ERH2

EMBRY-RIDDLE HYDROGEN

Electrolysis and Material Storage of Hydrogen Gas

ERH$_2$

Team Members

Dylan Astrup
Detail Team Lead

Hannah Spiller
Lead Material Storage Engineer

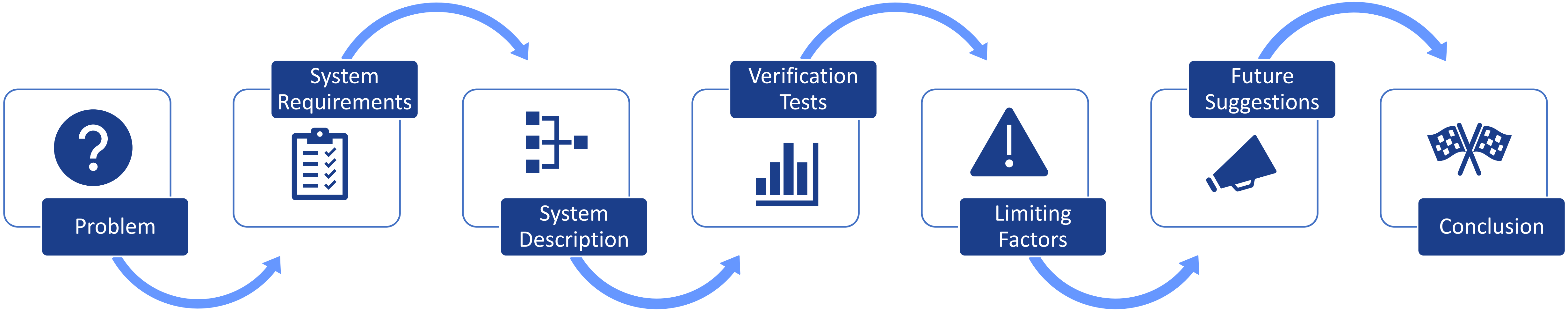
Grant Carrabine
Lead Electrolysis Engineer

Tesla Alford III
Lead Extraction Engineer

Titan Berson
Lead Interface Engineer

Jacob Wolf
Lead Piping Engineer

Agenda


Problem
System Requirements
System Description
Verification Tests
Limiting Factors
Future Suggestions
Conclusion

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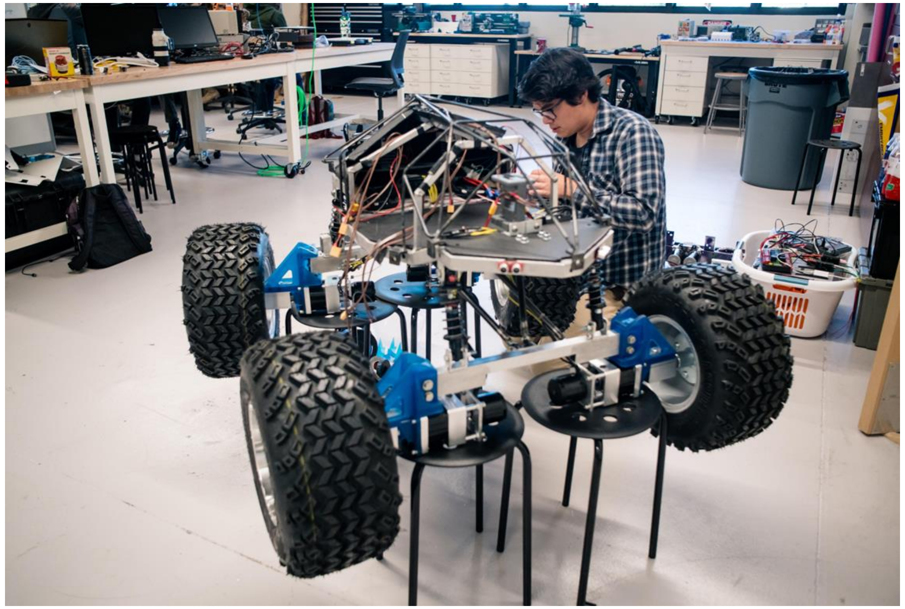
What Embry-Riddle Has

Wind Tunnel



Robotics Lab

Propulsion Lab

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What Embry-Riddle Needs

Energy Labs

Viewable Demonstrations

Create Interest in the Energy Track

Hydrogen Storage Applications

Personal Vehicles

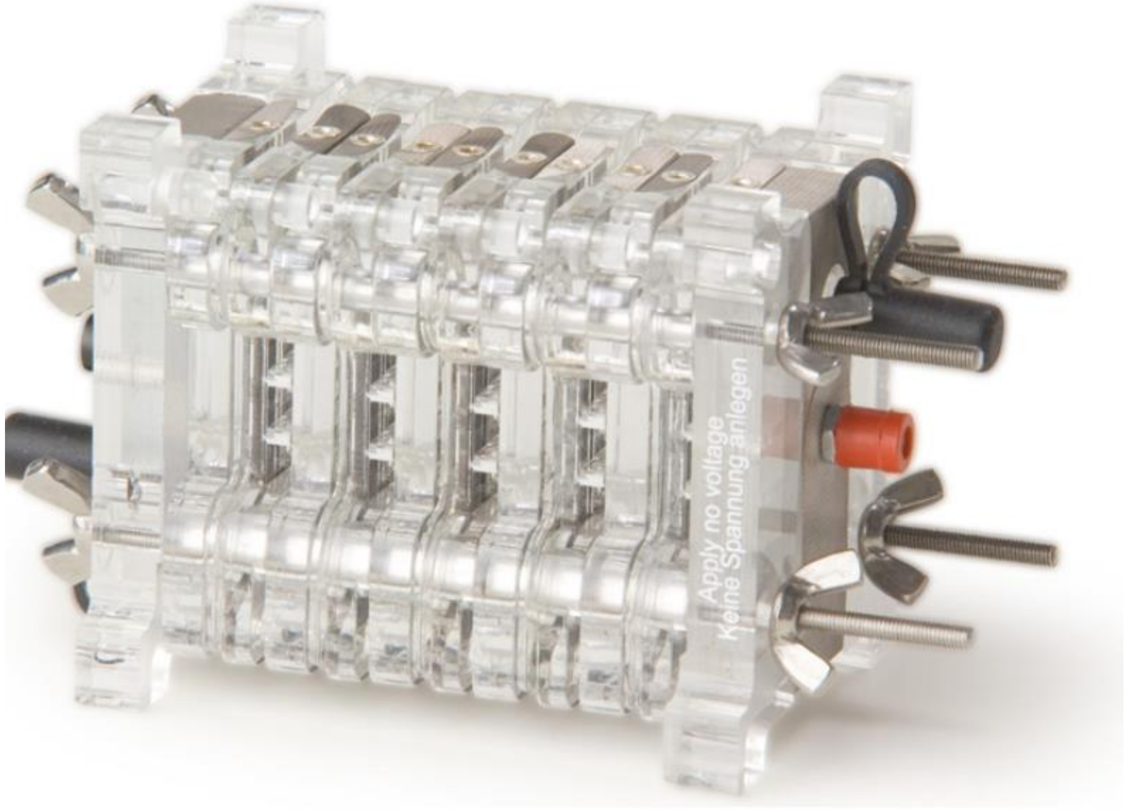
Commercial Vehicles

Aircraft

Storing hydrogen at high pressures and cryogenic temperatures is dangerous and heavy.

Generate and Store Hydrogen

ERH2's purpose is to create an energy demonstrator to generate and store hydrogen.



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System Requirements

Produce Hydrogen

1.1.1 The system must produce enough hydrogen to get the fuel cell to steady state and then run for 10 minutes at 1 watt.

1.1.2 The system must be able to determine the rate of hydrogen gas produced.

Store Hydrogen

1.2 The storage method must run the fuel cell for a minimum of 5 minutes.

1.2.1 The system must measure the amount of hydrogen stored.

Run Fuel Cell

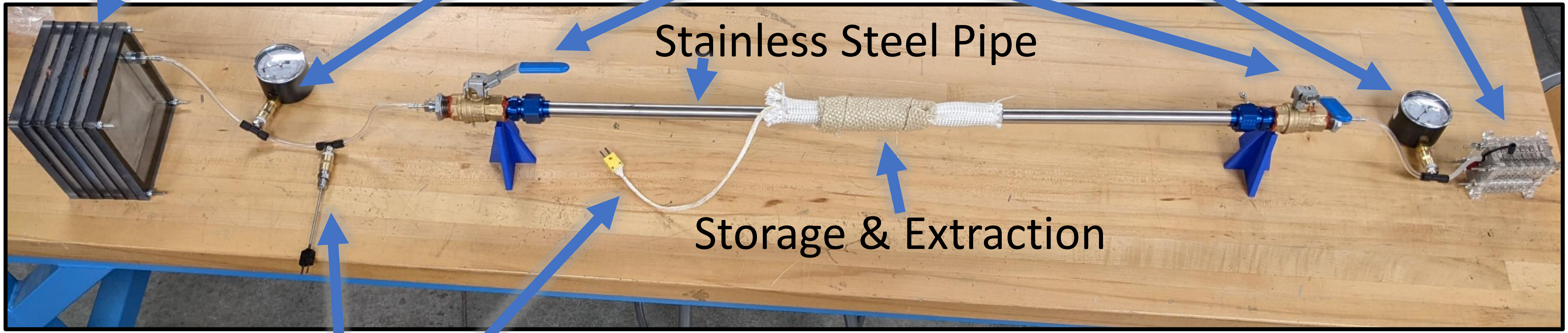
1.4 The system must interface with the Embry-Riddle fuel cell.

