SPS Special Power Sources
SUPPLYING YOUR REMOTE POWER NEEDS

Next Generation Durable, Cost Effective, Energy Efficient Tubular Solid Oxide Fuel Cell

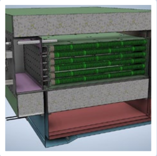
Contract: DE-FE0031674

Ted Ohrn, CTO

October 25, 2022

Project Objectives

Develop and optimize a YSZ electrolyte-based solid oxide fuel cell (SOFC) technology for low cost, low temperature (550~650°C), and high energy efficiency operation.



The developed technology will be implemented and demonstrated in a high efficiency 2-3kW SOFC with applicability to sub-MW system.

A modular design and cost analysis will be performed.

Company History

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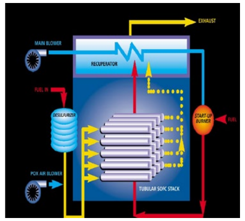
2000 | 2001 | 2005 | 2011 – 2012 | 2016 | 2019

2000

SOFC Division started at Acumentrics formed in Westland, MA

10 Watts

25 Watts



2001

1st 1kW NG Prototype

2002

5000W APU Core Module

2005

5kW NG Prototype

2009

1st Remote Demonstration on NG

Acumentrics
TRUSTED POWER INNOVATIONS®

2011 - 2012

1st Commercial Sales & SOFC Product Suite (2012)

250W to 1.5kW

ATREX ENERGY
POWERFUL POSSIBILITIES

2016

Acumentrics SOFC becomes Atrex Energy

CSA Certification for NG & LPG Systems

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2019

Special Power Sources purchases Atrex Energy

Enters in Strategic Partnership with Advanced Tech Works (ATW) for Manufacturing and Field Services

Relocates assets to Alliance OH

SPS acquired Atrex Energy and formed a new company including several former LG engineers and technicians

Field Installation Examples

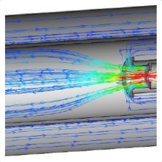
Radio Network Tower in Alaska

Cathodic Protection Site in Wyoming

- 600+ systems previously fielded across N America
- **6,000,000+ hours of field operations**
- Single unit operations of 35,000+ hours (25X)
- **99+% availability…when it must work in high-intensity cell applications…it will**

Wellhead Controls in New York

Project Update

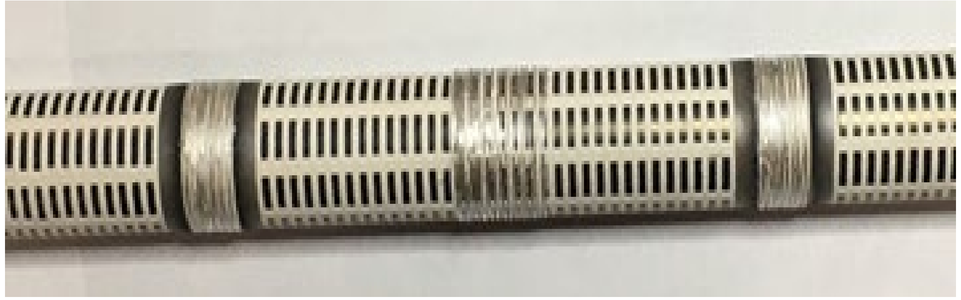


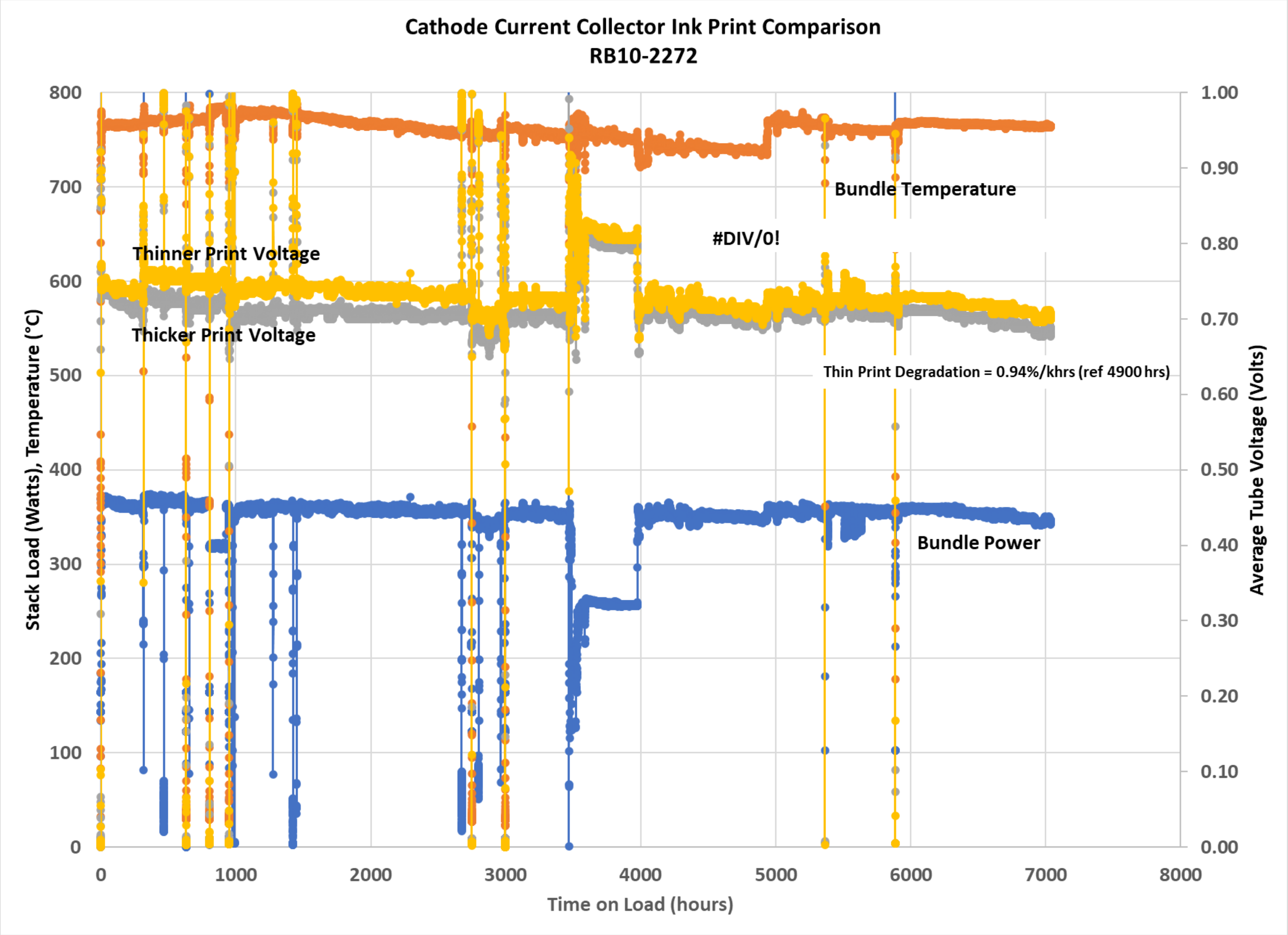
Task 2 – Cell Technology Development

Task 4 – Technology Implementation and Demonstration

2.1 Cathode Current Collector Development

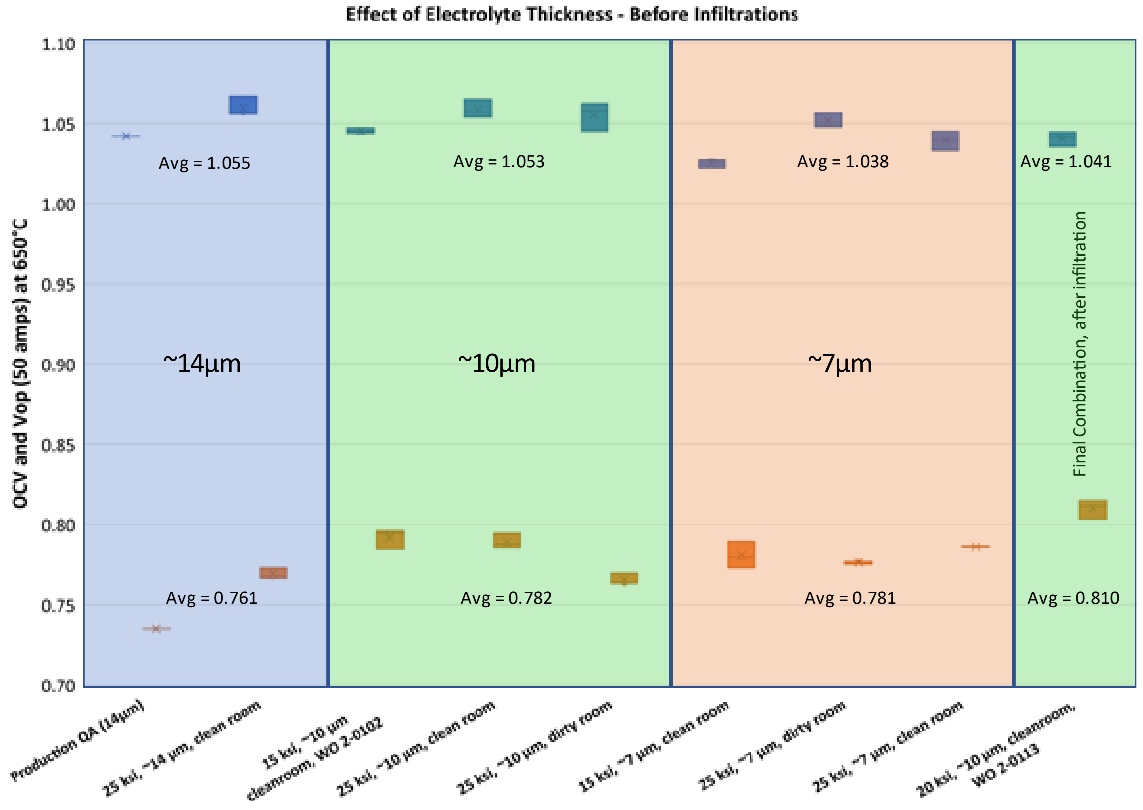
- New screen patterns evaluated for improved printing of Ag current collector mesh pattern
- Screen parameters optimized
- Long-term bundle test shows improved and stable performance
- New manufacturing specification developed to reduce cost

