Cummins Reversible-Solid Oxide Fuel Cell System Development

Project ID: FE0031971

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Public

R-SOFC Project Objectives

Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development

Overview

1. 2 year Project ($2M)
2. Component Development to enable $2/kg-H2 by reducing capital cost by 30%
   1. Cell/Stack
   2. Steam Ejector Fuel Loop
3. Project
   1. System Modeling
   2. CFD/Performance Simulation
   3. Experimental (Steam Ejector)
4. Deliverables

   Phase 1
   1. New Cell Design
   2. Steam Ejector Design/Test

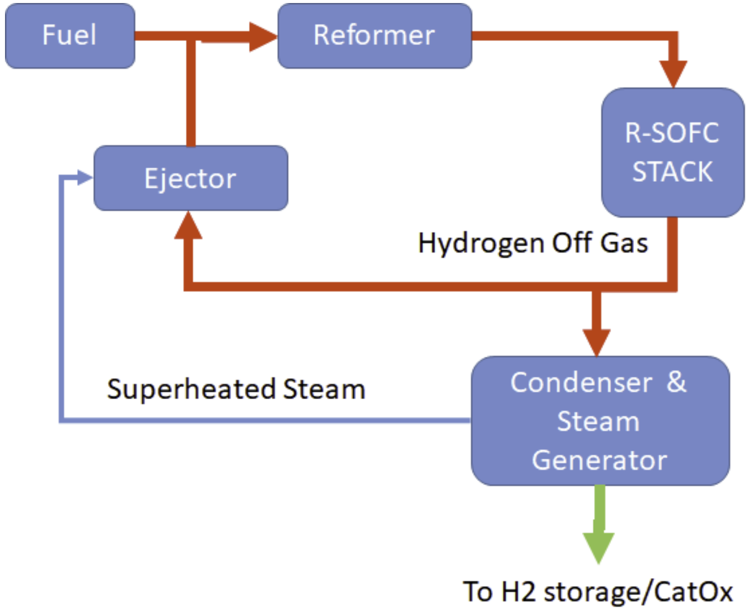
   Phase 2
   1. Prototype Cell Substrate
   2. Steam Ejector Demo. in hot fuel loop experiment

