ERH2

EMBRY-RIDDLE HYDROGEN

Electrolysis and Material Storage of Hydrogen Gas

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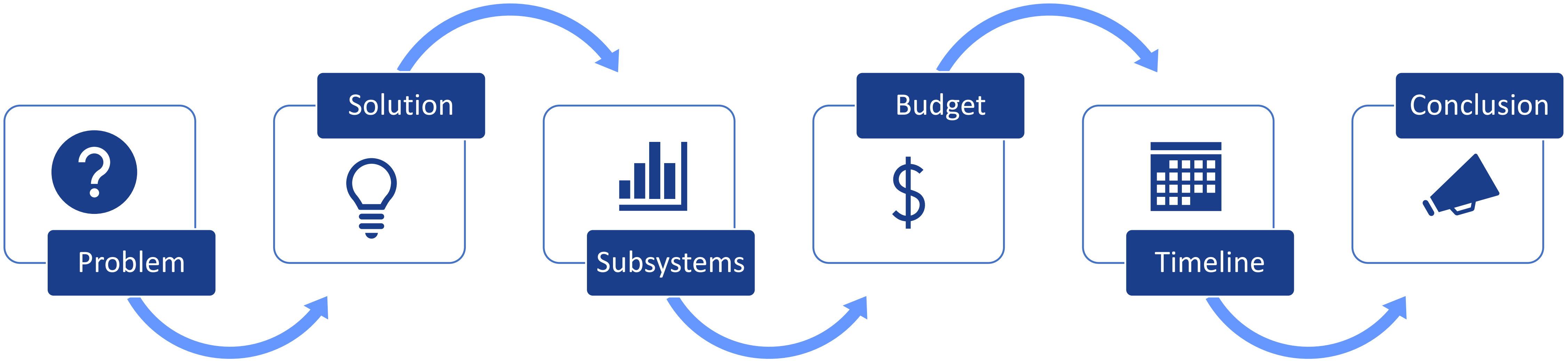
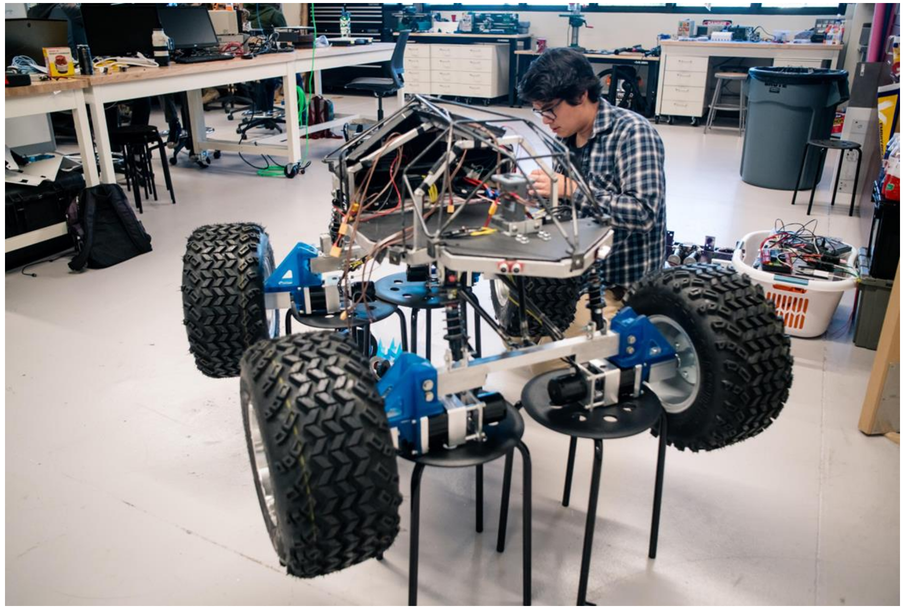
Agenda



What Embry-Riddle Has

Wind Tunnel



Robotics Lab

Propulsion Lab

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Embry-Riddle Needs Hydrogen Energy Demonstrators

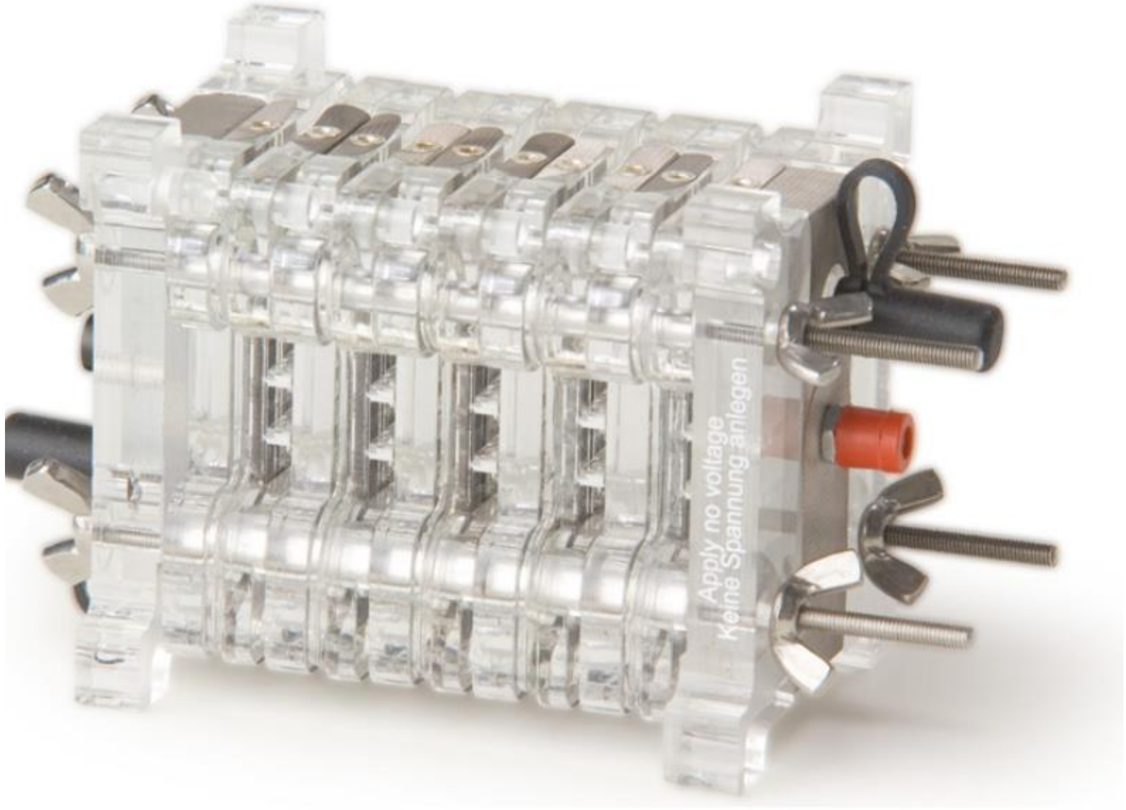
Develop Energy Labs

Create Interest in the Energy Track

Viewable Demonstrations for Visitors

Generate and Store Hydrogen

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



Embry-Riddle's Fuel Cell

Hydrogen Storage Applications

Personal Vehicles (Toyota Mirai)

Commercial Vehicles (Toyota)

Aircraft (Airbus)

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

ERH$_2$

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

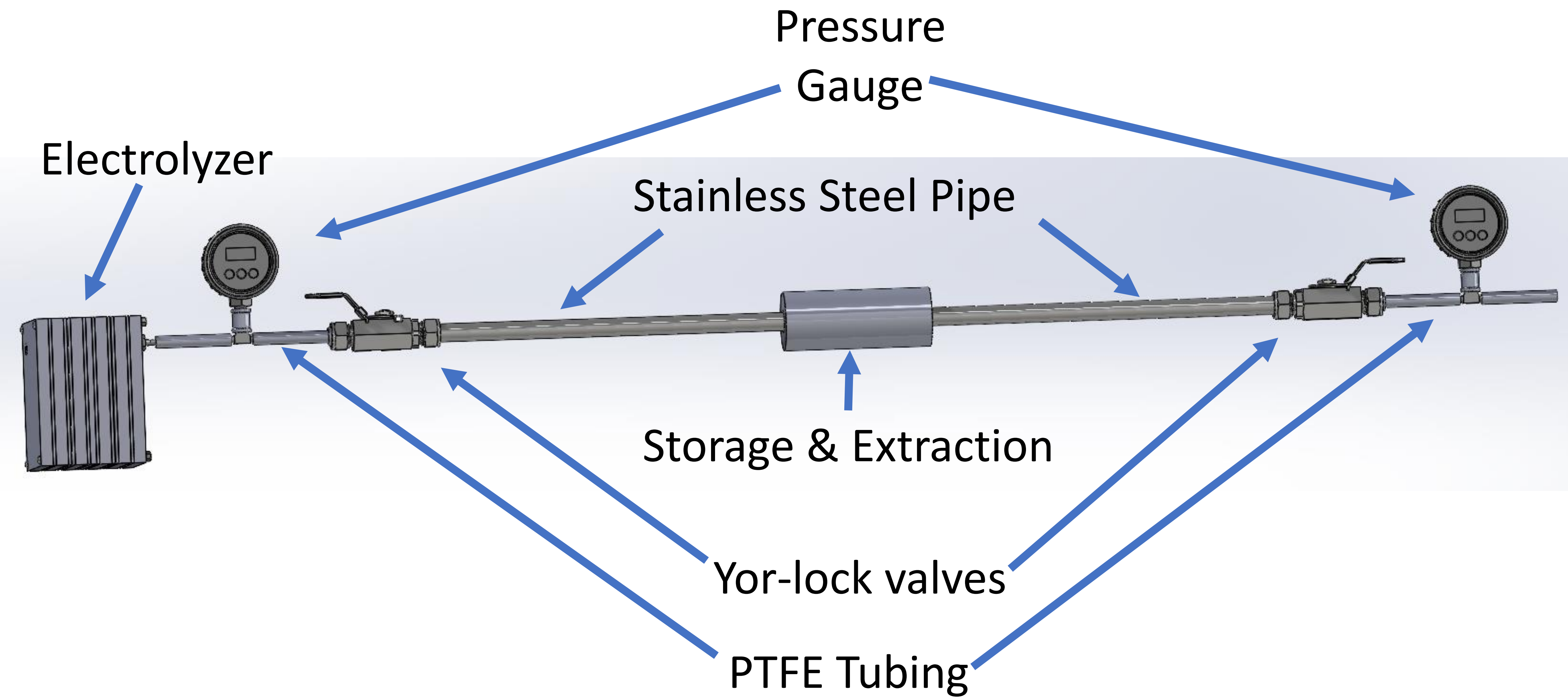
1.4 The system must interface with the Embry-Riddle fuel cell.

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

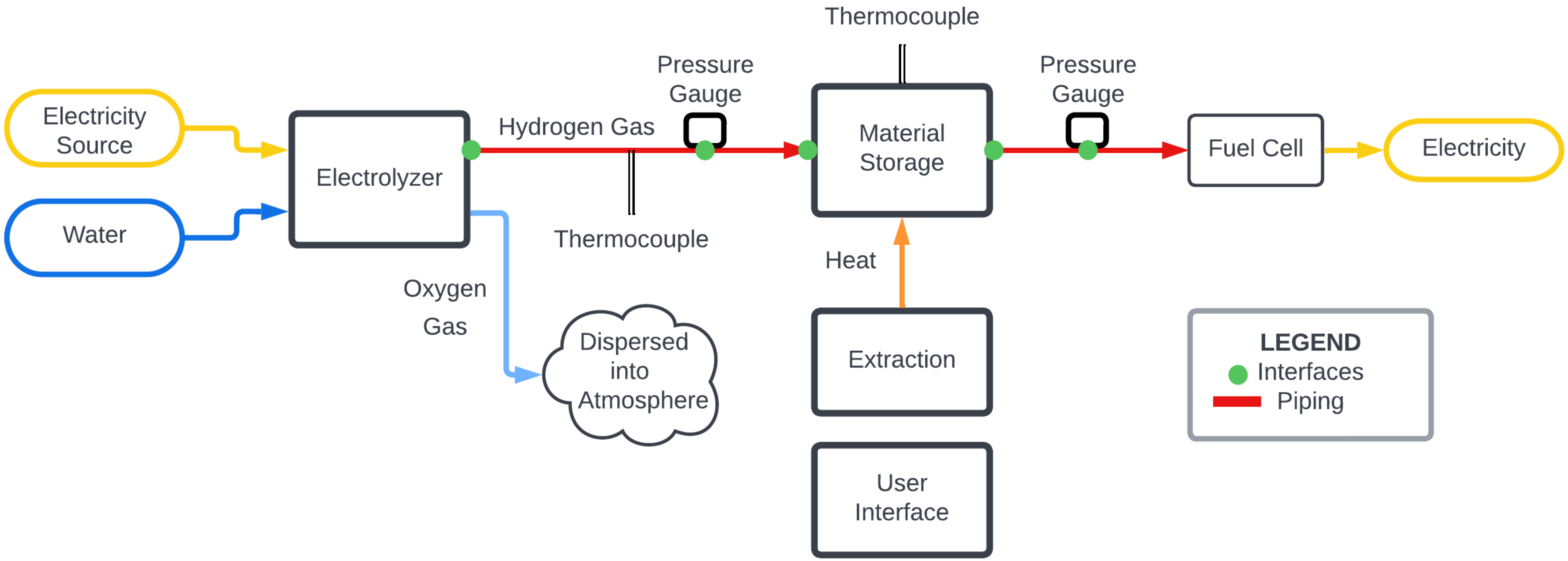
Energy Demonstrator

1.3 The system must fit into a 45"x25" box.

ERH2 Proposed System



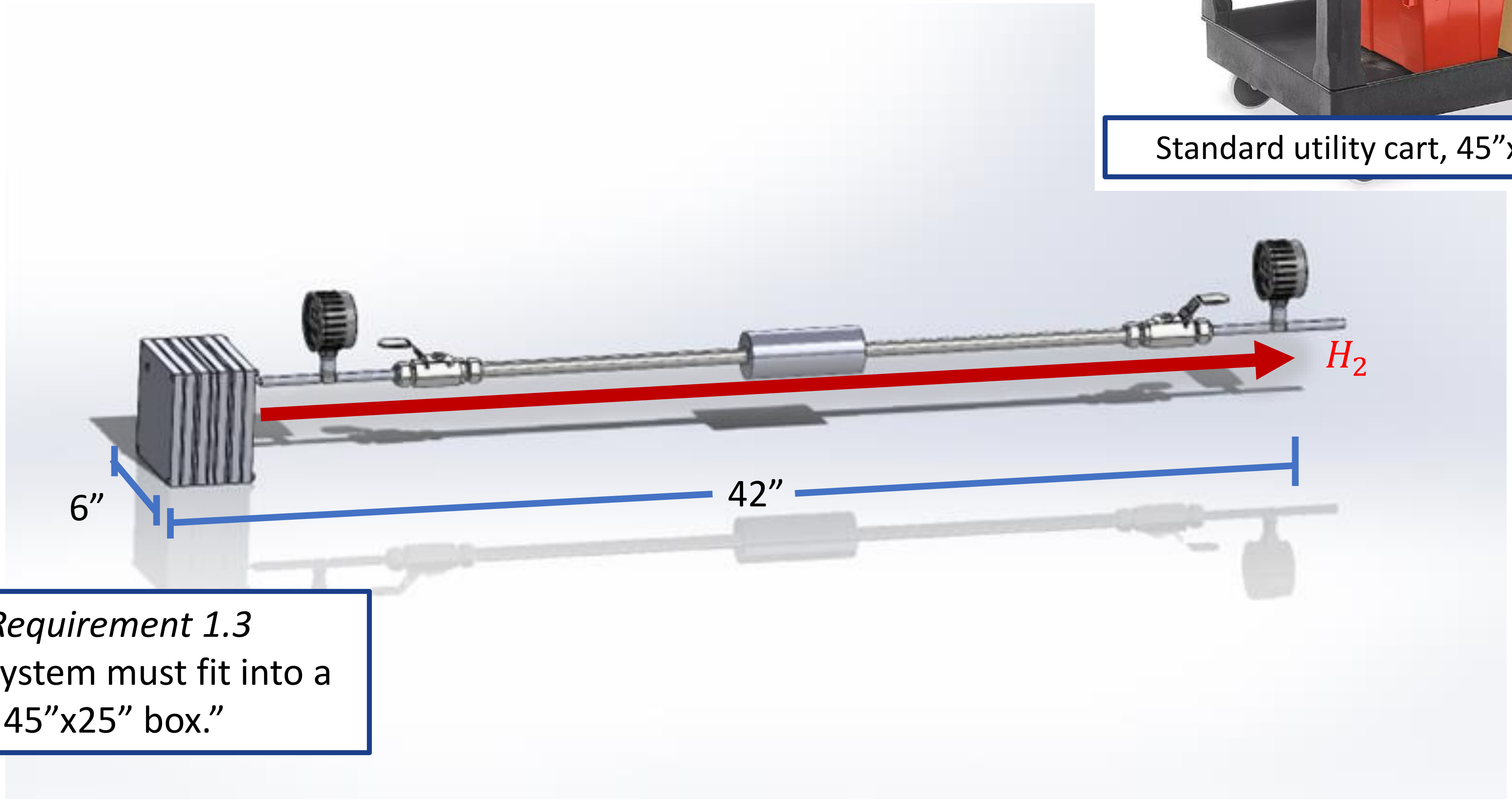
Process Flow Diagram



Simplified PFD

The ERH2 System

Standard utility cart, 45”x25” top shelf



Requirement 1.3
“The system must fit into a 45”x25” box.”

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Concept of Operations

1. Weigh material storage capsule
2. Load material storage capsule into pipe using loading rod
3. Attach yor-lock valve 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

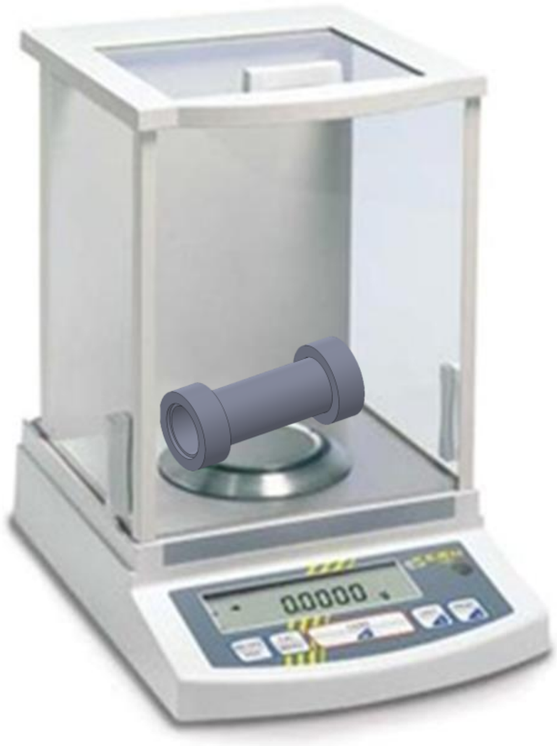
ERH$_2$

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 300C, slowly open exit valve to power fuel cell

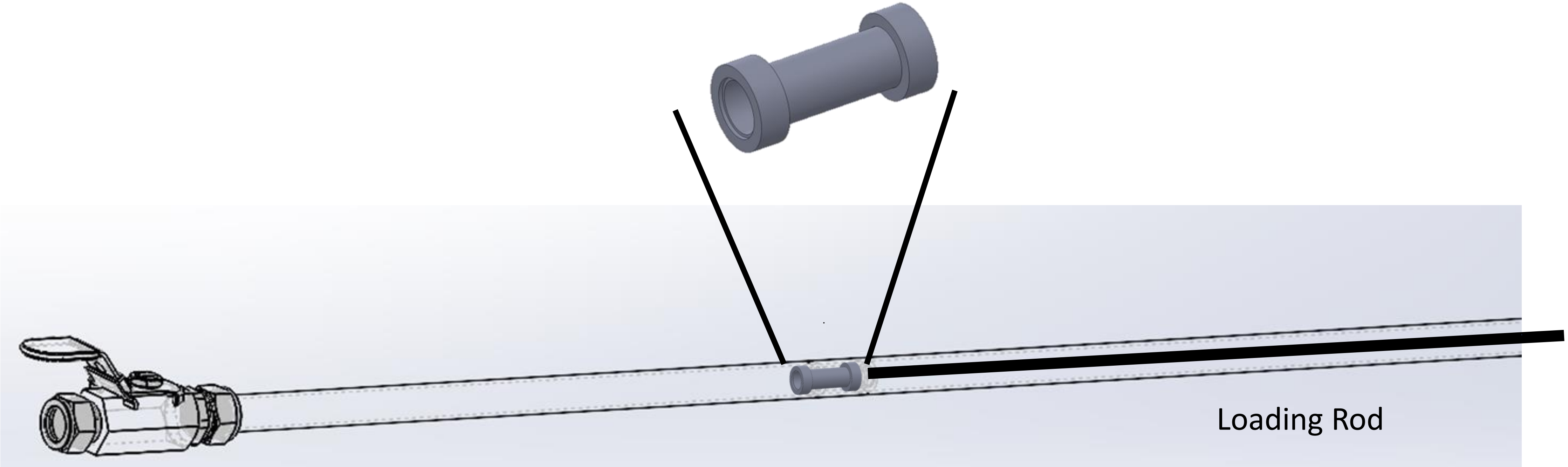
Concept of Operations

Step 1: Weigh the material storage capsule using scale and record mass.



