

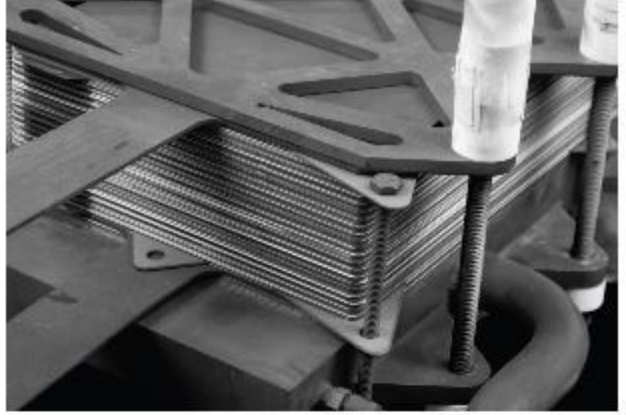



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Northwestern University

COLORADO SCHOOL OF MINES

Versatile Reversible Solid Oxide Cell System for Hydrogen and Electricity Production

Alexander Vaeth

Nexceris Mission

Our vision is to create a better world through energy innovations.

We collaborate with leading global customers and partners to transform powerful ideas into solutions that make energy production safer, more efficient, and environmentally responsible.

The Value of Nexceris

Nexceris is Vertically Integrated for SOC Development

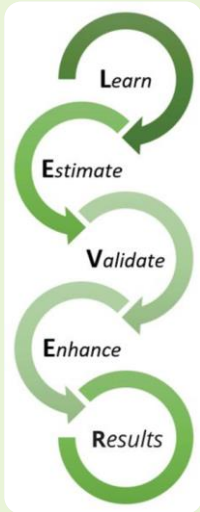
Products

- ***Fuel Cell Materials*** provides standard and custom SOC materials and components
  - Powders
  - Inks
  - Substrates
  - Cells

- We work with customers to provide materials and components from lab-scale to industrial-scale
- Quickly and accurately tailor powders and components to fit the needs and processes of our customers

Services

- Joint development and contract R&D services
- Leveraging our expertise and 25+ years of know-how in the SOC industry
- Accelerate customer development timelines on material, cell, and stack levels
- Our facilities accommodate a variety of synthesis and testing methods
- Fast-paced, versatile development structure



Nexceris Innovation

Materials	SOCs	Sensors	Catalysts	Protective Coatings
SOCs and energy storage	Stationary and military	Transportation and energy markets	H_2 and chemicals production	SOC and high temperature

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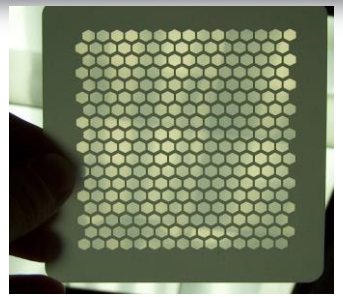
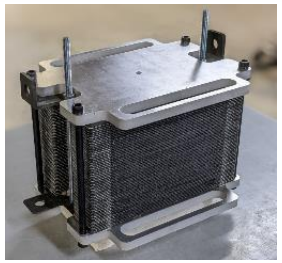
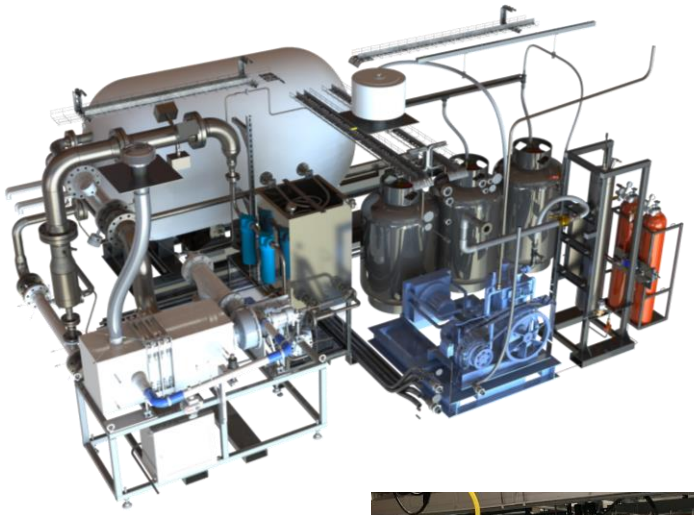
Nexceris Active Projects



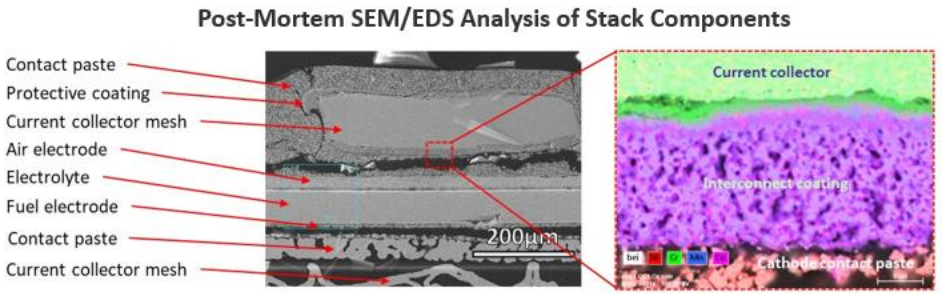
Low-Cost Manufacture of SOEC Stacks [DE-EE0009621]



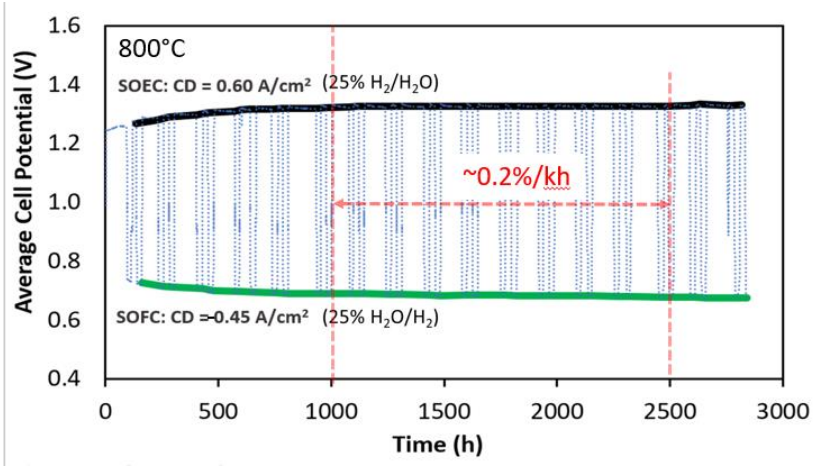


SOFC/Turbine Hybrid Power System [DE-AR0000956]

Integrated Coating for SOEC Degradation [DE-EE0008834]



Reversible Solid Oxide Cell for H_2 and Electricity [DE-FE0031986]



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Versatile Reversible Solid Oxide Cell System for Hydrogen and Electricity Production (DEFE0031986)

Project Objectives

- ≥ 1kW$_e$ power generation in fuel cell mode with roundtrip stack efficiency (RTE) of ≥ 60%.
- Achieve dynamic switching between modes in response to grid demands (6-hr cycles).
- Achieve long-term electrolysis and define a path to produce H_2 at ≤ $2/kg (at scale).
- Demonstrate versatile fuel composition in electrolysis mode (H_2O + CO_2).