1. NextGen Cell & Stack Design

Produce a metal substrate with higher performance and lower cost

2. Steam Ejector Concept Design

Demonstrate a steam ejector in a simulated hot fuel loop



Budget and Milestones

Complete

In Progress

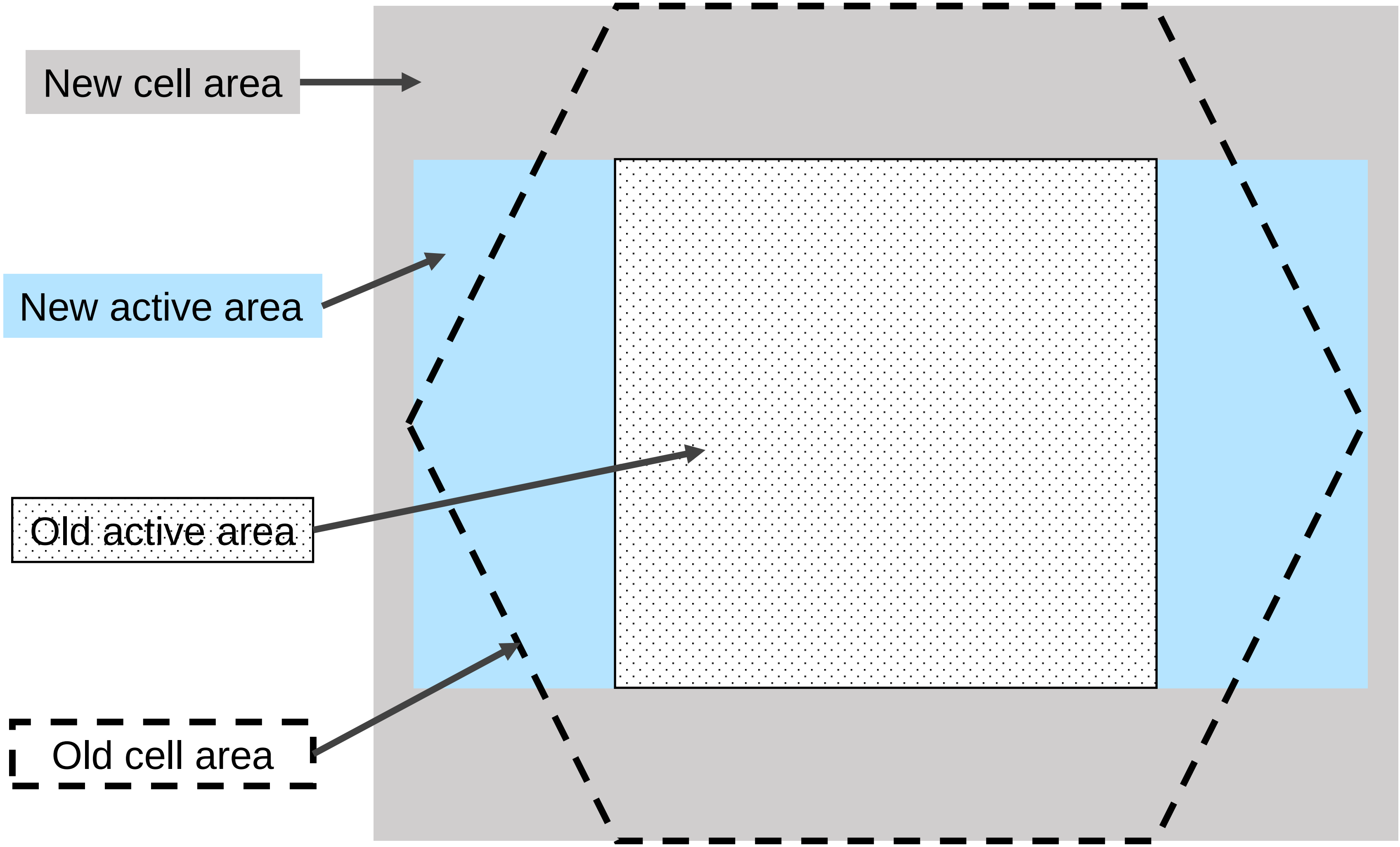
Timeline and Budget

- Project Start Date: January 1, 2021
- Project Duration: 24 months
- Total Project Budget: $2,501,031
  - Total DOE Share: $2,000,825
  - Total Cost Share: $500,206
  - Total DOE Funds Spent*: $1,334,149
  - Total Cost Share Funds Spent*: $337,598

* As of June 30, 2022

Task	Milestone	Planned Completion Date	Verification Method
2.0	M1: System Model Validated (TRL 3)	6/30/2021	System model calibrated to Baseline stack performance within 10% accuracy
3.0	M2: Cell Model Validated	9/30/2021	Cell model validated with Baseline stack data
4.0	M3: Steam Ejector Lab Tested (TRL 4)	11/30/2021	Steam Ejector demonstrated in lab test. Measure pressure, temperature, and flow rate
5.0	M4: Cell Substrate Design Finalized	3/30/2022	Cell Substrate design optimized based on the cell performance model results
5.0	M5: Make an Advanced Cell Substrate Prototype	6/30/2022	Demonstrate • Mass manufacture forming • Low cost joining • Robustness
6.0	M6: Steam Ejector Tested in Relevant Environment (TRL 5)	11/30/2022	Measure performance of the steam ejector in the hot test loop and compare with simulations. Measure pressure, temperature, gas composition, HX effectiveness and flow rate