1.4.1 The system output must be a ¼" PTFE tube.

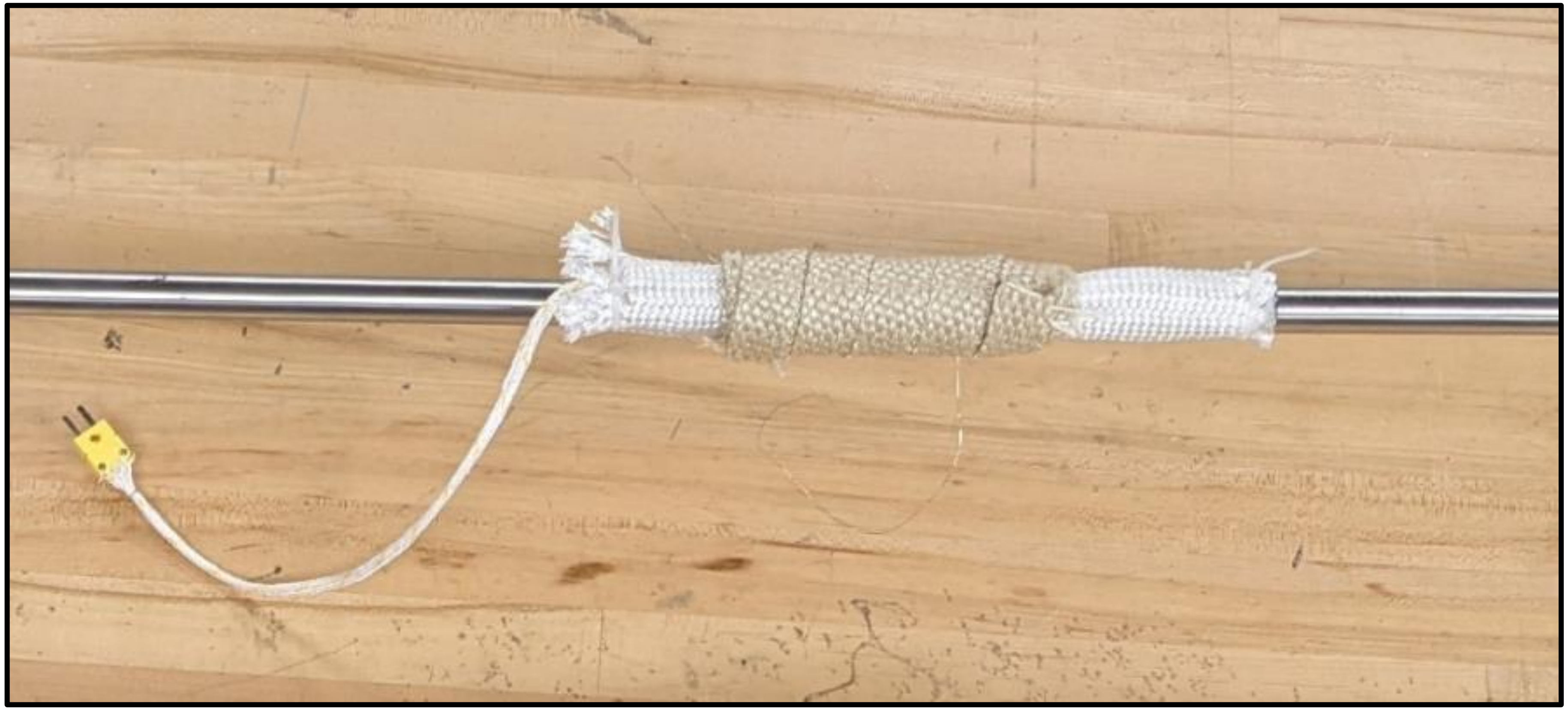
ERH2

System Description

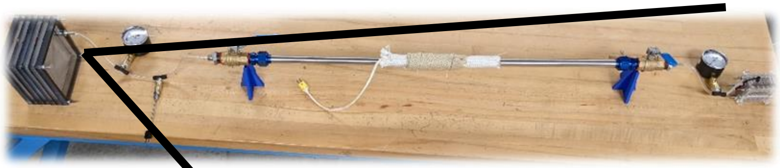
ERH2 System Overview



ERH2 System Overview



Electrolyzer Exploded View



System Interfaces – Tee Fittings

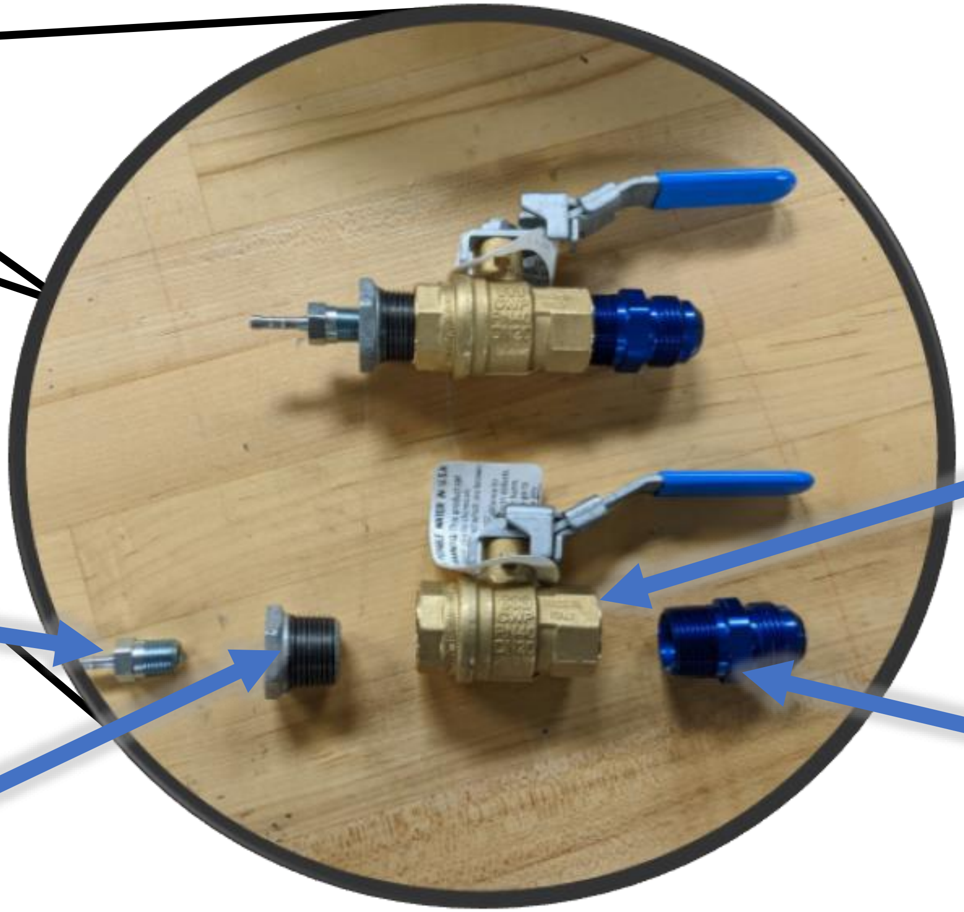
Pressure Gauge

J-Type Thermocouple

¼ NPT Female to ¼ NPT Female

¼ OD Compression Tee to ¼ NPT

System Interfaces – Valve Assembly



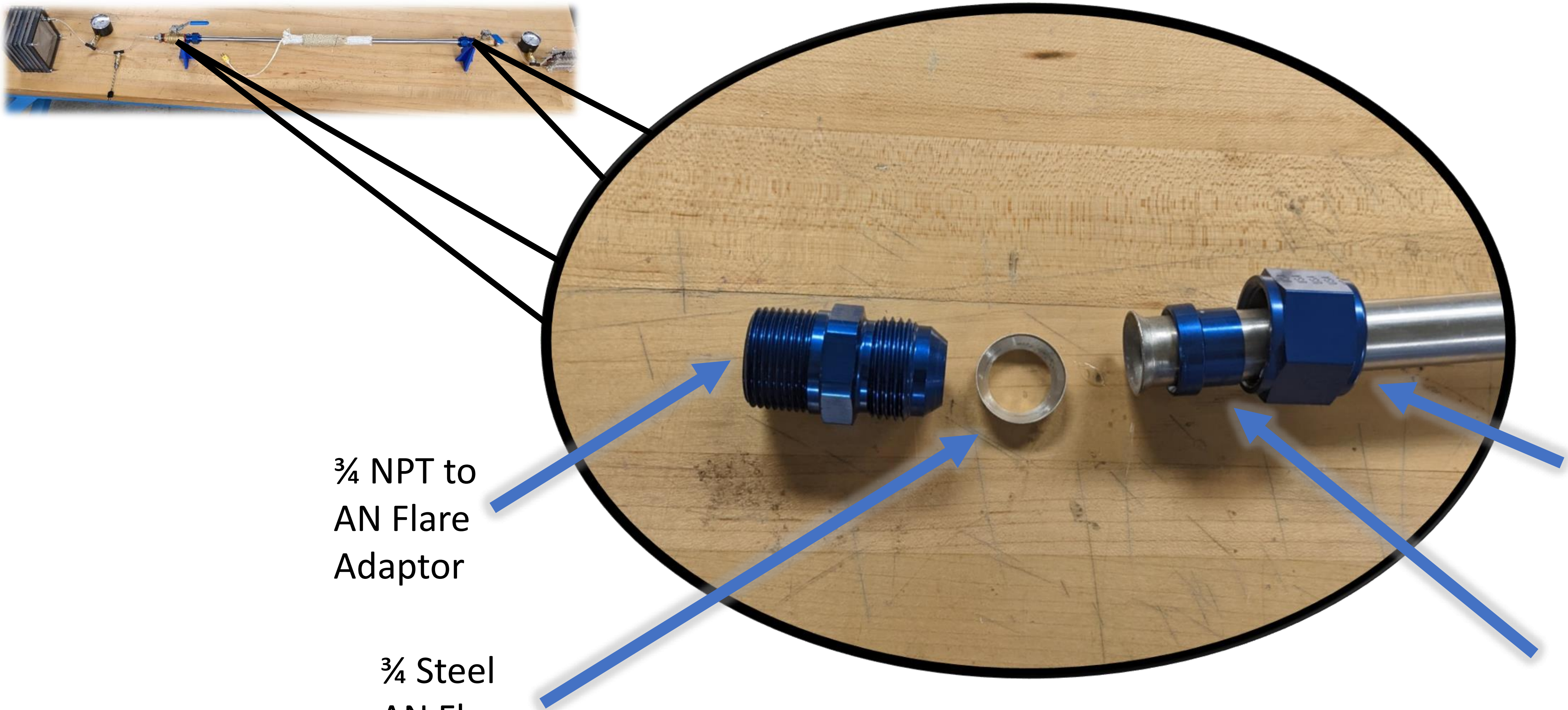
¾ NPT Brass Ball Valve

Barbed Fitting

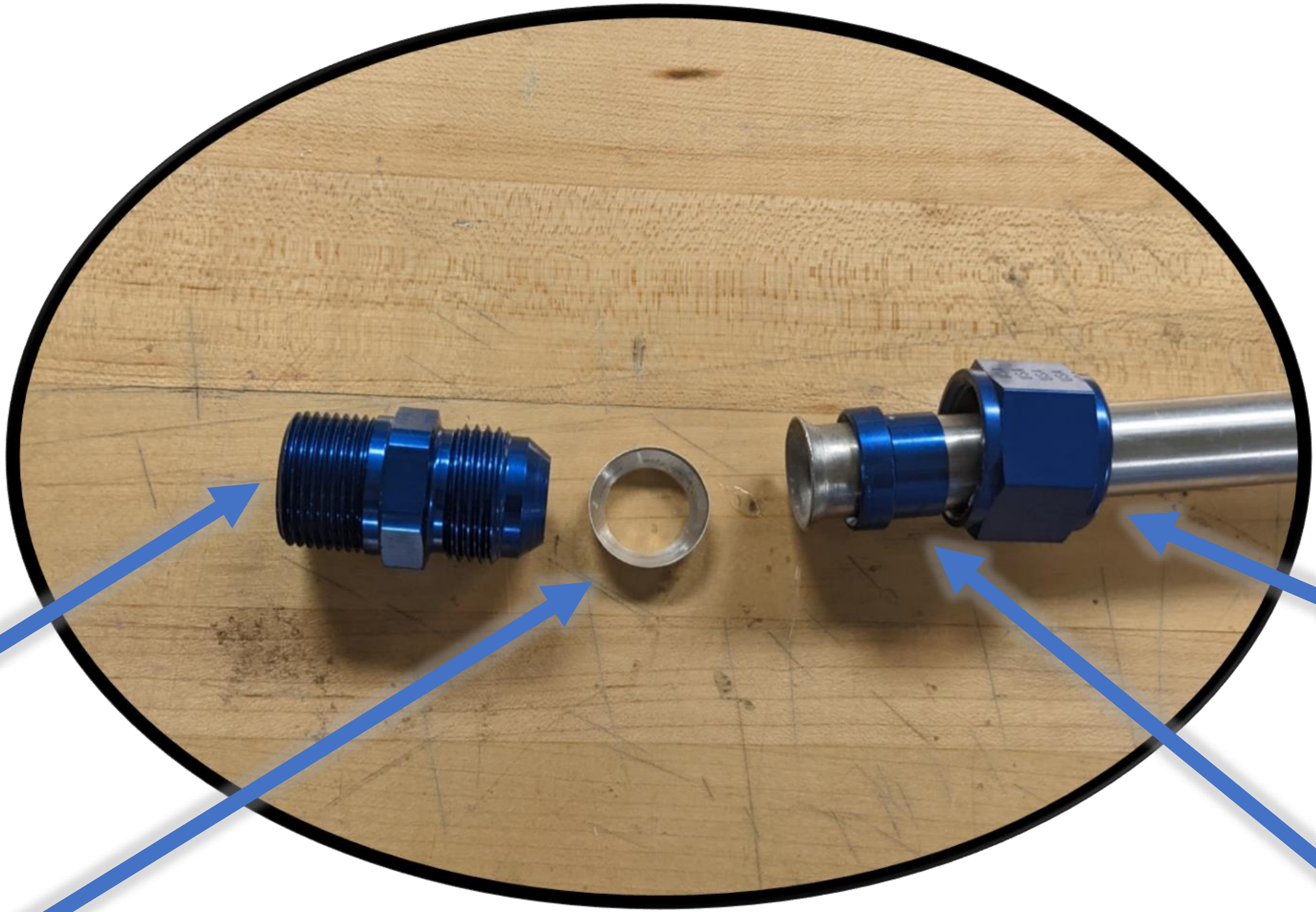
¾ NPT to AN Flare Adaptor

¼ to ¾ NPT Reducer

System Interfaces – Pipe Assembly



System Interfaces – Pipe Assembly



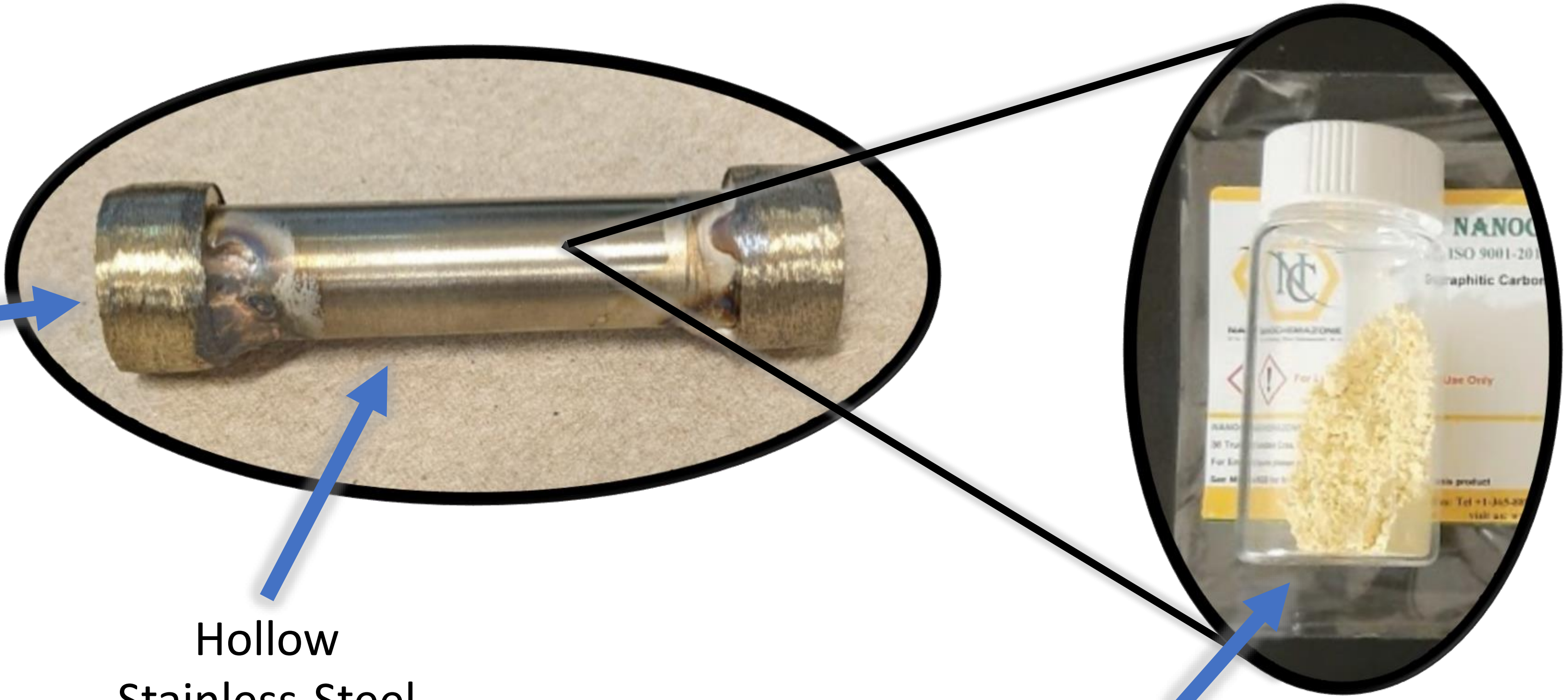
¾ NPT to
AN Flare
Adaptor

¾ Steel
AN Flare
Washer

¾ AN
Flare Nut

¾ AN
Flare
Sleeve

Material Storage



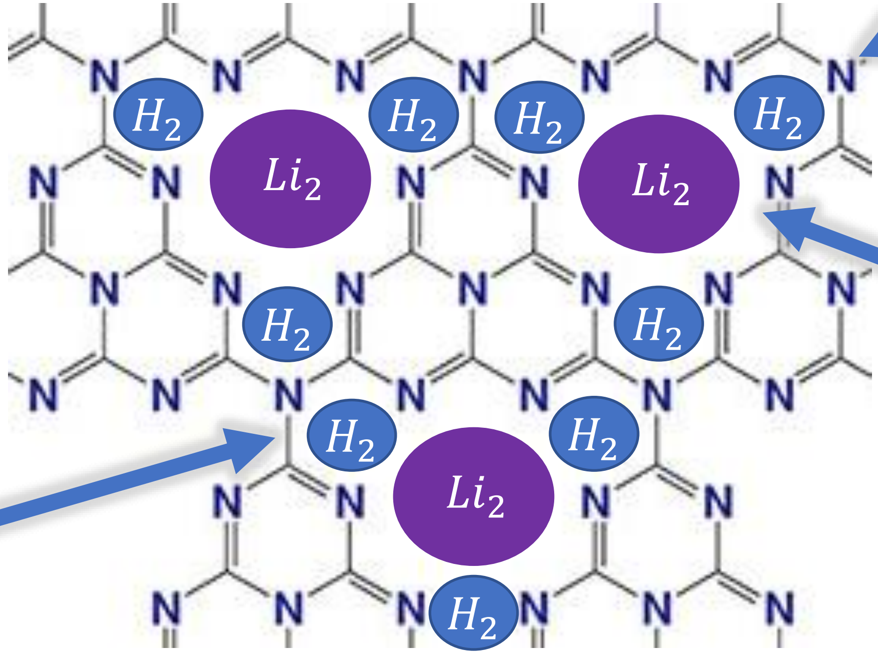
1 Micron Mesh

Hollow Stainless-Steel Capsule

Lithium-Doped Graphitic Carbon Nitride

Lithium-Doped Graphitic Carbon Nitride [$Li_2C_4N_4$]

