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Invited presentation J4Or2A-03 given at CEC-ICMC 2021, July 19-23, 2021, Virtual.

Design, construction, and commissioning of a deployable liquid hydrogen production and fueling system for unmanned aerial systems

Cryogenic Engineering Conference
July 22, 2021

Ian Richardson, Ph.D.

Postdoctoral Researcher
MHGU2 Project Lead
irichardson@wsu.edu

WASHINGTON STATE UNIVERSITY

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Hydrogen Properties for Energy Research Lab

U.S. Army grant supports development of hydrogen-powered Unmanned Aerial Vehicle

July 18, 2019

By Siddharth Vodnala
Voiland College of Engineering and Architecture

Jacob Leachman, associate professor in Washington State University's School of Mechanical and Materials Engineering, has received a $1.8 million grant from the U.S. Army to demonstrate a liquid hydrogen-powered UAV and refueling system.

The $7.2 million total grant includes researchers from Mississippi State University, Insitu Inc., and Navmar Applied Sciences Corporation. Insitu, a subsidiary of Boeing, will provide their ScanEagle3® UAV, equipped with a fuel cell-powered electric engine. MSU will measure performance characteristics of the drone.

Insitu employees Clay Christian and Jon Cantella holding the ScanEagle UAV.

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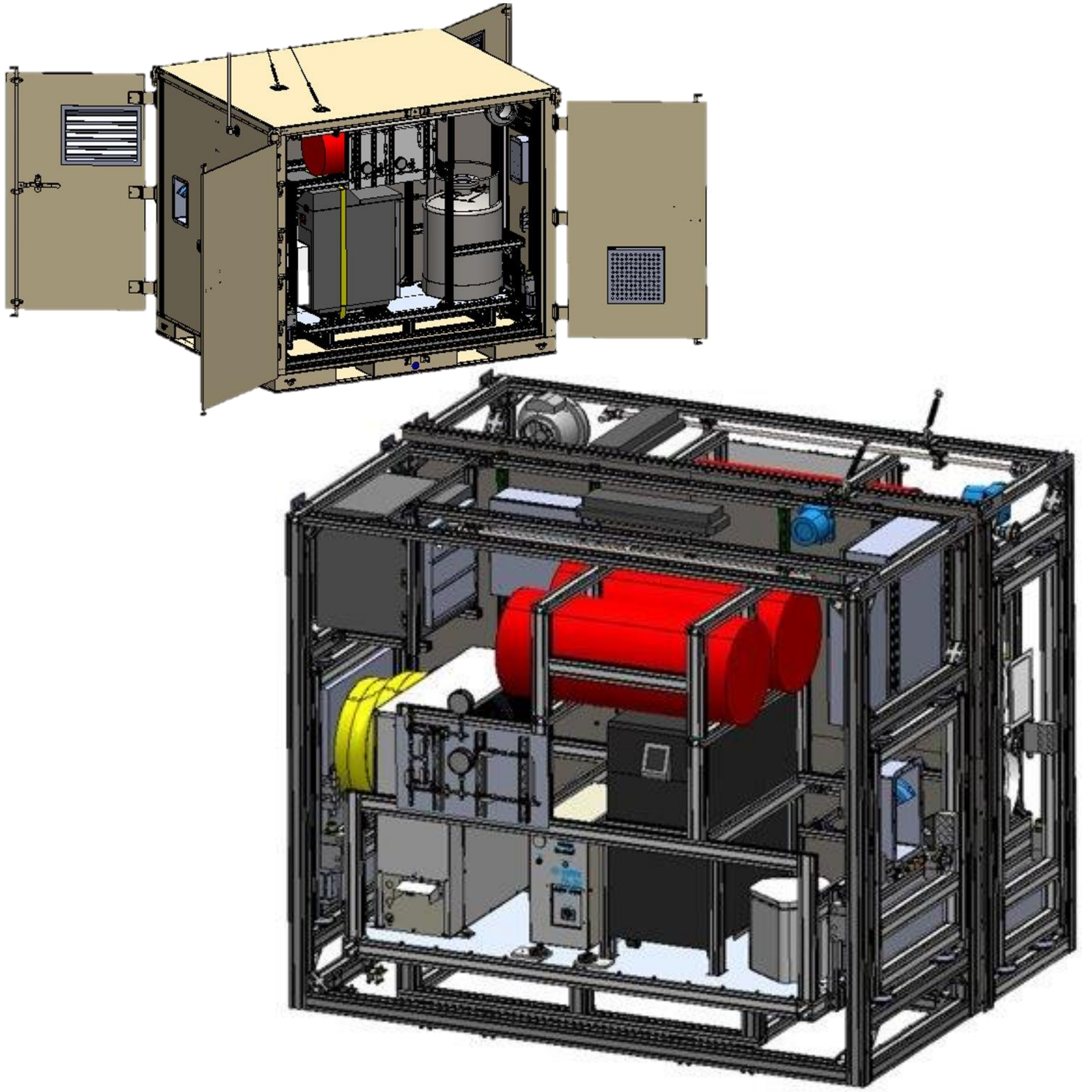
Liquid Hydrogen Fueling Infrastructure

- Lack of small-scale LH2 infrastructure
  - Smallest industrial gas liquefiers are 1 tonne/day, doesn't include H2 generation or storage.
- Small LH2 vehicles need a fueling solution
  - LH2 deliveries geographically limited and typically require orders of 1 tonne.
- WSU developed a containerized fueling station that generates, liquefies, and stores LH2