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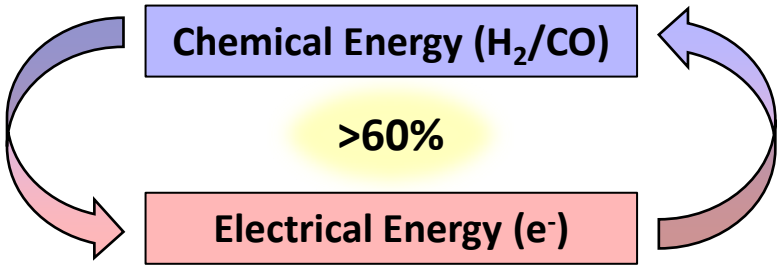
System Design

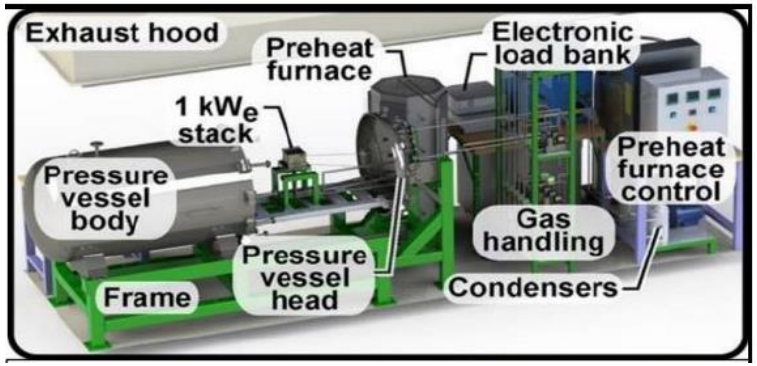
Pressurized System to Increase RSOC Stack Efficiency

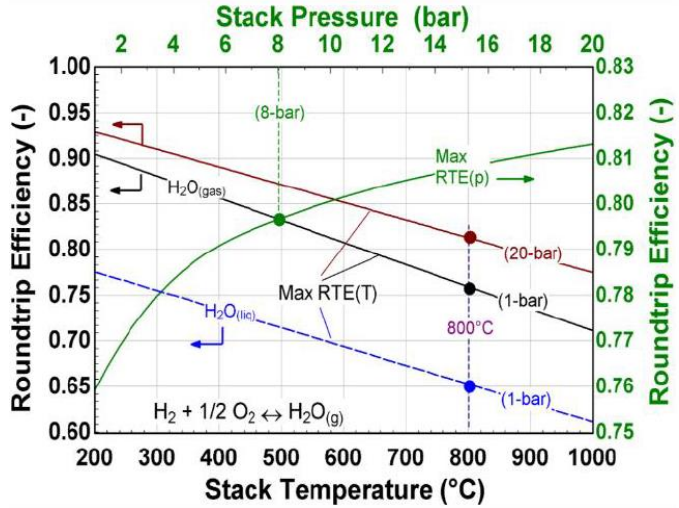
- Theoretical round-trip-efficiency (RTE) of the stack is a function of **temperature** and **pressure**

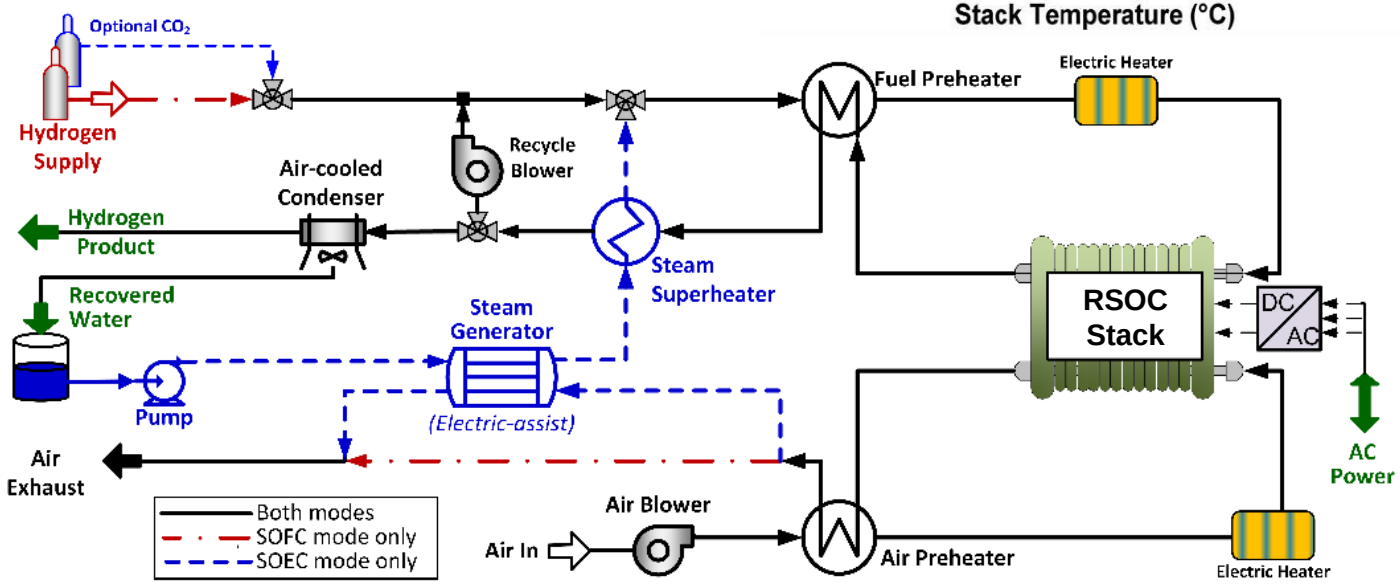


- RTE *increases* with **pressure**
  - Stack performance (kinetics, mass transport) also expected to increase with pressure

- Majority of RTE increase is gained up to ~8bar







System Design

Major Challenges and Goals for Proposed System

Electrode Performance & Stability

- *Cell performance → >1Acm^{-2}*
- *Cell durability → 0.5%/1000hrs*
- *Dynamic switching*

Stack Validation & Co-Electrolysis

- *Dynamic (6hr) stack cycling*
- *Stack RTE > 60%*
- *Co-electrolysis exhaust analysis with GC*

