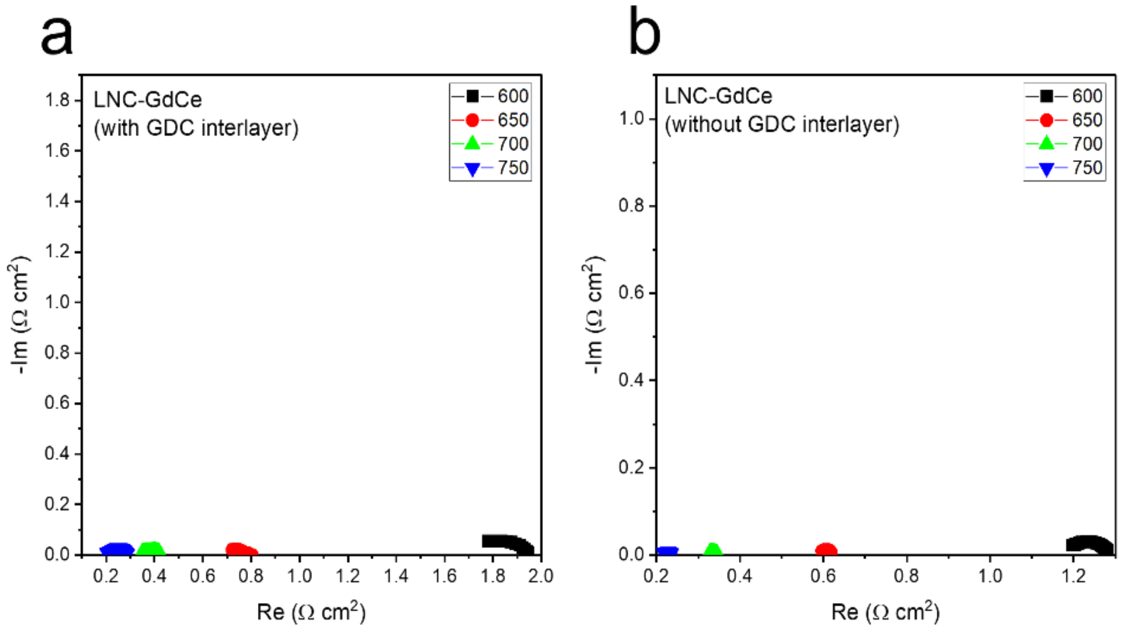


Electrolyte support cell of configuration LNC-GDC|GDC|YSZ|Ni-YSZ

Evaluation of LNC-GDC Oxygen Electrode

with and without GDC interlayer

AC Impedance Spectra

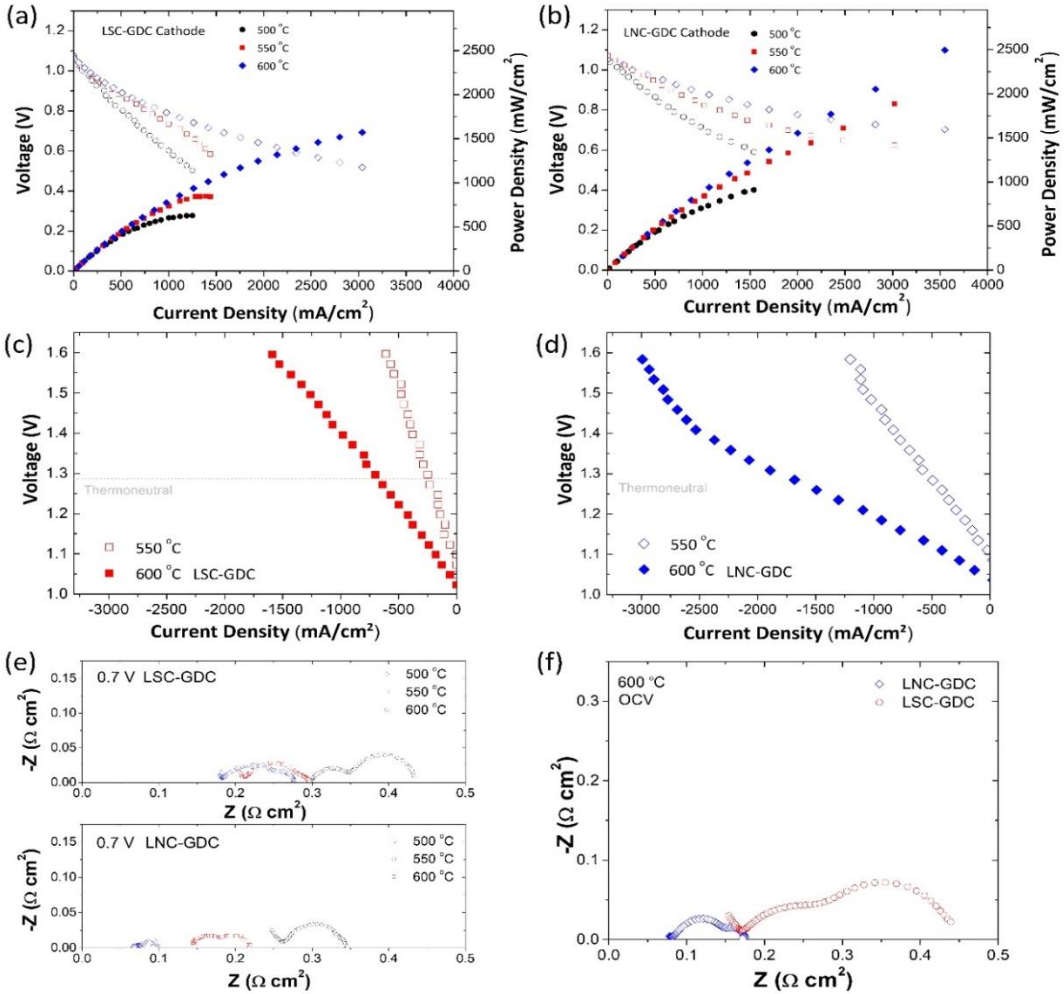


YSZ supported symmetric cell with the configuration of
(a) LNC-GDC|GDC|YSZ|GDC|LNC-GDC and (b) LNC-GDC|YSZ|LNC-GDC