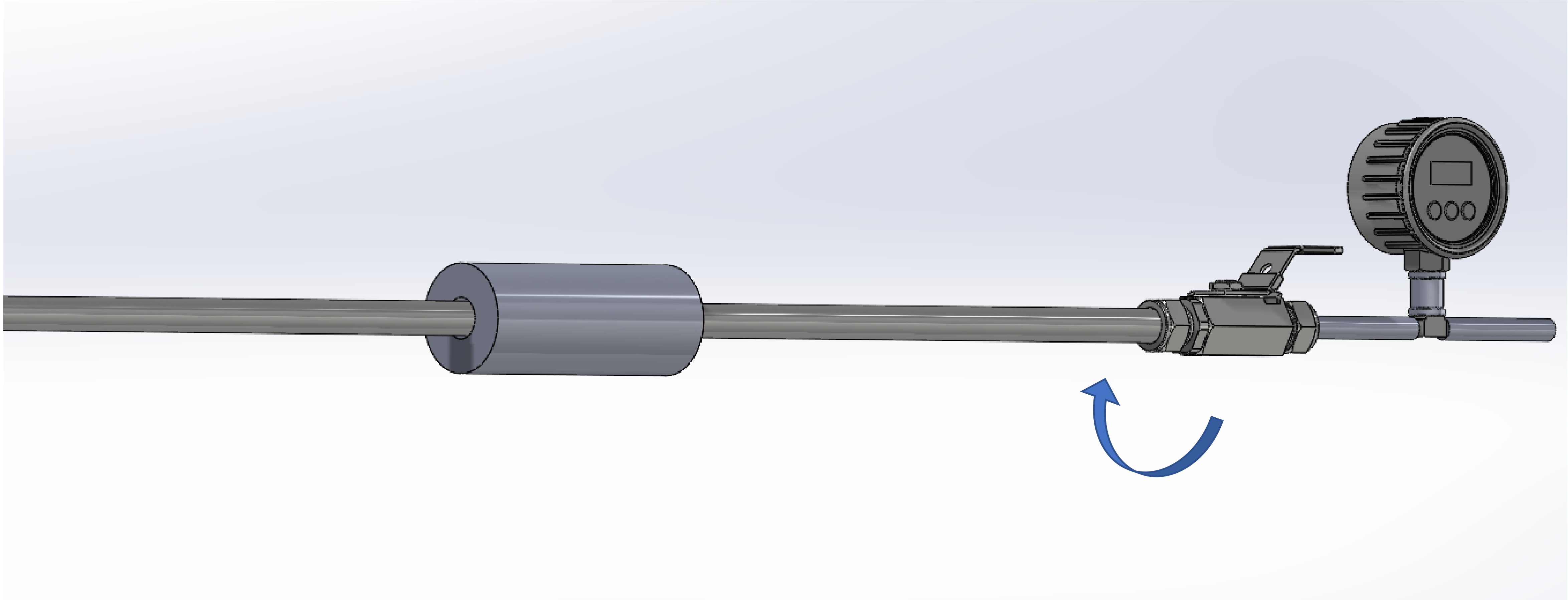
Concept of Operations

Step 2: Insert the material storage capsule using a loading rod to ensure the capsule is in the heating zone.



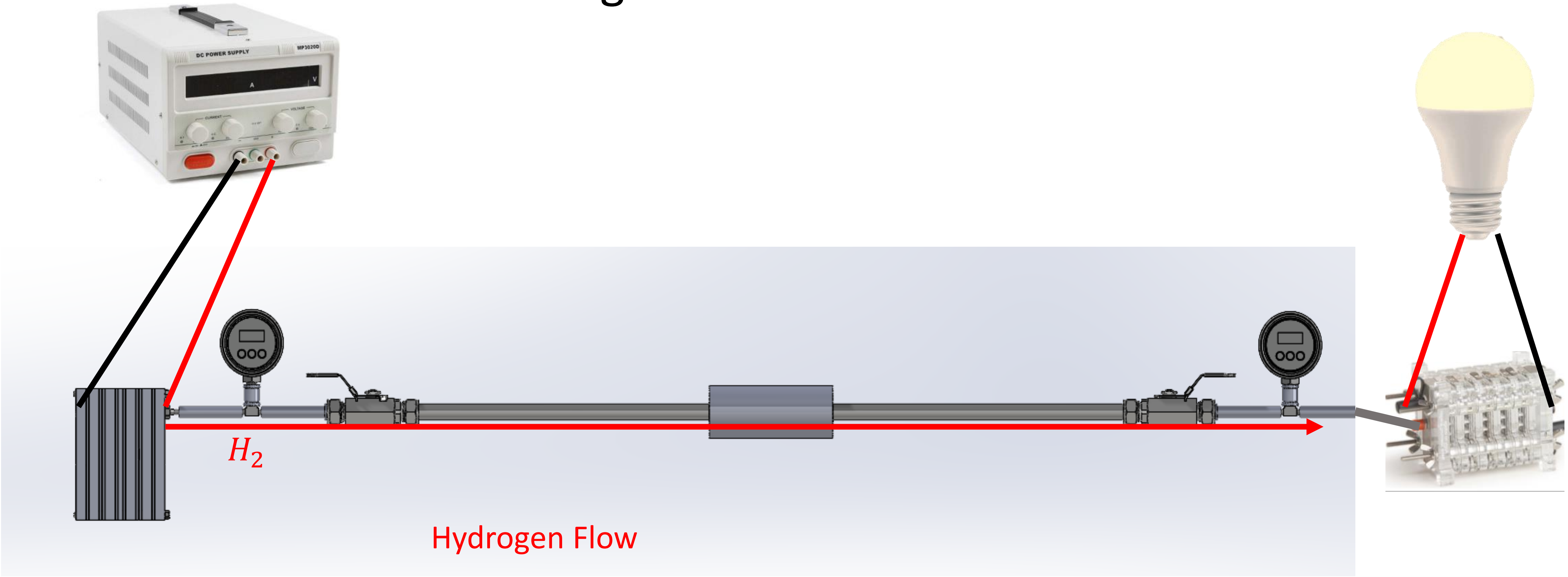
Concept of Operations

Step 3: Attach stainless steel pipe to Yor-lock valve until wrench tight.



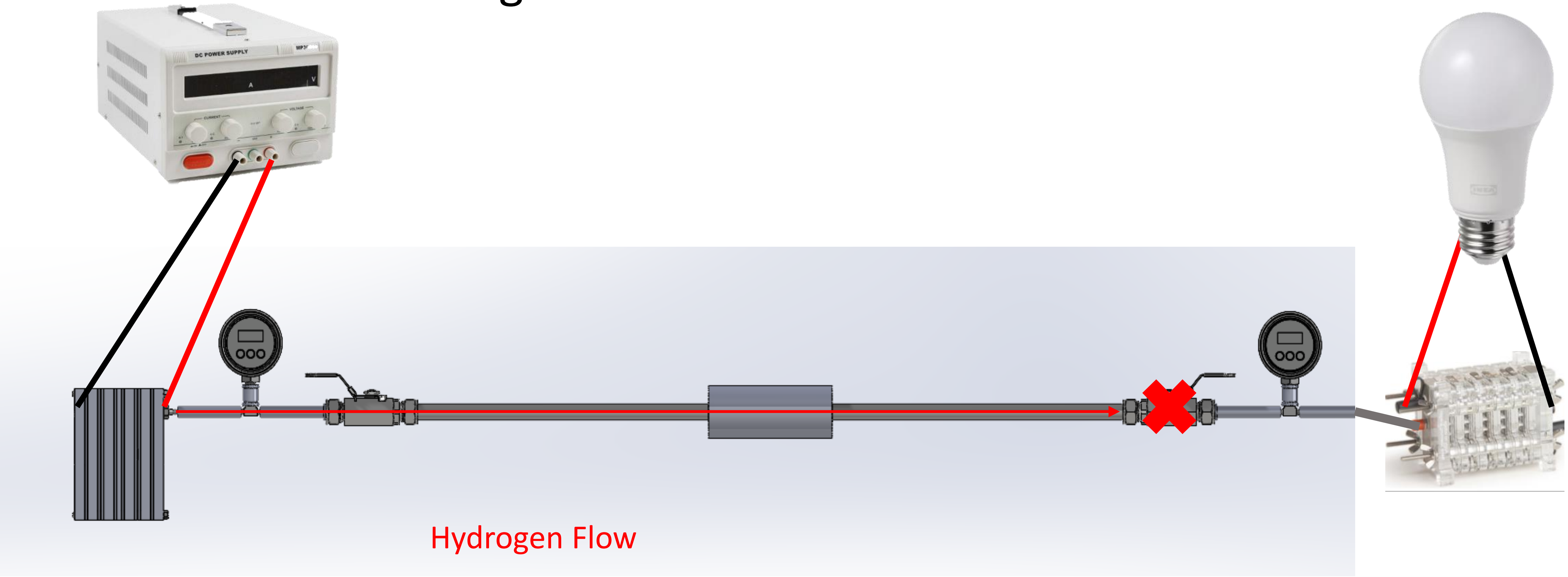
Concept of Operations

Step 4: Ensure all valves are open, turn on the electrolysis machine, and run until the fuel cell light comes on.



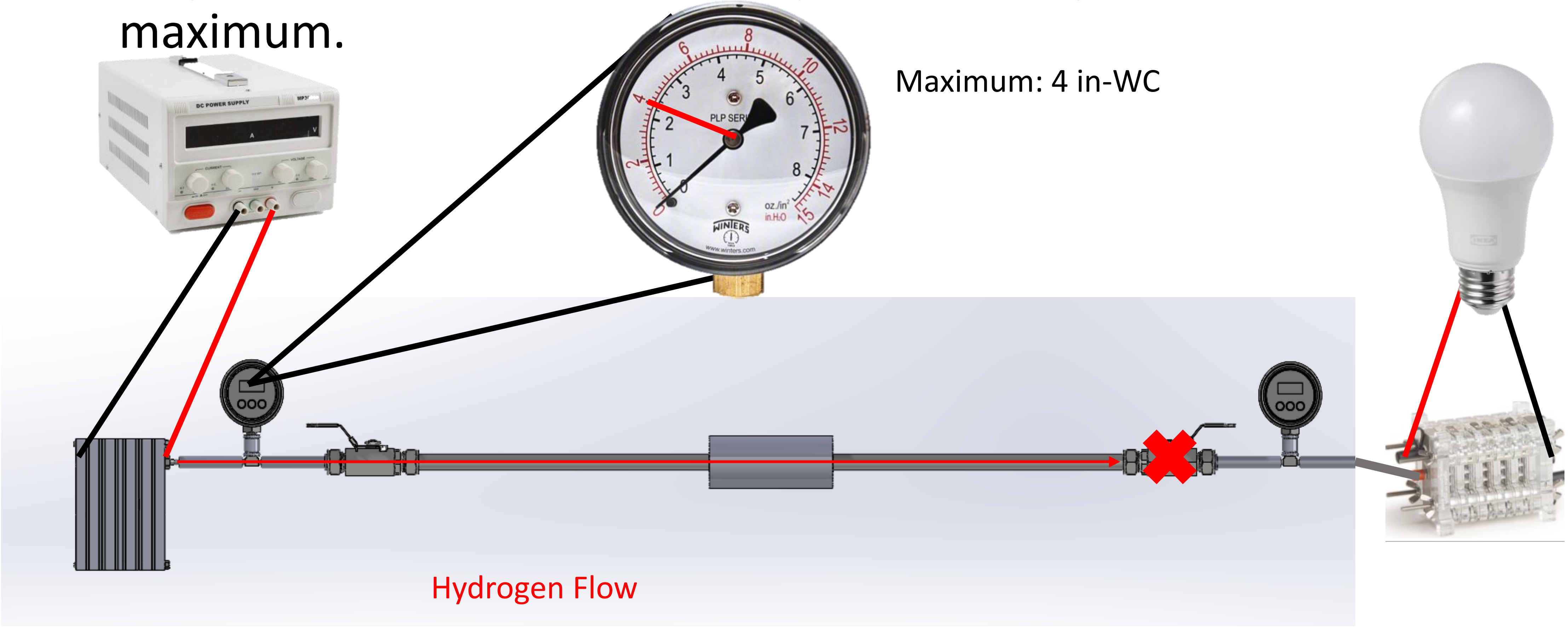
Concept of Operations

Step 5: Continue running electrolysis and close the valve connecting the material storage to the fuel cell.



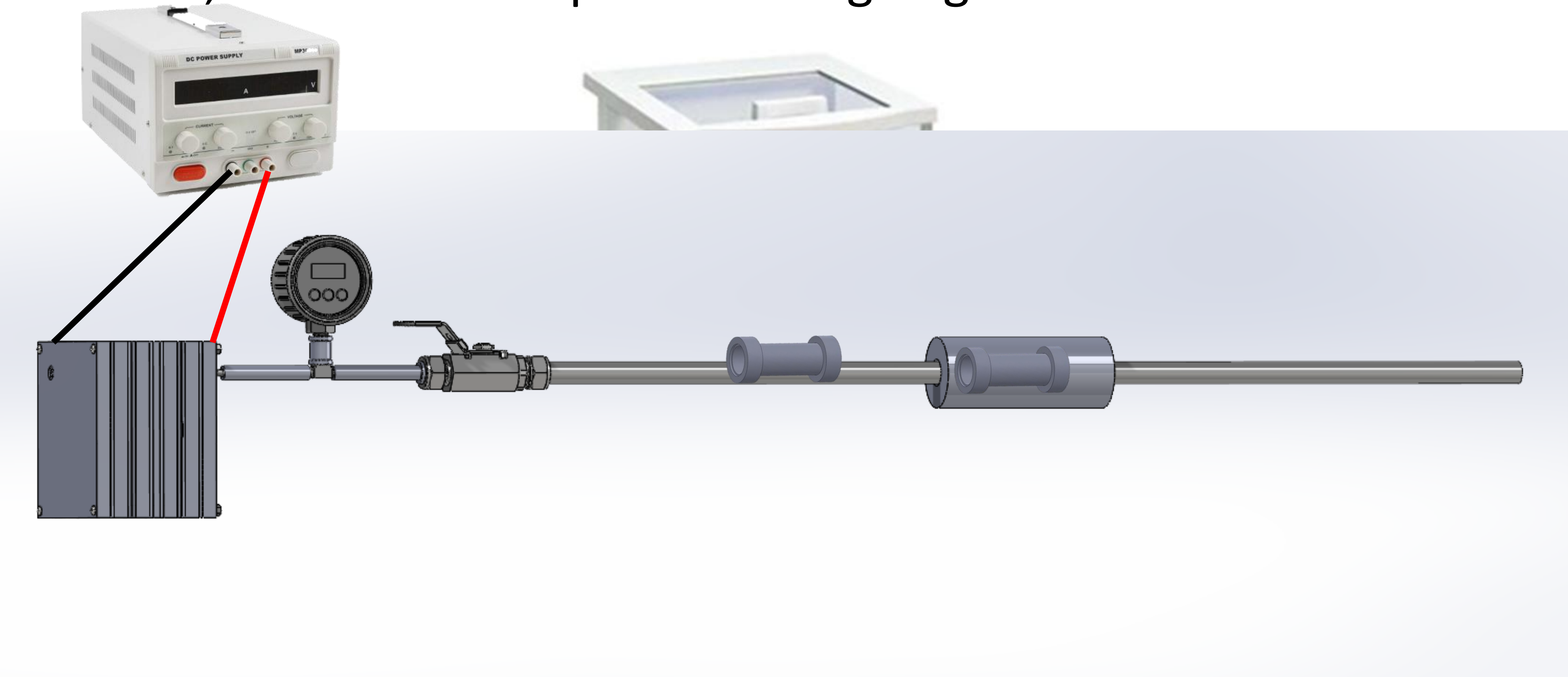
Concept of Operations

Step 6: Continue to run electrolysis until the pressure reaches maximum.



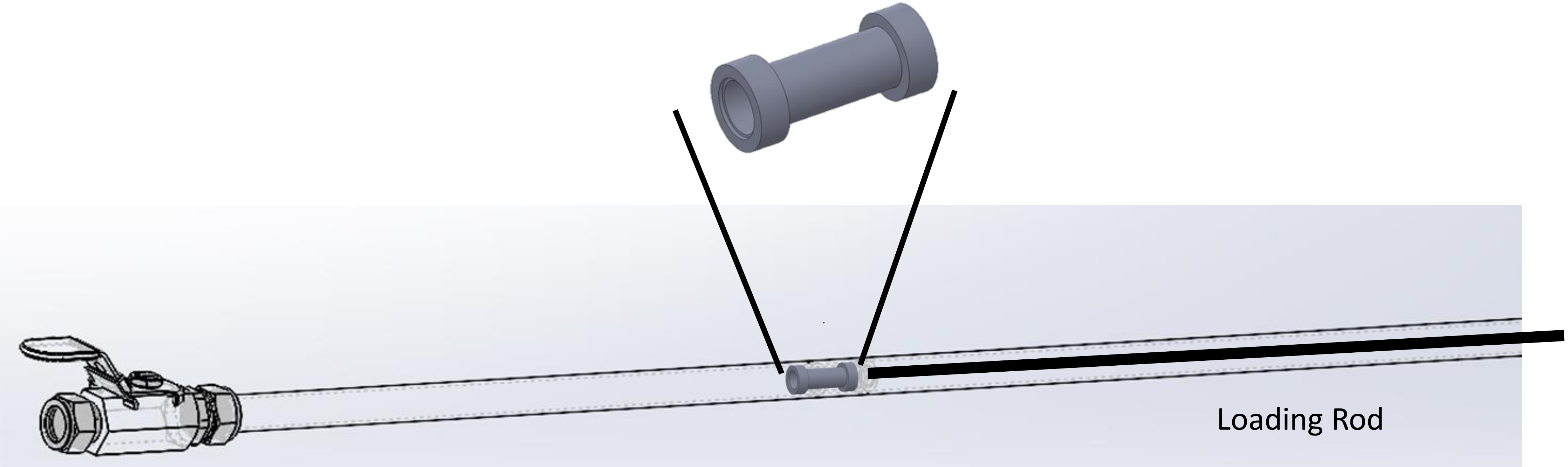
Concept of Operations

Step 7: Turn off electrolysis, disconnect pipe from valve in a ventilated area, and remove capsule to weigh again.