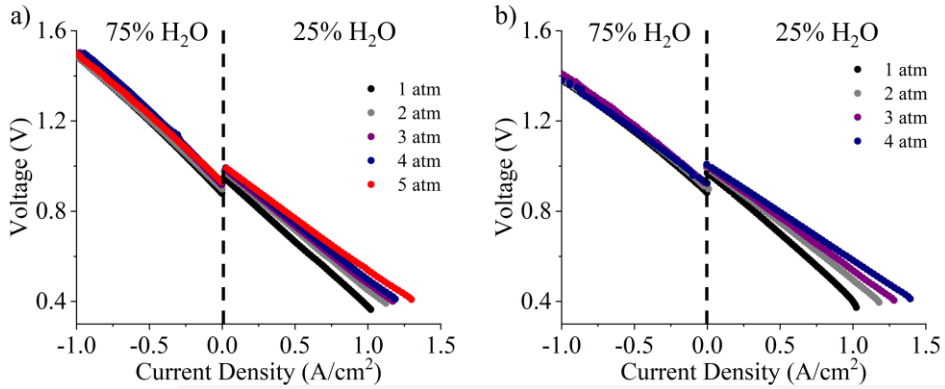
System Demonstration

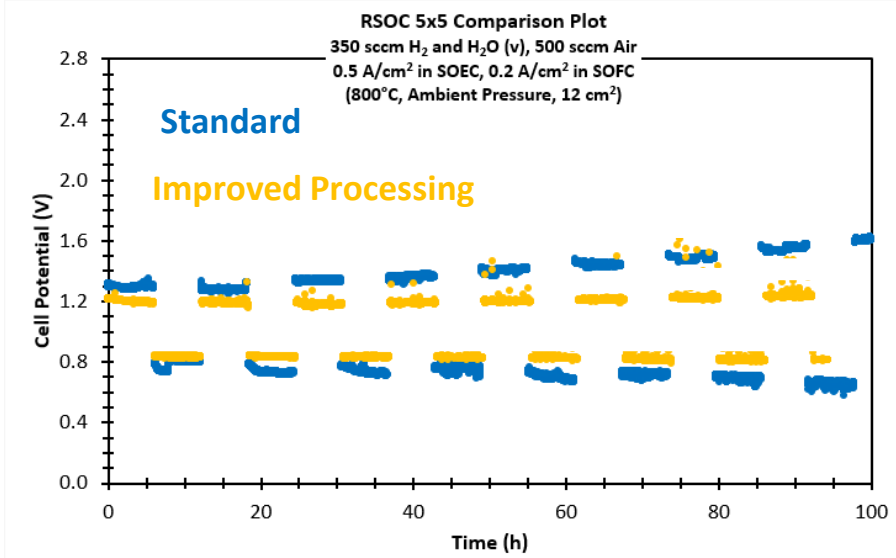
- *Pressurized BOP construction at CSM*
- *Ambient BOP construction at Nexceris*
- *1kW$_e$ with 60% stack RTE at 0.7 Acm^{-2}*

