Cummins Reversible-Solid Oxide Fuel Cell System Development

Project ID: FE0031971

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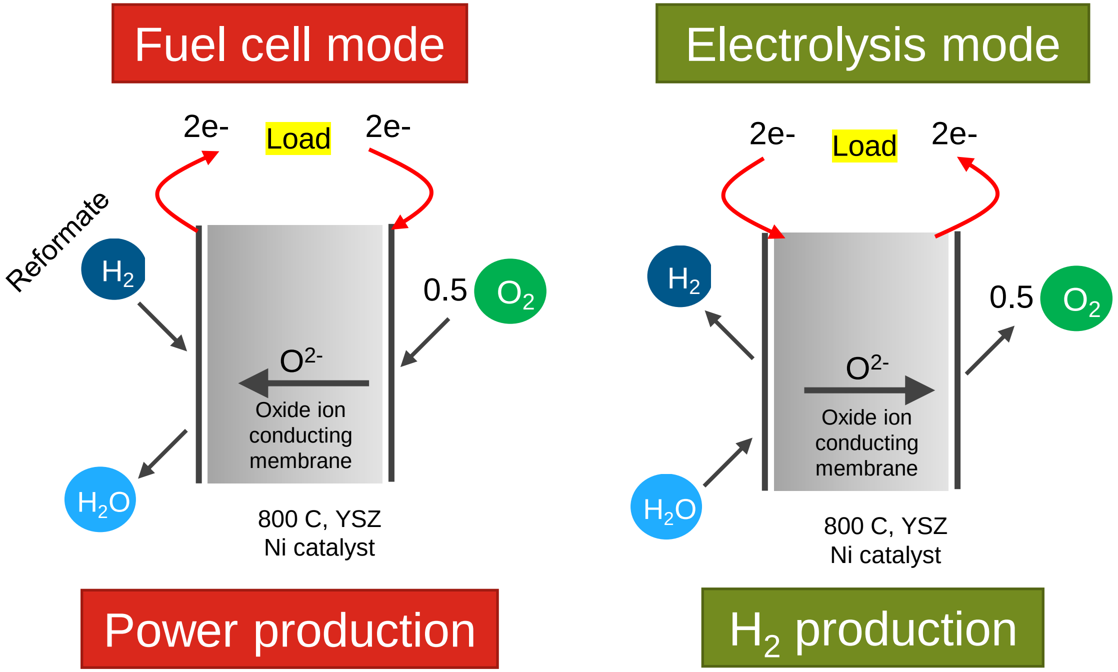
November 18, 2021

R-SOFC Relevance

Reversible-Solid Oxide Fuel Cell (R-SOFC): Single device able to operate in both fuel cell and electrolysis modes



Many Potential Use Cases

1. Ability to switch modes depending on the time-of-day electricity price
2. Grid firming
3. Hydrogen Energy Storage
4. Pathway to decarbonize the NG grid
5. Outputs:
    1. Hydrogen production
    2. Ammonia production
    3. Downstream Syn gas production (CH4, Methanol, etc.)
    4. Power

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

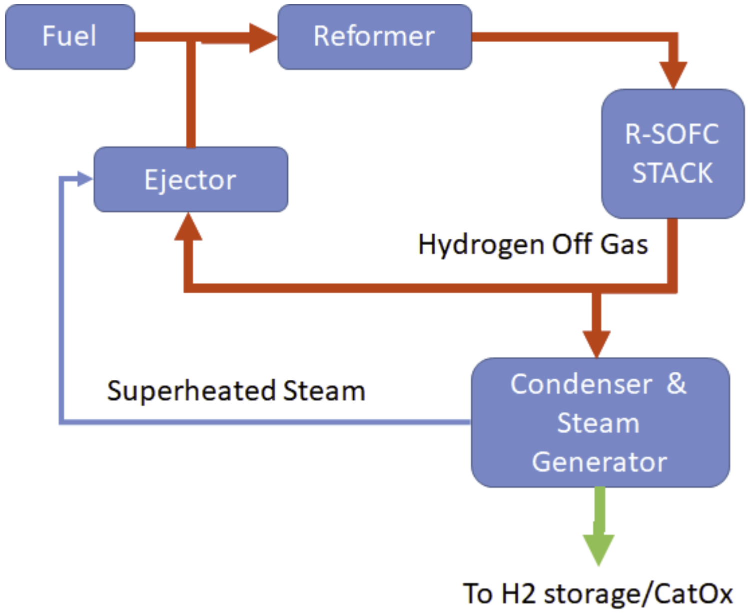
   Phase 2
   1. Prototype Cell Substrate
   2. Steam Ejector Demo. in hot fuel loop experiment