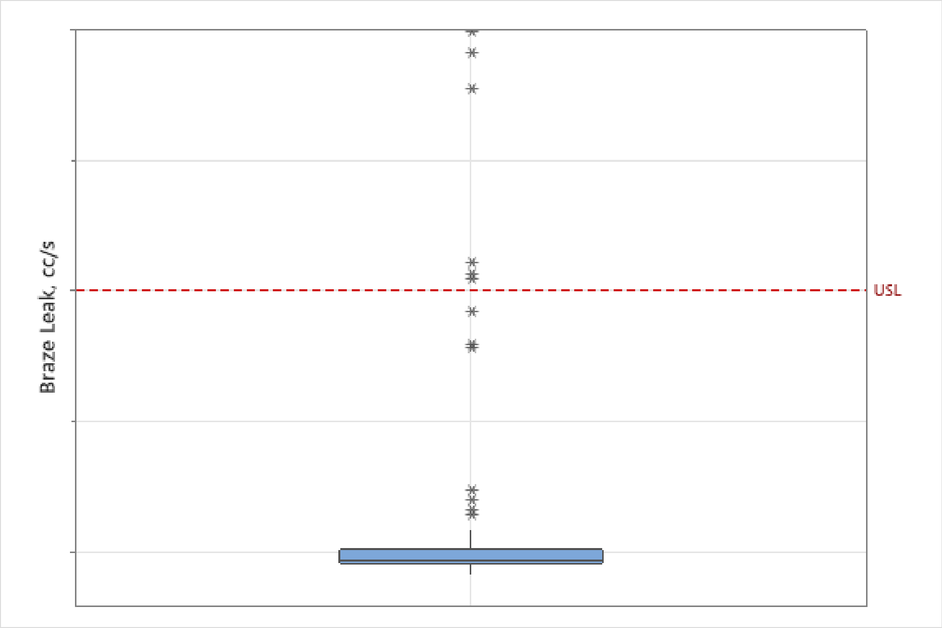
New Cell Design Footprint

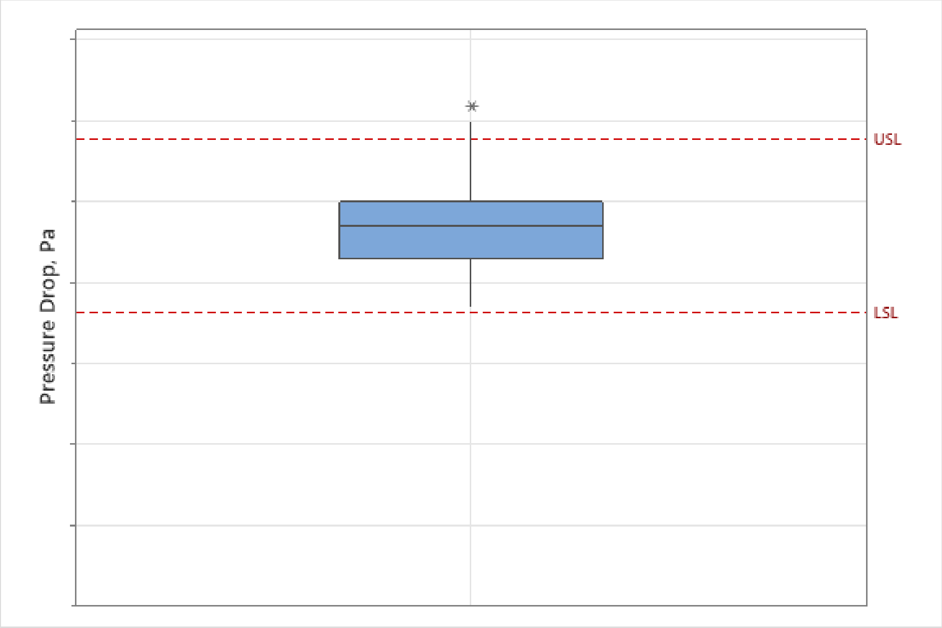


- Increased active area for same footprint
  - 780 cm^2 active area
  - Improved $/kW per cell
  - Fewer cells for same stack power – improved $/kW & kW/L

Cell Quality Checks

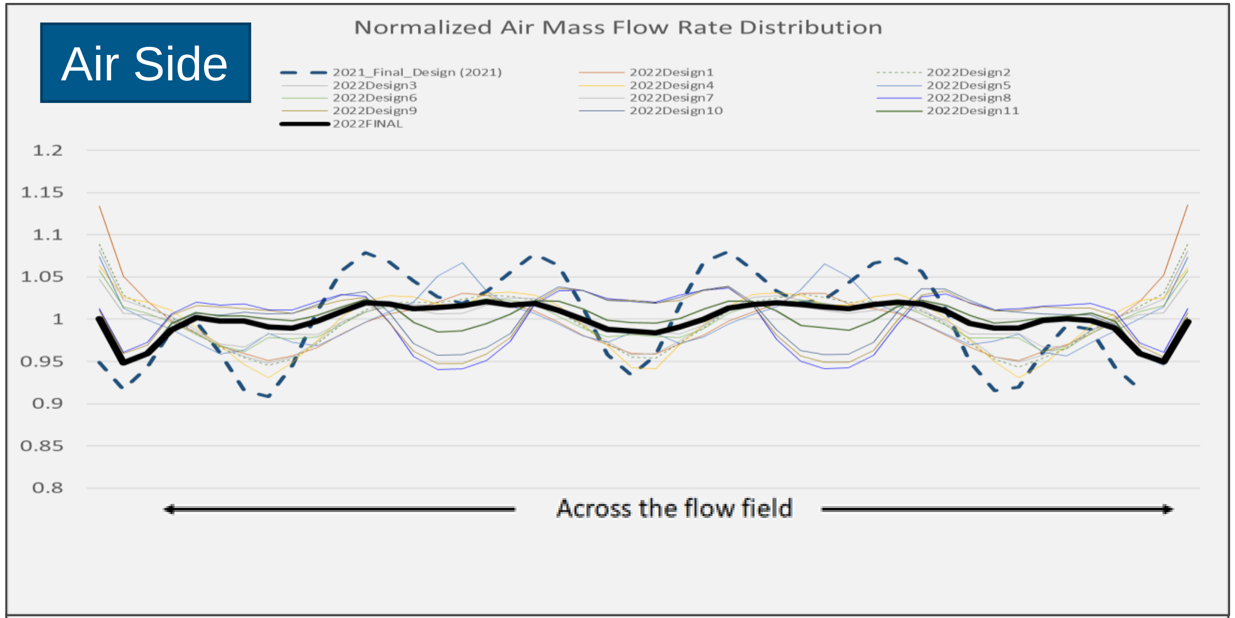
Measurement	Primary Variable of Interest	Specification
Braze Leak Rate	Metal is braze joined hermetic	Upper spec limit (cm^3/s)
Pressure Drop (fuel inlet to outlet)	Metal is formed and aligned properly during braze	+/- 10% from median value (Pa @ 15 LPM air flow)
Visual Inspection	Permeable membrane does not have any defects	Pass / Fail
Surface Roughness	Roughness of textured surface prior to coating deposition	Lower spec limit (microns)
Coating Leak Rate	Electrolyte coating adequately seals membrane, does not have defects	Upper spec limit (cm^3/s)
Flatness	Stress state of metal substrate with ceramic coating is reproducible	Upper spec limit (mm)