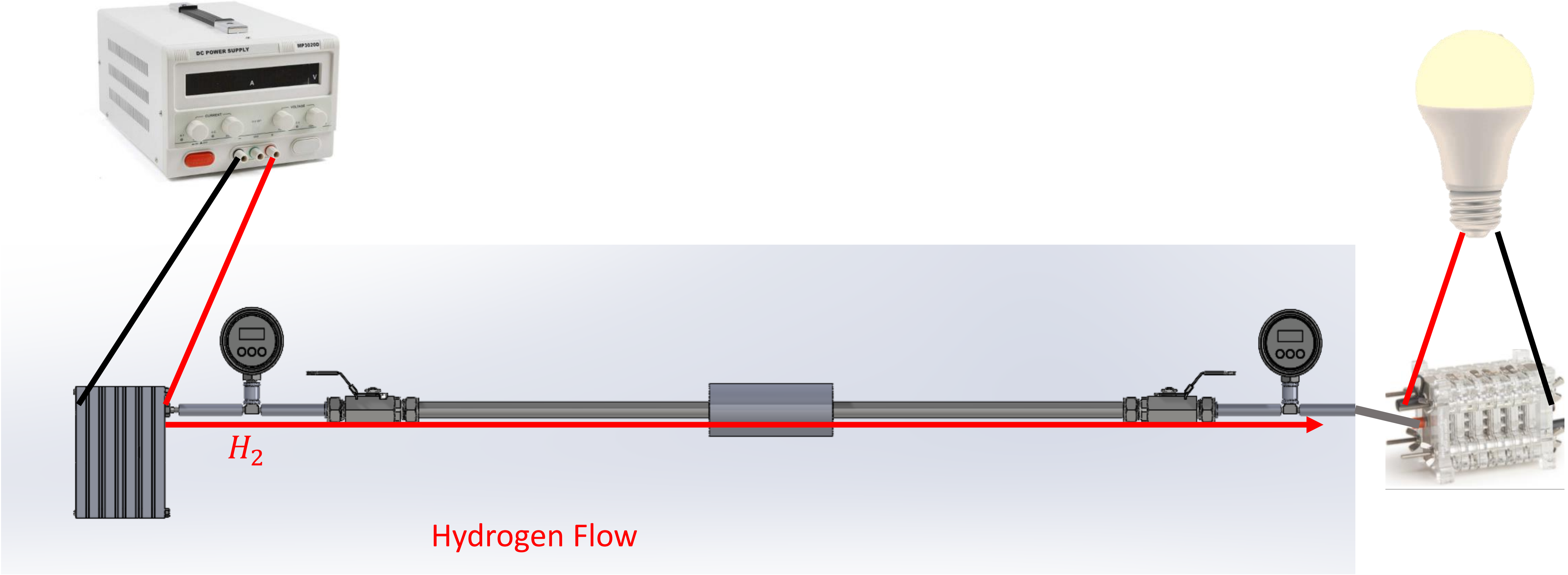
Concept of Operations

Step 8: Re-insert capsule by repeating step 2.



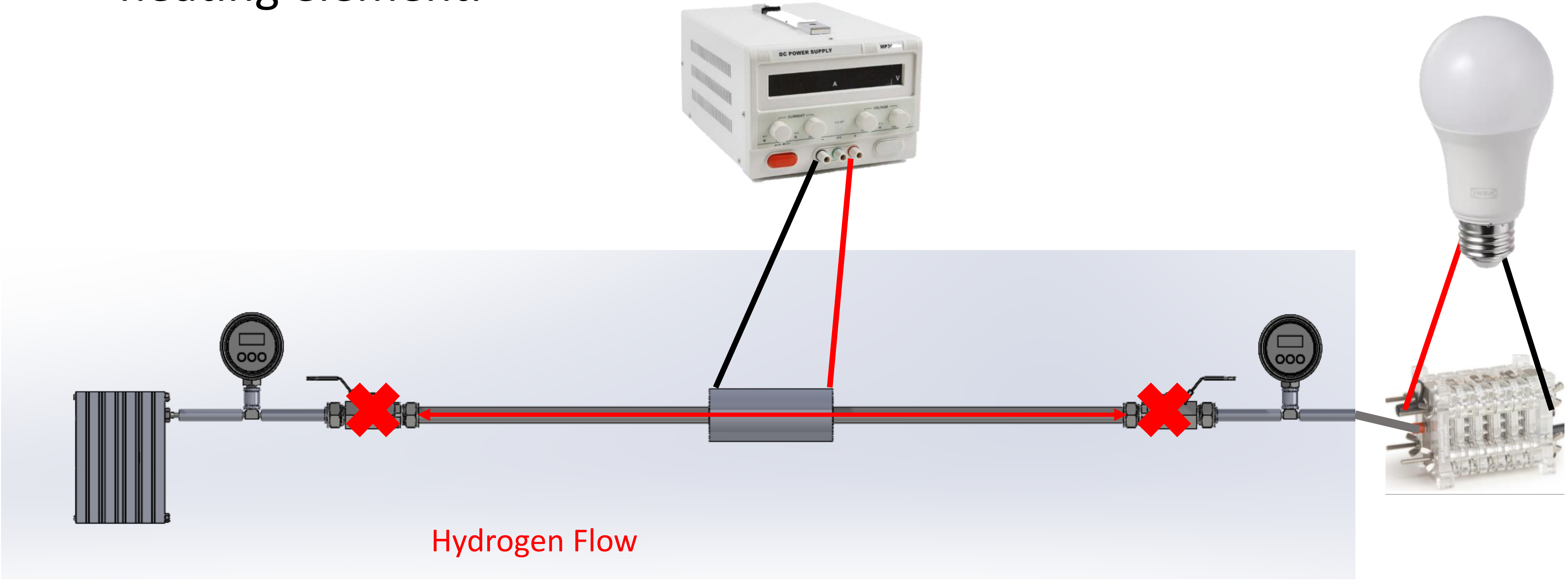
Concept of Operations

Step 9: Repeat step 4 and then turn off electrolysis.



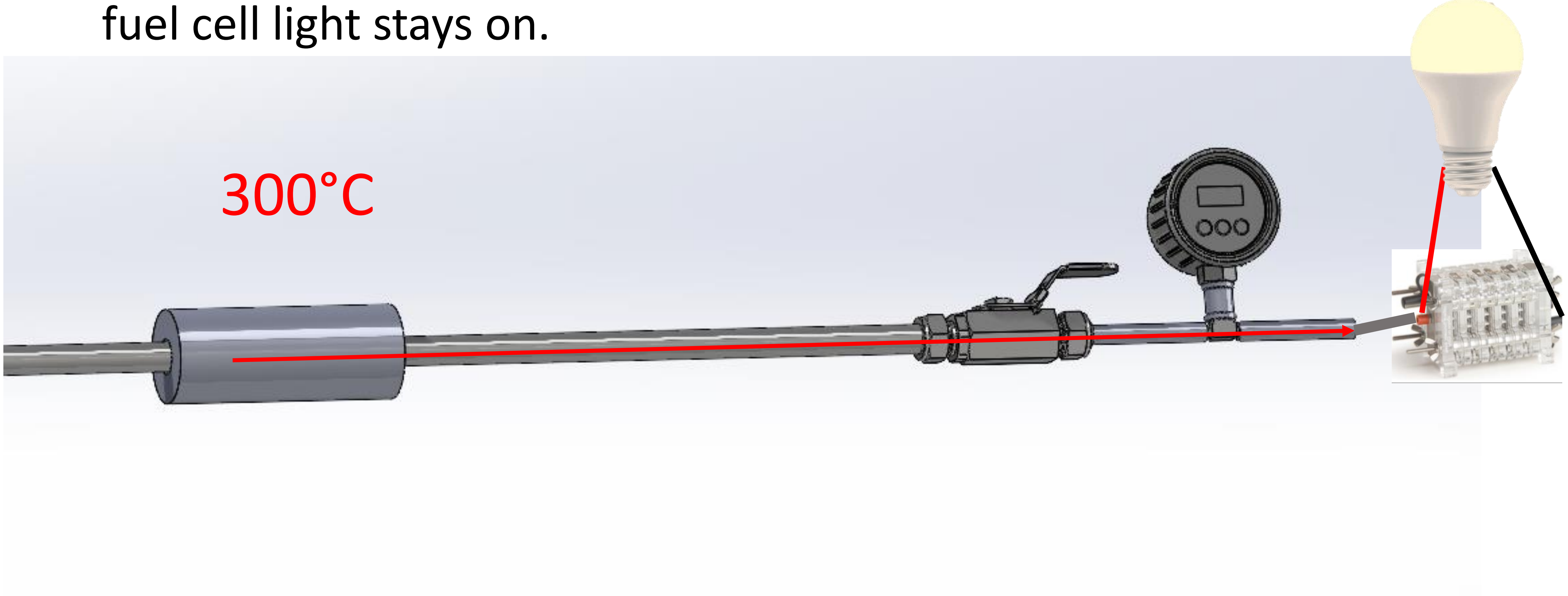
Concept of Operations

Step 10: Once fuel cell light turns off, close both valves, and turn on the heating element.



Concept of Operations

Step 11: Once the thermocouple reaches 300 degrees Celsius, slowly open the valve to the fuel cell and start timer to measure how long the fuel cell light stays on.

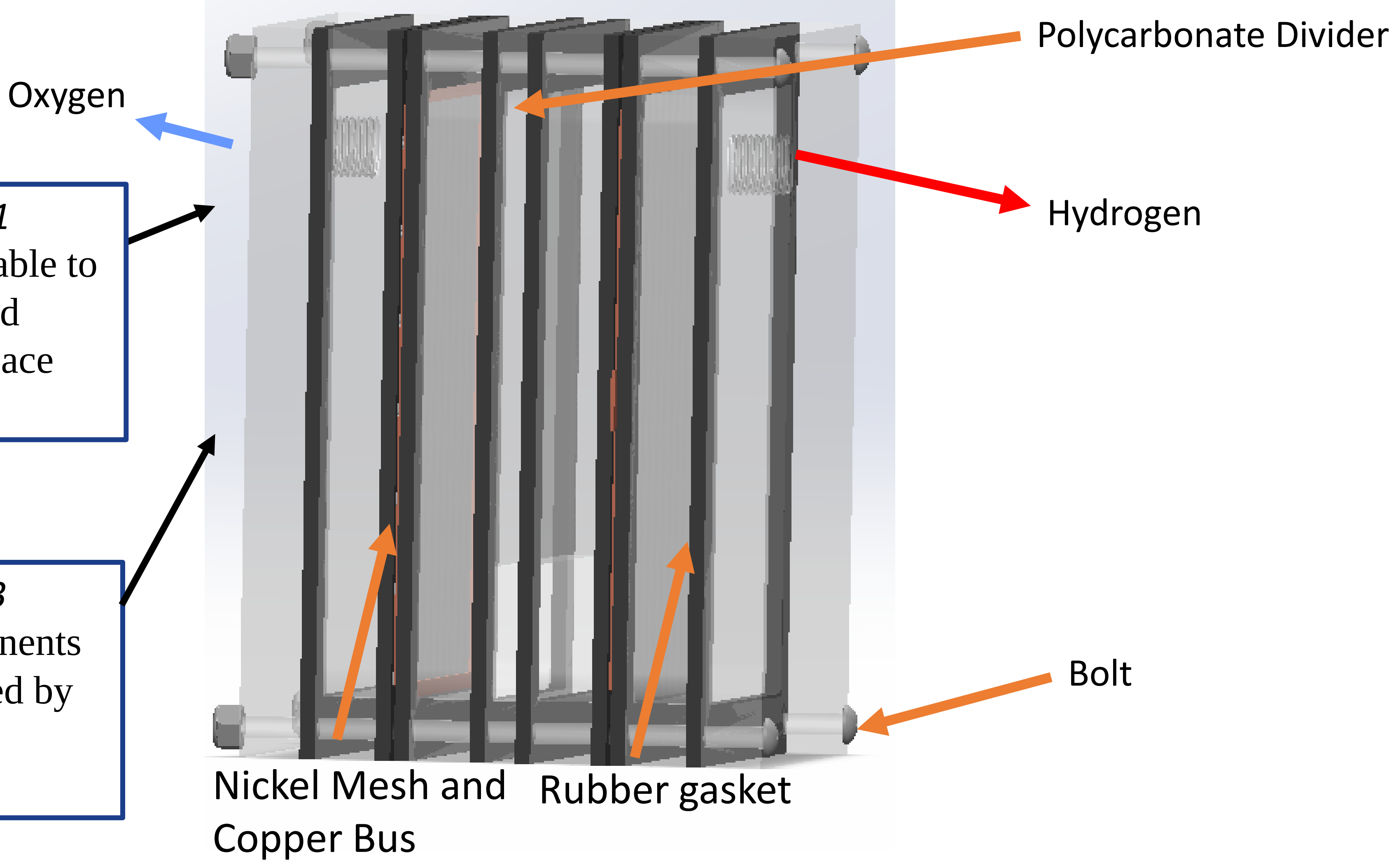


Electrolysis

Electrolysis Overview

- 1.1.1 Will produce hydrogen
- 3.1 Will be able to be dissembled
- 3.2 Hydrogen and oxygen will not mix
- 3.3 Components are hydrogen resistant
- 3.4 Amperage must be controlled

ERH2's Electrolysis System

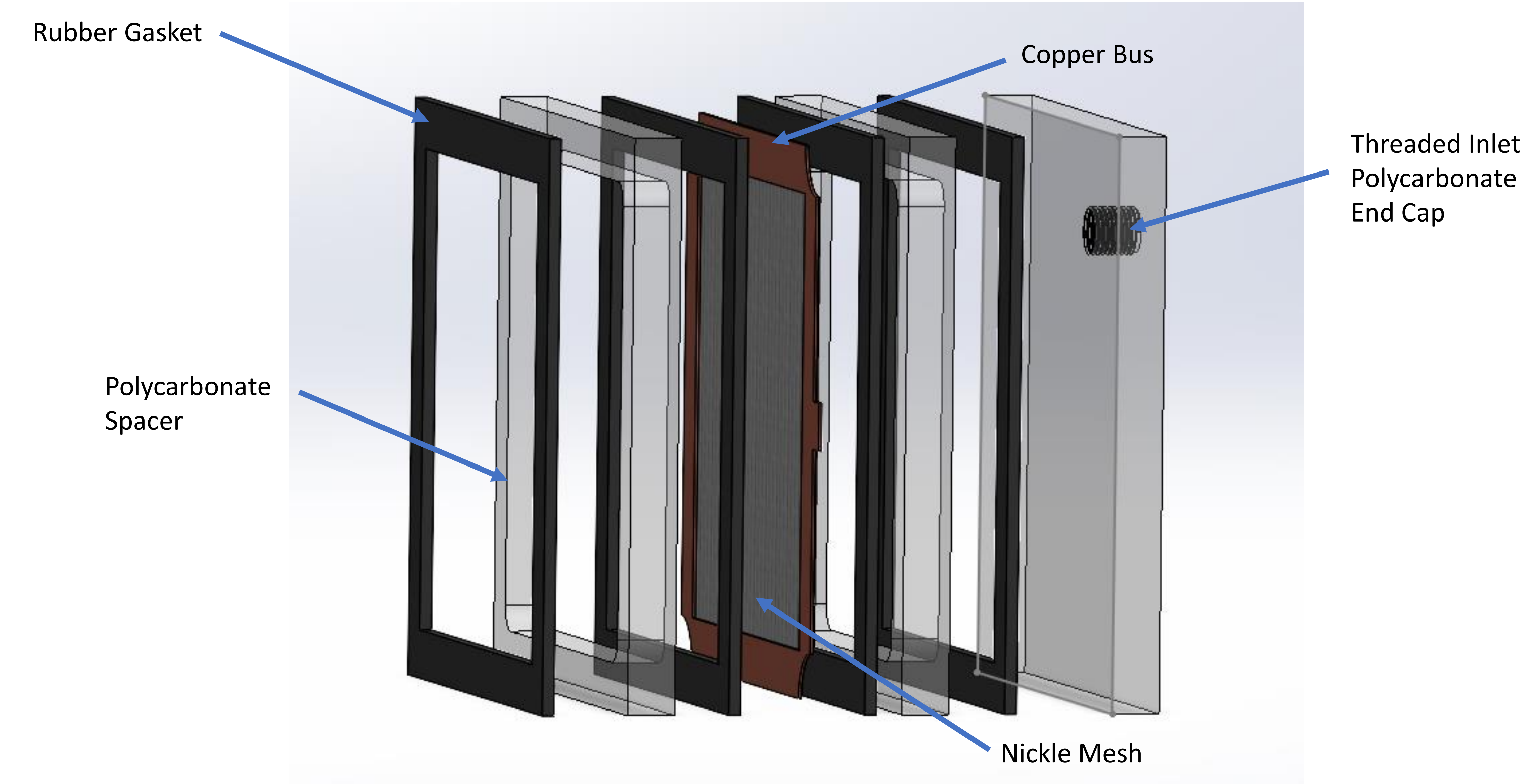


Model of ERH2's planned Electrolyzer

Requirement 3.1
"The system must be able to be dissembled and reassembled to replace parts."

Requirement 3.3
"The machine components must not be embrittled by hydrogen."

Electrolysis Exploded View



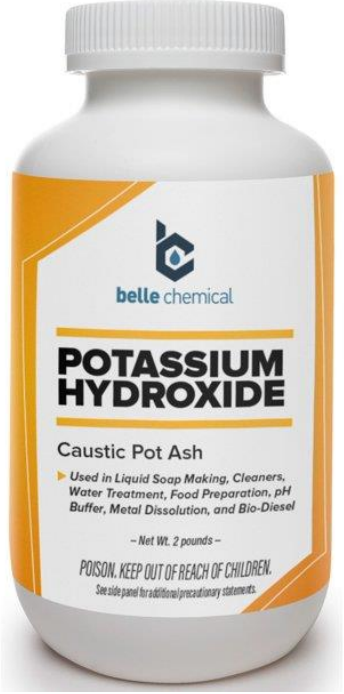
Alkaline Water

Made from Potassium hydroxide (KOH)

Our system will use a solution of 32%

Typical solution is 32% to 50% in strength [6]

320g KOH into 1 Liter of water



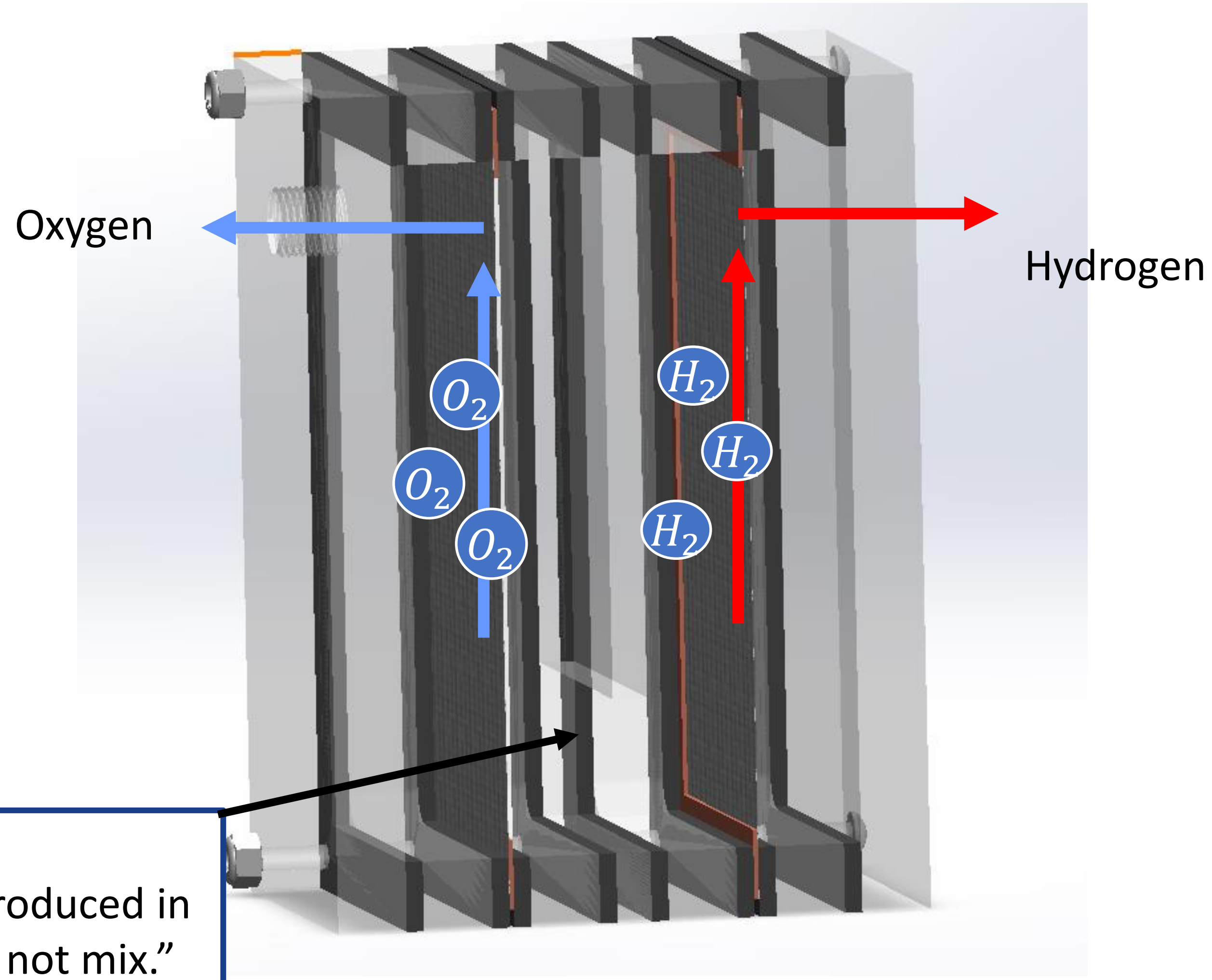
Alkaline Water Electrolysis

Cathode: $$2H_2O + 2e^- \xrightarrow{yields} H_2 + 2OH^-$$

Anode: $$2OH^- \xrightarrow{yields} \frac{1}{2}O_2 + H_2O + 2e^-$$

[5]

Mesh Section-View



Requirement 3.2
"The hydrogen and oxygen produced in the electrolysis system must not mix."