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

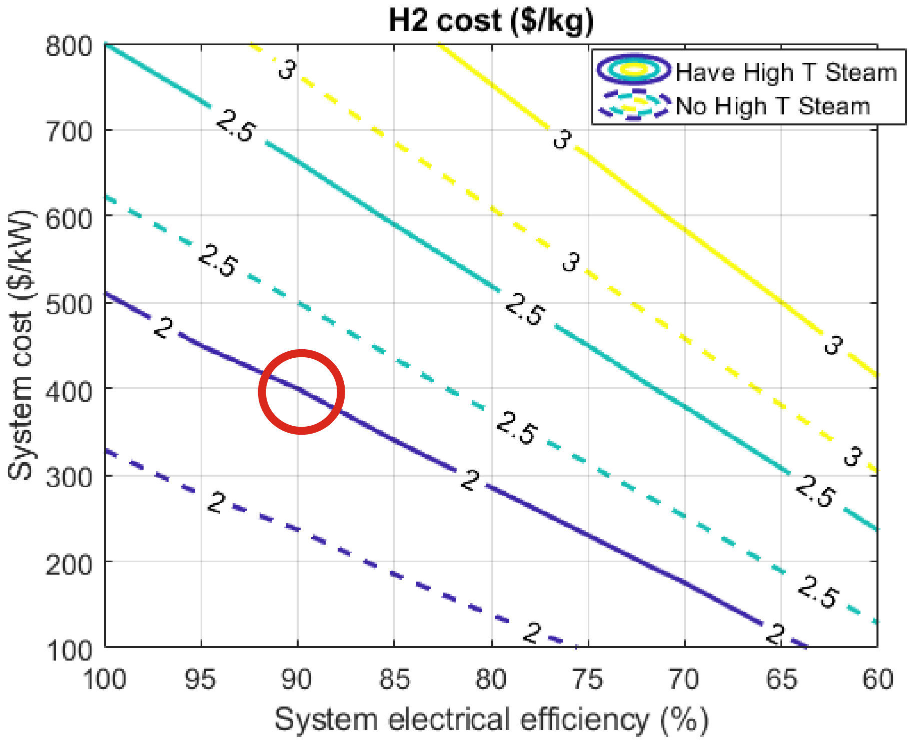
- Project Start Date: January 1, 2021
- Project Duration: 24 months
- Total Project Budget: $2,501,031
  - Total DOE Share: $2,000,825
  - Total Cost Share: $500,206
  - Total DOE Funds Spent*: $731,162
  - Total Cost Share Funds Spent*: $182,788

* As of September 30, 2021

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)	9/30/2022	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

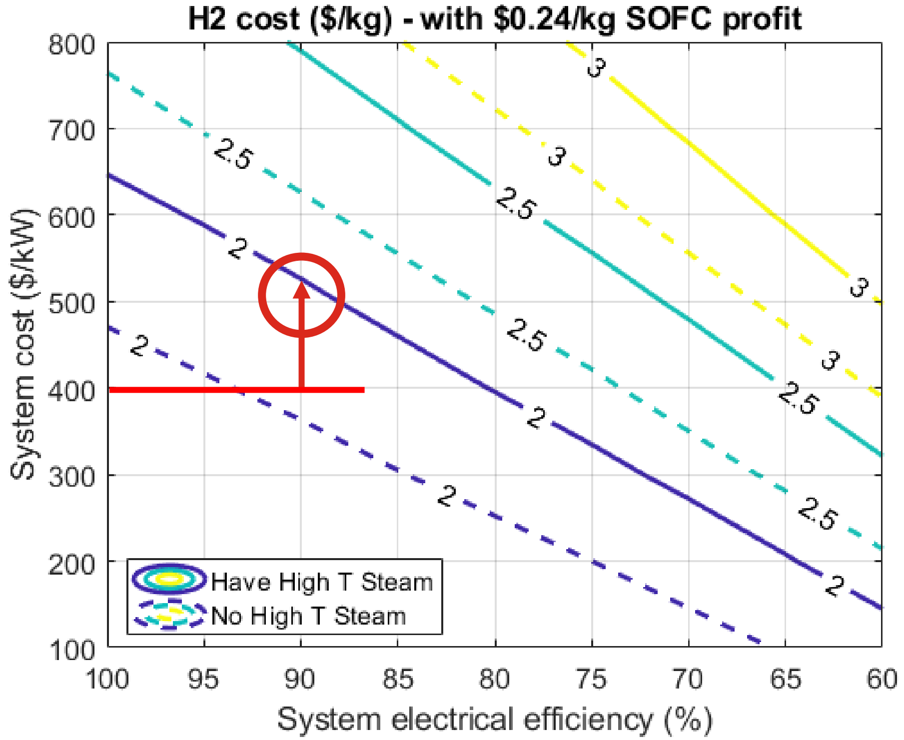
System Cost Targets for $2/kg-H2

Hydrogen cost as a function of system electrical efficiency and cost
Using NREL H2A Tool at $30/MWh electricity cost



