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1851

22nd Annual SOFC Project Review Meeting

Versatile Reversible Solid Oxide Cell System for Hydrogen and Electricity Production

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Project Overview

Project Partners

Dr. Emir Dogdibegovic (PI), Nexceris LLC
Dr. Robert Braun, Colorado School of Mines
Dr. Scott Barnett, Northwestern University

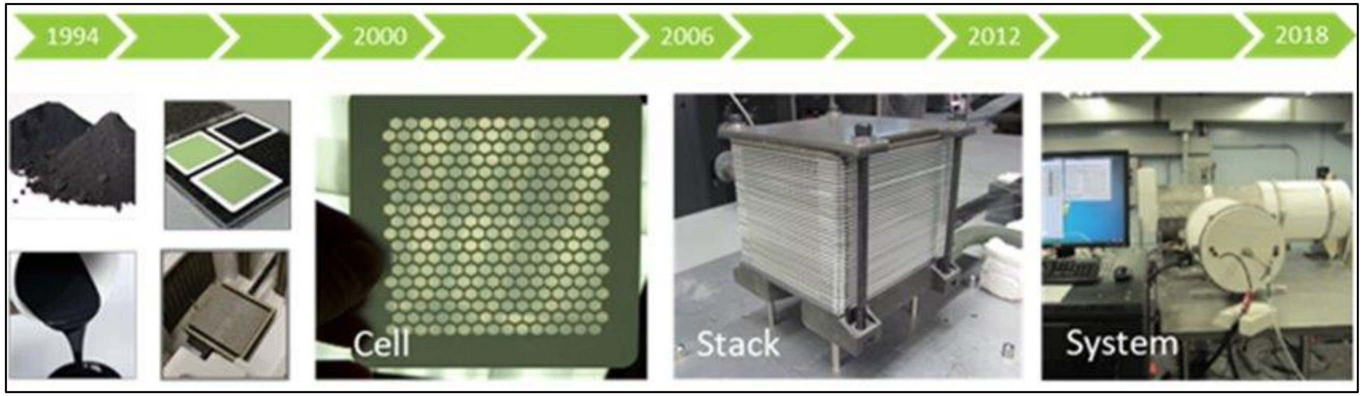
Project Vision

Demonstrate prototype system level reversible solid oxide stack technology with world-class performance to allow hydrogen production cost of less than $2/kg (at scale).

Project Impact

Efficient and durable RSOC systems will support the transition to renewable, energy-efficient, and low cost H_2, and create paths to more resilient grid and the lowest cost grid balancing solution.

Award #	DE-FE0031986 FOA2300
Start/End Date	12/01/2020-11/31/2023
Total Project Value* Cost Share %	$3.75M (DOE + Cost Share) Cost Share: 20%



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Approach-Summary

Project Motivation

- Nexceris has over 27 years' experience building and testing SOC stacks.
- Successfully commercialized protective and catalyst coatings for the SOFC market.
- Leverage this expertise to advance RSOC technology readiness.

Partnerships

- *This project is a collaboration among three world-leading developers of solid oxide cell (SOC) technology: Nexceris. LLC (Nexceris) as the prime, and Northwestern University (NU) and Colorado School of Mines (MINES) as subcontractors.*
- Dr. Barnett (NWU) brings an in-depth research background in the field of RSOC and fuel electrodes along with pressurized cell operation.
- Dr. Braun (CSM) brings an in-depth knowledge on RSOC system design, TEA, and pressurized stack testing.
- This exciting collaboration positions the team well for path to commercialization of RSOC technology.

Key Impact

Metric	State of the Art	Expected Advance
Stack degradation rate	2-10%/kh	< 0.5 %/kh
Hydrogen cost (at scale)	~$4-6/kg	≤ $2/kg
Current Density @ 1.4 V/cell	< 1.0 A/cm^2	2.0 A/cm^2

Barriers

- Deconvolution of degradation mechanisms in reversible modes – use team's established knowledge from other/internal projects
- Demonstration of coating technology at production relevant scale - use Nexceris' existing stack platform
- Pressurized demonstration to increase efficiency – use team's established knowledge

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Project Contributions

- Reversible operation requires robust electrodes in both operation regimes. Oxygen electrode(s) must have capability for ORR and OER without delamination at interface.
- Fuel electrode(s) must have ability to provide high fuel utilization (activity) and ability to electrolyze steam (or steam and CO_2), both at high efficiency.
- Commercialized coatings will suppress chromium poisoning.
- Pressurized cell/stack operation will provide realistic performance and degradation to be seen in a prototype system and eventually products.
- Techno economic analysis will estimate hydrogen production cost based on RSOC stack and ultimate system.
- Customers will be identified, and their specific needs/requirements will be better understood.

From electrodes to cells, from cells to stacks, from stacks to a prototype system.

Technologies and Proposed Demonstration Metrics

- Existing RSOC technology and capabilities at the three sites will serve as a starting point.
- Minimum of 1 kW power generation in fuel cell mode (2+ kW in electrolysis mode) and roundtrip stack efficiency (RTE) of at least 60 percent.
- Capability for dynamic switching between fuel cell and electrolysis modes in response to fluctuating grid demands.
- Low degradation rates.
- $1kW_E$ roundtrip stack efficiency of ≥ 70%.

Table 1. Nexceris' RSOC cell and stack technologies.

Current Density Metrics (A/cm^2)	*Single Cell*		*Stack*
	DOE Target	*This Project*	*This Project*
SOEC (1.40 V)	$-1.0\ A/cm^2$	$-2.0\ A/cm^2$	$-1.5\ A/cm^2$
SOFC (0.70 V)	N/A	$1.2\ A/cm^2$	$1.0\ A/cm^2$

Table 2. Target demonstration system metrics for this project.

RSOC demo system size (SOFC mode)	*Roundtrip stack efficiency*	*Stack degradation target*	*Roundtrip stack efficiency at 5 bar (model)*
1 kW_E	60 %	<0.5%/1,000 h	≥70 %

Project performance, durability, and RTE targets.