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MHGU Specifications

- Refuel a small LH2 fuel tank in the field
- Liquefy 1-2 liter of hydrogen per hour
- Store approximately 50L of LH2
- Power requirements:
  - 208 V or less
  - 200 A or less
  - Single or three phase power
- Consumables:
  - Tap water
  - Gaseous helium
- Refill LH2 fuel tank in 20 minutes or less
- Standard military C130 container – minimal footprint
- Operate with minimal human interaction
- Comply with NFPA codes and industry best practices for hydrogen

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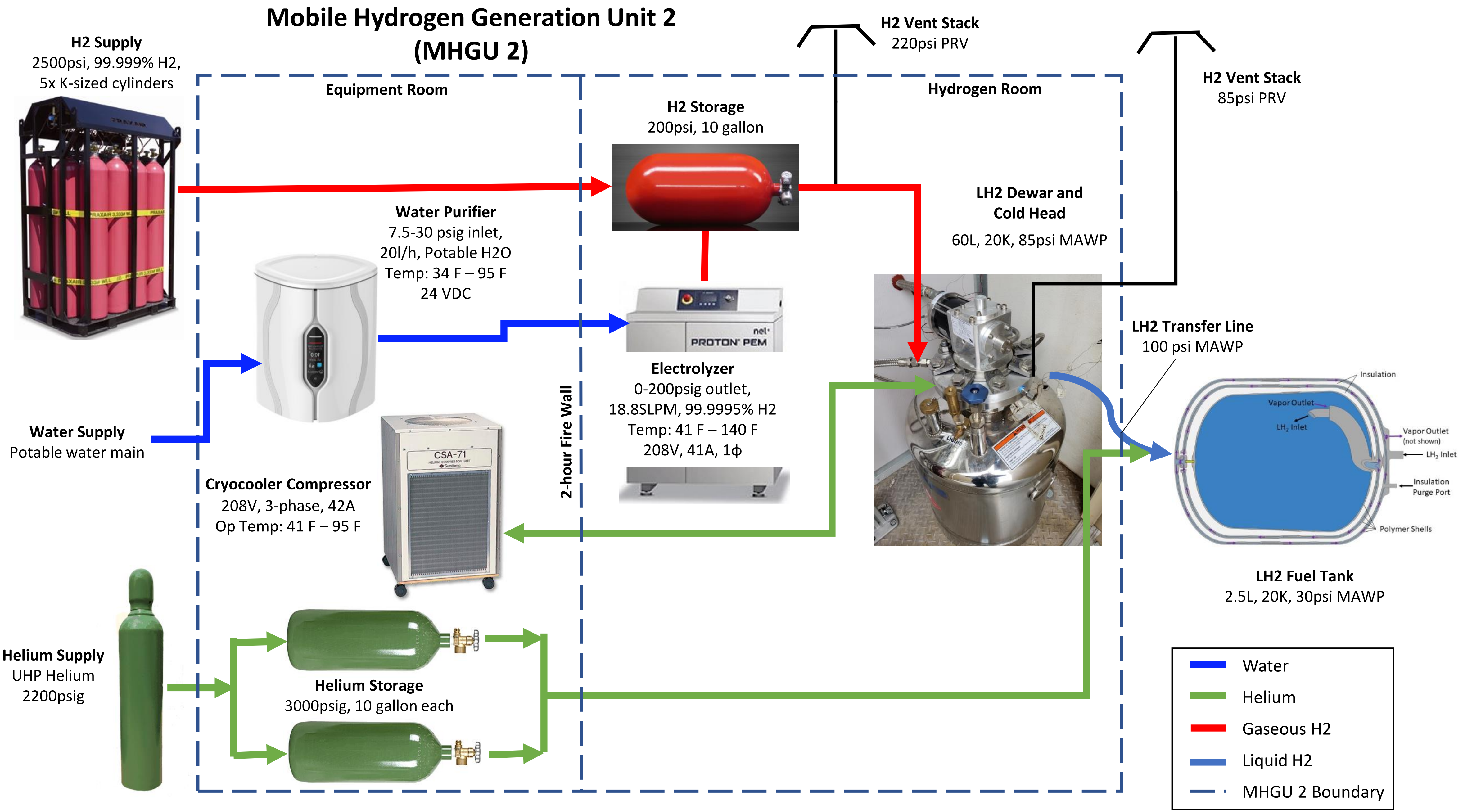
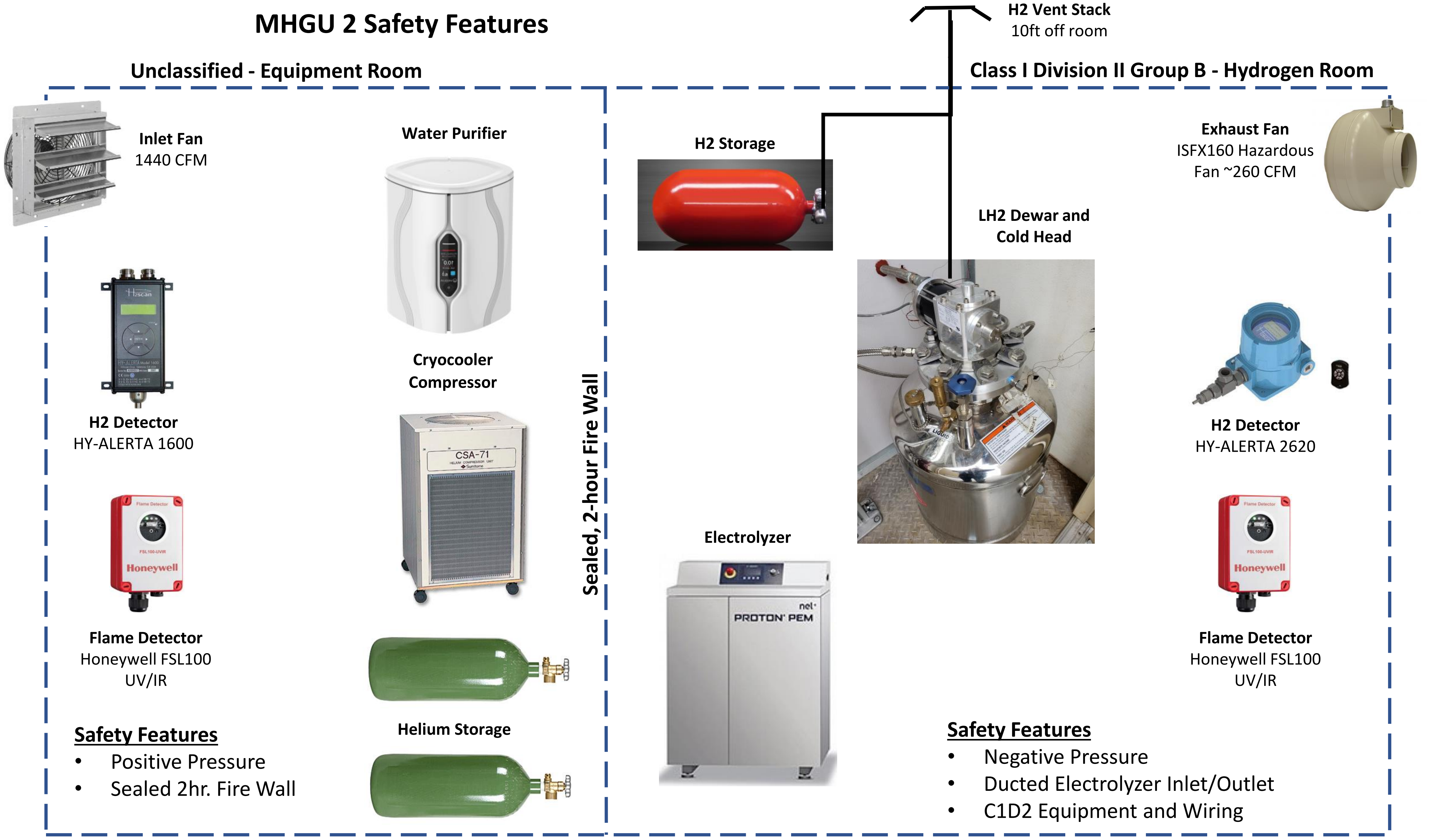
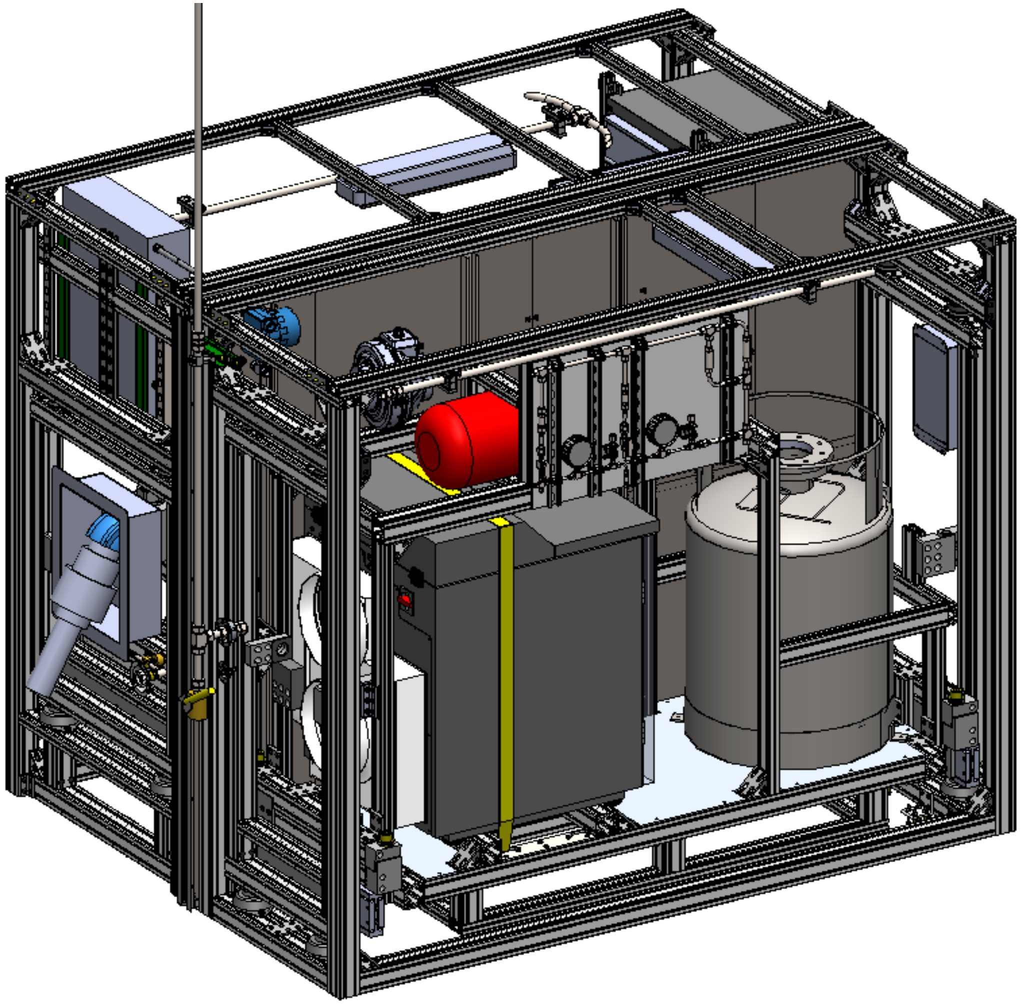