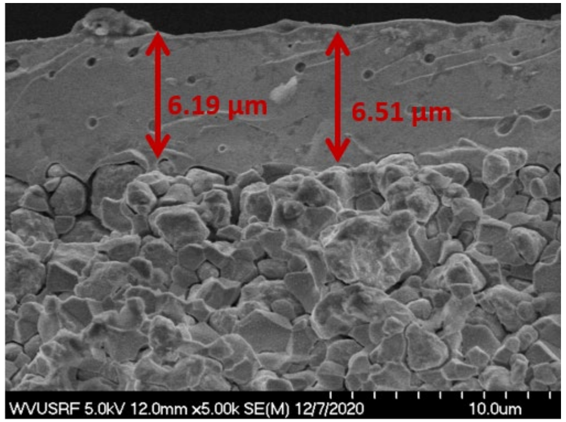




2.2 Thin Electrolyte

- Electrolyte slurry formulated with different solids loading and applied with different translations speeds during spraying
- Clean room was installed to minimize possible defects caused by the processing environment





10 micron thick electrolyte provides best combination of sealing and performance

2.3 Effect of Cathode Infiltration

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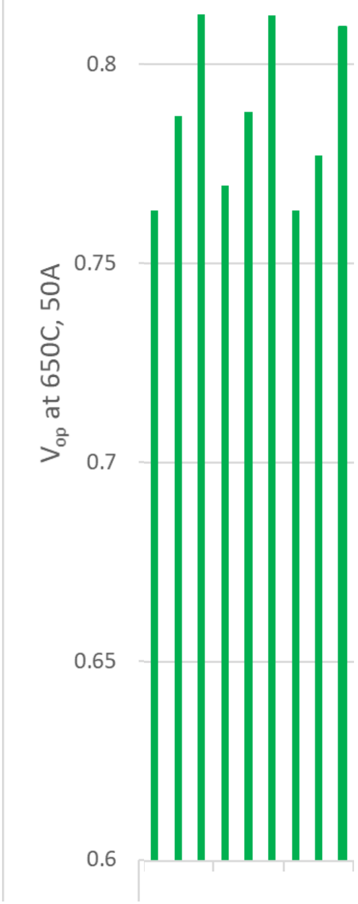
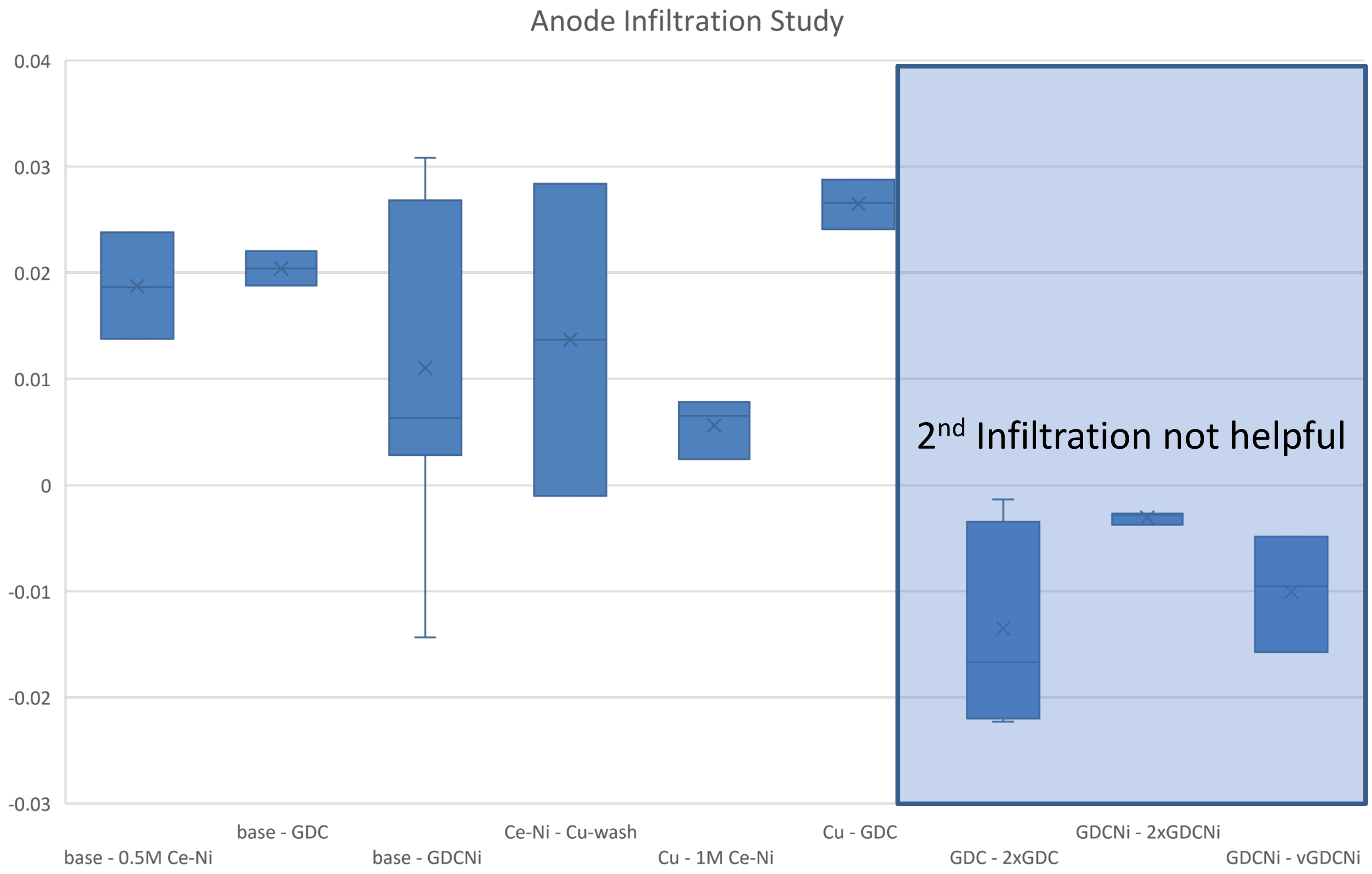
- PrOx infiltration chosen
- Cathode delamination issues developed – related to over-wetting of the surface
- A more concentrated solution was more robust

Avg improvement 0.027V



2.4 Effect of Anode Infiltration

- Ce-Ni and GDC showed similar improvement
- Results of Cu-wash were inconsistent, but process kept for carbon formation considerations



2.5 Internal Reformer Validation - Carbon Prevention using Internal Recycle

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Potential for Carbon Increases with:

- Higher Cx
- Lower temperature
- Lower Fuel Utilization (FU)
- Lower CPOX O/C ratio

Anode Recycle Ratio must be increased to compensate.

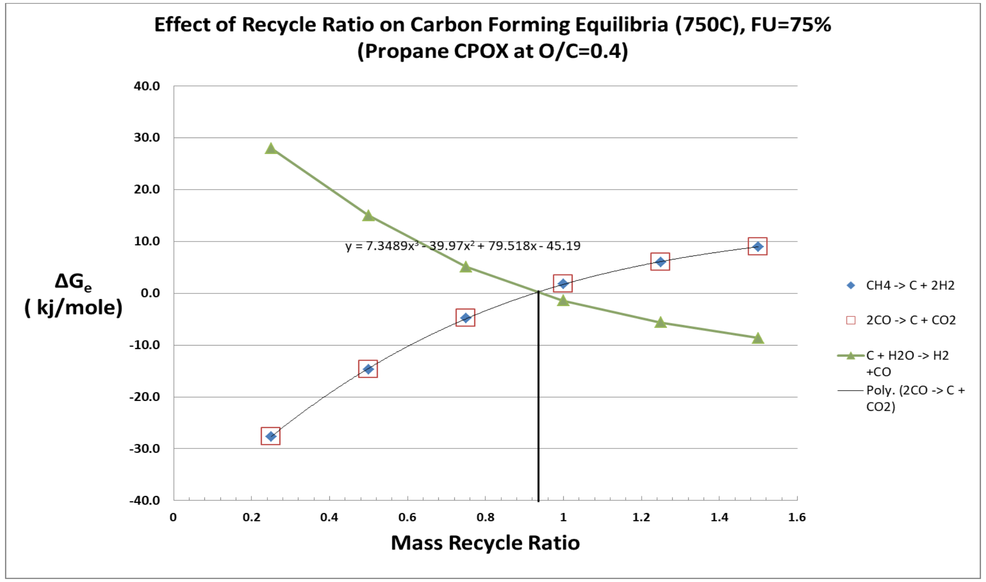
Target for propane: O/C = 0.6, ARR = 3-4