Power Requirements

Minimum 1.23 V [7]

0-20 Amps

Will be able to vary based on production wanted

Requirement 3.4
"The amperage going into the system must be controlled and limited to 22.89 amps."

Estimate of Hydrogen Needed

$$\frac{Power\ wanted(kW) \cdot time(sec.)}{Percent\ Eff\ of\ fuel\ cell \cdot Lower\ heating\ value\left(\frac{KJ}{Kg}\right)} = Amount\ needed(g\ H_2)$$

$$\frac{.001kW \cdot 60\ (sec.)}{0.25 \cdot 120{,}000\left(\frac{KJ}{Kg}\right)} = \boxed{.002\ (g\ H_2)/min}$$

Faraday's Law of Electrolysis

Rate of H2 Production

$$\frac{Max\ theoretical\ Current}{Valence} \cdot Molar\ weight\ of\ H$$

$$\frac{20\ (C)}{1\ (s)} \cdot \frac{60\ (s)}{96{,}485\ \left(\frac{C}{mol\ e^-}\right)} \cdot \frac{1\ (mol\ H_2)}{2\ (mol\ e^-)} \cdot \frac{2.007\ (g\ H_2)}{1\ (mol\ H_2)} = 0.0125\ (g/min\ H_2)$$

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."

Production　　　　Consumption

$$.0125\ (g\ H_2)/min > .002\ (g\ H_2)/min$$

Electrolysis Verification

1.1.1 Will produce hydrogen	• Alkaline electrolizer will produce hydrogen
3.1 Will be able to be disassembled	• Bolts are threaded and reusable gasket
3.2 Hydrogen and oxygen will not mix	• The stalactite layer is used
3.3 Components are hydrogen resistant	• Hydrogen embrittlement resistant
3.4 Amperage must be controlled	• Control knob on power supply

Material Storage

Material Storage Overview

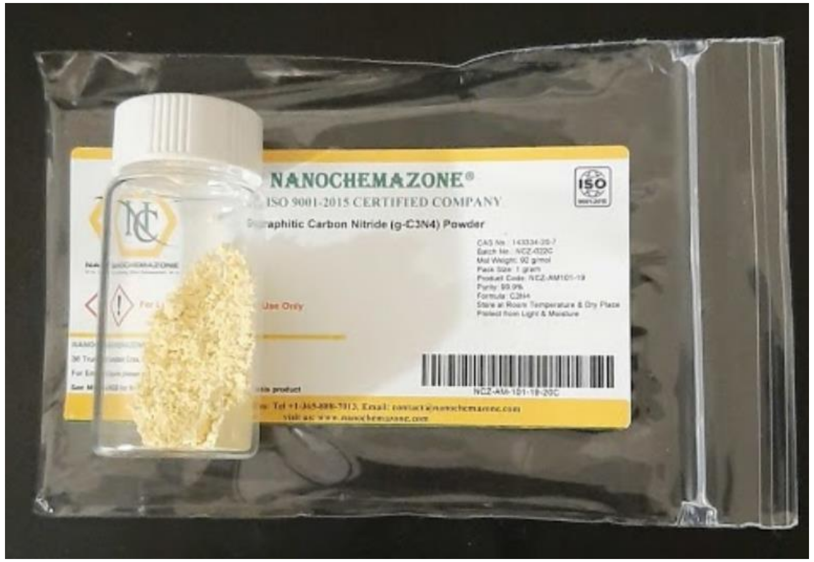
1.2 The storage method must run the fuel cell for a minimum of 5 minutes

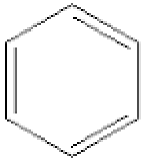
4.2 The storage material must be fully contained within the system.

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.

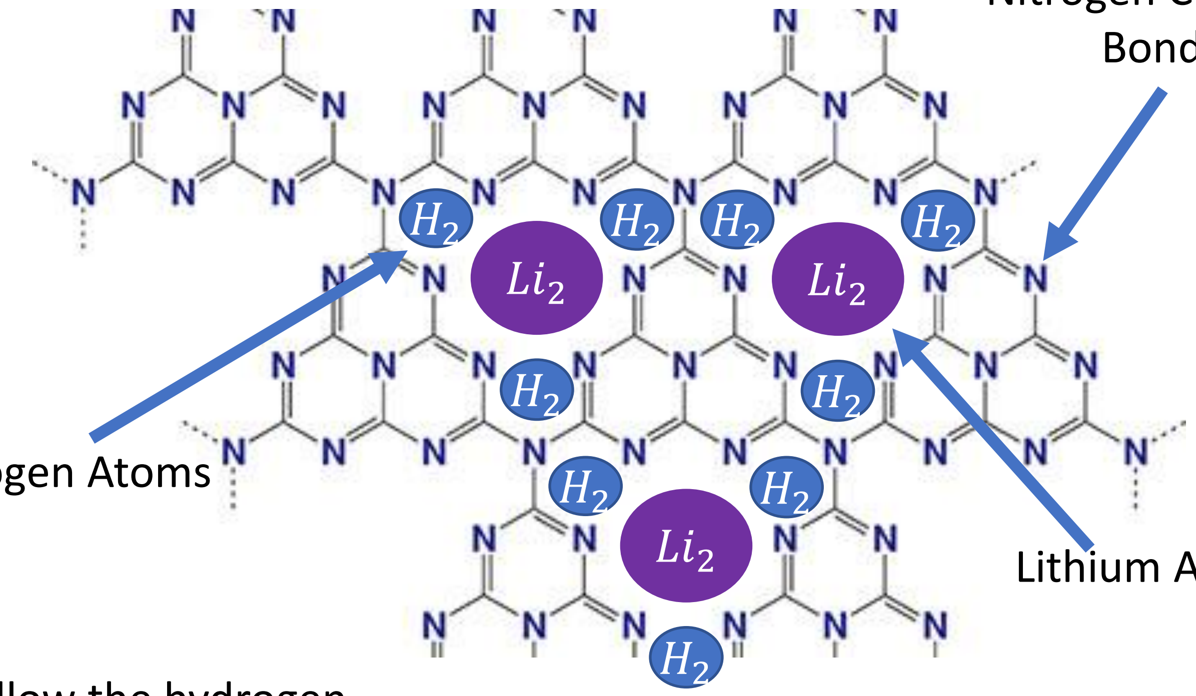
Lithium-Doped Graphitic Carbon Nitride [$Li_2C_4N_4$]





=> Carbon Ring

Nitrogen Covalent Bonds



Hydrogen Atoms

Lithium Atoms

Graphitic Carbon Nitride

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

Molecular Level

ERH$_2$

Material Capacity

"…it was found that the gravimetric and volumetric densities of hydrogen in both $Li_2C_4N_3$ and $Li_2C_4N_4$ were greater than 10 wt% and 100 g/L respectively" [1].

Needed: 1 g $Li_2C_4N_3$

$$m_{H_2Stored} = m_{final} - 1$$

$$\%_{wtH_2} = \frac{m_{H_2Stored}}{m_{final}} \cdot 100$$

At 2% wt Hydrogen, the material will store 0.02 grams of hydrogen the amount needed to run the fuel cell for a maximum of 10 minutes.

Requirement 4.4
"Material must store hydrogen with at least 2% weight of hydrogen gas."

Requirement 1.2
"The material storage must run the fuel cell for a minimum of 5 minutes."

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probe • perform • practice • Plastics

Material Storage Benefits

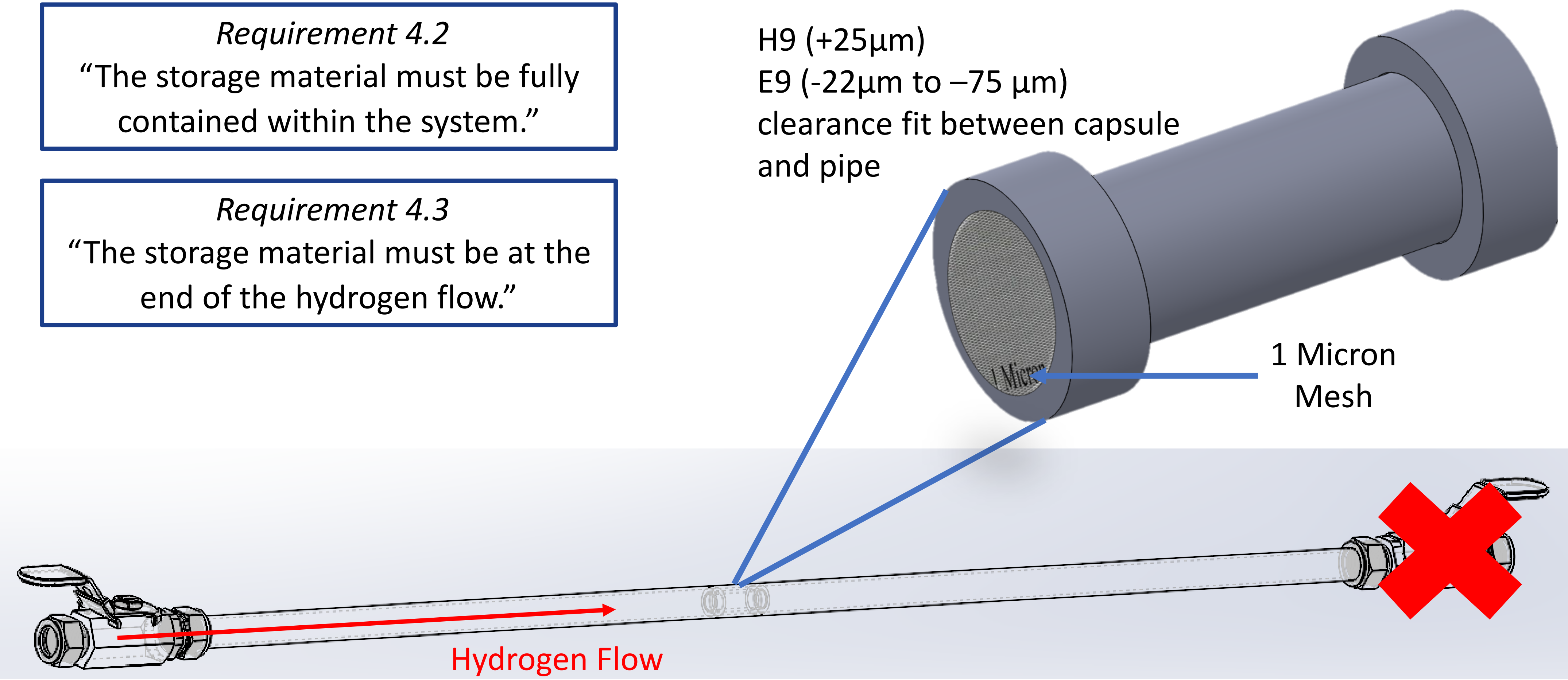
	Compressed Storage 	Material Storage 
Energy Density	592.9-3796 J/m^3	140-280 J/m^3
Weight Percentage	3.53%	2-10%
Storage Pressure	60-500 bar	1 bar

ERH_2

Material Integration

Requirement 4.2
"The storage material must be fully contained within the system."

Requirement 4.3
"The storage material must be at the end of the hydrogen flow."



ERH$_2$

Material Storage Verification

1.2 The storage method must run the fuel cell for a minimum of 5 minutes.	• Material will store at least 0.02 grams of hydrogen, which will run the fuel cell for at least 5 minutes.
4.2 The storage material must be fully contained within the system.	• The material is in a sealed capsule using a 1-micron mesh press fit.
4.3 The storage material must be at the end of the hydrogen flow.	• Material area closed by valves to restrict flow
4.4 The storage material must have a minimum hydrogen density of 2%wt.	• Material has a potential capacity of 10%wt.

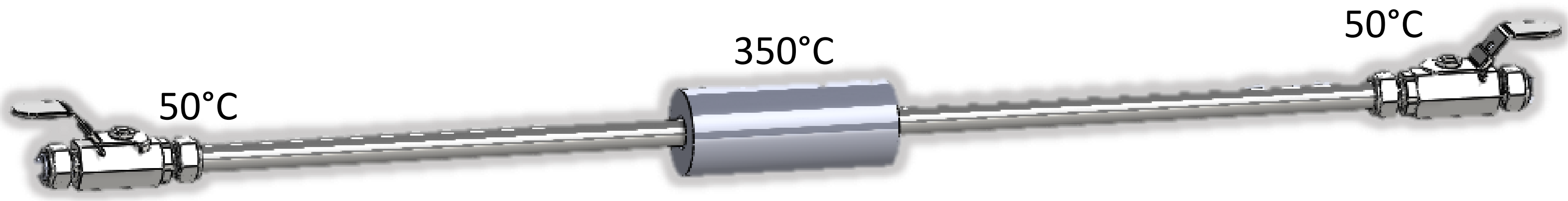
Piping

Piping Overview

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

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

Heat Transfer: Piping's Purpose



[4]

Smooth-Bore Seamless 304 Stainless Steel Tubing, 3/4" OD, 0.035" Wall Thickness

Length, ft.

1

3

6

Temperature Range -425° to 1500° F

$$1500°F = 815°C > 350°C$$

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

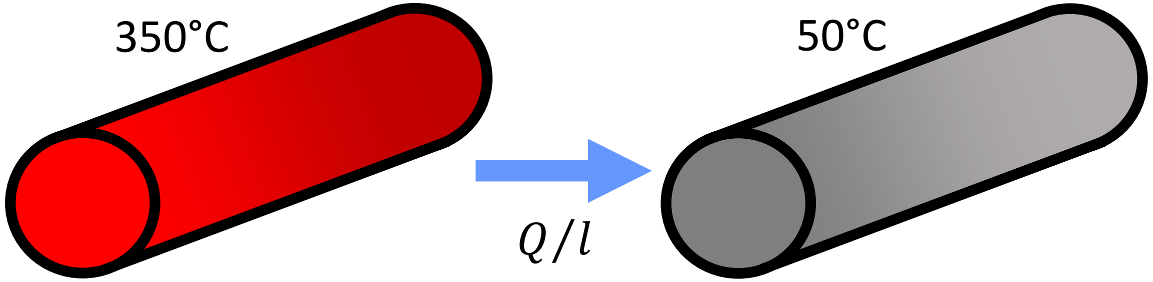
To keep the valves below 50°C, what is the pipe's required length?

Determining Heat Transfer Model

Steel pipe vs. hydrogen gas:

How much energy will each material release over a 350°C to 50°C temperature drop?

$$\frac{Q}{l} = \rho A_c c_p \Delta T$$



Where:

Q/l = Energy per unit length, (J/m)
ρ = Density, (kg/m^3)
A_c = Cross-sectional area, (m^2)
c_p = Specific heat, (J/kg*K)
ΔT = Temperature change = 300°C

Steel Dominates Thermally

$$\frac{Q}{l} = \rho A_c c_p \Delta T$$

Steel Pipe

ρ = 7,500 (kg/m^3)
A_c = $5 \cdot 10^{-5} (m^2)$
c_p = 468 $(J/kg \cdot K)$
ΔT = 300°C

$(Q/l)_{steel\ pipe}$ = 53,410 (J/m)

Hydrogen Gas

ρ = 0.076 (kg/m^3)
A_c = $2.3 \cdot 10^{-4} (m^2)$
c_p = 14,500 $(J/kg \cdot K)$
ΔT = 300°C

$(Q/l)_{hydrogen\ gas}$ = 77 (J/m)

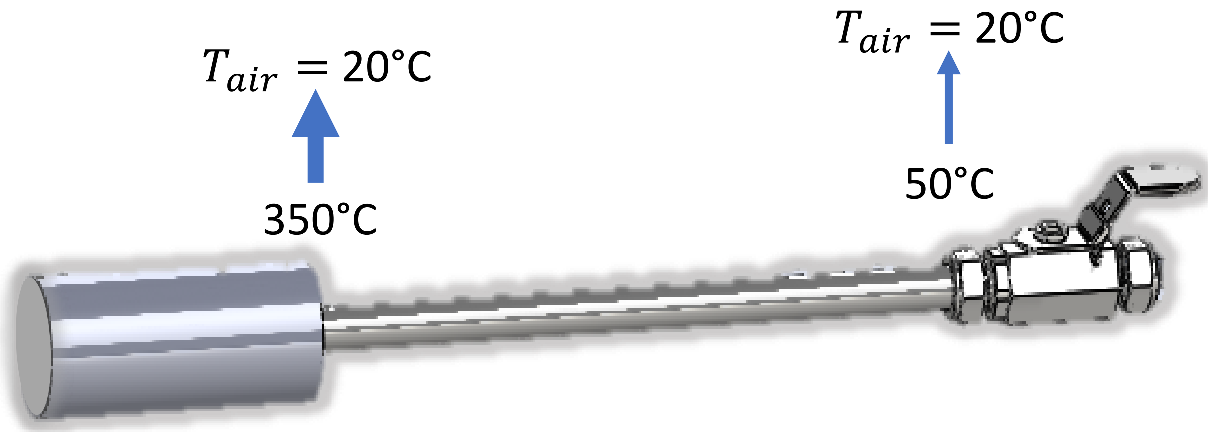
Steel/hydrogen energy ratio:

$$\frac{(Q/l)_{steel\ pipe}}{(Q/l)_{hydrogen\ gas}} = \frac{53{,}410 (J/m)}{77 (J/m)} = \boxed{690}$$

Thermal energy in hydrogen is negligible compared to thermal energy in steel.

Valve temperature depends primarily on the pipe temperature.

How to Model the Pipe?
Like an Adiabatic Tipped Fin!



Heat transfer is due primarily to convection between the pipe and air.

$$\dot{Q}_{convection} \propto \Delta T$$

$$\Delta T_{hot\ side} = 330°C \gg \Delta T_{cold\ side} = 30°C$$

$$\dot{Q}_{hot\ side} \gg \dot{Q}_{cold\ side}$$

Treat the system as a fin with an adiabatic tip.