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BP1 Milestones and Progress

Colorado School of Mines — Earth • Energy • Environment

Northwestern University

BP1

Screening sub-scale/rainbow stacks
Downselection of best electrode sets (NEX)

Finalizing 1 kW_E system design (NEX, MINES)

Fuel electrode development
Pressurized operation on button cells (NWU)

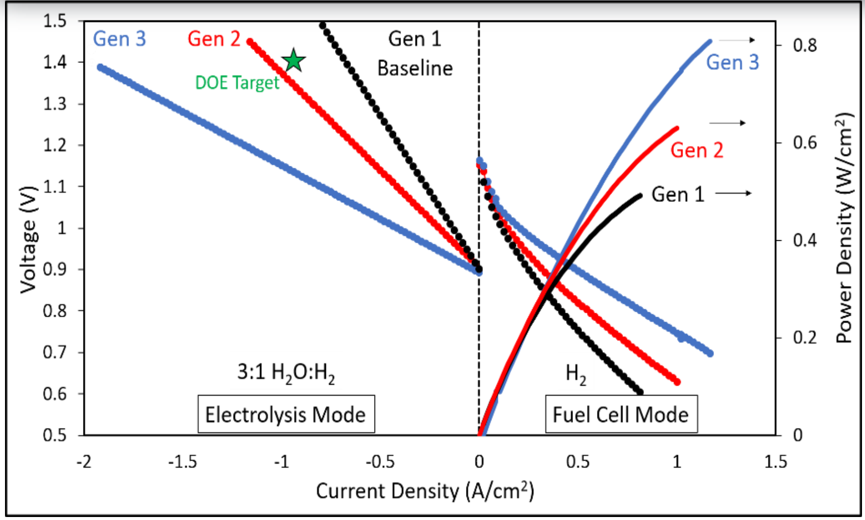
Design for pressurized test rig completed (NEX, MINES)

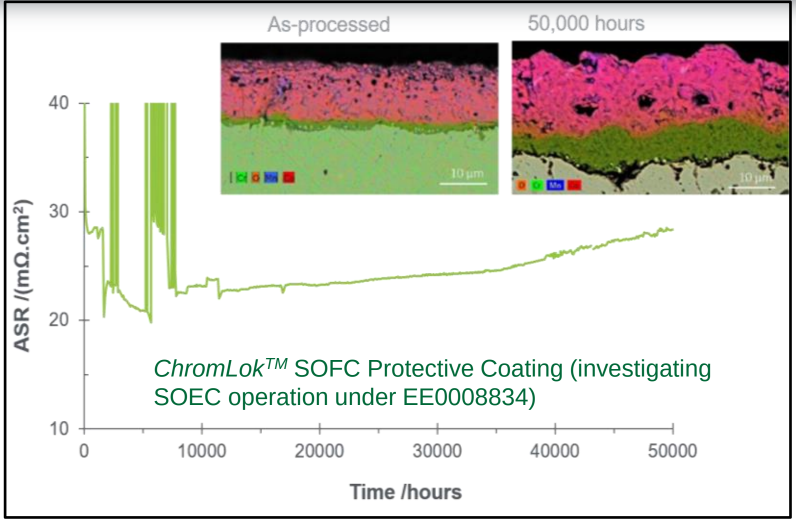
Demonstrate 60% RTE via
in-furnace testing
Go/No-Go

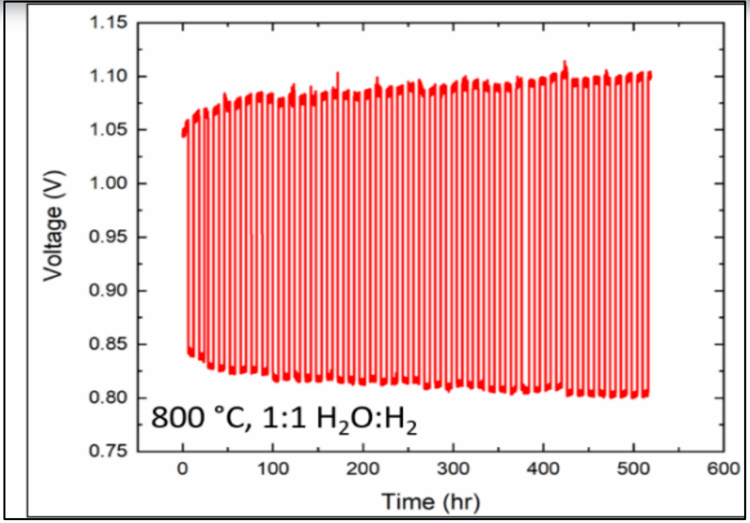
Milestone #	Milestone Description (BP1)	Target Month (Project Quarter)	Completion Status
2.1	*Demonstrate successful reversible pressurized operation (up to 10 atm) on full button cells at 750-800 °C with steam electrolysis and co-electrolysis using the highest performing air and fuel electrodes.*	*9 (Q3)*	*Partially completed (70%)*
2.2	*Initiate pressurized durability tests (reversible operation) on full button cells at 800 °C using the highest performing electrode set. Demonstrate at least 100-hour operation at 750-800 °C.*	*12 (Q4)*	*In progress*
3.1	**Electrochemical characterization of electrode materials sets is completed in stacks. ASR data obtained in both fuel cell and electrolysis modes.**	**6 (Q2)**	**Completed**
3.2	**Electrochemical durability tests completed on baseline RSOC stacks with dynamic operation. A 500-hour test in both fuel cell and electrolysis modes will be completed at a nominal stack operating temperature of 800 °C.**	**9 (Q3)**	**Completed**
3.3	**Electrochemical durability tests completed on RSOC stacks with down-selected electrodes and current collecting paste. Tests with at least 1,000 hours of operation will be completed in reversible mode at a nominal stack operating temperature of 800 °C.**	**12 (Q4)**	**Completed**
3.4	*Design of pressurized stack test rig completed for testing up to 10 bar at 800 °C and capability to operate long-term*	*12 (Q4)*	*Partially completed (60%)*
4.1	**RSOC system concepts developed and down-selected to two most promising concepts with target stack RTE of 60 percent.**	**3 (Q1)**	**Completed**
4.2	*The prototype RSOC demonstration system design completed, and long lead items ordered.*	*12 (Q4)*	*Partially completed (60%)*
DP1	**Go/No-Go Decision Point: Demonstrate 60% stack round-trip efficiency on via in-furnace testing.**	**12 (Q4)**	**Completed (60% RTE achieved)**