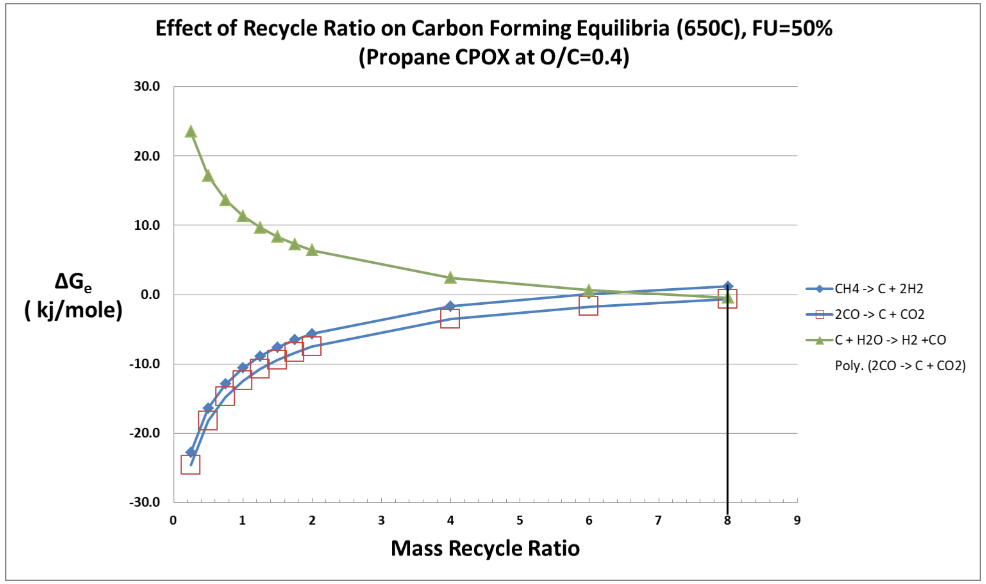
750°C

CPOX O/C	Minimum Recycle Ratio	
	FU 50%	FU 75%
0.4	1.6	0.94
0.8	0.44	0.3
1.2	0	0

650°C

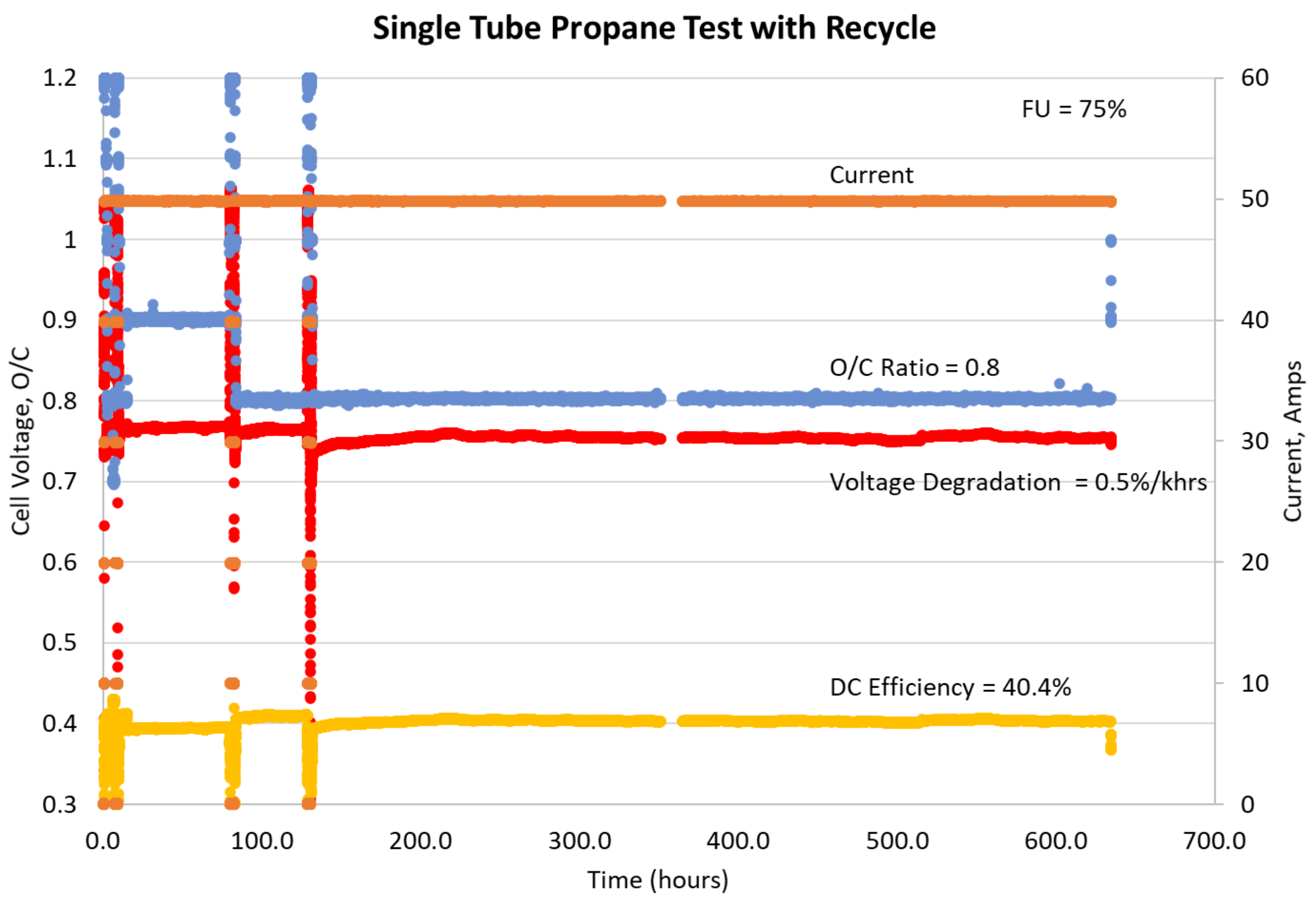
CPOX O/C	Minimum Recycle Ratio	
	FU 50%	FU 75%
0.4	8	2.5
0.8	2.25	1.08
1.2	0.6	0.36

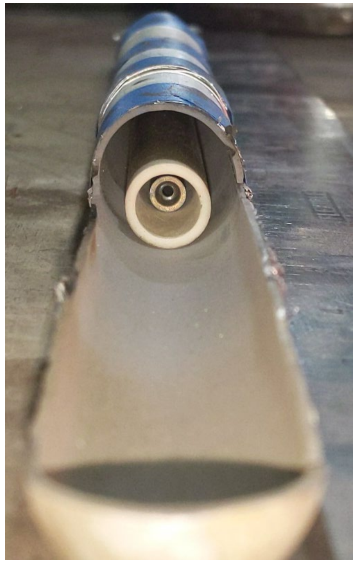




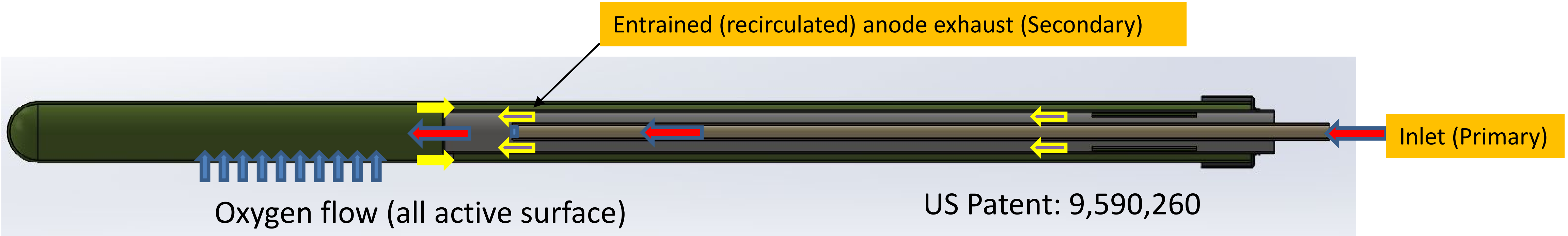
2.5 Internal Reformer Validation Previous Results

- Proof of concept completed in 2021
- Demonstrated carbon free operation at O/C = 0.8 for >500 hours
- Arrangement was not DFM friendly

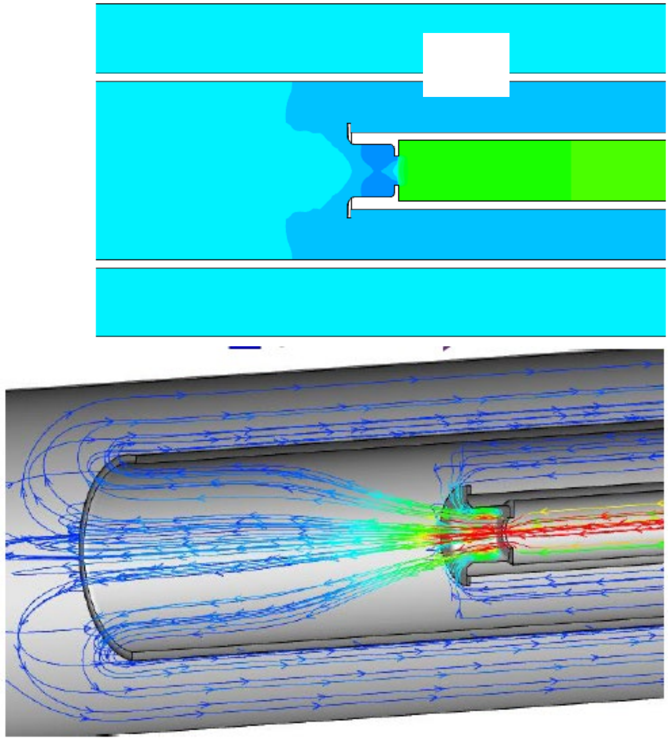




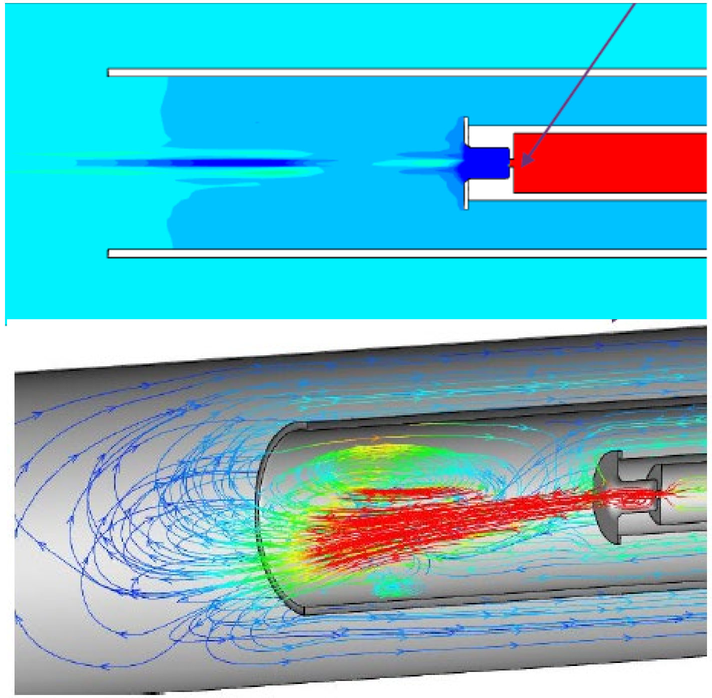
2.5 Internal Reformer Validation
CFD Modeling – shows path to higher ARR



