ERH$_2$

EMBRY-RIDDLE HYDROGEN

Electrolysis and Material Storage of Hydrogen Gas

Team Members

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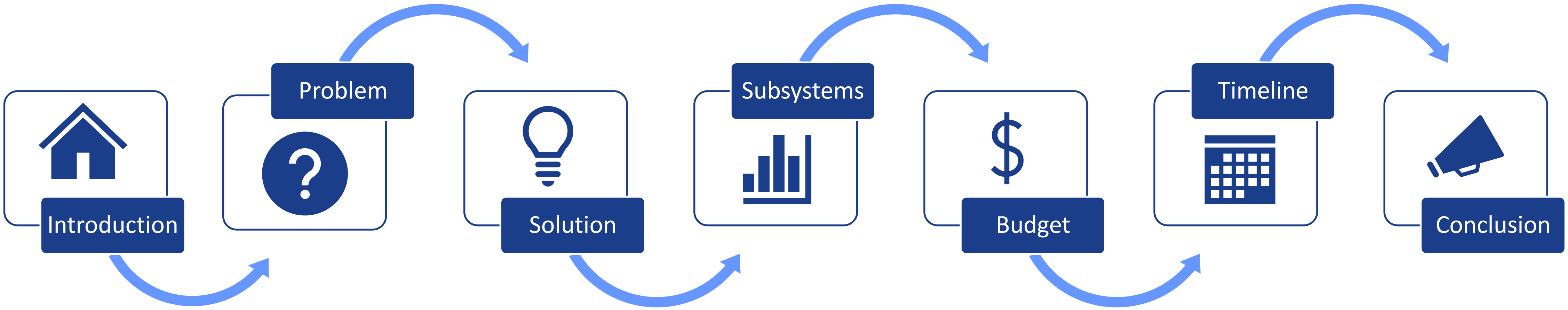
Agenda


Introduction
Problem
Solution
Subsystems
Budget
Timeline
Conclusion

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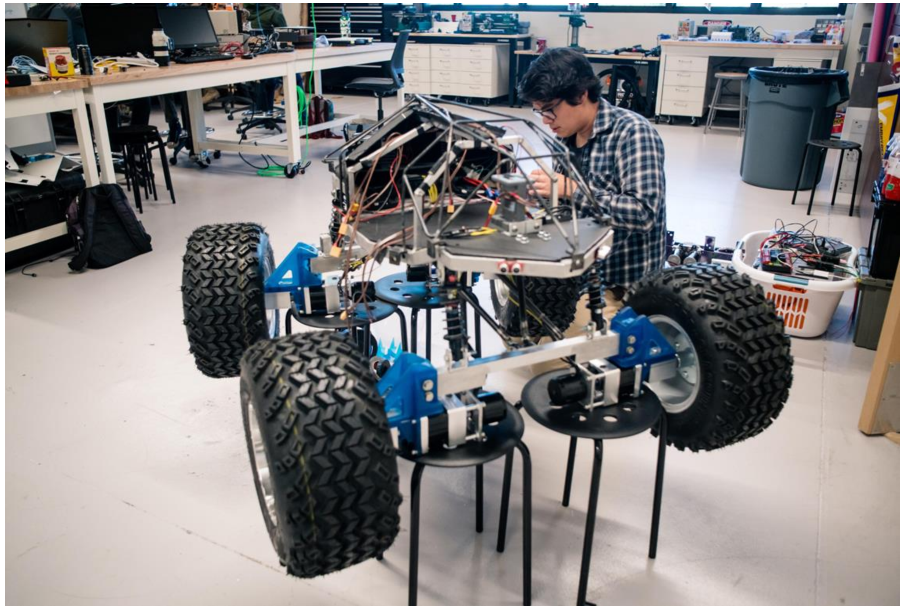
What Embry-Riddle Has

Wind Tunnel



Robotics Lab

Propulsion Lab

Embry-Riddle does *not* have

Energy Labs

Energy Classrooms

Viewable Demonstrations

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DOE Research into Hydrogen

The DOE is researching multiple uses for hydrogen gas, producing the need for more hydrogen. This creates interest within Embry-Riddle to create an alternative energy demonstrator that teaches the general public about hydrogen fuel and storage.

Funding Notice: Clean Hydrogen Production, Storage, Transport and Utilization to Enable a Net-Zero Carbon Economy