LNC-GDC electrodes without GDC interlayer showed better performance

Performance of Sputtered Cells

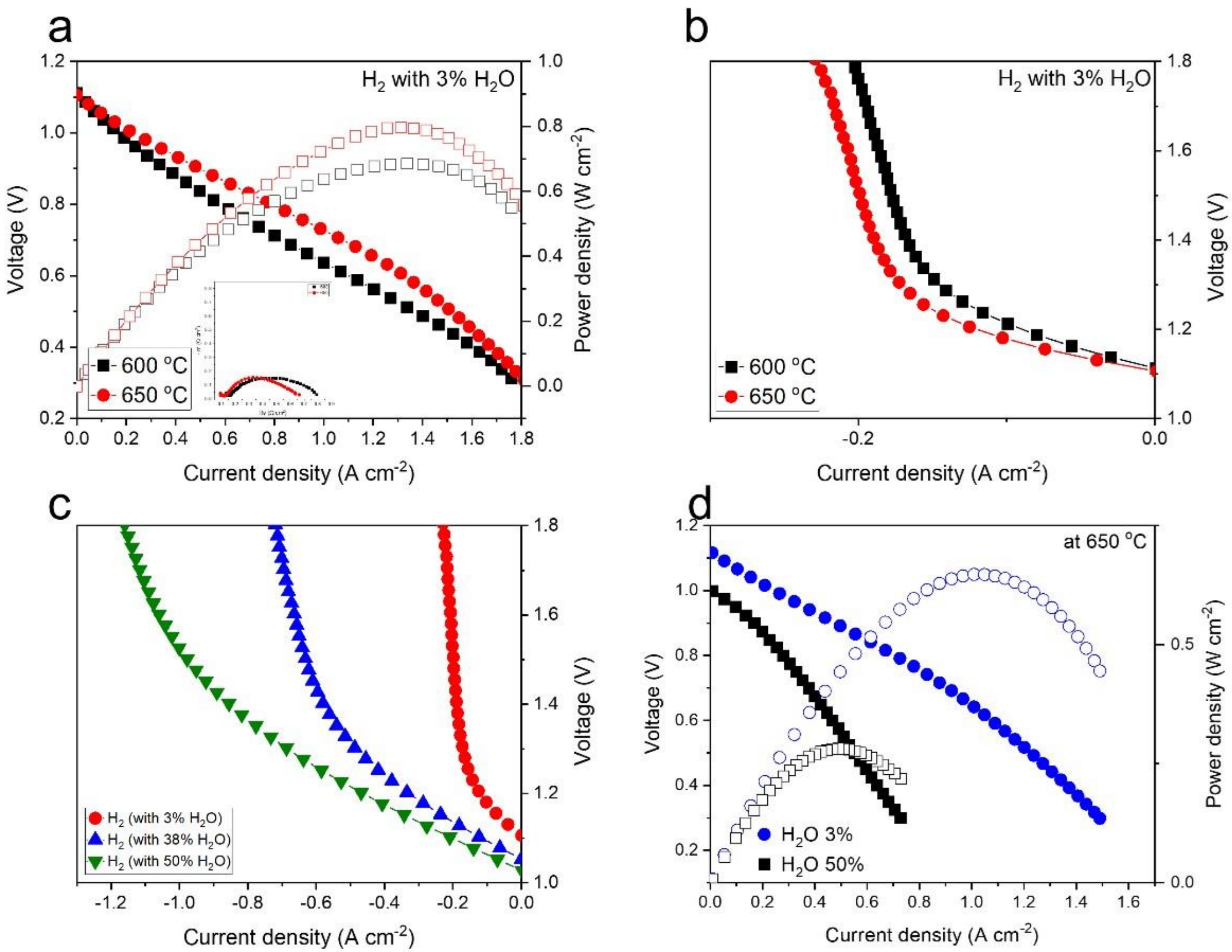
Comparison of LNC-GDC with LSC-GDC