Electrode Performance & Stability

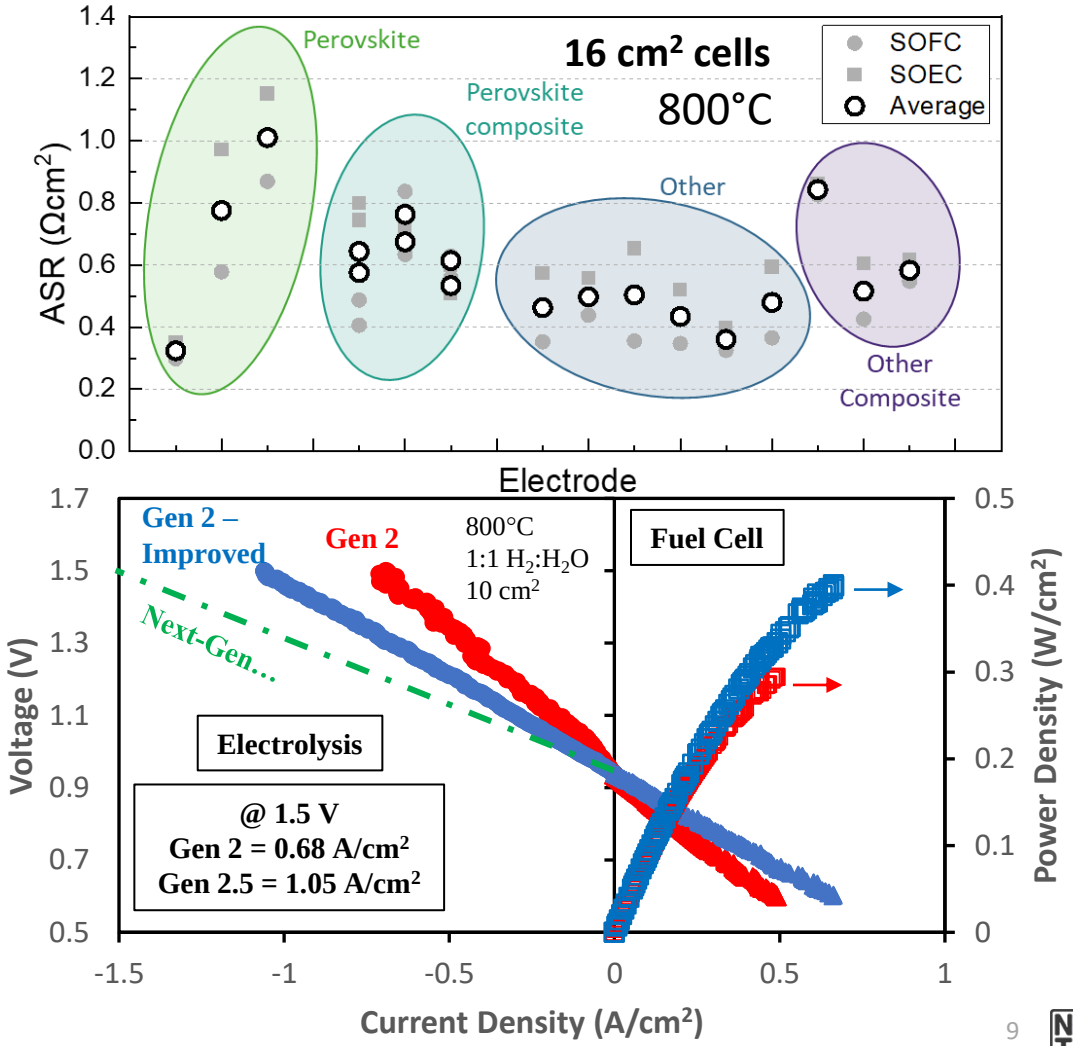
Electrode Evaluation for SOEC/SOFC

Developing & Understanding Pressurization





Screening & Scaling High Performance



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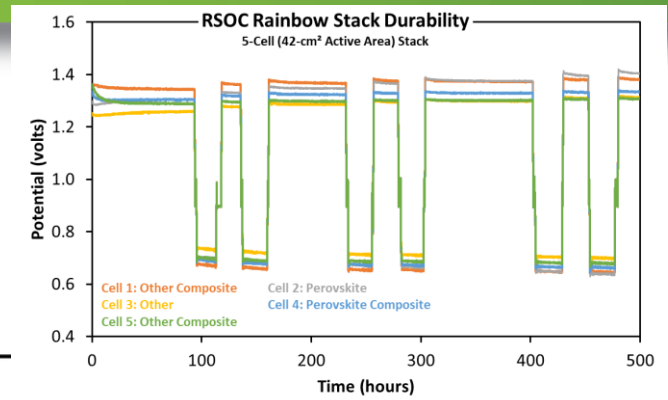
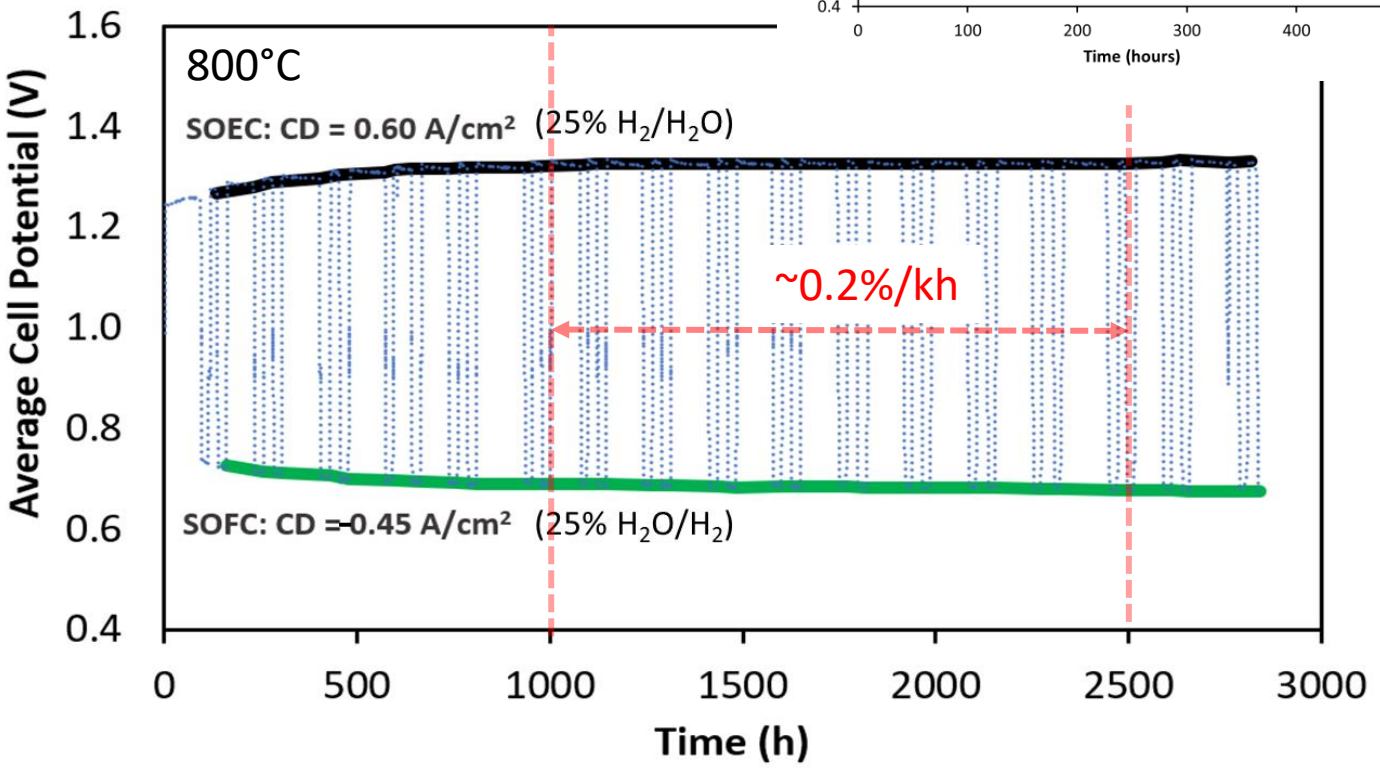
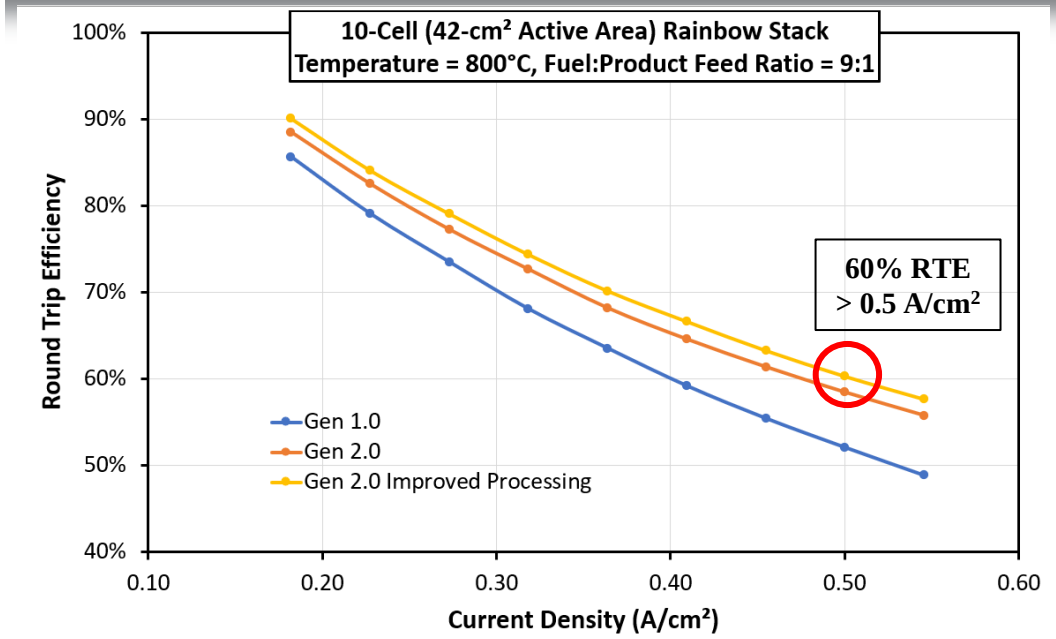
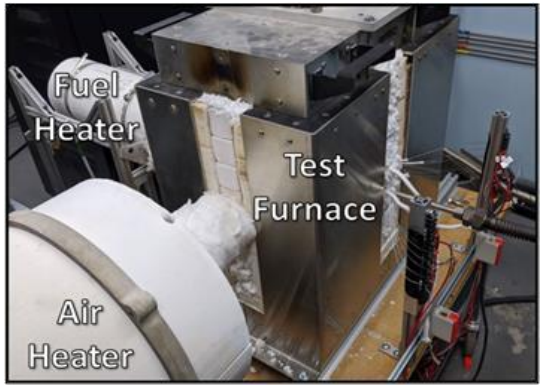
Stack Level Performance & Stability