Nitrogen Covalent Bonds



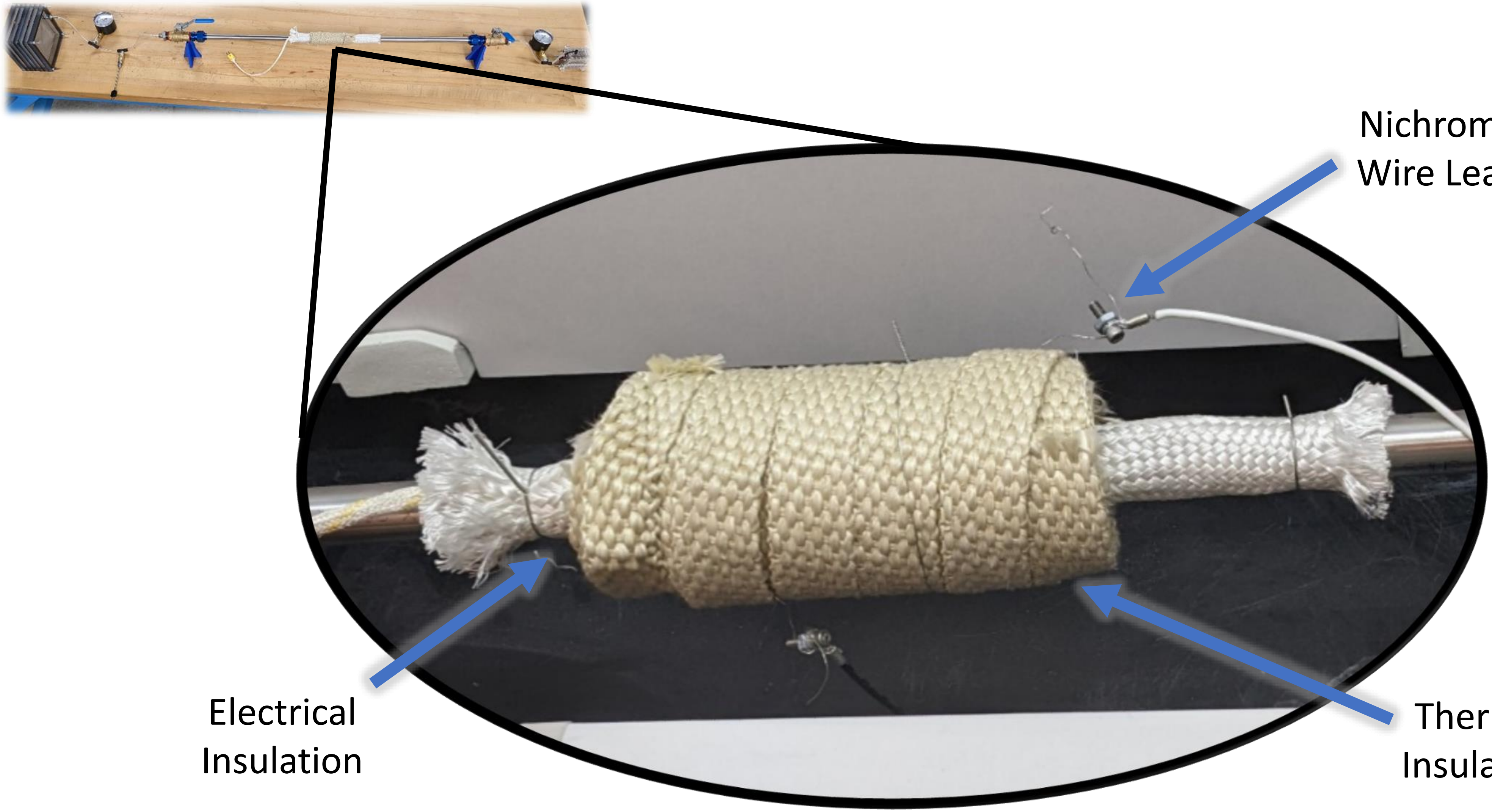
Lithium Atoms

Hydrogen Molecules

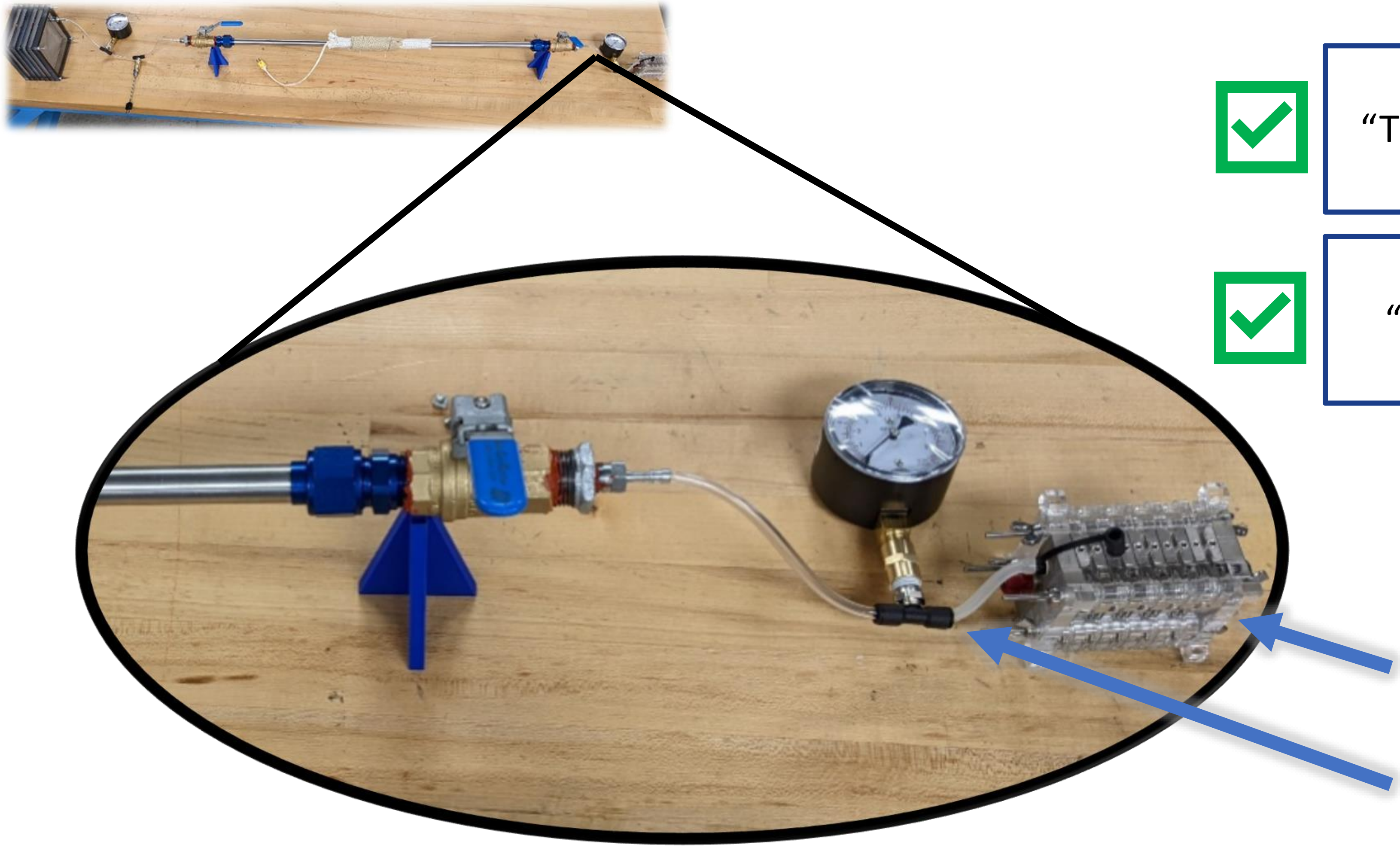
Graphitic Carbon Nitride
(Molecular Level)

300°C will break the bonds to allow the hydrogen to escape.

Extraction Zone



Fuel Cell Integration



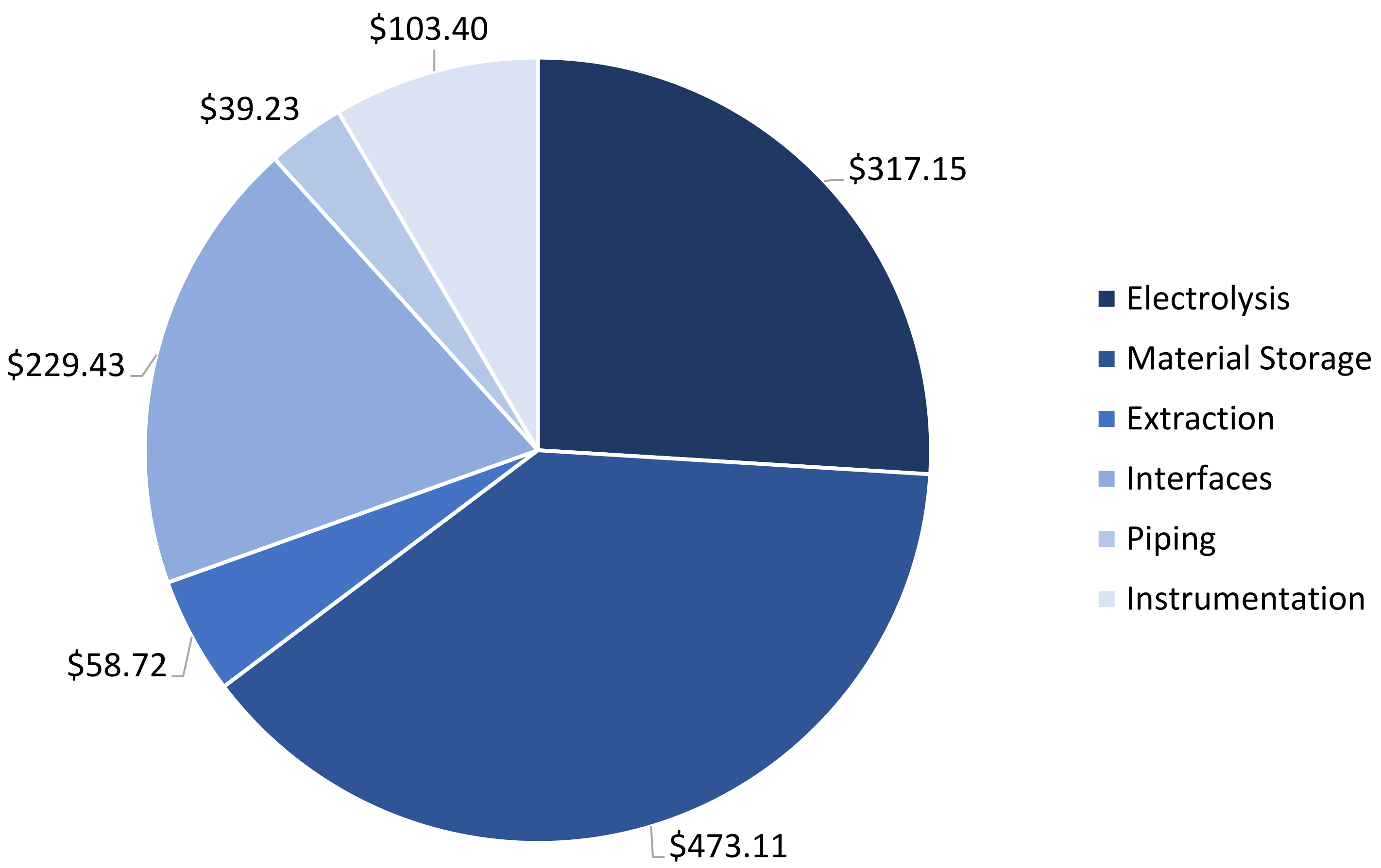
Requirement 1.4
“The system must interface with the Embry-Riddle fuel cell.”

Requirement 1.4.1
“The system output must be a ¼” PTFE tube.”

Budget

Total:
$1221.04

$78.96 under budget



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Concept of Operations

1. Weigh material storage capsule
2. Load capsule into pipe with rod
3. Attach valve assembly onto pipe
4. Turn on electrolysis and flush pipe until light turns on
5. Close exit valve to begin loading material storage
6. Run electrolysis until pressure gauge reads maximum pressure

ERH$_2$

Concept of Operations

7 Turn off electrolysis, disconnect pipe from valve, remove and weigh the capsule

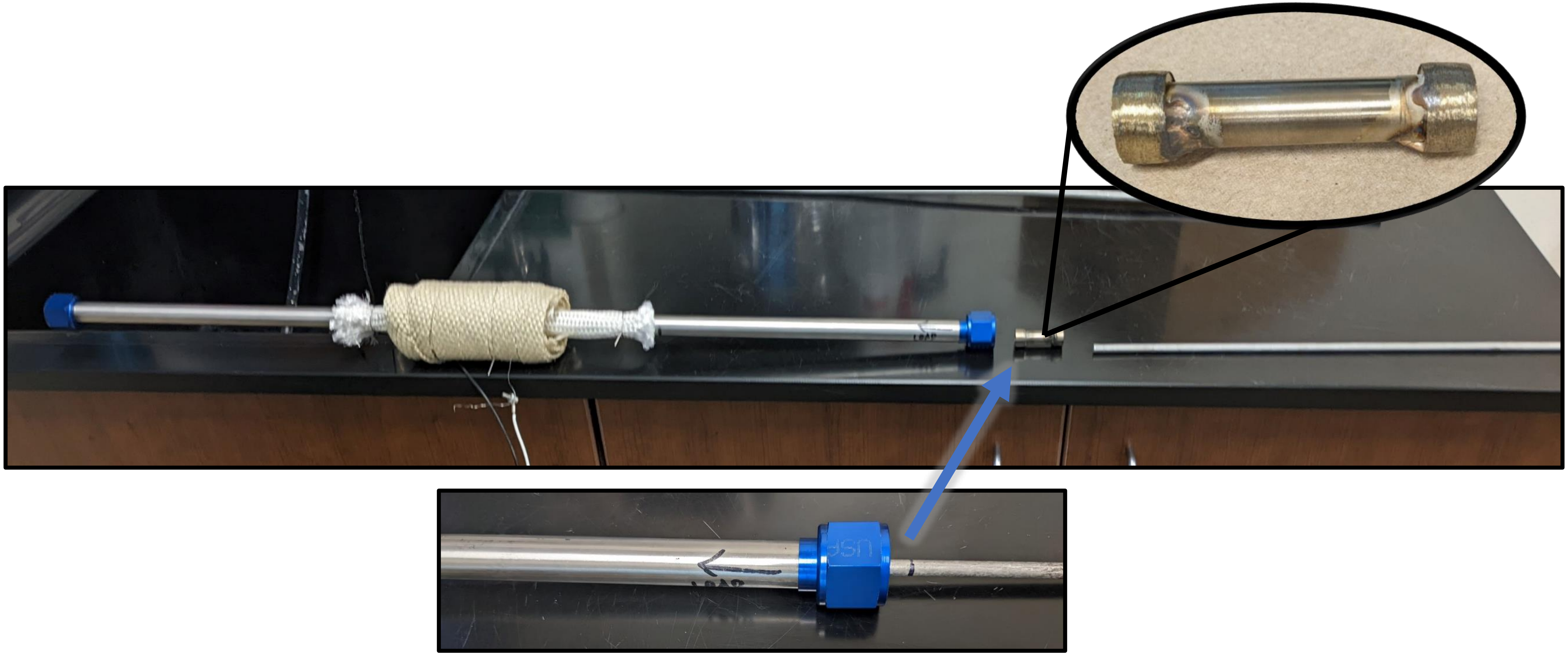
8 Reinsert capsule into pipe using loading rod