Amount: $32 million

Generate and Store Hydrogen

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

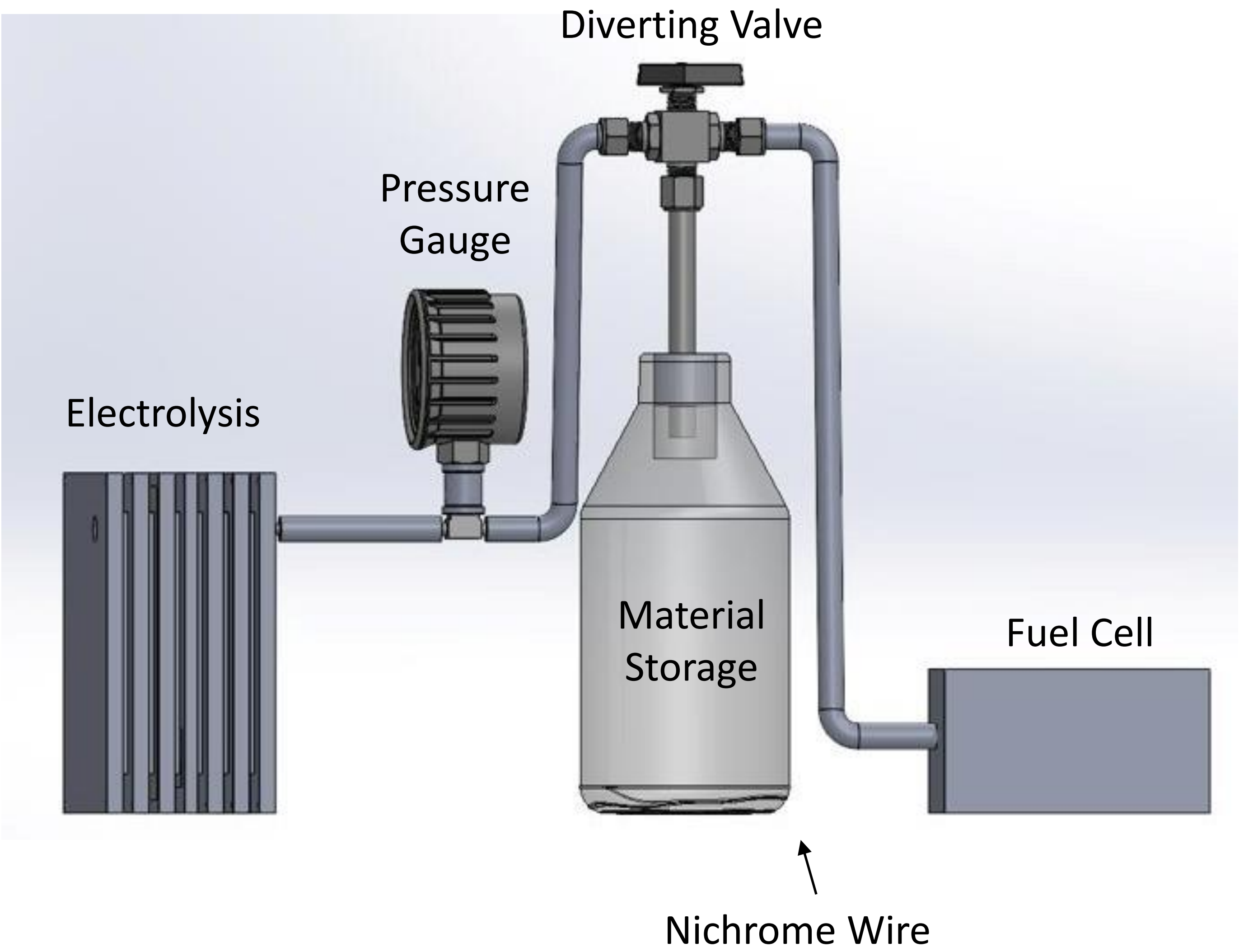
Benefits of ERH2 System

Alternative Energy Storage

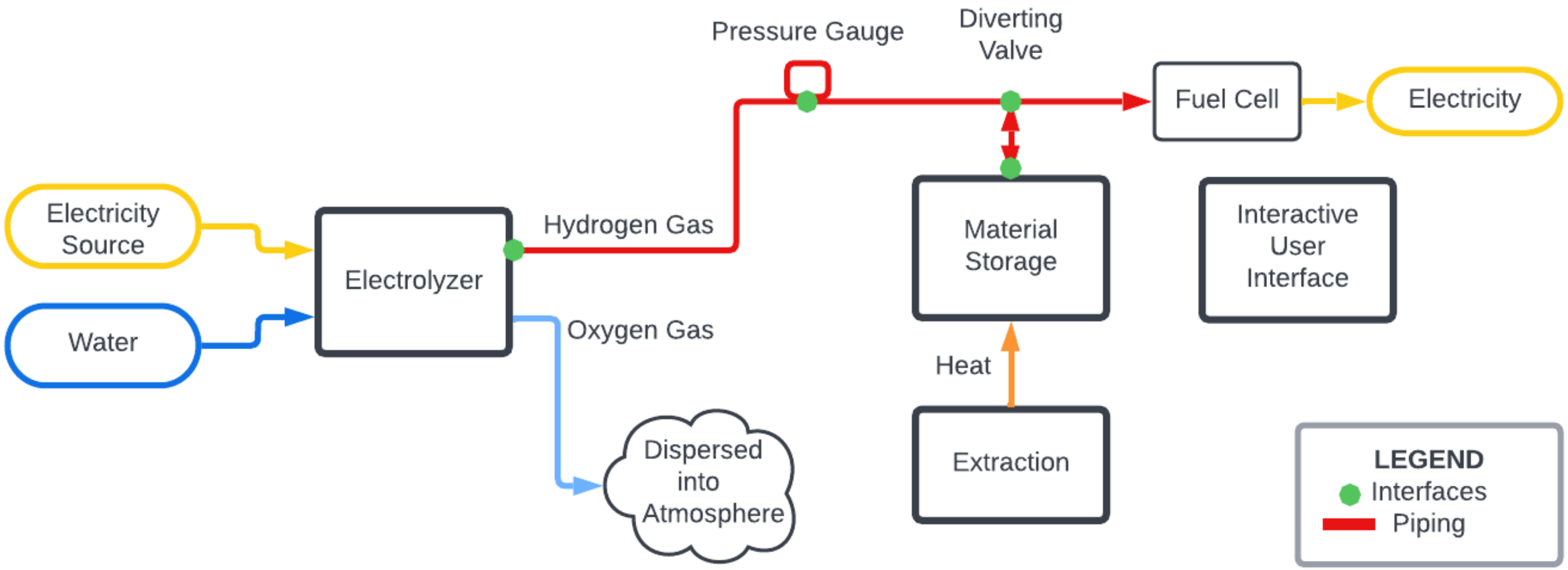
Scalable Production Rate

Sole Source of H^2 on Campus

The ERH2 System



Process Flow Diagram



Simplified PFD

Critical System Requirements

Produce 0.02 grams of hydrogen over 10 minutes
Store 0.04 grams of hydrogen
Safely extract hydrogen from system
Internal components visible

Electrolysis Equation

$$2H_2O \longrightarrow 2H_2 + O_2$$

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Hydrogen Production Requirement

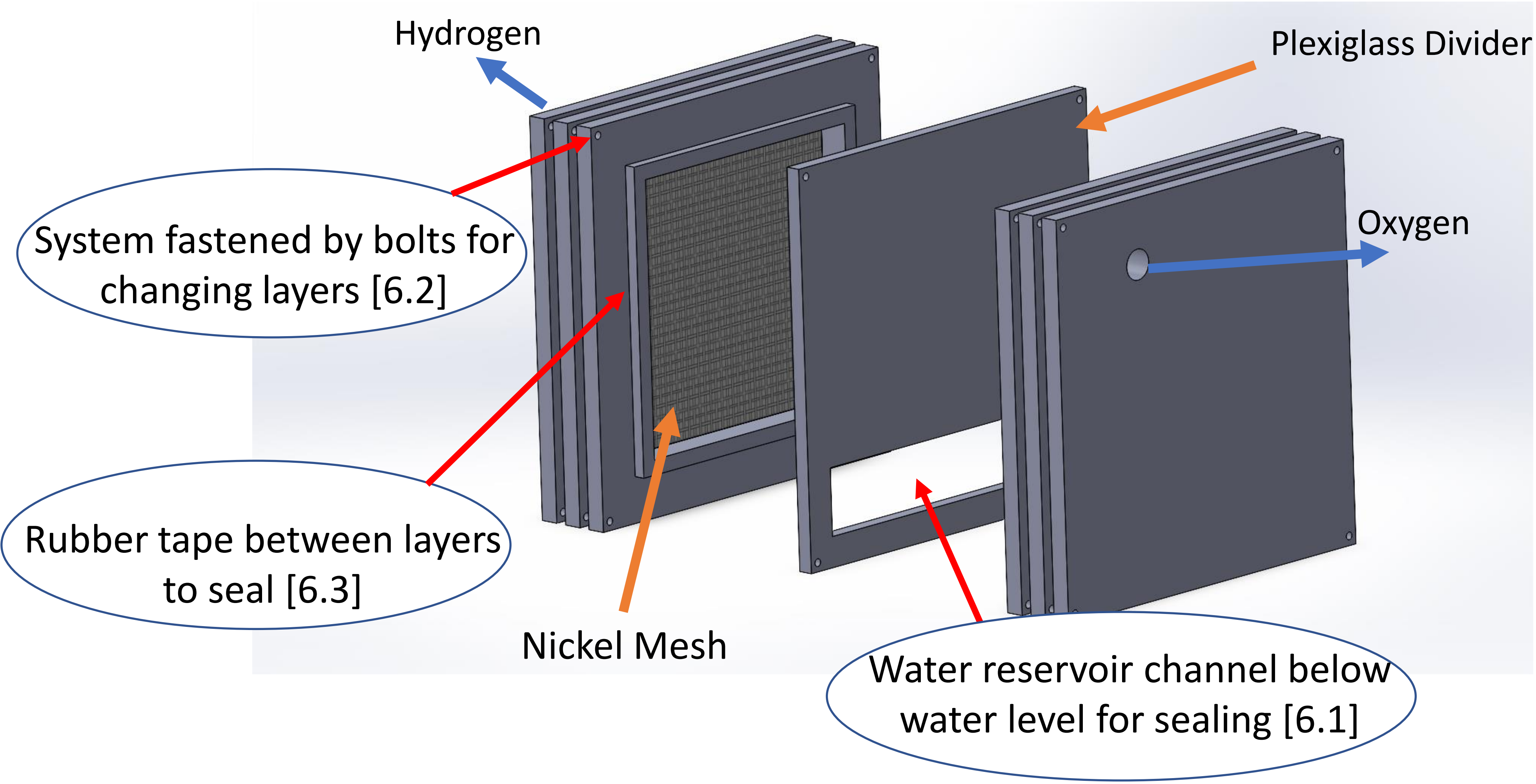
$$\frac{Power\ wanted(kW) * Time(sec.)}{Percent\ Eff\ of\ fuel\ cell * Lower\ heating\ value\left(\frac{KJ}{Kg}\right)} = Amount\ needed(g\ H_2)$$

$$\frac{.001kW * 600\ (sec.)}{0.25 * 120{,}000\left(\frac{KJ}{Kg}\right)} = .02\ (g\ H_2)$$