RSOC Durability Test on a 5-cell "Rainbow" Stack









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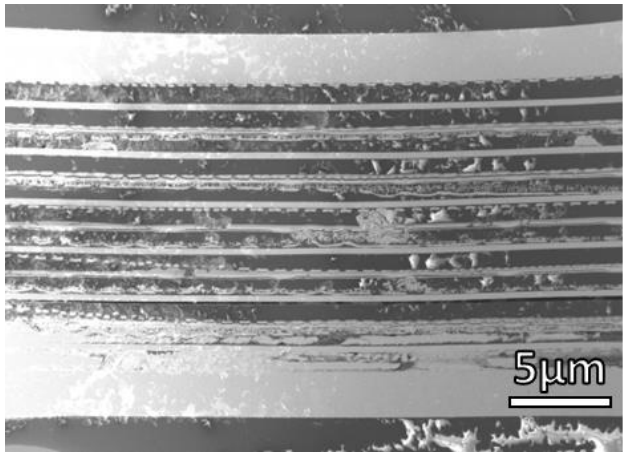
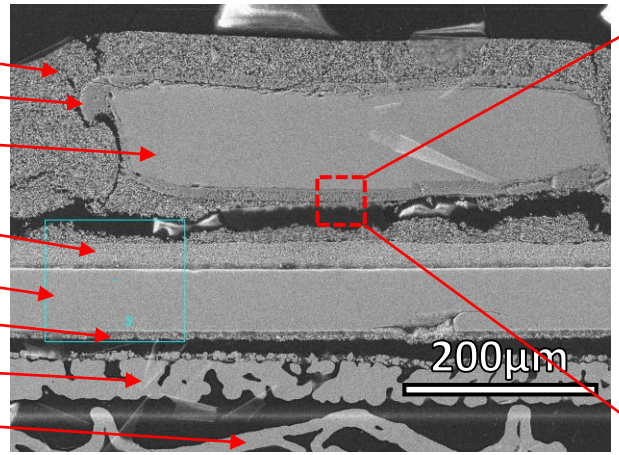
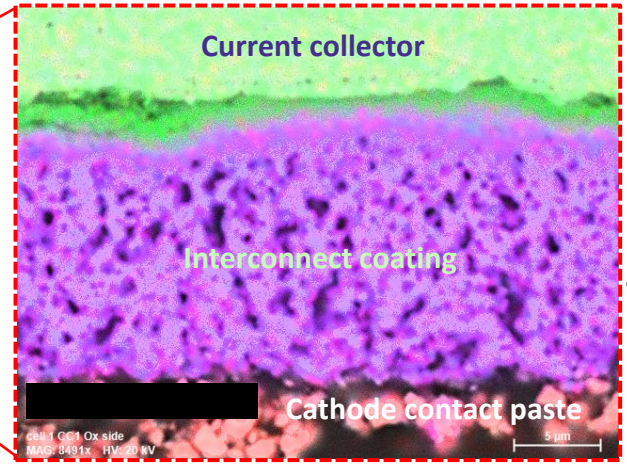
Stack Level

3000hr Post-Mortem SEM-EDS Analysis

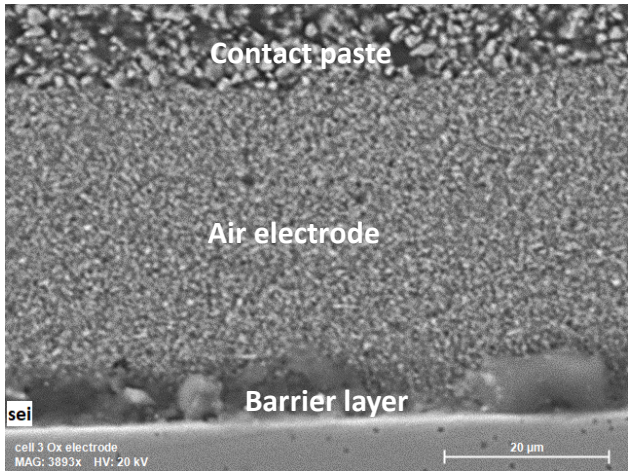


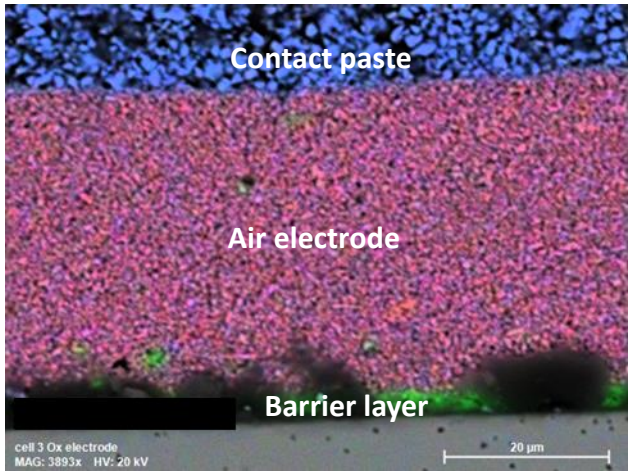
Contact paste
Protective coating
Current collector mesh
Air electrode
Electrolyte
Fuel electrode
Contact paste
Current collector mesh





3000hr stack operation





- Protective coating locks Cr evaporation in source.
- No evidence of Cr deposition in cathode.
- No evidence of air electrode or barrier layer delamination.
- Collaboration with PNNL