24-hour electrolysis operation

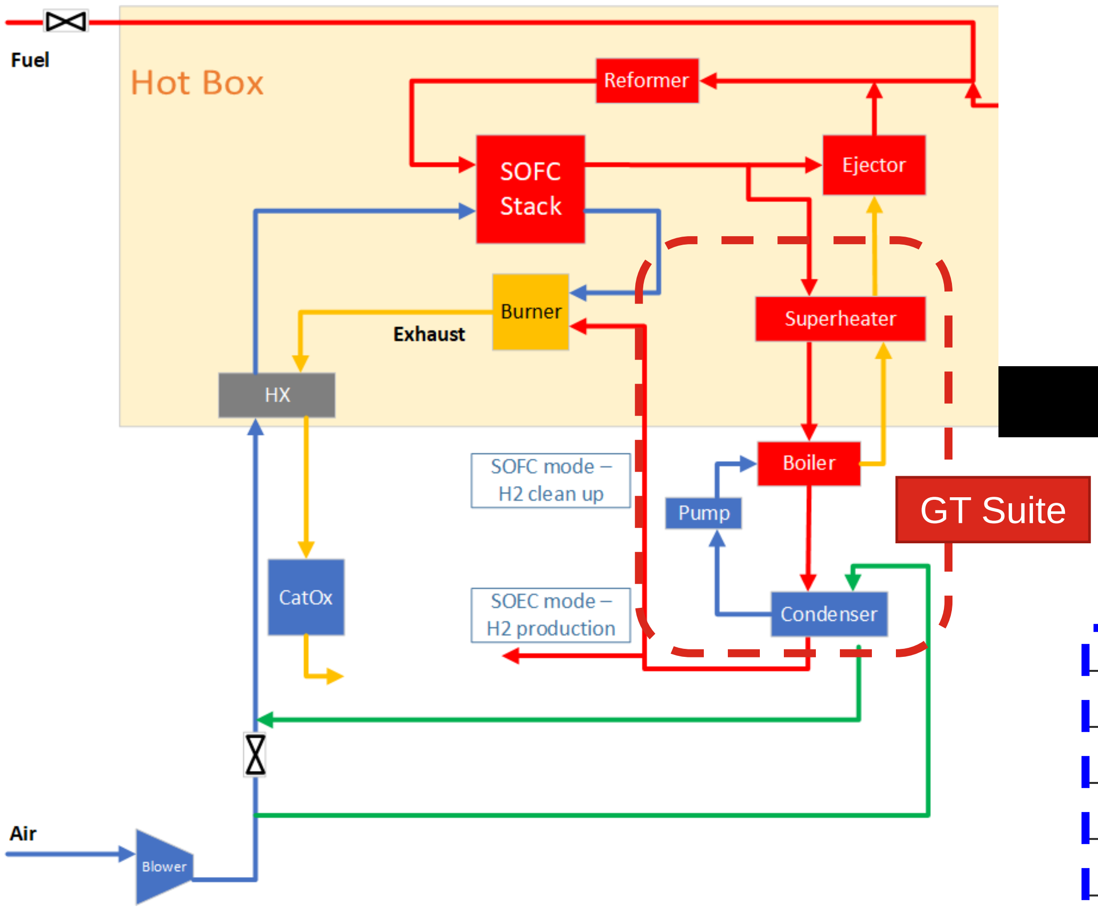
Solid lines: no added NG to make High T steam
Dashed lines: added NG for producing steam



12-hour electrolysis operation and 12-hour fuel cell operation
Assuming a fuel cell profit of $0.02/kWh