Electrolysis

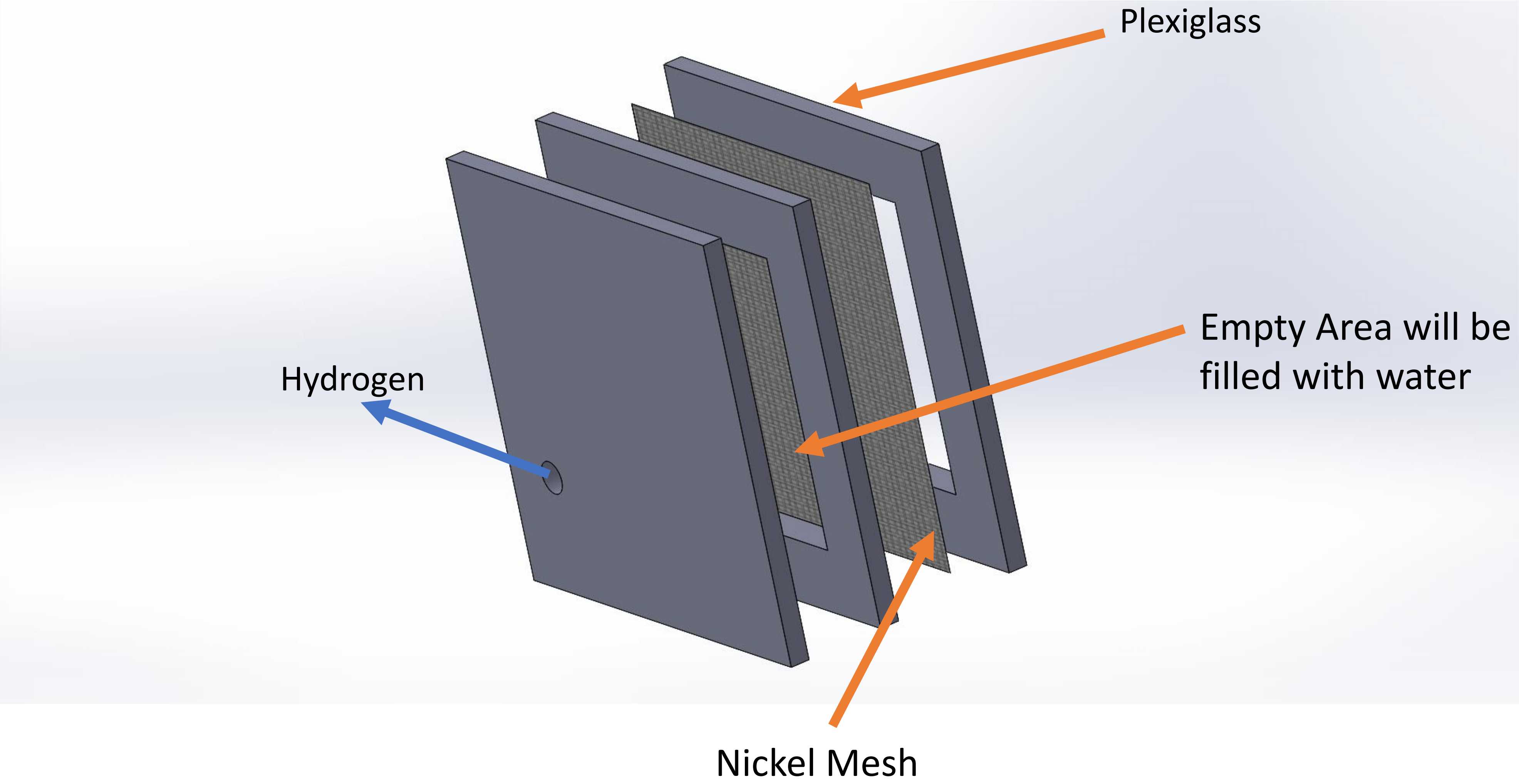
ERH2

Electrolysis Breakdown



Model of ERH2’s planned Electrolyzer

Mesh Section-View



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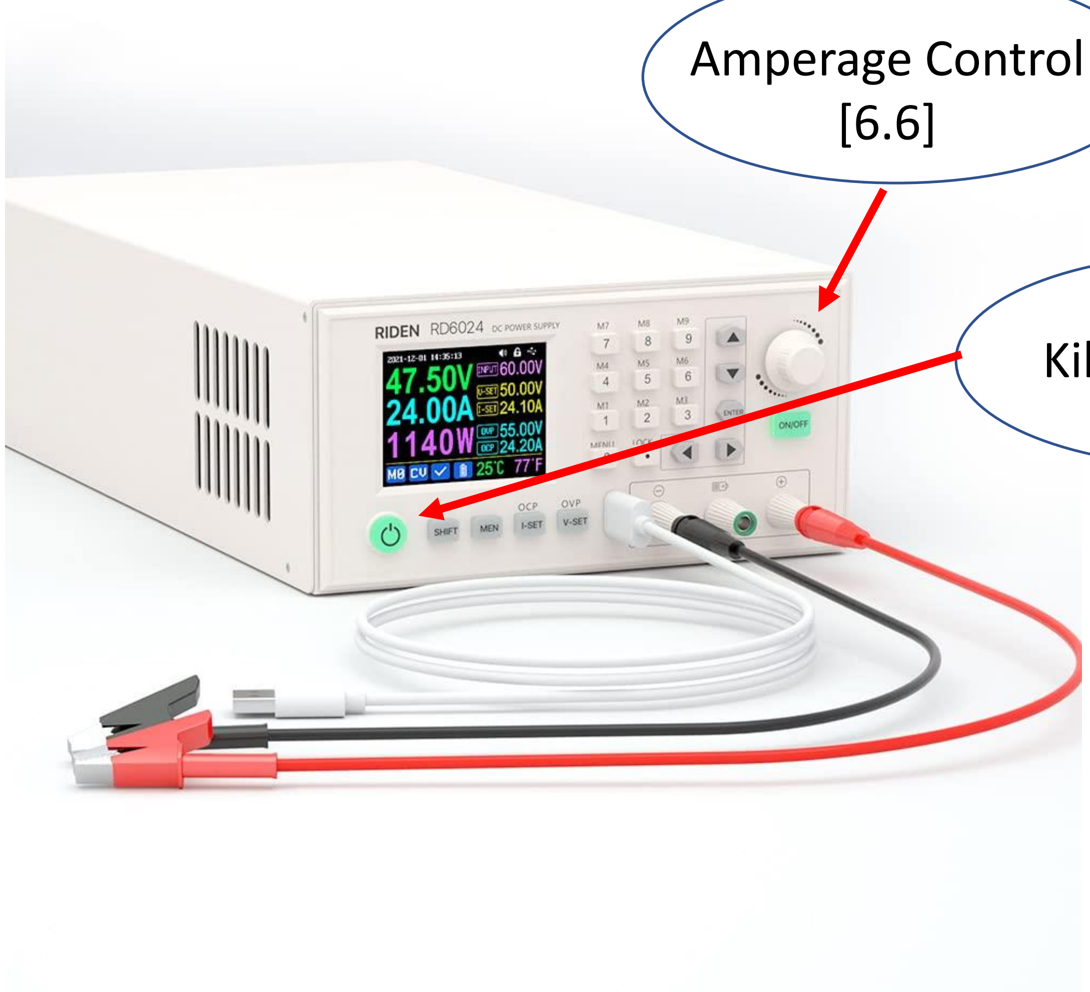
Power Supply