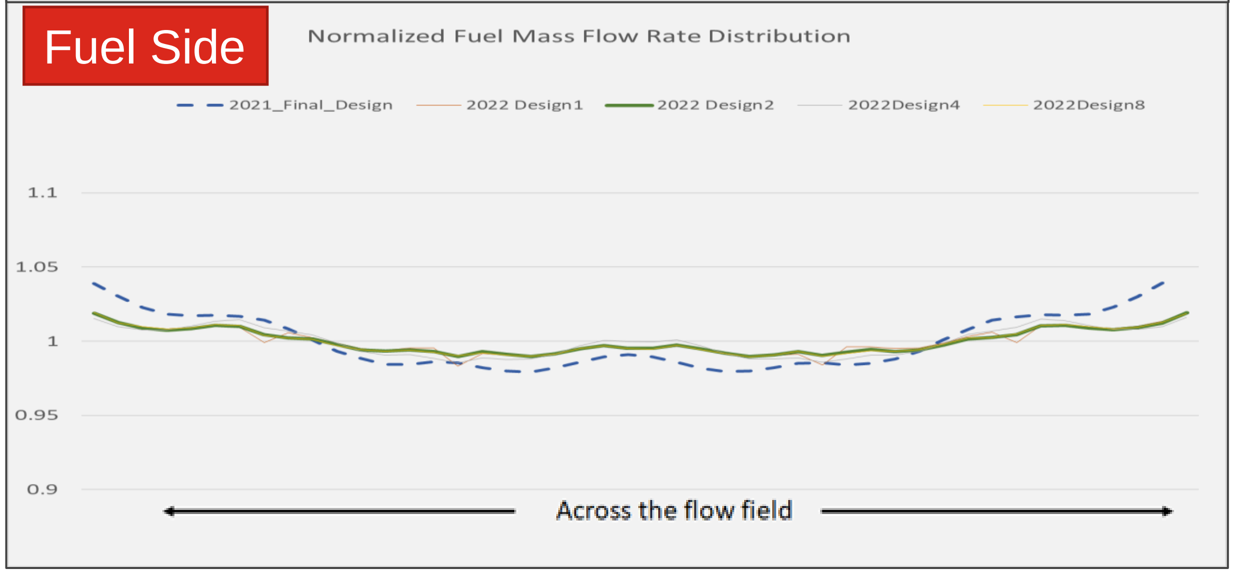




CFD Optimization of Cell Flow Field

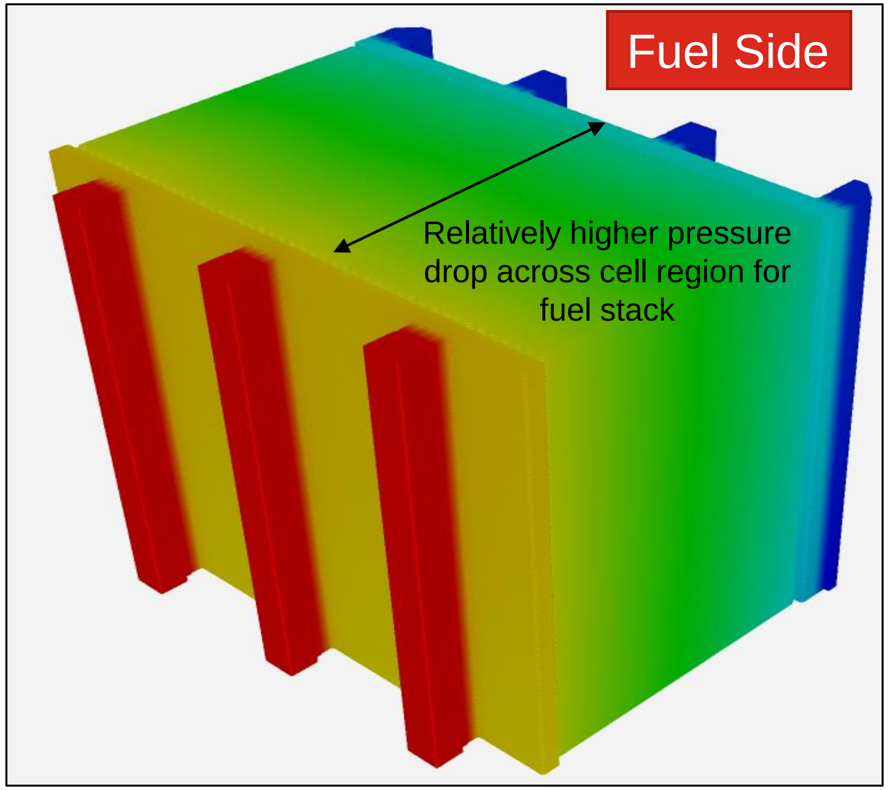
- Iterative CFD analysis to optimize cell flow field
  - Minimize channel-to-channel mass flow variation
- Design of experiments approach
  - Multiple manifold designs
  - Varying numbers of input and output ports
  - Forward and reverse flow directions
- Best design flow variation
  - Air side: 7% variation across channels
  - Fuel side: 3% variation across channels