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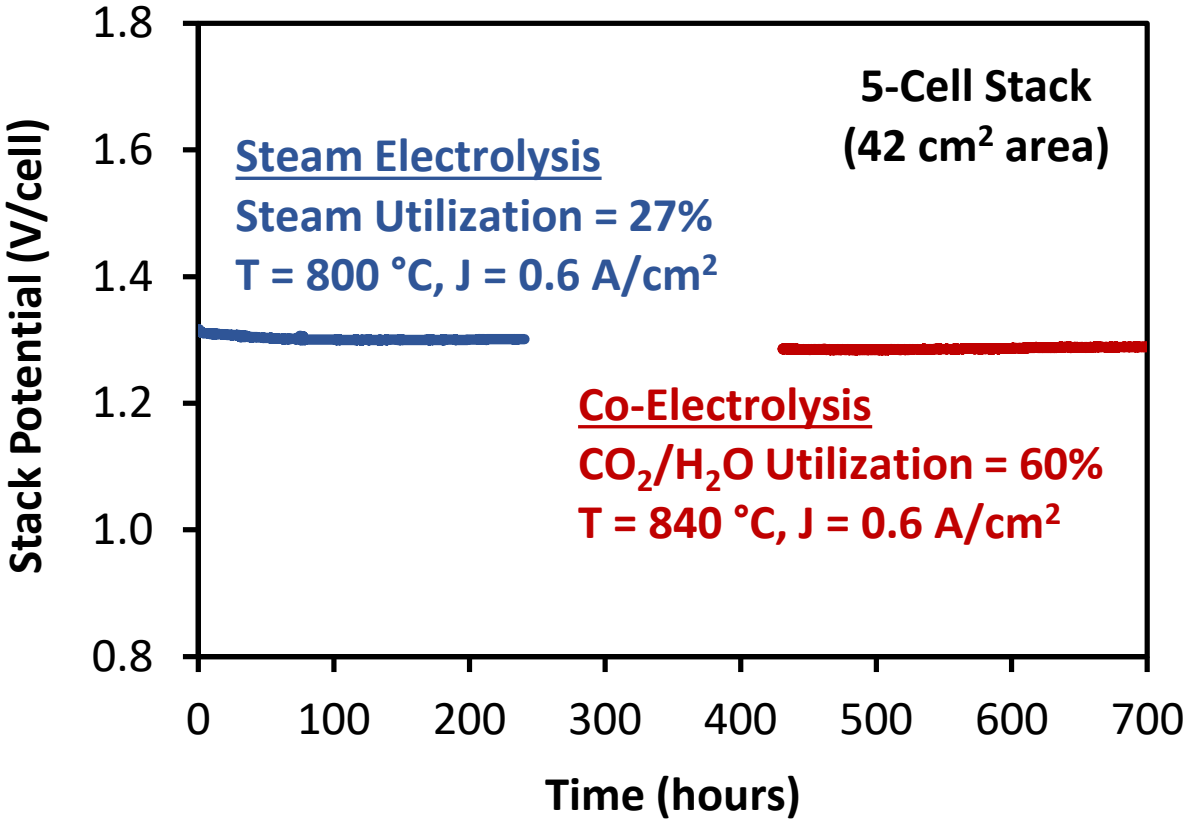
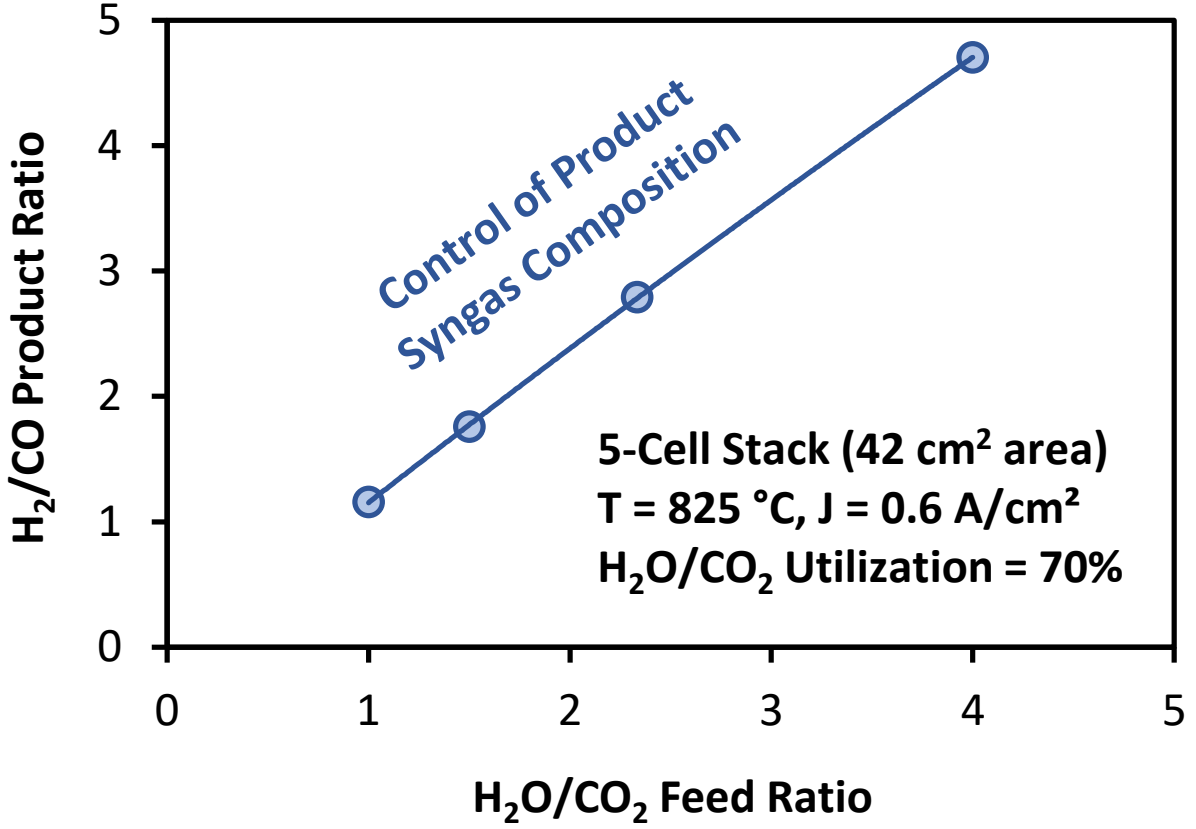
Stack Level Performance & Stability

Co-Electrolysis on a 5-cell Stack





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Fully Integrated Demonstration System

