GTI ENERGY

solutions that transform

Cost-Effective Pre-Cooling for High-Flow Hydrogen Fueling

AMR Project ID: IN036

DOE Project Award #DE-EE0009625

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GTI Energy

2024 Annual Merit Review | May 7, 2024

Project Goal

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- Deliver a validated high-flow chiller design ready for manufacture and installation in a heavy-duty fueling station
- Provide marketable, optimized system to accelerate construction of heavy-duty hydrogen fueling stations
- Ensure design is sustainable and withstands future refrigerant regulations

Overview

Timeline

Project start date: August 2022

Project end date: October 2025

Percent complete: 30%

Budget

Total project budget: $2.75M

Total cost share budget: $0.550M

Total federal share: $2.2M

Total DOE funds spent*: $0.42M

Cost share funds spent*: $0.19M

*As of 02/29/2024

Barriers and Targets

Barrier – lack of commercial pre-cooling technology

Target < 200 kW peak load

Target < $500,000 capital cost

Partners

Creative Thermal Solutions

Argonne National Laboratory

Potential Impact

DOE Goals	Project Impact
Build clean energy infrastructure	Create path to market for key component in heavy-duty fueling stations
Lower greenhouse gas emissions and criteria pollutants	Enables heavy-duty fuel cell vehicles, displacing diesel vehicles
Lower price of delivered hydrogen	Cost-effective pre-cooling will reduce cost of fueling
Provide pathways to private sector uptake	Technology transfer and commercialization at the end of the project will lead to private sector ownership of chiller design

Approach: Project Plan

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Completed Oct 2023

Budget Period 1

Preliminary Chiller Design

- Develop detailed understanding of duty cycle and system requirements
- Consider several configurations and select best option

- Go/No-Go #1: Modeling shows system capable of 10 kg/min with power under 200kW

Budget Period 2

Detailed Design and Build

- Design for 1/5th capacity to allow for cost-effective testing
- Incorporate learnings from early heat transfer testing

- Go/No-Go #2: Economic analysis shows cost < $500,000 per unit

Budget Period 3

Testing and Final Design

- Test results used to update design
- Technology transfer and commercialization top priority to ensure unit gets to market

Approach: Budget Period 2 Work Plan

		2024											
Subtask	Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.2	On-Demand Cooling Testing												
2.1	Detailed Design												
2.2	Test Unit Construction & Delivery												
2.3	Economic Analysis												