9 Turn on electrolysis and flush pipe until light turns on

10 Let fuel cell light turn off, close both valves and turn on heating element

11 Once at 300°C, slowly open exit valve to power fuel cell

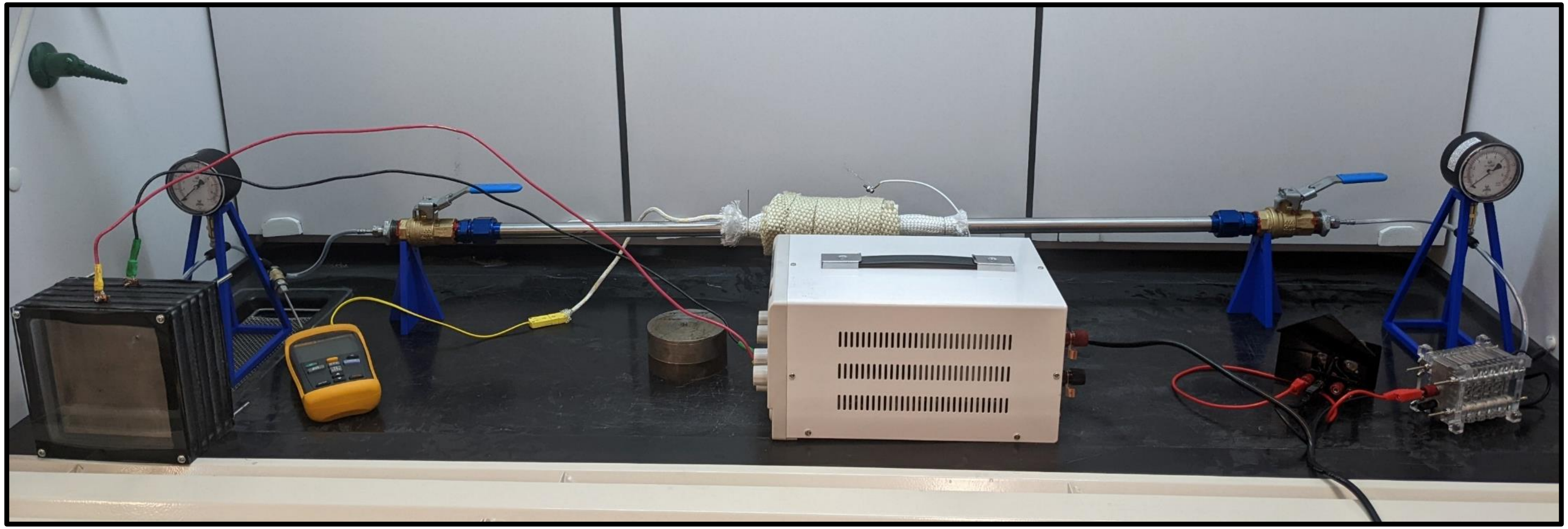
Concept of Operations



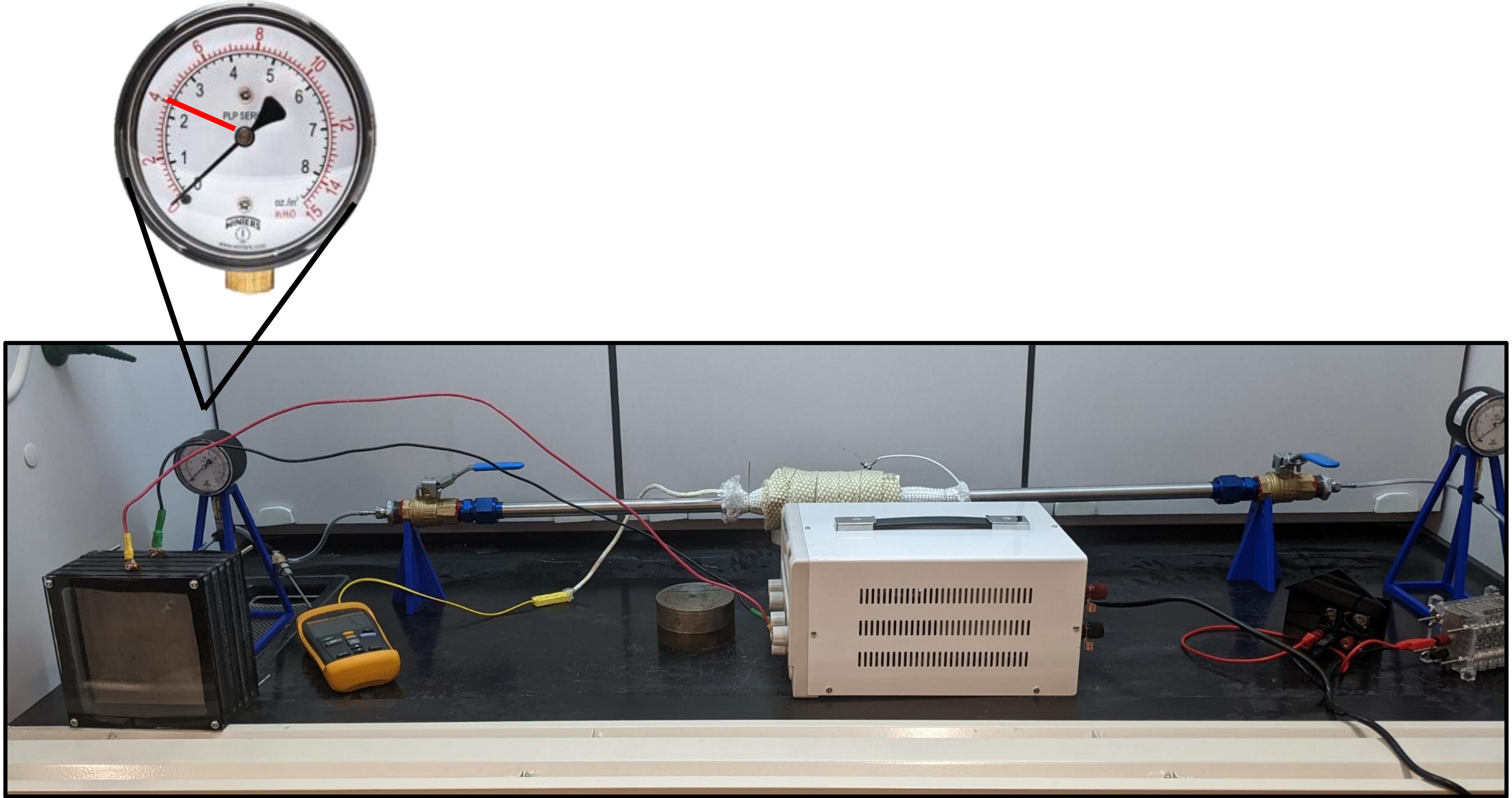
Concept of Operations

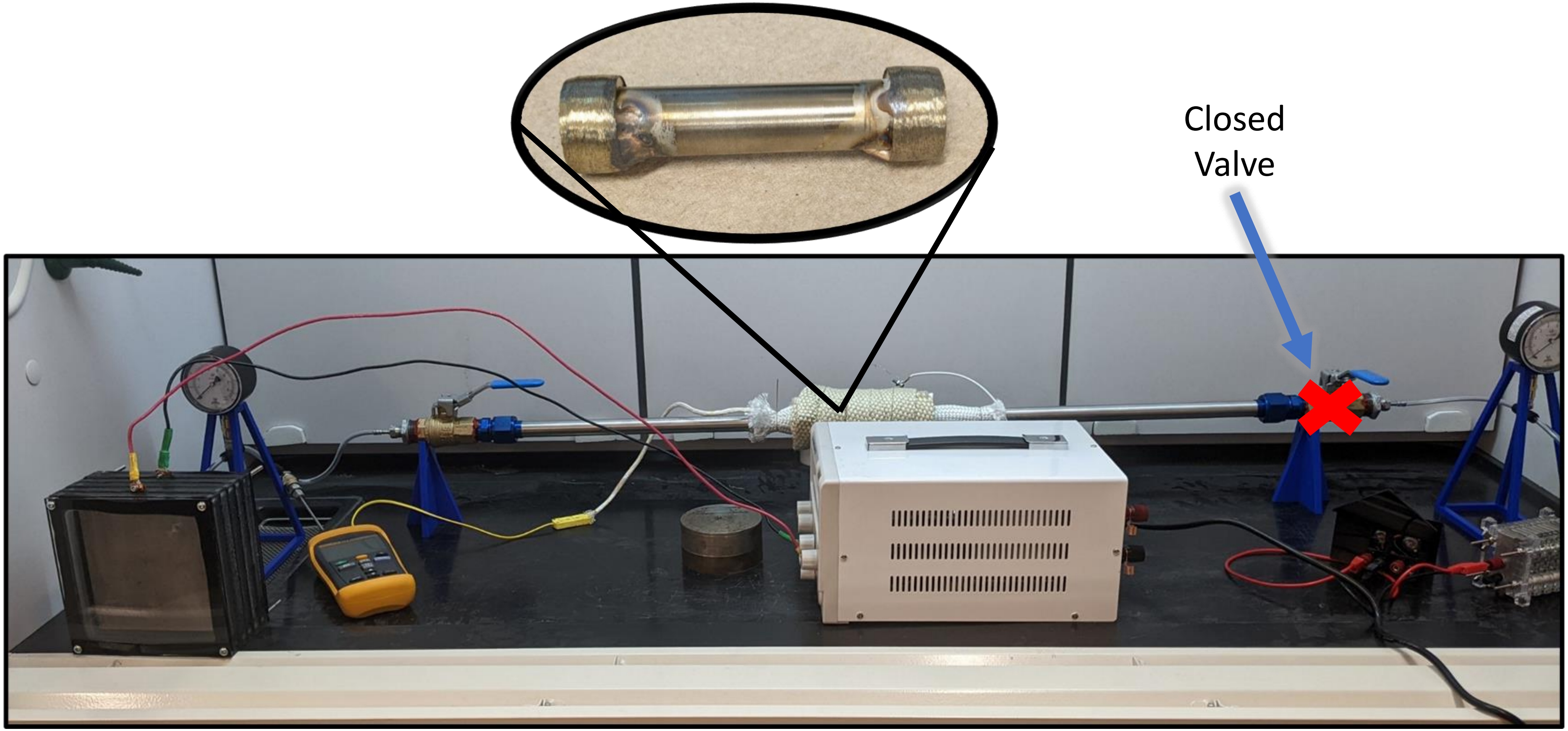
Step 3: Reattach interfaces, ensure all valves are open.

Step 4: Turn on the electrolyzer and run until the fuel cell light turns on.



Concept of Operations




Closed
Valve

ERH$_2$

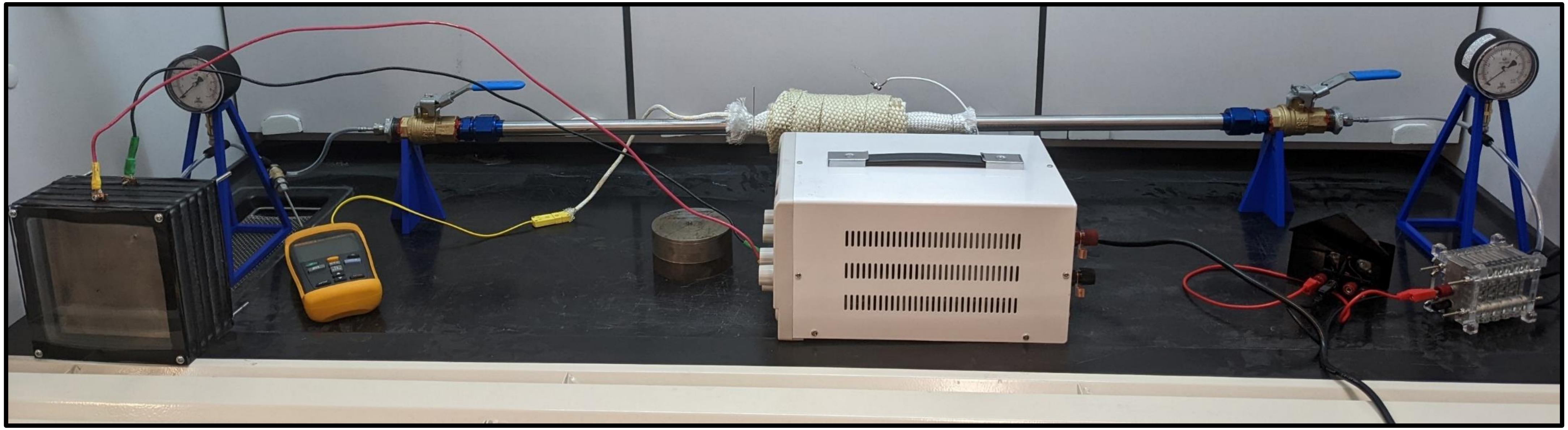
Concept of Operations

Step 7: Turn off electrolyzer, disconnect pipe from valve, remove capsule, and weigh again.

