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# DEVELOPMENT OF AN ADVANCED HYDROGEN ENERGY STORAGE SYSTEM USING AEROGEL IN A CRYOGENIC FLUX CAPACITOR (CFC)

# Acknowledgement and Disclaimer

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# Overview

- Project Team
- Objectives
- Background on the Technology
- Project Update
- Future Technology Development

# Project Team

**Principal Investigator** — SwRI, Southwest Research Institute

**IAA with DOE**

- **Development of Test and Validation of Test Setup** — University of Central Florida; Air Liquide
- **Performance of Test and Data Analysis** — University of Central Florida; SwRI
- **Commercialization and Development Pathway** — SwRI; TTS
- **Development of Test, Validation of Test Setup, and Data Analysis** — NASA

# Project Objectives

- Project Goals
  - Validate CFC hydrogen performance at a smaller scale
  - Develop and commission test-scale lab to support planned test plan
  - Perform test campaign on pure hydrogen from gas bottles and an electrolyzer
  - Analyze data and feed into techno-economic analysis (TEA)
  - Pair the CFC with an electrolyzer to demonstrate system dynamics
- Test Goals
  - Physisorption performance will be demonstrated between 80K and 120K
  - Estimated storage size is 100 kWh(t) of hydrogen, which is approximately 3 kg
  - Current estimated size of the electrolyzer is 5 kW or 1,000 normal l/hr
  - Charge and store at atmospheric pressure and discharge between atmospheric and 20 bar

# Background – Past Work

- Pursued by NASA for high density storage of fluids such as oxygen, hydrogen, natural gas, and nitrogen
- Storage demonstrated that has the dynamic capabilities of a gas bottle, but with much higher storage density
- Explored aerogel, a nanoporous, composite material
- Tests developed to demonstrate physisorption of various fluids into aerogel
- Physisorption: the individual fluid molecules are physically bonded within the pores of a meso- or nano-porous storage media

SwRI NASA Air Liquide TTS

# Background – Technology Readiness

- NASA development of various aerogel packaging for containment in a pressure vessel
- Improved storage at a range of temperatures: 200K, 100K, 77K
- Demonstrated storage performance for nitrogen, air, oxygen, and argon
- Mass uptake measurements to demonstrate CFC aerogel material performance