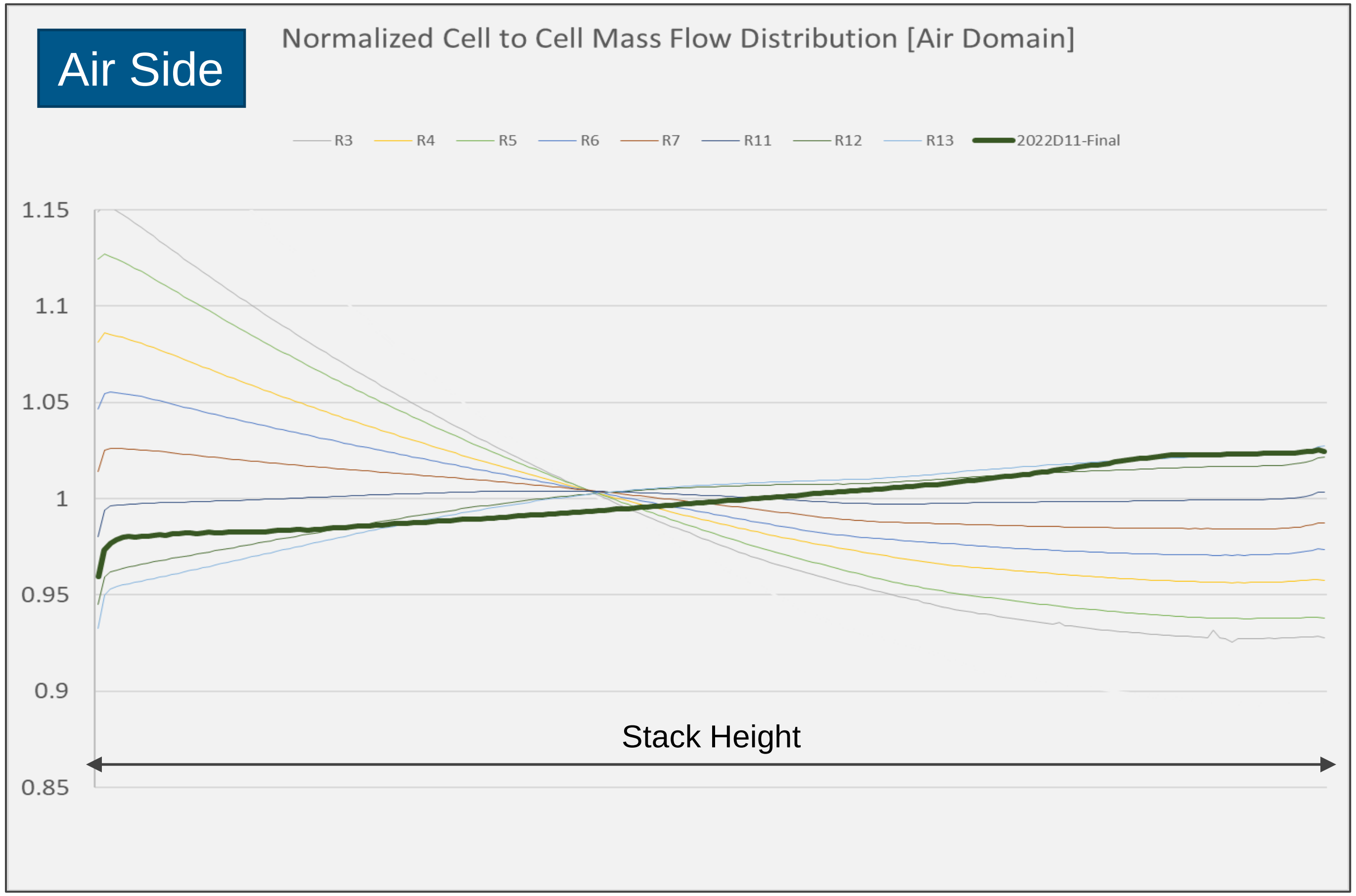




CFD Optimization of Stack Flow Field

- Cell to cell flow distribution through air stack is optimized by adjusting inlet/outlet header sizes, cell resistance
- Cell to cell flow distribution for fuel stack is minimal due to relatively higher resistance across fuel flow path