Concept of Operations

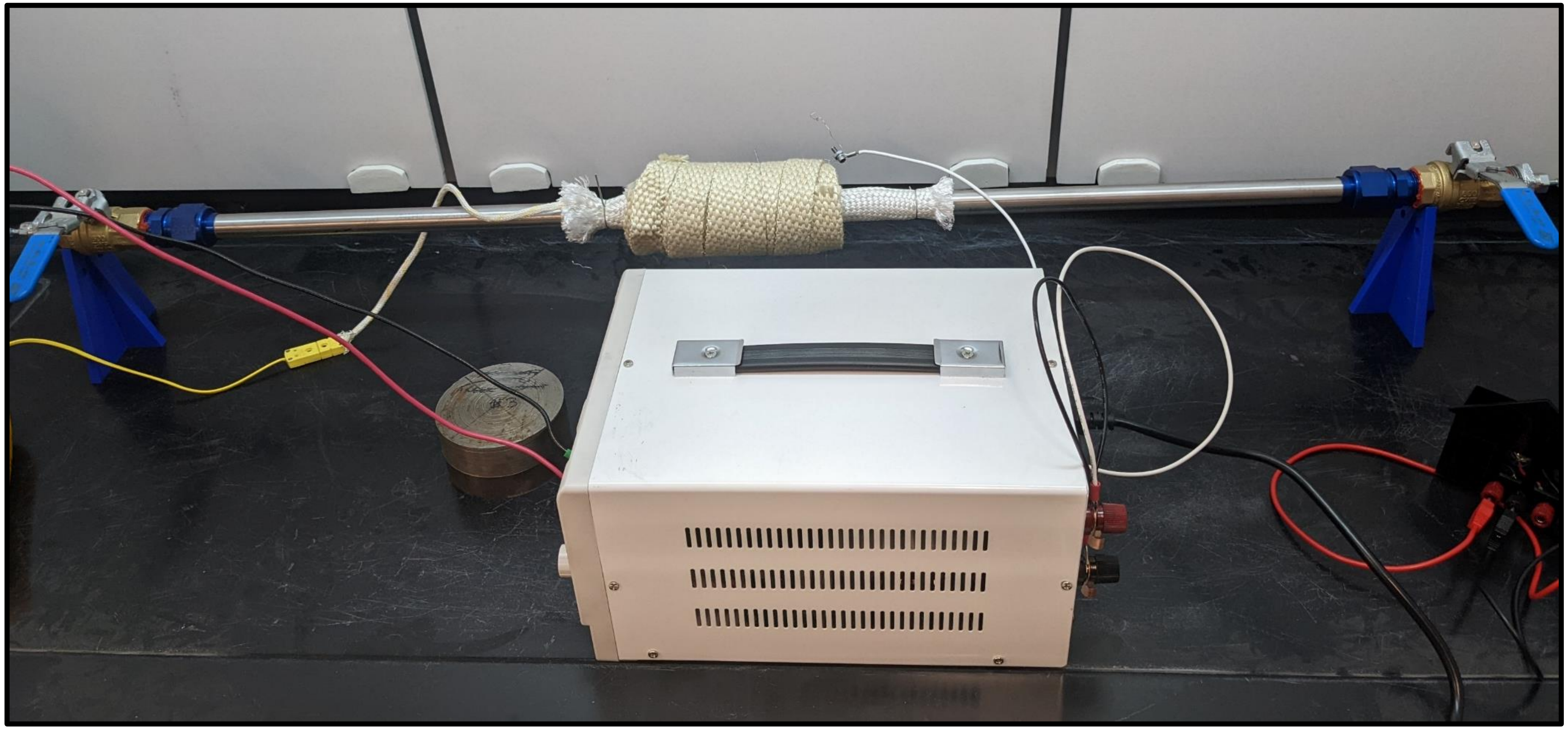
Step 8: Reload capsule into pipe.

Step 9: Run another flush.



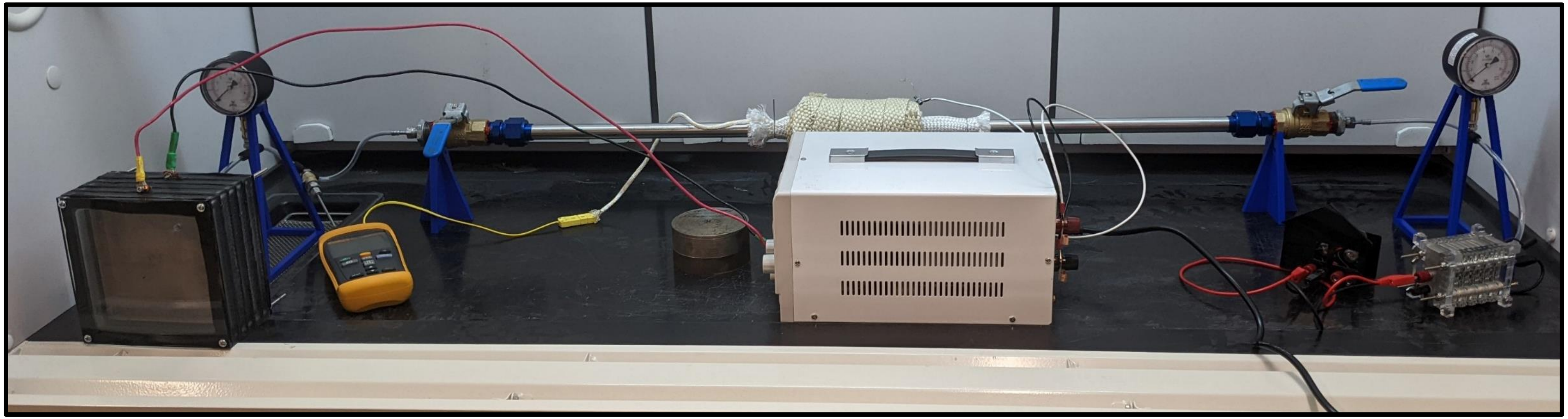
Concept of Operations

Step 10: Close both valves and turn on the heating element.



Concept of Operations

Step 11: Once the capsule reaches 300°C, slowly open the valve to the fuel cell. Start a timer to measure how long the fuel cell light stays on.

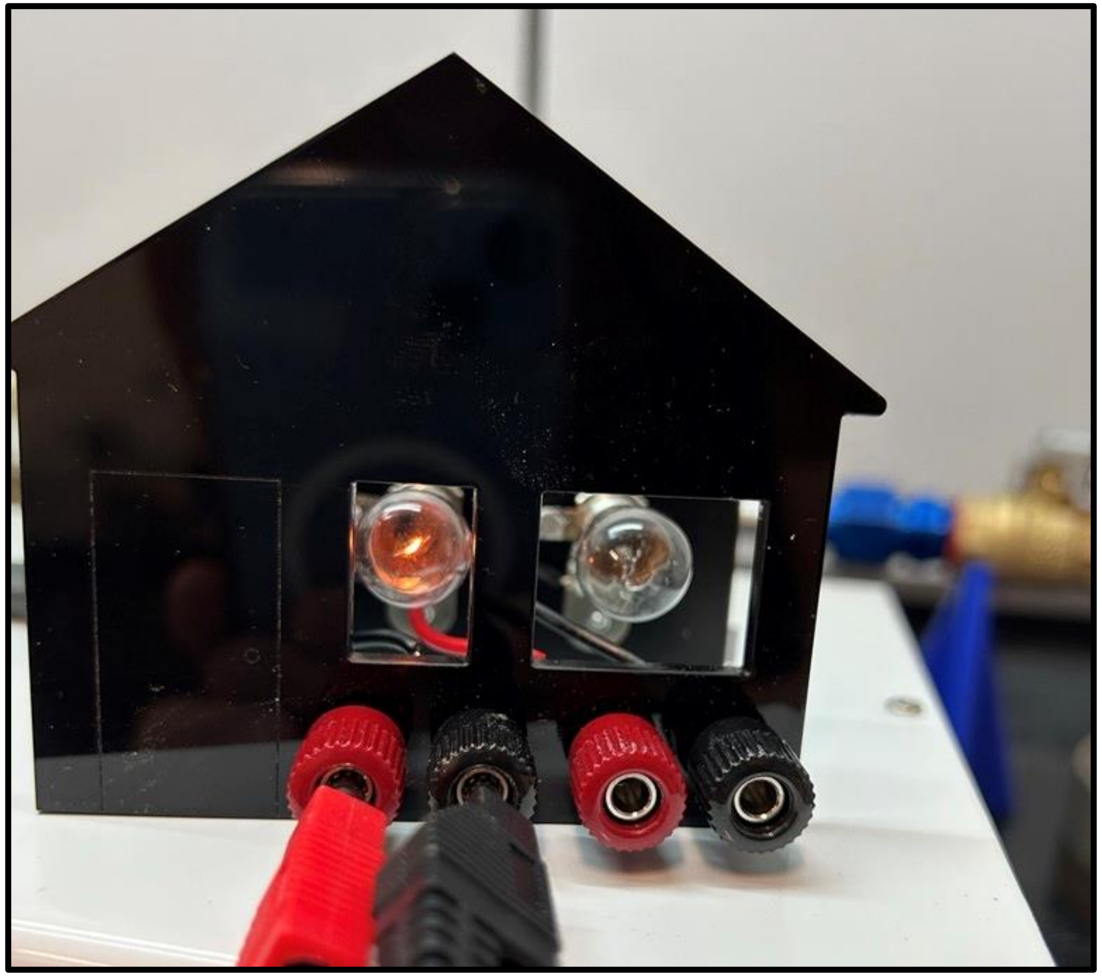


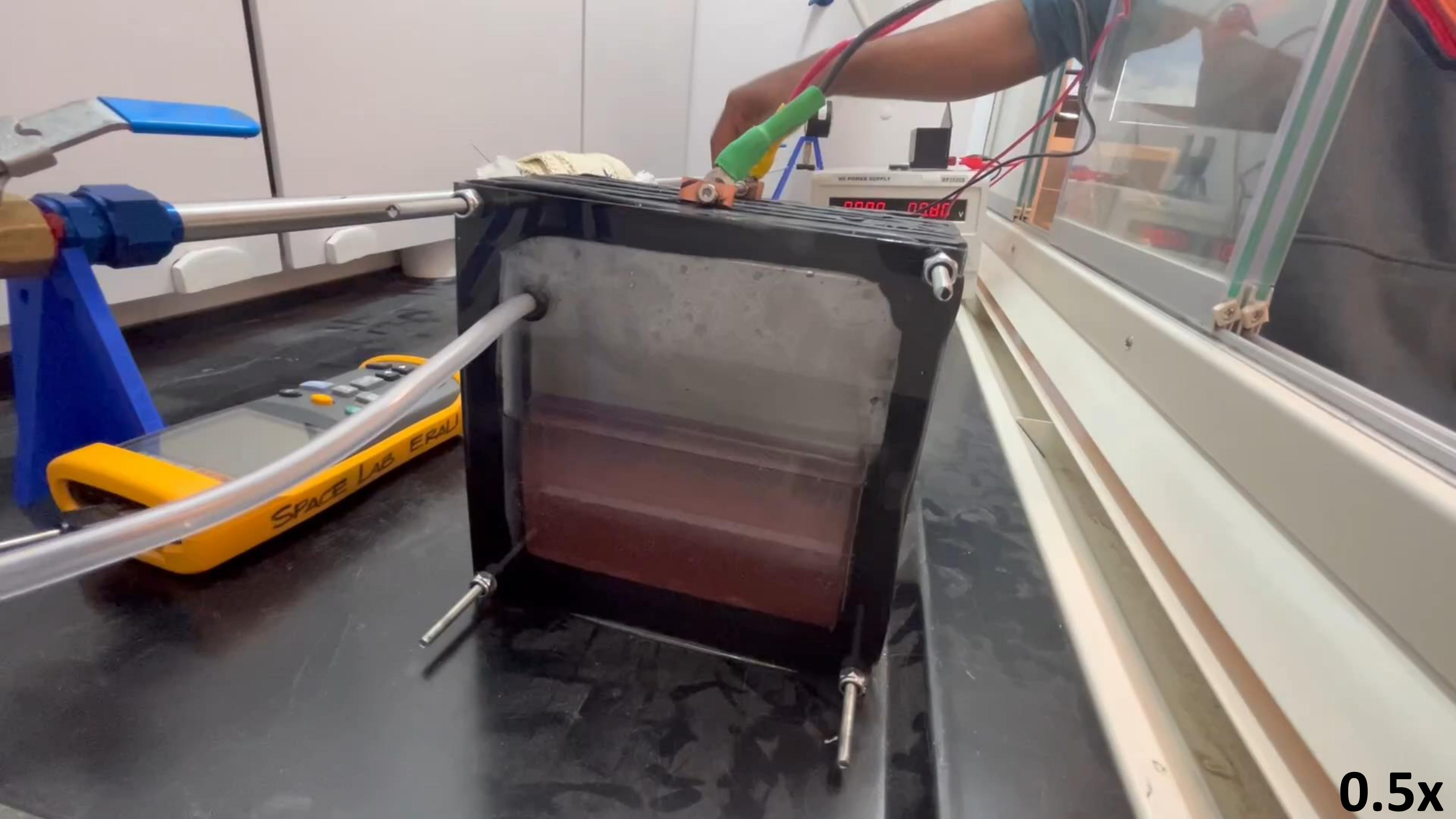
Verification Tests

Production Rate

Requirement 1.1.1
“The system must produce enough hydrogen to get the fuel cell to steady state and then run for 10 minutes at 1 watt.”

☑




SPACE LAB ERAU
0.5x

Material Storage

Starting Mass:
$37.294(g)$

Ran the electrolyzer for 30 minutes.

Ending Mass:
$37.314(g)$

$37.314(g) - 37.294(g) = 0.020(g)$ of hydrogen stored

Material Capacity

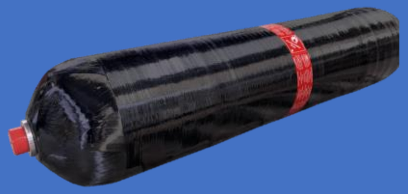
Mass of Stored Hydrogen: 0.020 (g)
Mass of Material Total: 0.517 (g)

$$wt\ \% = \frac{m_1}{m_{tot}} 100\% = \frac{0.020(g)}{0.517(g)} 100\% = 3.87\%$$

Requirement 4.4
"The storage material must have a minimum hydrogen density of 2 wt%."

TEST INCOMPLETE

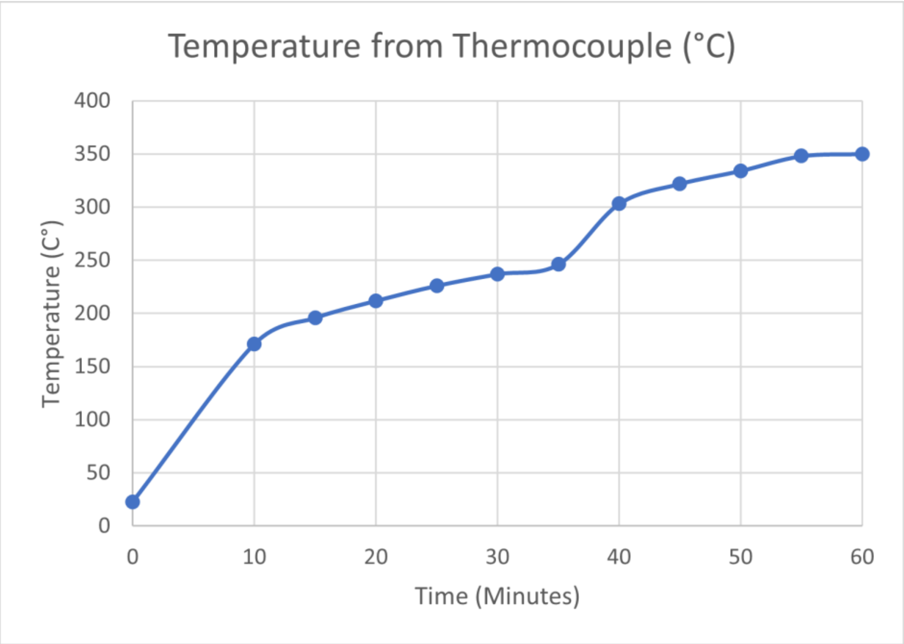
Material Storage Benefits

	Compressed Storage 	Material Storage 
Energy Density	592.9-3796 J/m	140-280 J/m^3
Weight Percentage	3.53%	3.87%
Storage Pressure	60-500 bar	1 bar

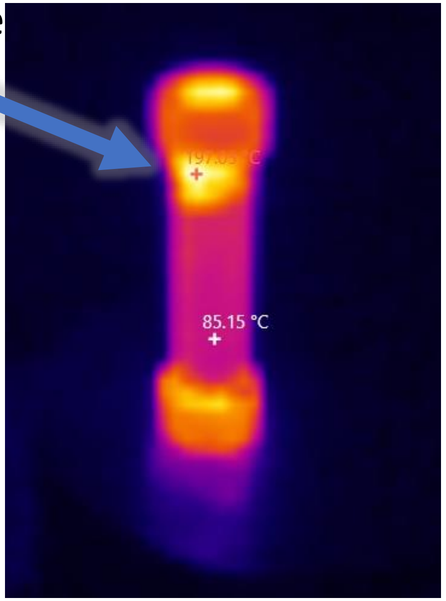
System Heating

Requirement 4.1
"The storage material must be heated to 300°C and not exceed 350°C."