Amperage Control [6.6]

Kill Switch [6.7]

ERH₂

Faraday's Law of Electrolysis

Rate of H2 Production

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

$$\frac{20\ (C)}{1\ (s)} * \frac{600\ (s)}{96{,}485\ (C)} * \frac{1\ (mol\ H_2)}{2\ (mol\ e^-)} * \frac{2.007\ (g\ H_2)}{1\ (mol\ H_2)}$$

$$= 0.125\ (g/10min\ H_2)$$

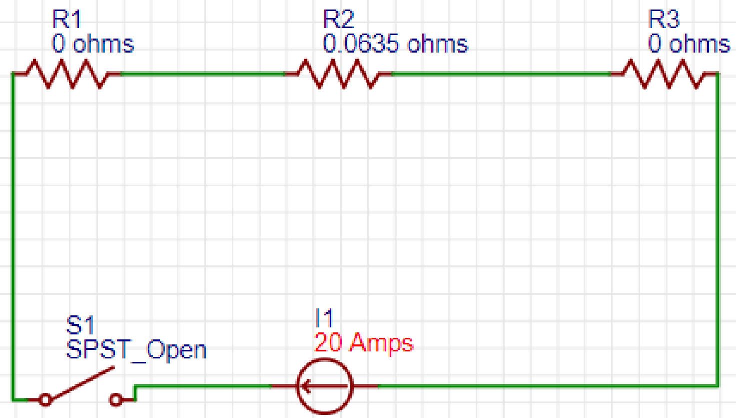
Electrolysis Power Circuit

R1 = R3

- Nickel Mesh

R2

- Salt Water



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Electrolysis Summary

Requirement	Design	Expected Performance	Verification
6.1	The hydrogen and oxygen will be separated at creation	100%	Fuel Cell Runs
6.2	The system was designed to be sandwiched together into different layers making it replaceable	Life of bolts used	It will come apart
6.3	Ability to bolt together	The life span of seals	It will come apart

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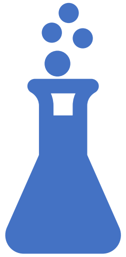
Electrolysis Summary

Requirement	Design	Expected Performance	Verification
6.4	Will be made of plastic	Nonconductive	Voltmeter
6.5	Will use 12-gauge wire	Rated for 20 amp	National Electrical code
6.6	Will set power supply to max 20 amps	Max 20 amps	Power supply read out
6.7	Have and on off switch	100%	System turns off

Material Storage

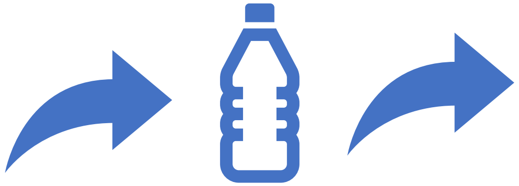
ERH_2

System Requirements



1.2

"The system must store 0.04 grams of hydrogen gas."

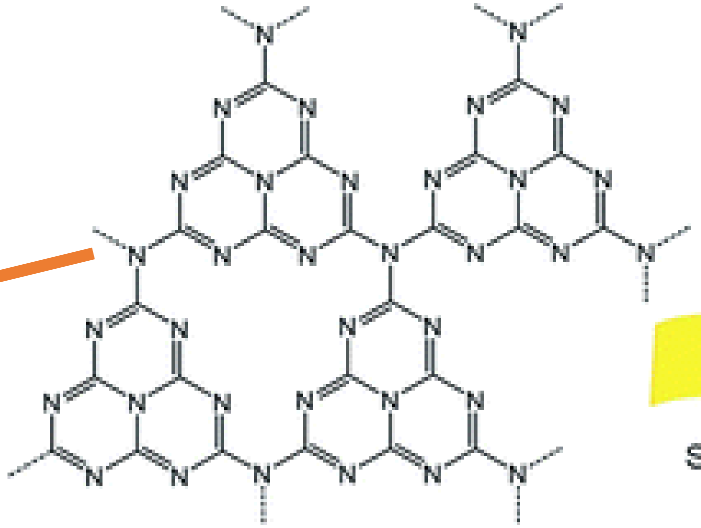


4.1

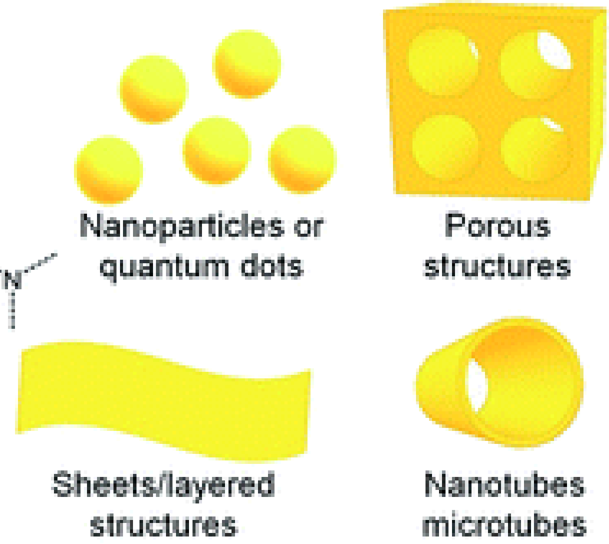
"The material storage efficiency (hydrogen in vs. hydrogen out) must be at least 50%."