Equations for Adiabatic-Tipped Fins

Where:

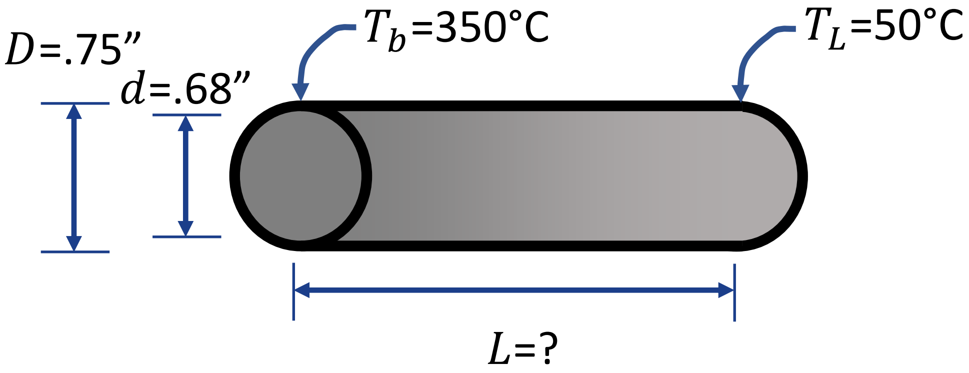
- L = pipe length
- D = outer diameter
- d = inner diameter
- T_L = tip temperature
- T_b = base temperature
- T_∞ = air temperature
- p = external perimeter
- A_c = cross-sectional area
- k = thermal conductivity of steel
- h = convection coefficient

[8] $$\frac{T(x)-T_\infty}{T_b-T_\infty}=\frac{\cosh(m(L-x))}{\cosh(mL)} \qquad m=\sqrt{\frac{hp}{kA_c}}$$

$$x=L: \quad \frac{T_L-T_\infty}{T_b-T_\infty}=\frac{\cosh(m(L-L))}{\cosh(mL)}=\frac{\cosh(0)}{\cosh(mL)}=\frac{1}{\cosh(mL)}$$

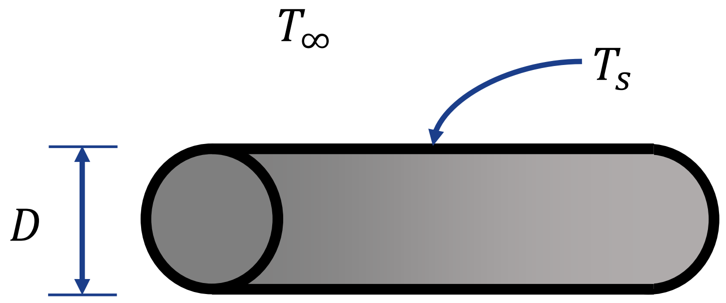
$$L=\frac{1}{m}\cosh^{-1}\left(\frac{T_b-T_\infty}{T_L-T_\infty}\right)$$

Needed: convection coefficient



Worst-Case Scenario: Only Natural Convection

$$h = \frac{k_{air} Nu}{D}$$



[8] $$Nu = \left(0.6 + \frac{0.387 Ra_D^{1/6}}{\left(1 + (0.559/Pr)^{9/16}\right)^{8/27}}\right)^2 \qquad Ra_D \leq 10^{12}$$

Nusselt Number for *isothermal* horizontal cylinders experiencing natural convection

Where:

Nu = Nusselt Number
k_{air} = air thermal conductivity
Ra_D = Rayleigh Number
Pr = Prandtl Number
T_s = surface temperature
T_{film} = film temperature

Evaluate at T=350°C and T=50°C, see which case requires the longest pipe

Needed: Rayleigh Number

Finding Rayleigh Numbers

[8] $$Ra_D = Gr_D Pr = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2} Pr$$

Where:

Pr = Prandtl Number
g = gravitational acceleration = 9.81(m^2/s)
β = coefficient of volume expansion
ν = kinematic viscosity
D = outer diameter = 0.019 (m)
T_∞ = bulk temperature = 20°C

*Air properties evaluated at film temperature:

$$T_{film} = \frac{1}{2}(T_s - T_\infty)$$

T_s = 350°C

$T_{film} = 185°C$
$\beta = 1.6 \cdot 10^{-3}(1/K)$
Pr = 0.70
$\nu = 3.3 \cdot 10^{-5}(m^2/s)$

$Ra_D = 2.4 \cdot 10^4$

T_s = 50°C

$T_{film} = 35°C$
$\beta = 3.1 \cdot 10^{-3}(1/K)$
Pr = 0.73
$\nu = 1.7 \cdot 10^{-5}(m^2/s)$

$Ra_D = 1.7 \cdot 10^4$

Finding Required Length

Equations

$$Nu = \left(0.6 + \frac{0.387 Ra_D^{1/6}}{(1 + (0.559/Pr)^{9/16})^{8/27}}\right)^2 \qquad h = \frac{k_{air} Nu}{D} \qquad m = \sqrt{\frac{hp}{kA_c}} \qquad L = \frac{1}{m}\cosh^{-1}\left(\frac{T_b - T_\infty}{T_L - T_\infty}\right)$$

Constant Values

$$\frac{T_b - T_\infty}{T_L - T_\infty} = \frac{350°C - 20°C}{50°C - 20°C} = 11 \qquad p = \pi D = \pi 0.75(in)\frac{0.0254(m)}{1(in)} = 0.06(m)$$

$$k_{steel} = 20(W/mK) \qquad A_c = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}\left(0.75^2(in^2) - 0.68^2(in^2)\right)\frac{0.0254^2(m^2)}{1^2(in^2)} = 5.1 \cdot 10^{-5}(m^2)$$

T_s = 350°C

$Ra_D = 2.4 \cdot 10^4$

Nu = 5.4

k_{air} = 0.037 $(W/m \cdot K)$

h = 10.4 (W/m^2K)

m = 24.7 $(1/m)$

L = 4.9 (in)

T_s = 50°C

$Ra_D = 1.7 \cdot 10^4$

Nu = 5.0

k_{air} = 0.026 $(W/m \cdot K)$

h = 6.8 (W/m^2K)

m = 20.1 $(1/m)$

L = 6.0 (in)

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

Minimum length: 6 inches

Chosen Design

Smooth-Bore Seamless 304 Stainless Steel Tubing, 3/4" OD, 0.035" Wall Thickness

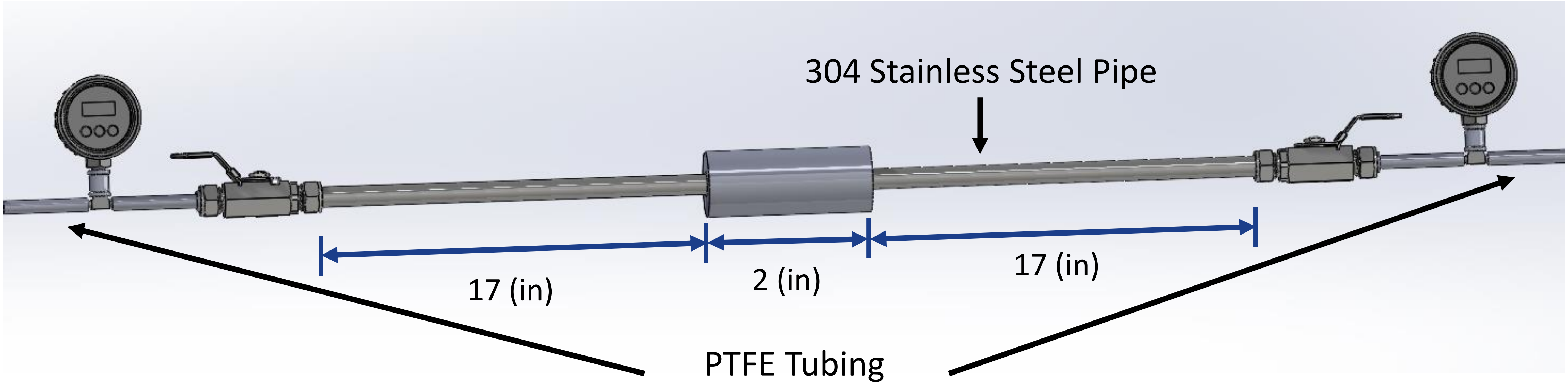
Length, ft.
- 1
- 3 ←
- 6

[4]

Extreme-Temperature Teflon® PTFE Semi-Clear Tubing for Chemicals, 1/4" ID, 5/16" OD

Length, ft.
- 5

[4]



Piping Verification

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

- Steel withstands 815°C

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

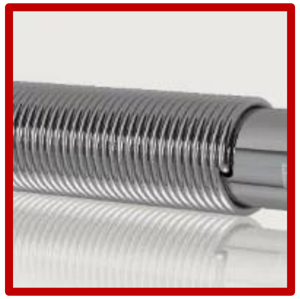
- Heat transfer analysis

Extraction

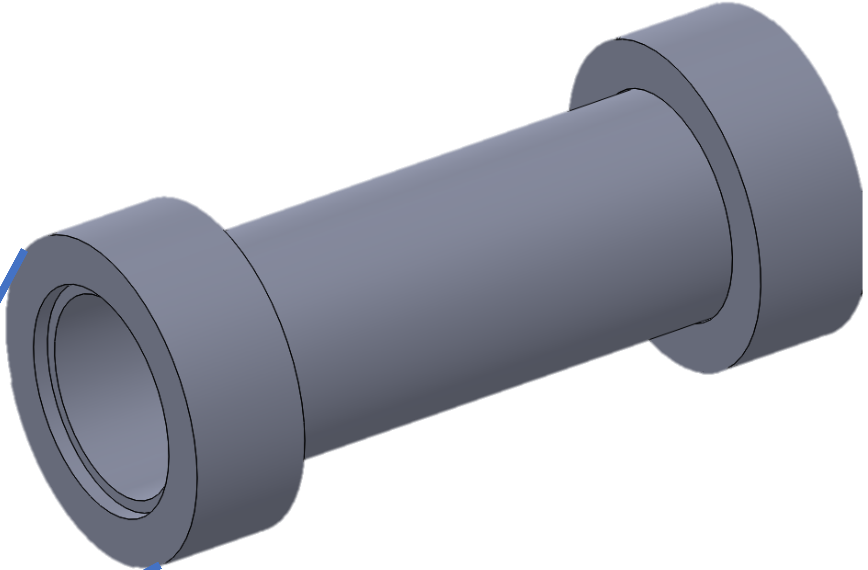
Extraction Overview

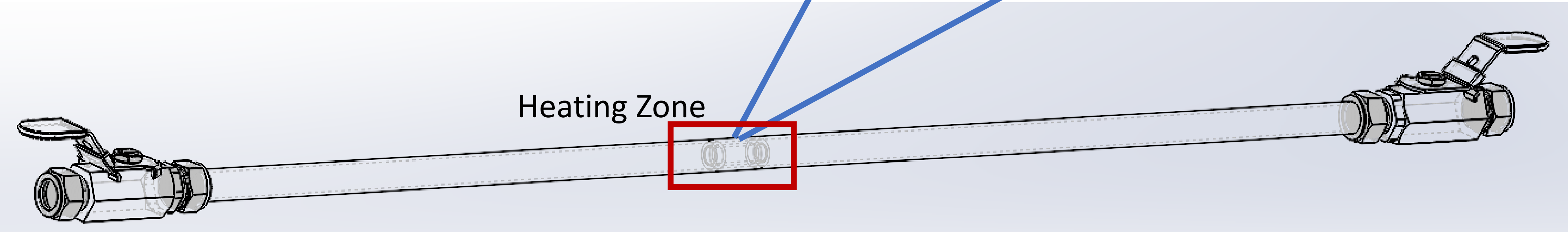
4.1 Must heat to 300°C and not exceed 350°C

Extraction System

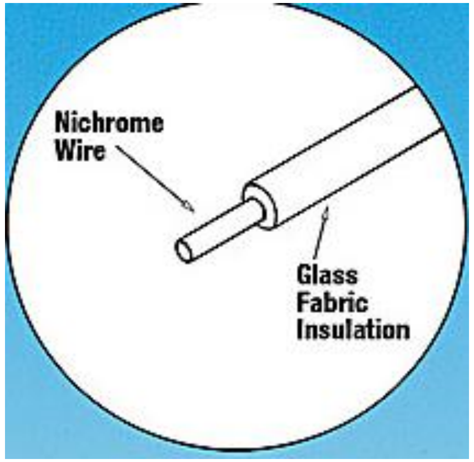


Heating Element





Heating Element – Nichrome Wire



Target Temperature for H_2 Release: 300°C

Wire Resistance: 2.1Ω/ft.

2in. Heating zone = 10ft of wire

Heater control and Verification

- Power supply
- Thermocouples

Heat Transfer Rates

Equation

$$\dot{Q} = \sqrt{hpkA_c}(T_b - T_\infty)\tanh(mL)$$ [8]

Constant Values

$k = 20(W/mK)$ $A_c = 5.1 \cdot 10^{-5}(m^2)$ $p = 0.06(m)$ $L = 17(in) = 0.43(m)$

T_b = 300°C

$\dot{Q} = 12.9(W)$

T_b = 350°C

$\dot{Q} = 15.4(W)$

Heat Loss & Required Power

Power Required (P), 10ft. of wire @ 300°C: 12.9W

350°C: 15.42W

Heater Resistance (R): $2.1\frac{\Omega}{ft.} \cdot 10ft. = 21\Omega$

$$V = (\frac{P}{R})^{.5} \qquad I = (P \cdot R)^{.5}$$

300°C Minimum

Voltage: **16.464V** Amperage: **0.784A**

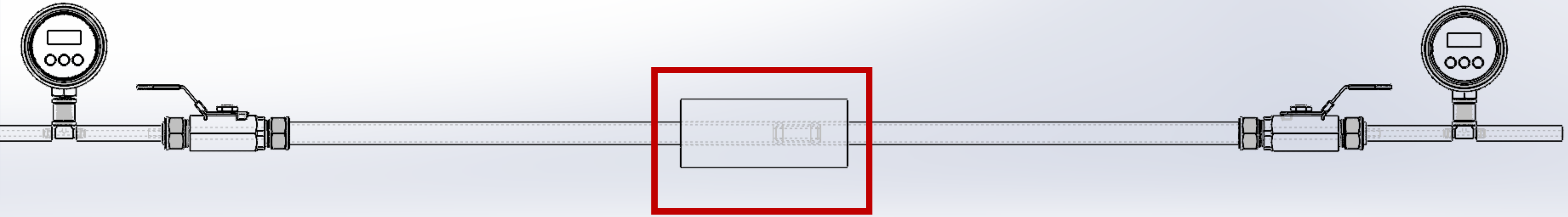
350°C Maximum

Voltage: **17.995V** Amperage: **0.857A**

Thermal Insulation

Aluminum Silicate Fiber

Thermal Conductivity: .085$\frac{W}{m \cdot K}$ @ 400°C [7]



Insulation Wrap

Extraction Verification

4.1 Must heat to 300°C and not exceed 350°C

- Thermocouple – Adjustable by power supply

Instrumentation

Instrumentation Overview

1.1.2 Determine rate of hydrogen production

1.2.1 Measure amount of hydrogen stored

6.1 Instrumentation system must be self-reliant

Pressure Gauges

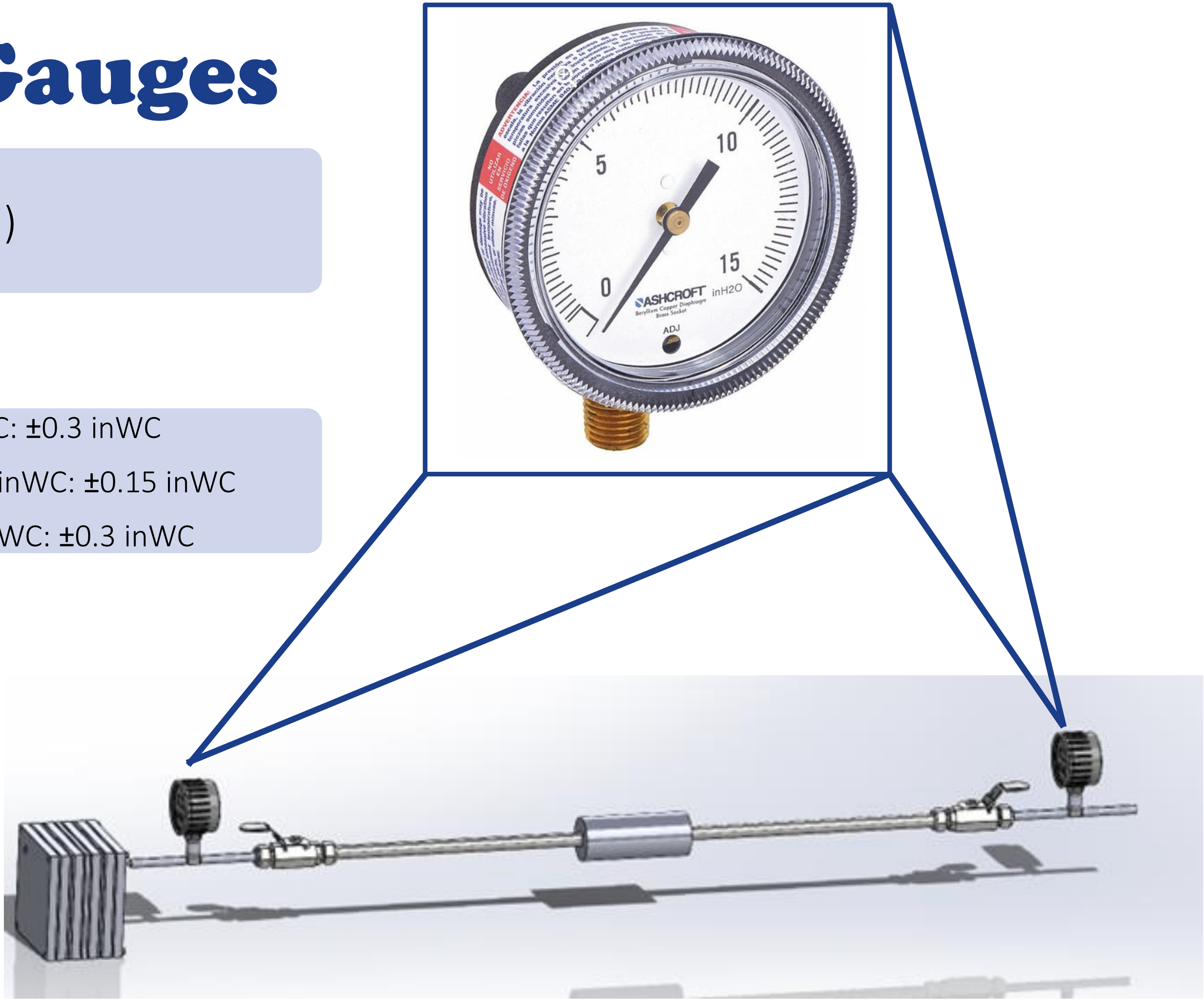
0-15 inWC (0-0.541 psi)

±2-1-2% accuracy

0-3.75 inWC: ±0.3 inWC

3.75-11.25 inWC: ±0.15 inWC

11.25-15 inWC: ±0.3 inWC



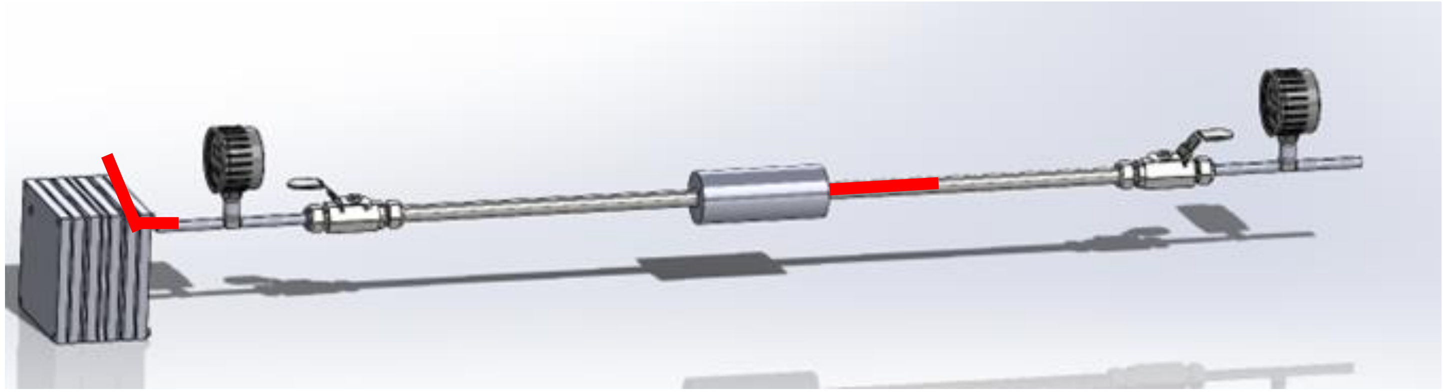
Requirement 1.1.2
"The system must be able to determine the rate of hydrogen gas produced."