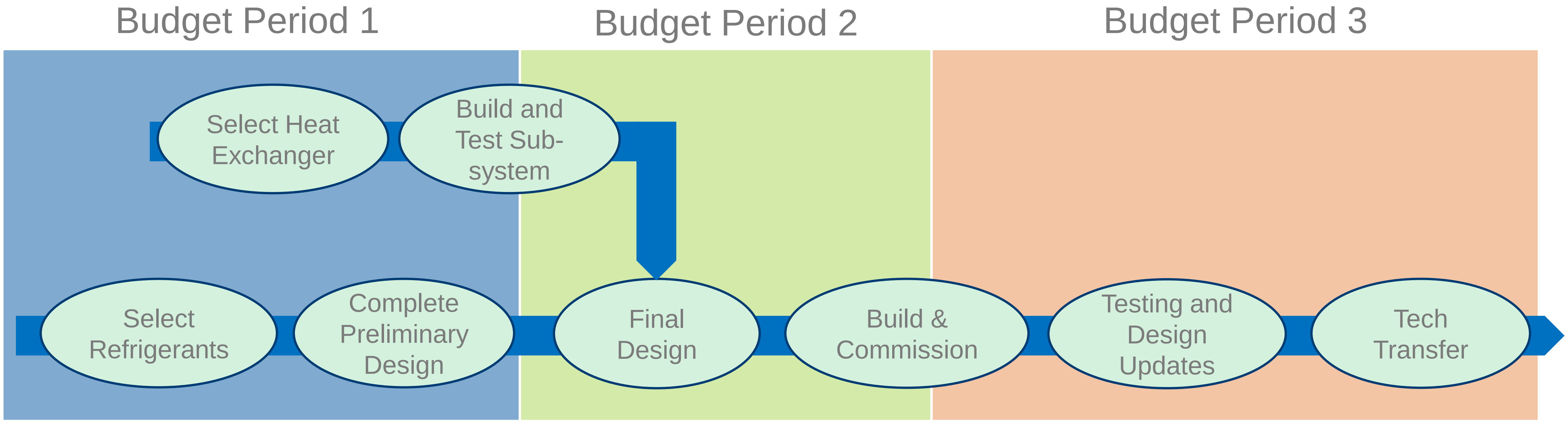
Original Plan

Adjusted Plan

- One carryover task from BP1: low stage unit testing
- BP2 milestones:
  - 2.1.1: Test Loop Balance of Plant design complete: **IN PROGRESS (50%)**
  - 2.1.2: Sub-scale system detailed design completed: **IN PROGRESS (40%)**
  - 2.2.1: Construction and delivery of test unit to GTI: **NOT STARTED**
  - 2.3.1: Economic Analysis: **NOT STARTED**
  - Go/No-Go: Analyses show capital cost <$500,000, 60kg fill in 6 minutes, power <200kW.

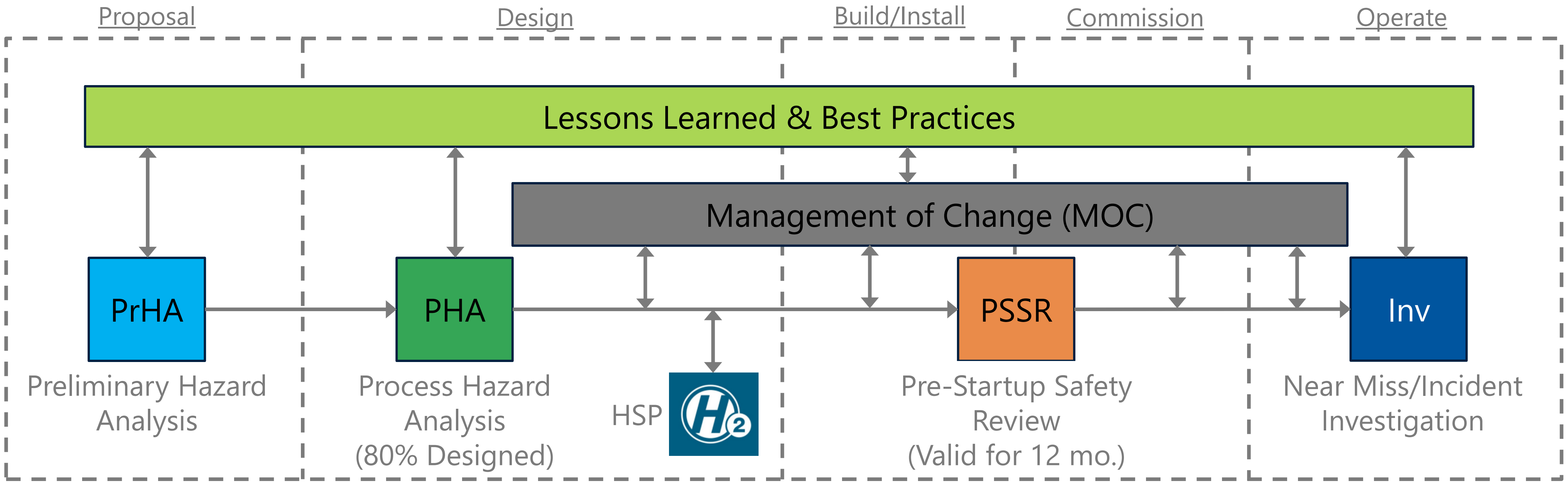
Approach: Early Testing of Heat Exchanger

- Risk: Heat exchanger performance carries many unknowns
  - Direct expansion heat exchanger, with high pressure H_2, in a highly transient duty cycle
- Mitigation: Test sub-system early and apply learnings to design
  - Goals are to model heat exchanger performance and determine approach to transient nature