Fully integrated and automated Reversible Solid Oxide Cell

Utilizing heat exchangers and recycler system to utilize exhaust heat

Bi-directional load box for automated mode switching

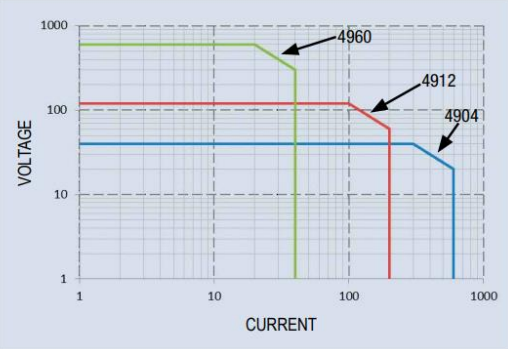
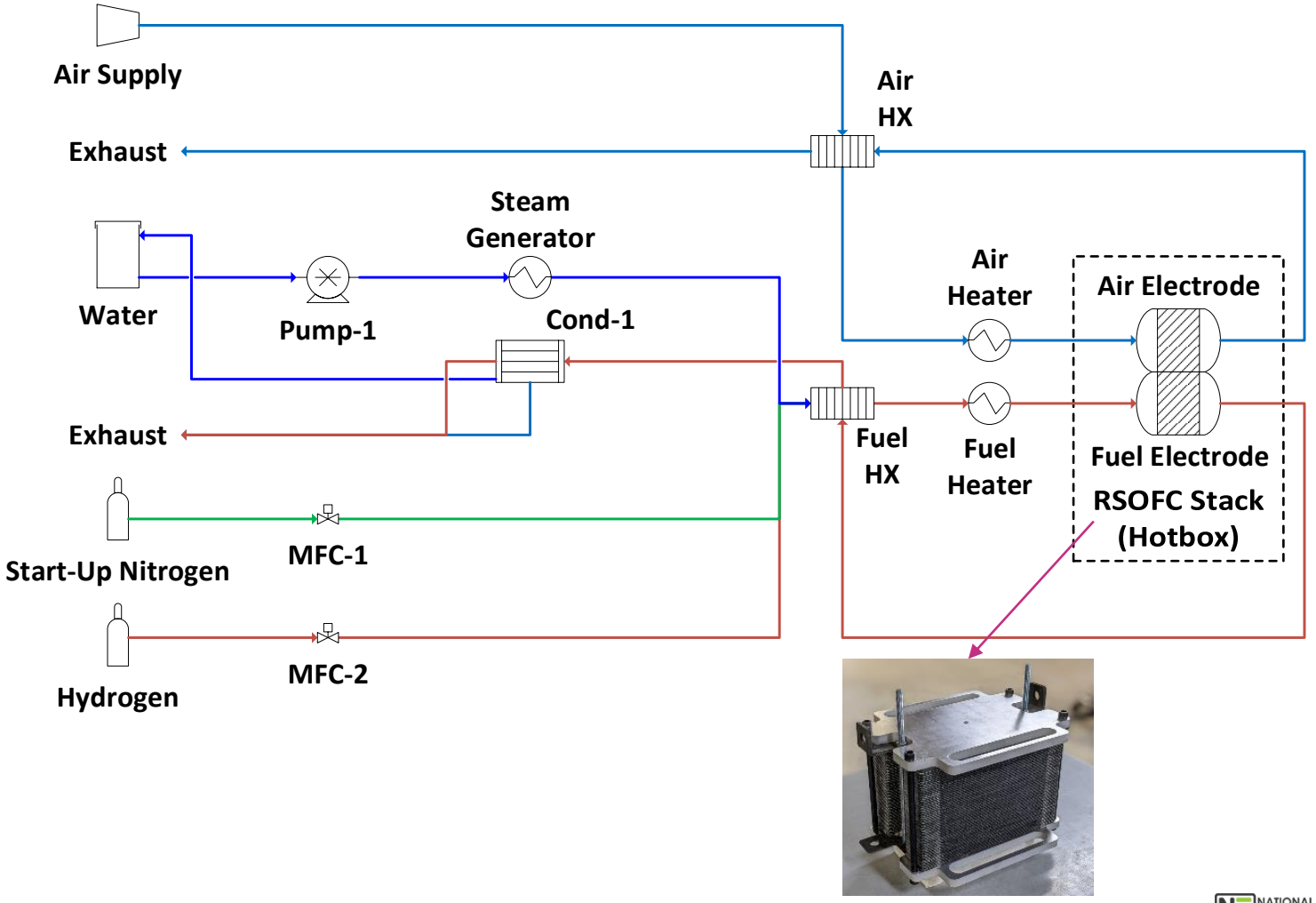


Figure 2 - Discharge Operating Envelope

Q3 2023 Nexceris will demonstrate a 1 kW_E stack and achieving >60% RTE using a 36-cell 96cm^2 active area cells



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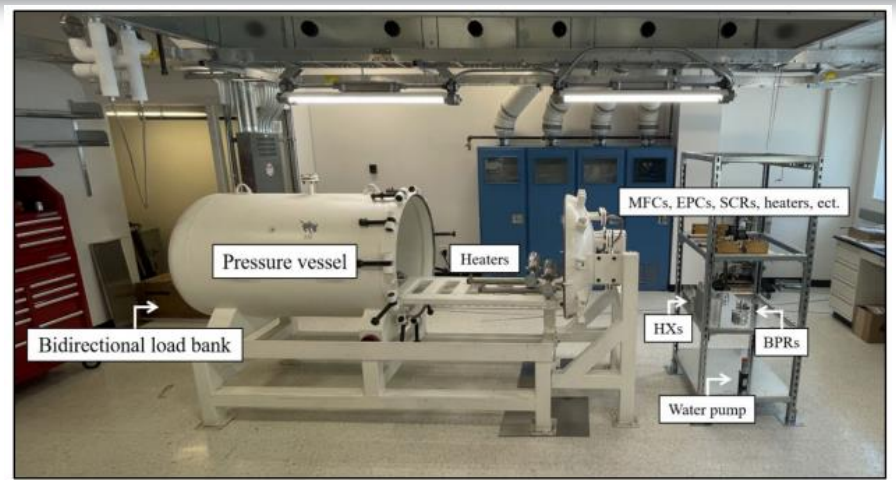
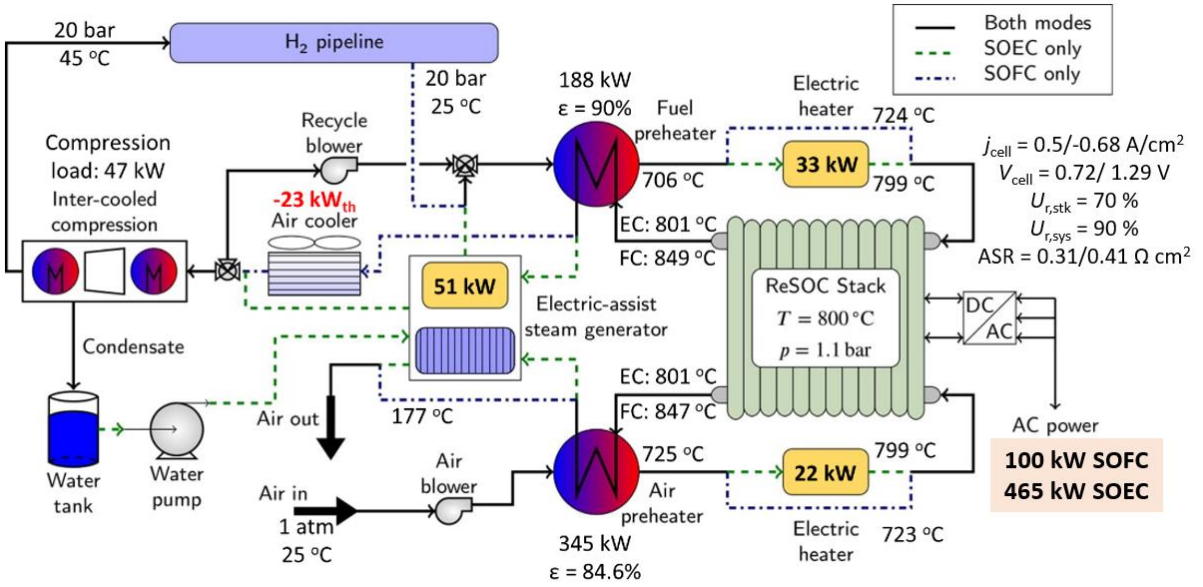
System Level