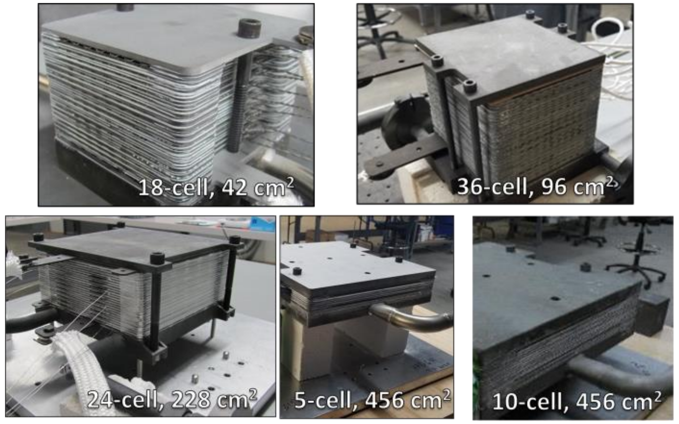
Project is on track and BP 1 Go/No-Go was successfully completed.

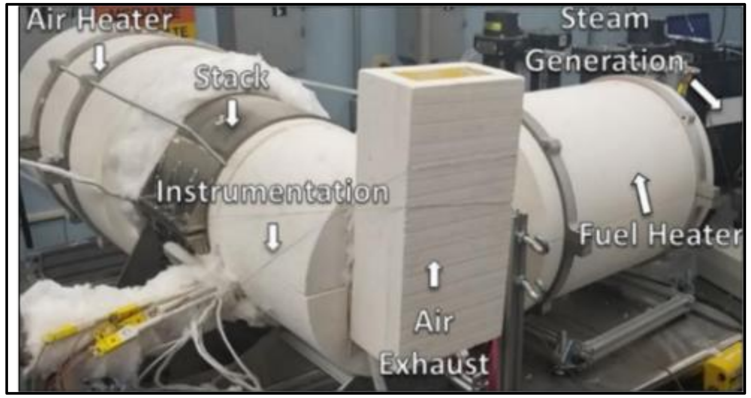
Leveraging Existing Technologies within the Team