0.07" Orifice
Velocity = 72 m/s
ARR = 0.2

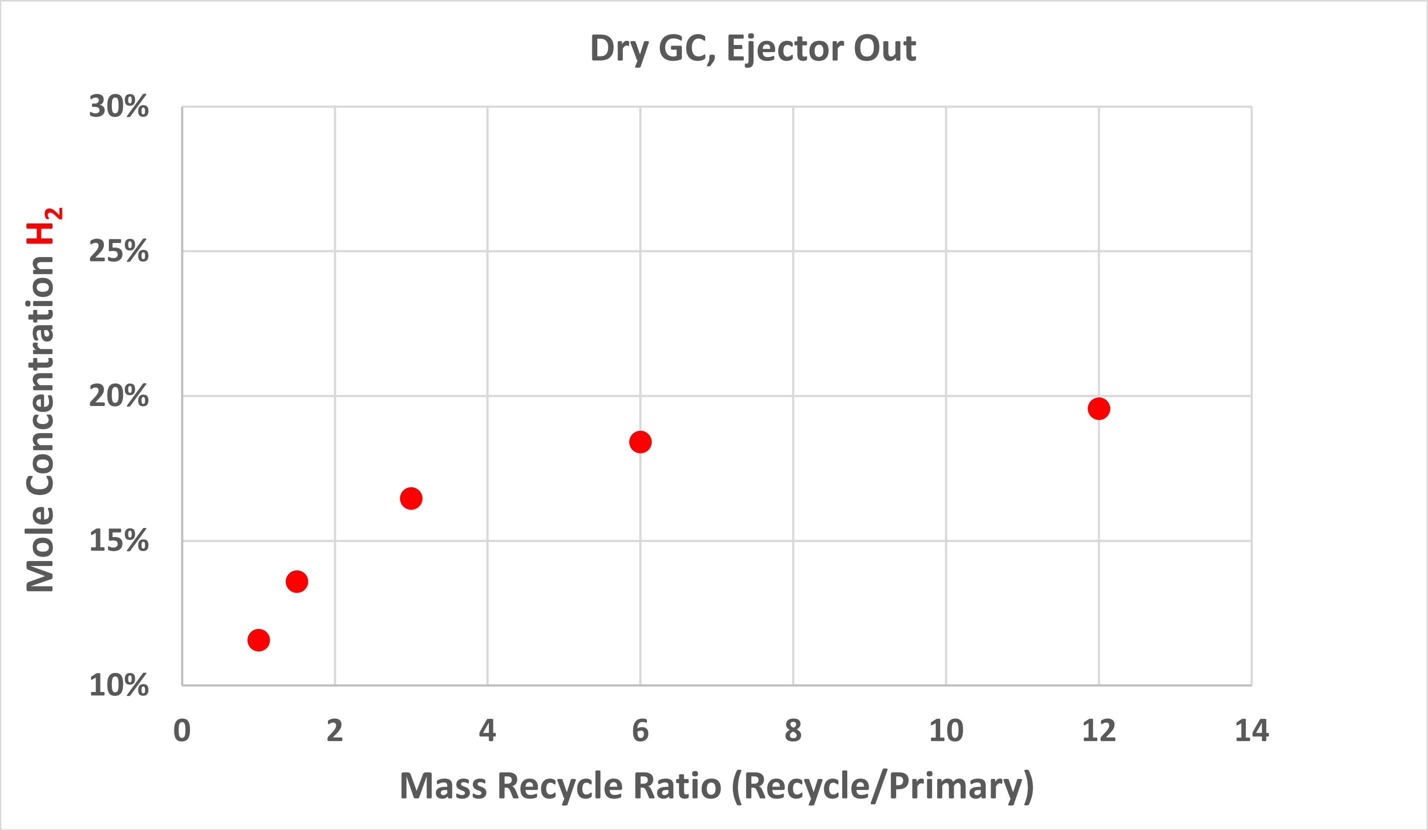


0.02" Orifice
Velocity = 830 m/s
ARR = 3.2



Ejector Testing Plan

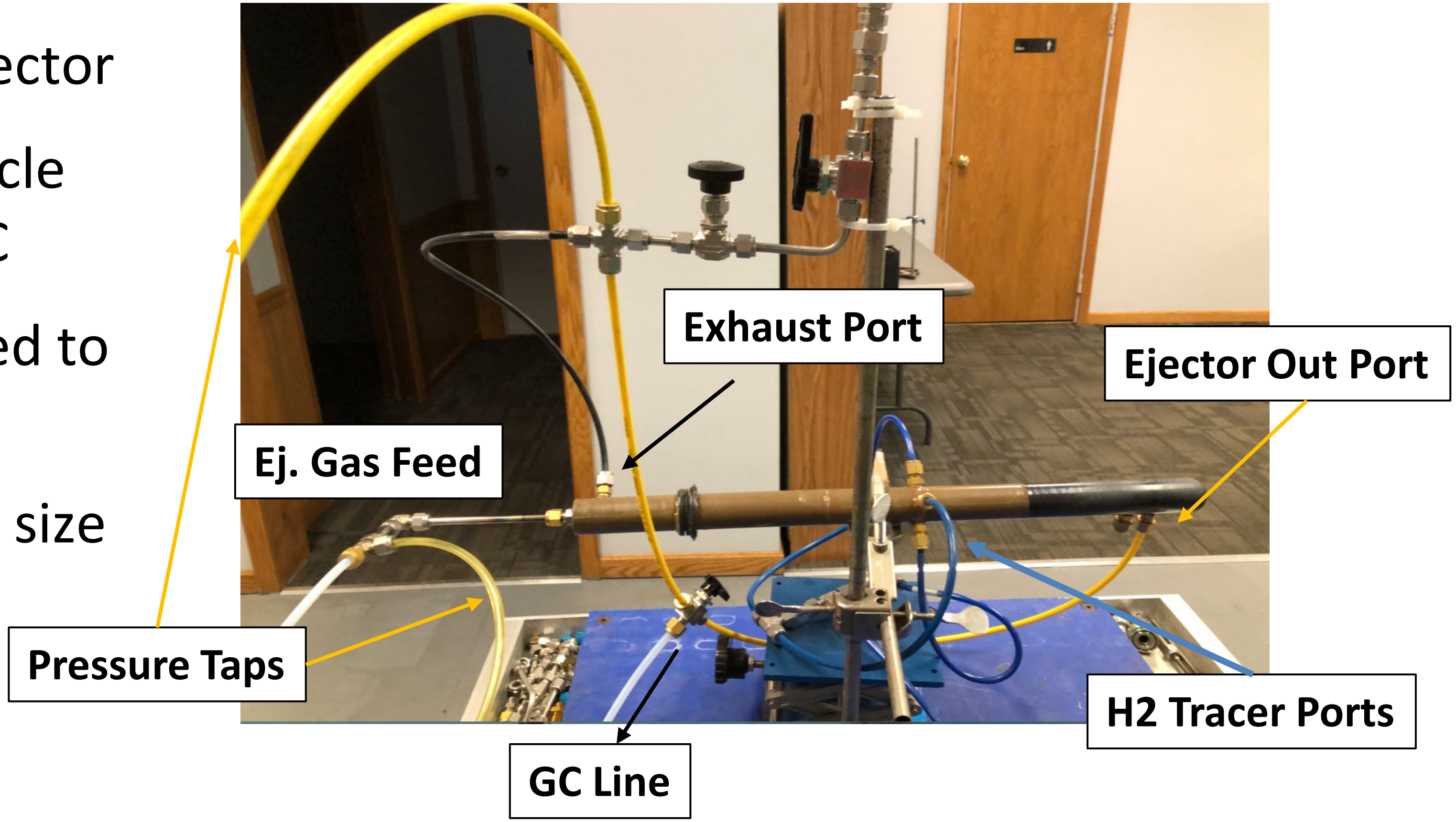
- Cold test with tracer gas and GC to confirm optimum orifice size and geometry
- Hot performance test for insertion depth to maximize performance
- Long-term (500-hr) test to confirm no carbon formation
- Bundle implementation for 2.5kW test



Cold Flow Test: Air/CO_2/H_2

Cold Recycle Flow Testing Set-up

- Feed actual fuel/N_2 blend into ejector
- Use H_2 as tracer to calculate recycle based on H_2 concentration via GC
- Estimate ejector pressure required to achieve adequate recycle rates
- Provide a basis to scale up orifice size for given O/C and operating temperature



Cold Anode Recycle Test Results

Recycle rates of 8 - 10 are possible

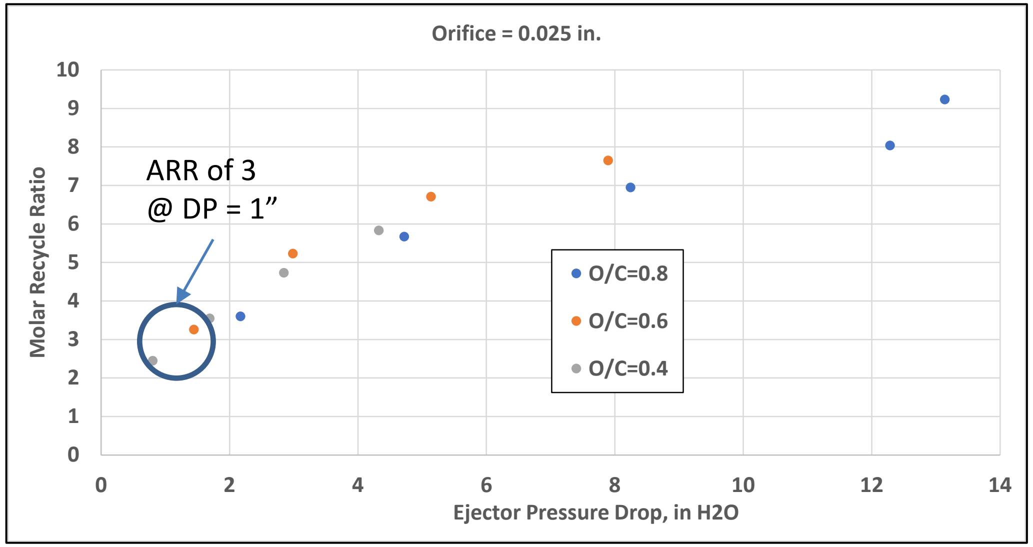
- With pressure drop less than 10 in H_2O

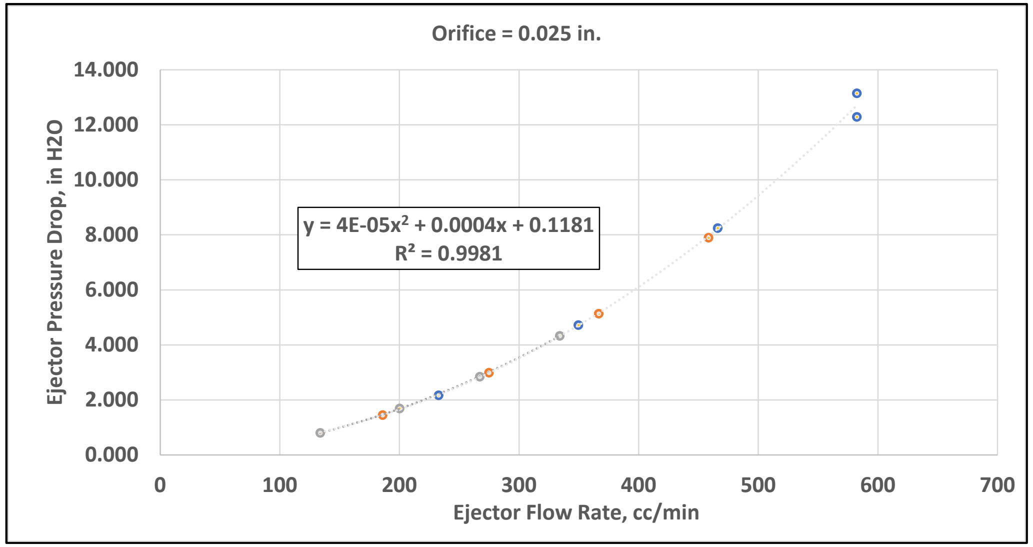
For recycle ≥2, cold flow test show:

- Min ejector pressure ~1 in. H_2O
- 50% to 100% load of 2-10 in H_2O

Hot Flow Testing will occur in single cell test stand to:

- Verify orifice size at the anticipated operating conditions
- Assess potential issues with coke formation or reaction exotherm





Single Tube Tests with Propane

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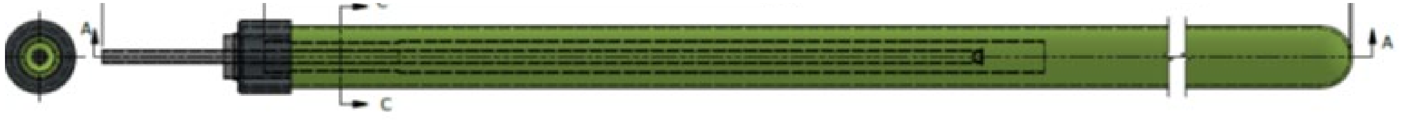
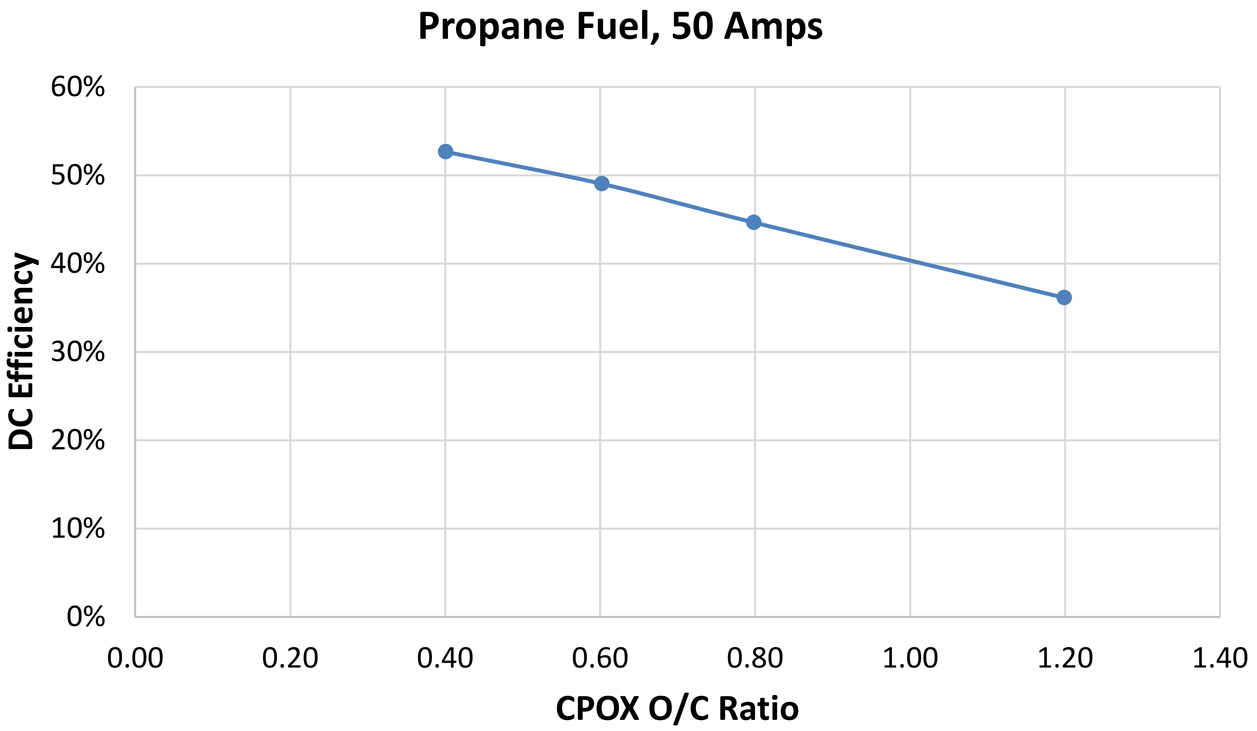
- Concept designed which can be more easily produced
- Single-cell testing confirms good efficiency with low O/C operation
- Long-term operation at low O/C now ongoing
- Bundle configuration being implemented



US Patent: 9,590,260



Task 2.6 Result of Combined Effects

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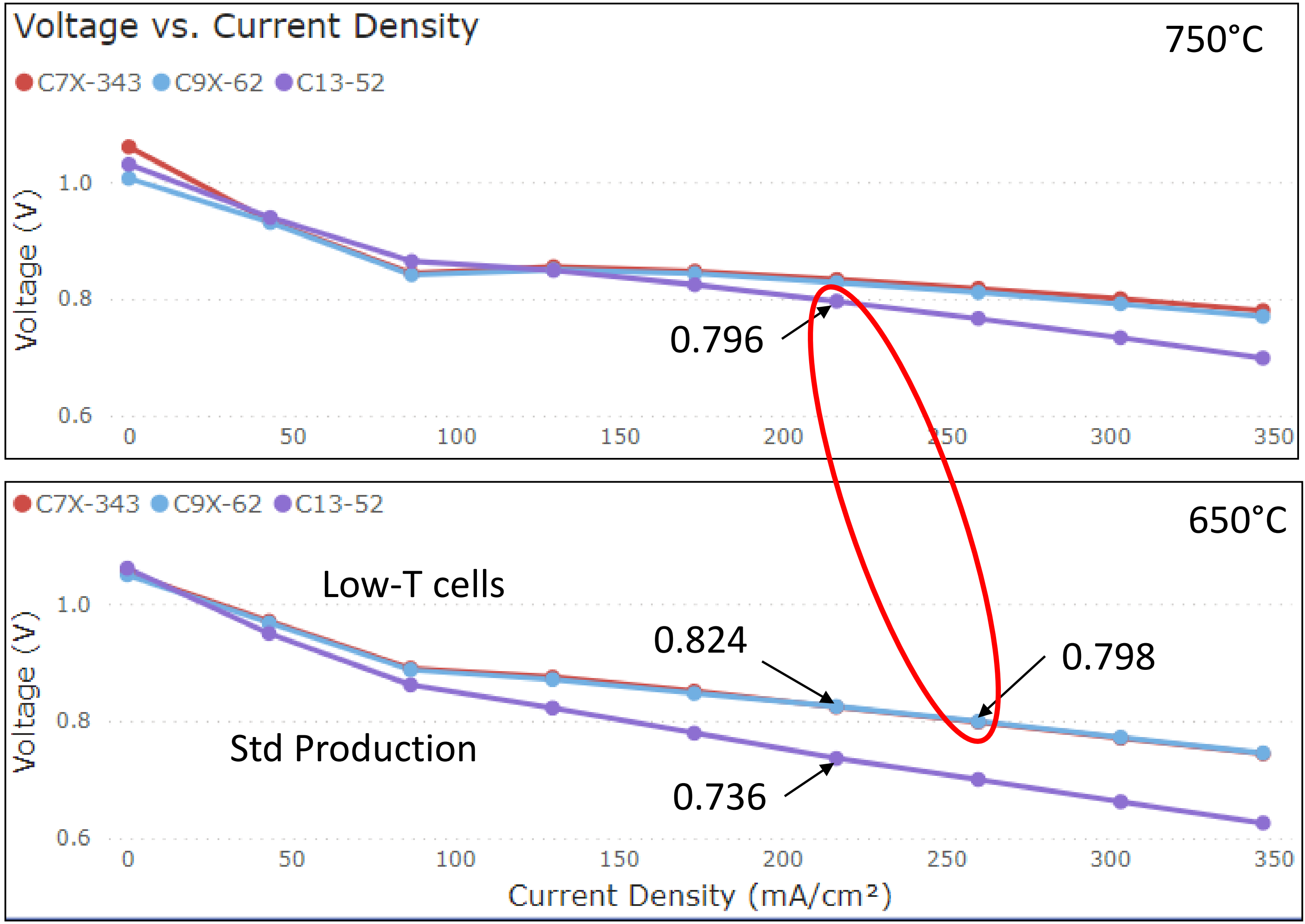
Final Process

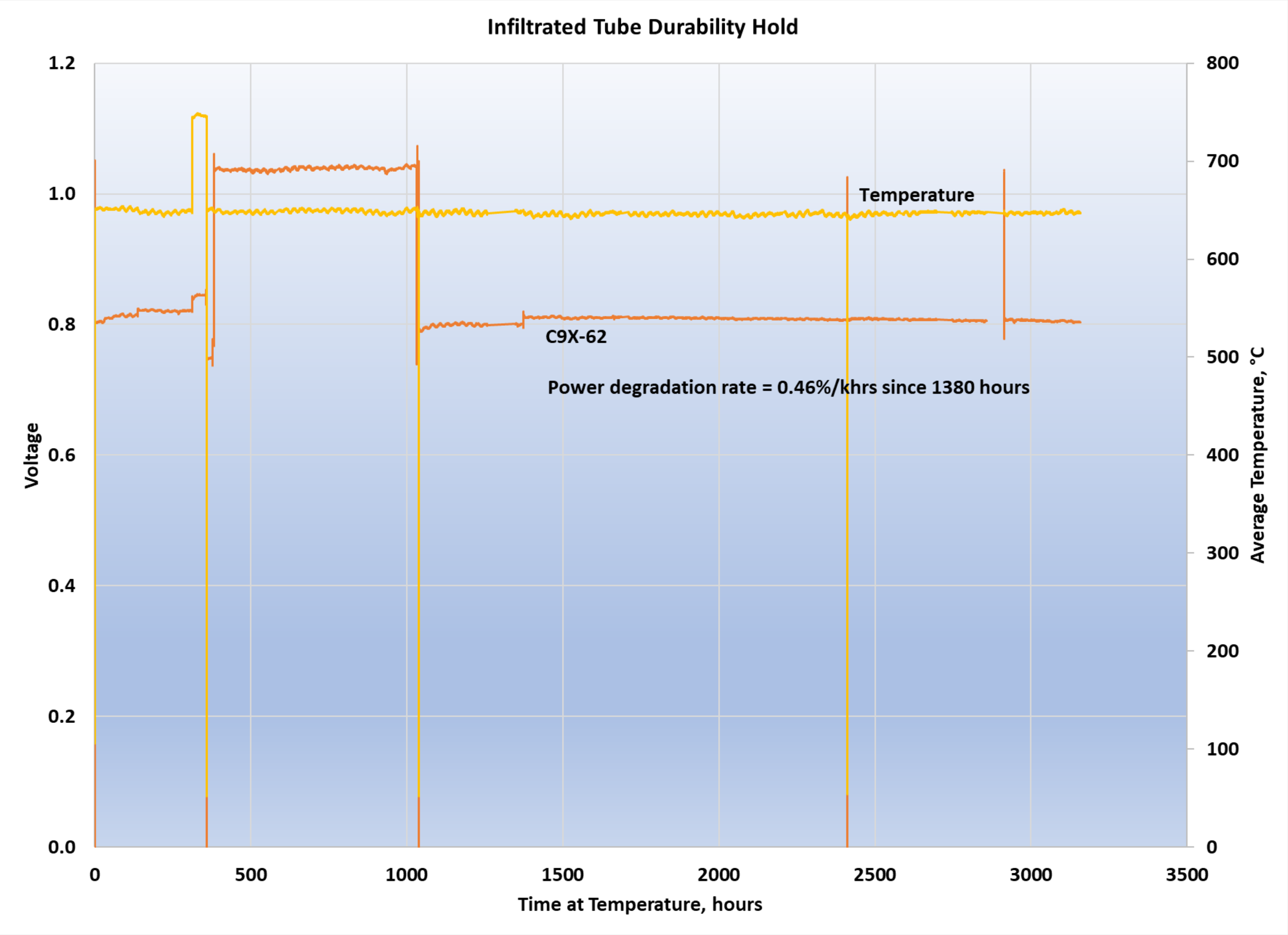
- Cells reduced
- Anode/Cathode infiltration
- Thermal treatment to 400C
- Anode Cu wash
- CCC screen print