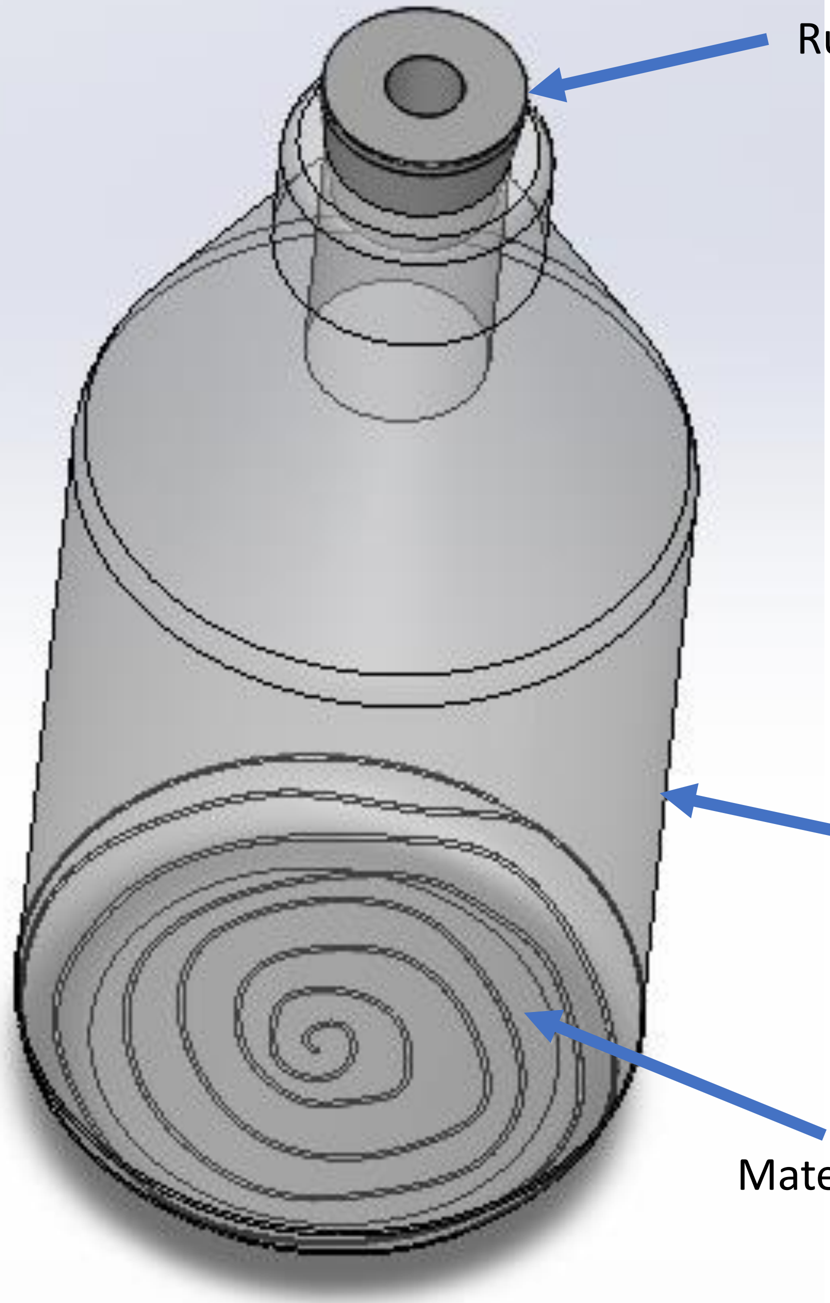
Lithium-Doped Graphitic Carbon Nitride [$Li_2C_4N_3$/ $Li_2C_4N_4$]

Naked Eye



Molecular Level





Subsystem Definition

The material storage subsystem is made up of a graduated bottle holding graphitic carbon nitride and rubber stopper to seal the bottle.

Equations

$$E_{Material} = \frac{m_{H_2out} - m_{H_2in}}{m_{H_2in}} \qquad m_{Stored} = m_{initial} - m_{final} \qquad \%_{wtH_2} = \frac{m_{Stored}}{m_{final}} * 100$$

Where:

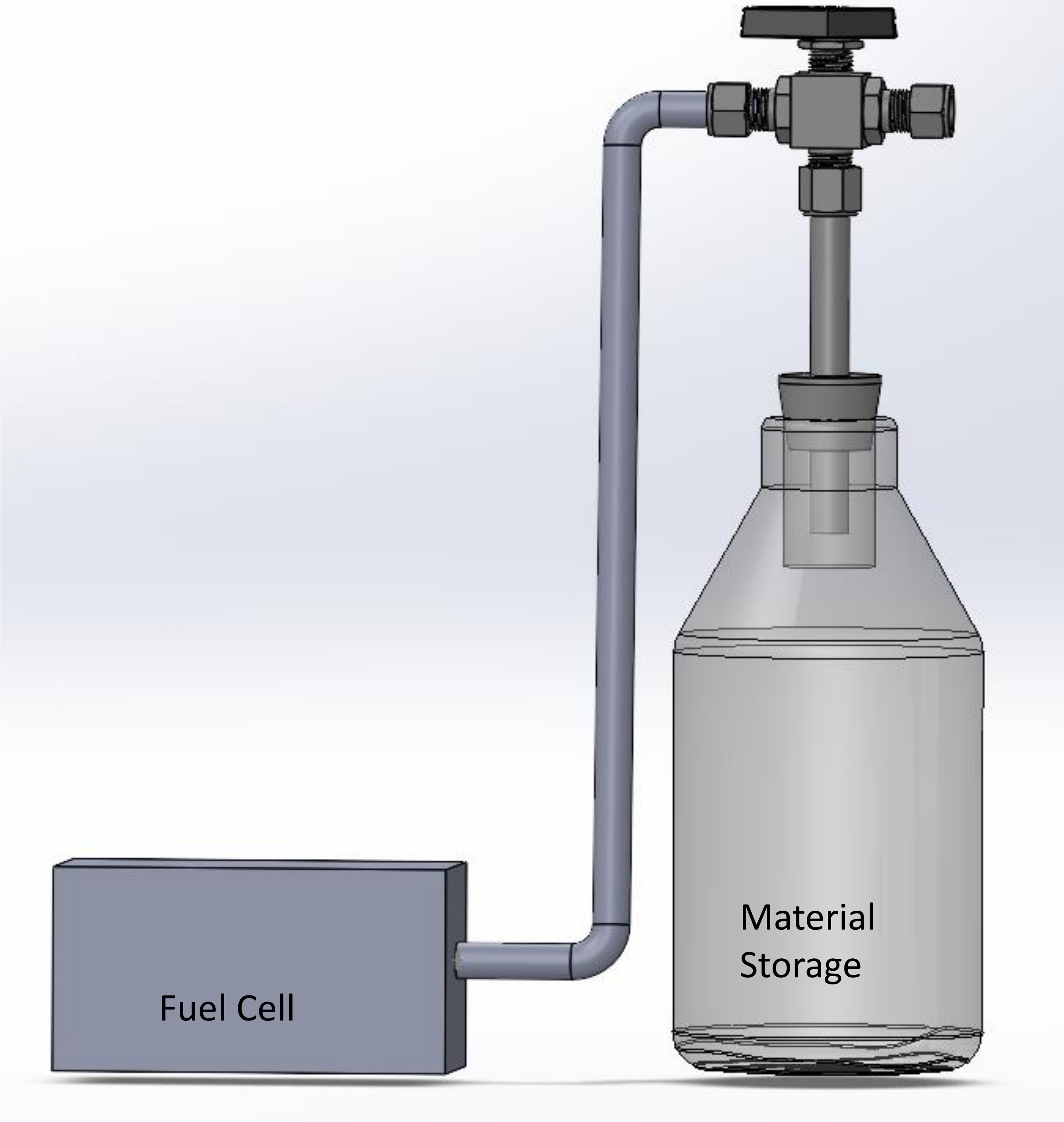
$E_{Material}$ = Material Efficiency
m_{H_2in} = Mass of hydrogen into the material storage system
m_{H_2out} = Mass of hydrogen leaving the material storage subsystem.
m_{Stored} = Mass of hydrogen stored in material storage
$m_{initial}$ = Mass of the storage before hydrogen is introduced
m_{final} = Final mass of the material after hydrogen loading
$\%_{wtH_2}$ = Weight percentage of hydrogen in the material storage

7.1 Release

RELEASE RATE TESTING

SCALABLE MASS TO INCREASE HYDROGEN BEING RELEASED

VALVE TO CONTAIN HYDROGEN IF SLOW RELEASE



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7.2 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" [Wu et al.]