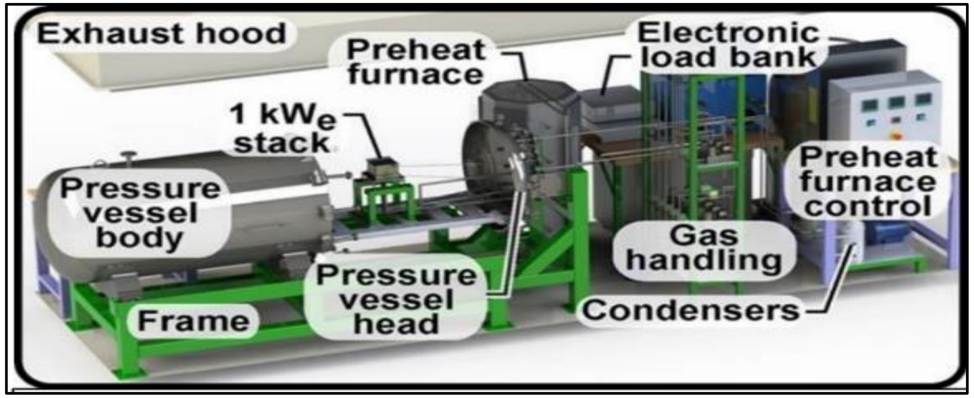






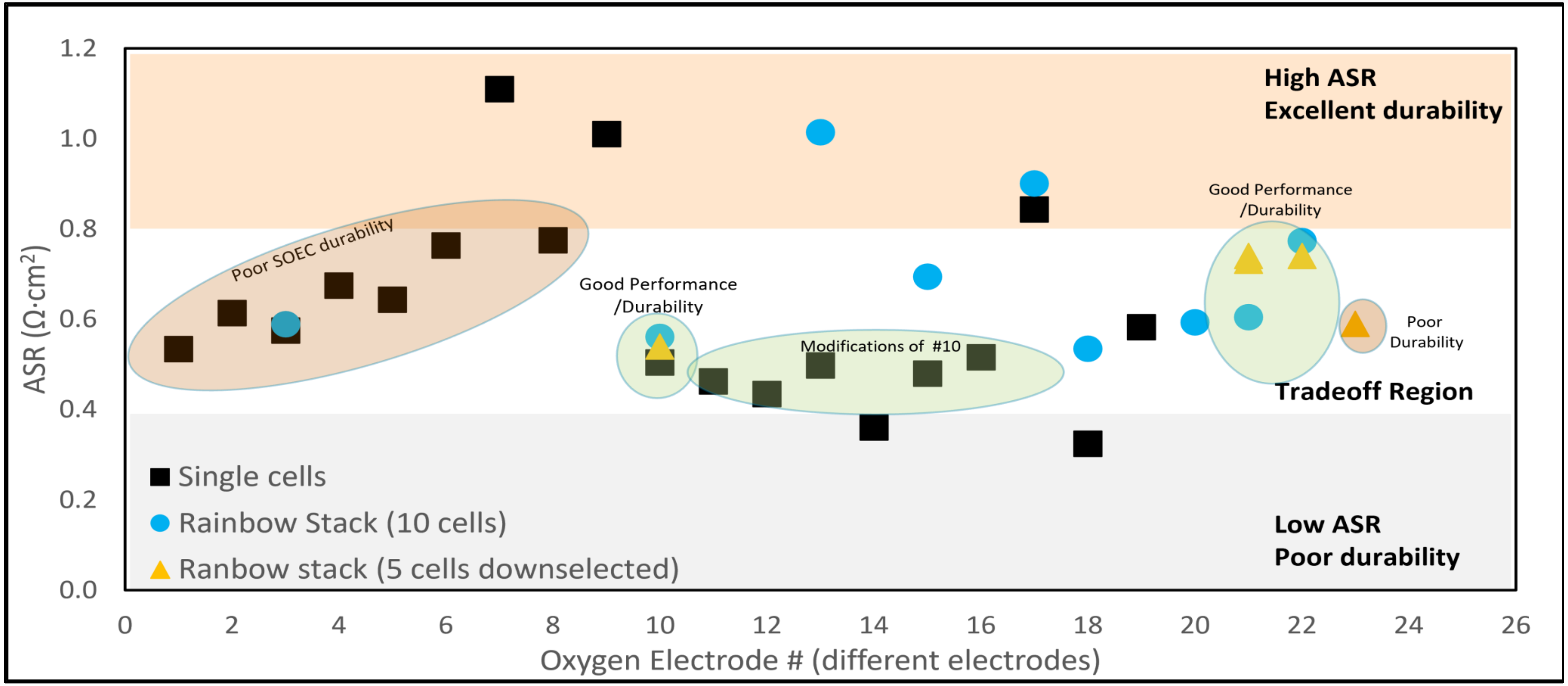






Combination of various platforms/expertise at the three sites positions the project for success.

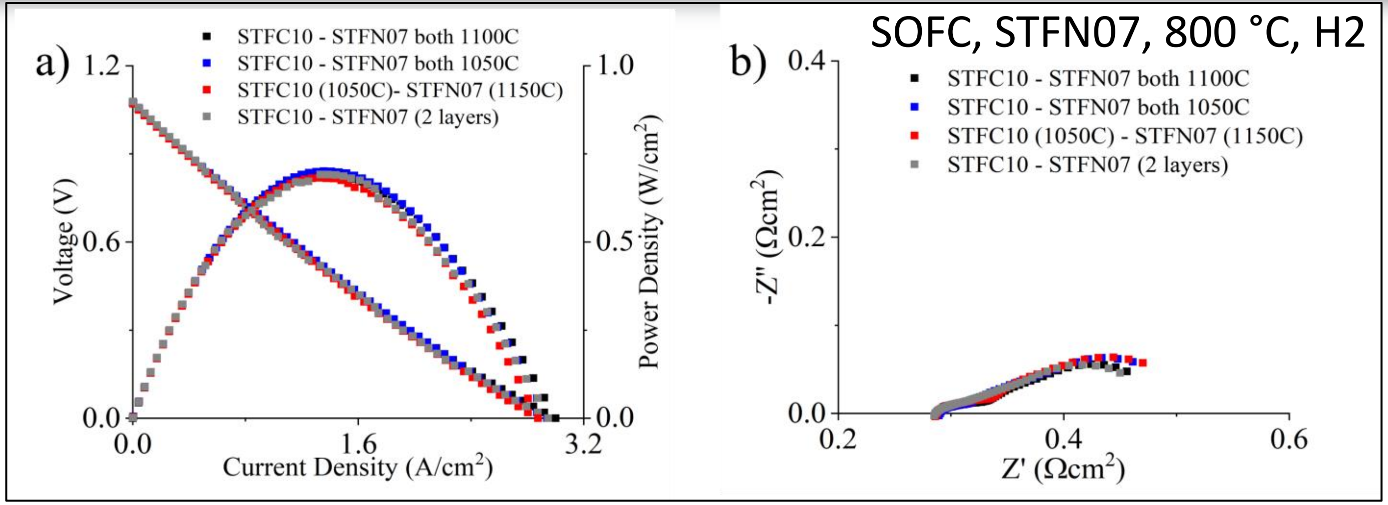
ASR Analysis (Cells and Stacks)

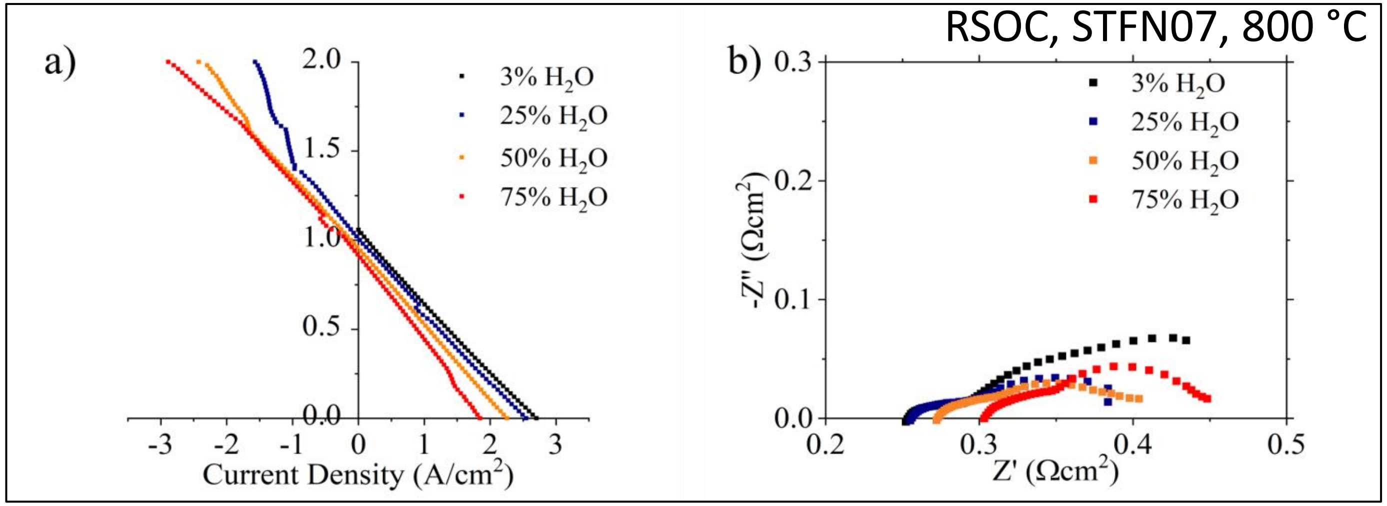


Downselected electrode sets for activity and durability testing, tradeoff.