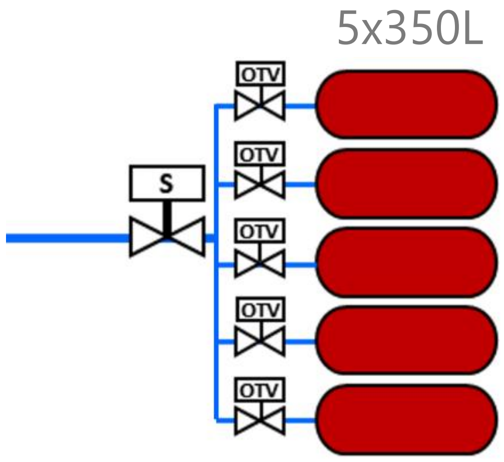
Approach: Safety Planning and Culture

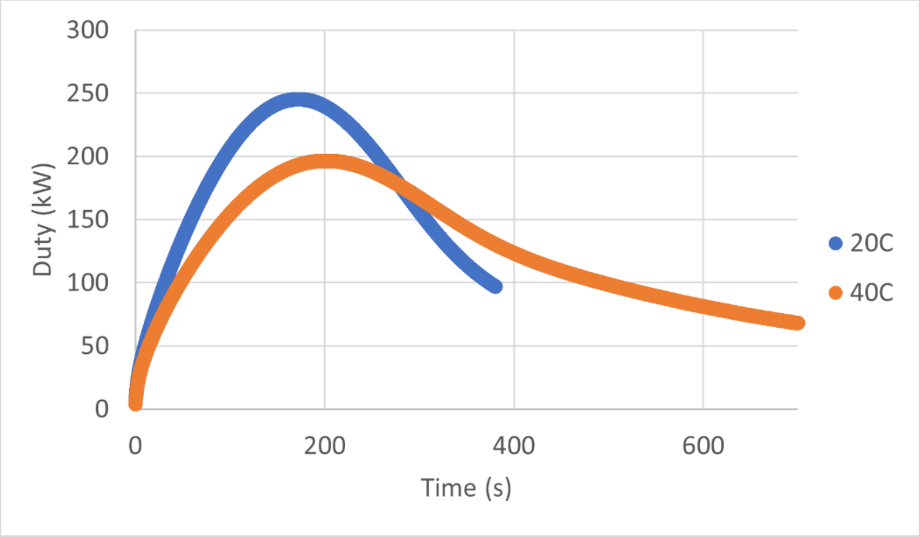
- This project will submit safety plan to HSP – Due April 4, 2024
- GTI process safety management program has been improved over last few years (below)
- There are 2 designs in this project – one is in Build phase, one is in Design phase



Progress: Prior to 2023 AMR

- Task 1: Create demand profile from DOE goals, without published fueling protocols
  - Start with DOE goal in FOA to fuel 60kg in 6 minutes
    - No information on ambient temperature or configuration of tank system
  - Argonne National Lab conducted H2SCOPE modeling:
    - Defined tank system as 5x350L tanks, 70kg total
    - Goal of 10kg/min average at constant APRR, 20°C
    - Determined pre-cooling temperature needed (-30°C)
    - Determined APRR for 40°C ambient fueling (7MPa/min)
    - Determined duty profiles for 20°C and 40°C cases ➔





Progress: Refrigerant Selection

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- Requirements:
  - Capable of achieving -35°C evaporator temperature
  - Minimal risk of future regulations (zero ozone depletion potential (ODP), low global warming potential (GWP))
  - Consider flammability and toxicity as added risks
  - Cost