TEST INCOMPLETE



Max Temperature (200°C)



Applied Power

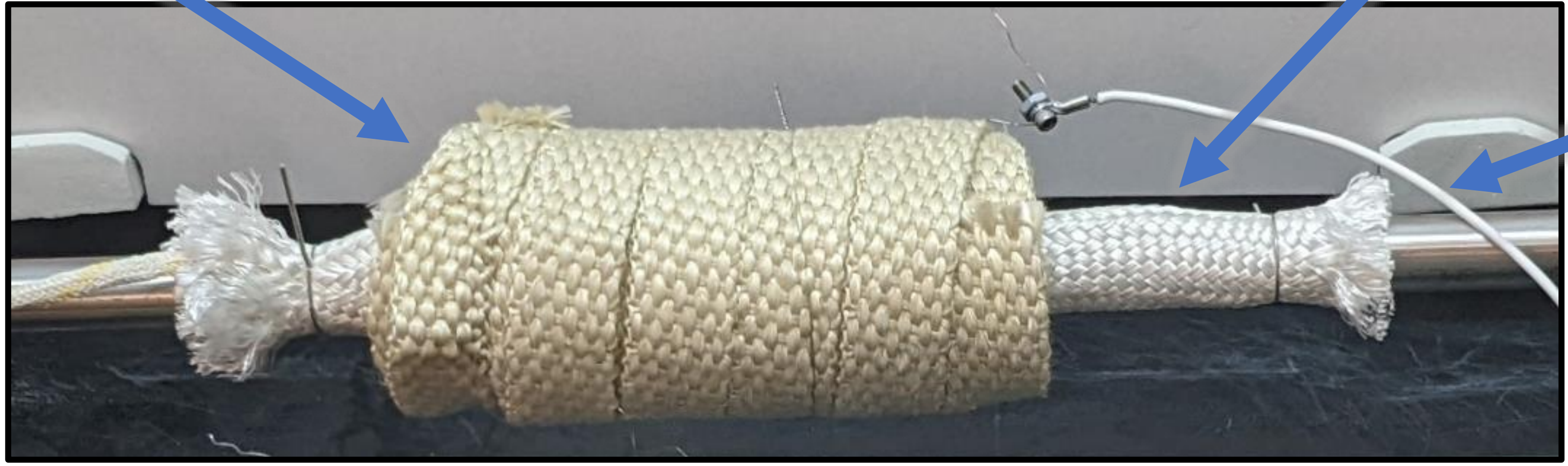
300°C Minimum Power: **16.77W**	350°C Minimum Power: **23.56W**

Thermal Survivability

Aluminum Silicate Fiber
Resistant to 815 °C

Requirement 5.2
"The system must withstand temperatures up to 350°C."

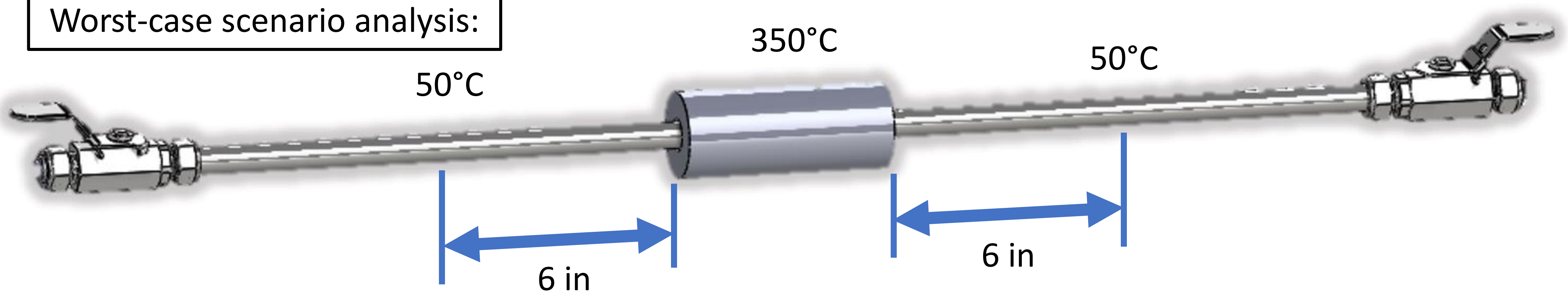
Silica Sleeve
Resistant to 1260 °C



Nichrome Wire Lead

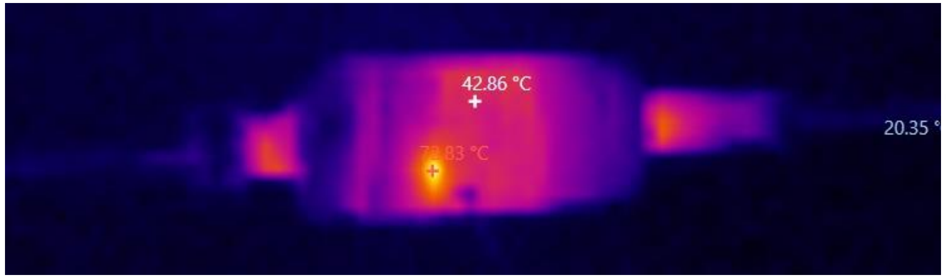
Pipe Heat Transfer

Worst-case scenario analysis:



Worst-case scenario testing:

350°C



Room Temperature (20°C)

Requirement 5.3
"The temperature at the valves must not exceed 50°C."

Number	Requirement	Status
1.1	The system must produce hydrogen gas.	✓
1.1.1	The system must produce enough hydrogen to get the fuel cell to steady state and then run for 10 minutes at 1 watt.	✓
1.1.2	The system must be able to determine the rate of hydrogen gas produced.	✗
1.2	The storage method must run the fuel cell for a minimum of 5 minutes.	⚠
1.2.1	The system must measure the amount of hydrogen stored.	✓
1.3	The system must fit into the STEM 114 vent hood.	✓
1.4	The system must interface with the Embry-Riddle fuel cell.	✓
1.4.1	The system output must be a ¼” PTFE tube.	✓
1.5	The fuel cell must not exceed the pressure of 0.29 psi.	✓
2.1	The system must allow for safe production and extraction of hydrogen gas.	✓
2.2	The system must follow Embry-Riddle Prescott Campus’ safety requirements.	✓
3.1	The system must be able to be dissembled and reassembled to replace parts.	✓
3.2	The machine must not allow the hydrogen and oxygen produced to mix.	✓
3.3	The machine components must not be embrittled by hydrogen.	✓
3.4	The amperage going into the system must be controlled and limited to 22.89 amps.	✓
4.1	The storage material must be heated to 300°C and not exceed 350°C.	⚠
4.2	The storage material must be fully contained within the system.	✓
4.3	The storage material must be at the end of the hydrogen flow.	✓
4.4	The storage material must have a minimum hydrogen density of 2%wt.	⚠
5.1	The subsystem must transport hydrogen gas from the electrolyzer to the material storage, and from the material storage to the fuel cell.	✓
5.2	The system must withstand temperatures up to 350°C.	✓
5.3	The temperature at the valves must not exceed 50°C.	✓
6.1	The instrumentation subsystem must be self-reliant	✓

Limiting Factors

“Murphy always gets a vote.”

- Dr. Michael Fabian

Blown-up Material Storage Capsule

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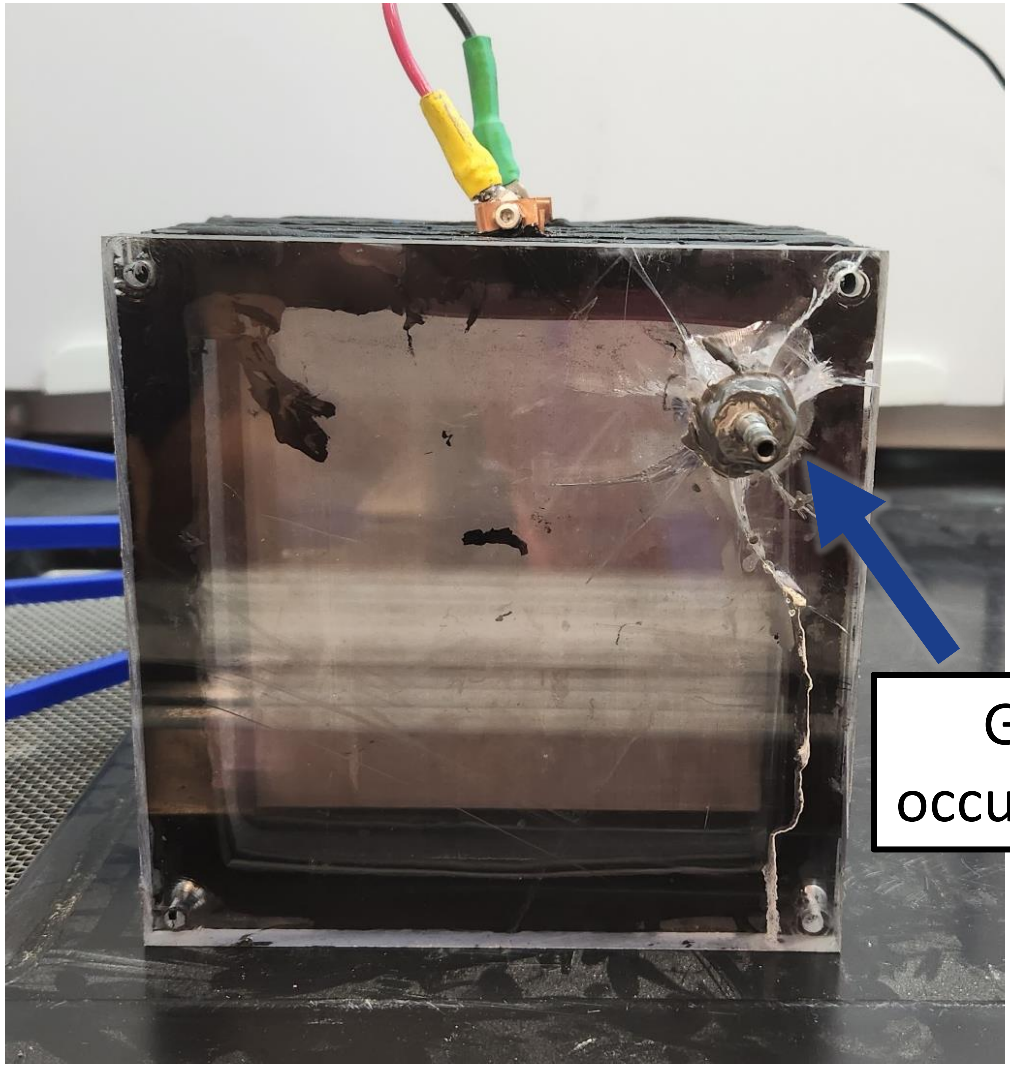
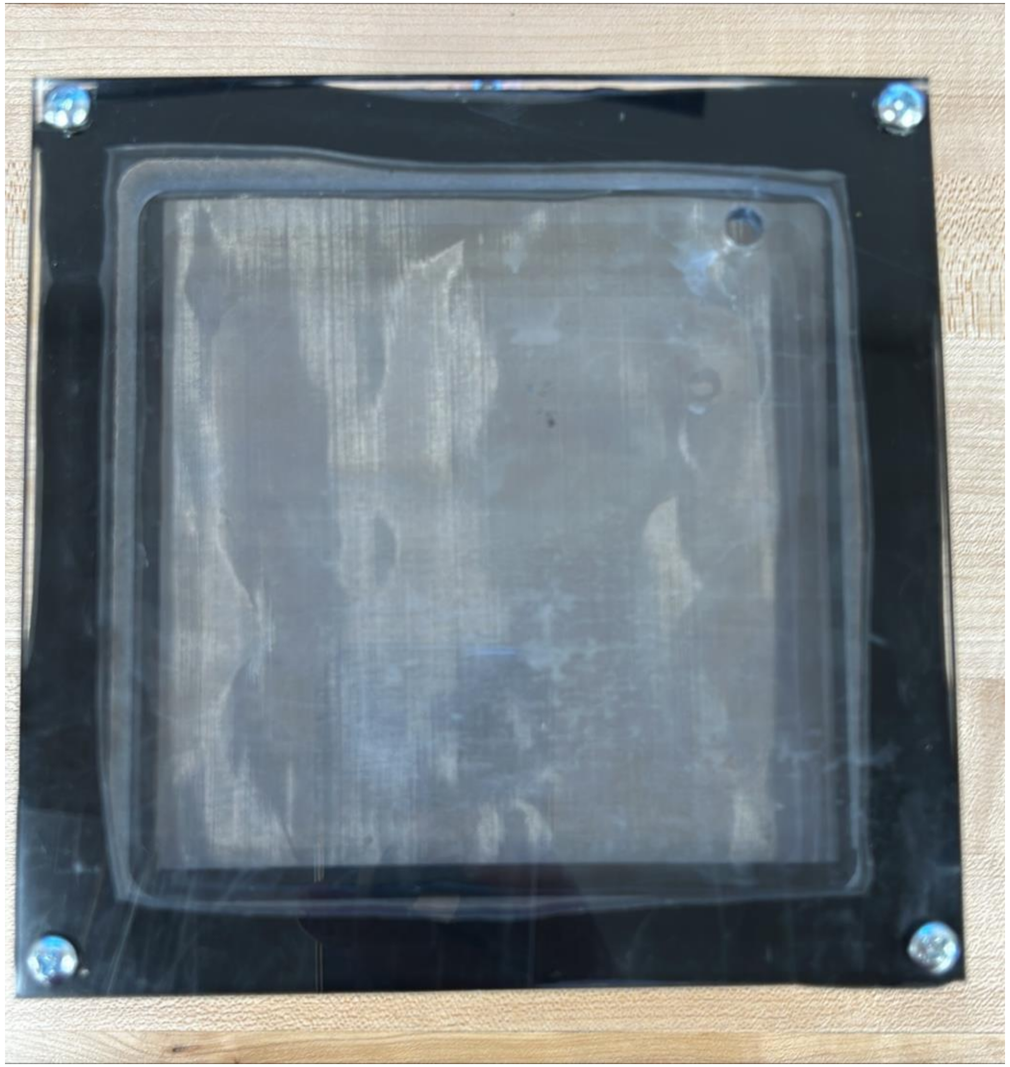
New Material Storage Capsule