Fuel Electrodes – Performance Comparison

- Firing conditions were optimized.
- No performance enhancement was observed for thicker (~20 µm) STFN07 ($Sr_{0.95}Ti_{0.3}Fe_{0.63}Ni_{0.07}O_3$) fuel electrodes
- Cell with optimal STFN07 fuel electrodes (STFC oxygen electrodes) show the higher current density and lowest R_p
- Pressurized test are in progress for downselected oxygen and fuel electrodes





STFN07 is one of the downselected fuel electrode candidates.

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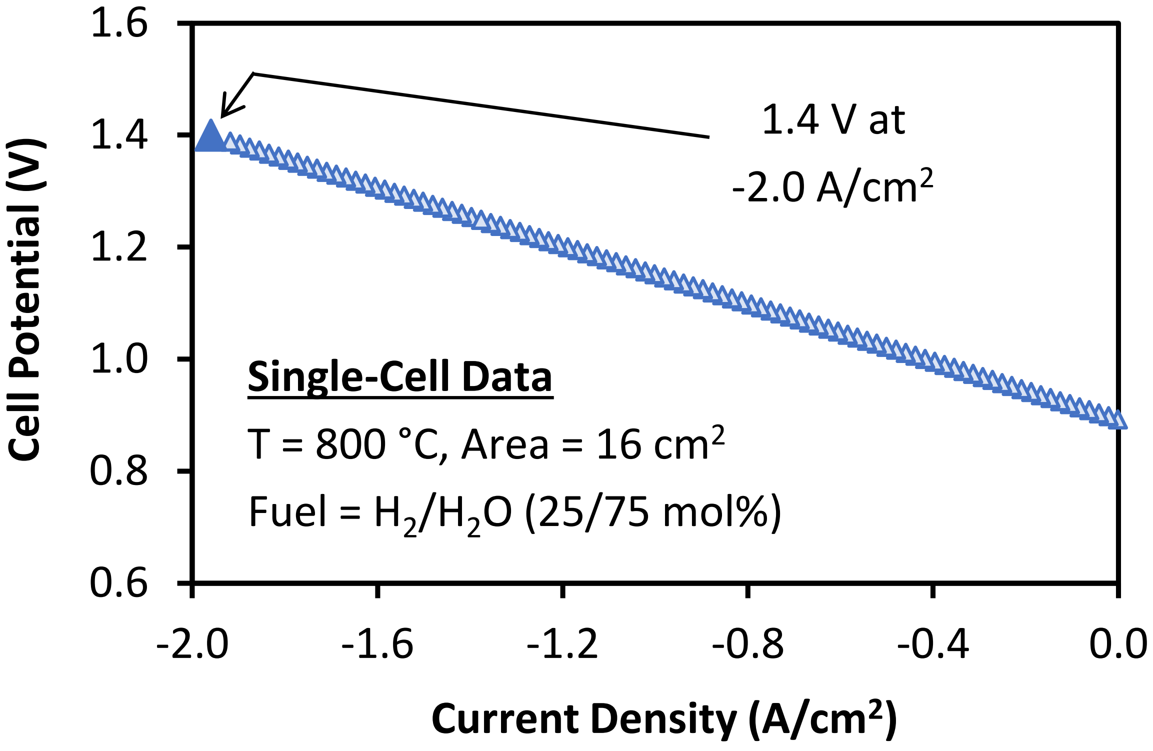
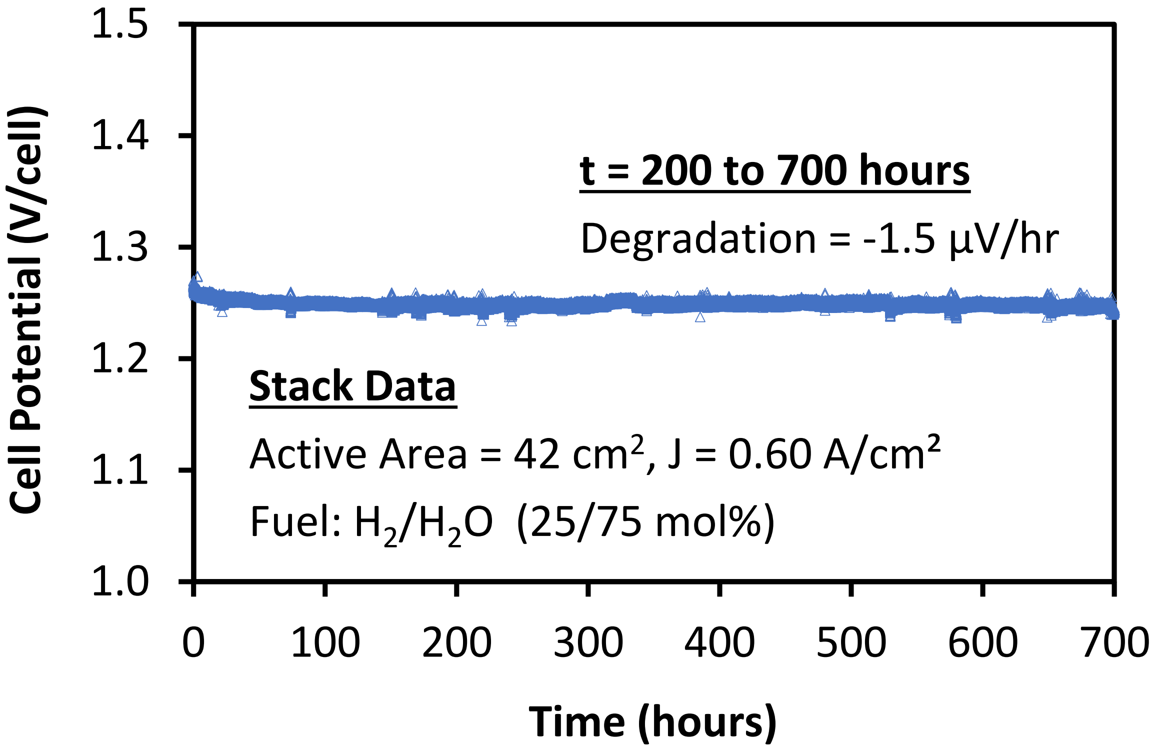
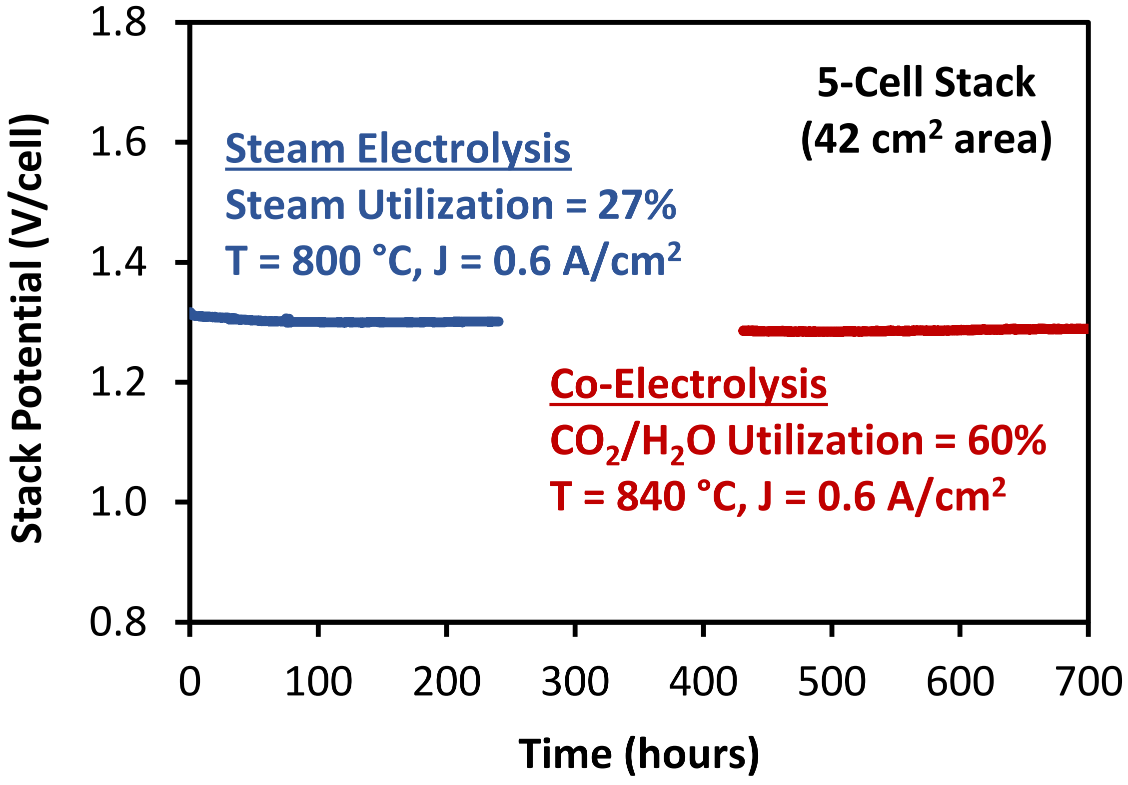
Improved SOEC Electrode Materials Sets