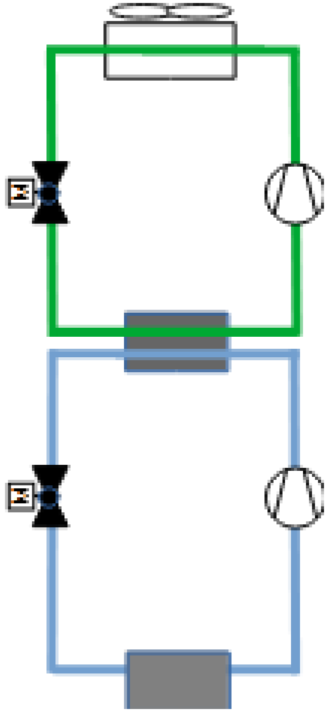
Refrigerant	GWP	ODP	Safety group	Evaporating pressure [kPa(a)] @ - 40 °C	$/lb
R-744	1	0	A1	1004.5	1.36
R-717	0	0	B2L	71.6	3.06
R-290	3	0	A3	111.1	13
R-448A	1387	0	A1	101	14.6
R-449A	1397	0	A1	120.7	19
R-1234ze	7		A2L	36.8	

Consider these 3

Progress: Preliminary Design

- Cascade systems take advantage of high COP for ammonia; other advantages?