Mobile Hydrogen Generation Unit 2 (MHGU 2)
H2 Supply
2500psi, 99.999% H2,
5x K-sized cylinders
Equipment Room
Hydrogen Room
H2 Vent Stack
220psi PRV
H2 Vent Stack
85psi PRV
H2 Storage
200psi, 10 gallon
Water Purifier
7.5-30 psig inlet,
20l/h, Potable H2O
Temp: 34 F – 95 F
24 VDC
LH2 Dewar and
Cold Head
60L, 20K, 85psi MAWP
Electrolyzer
0-200psig outlet,
18.8SLPM, 99.9995% H2
Temp: 41 F – 140 F
208V, 41A, 1ϕ
LH2 Transfer Line
100 psi MAWP
Water Supply
Potable water main
Cryocooler Compressor
208V, 3-phase, 42A
Op Temp: 41 F – 95 F
2-hour Fire Wall
Insulation
Vapor Outlet
LH2 Inlet
Vapor Outlet
(not shown)
LH2 Inlet
Insulation
Purge Port
Polymer Shells
LH2 Fuel Tank
2.5L, 20K, 30psi MAWP
Helium Supply
UHP Helium
2200psig
Helium Storage
3000psig, 10 gallon each
Water
Helium
Gaseous H2
Liquid H2
MHGU 2 Boundary

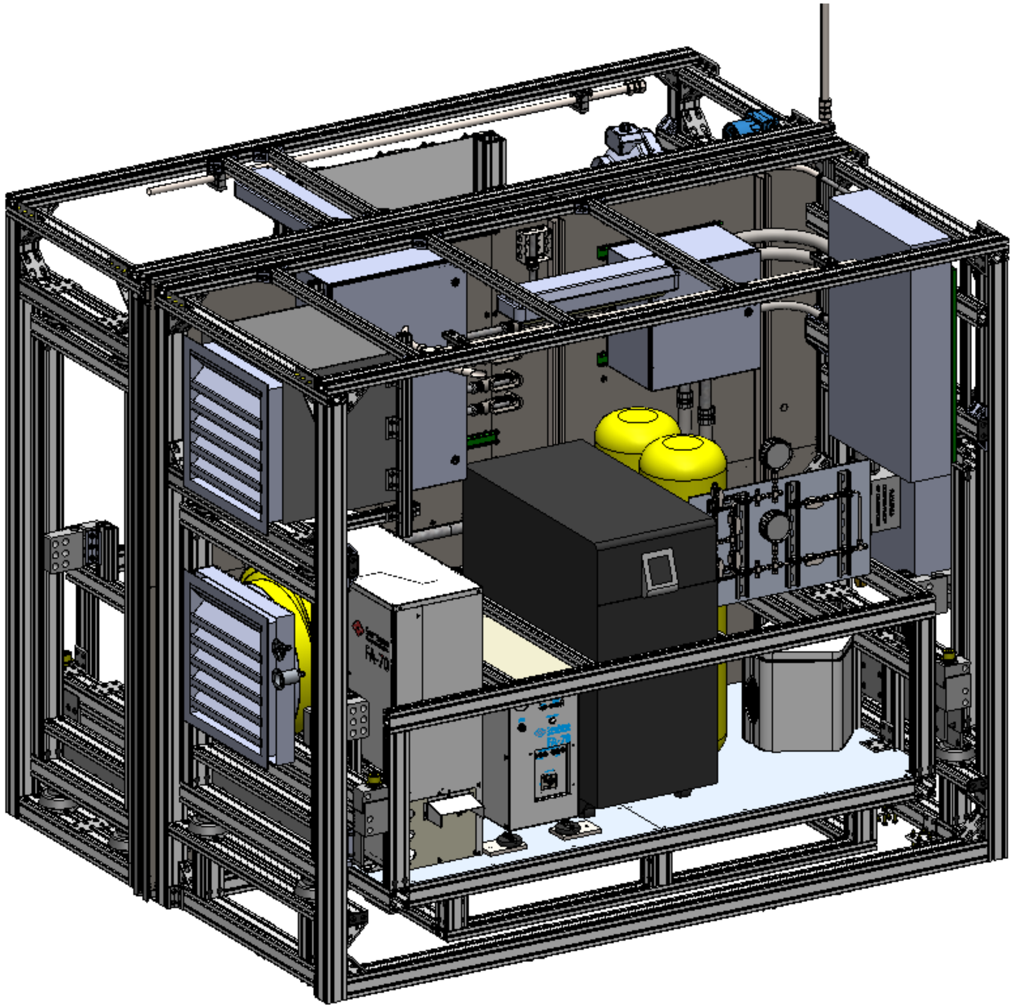

MHGU 2 Safety Features
H2 Vent Stack
10ft off room
Unclassified - Equipment Room
Class I Division II Group B - Hydrogen Room
Inlet Fan
1440 CFM
Water Purifier
H2 Storage
Exhaust Fan
ISFX160 Hazardous
Fan ~260 CFM
LH2 Dewar and
Cold Head
H2 Detector
HY-ALERTA 1600
Cryocooler
Compressor
CSA-71
Sealed, 2-hour Fire Wall
H2 Detector
HY-ALERTA 2620
Honeywell
Electrolyzer
nel
PROTON PEM
Flame Detector
Honeywell FSL100
UV/IR
Flame Detector
Honeywell FSL100
UV/IR
Helium Storage
Safety Features
• Positive Pressure
• Sealed 2hr. Fire Wall
Safety Features
• Negative Pressure
• Ducted Electrolyzer Inlet/Outlet
• C1D2 Equipment and Wiring