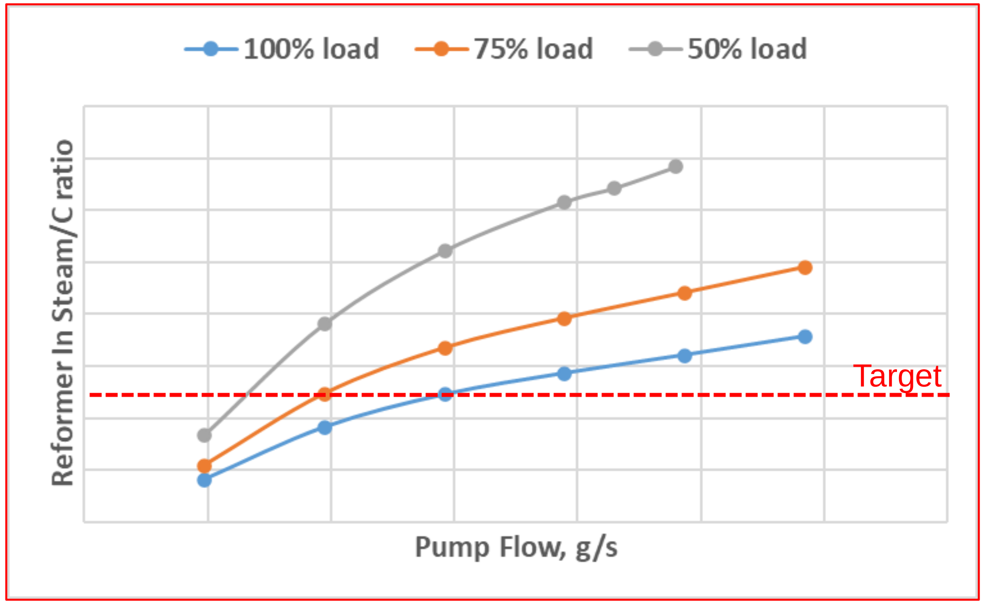


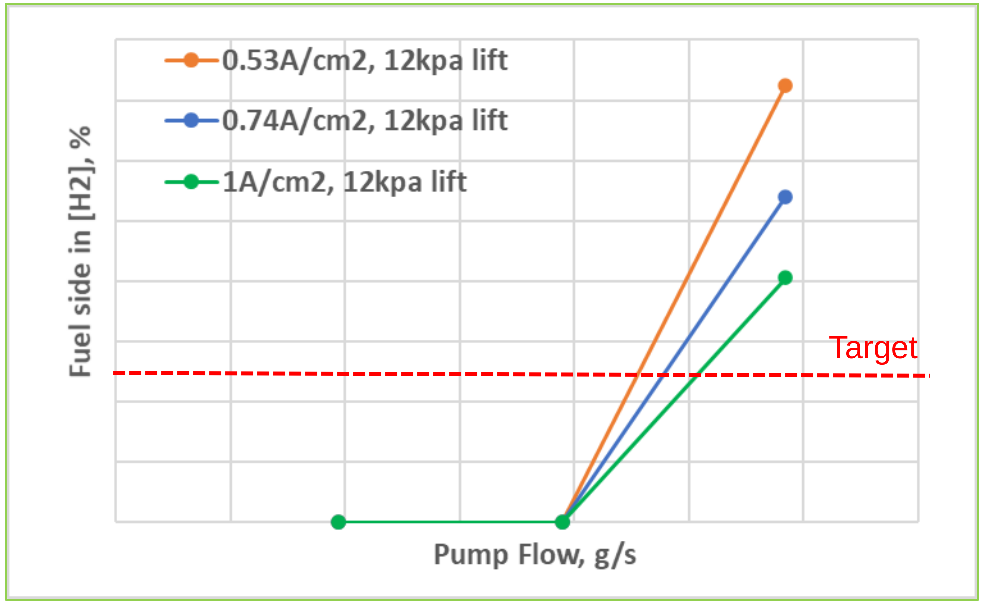


Air stack cell to cell variation 6.5%

Fuel stack cell to cell variation < 1%

R-SOFC System Simulations





- R-SOFC system simulations using ejector performance curves from validated CFD model