- Cooling duty can be split between both systems, saving power ($10k/yr) and other components
- Downside: requires additional hydrogen heat exchanger (~$50,000)

1 Evaporator to cool H_2



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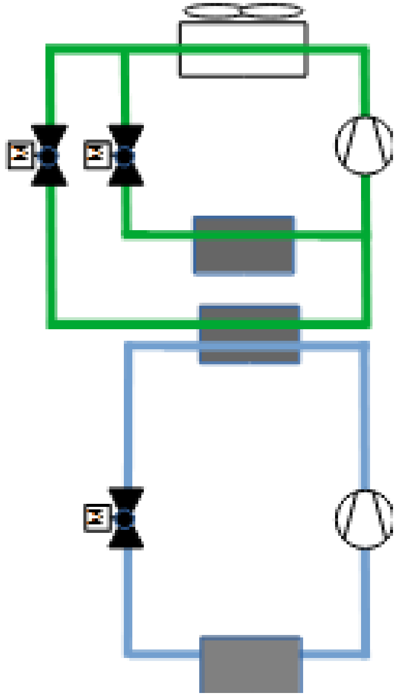
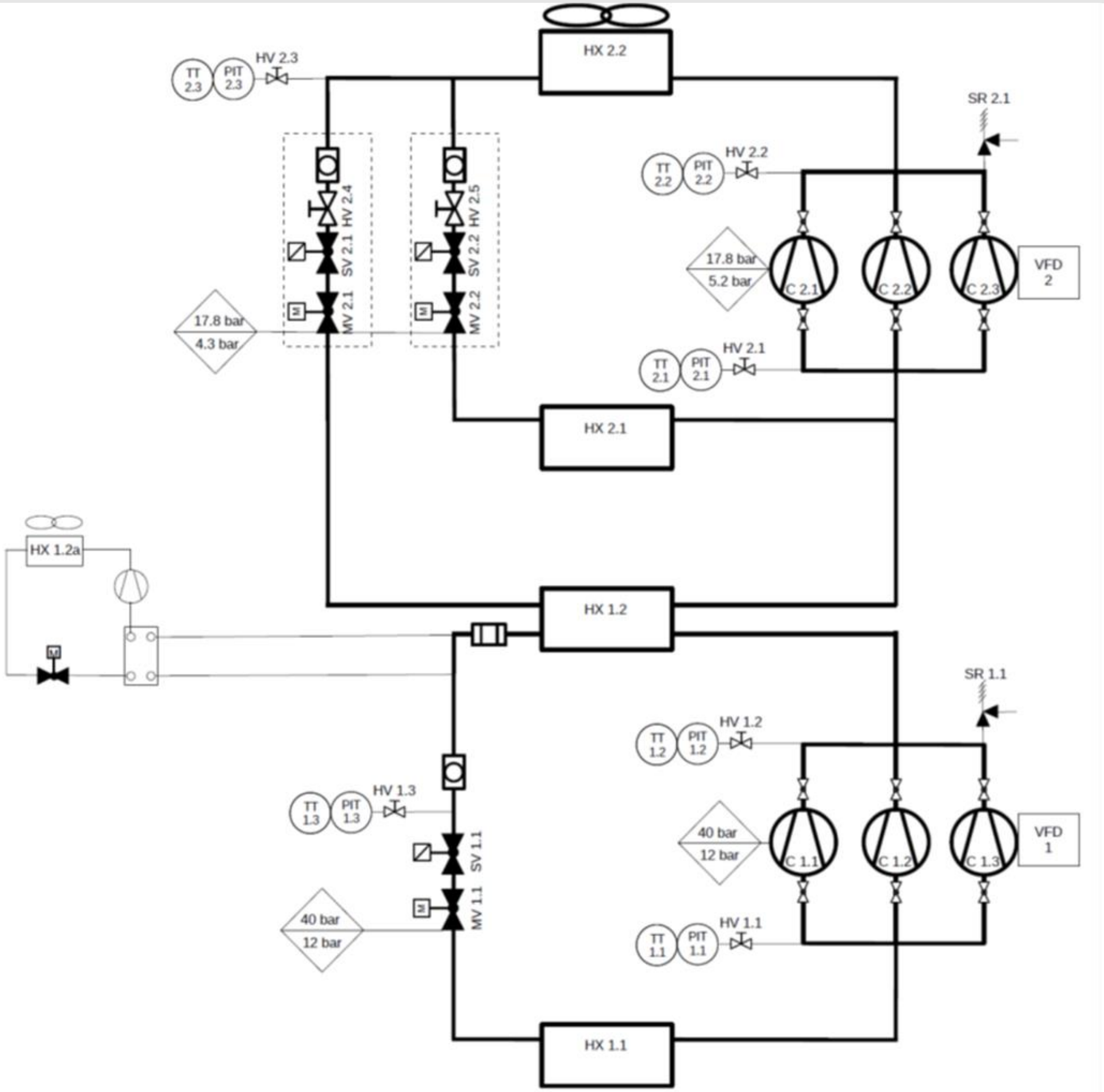