Thermocouples

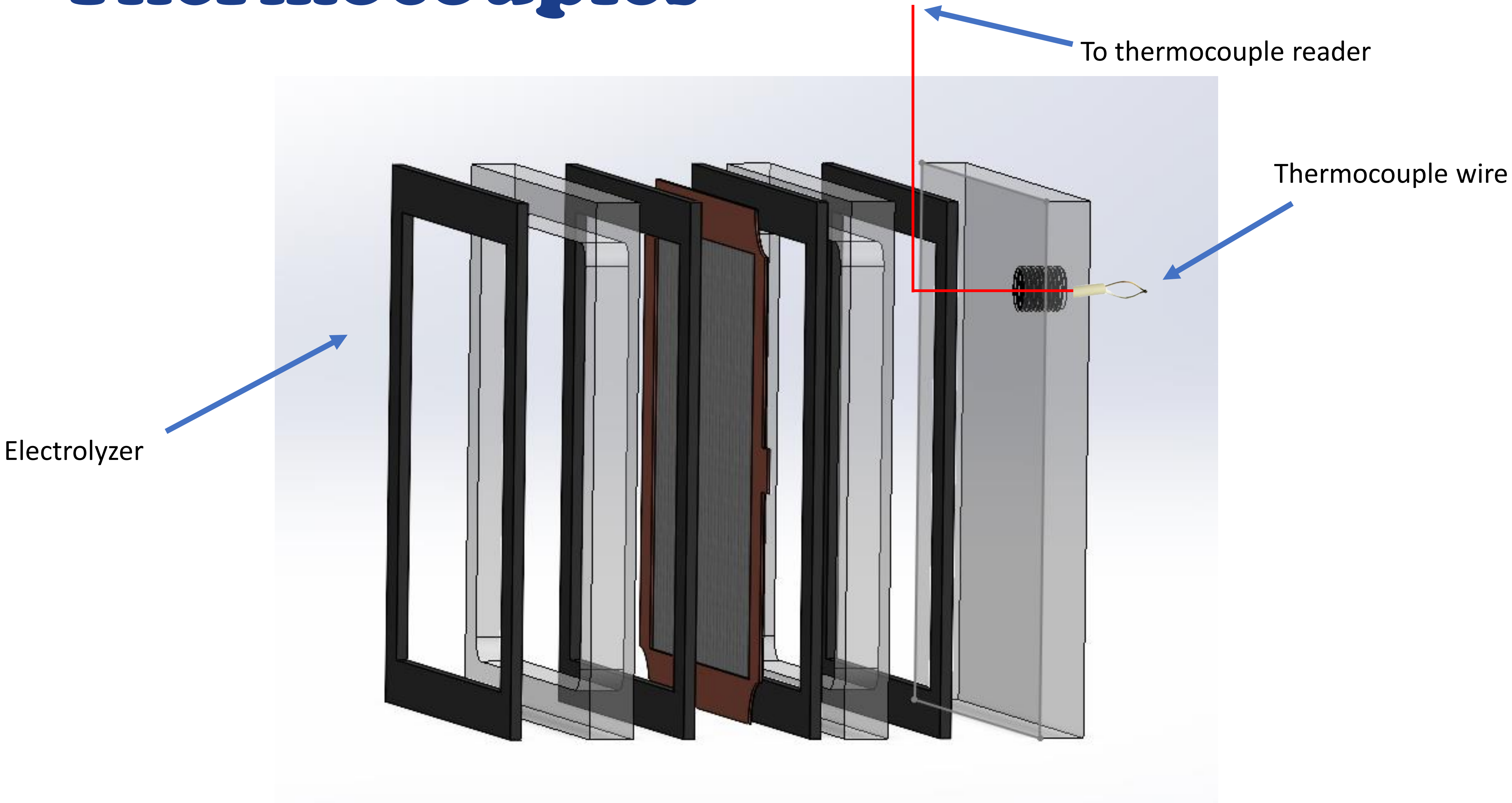
2 thermocouples

Integrated at Electrolysis and PTFE interface

Integrated under insulation in heat zone (high temperature insulated probe)



Thermocouples



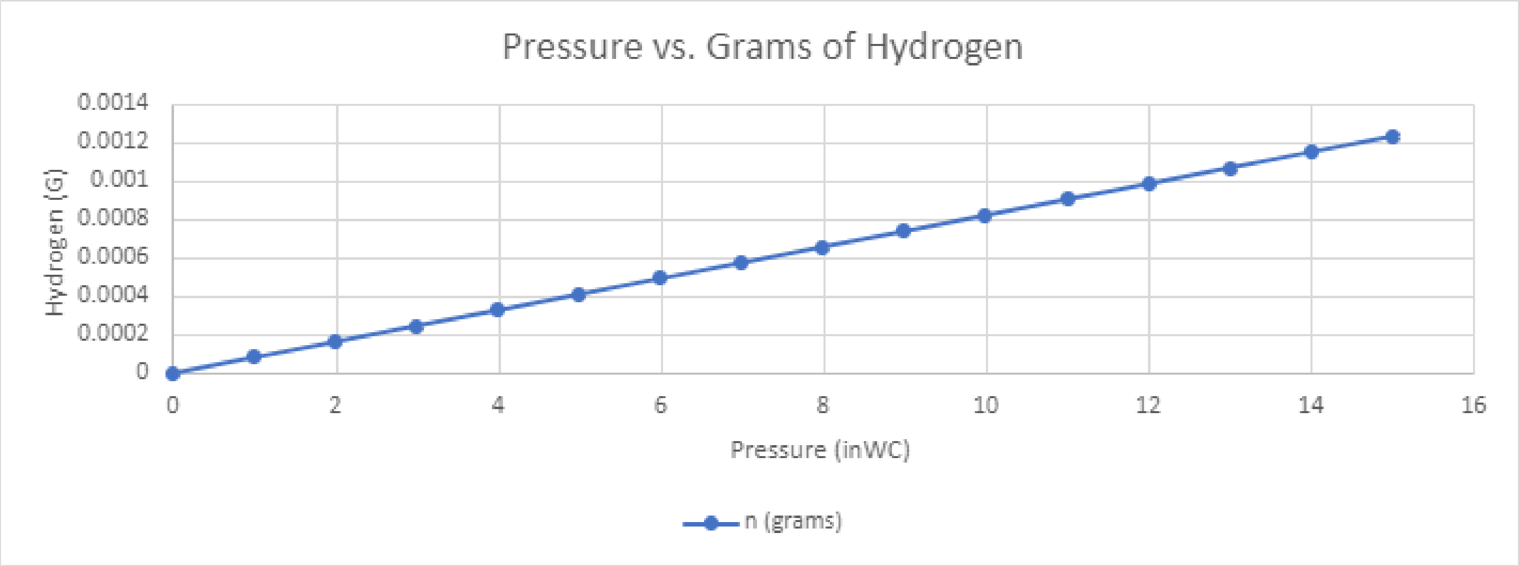
Governing Equations

$$PV = mRT$$

Where:

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

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



Mass Measurement

Chemistry lab scale to measure storage system mass

±0.0001 accuracy, 220 g Max

Storage capsule is about 20 grams

Requirement 1.2.1
"The system must measure the amount of hydrogen stored."

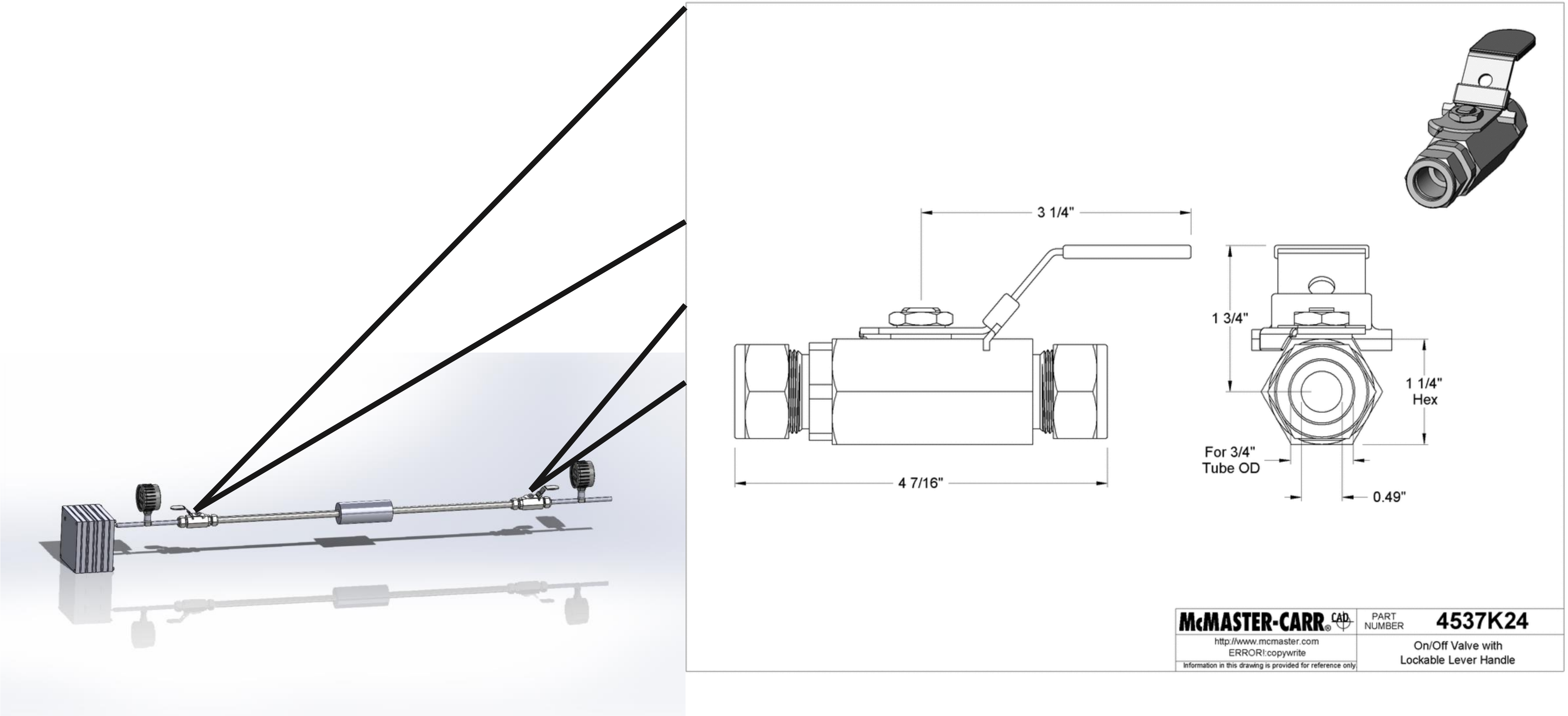
Instrumentation Verification

1.1.2 Determine rate of hydrogen production	• Verified with the pressure gauges and thermocouples using the Ideal Gas Law
1.2.1 Measure amount of hydrogen stored	• Verified with the chemistry scale
6.1 Instrumentation system must be self-reliant	• All instrumentation is self-contained (analog pressure gauges, battery powered thermocouple reader, battery powered scale)