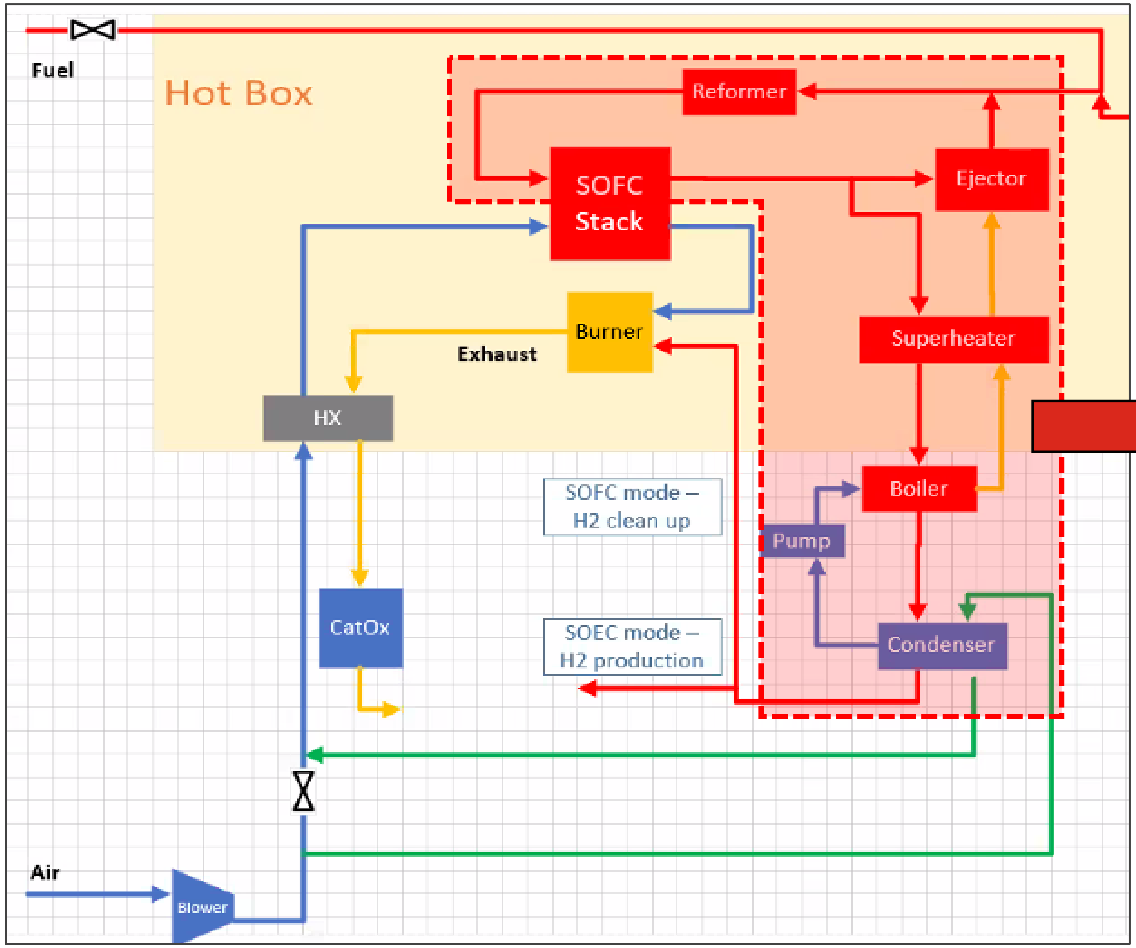
Fuel cell mode

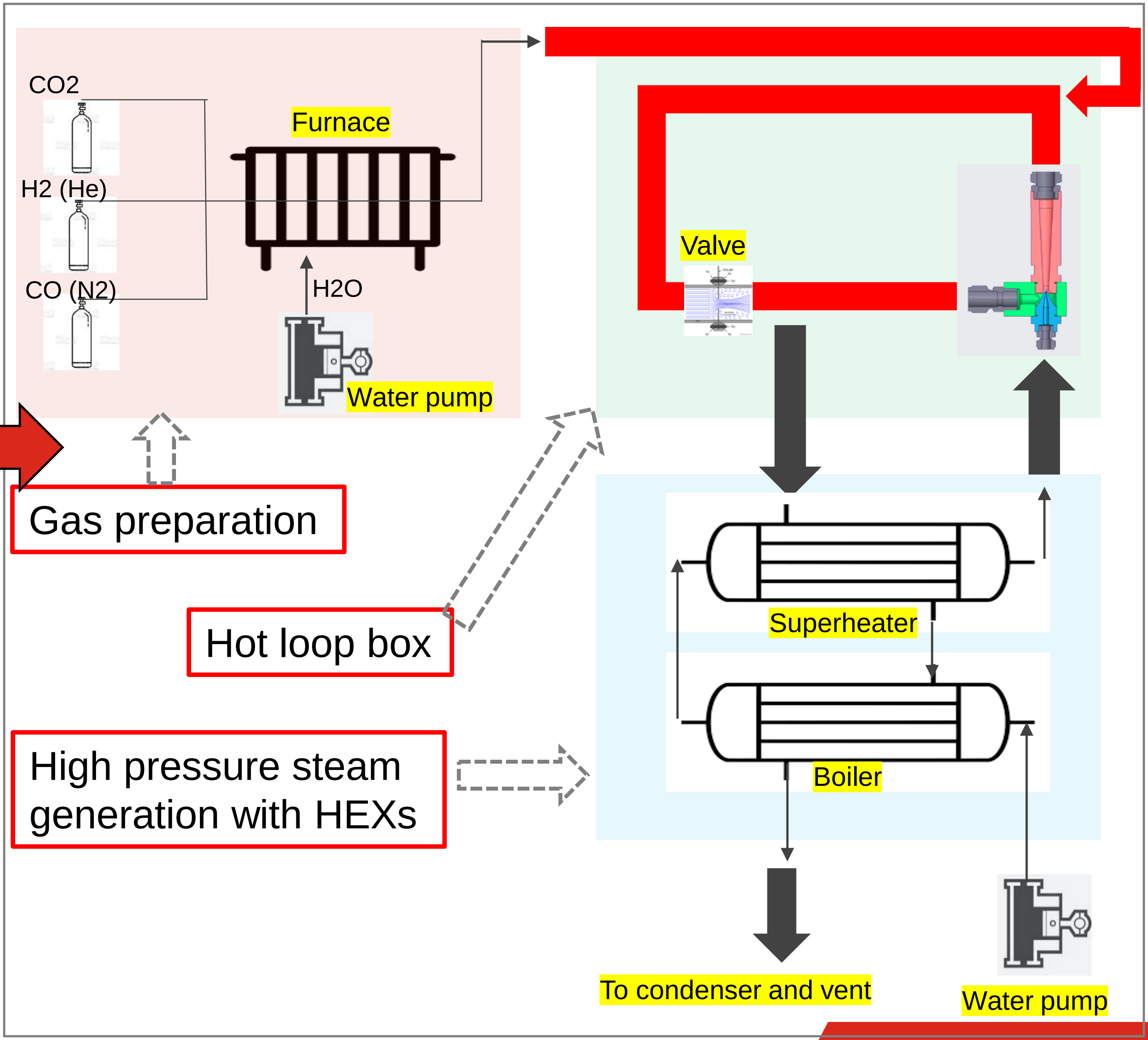
- Criterion: Steam/Carbon > 2.5 for 50 – 100% load
  - Threshold to avoid carbon formation and coking in system
  - Able to adjust Steam/Carbon ratio using water pump flow

Electrolysis mode

- Criterion: Target sufficient H_2 at stack fuel side inlet
  - Sufficiently rich to prevent Ni catalyst from oxidizing
  - Able to achieve even for 12 kPa Lift Pressure case