R-SOFC Model Development

Simulink + GT Suite system model



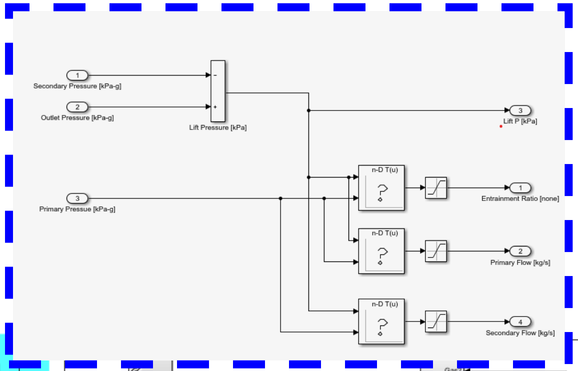
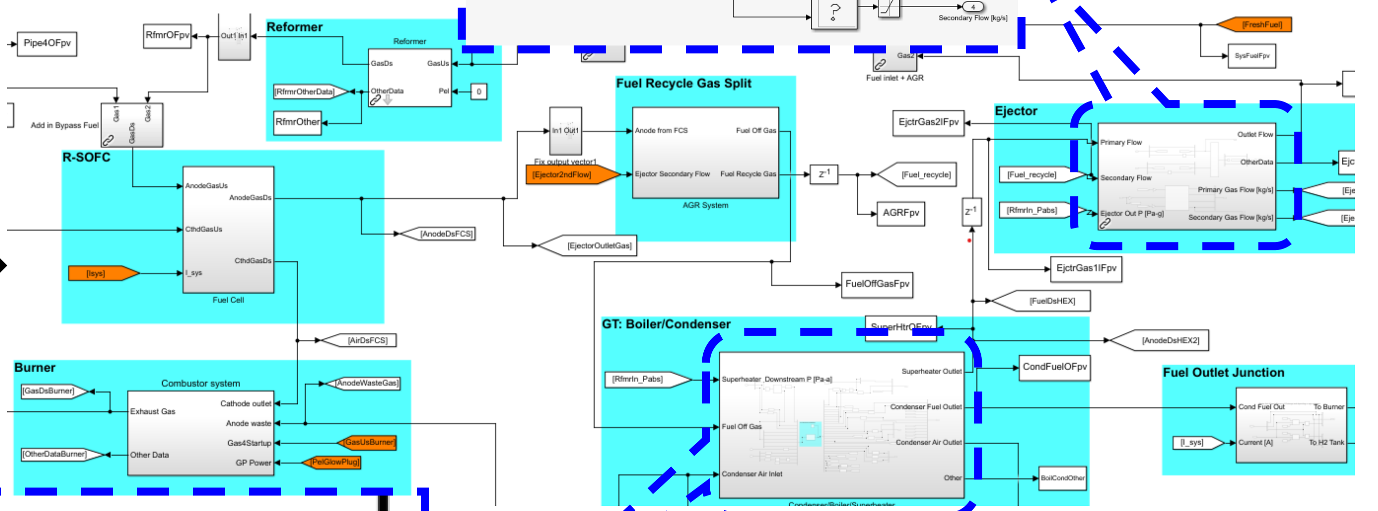
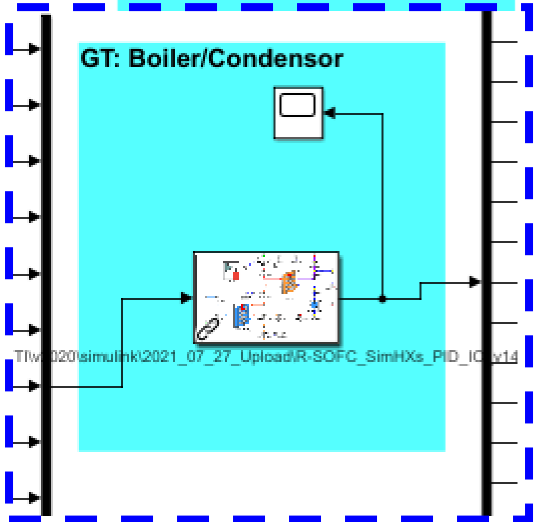