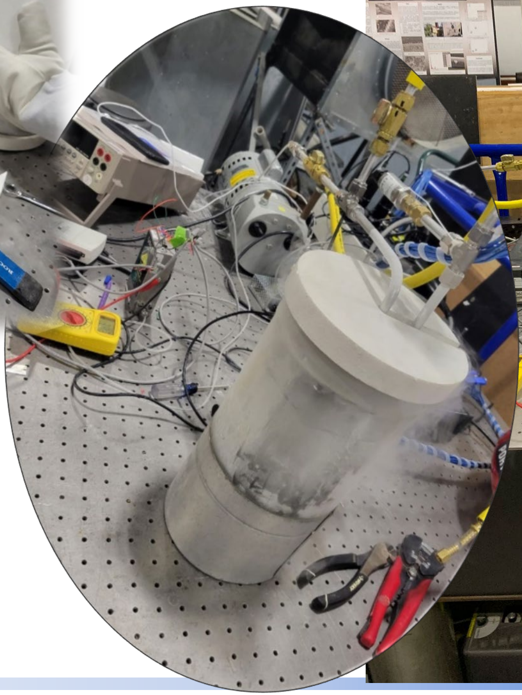
Project Status

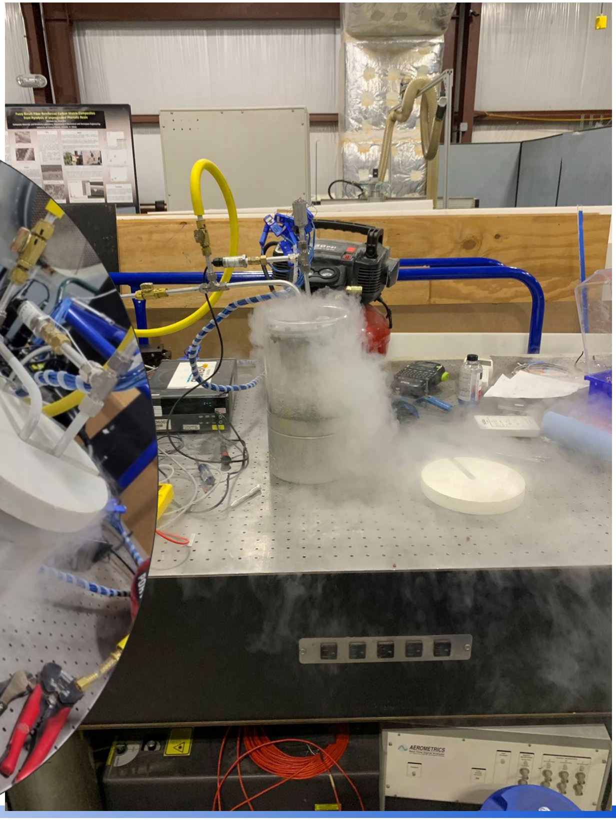
# SMALL SCALE RIG

# Small Rig for Hydrogen Adsorption

- Small scale rig experimental results will improve final design for CFC demo scale hydrogen storage apparatus
  - Aerogel cooling rates from $LN_2$ as cooling fluid
  - Rate of adsorption for Nitrogen and Hydrogen
  - Provide validation data for numerical models
- With scale of rig, a large experimental parameter space can be explored with low risk and cost

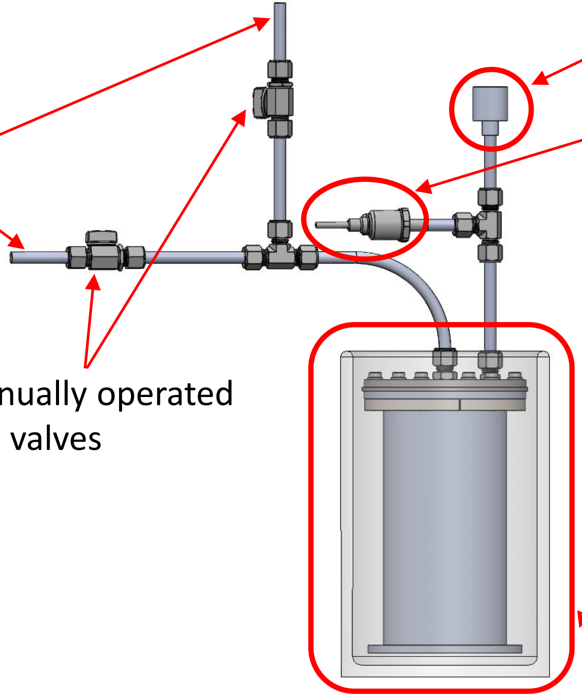
# Experimental Mini Vessel Rig





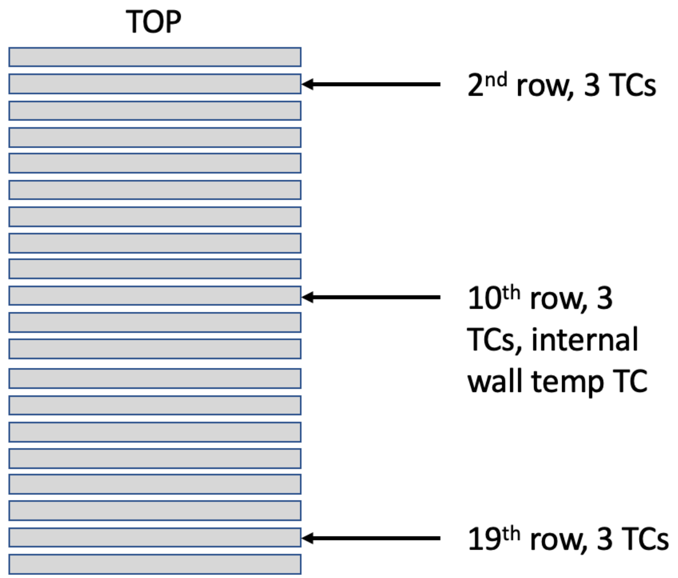
SwRI NASA University of Central Florida Air Liquide TTS

# Experimental Mini Vessel Rig Overview

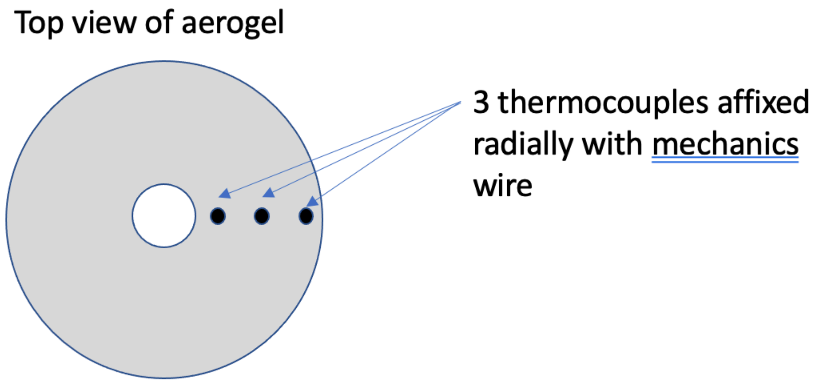



$N_2$ feeds through an 800 SCCM mass flow controller from a high-pressure gas cylinder regulated to 50 PSI