2 Evaporators to cool H_2

COP: 2.21 (2.32)

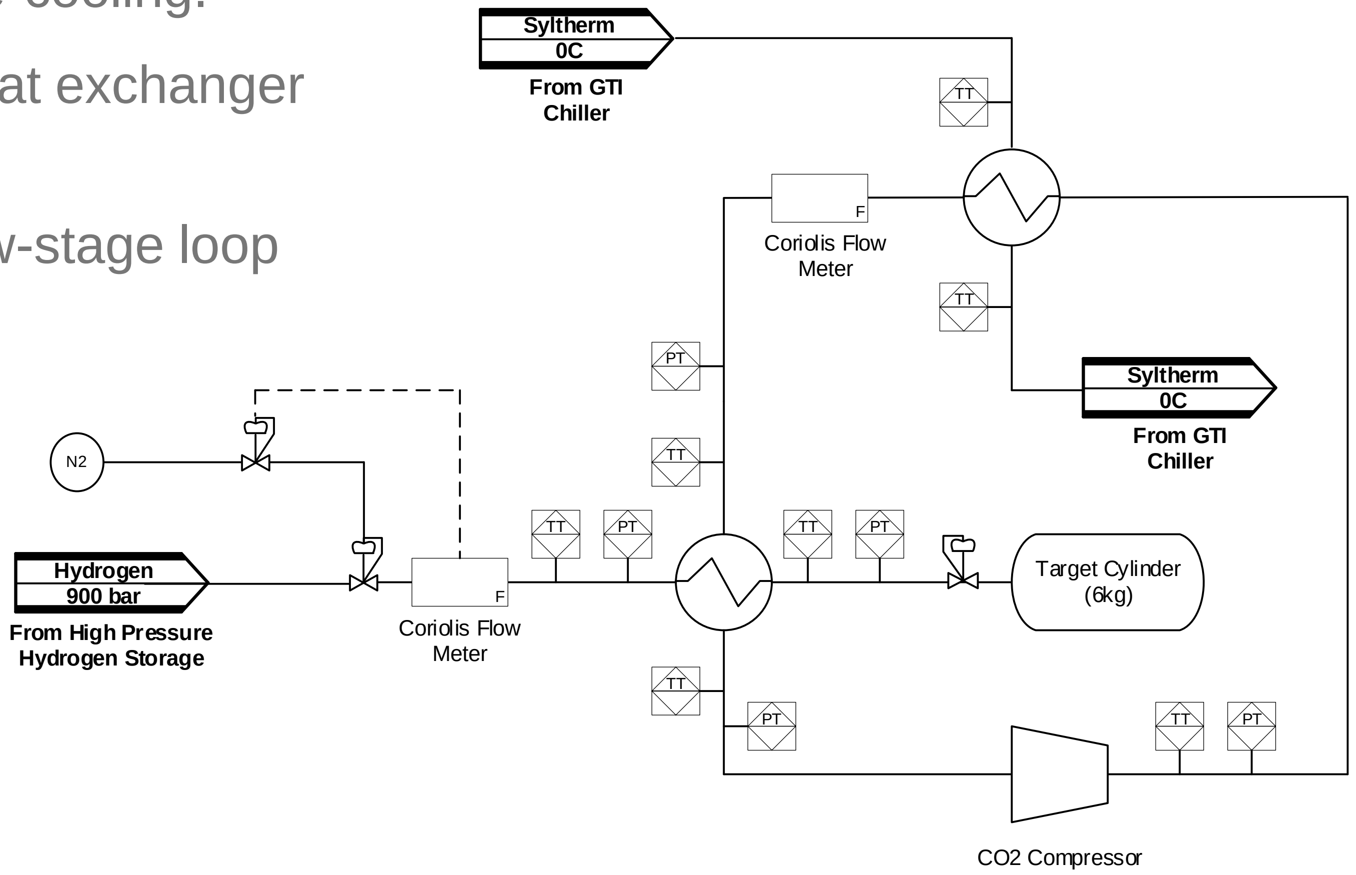
Progress: Preliminary Design

- NH3 selected for high temperature stage due to high efficiency
  - System can be completely located in restricted area to limit charge and mitigate risk
- CO_2 selected as low-temperature stage
  - Performance slightly favors CO_2
  - Capital cost slightly favors propane
  - Safety favors CO_2
  - Marketability favors CO_2
  - CO_2 more common at commercial scale (AHJs likely more familiar)



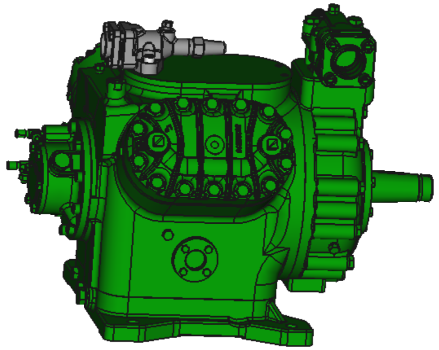
Progress: Heat Exchanger / Low Stage Testing

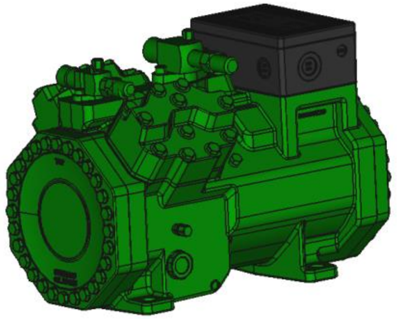
- Goal: De-risk later testing by understanding transient effects of heat exchanger utilized for pre-cooling.
- Original Task 1.2: Test high-pressure heat exchanger & quantify performance
  - Updated: Test heat exchanger and low-stage loop for control/transient impacts
- Commissioning – Late March