Table Based Ejector Model from CFD Sims

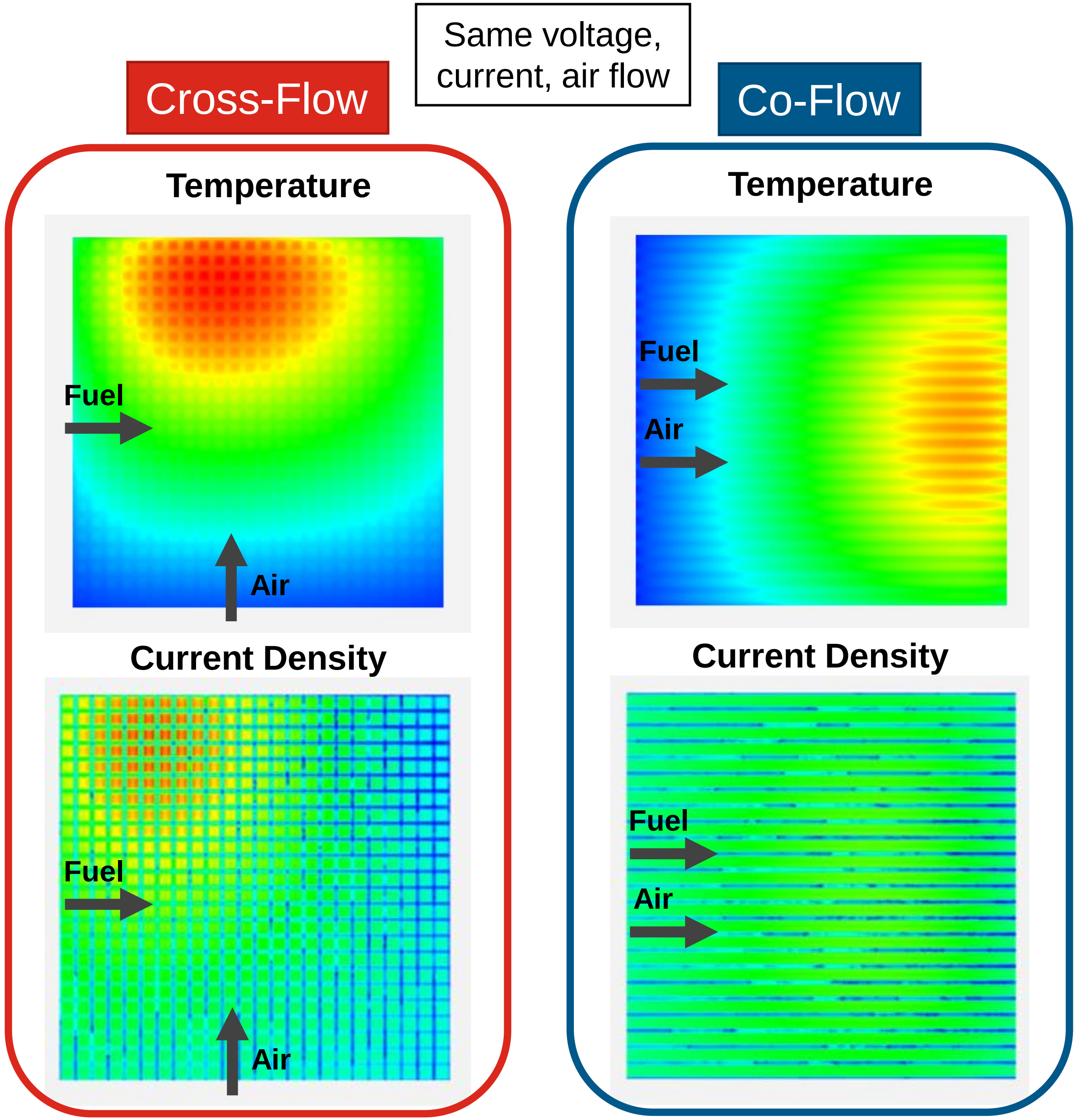




Physics Based Boiler and Condenser Models in GT Suite

R-SOFC system simulations in progress

New Cell Design Concept – Co-Flow

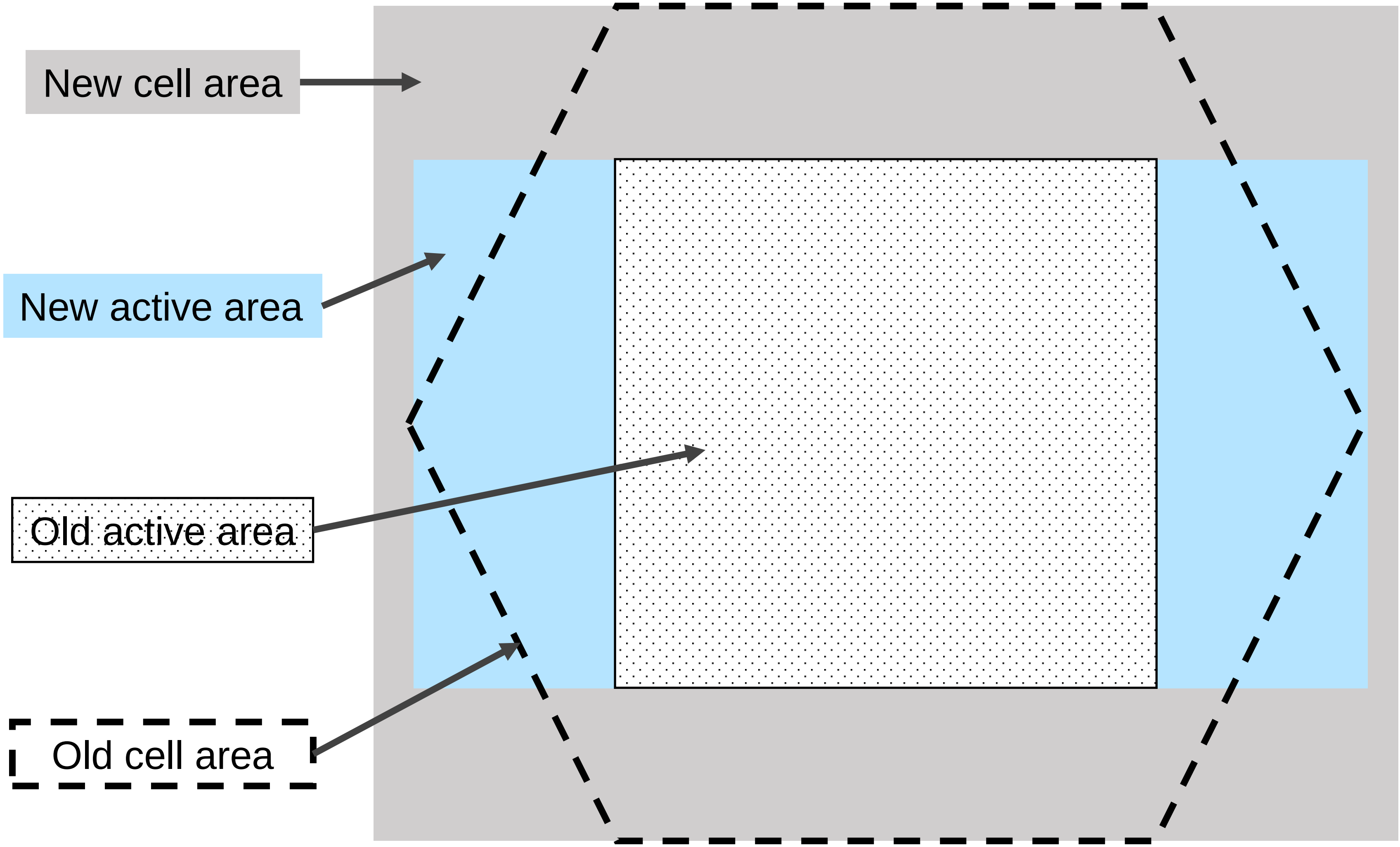


- Improved thermal gradients – reduced cell stress
- More uniform current density – reduced degradation
- Outlet gas temperature very close to peak cell temp
  - Better stack control

? Risks:

- Integration into manufacturing processes
- Stack sealing

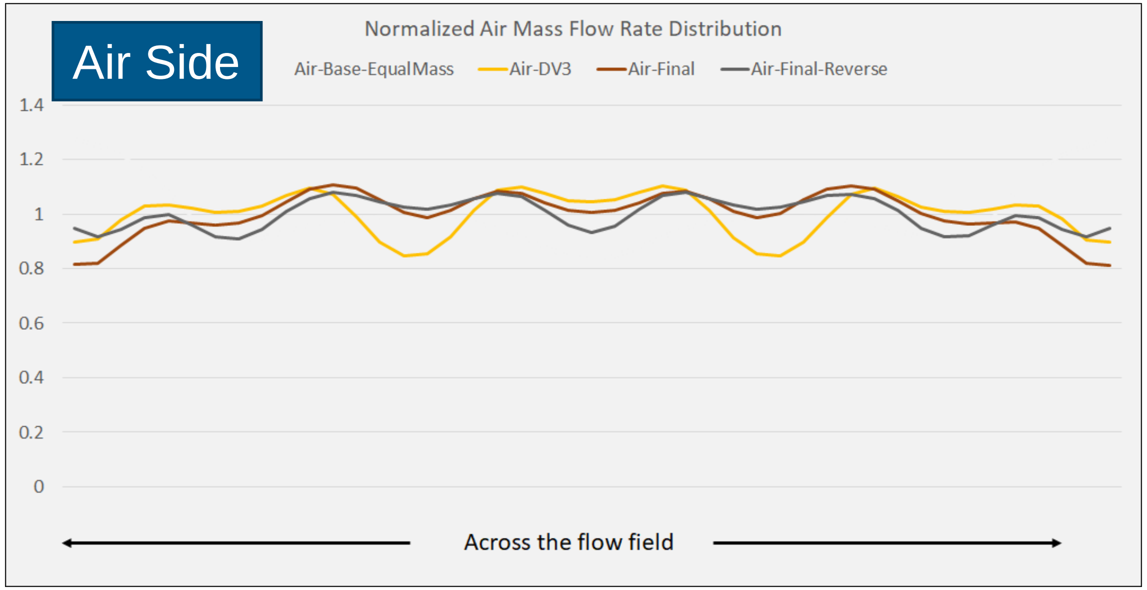
New Cell Design Footprint

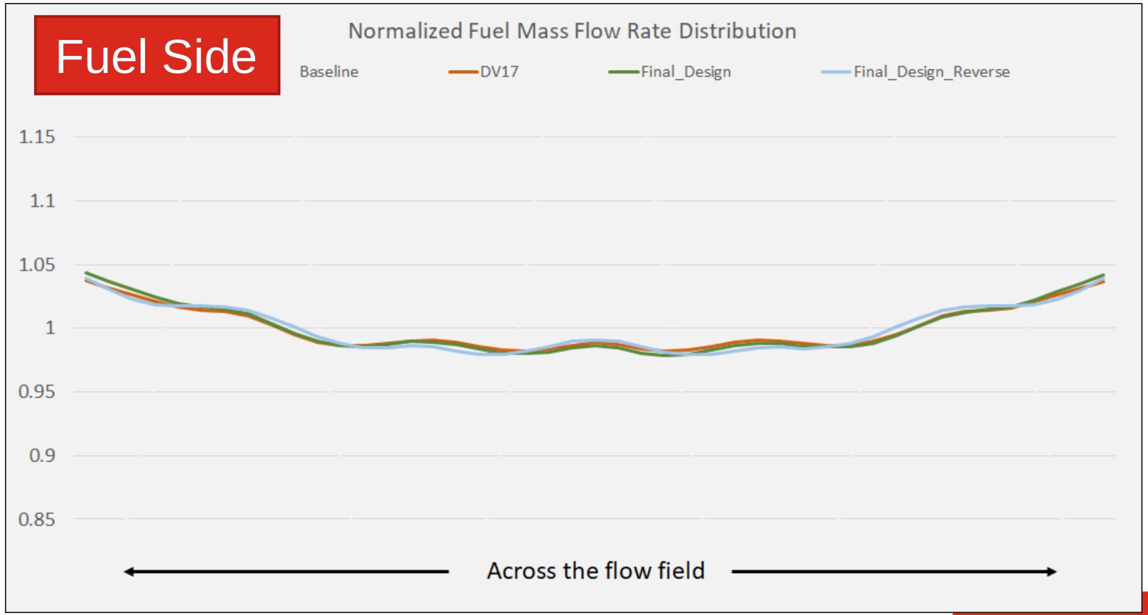


- Maintain same overall footprint
  - Manufacturing compatibility
- Increased active area for same footprint
  - Improved $/kW per cell
  - Fewer cells for same stack power – improved $/kW & kW/L

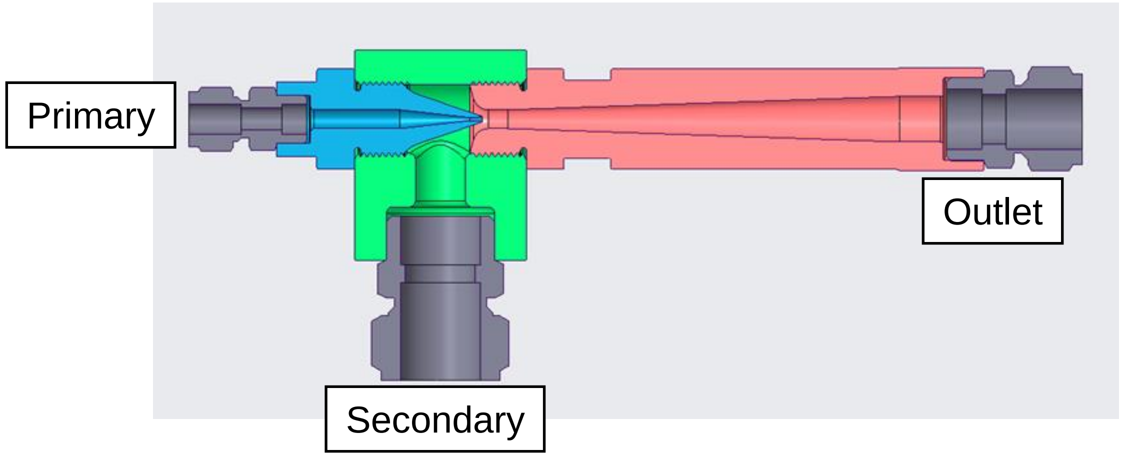
CFD Optimization of Cell Flow Field