# Thermocouple Instrumentation



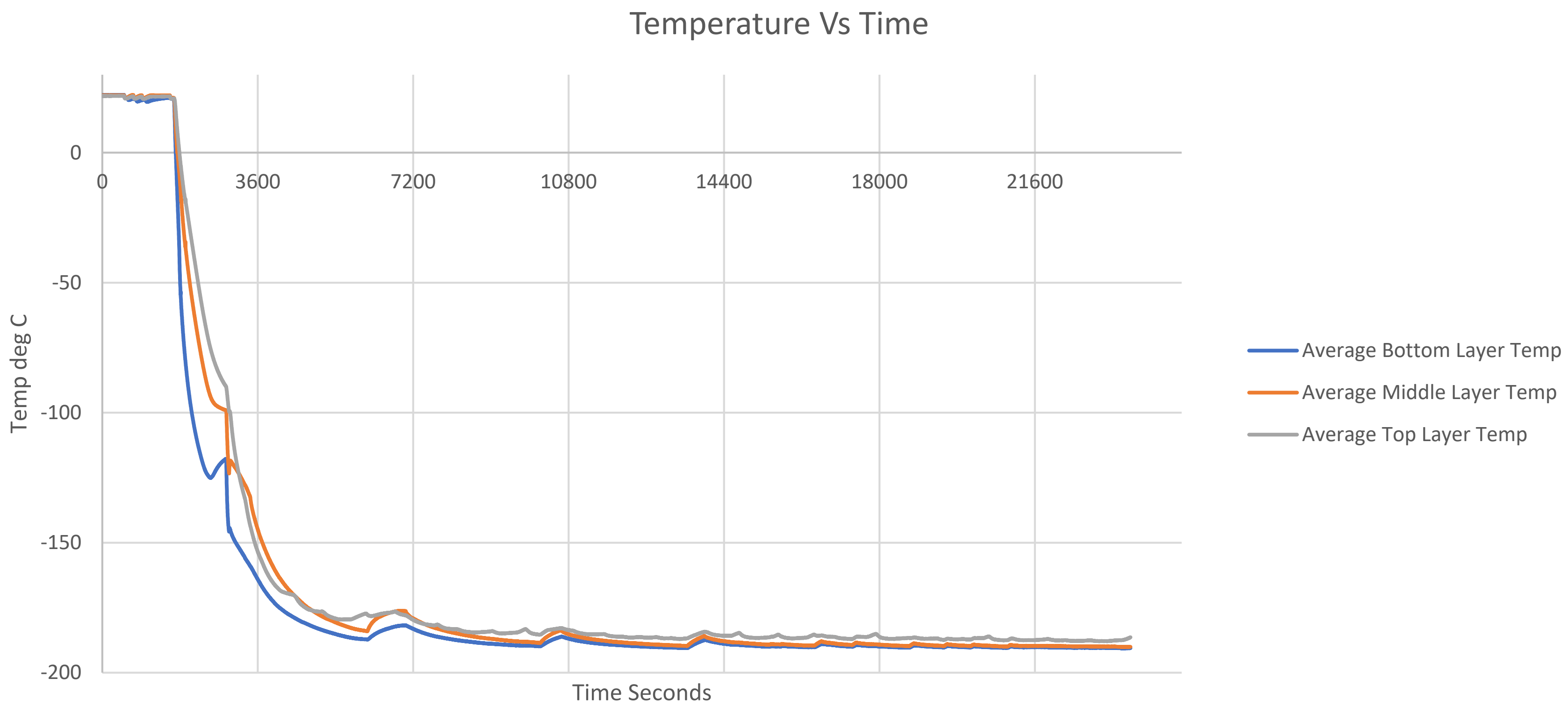

- 10 thermocouples total
- 3 locations axially
- 3 thermocouples radially per axial location
- 1 internal wall temperature thermocouple