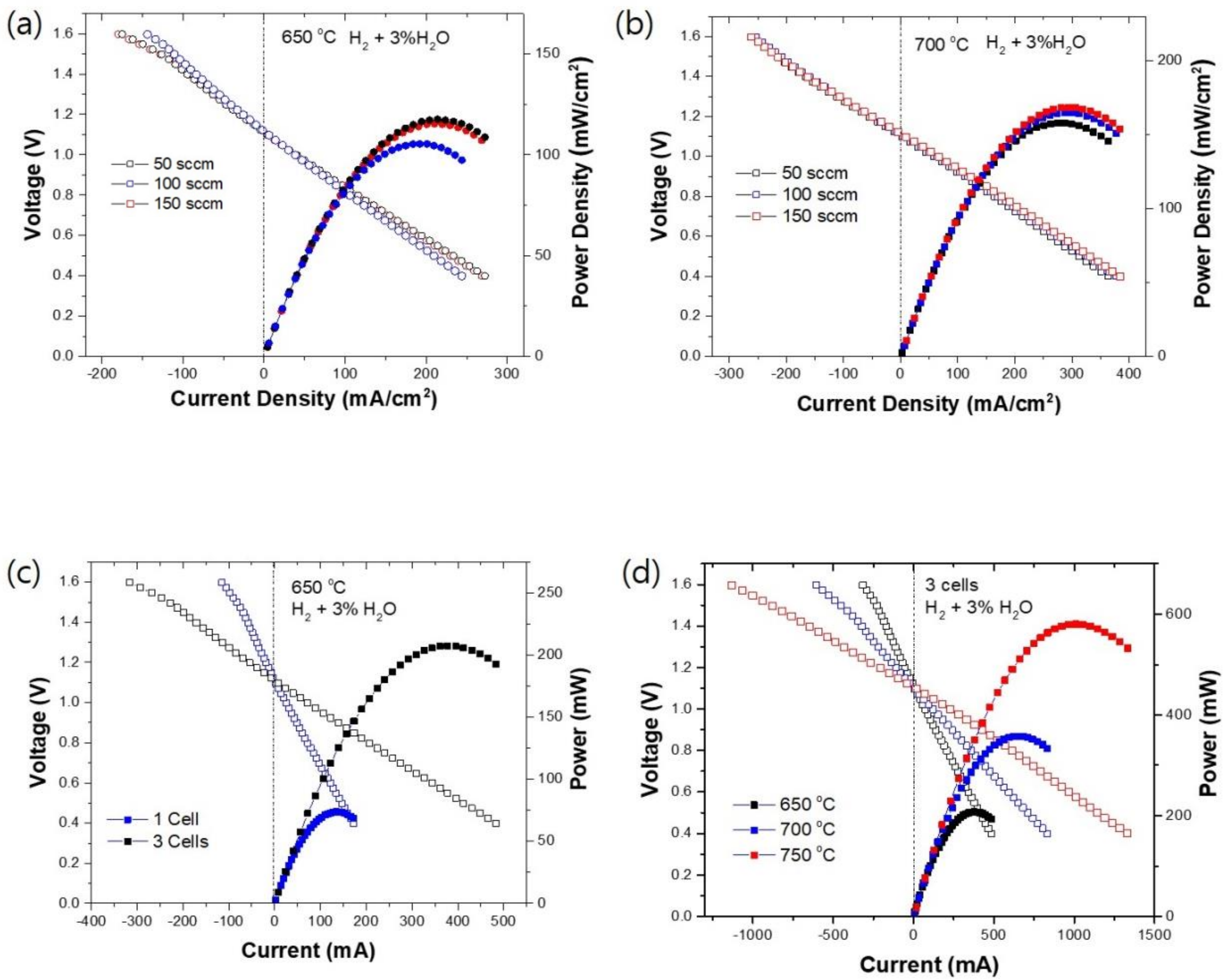
Extraordinarily high cell performance with LNC-GDC oxygen electrode at reduced temperatures (550°-600°C)