Steam Ejector Loop Demonstration

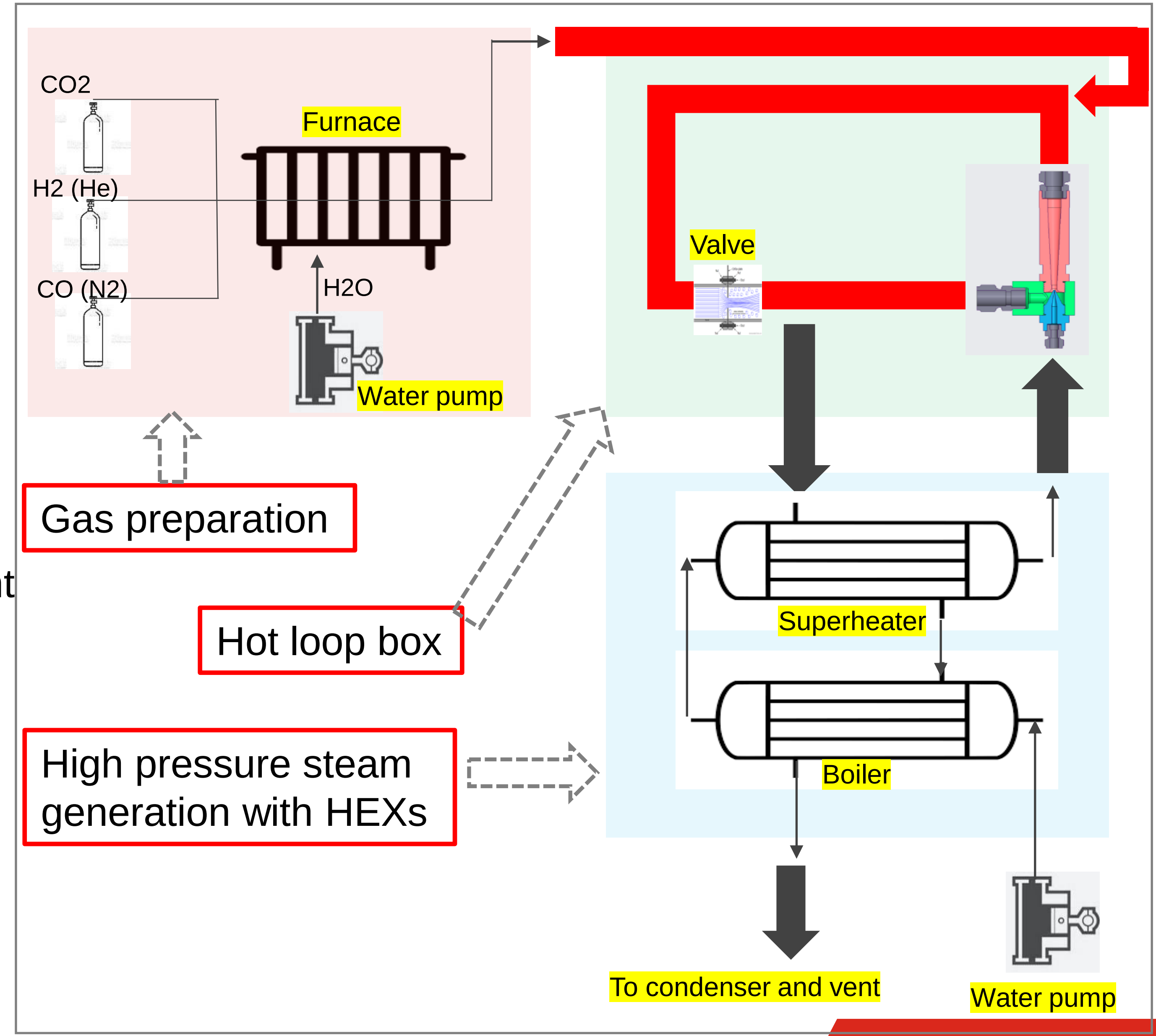




SOFC = Solid Oxide Fuel Cell
SOEC = Solid Oxide Electrolysis Cell

Steam Ejector Loop Demonstration

- **Objective**
  - From SOPO: "advance the steam ejector TRL by testing in a relevant environment … using realistic gas compositions and temperatures"
  - Advance to TRL 5
- **In Scope**
  - Test ejector with steam generation components
  - High temperature steam/H_2/CO_2/CO (SOFC) or steam/H_2 (SOEC)
  - Relevant SOFC & SOEC operation environment
  - Verify ejector performance and CFD model for high temperature steam operation
  - Impact of ejector on total system cost
- **Out of Scope**
  - Testing with full R-SOFC system – no stack, reformer, air side components
  - Ejector durability – long range testing



SOPO = Statement of Project Objectives

SOFC = Solid Oxide Fuel Cell
SOEC = Solid Oxide Electrolysis Cell

Project Next Steps

- Budget Period 2 Tasks:
  - Task 6.0: Steam Ejector Loop Demonstration
    - Test ejector in full hot steam loop using all steam generation components
    - Utilize temperatures, pressures, and flow rates expected in a final R-SOFC application (TRL 5)
  - Task 7.0: Techno-economic Analysis (TEA)
    - Projecting R-SOFC costs in high volume production
- Submit Final Project Report

Q+A


Cummins