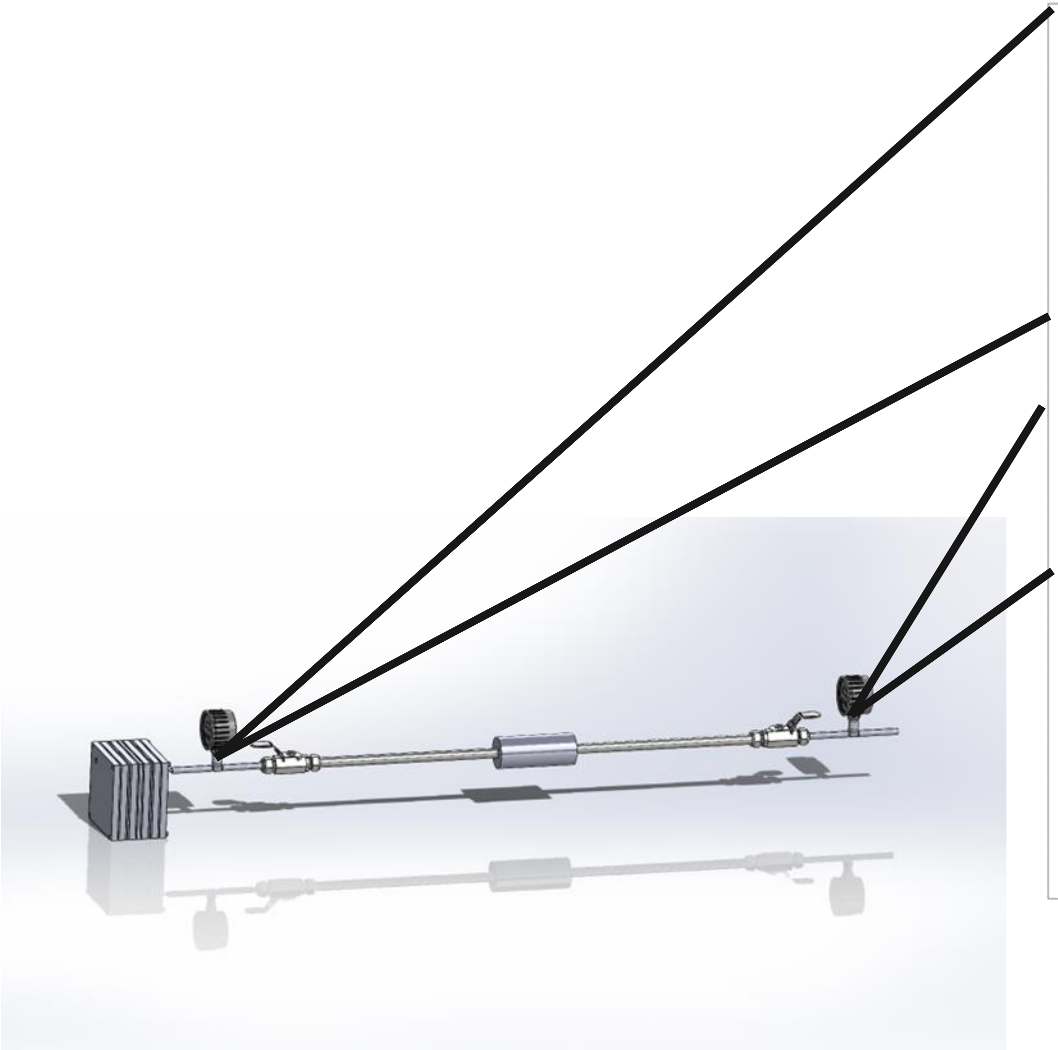
Interfaces

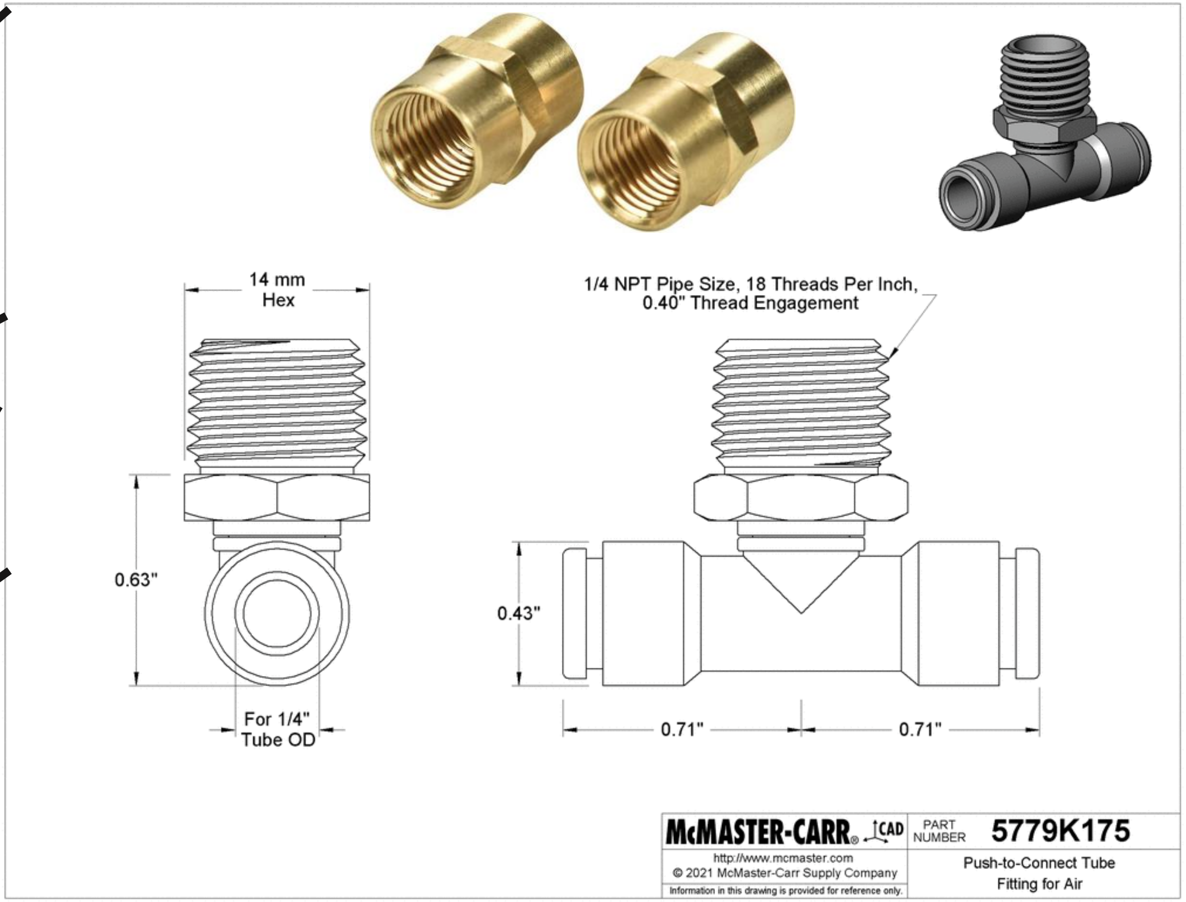
ERH2

Interfaces - Valves

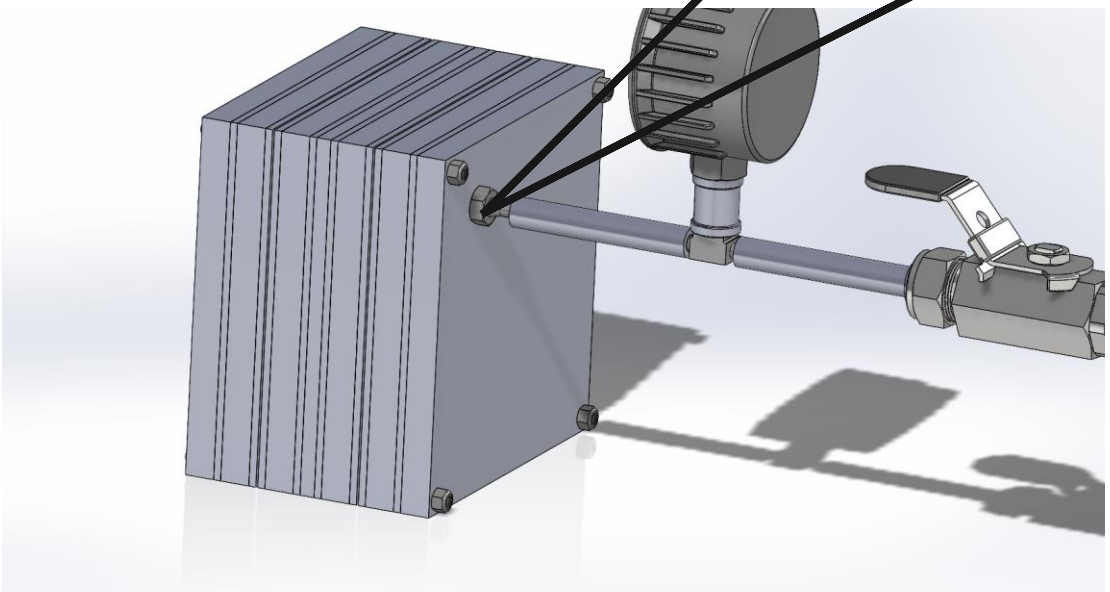


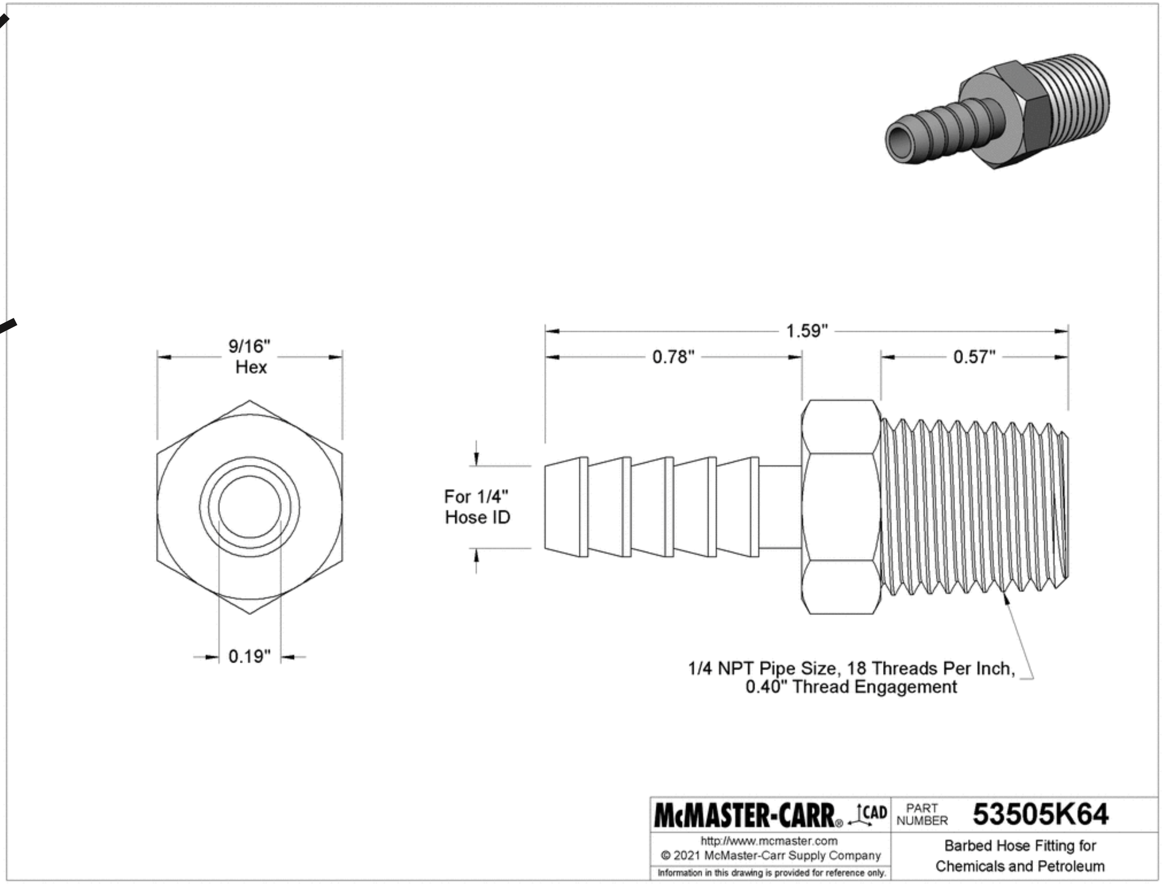
Interfaces – Tee Fittings





Interfaces – Electrolyzer Fitting

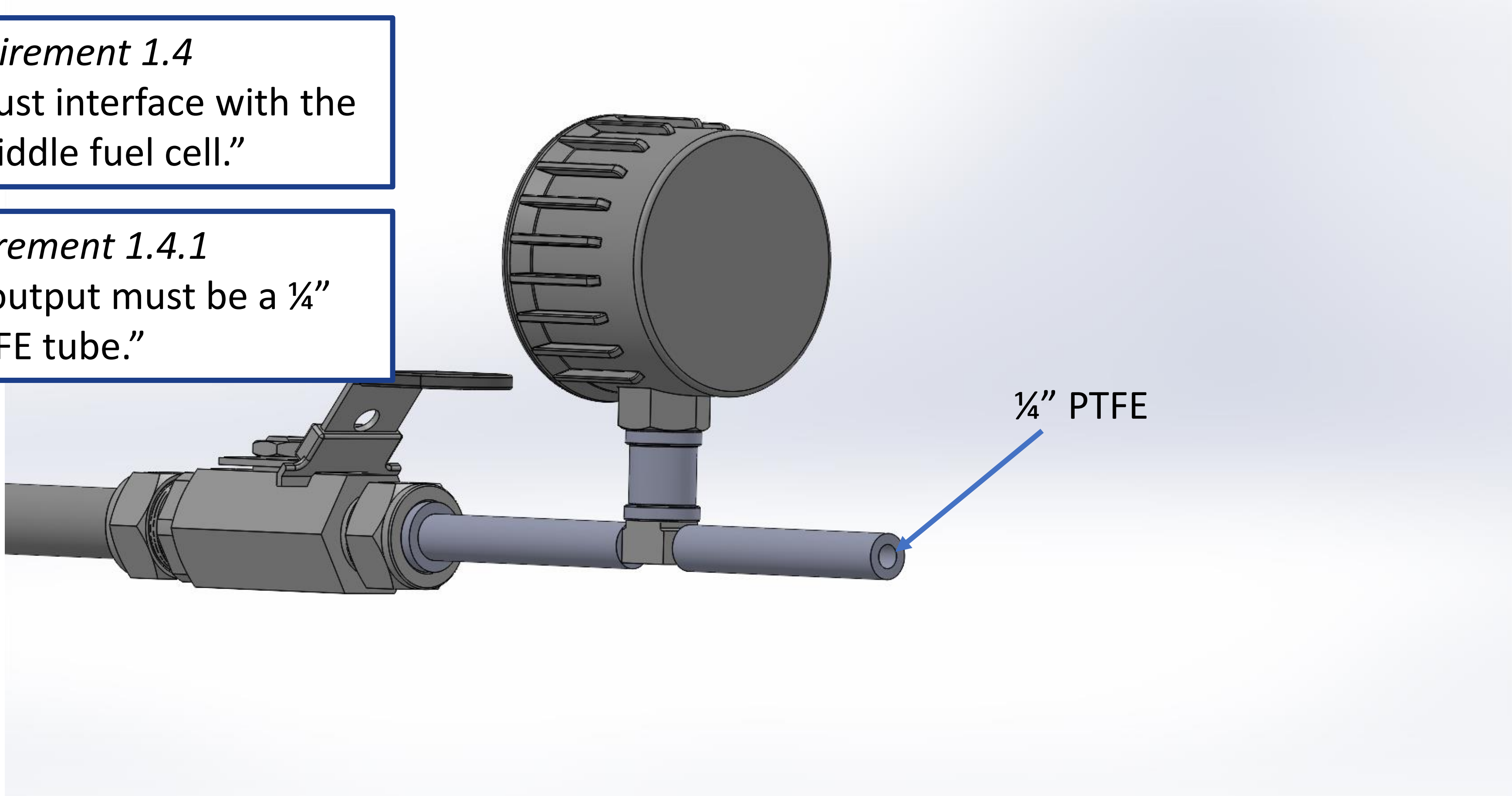




Fuel Cell Integration

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."



Detecting Leaks

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

[2]

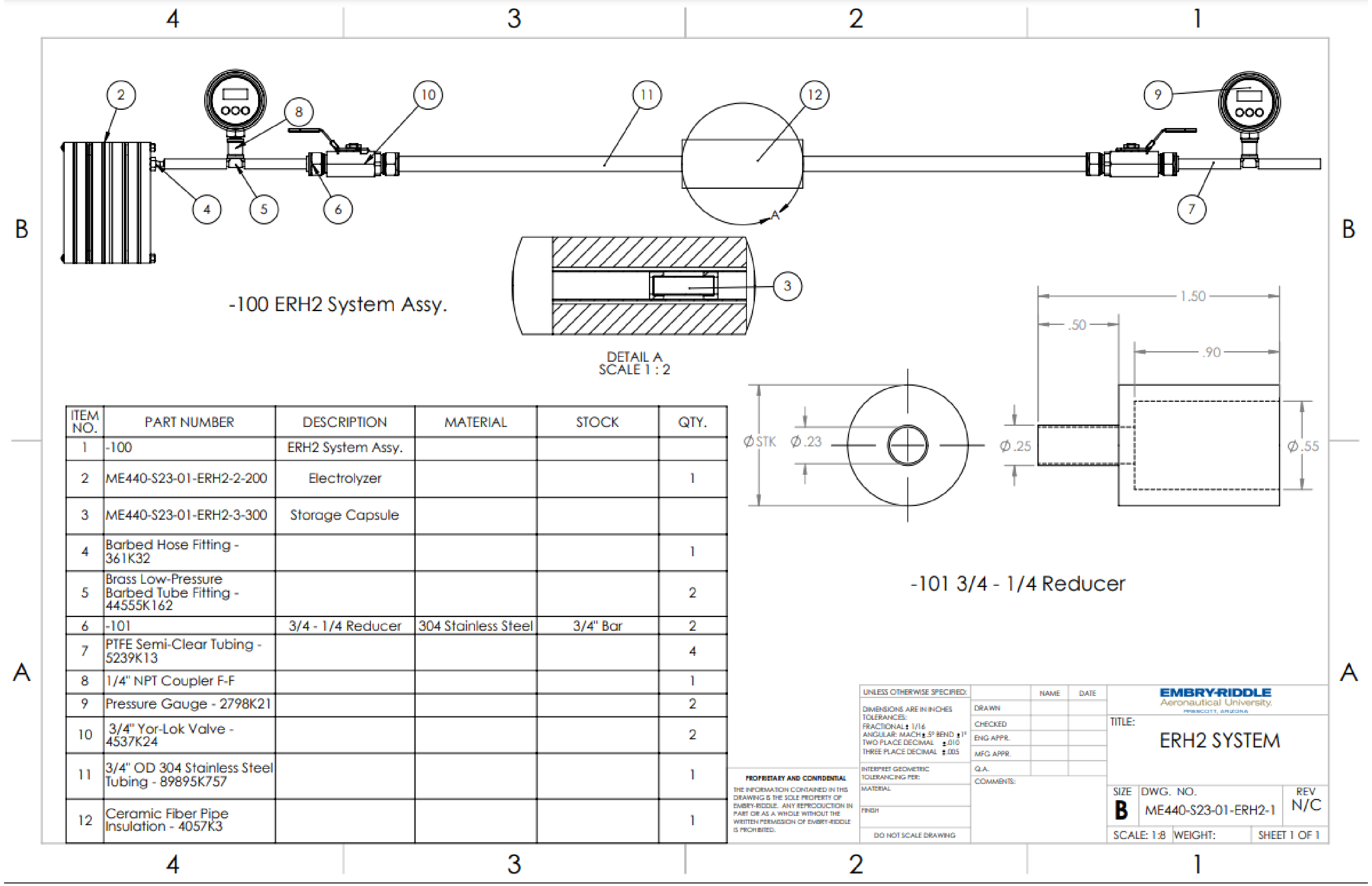
Drawings

Drawing Tree

- ME440-S23-01-ERH2-1 ERH2 System Assy. ✓
  - ME440-S23-01-ERH2-2 Electrolyzer ✓
    - -200 Electrolyzer
    - -201 Walls
    - -202 Space
    - -203 Stalactite
    - -204 Copper Bus
    - -205 Mesh
    - -206 Rubber Gasket
  - ME440-S23-01-ERH2-3 Storage Capsule ✓
    - -300 Storage Capsule
    - -301 Capsule Body
    - -302 Cap

✓ - In Review

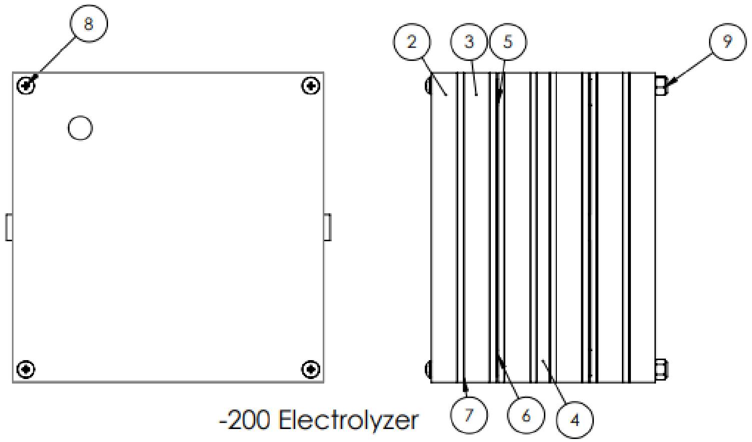
ERH2 Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	STOCK	QTY.
1	-100	ERH2 System Assy.			
2	ME440-S23-01-ERH2-2-200	Electrolyzer			1
3	ME440-S23-01-ERH2-3-300	Storage Capsule			
4	Barbed Hose Fitting - 361K32				1
5	Brass Low-Pressure Barbed Tube Fitting - 44555K162				2
6	-101	3/4 - 1/4 Reducer	304 Stainless Steel	3/4" Bar	2
7	PTFE Semi-Clear Tubing - 5239K13				4
8	1/4" NPT Coupler F-F				1
9	Pressure Gauge - 2798K21				2
10	3/4" Yor-Lok Valve - 4537K24				2
11	3/4" OD 304 Stainless Steel Tubing - 89895K757				1
12	Ceramic Fiber Pipe Insulation - 4057K3				1

Electrolyzer Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	Material	Stock	QTY.
1	-200	Electrolyzer			1
2	-201	Walls	Polycarbonate	1/2" Sheet	2
3	-202	Space	Polycarbonate	1/2" Sheet	4
4	-203	Stalactites	Polycarbonate	1/2" Sheet	1
5	-204	Copper Bus	Copper	π*10^-2	2
6	-205	Mesh	Nickel 400	200x200 Mesh	2
7	-206	Rubber Gasket	Rubber	1/2" Butyl Rubber	8
8	8-32 4.75" Pan Head Phillips Screw - 90272A363				4
9	8-32 Steel Nylon Locknut - 90631A009				4



-200 Electrolyzer

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± .5° BEND ± 1°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

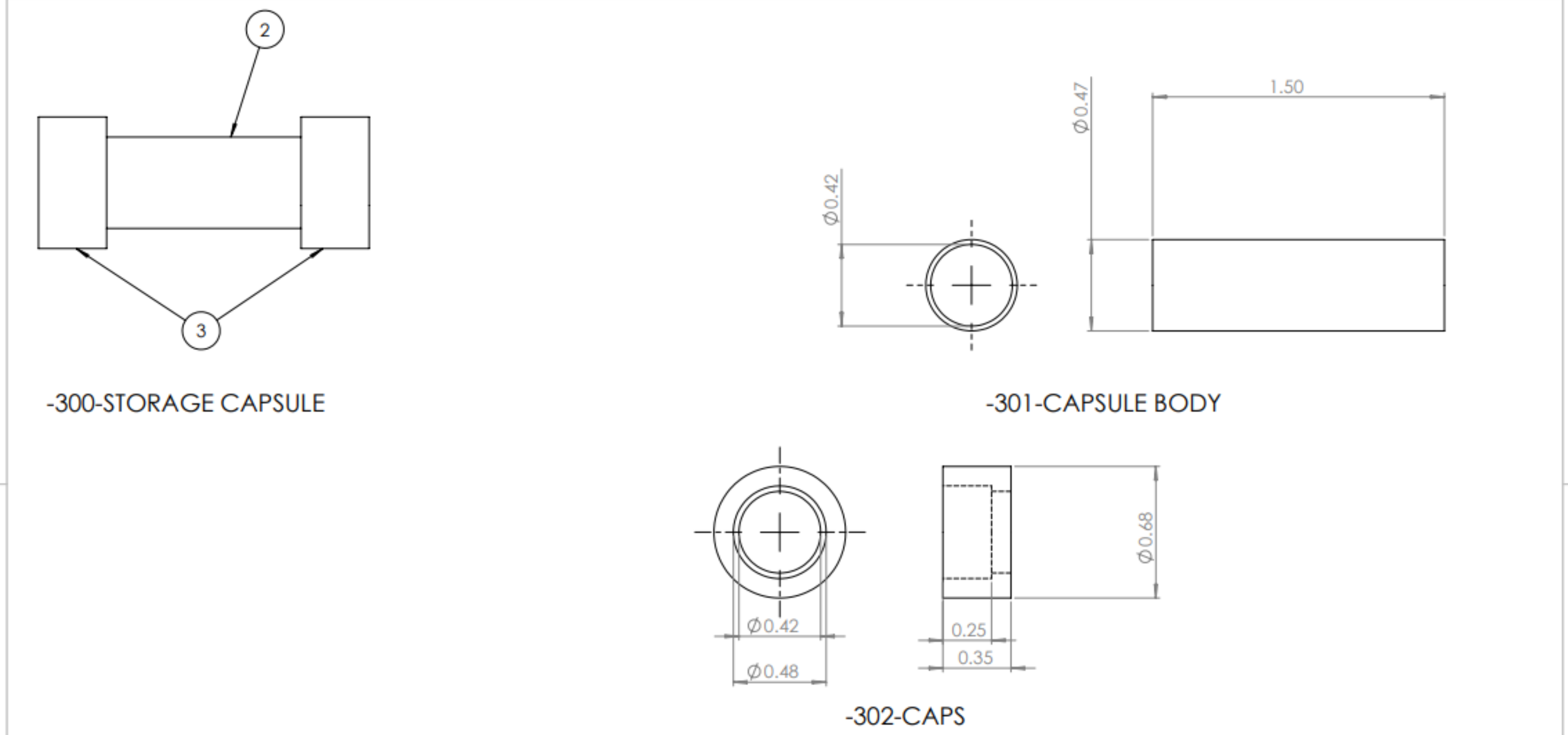
EMBRY-RIDDLE Aeronautical University PRESCOTT, ARIZONA

TITLE: ERH2 Electrolyzer

SIZE B | DWG. NO. ME440-S23-01-ERH2-2 | REV N/C

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 3

Storage Capsule Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	STOCK	QTY.
1	-300	STORAGE CAPSULE			
2	Capsule Body		304 Stainless Steel	3/4" Bar	1
3	Caps		304 Stainless Steel	3/4" Bar	2

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DIMENSIONS ARE IN INCHES
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MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

EMBRY-RIDDLE Aeronautical University. PRESCOTT, ARIZONA

TITLE: Storage Capsule

SIZE: B | DWG. NO. ME440-S23-01-ERH2-3 | REV N/C

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

Test Matrix

Test Overview	Brief Description	Success Criteria
Leak test	Apply soap solution to interfaces and run compressed air through system.	The test is successful if no bubbles form
Temperature verification	Turn on nichrome wire and measure temperature at heating zone and pipe outlet.	Ends of the pipe do not exceed 60 C and find temperature/power relation
Electrolysis hydrogen production rate	Run electrolysis at different amperages and record change in pressure to determine amount of hydrogen produced.	Electrolysis produces at least 0.002 grams of hydrogen every minute
Material storage capacity	Load material with hydrogen and weigh before and after.	Final mass of the capsule is at least 0.02 grams heavier than the initial mass
Material storage release ratio	Extract hydrogen from material, time how long it runs fuel cell, and weigh the material after.	Final mass of the capsule is equal to the initial mass of the capsule OR the fuel cell is able to run for at least 5 minutes
Material release rate	Extract hydrogen from material and monitor amount with pressure gauge over time.	Pressure gauge indicates a change in pressure equivalent to 0.02 grams of hydrogen over a 10 minute time period