Improved tubes generate 20% more power than standard tubes at same voltage, yet at 100°C lower temperature

2.6 Combined Testing – Single Cell

- Operation at 650°C
- Current = 50 amps
- FU = 75%
- Power degradation: <0.5%/1000 hours



2.6 Combined Testing
5000-hour System Test

Commercial bundles operation 750-775°C

Targeting low temperature operation 650C-700°C

Test started week of 5/9/2022

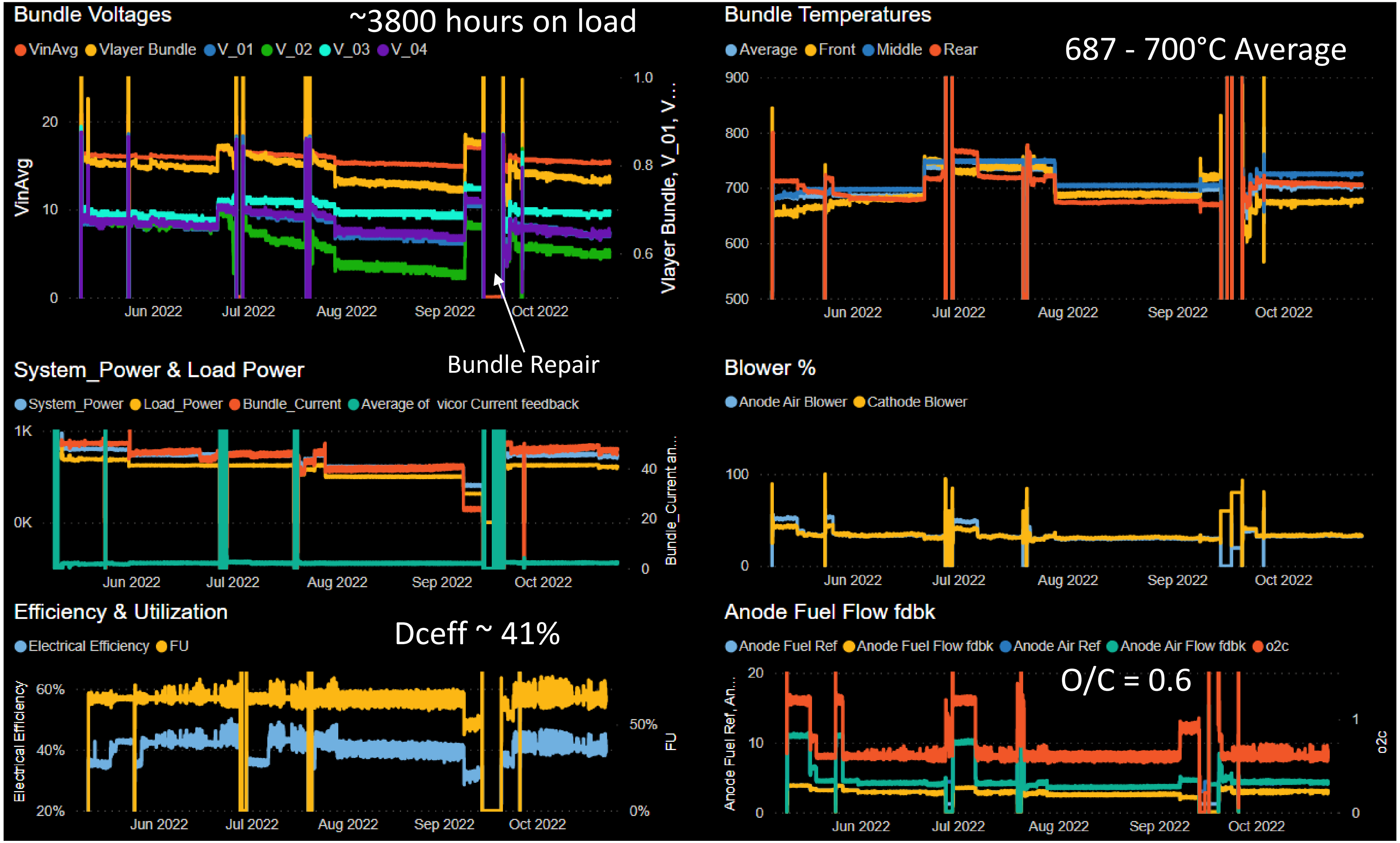
Scheduled completion of 5000 hrs Dec 5, 2022

20 tube bundle in a full system

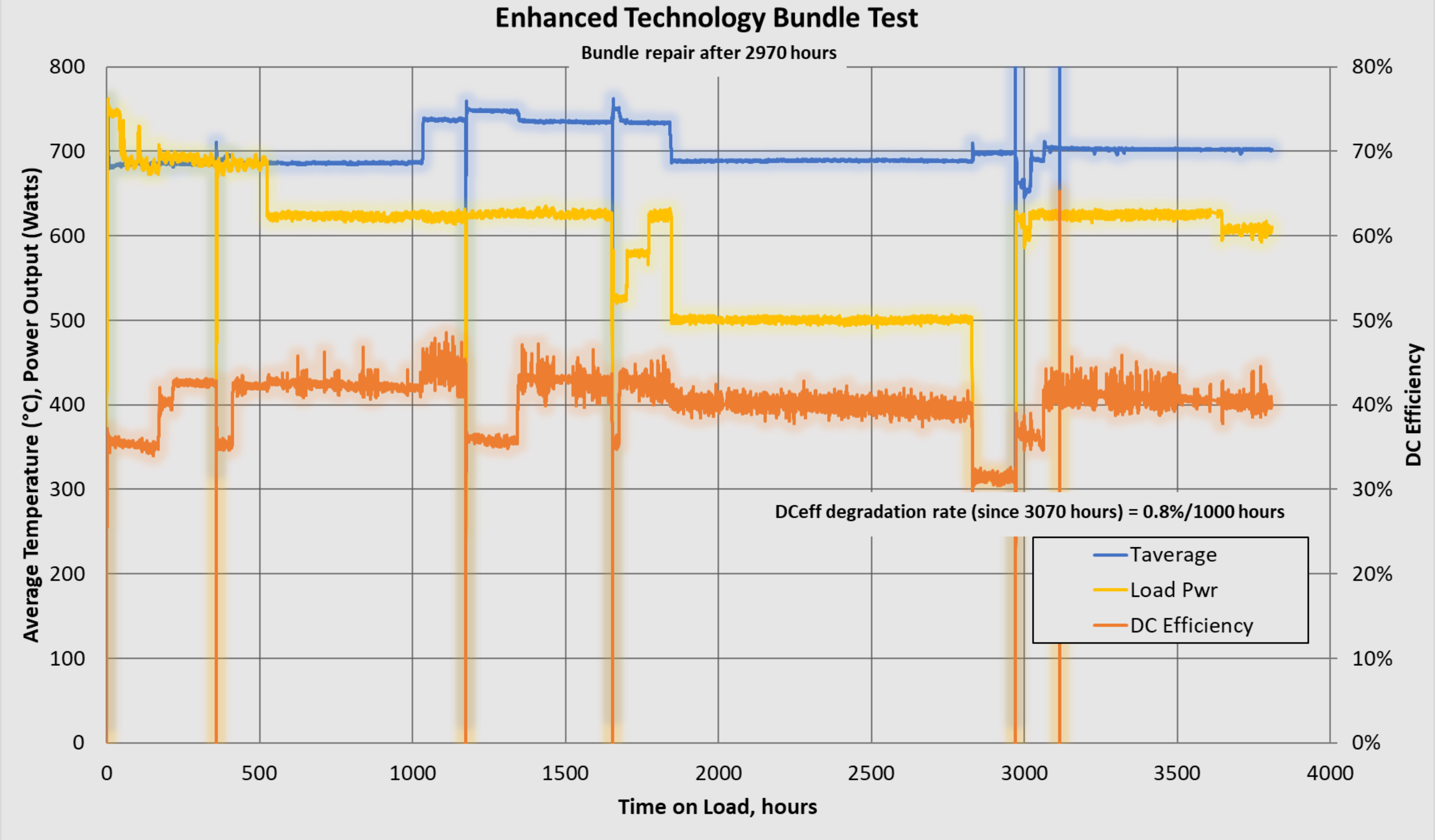
Capable of 625W rated power

DC efficiency > 40%

5000 Hour System Test Progress



5000-hr System Test Performance Summary



5000-hour System Test Plan

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- 500 hours at max load (50 amps) ✓
- 1000 hours at 100% load (625W) ✓
- 500 hours at 100% load, FU = 75% (625W)
- 500 hours at 80% load (500W), 680C ✓
- 100 hours at 50% load – O/C = 1.2 (313W) ✓
- <u>*Bundle layer 2 repaired after 2970 hours*</u>
- **500 hours at 100% load** (625W) ✓
- ➡ 500 hours at 100% load, FU = 75% (625W)
- 500 hours at 80% load (500W), 680C
- 100 hours at 20% load – O/C = 1.2, FU < 50%
- 500 hours at 100% load (625W)