Cracked Electrolyzer



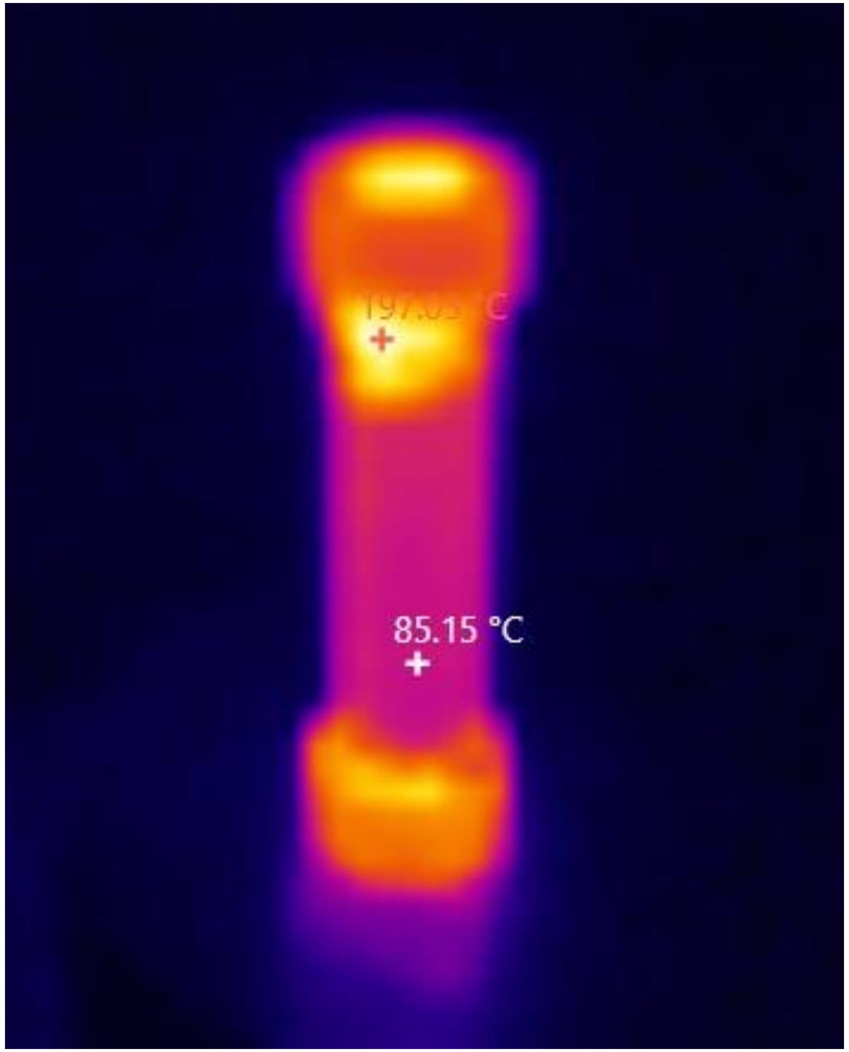
Greatest chemical attack occurs at stress concentrations.

New Electrolyzer End Panels

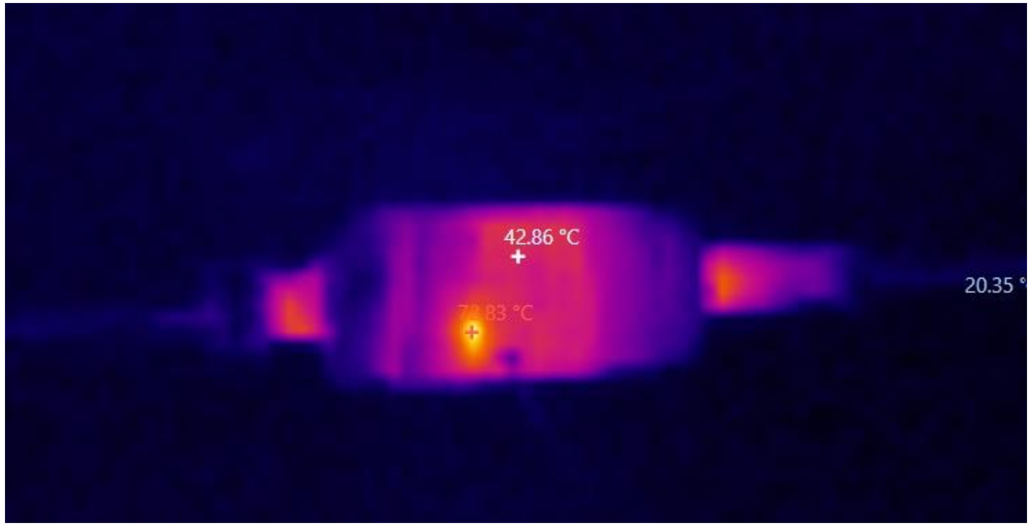


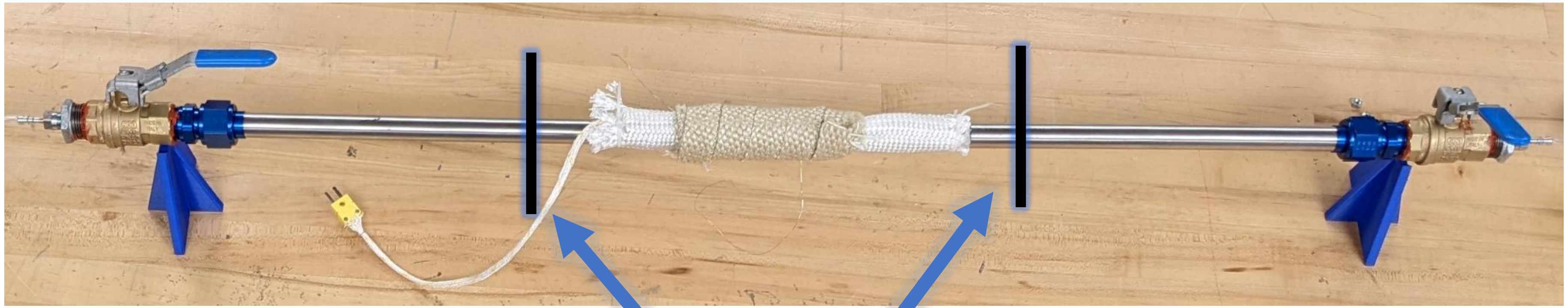
Future Recommendations

Improve Heat Transfer to Capsule



Shorten Pipe

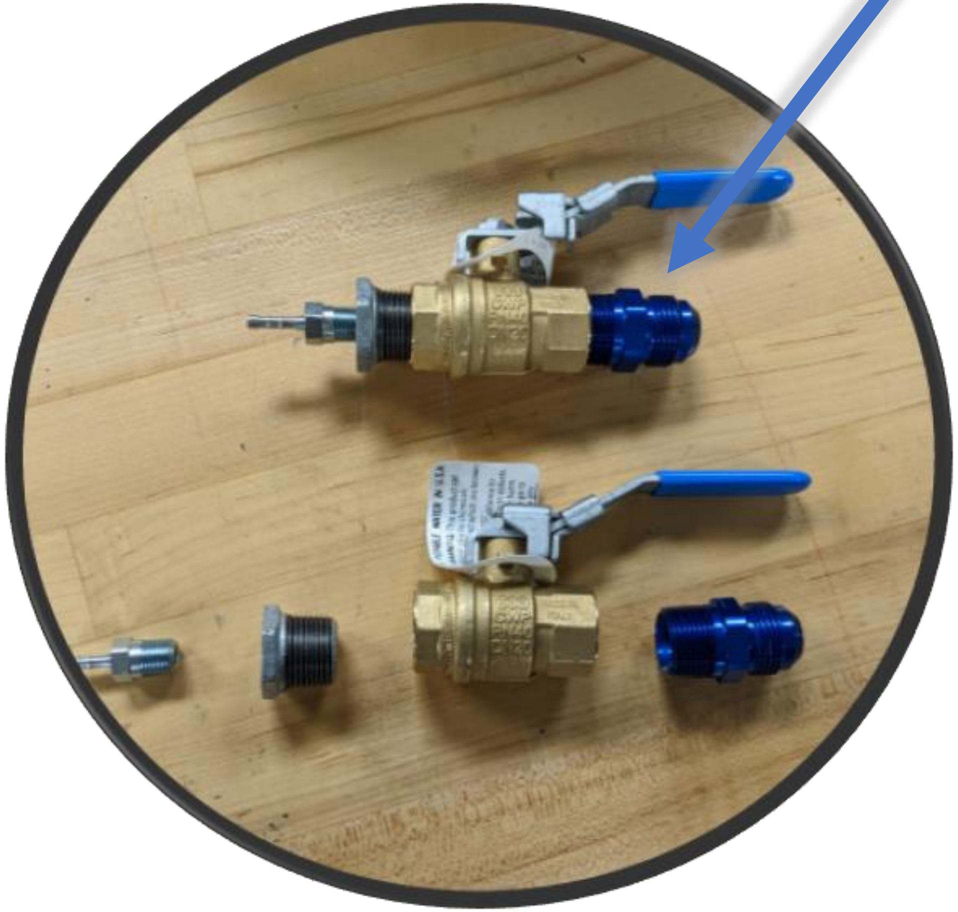




Cut & Reflare

Prevent Hydrogen Leakage

Potential Problem Spots



Future Tests

Capacity Tests

Release Tests

To be performed next Monday

Questions?

References

- [1] A. Murali, M. Sakar, S. Priya, R. J. Bensingh, and M. A. Kader, “Graphitic-Carbon Nitride for Hydrogen Storage,” in Nanoscale Graphitic Carbon Nitride, Elsevier, 2022, pp. 487–514. doi: 10.1016/B978-0-12-823034-3.00017-0.
- [2] “Fast leakage test,” *Unitem Wrocław*, 28-Apr-2022. [Online]. Available: https://unitemmachines.com/our-offer/fast-leakage-test/. [Accessed: 08-Dec-2022].
- [3] “Remington Industries.” [Online]. Available: https://www.remingtonindustries.com/
- [4] “McMaster-Carr.” [Online]. Available: https://www.mcmaster.com/
- [5] https://www.scielo.br/j/qn/a/KyQvF9DMHK6ZJXyL5zQNy7N/?lang=en&format=pdf
- [6] https://www.gichemicals.ie/Potassium-hydroxide.html#:~:text=Potassium%20Hydroxide%20is%20manufactured%20using,concentrated%20to%2050%25%20using%20evaporation.
- [7]“Aluminum silicate fiber felt and board,” *Aluminum Silicate Fiber Felt and Board*. [Online]. Available: https://www.samaterials.com/ceramic-material/2515-aluminum-silicate-fiber-felt-and-board.html. [Accessed: 21-Feb-2023].
- [8] Heat Transfer Textbook

Additional Slides

- Requirements
- Generation
  - Natural Gas
  - Photobiological
  - Microbial Biomass conversion
- Storage
  - Physical
  - Material
- Equations
- Graphic Design
- Schedule
- Ideal Gas

Generation - Natural Gas

Methane Resource

- Methane is collected from a source (usually from natural gas)