PFD, TEA, Breadboard Validation

Path to Commercialization

- Process flow diagram (PFD) developed for initial techno-economic analysis (TEA).
- PFD will be combined with an electrochemical model for TEA of a pressurized system.
- Pressurized stack testing capabilities (< 10 bar) under construction at Colorado School of Mines.
  - Long-term, stack-level durability testing under RSOC conditions

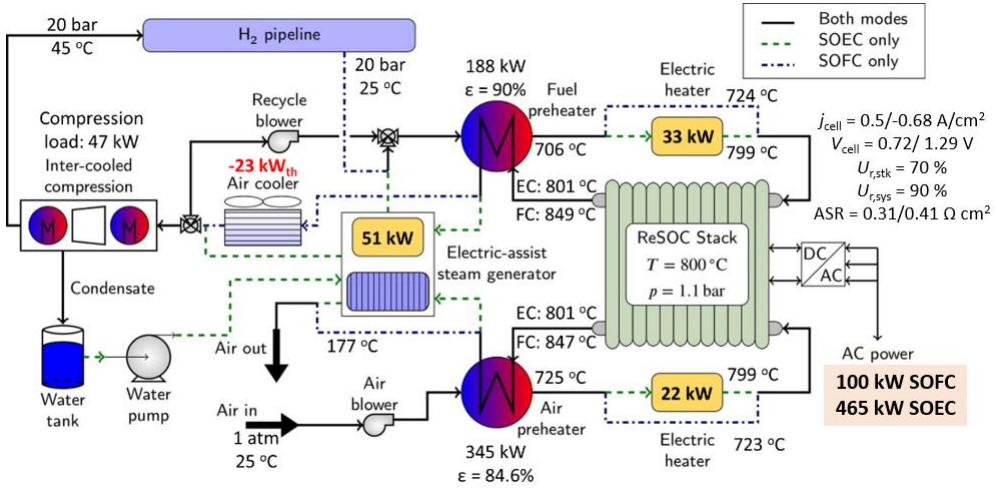




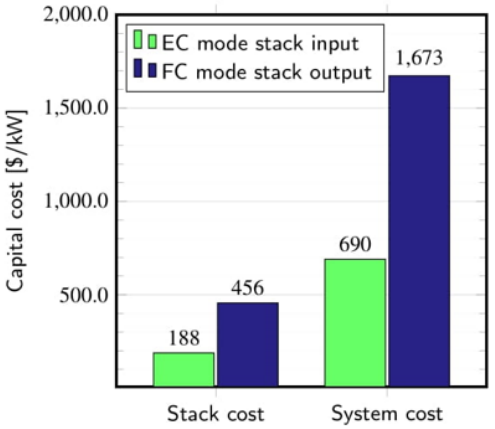
Techno-Economic Analysis

PFD, TEA, Breadboard Validation

TEA Overview (gPROMS model)

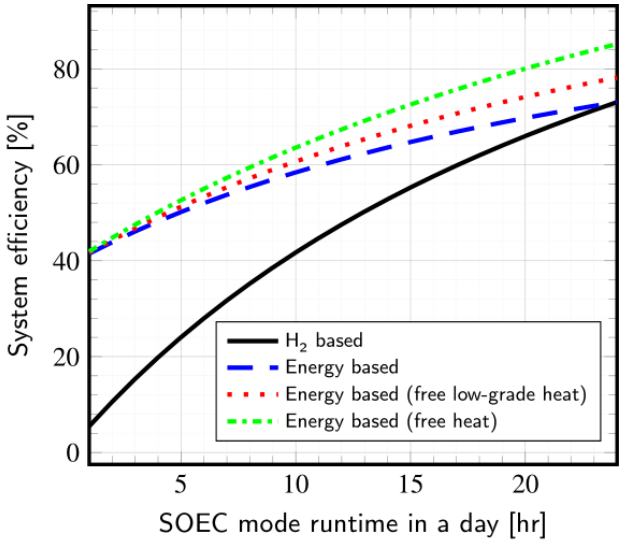


Model Parameters



- System life: 20 years
- Stack life: 5 years
- Installation factor: 1.4
- Indirect factor: 1.5
- Capacity factor: 90%
- Variable O&M cost
  - 5 ¢/kWh
  - Converted from kg H_2 to kWh using LHV of hydrogen

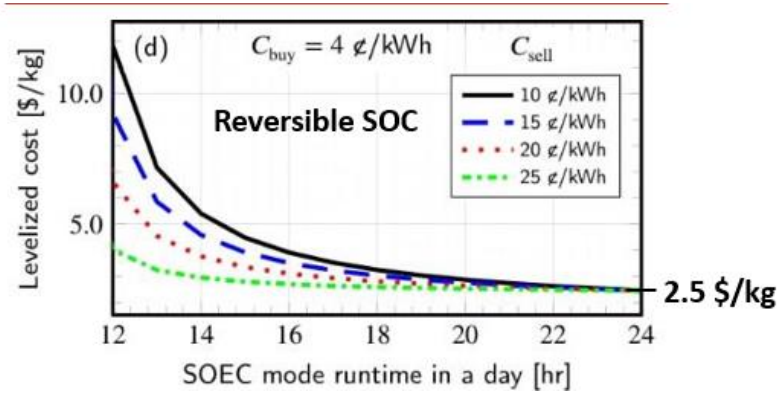
Better Definition of System Efficiency

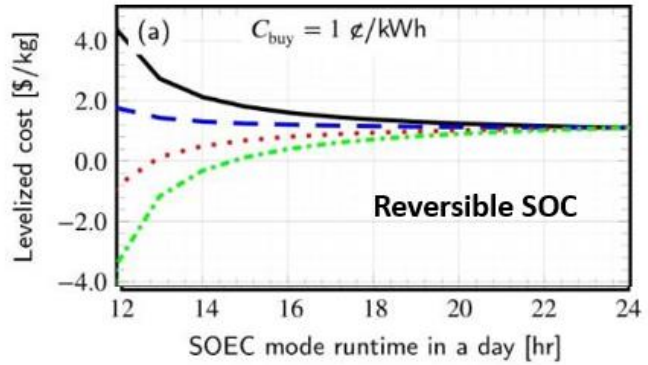


$$\eta_{H_2} = \frac{E_{H_2,LHV,SOEC}}{E_{H_2,LHV,SOFC} + E_{elec,SOEC}}$$

$$\eta_{En} = \frac{E_{H_2,LHV,SOEC} + E_{elec,SOFC}}{E_{H_2,LHV,SOFC} + E_{elec,SOEC}}$$

SOEC or SOFC? Dependent on electric buy and sell price





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Sergio Ibanez
Chad Sellers
Bradley Glenn

Questions? Feel free to say hi!