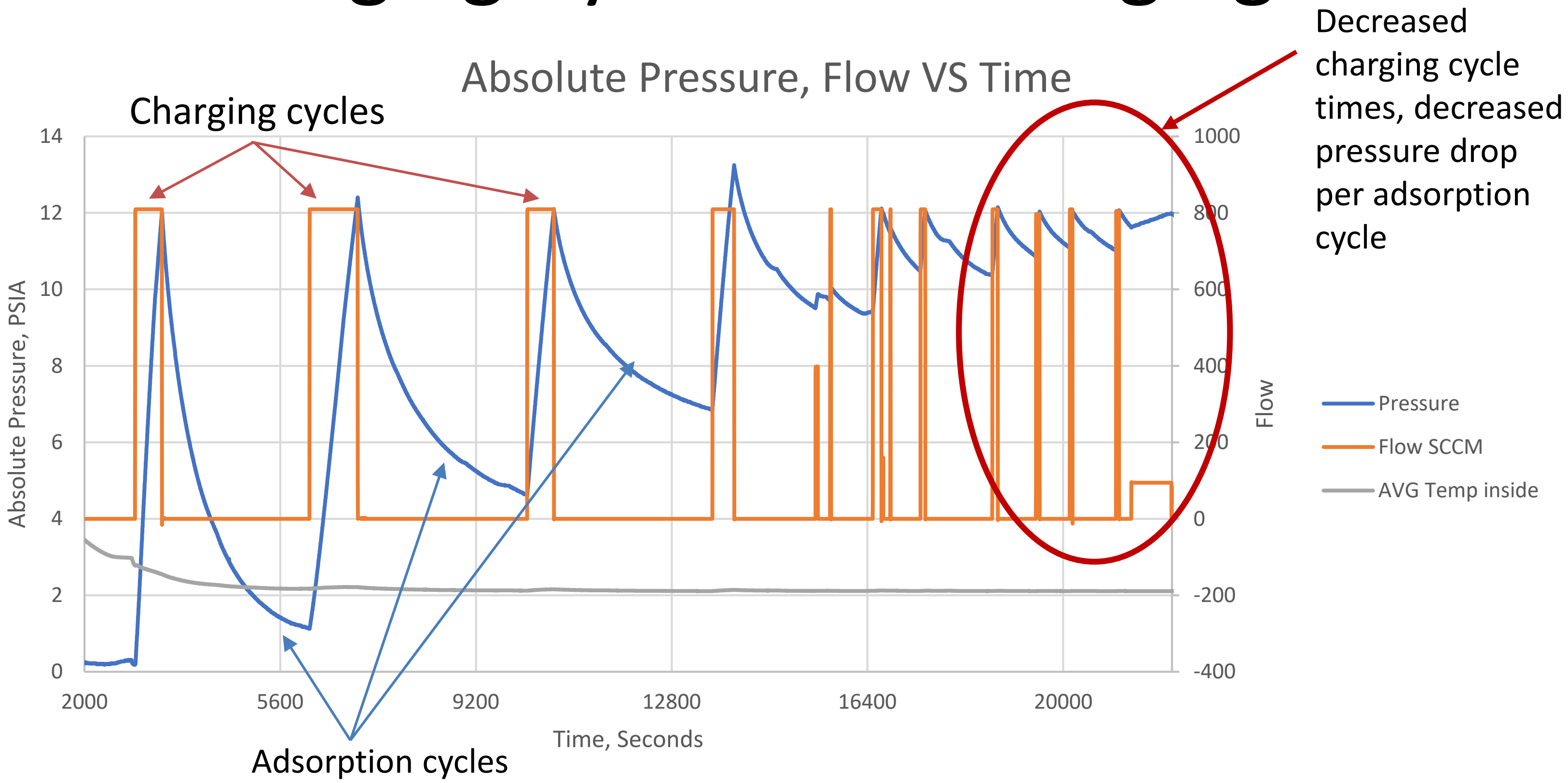
# Small Scale Testing Methodology

- Purging cycles (air displacement cycles, 3 cycles total)
- Initial precooling (110K average internal temperature before charging starts)
- Pressurizing cycle (12-14 PSIA internal pressure)
- Adsorption cycle (internal pressure drop rate <0.01 PSI/min)
- Repetition of adsorption and pressurization cycles until pressure drop between pressurizing and adsorption cycles is less than 0.1 PSI