Performance of HE Supported Cells

with LNC-GDC Oxygen Electrode



Testing of 3-Cell Module



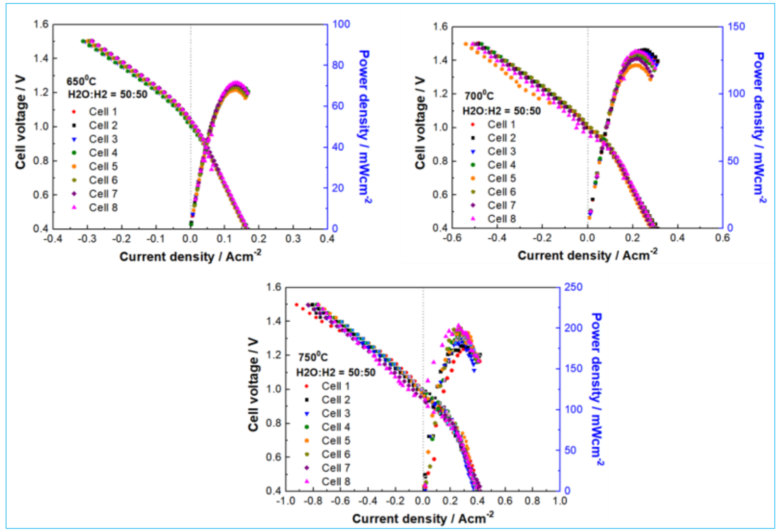
2cmx2cm electrolyte supported cells

RSOC Stack Development

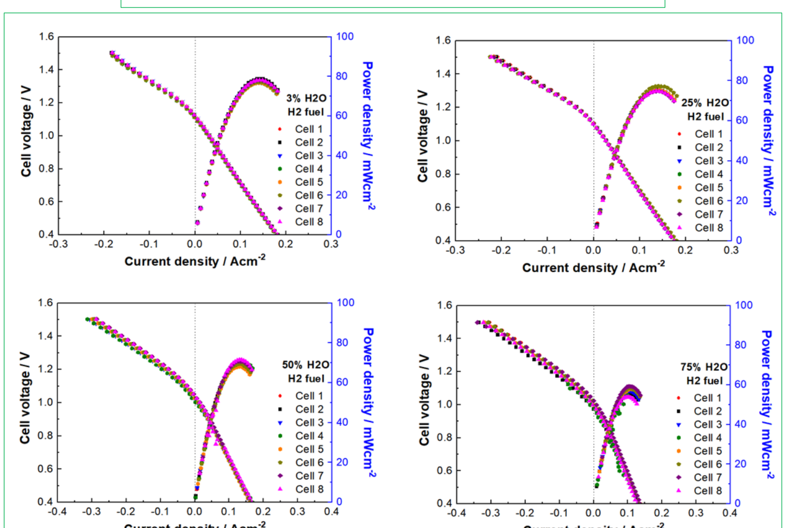
Testing of 8-Cell Module –Performance Map