Risk Analysis

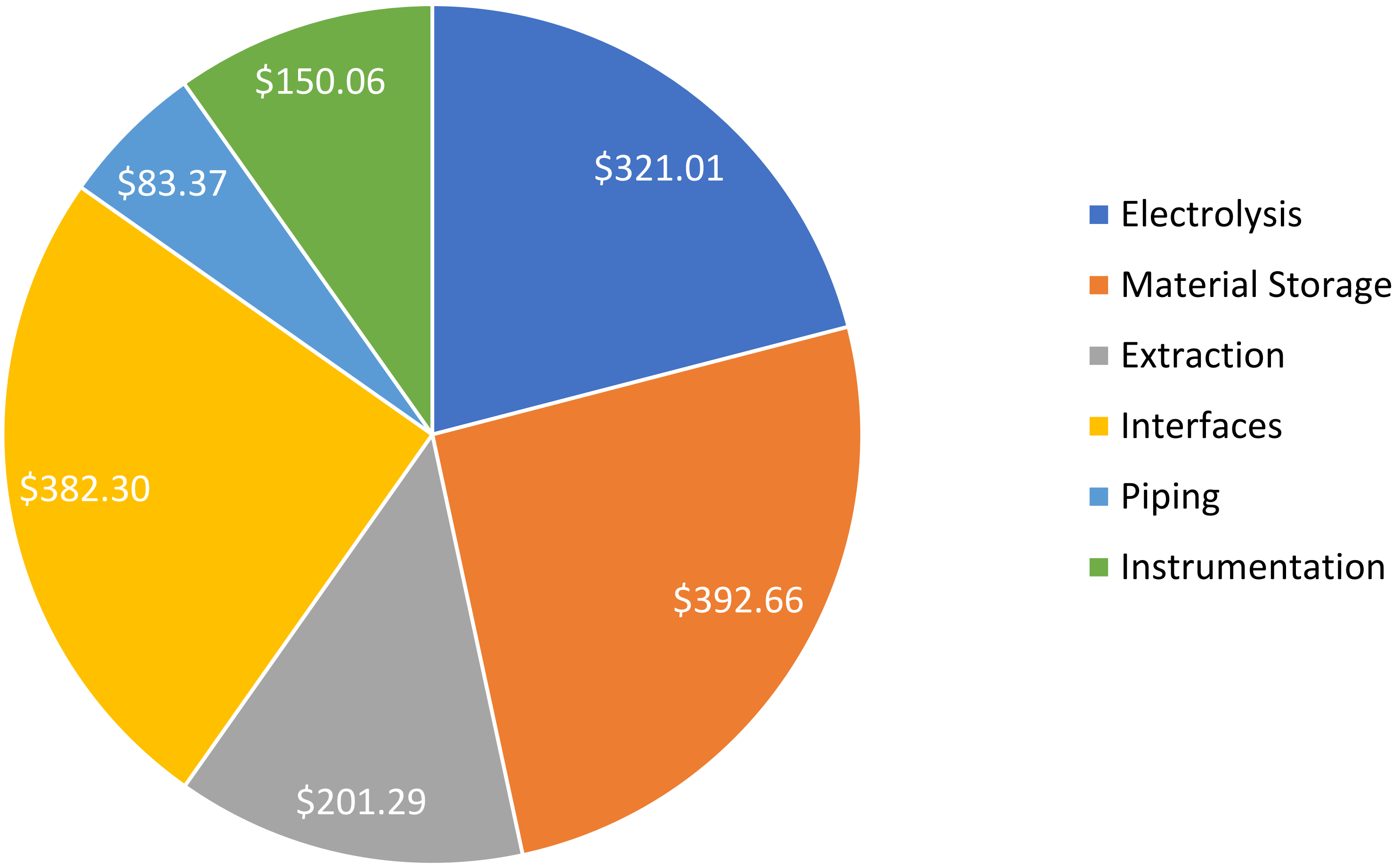
Asset or Operation at Risk	Hazard	Scenario	Probability	Overall Hazard Rating
Overall System	Explosion	Hydrogen Leak, normal operation	Improbable	1D
Electrolysis	Electrocution	Short Circuit	Improbable	1C
Electrolysis	Fire	Excess Oxygen	Improbable	1E
Electrolysis	Ozone	Ozone production	Improbable	1C
Heating Element	Burns	Contact with Heating Element	Seldom	2D

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

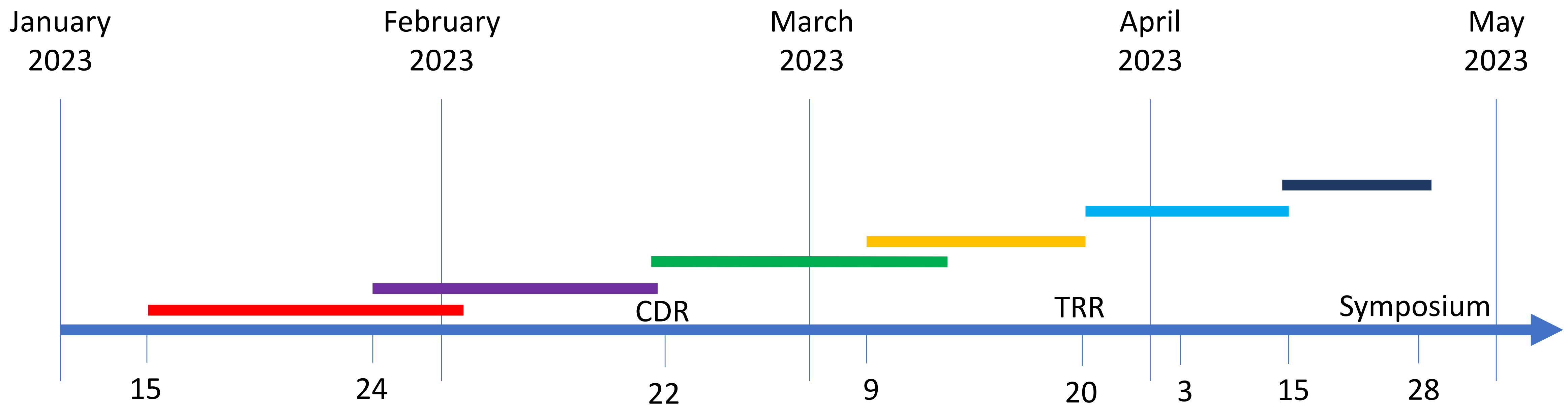
Budget and Schedule

Budget

- Total: $1530.69
- $230.69 over budget
- Bill of Materials



Schedule



- Delta PDR prep
- Drawings and CDR prep
- Procurement and Fabrication
- Test Plans and TRR prep
- Testing
- Final Report

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

Questions?

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)

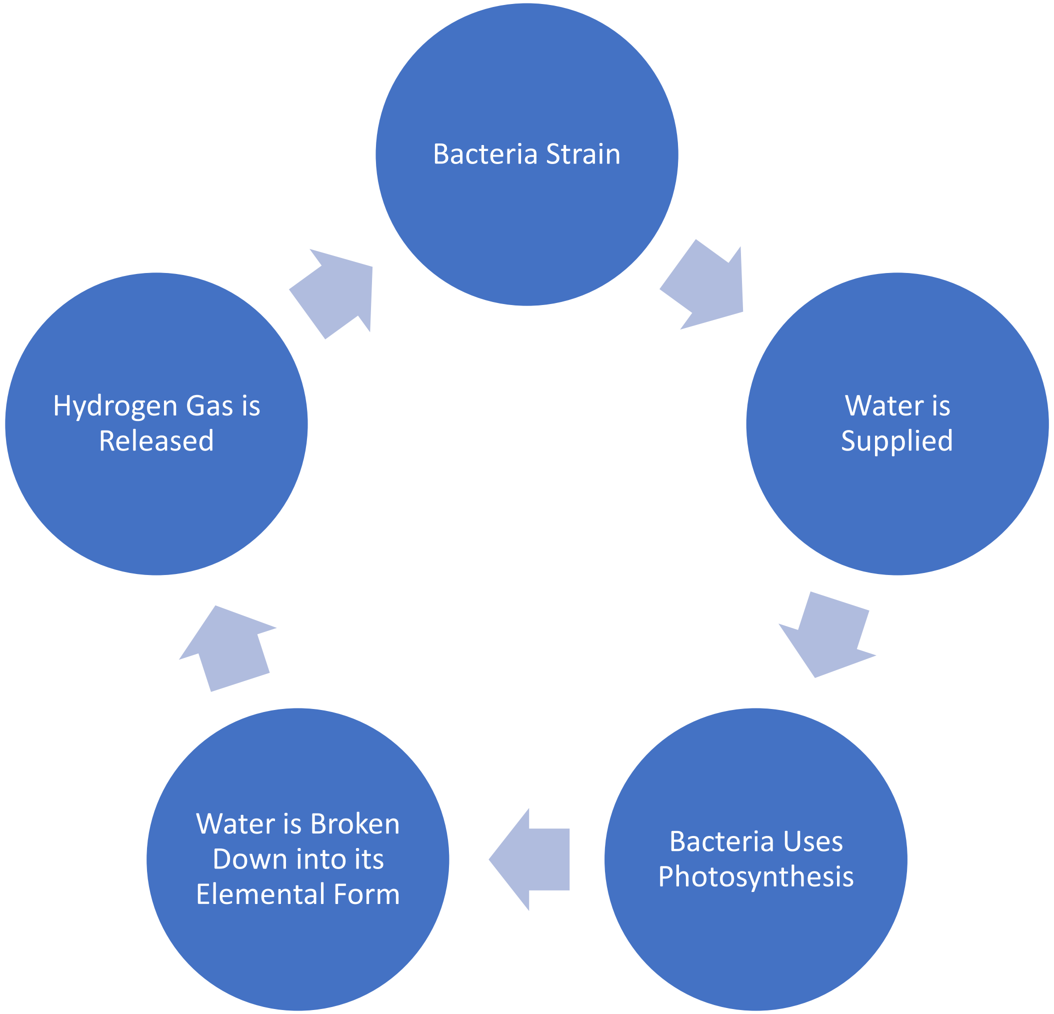
Steam-Methane Reforming

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

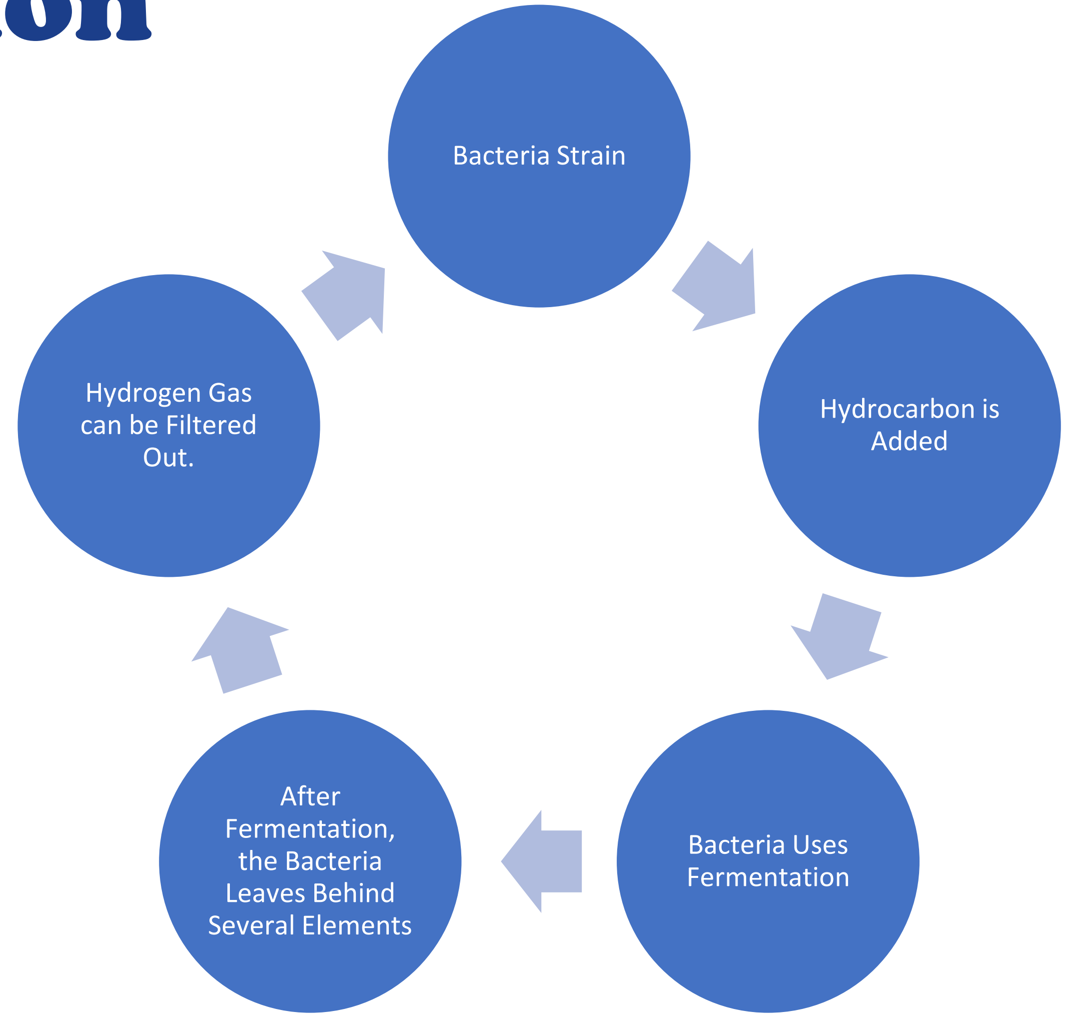
Hydrogen Extraction

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

Generation - Photobiological



Generation - Microbial Biomass Conversion



ERH$_2$

Storage – Physical Storage

Compressed

- 5,000-10,000 PSI
- Unique Pressure Vessels

Cryogenic

- Liquid H2 at -252.2 °C
- Solid H2 at -259.14°C

Storage – Material Storage

Adsorbtion

Hydrogen is Stuck to the Compound's Surface

Absorption

Hydrogen is Encased by the Compound

ERH$_2$

Equations – Area of Mesh

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

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

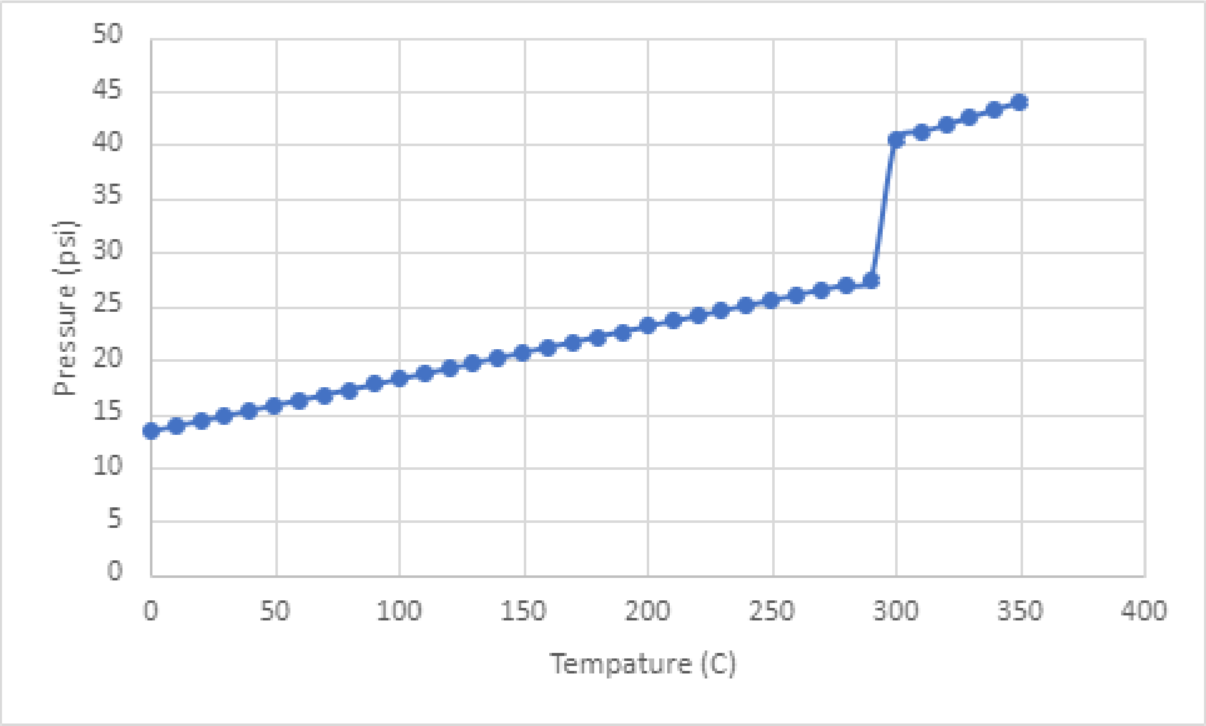
Heat Loss / Required Power

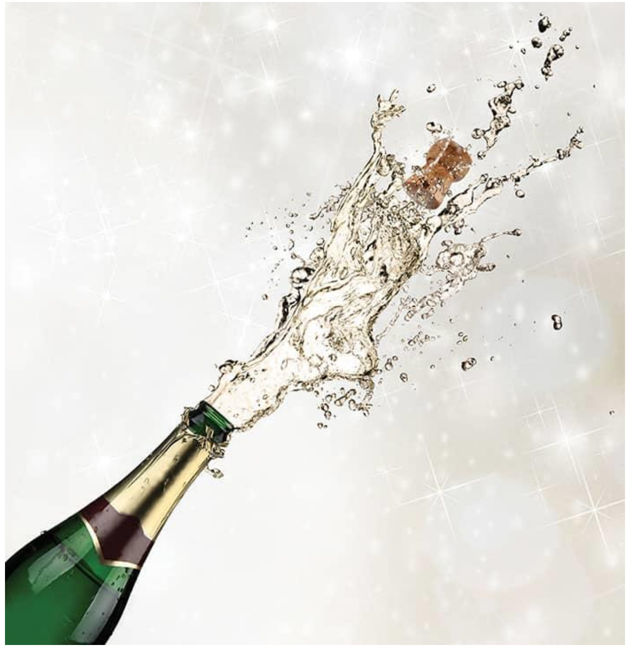
Outer Diameter:	0.75	0.75	(in)
Inner Diameter:	0.68	0.68	(in)
Thermal Conductivity	20	20	(W/m*K)
Surface Temperature	350	50	(°C)
Outer Diameter	0.01905	0.01905	(m)
Gravitational Constant	9.81	9.81	(m/s^2)
Bulk Temperature	20	20	(°C)
Volume Expansion Coefficie	2.18E-03	3.27E-03	(K^-1)
Kinematic Viscosity	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





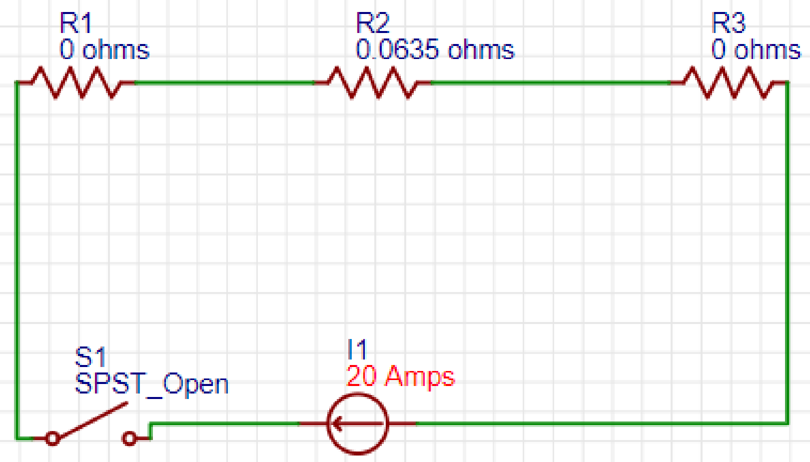
Electrolysis Power Circuit

R1 = R3

- Nickel Mesh

R2

- Salt Water



ERH2

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