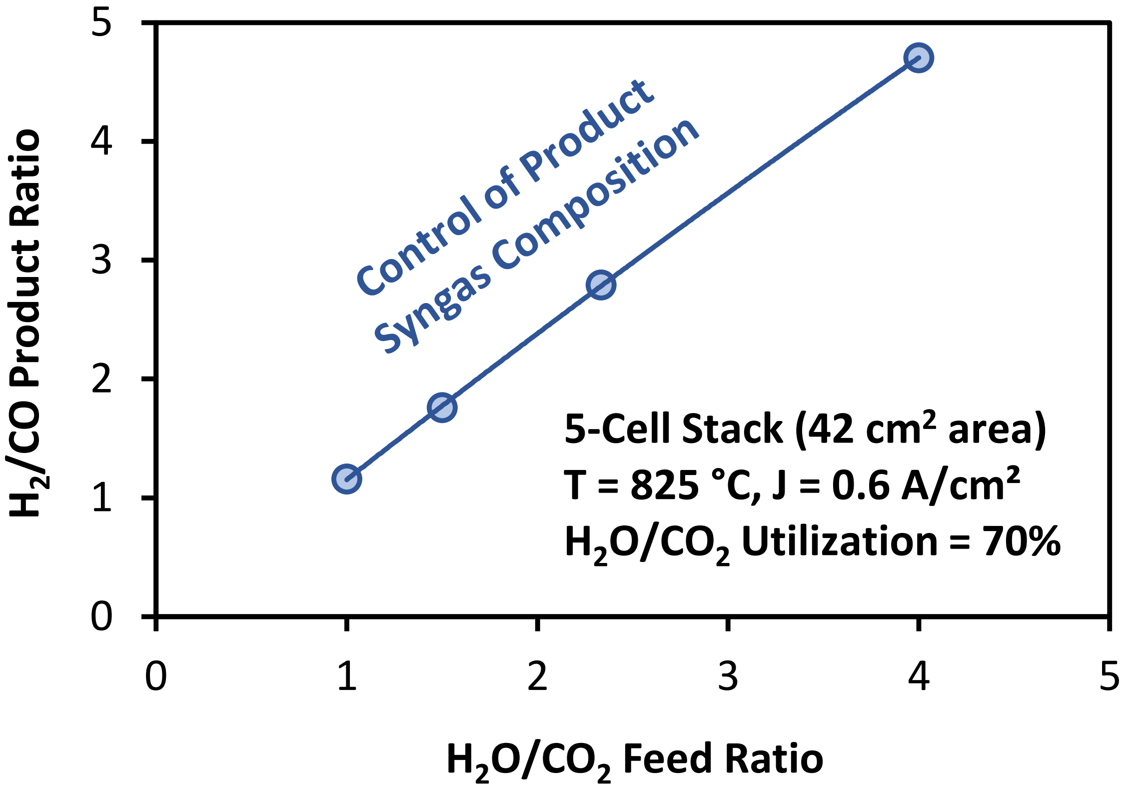




Nexceris' SOEC electrode materials enable state-of-the-art performance and stability.