2cm x 2cm cell

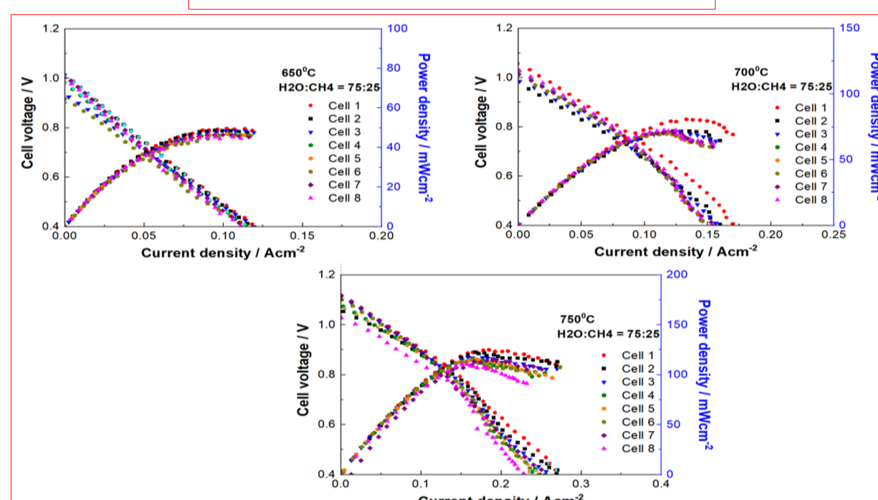
Different Temperature



Different Steam Composition at 650ºC

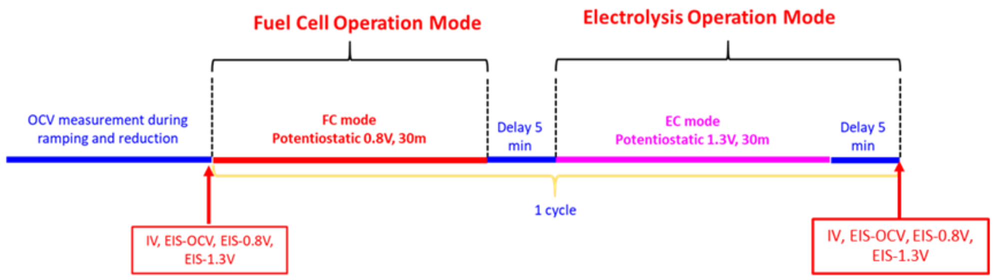


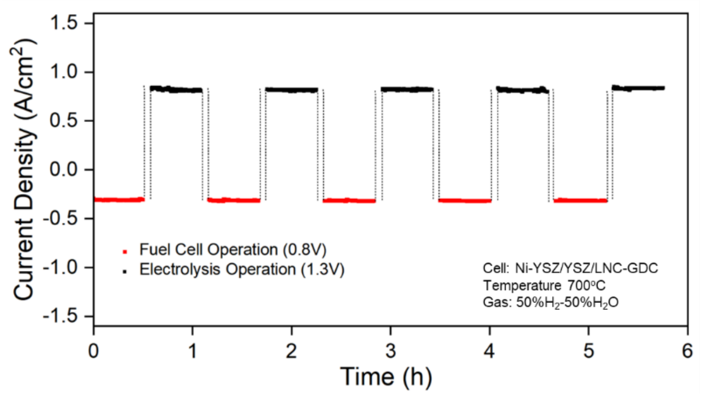
Fuel Cell Mode with Methane Fuel

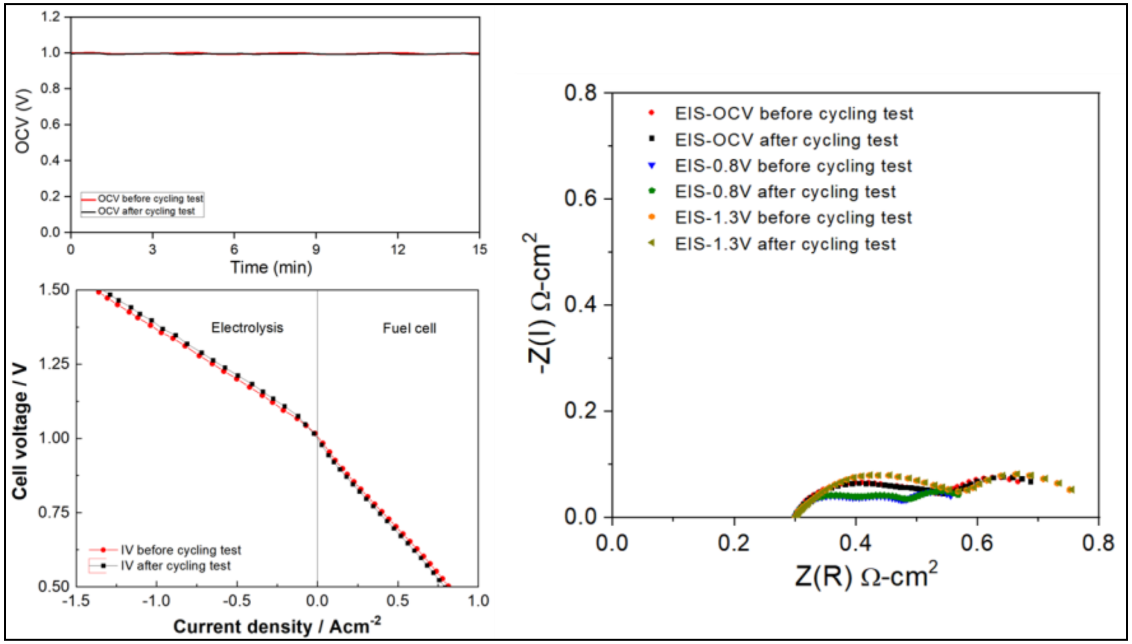


RSOC Stack Development

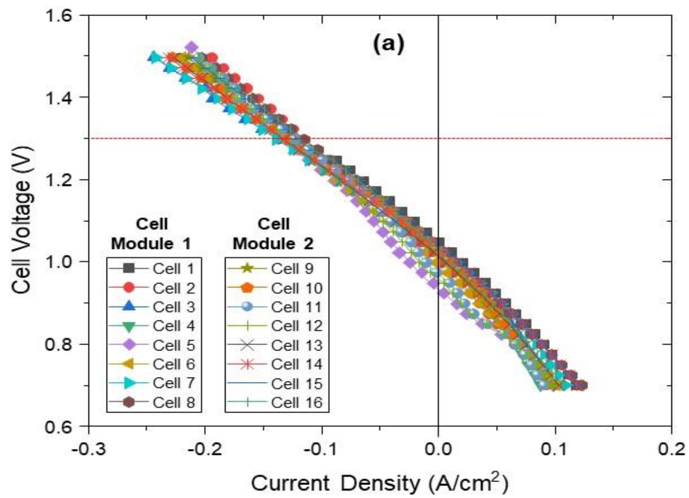
Cyclic Testing

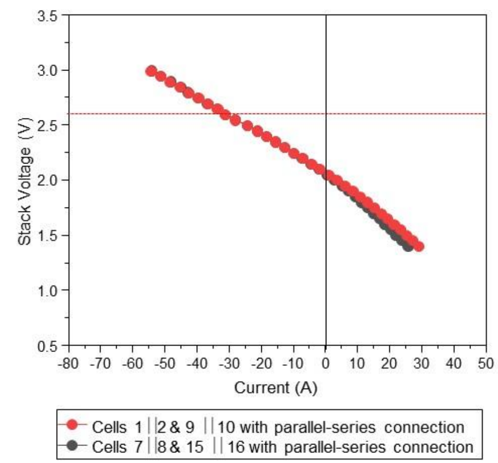




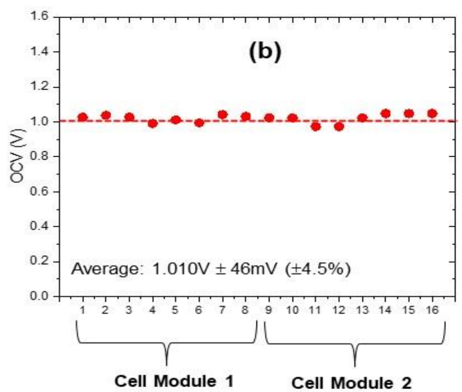