Shutdown Table and Controls

Type of Consequence	Trigger	Outcome	Control System	Cleared By
Process Stop 1	-H2 above 1% -Loss of ventillation	-Electrolyzer OFF -Isolate H2 -Alarm strobe ON	PLC	Process Stop Reset Button
Process Stop 2	-H2 above 2%	-Electrolyzer OFF -Cryocooler OFF -Vent H2 out stack -Alarm horn and strobe ON	PLC	Process Stop Reset Button
E-Stop	-Fire -Dewar pressure < 3psig -E-stop button	-Electrolyzer OFF -Cryocooler OFF -Vent H2 out stack -Alarm horn and strobe ON	Safety Controller	E-Stop Reset Button

MHGU2 Overview





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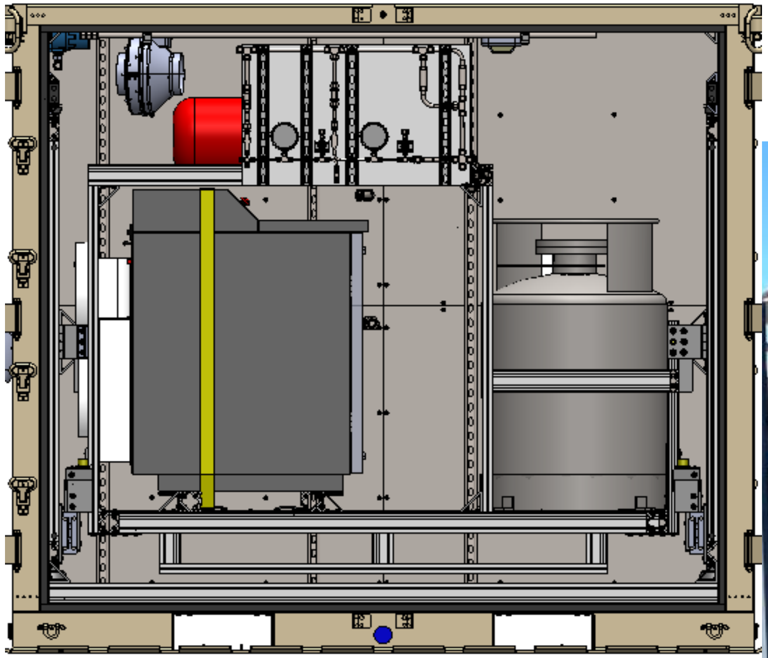
Hydrogen Room



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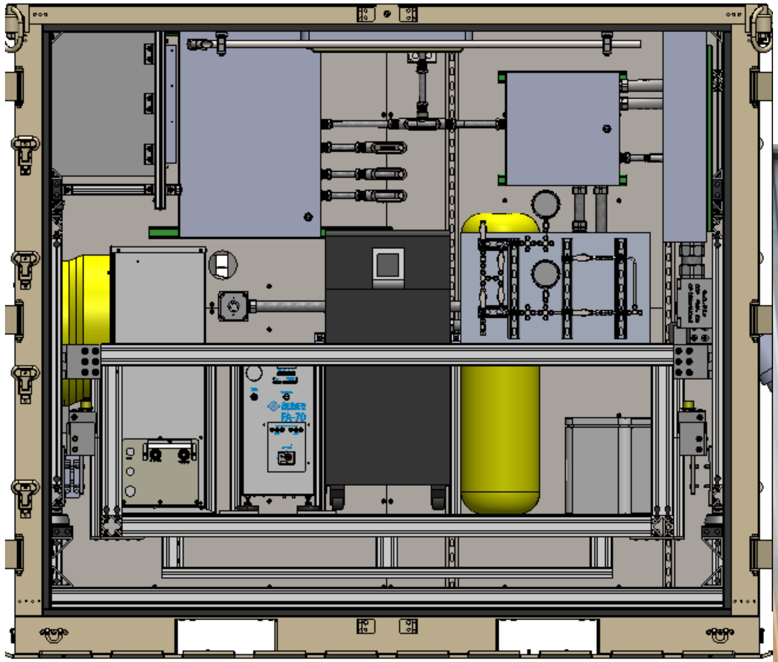
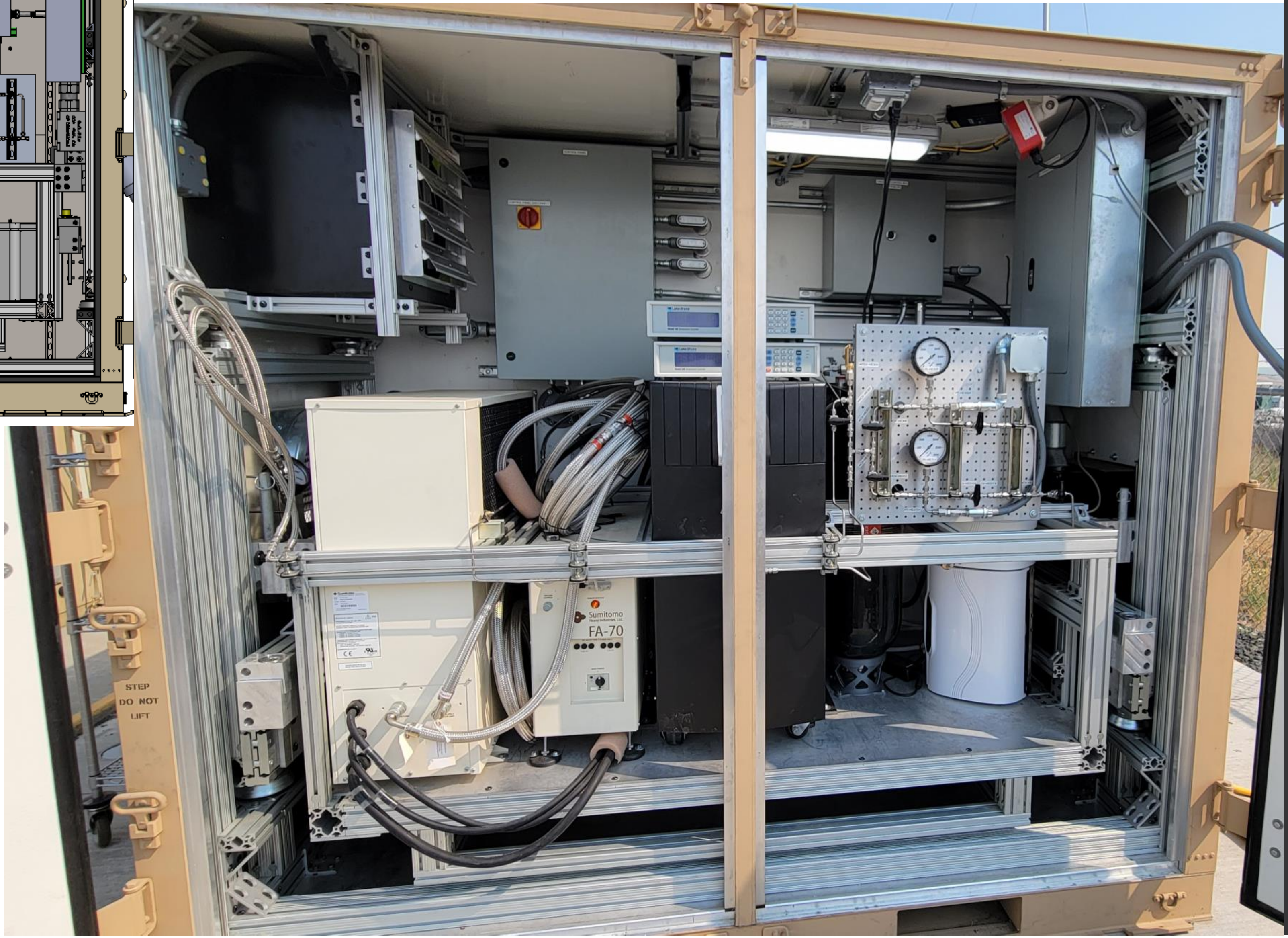
Equipment Room