# Temperature (averaged per layer)



# Charging Cycles After Purging

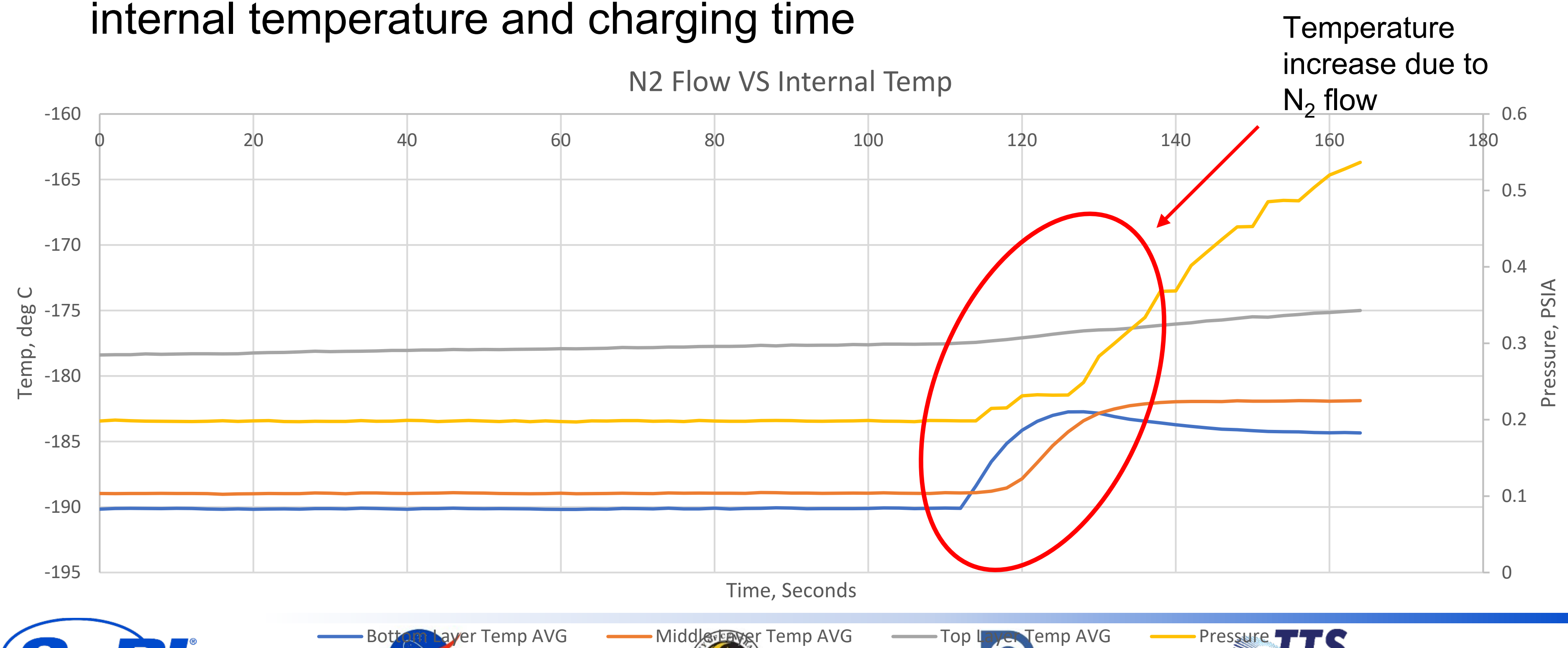


# Initial Small Scale Results

- Total flow in 45.7L (Overall volume of the rig is 1.51L)
- Total mass in 57g
- Density inside of the rig 37.7 kg/m^3
- For reference: Density of $N_2$ at rig P&T conditions inside of the rig with no adsorption would only be 3.38 kg/m^3
- **Density increased 11.15 times**