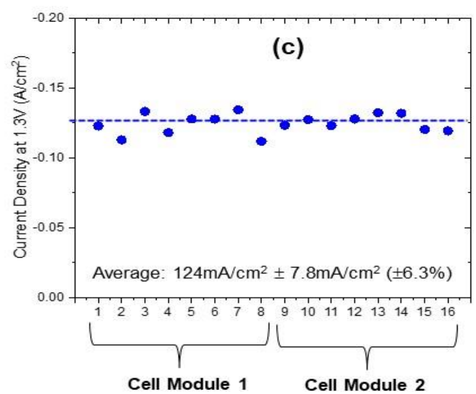
Testing of Stack of Two 8-Cell Modules





Cell Parallel-Series Connection

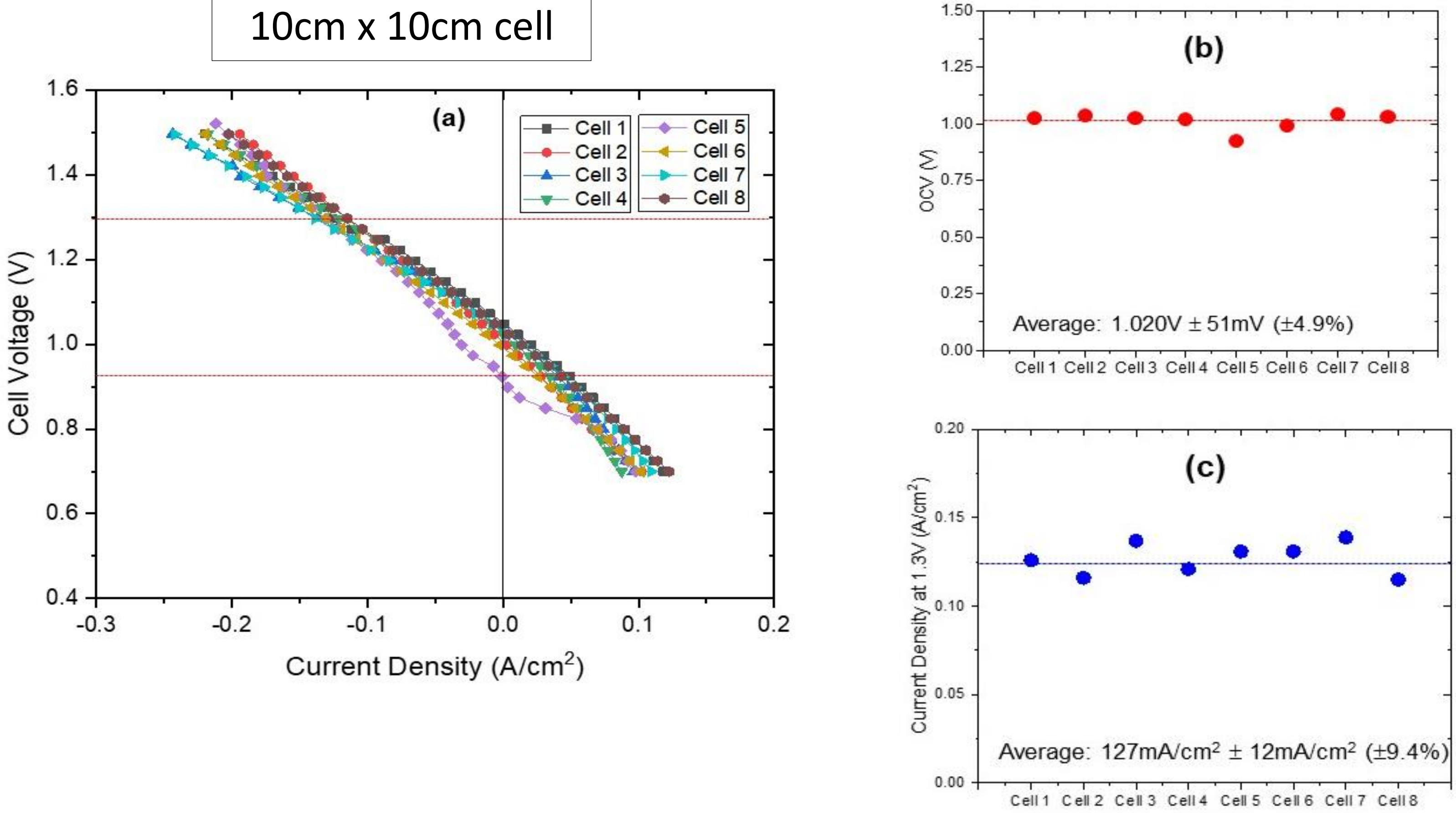




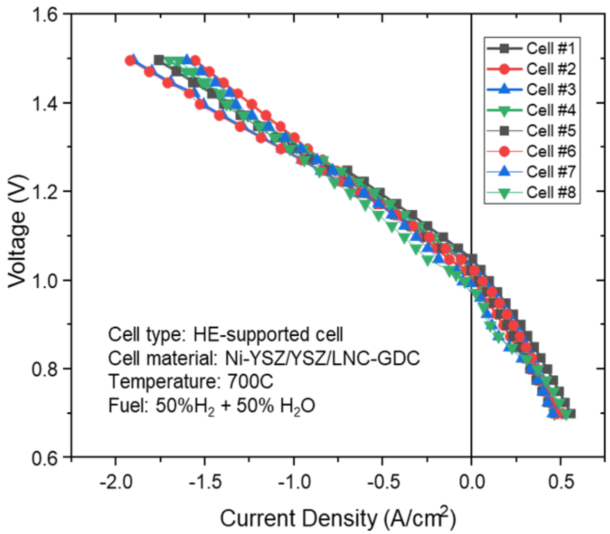
2.5cm x 2.5cm cell
700°C
50%H_2-50%H_2O

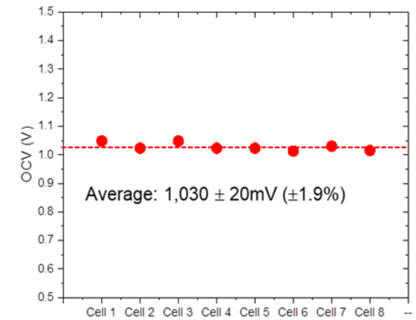
Testing of 8-Cell Modules 10 cm x 10 cm cell

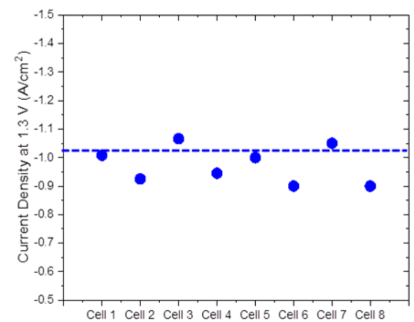
10cm x 10cm cell



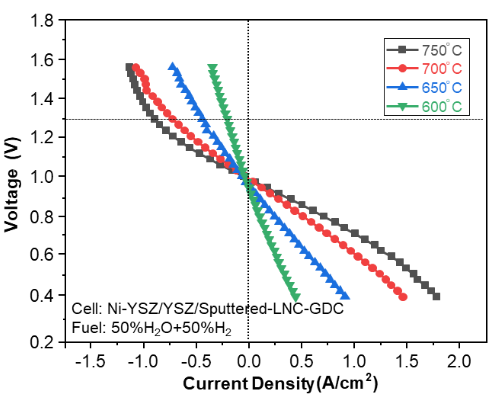