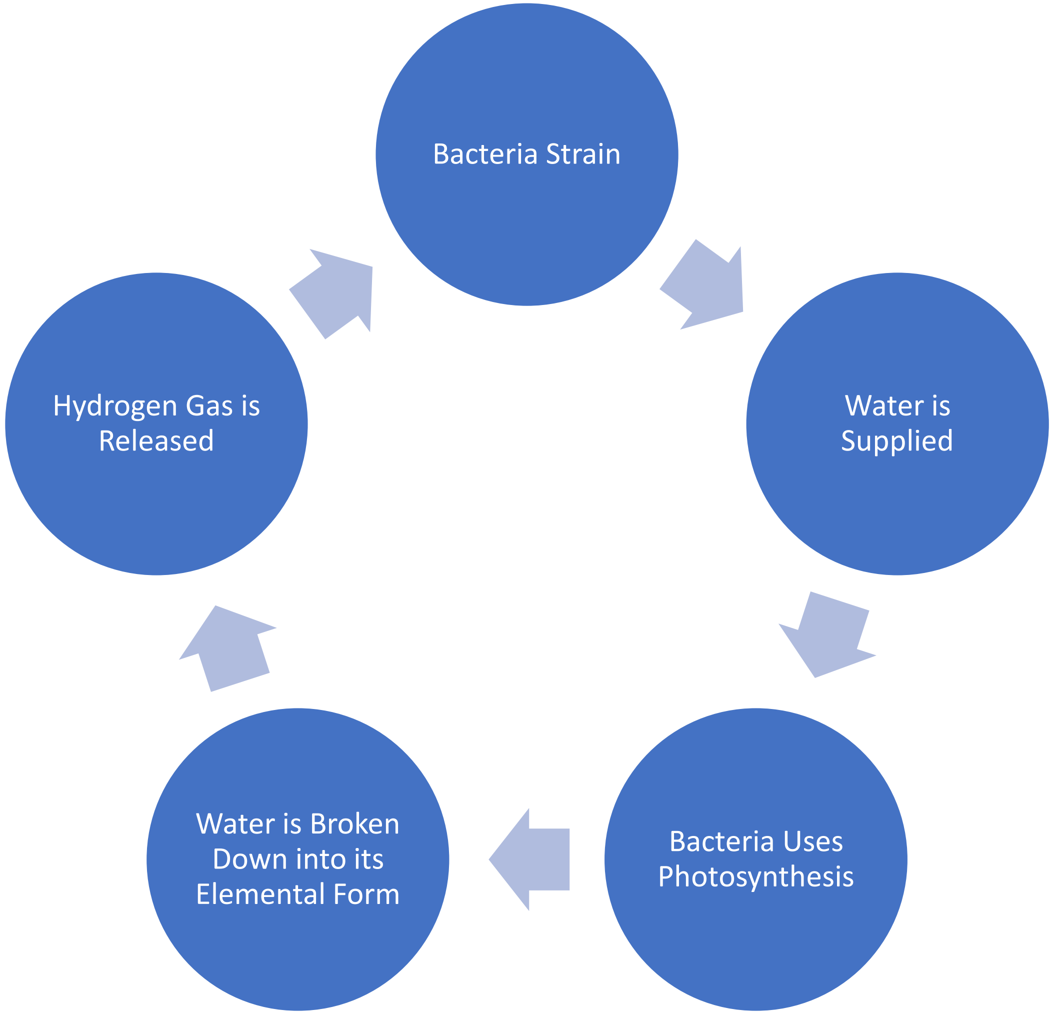
Steam-Methane Reforming

- High temperature steam (at 700-1,000 °C) is added to the methane gas

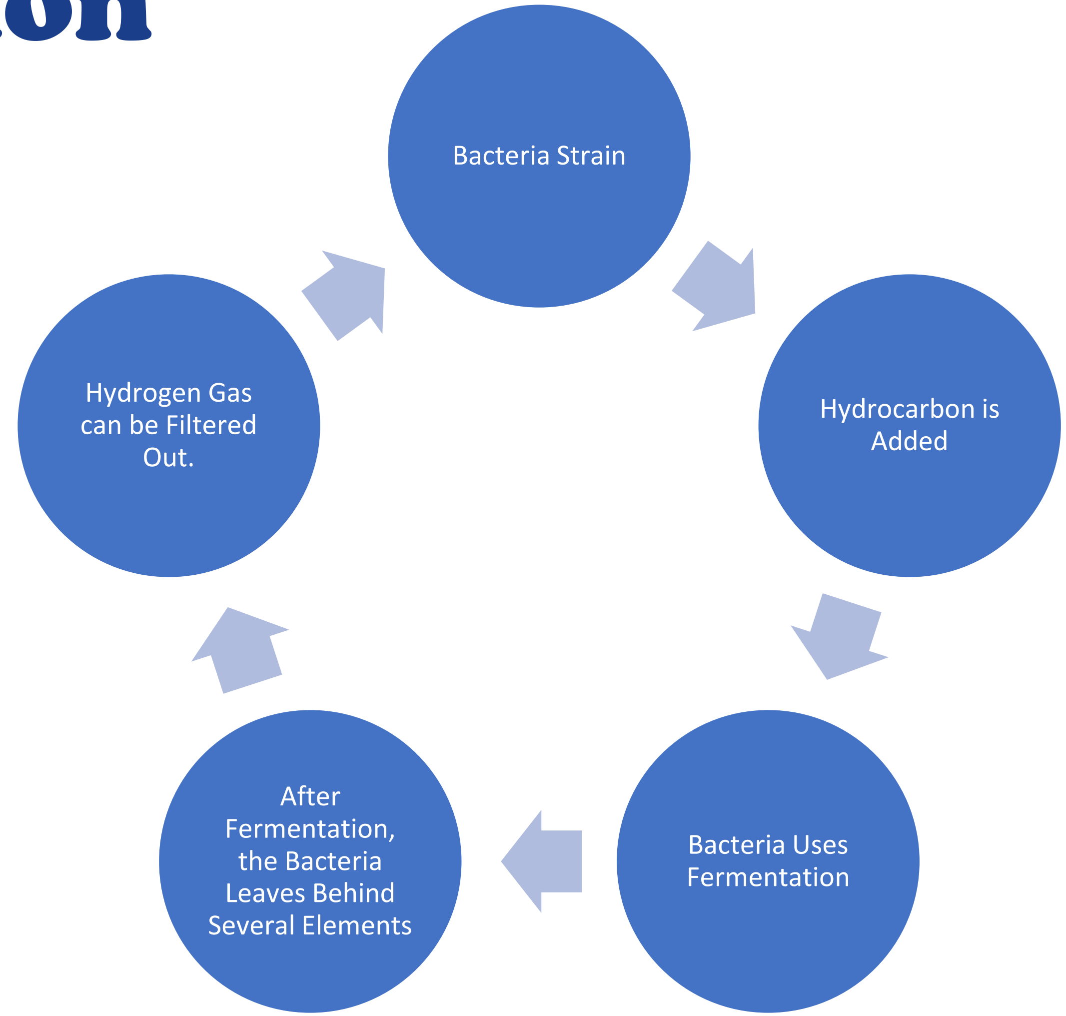
Hydrogen Extraction

- Hydrogen gas is extracted from the steam-methane mix from an added catalyst

Generation - Photobiological



Generation - Microbial Biomass Conversion



Storage – Physical Storage

Compressed

5,000-10,000 PSI

Unique Pressure Vessels

Cryogenic

Liquid H_2 at -252.2 °C

Solid H_2 at -259.14°C

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Storage – Material Storage

Adsorbtion

Hydrogen is Stuck to the Compound's Surface

Absorption

Hydrogen is Encased by the Compound

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Equations – Area of Mesh

$$64\ (in^2) * 0.66 = 42.24\ (in^2)$$

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Equations – Max Current

$$\frac{0.084\ (A)}{1\ (cm^2)} * \frac{1\ (cm^2)}{0.155\ (in^2)} * 42.24\ (in^2) = 22.89\ (A)$$

Equations – Rate of O2 Production

$$\frac{22.89\ (C)}{1\ (s)} * \frac{600\ (s)}{96{,}485\ (C)} * \frac{1\ (mol\ O_2)}{4\ (mol\ e^-)} * \frac{31.998\ (g\ O_2)}{1\ (mol\ O_2)}$$

$$= 1.139\ (g\ O_2)$$

Schedule of Project

- Date tracking Gantt ERH2 (version 1).xlsb.xlsx

Milestone description	Assigned to	Progress	Start	Days
Request for Proposals				
Requirements		100%	8/29/2022	4
Deadlines		100%	8/29/2022	3
Budget		100%	8/29/2022	2
Schedule		100%	8/29/2022	1
Design Concept Review				
Draft		100%	9/20/2022	15
Slide Design Review		100%	10/3/2022	9
Design Concept Proposal				
Front Matter		100%	9/12/2022	10
Similar Systems		100%	9/12/2022	10
Potential Risks		100%	9/12/2022	10
System Concept		100%	9/9/2022	19
Trade Studies		100%	9/20/2022	6
Budget		100%	9/19/2022	7
Energyland Layout		100%	9/27/2022	4
Conclusions		100%	9/12/2022	14
Draft		100%	9/9/2022	26
System Drawings		100%	9/20/2022	6
Schedule		100%	9/12/2022	13
Preliminary Design Review				

Ideal Gas Law

$PV = nRT$

Where:

P = Absolute pressure of the gas (KPa)
V = Volume of the gas (L)
n = Amount of the gas (g)
R = Ideal gas constant (KJ/Kg*K)
T = Absolute temperature of the gas (K)

Calculations

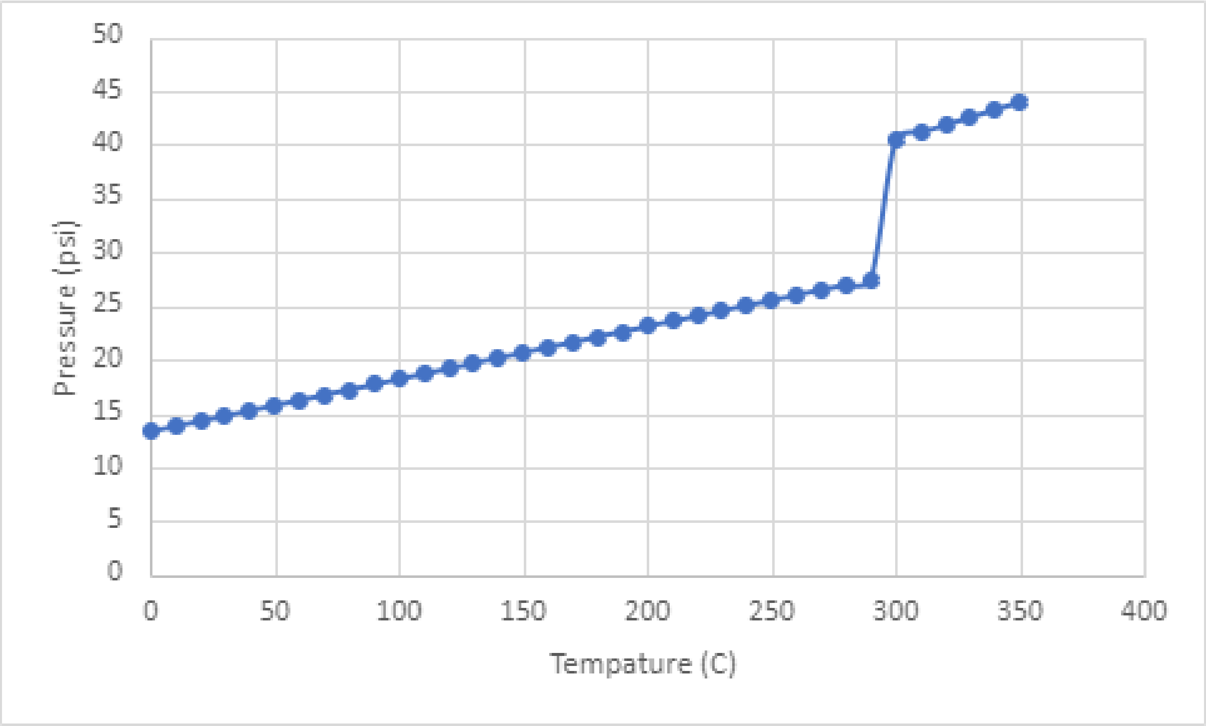
Heat Loss / Required Power

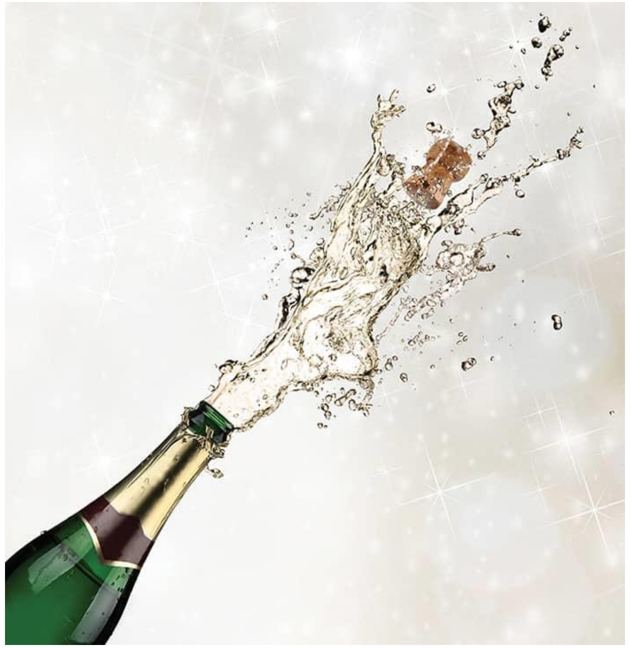
Outer Diameter:	0.75	0.75	(in)
Inner Diameter:	0.68	0.68	(in)
Thermal Conductivity	20	20	(W/m*K)
Surface Temperature	350	50	(°C)
Outer Diameter	0.01905	0.01905	(m)
Gravitational Constant	9.81	9.81	(m/s^2)
Bulk Temperature	20	20	(°C)
Volume Expansion Coefficie	2.18E-03	3.27E-03	(K^-1)
Kinematic Viscosity	3.26E-05	1.66E-05	(m^2/s)
Grashof Number	4.59E+04	2.43E+04	
Prandtl	0.69884	0.7268	
Rayleigh	3.21E+04	1.76E+04	
*Rayleigh < 10^12, we can use the book's equation!			
Nusselt Number	5.80E+00	5.03E+00	
Thermal Conductivity	0.036726	0.02625	(W/m*K)
Convection Coefficient	1.12E+01	6.93E+00	(W/m^2*K)
Inner Diameter	0.017272	(m)	
Perimeter	0.05984734	(m)	
Cross-sectional Area	5.07214E-05	(m^2)	
Thermal Conductivity	381.62	395.5433071	(W/m*K)
x	11		
Convection Coefficient, Avg	9.06E+00	(W/m^2*K)	
Thermal Conductivity, Avg	20	(W/m*K)	
m	2.31E+01		
cosh^-1(x)	3.088969905		
Length	1.34E-01	(m)	
Qdot through Fin	7.71E+00	(W)	

Outer Diameter:	0.75	0.75	(in)
Inner Diameter:	0.68	0.68	(in)
Thermal Conductivity	20	20	(W/m*K)
Surface Temperature	300	50	(°C)
Outer Diameter	0.01905	0.01905	(m)
Gravitational Constant	9.81	9.81	(m/s^2)
Bulk Temperature	20	20	(°C)
Volume Expansion Coefficient	2.18E-03	3.27E-03	(K^-1)
Kinematic Viscosity	3.26E-05	1.66E-05	(m^2/s)
Grashof Number	3.89E+04	2.43E+04	
Prandtl	0.69884	0.7268	
Rayleigh	2.72E+04	1.76E+04	
*Rayleigh < 10^12, we can use the book's equation!			
Nusselt Number	5.57E+00	5.03E+00	
Thermal Conductivity	0.036726	0.02625	(W/m*K)
Convection Coefficient	1.07E+01	6.93E+00	(W/m^2*K)
Inner Diameter	0.017272	(m)	
Perimeter	0.05984734	(m)	
Cross-sectional Area	5.07214E-05	(m^2)	
Thermal Conductivity	381.62	395.5433071	(W/m*K)
x	9.333333333		
Convection Coefficient, Avg	8.83E+00	(W/m^2*K)	
Thermal Conductivity, Avg	20	(W/m*K)	
m	2.28E+01		
cosh^-1(x)	2.92385707		
Length	1.28E-01	(m)	
Qdot through Fin	6.45E+00	(W)	

Vessel Pressure

- Maximum Vessel Pressure: 40.43psia
  - Champagne Bottle: 90psia
  - Soda Can: 30psia





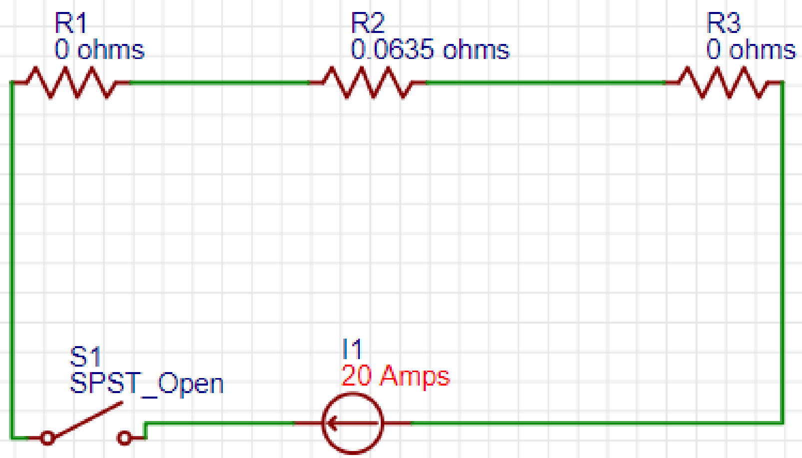
Electrolysis Power Circuit

R1 = R3

- Nickel Mesh

R2

- Salt Water



ERH$_2$

Risk Matrix – Before Mitigation

Asset or Operation at Risk	Hazard	Scenario	Opportunities for Prevention or Mitigation	Probability	Overall Hazard Rating
Overall System	Explosion	Hydrogen Leak, normal operation	Sealant	Seldom	2B
Electrolysis	Electrocution	Short Circuit	Insulator	Seldom	2C
Electrolysis	Fire	Excess Oxygen	Planned Dispersion	Seldom	2B
Electrolysis	Ozone	Ozone production	Capture	Improbable	1C
Heating Element	Burns	Contact with Heating Element	Warning Sign	Occasional	3C

Risk Probability	Risk Severity				
	Catastrophic A	Critical B	Moderate C	Minor D	Negligible E
5 – Frequent	5A	5B	5C	5D	5E
4 – Likely	4A	4B	4C	4D	4E
3 - Occasional	3A	3B	3C	3D	3E
2 – Seldom	2A	2B	2C	2D	2E
1 – Improbable	1A	1B	1C	1D	1E

Detecting Leaks

ERH2 will follow ASHRAE Bubble Method under Chapter 29.9 Leak Detection in the 2017 edition ASHRAE Handbook.

[2]