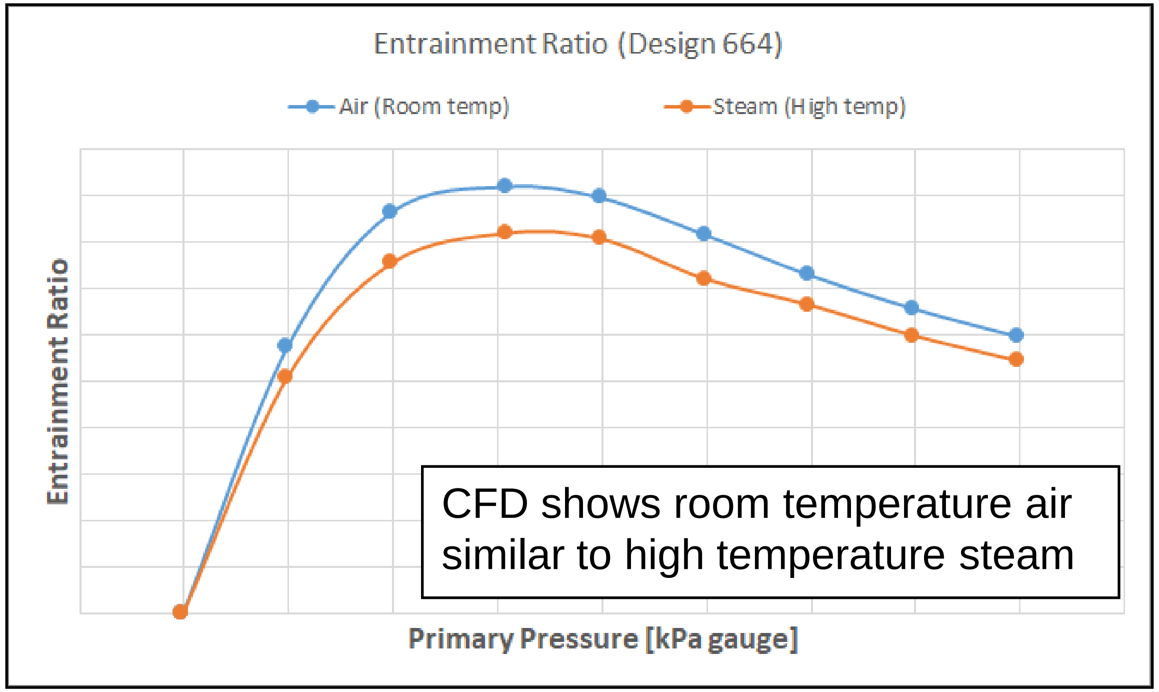
- Iterative CFD analysis to optimize cell flow field
  - Minimize channel-to-channel mass flow variation
- Design of experiments approach
  - Multiple manifold designs
  - Varying numbers of input and output ports
  - Forward and reverse flow directions
- Best design flow variation
  - Air side: 17% variation across channels
  - Fuel side: 6% variation across channels