CIPET सि पे ट

probe • perform • practice • Plastics

7.3 Material Needed

4% yield Urea to Graphitic Carbon Nitride

https://www.google.com/search?q=urea&rlz=1C1GCEJ_enUS1034&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjL07Cd_dn7AhVxBEQIHctsDisQ_AUoAXoECAEQAw&biw=1920&bih=969#imgrc=uJswUlCxh-9elM

https://www.homesciencetools.com/product/lithium-chloride-30-g/

Storage Summary

Requirement	Design	Expected Performance	Verification
7.1	Extraction heats material to release temperature	Releases at least 0.02 grams per 10 minutes	Runs the fuel cell
7.2	Doped graphitic carbon nitride	Capacity of 10% wt hydrogen	Numerically, Greater than 2% Testing
7.3	2 grams of Graphitic Carbon Nitride	Synthesize 50 grams for 4% yield	Greater than 2 grams

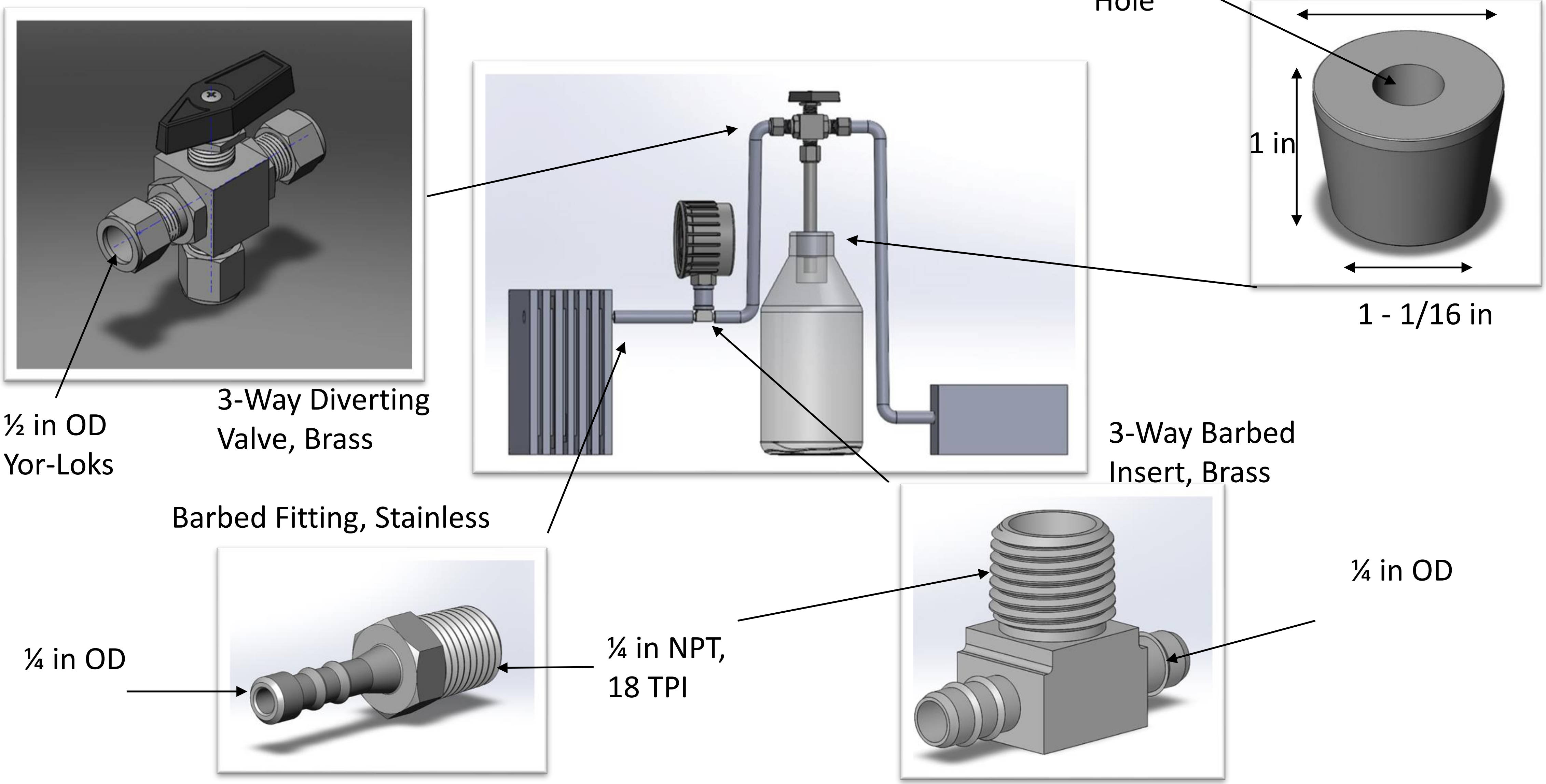
System Interfaces

System Requirements

4.4

“all subsystem interfaces must be sealed.”

Interface Map



Detecting Leaks

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

[Fast leakage test – Unitem Wrocław (unitemmachines.com)]

Extraction

System Requirements

2.1

"The system must allow for safe extraction of hydrogen gas without risk of major leaks."

4.3

"The material storage to fuel cell system must be able to run for 10 minutes."

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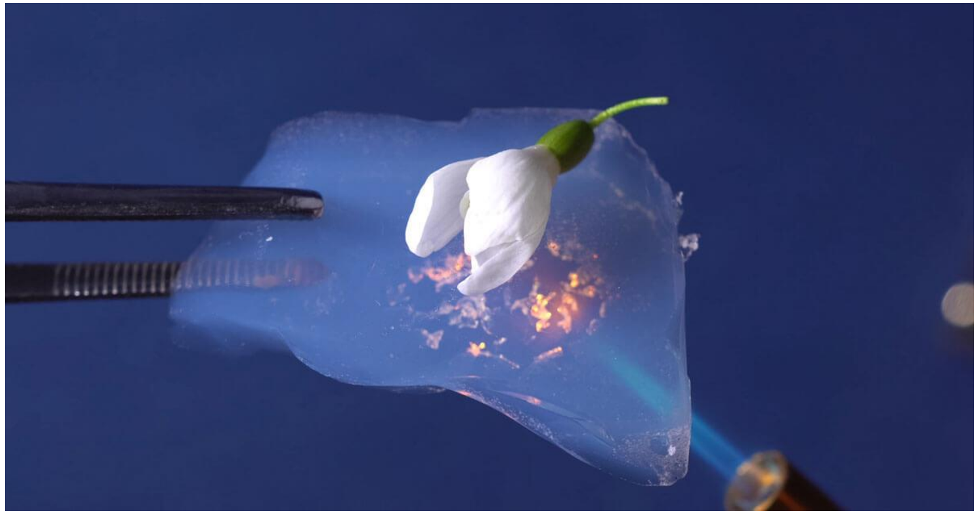
Heating Element – Nichrome Wire

Target Temperature: 300°C
Maximum Temperature: 350°C



Thermal Insulation:

Aerogel - 650 °C

- Type: Resistance Wire
- Material: Nichrome 80 Alloy (nom. 80% Ni, 20% Cr)
- Specification: ASTM B267
- Temperature Rating: 1177°C (2150°F)

20 AWG	0.0320"	0.6348 Ω/ft

-Remington Industries

Heat Loss Calculations

Energy Loss, 10ft. Of wire @ 300°C: 2.683W

$$Heat\ Rate\ Out = Conduction\ loss + Convection\ loss$$

$$Conduction\ loss = h_{air} A_1 \Delta T \quad Convection\ loss = -k A_2 \Delta T$$

h_{air}= 2.5 for still air

A_1= .0038m^2 (50% surface area)

A_2= .0019m^2 (25% surface area)