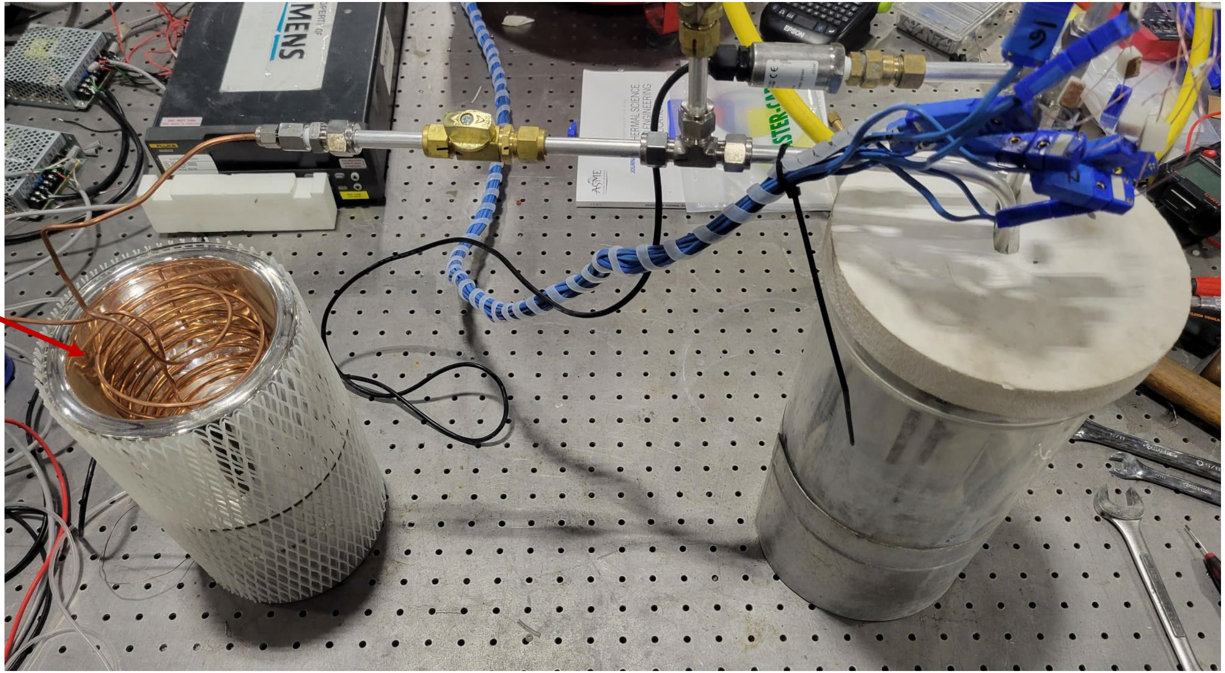
# Challenges

- Feeding ambient temperature $N_2$ into cooled aerogel, increases internal temperature and charging time



# Small Scale Precooler

- To help mitigate the effect of feed temperature, a precooler will be used
- 12 ft of 1/8 in coiled copper tubing submerged in $LN_2$



# Next Steps

- Install a thermocouple for $N_2$ feed line after the HX (inlet of the rig)
- Full LabView control over the rig (purging, charging, discharging cycles, PID control of feeding rates)
- Solenoid valves instead of manually operated ball valves
- Further testing and optimization of the rig with $N_2$
- Repositioning of the rig to a rolling cart (transportable standalone unit for future Hydrogen tests)
- Transferring the rig to a different lab with $H_2$ access
- Determining adsorption rates of $H_2$ per aerogel volume