On track to complete 5000 hours by end of 2022

Task 4.4 – Megawatt Performance, Cost, and Reliability Feasibility

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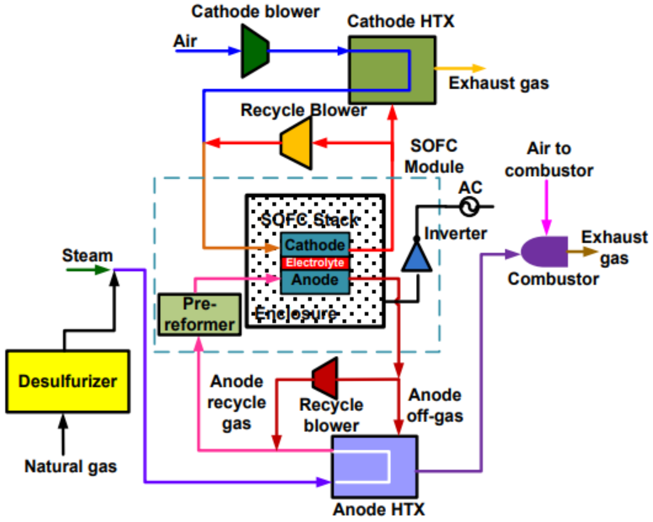
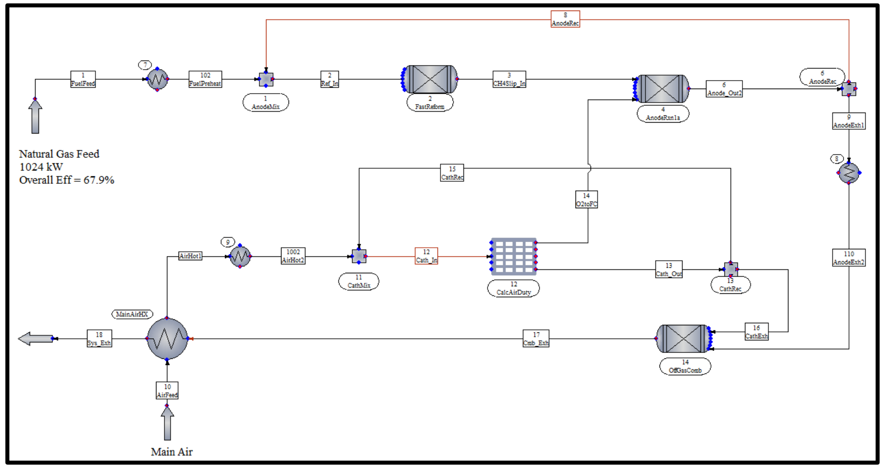
- Modeling 1 Megawatt using ChemCad
  - Modeling based in DOE system. "Distributed Generation as a Potential Market for SOFC"
  - Simulate DOE baseline case as benchmark
    - **Chem-Cad Model successfully matched fuel utilization at specified efficiency.**

- Mechanical Design of 5 to 10 KW Module
  - Building block for 1 MW system
  - Use for costing purposes





Model Result: FC Condition @ 90% Utilization

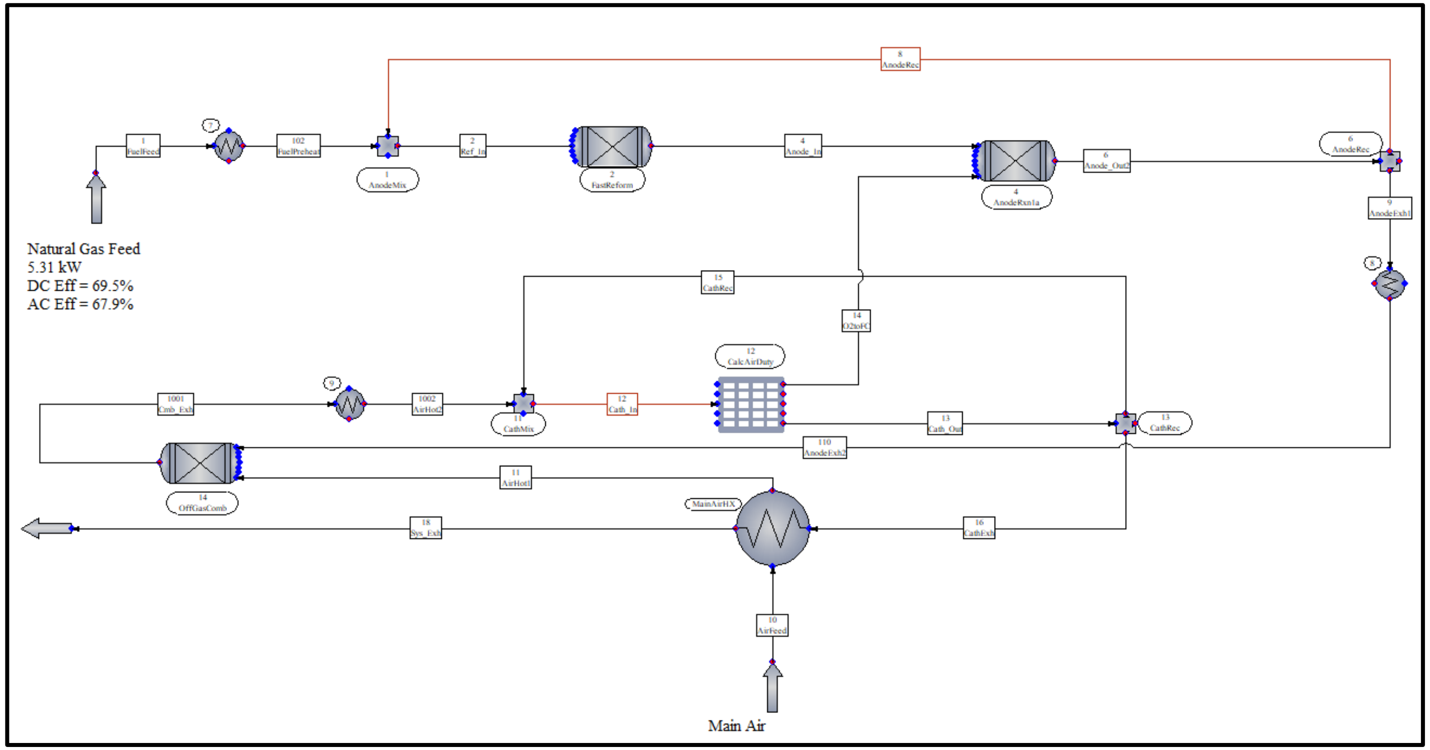
Property	Inlet	Outlet
Composition		
N2	0.53	0.52
CO	16.17	4.44
CO2	17.70	29.53
H2	38.54	12.55
H2O	26.77	52.96
CH4	0.29	0.001
Average Temperature, °C	750	
Current Density, mA/cm^2	400	
Vop, volts	0.83	
Average Vrev, volts	0.927	
Average ASR, ohm-cm^2	0.242	

SPS legacy cells operate at 210 mA/cm^2 nominally

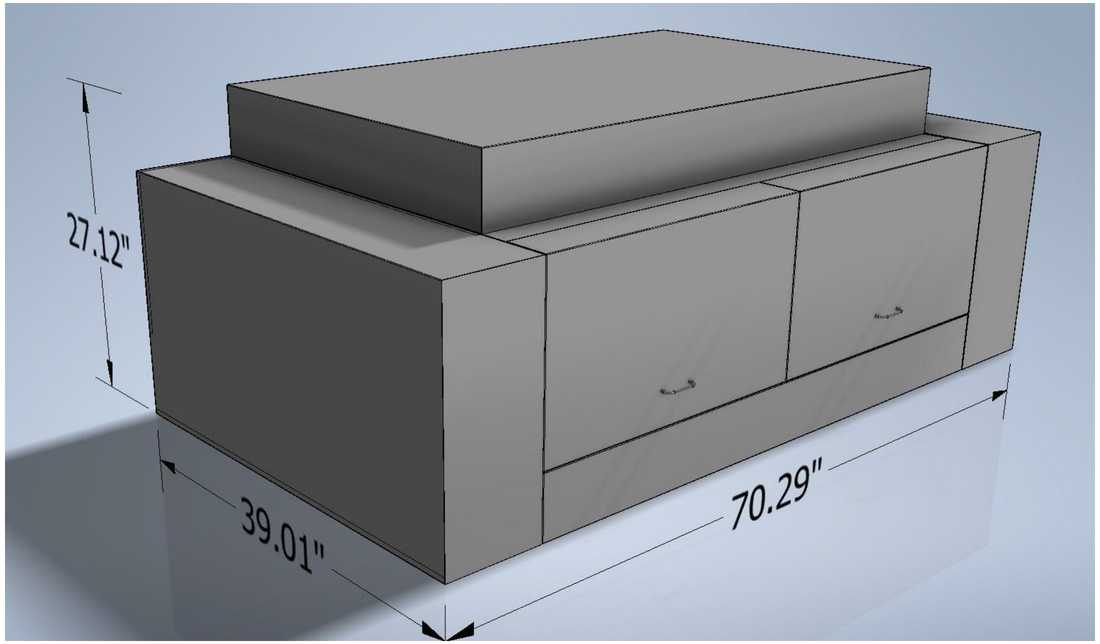
Projected voltage of 0.75V at 400 mA/cm^2 based on enhanced performance cells