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Liquefier

- Major Components
  - 60 L Dewar
  - Cryocooler Coldhead
  - Thermocouple Rake
  - $AlSi_{10}Mg$ Additively Manufactured Heat Exchanger
  - Heater Block
  - Superconducting Liquid Level Gauges with Heaters

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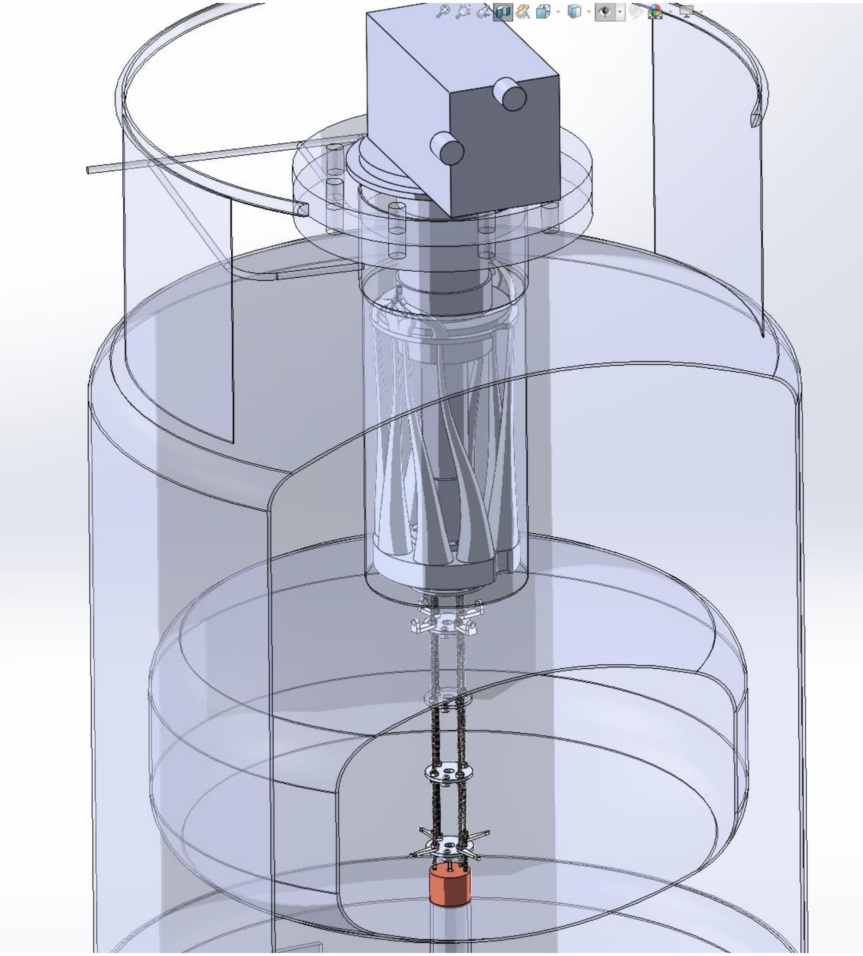
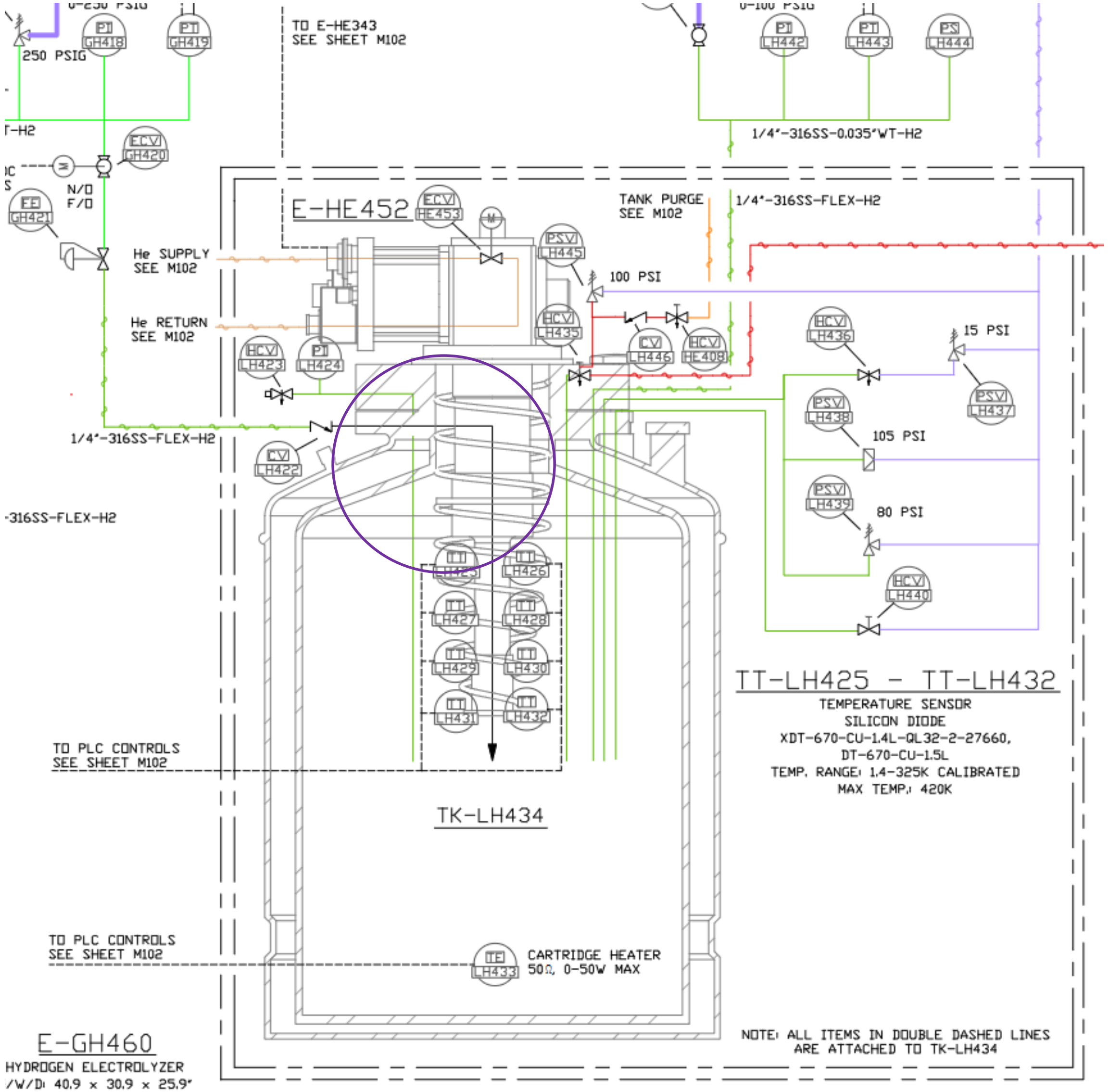
Liquefier

- Safety Features
  - Dual PSV – 80 psig & 105 psig
  - Active temperature controls