Testing of 8-Cell Modules 15 cm x 15 cm Cell



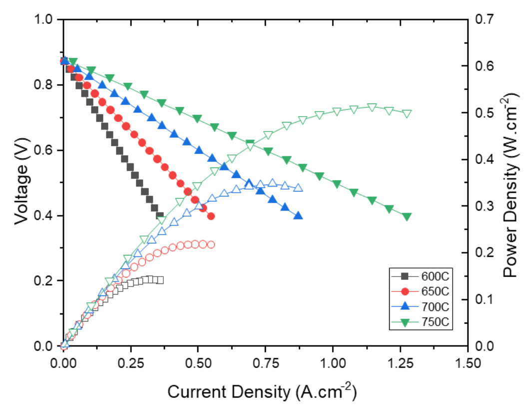




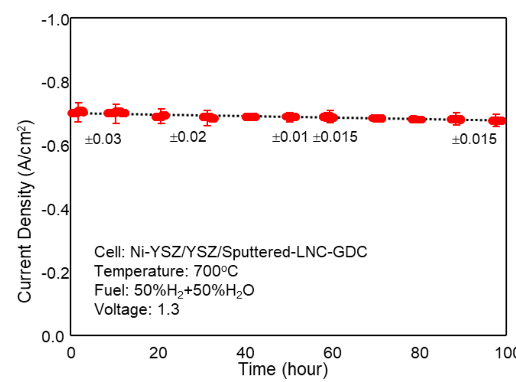
Cell Performance (Reversible)



Cell Performance (Fuel Cell Mode with Methane)



Short-term Durability



Highlights

- Conducted **techno-economic assessment** and indicated potential for **low stack cost and cost of hydrogen** for systems incorporating **sputtered cells**
- Demonstrated **scalability of sputtering** process
- Demonstrated **superior cell performance** with **LNC-GDC** oxygen electrode
- Showed **reversible** operation
- Showed **feasibility of the stack architecture** with operation of multi-cell stacks with **uniform cell performance** in fuel cell and electrolysis modes

Acknowledgments

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- SOFC/SOEC/RSOC team at UCSD and OxEon