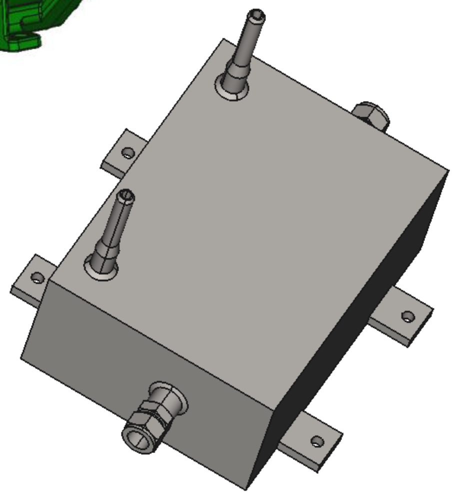


Progress: Detailed Design

- Code Review:
  - Ammonia: general purpose electrical components, 20ft from buildings
  - CO_2: gas detection/shutdown likely required at dispenser, relief valve venting details
- Component specification/selection/procurement
  - Main components identified, longest lead likely to be cascade exchanger
  - Some components are more prevalent in Europe, need to bring them over







Response to 2023 Reviewers Comments

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Reviewer Comment	Project Team Response
Reconsider project as majority of stations are likely to be supplied with liquid H2	This project was selected from a DOE solicitation; this strategy decision was made by DOE. The team feels that development for gaseous-fueled stations should continue as LH2 has many drawbacks and is not practical for all stations.
Why select -30°C precooling? Industry is leaning toward -40°C.	The solicitation for this project asked for 6 minute fueling times, which can be achieved with -30C precooling. This higher temperature will result in a lower-cost unit and increased reliability of the dispenser components, both contributing to a decreased refueling cost.
Heat exchanger design and evaluation method unclear	The heat exchanger is a micro-channel diffusion bonded design. The performance of the heat exchanger will be evaluated through H2 precooling process with a CO2 refrigeration loop on the cold side.

Collaboration and Coordination

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Organization	Project Roles	Importance to Project
GTI	Project lead, management and coordination. Lead for commissioning and testing of units. Responsible for ensuring the chiller design meets fueling requirements.	Extensive experience with hydrogen fueling protocols and building, commissioning, and testing hydrogen fueling systems.
Creative Thermal Solutions	Chiller design lead. CTS will also source components and assemble the chiller test unit.	Decades of experience with natural refrigeration systems, refrigerant heat transfer behavior, and test unit assembly and commissioning.
Argonne National Lab	Duty cycle modeling, integration into heavy duty fueling stations.	Vast hydrogen fueling knowledge and experience with current pre-cooling systems and J2601 standard
???	Commercialization Partner – To be determined in late 2024/early 2025	Input on final design and commercialization plan, technology transfer

Remaining Challenges and Barriers

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- Determine impacts of transient duty profile
  - Low-stage testing will help understand this early on
    - What temperature does the HX need to be held at between fills?
    - What controls are necessary for wide range of fueling rates/conditions
    - How much duty cycle peak-shaving occurs with HX mass and liquid CO_2 charge
- Understand safety and code requirements for ammonia/CO_2 refrigeration systems
- Now that the heavy-duty fueling protocols are released, update modeling and determine if changes to design are necessary

Proposed Future Work

- Complete commissioning and testing of low-stage unit
  - Use results to modify design of full test unit
- Complete design and fabrication of full test unit – Delivery to GTI targeted for 10/31/24
- Go/No-Go (end of BP2 is 10/31/24): Updated modeling shows target performance achievable
  - <$500,000 capital cost at 100 units/yr
  - Updated modeling shows 60kg fill in 6 minutes possible (update with fueling protocol)
  - Peak power consumption < 200kW
- Budget Period 3 scheduled for following 12 months
  - Test full unit and update design
  - Complete commercialization plan

Summary

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Objective:	Develop and validate chiller design for high-flow heavy-duty hydrogen fueling
Potential Impact:	Accelerate adoption of heavy-duty hydrogen vehicles, leading to emissions and other benefits
Approach:	- Target lowest total cost of ownership of system - Ensure compliance with fueling protocol and potential future refrigerant regulations
Progress:	- Preliminary design complete for full chiller system - Low-stage test unit being assembled as of early March
Next Steps:	- Complete low-stage unit testing - Complete design and fabrication of full test unit