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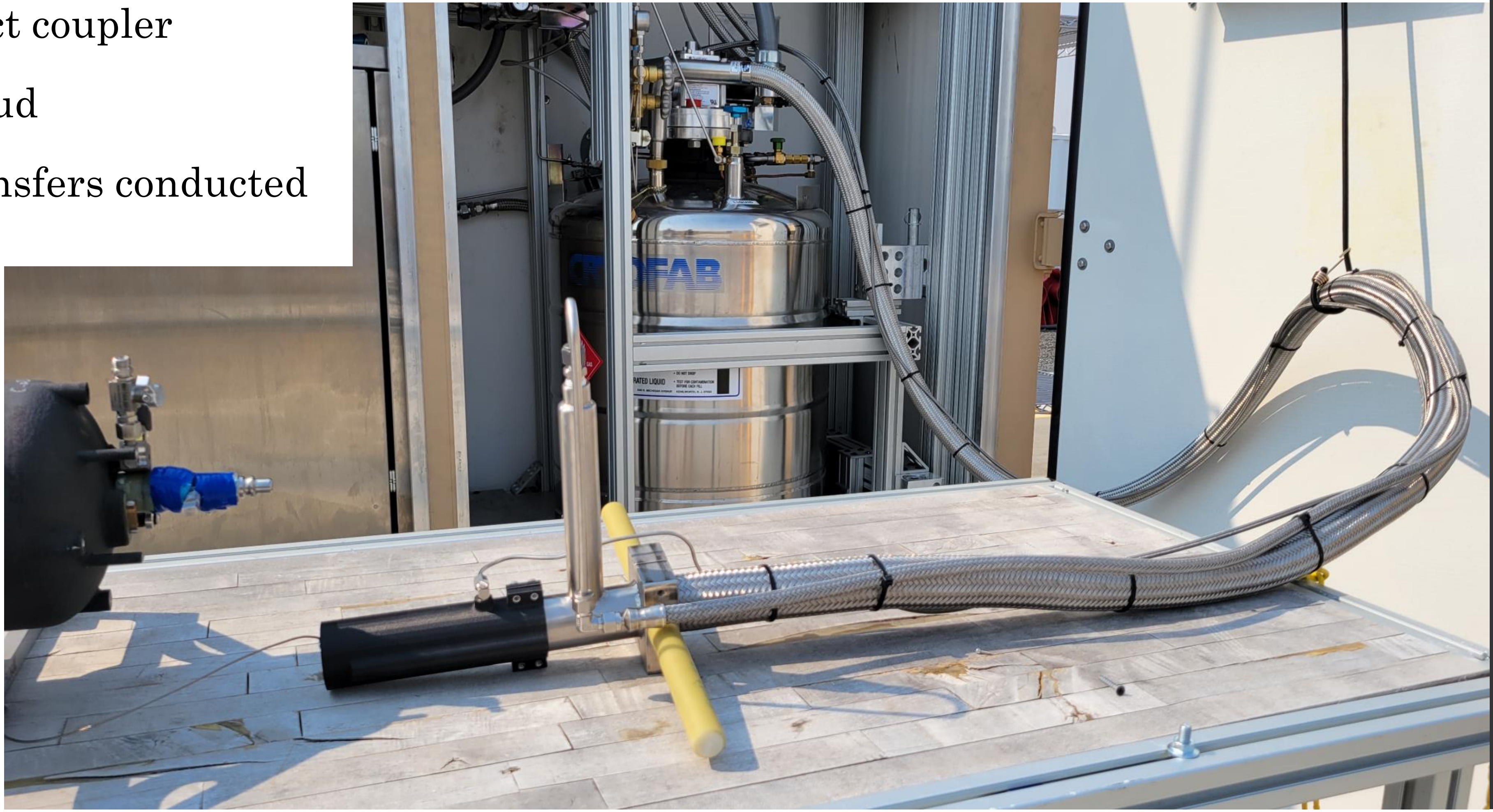
Liquid Hydrogen Transfers

- Vacuum-jacketed transfer line
- Quick connect coupler
- Helium shroud
- 50+ LH2 transfers conducted



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User Interface

- Touch screen display
  - Monitoring and control
- Push button operation
- Remote access

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External Interfaces

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Outdoor Liquid Hydrogen Test Facility

Hydrogen Storage Requirements

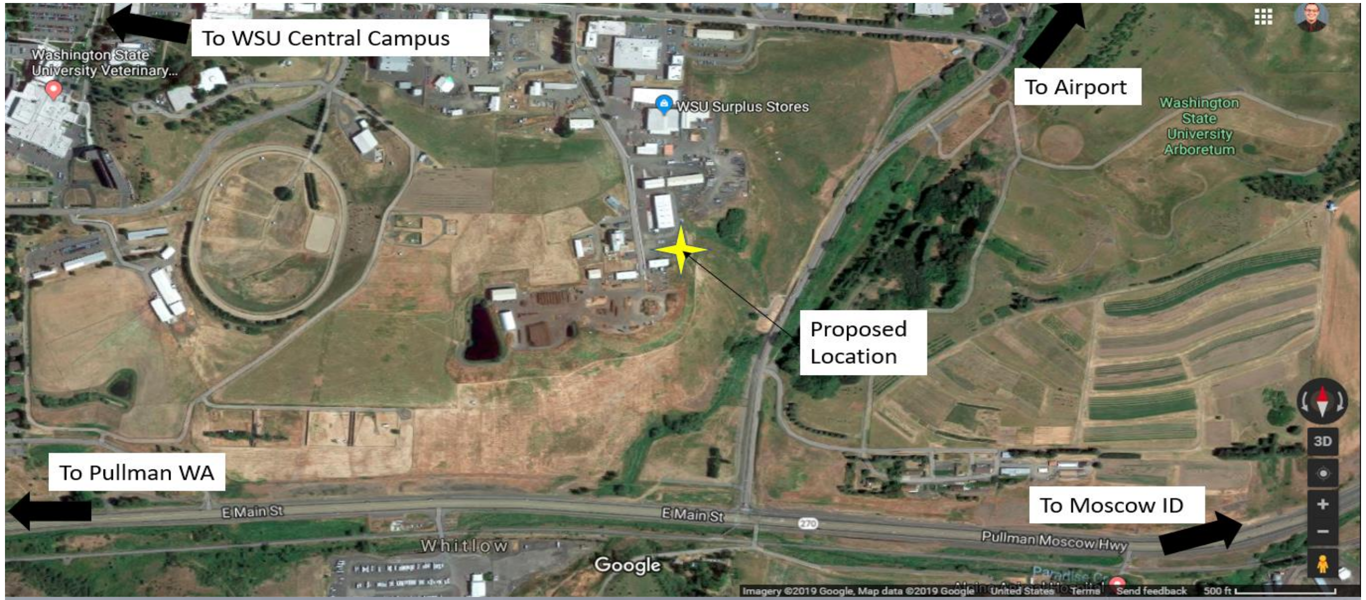
- LH2: up to 150 L
- gH2: up to 68 std. m^3 (2400 std. ft^3)

Power Requirements

- 200 A, 208V, 3-Phase

Site Requirements

- Water
- Lighting
- Video Monitoring
- Fire/EMS access
- Near Fire Hydrant



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Liquid Hydrogen Test Facility

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Summary

- Developed a transportable LH2 fueling station
- Developed an outdoor LH2 test facility
- Field testing later this summer

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Thank you!

http://www.hydrogen.wsu.edu