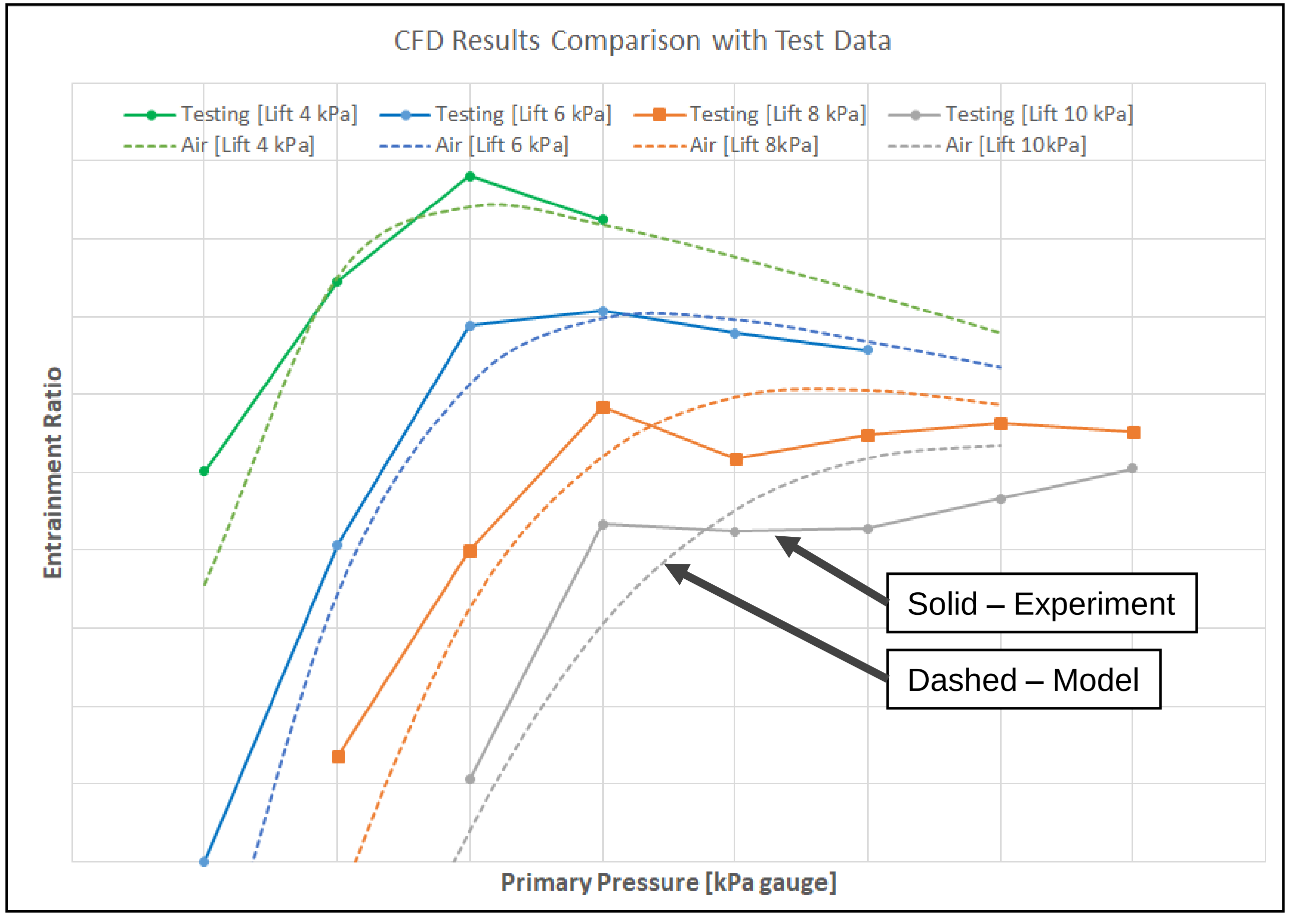




Task 4.0 – Steam Ejector Component Development







CFD model validated against experimental data using room temperature air

Project Next Steps

- Completion of R-SOFC system simulations
- Submission of Go/No-Go Report
- Budget Period 2 Tasks:
  - Task 5.0: R-SOFC Substrate Fabrication
    - Create prototype substrates
    - Validate substrates in a laboratory environment by thermally spraying and evaluating (TRL 4)
  - 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

Q+A


Cummins