K= 11.3$\frac{W}{m * °K}$

ΔT= 280°

Power Input Calculations

Voltage Requirement: 2.402V   Amperage: 1.118A

$$Q = V^2/R \quad \mathrm{V} = I * R$$

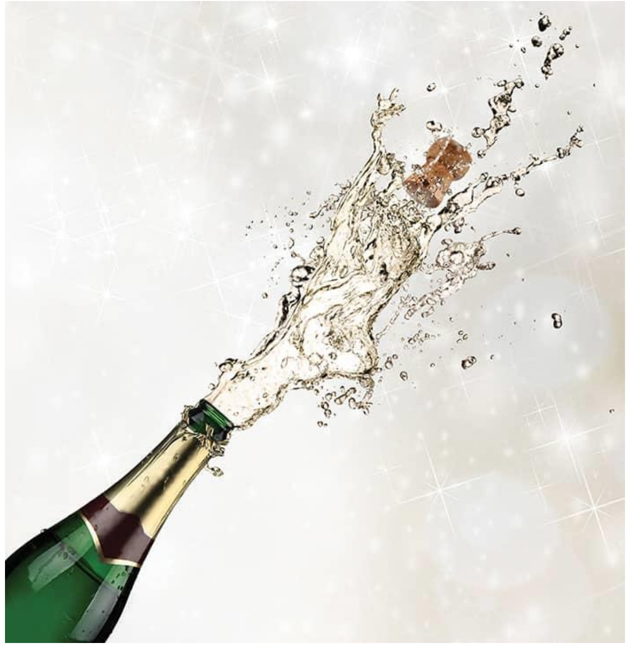
$$Q = 2.683W \qquad R = .705\frac{\Omega}{m} * 3.048m\ (10ft.)$$

Vessel Pressure

- PV=nRT

  V = 1.1L   T = 300°C   R = $287\frac{J}{kg*K}$

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



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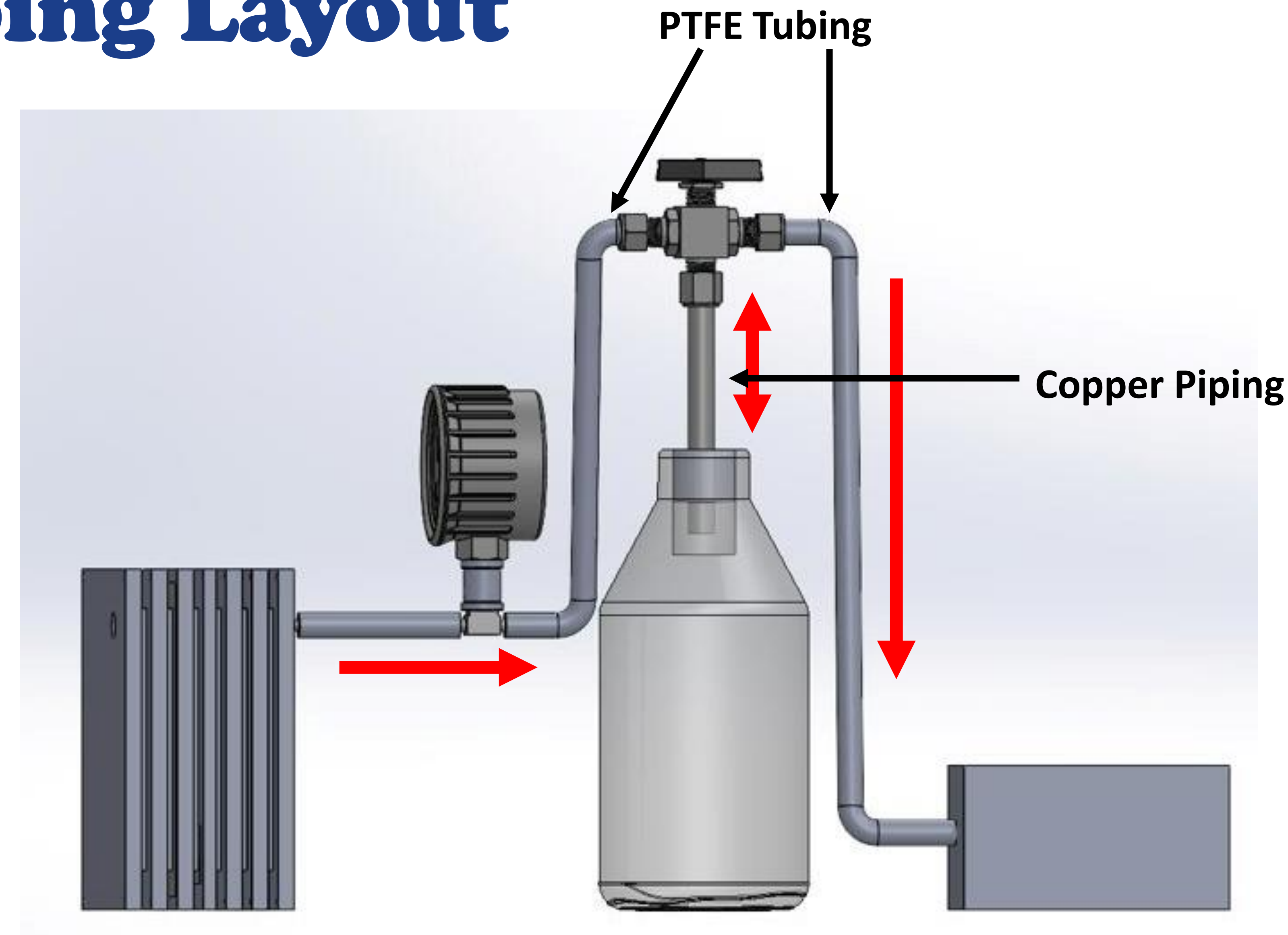
Extraction Summary

Requirement	Design	Expected Performance	Verification
9.1	Nichrome wire achieves steady state temperature of 300°C	Hydrogen release from storage medium	Fuel cell produces electricity
9.2	Voltage supplied to Nichrome wire ≈ 2.4V	Steady state temp. < 350°C	Thermal Camera (Propulsion Lab)

Piping

Piping Layout



Heat Transfer Analysis

1. Use a 6in long pipe at constant 100°C that reduces internal gas temperature from 300°C to 150°C to determine flow regime.

2. Analyze 0.0001in long sections where pipe is average temperature of internal and external air.

R convection, inside	14.48	(K/W)
Copper Thermal Conductivity	[illegible]	(W/m*K)
R conduction	[illegible]	(K/W)
R convection, outside	20.35	(K/W)

To reduce the gas from 350°C to 50°C, the copper pipe must be 2.63 inches long.

Conduction through the pipe is negligible. Convection on the outside and inside of the pipe have similar magnitudes.