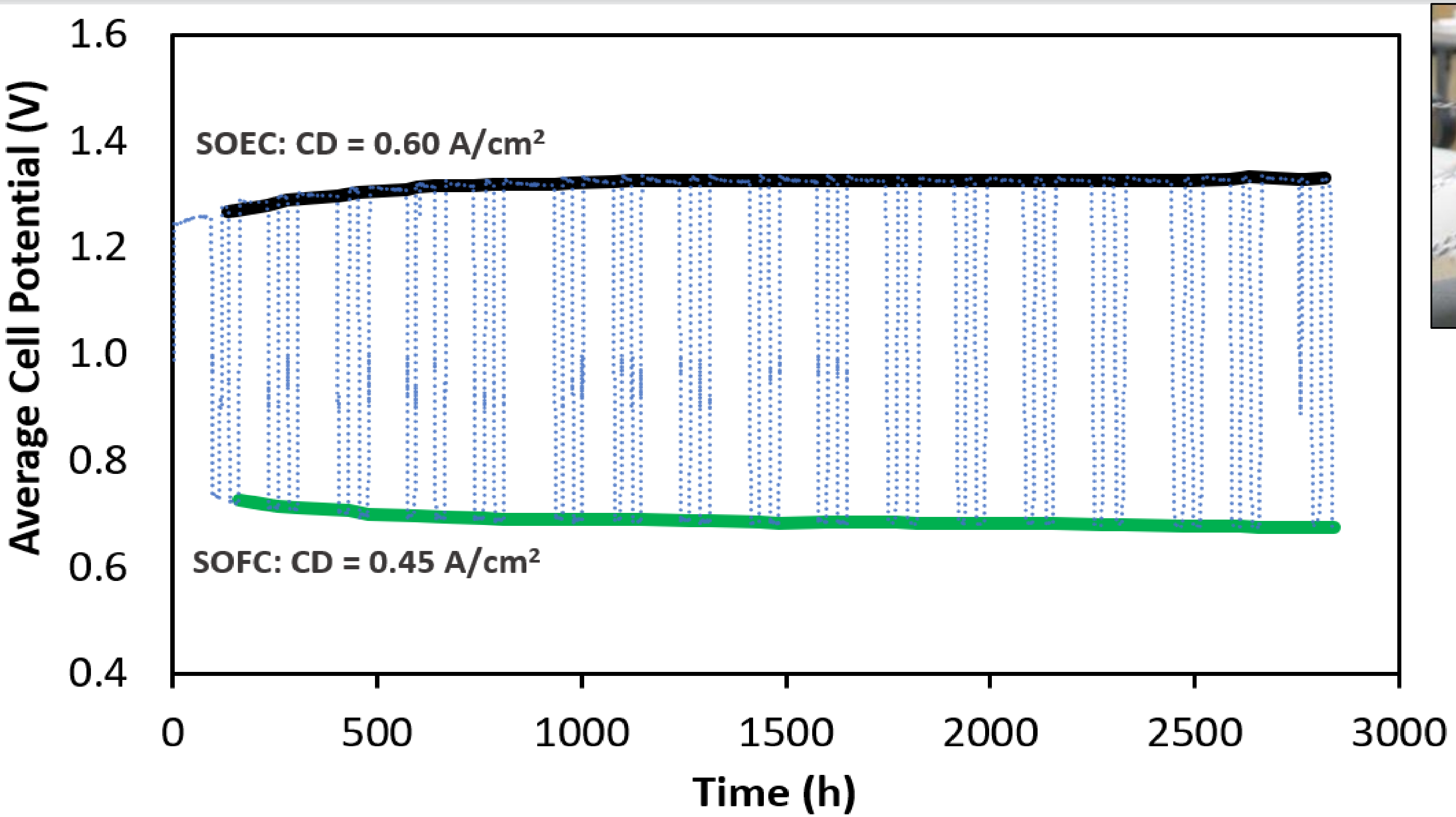
Co-Electrolysis Data on Stacks





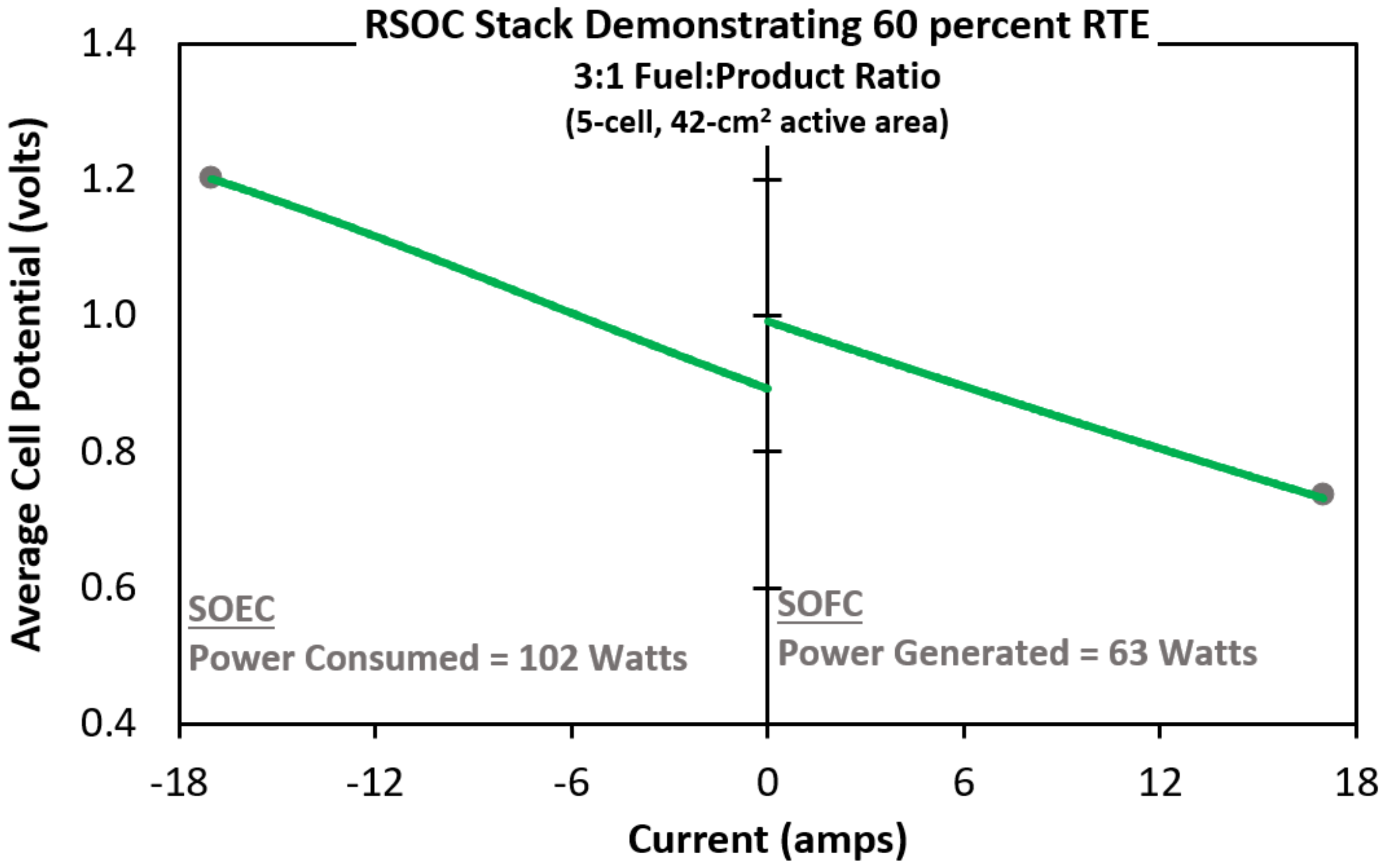
Stable stack operation and control of syngas composition in co-electrolysis mode.