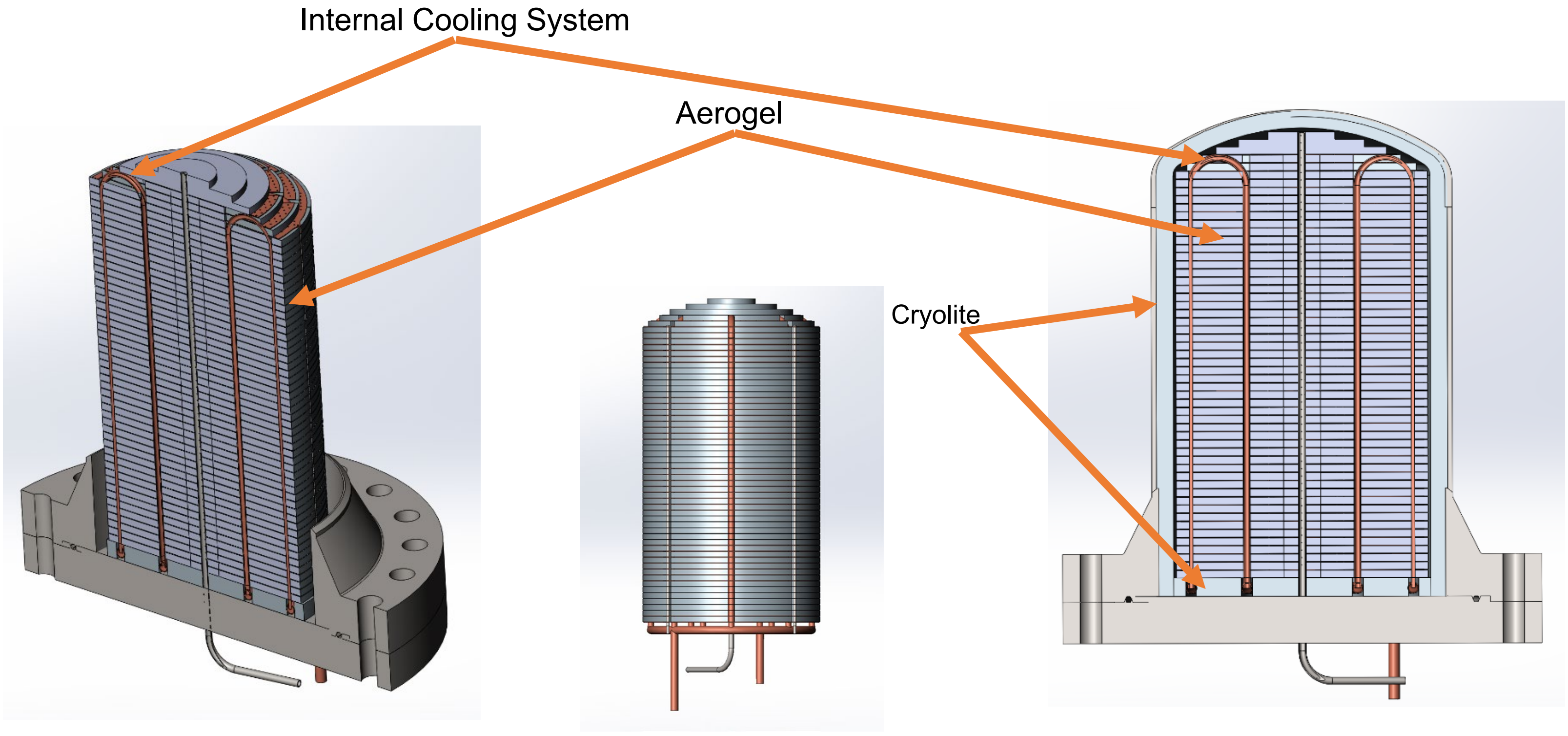
# Testing with Hydrogen

- Utilize the same testing technique as used with $N_2$ experiments
- Determine the adsorption rates of $H_2$ per volume of aerogel
- Determine the optimal charging technique for $H_2$ (constant
- Pressure vs constant mass flow charging cycles)
- Determine the $H_2$ flow rate needed for the CFC