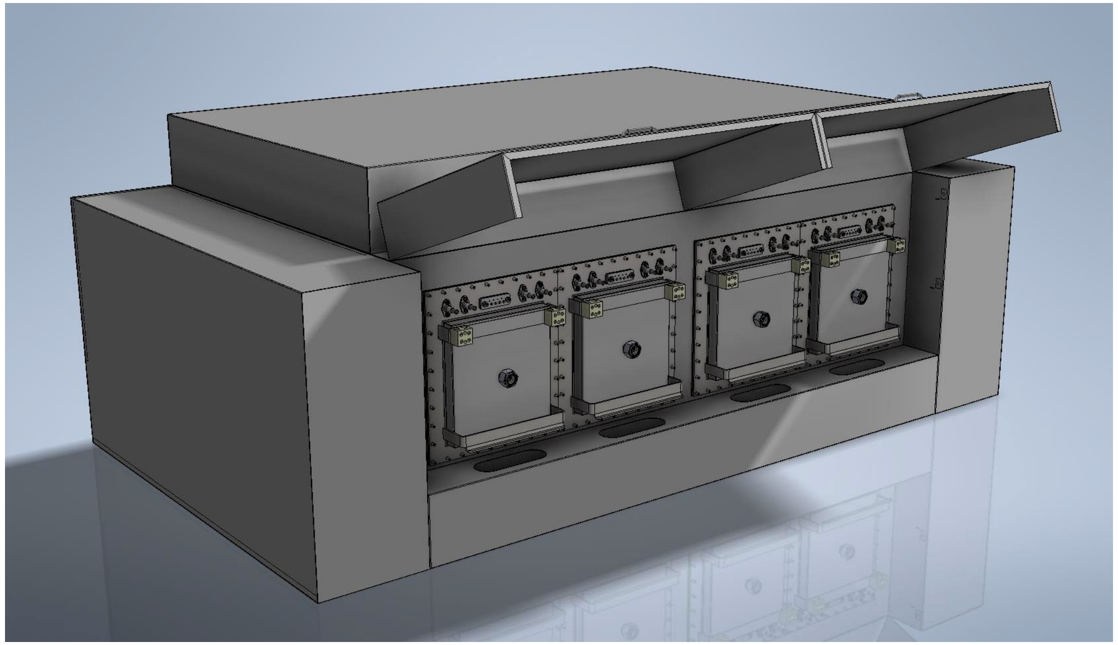
Modelling Approach

- **SPS configuration modeled for 5 kW_e product**
  - Natural Gas and Propane cases
  - Combination of CPOX and Internal Reforming with Recycle
  - No cathode recycle
  - Combustor located at cathode inlet
  - Estimated number of cells for current performance (64 to 144)
  - Cost will be based on these features



SPS 10kW System Concept





Concept based on 2 (two) parallel 5kW system, each using 2 (two) 2.5kW modules
Desulfurization on the top, Controls on the side

SPS 10kW System Concept

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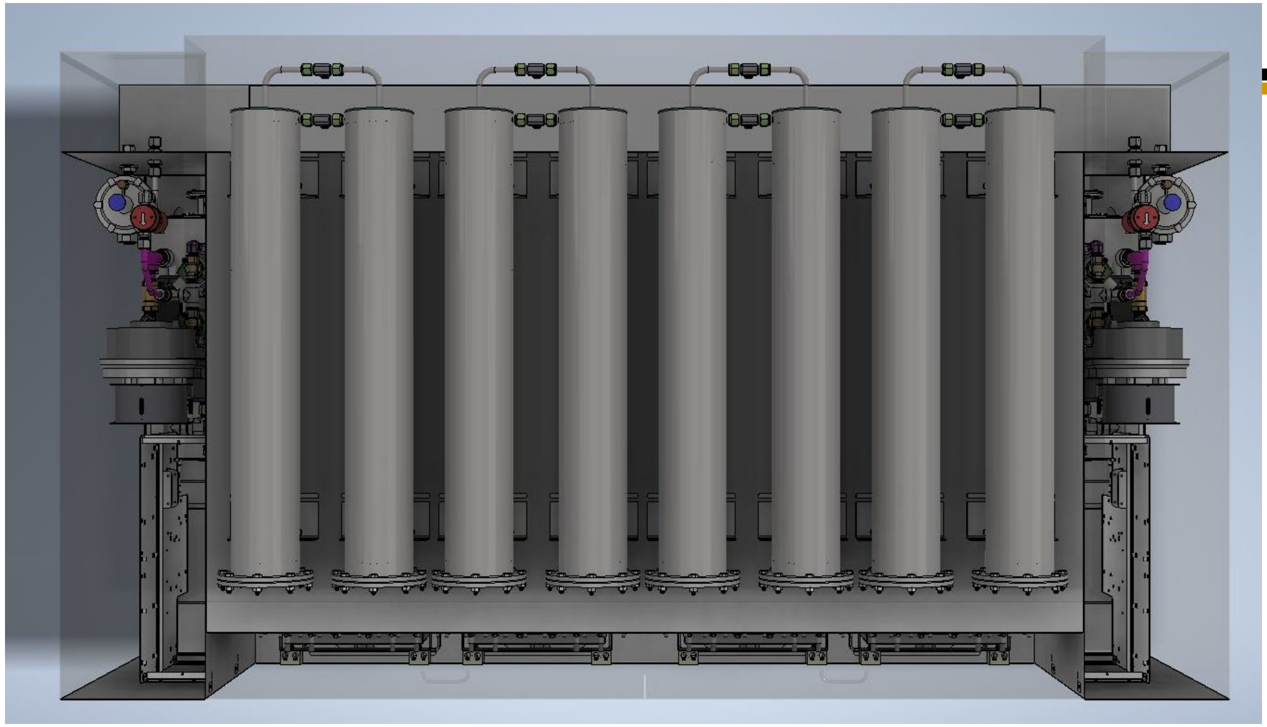

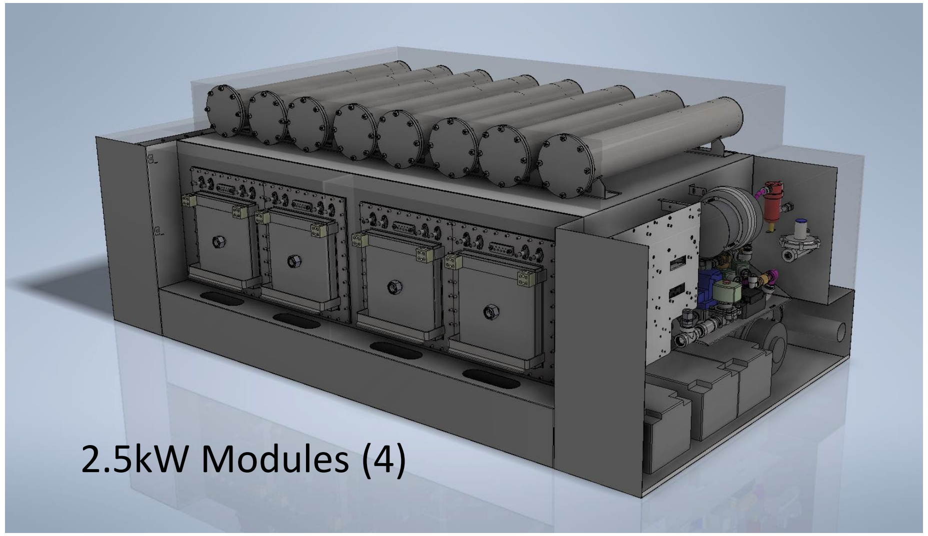

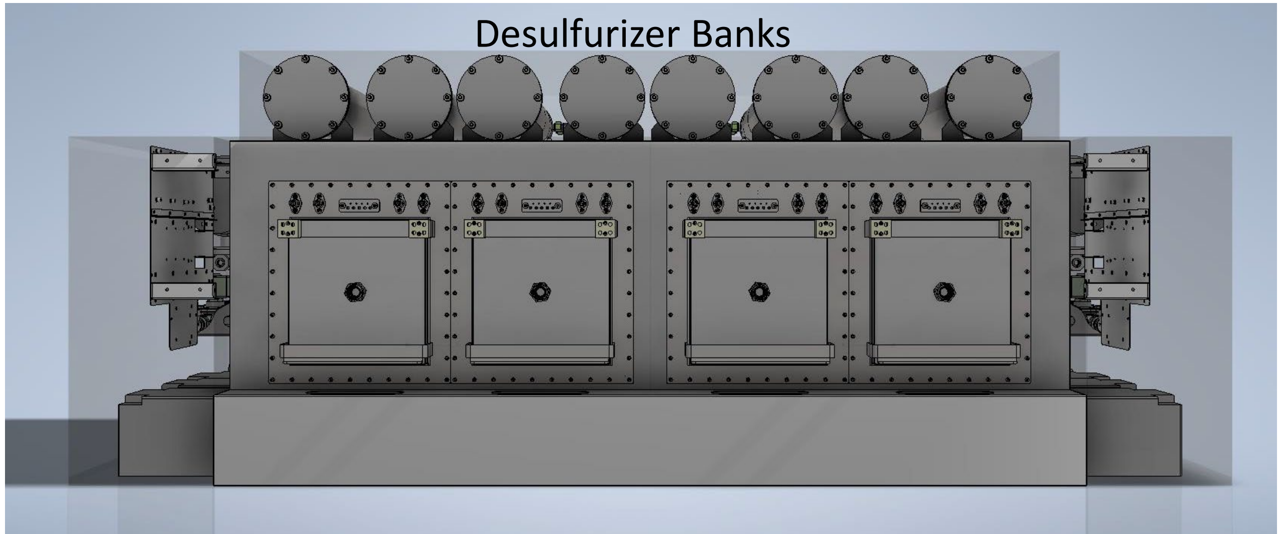

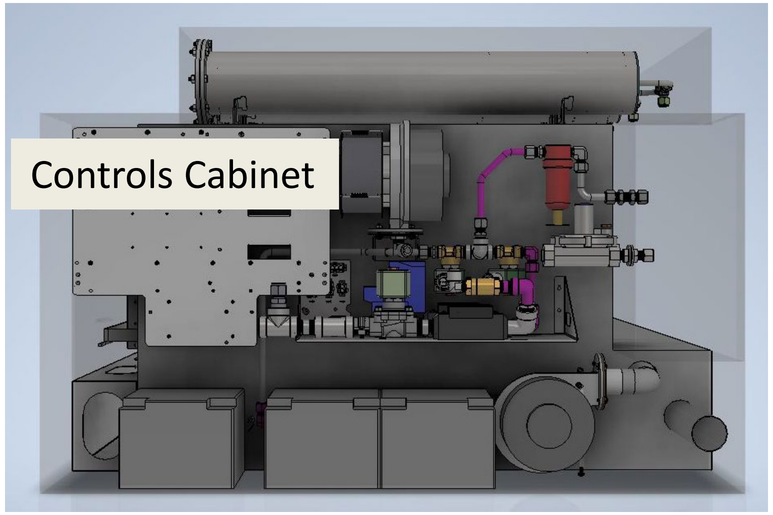

Summary

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- Improved fundamental cell technology has been demonstrated at single tube and system scales which has improved power output by 20% while operating at 100°C lower temperature.
- SPS patented internal recycle arrangement has been further developed to operate heavier hydrocarbon fuels directly in a compact, high efficiency system.
- System testing is ongoing to prove out long-term durability of cell improvements.
- System designs at 5 and 10kW are being developed for cost study and will form the basis for near-term commercial opportunities.

Acknowledgement

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