Reversible SOC Stack Operation



State-of-the-art performance and durability demonstrated in reversible SOC stack.

Achieving Stack RTE of 60 %



In-furnace stack RTE of 60% achieved.

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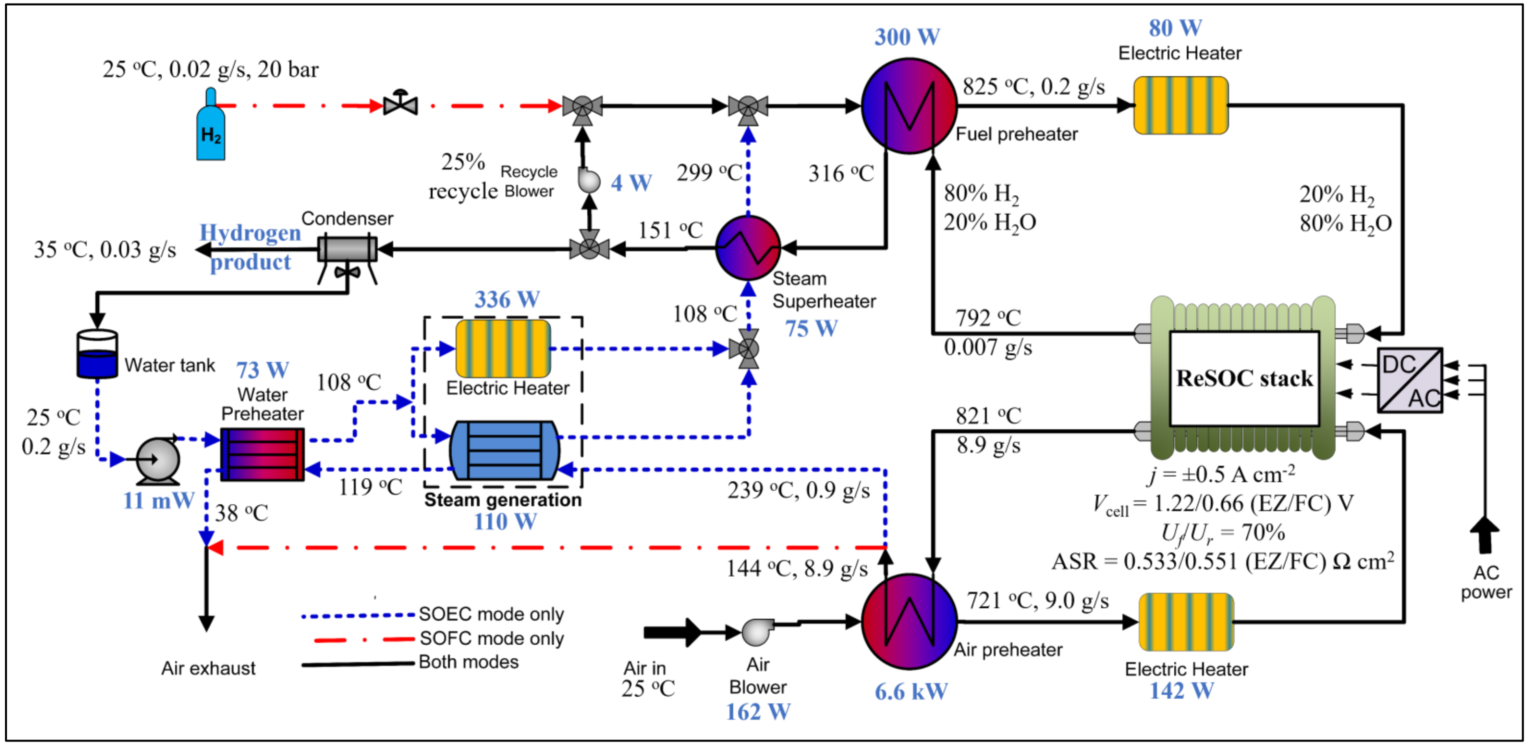
System Concept to be Built in BP2

Representative system design schematics



- Primary features: recuperative reactant gas pre-heating with simulated functions of steam generation and water reclamation.
- Capable of 60% RTE and system RTE assessment.
- Lowest risk of initial system design.
- Demonstrates water recycle and steam generation.
- System RTE will be reduced due to removal of recycle blower; simulation of recycle using process modeling and gas delivery to simplify control.

Preliminary system designs have been downselected.

Acknowledgments

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Northwestern University

U.S. DEPARTMENT OF ENERGY | Fossil Energy

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Special thanks to Nexceris team members and to all of Nexceris' customers and collaborators!

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Thank you!