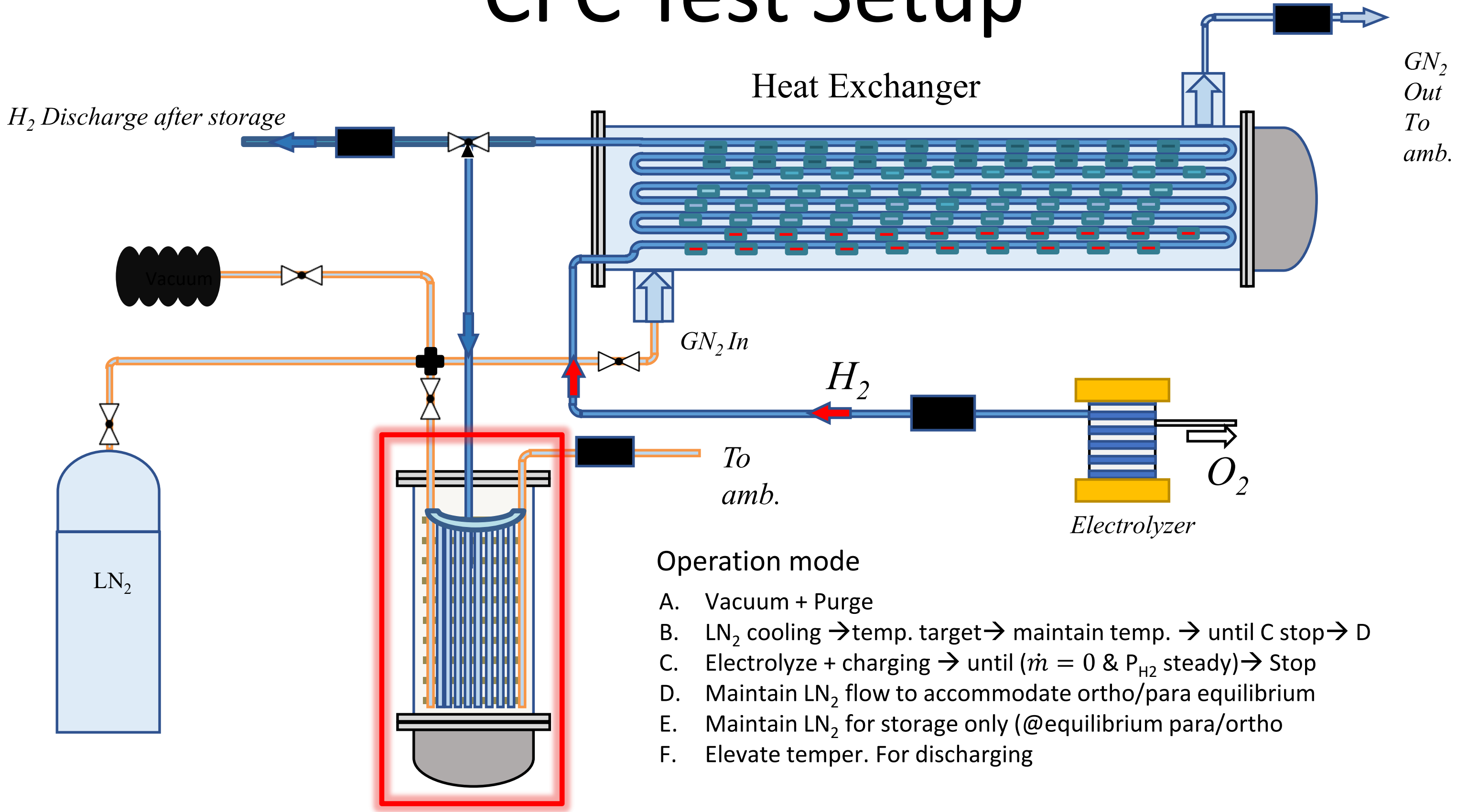
Project Status

# TEST SCALE RIG

# CFC Design Cross-section



# CFC Test Setup




Operation mode

A. Vacuum + Purge
B. $LN_2$ cooling →temp. target→ maintain temp. → until C stop→ D
C. Electrolyze + charging → until ($\dot{m} = 0$ & $P_{H2}$ steady)→ Stop
D. Maintain $LN_2$ flow to accommodate ortho/para equilibrium
E. Maintain $LN_2$ for storage only (@equilibrium para/ortho
F. Elevate temper. For discharging

Project Status

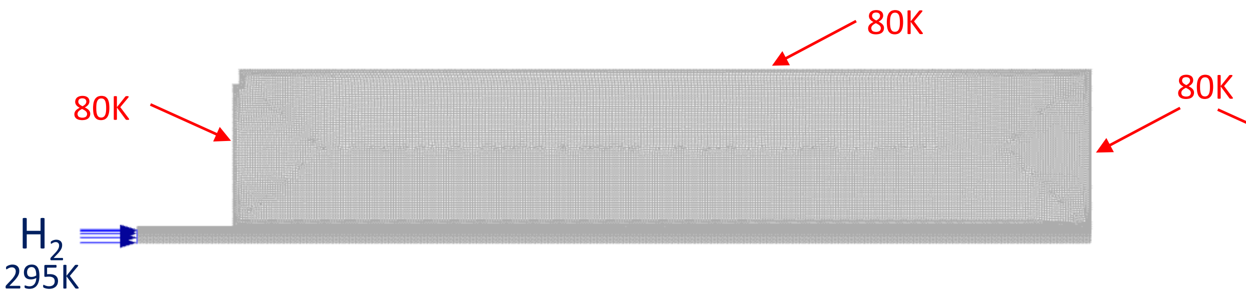
# ANALYTICAL MODELING

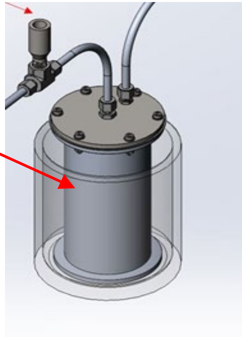
# Analytical Model and Numerical Simulation

- ANSYS Fluent is the chosen analytical tool
- Due to complex nature of adsorption physics, User-Defined Functions are implemented which account for adsorption kinetics and energy
- Small scale experimental data is used to validate the numerical method, and provide parametric data for model constant calibration if needed
- Fully validated/calibrated numerical model will be used for design exploration of cooling schemes for the test scale CFC

# Experimental Data Validation

- Current models use a simplified 2D axisymmetric model for the tank simulation
- Adsorption of $H_2$ in silica aerogel contained in a vessel submerged in a bath of $LN_2$
- The grey area is a bed of silica aerogel (adsorbent) and cryogenic hydrogen (adsorbate).
- Recreating the adsorption in the simulation, three parameters must be adjusted
  - Mass and energy conservation equations are modified
  - The Mass Flux User Defined Function (UDF) is hooked to the inlet to regulate the filling and discharge



# Future Technology Development

- Commercialization Potential
  - Aerogels are currently commercially available, so there is no barrier to production
  - Scalability of materials is not an issue like lithium ion battery
  - CFC is high density and could support monthly cycling, which corresponds to 10 to 100 hours of storage duration
- Future Integration with Target Fossil Application
  - Primary target asset is ground-based gas turbines used for electricity generation
  - CFC is intended to be modular and mounted on racks, like cells in a battery
  - For a reference plant of 100 MW net power output with a 50% net thermal-to-electric efficiency,
  - 100 hours of duration would require 9,090 $m^3$

# Thank You