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Piping Requirement Summary

Hard Copper Pipe 0.5”OD x 0.05”Wall Thickness x 2.63” Long
PTFE Tubing 0.31”OD x 0.03” Wall Thickness x 2’ Long

Requirement	Design	Expected Performance	Verification
10.1	PTFE tubing and copper pipe.	Transportation of hydrogen gas	Pressure gauge, mass of material storage, operation of fuel cell
10.2	Material chosen to withstand pressures.	No leaks	Bubble method
10.3	Copper piping sufficiently transfers heat.	Temperature reduced to 50°C at diverting valve	Thermal imaging

Interactive User Interface (IUI)

11.1 Pressure Gauge

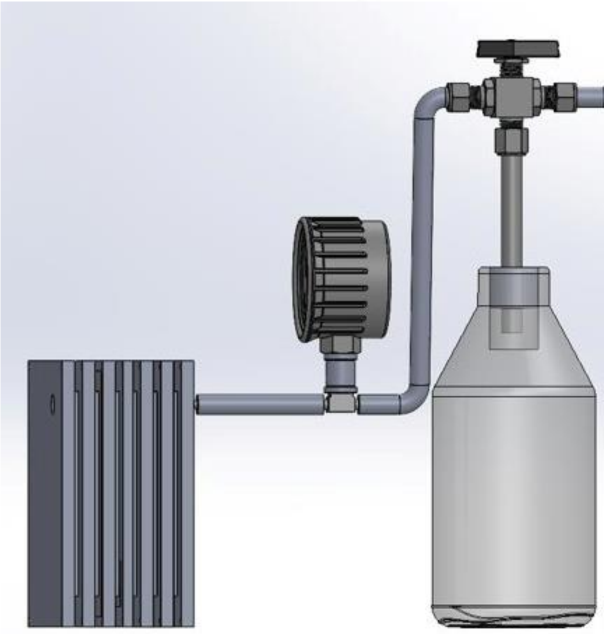
0-30 inWC (0-1.08 psi)

±3-2-3% accuracy

0-7.5 inWC: ±0.9 inWC

7.5-22.5 inWC: ±0.6 inWC

22.5-30 inWC: ±0.9 inWC



Governing Equations

$PV = nRT$

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)

In. wc	PSI	Grams of Hydrogen
0	0	0
1	0.0360912	0.000247124
2	0.0721824	0.000494249
3	0.1082736	0.000741373
4	0.1443648	0.000988497
5	0.180456	0.001235621
6	0.2165472	0.001482746
7	0.2526384	0.00172987
8	0.2887296	0.001976994
9	0.3248208	0.002224119
10	0.360912	0.002471243
11	0.3970032	0.002718367
12	0.4330944	0.002965492
13	0.4691856	0.003212616
14	0.5052768	0.00345974
15	0.541368	0.003706864
16	0.5774592	0.003953989
17	0.6135504	0.004201113
18	0.6496416	0.004448237
19	0.6857328	0.004695362
20	0.721824	0.004942486
21	0.7579152	0.00518961
22	0.7940064	0.005436735
23	0.8300976	0.005683859
24	0.8661888	0.005930983
25	0.90228	0.006178107
26	0.9383712	0.006425232
27	0.9744624	0.006672356
28	1.0105536	0.00691948
29	1.0466448	0.007166605
30	1.082736	0.007413729

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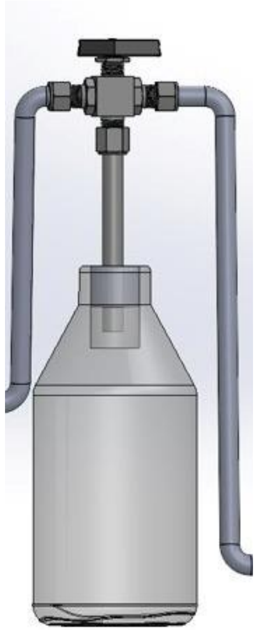
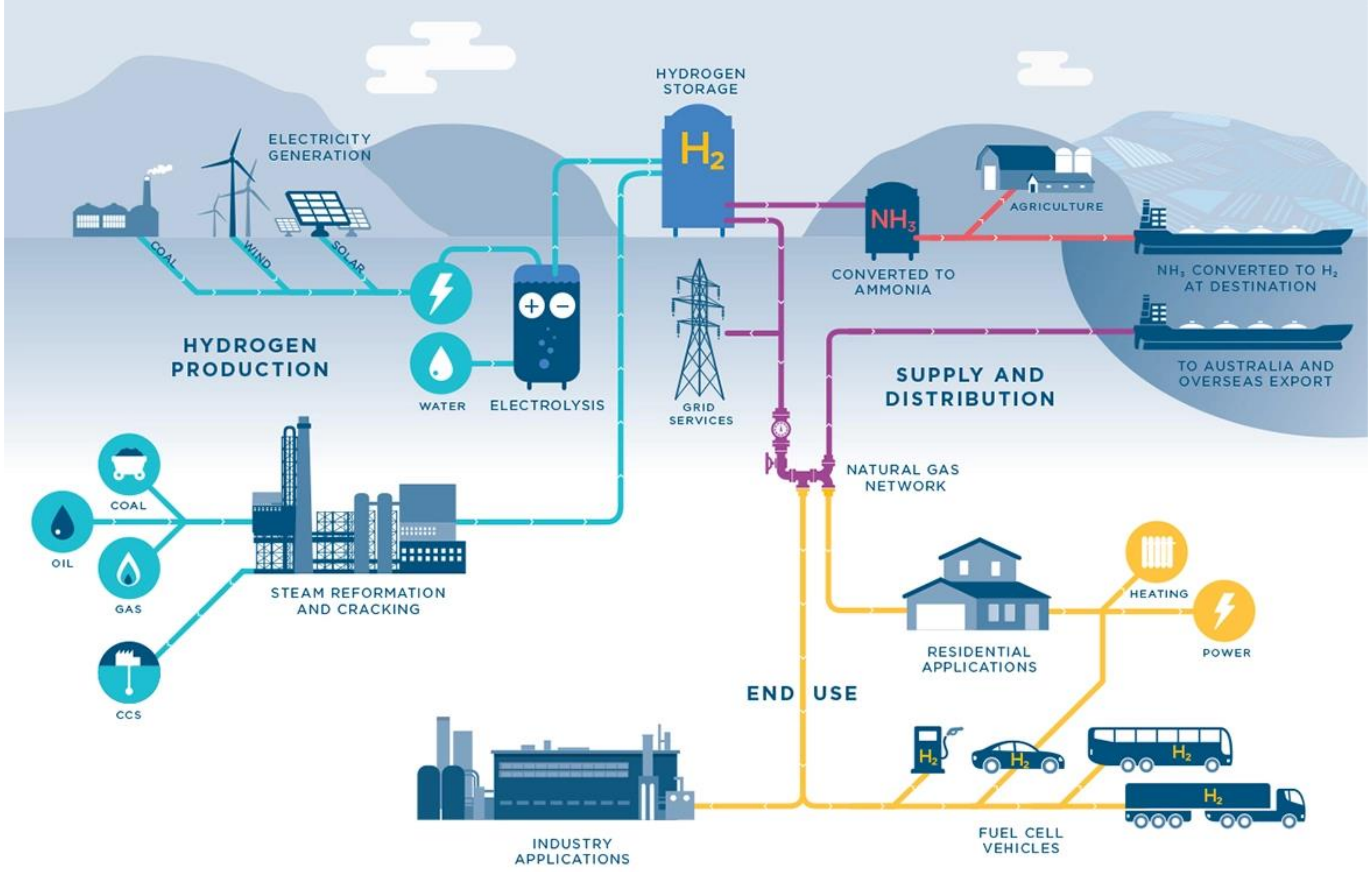
11.2 Mass Measurement

Chemistry lab scale to measure storage system mass

±0.0005 accuracy



11.3 Infographic



[Hydrogen Economy Infographic – Herbert Smith Freehills]

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IUI Summary

Requirement	Design	Expected Performance	Verification
11.1	0-30 inWC Pressure Gauge	Display accurate pressure of system	Visual Inspection
11.2	Chemistry lab digital scale	Display mass of hydrogen in storage system	Visual Inspection
11.3	Hydrogen Economy Infographic	Inform about hydrogen economy	Visual Inspection
11.4	Pressure gauge and scale have measurement displays	Display measurements	Visual Inspection
11.5	Pressure gauge and scale have English unit on the displays	English Units	Visual Inspection

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Risk Matrix – Before Mitigation

Asset or Operation at Risk	Hazard	Scenario	Opportunties for Prevention or Mitigation	Probability	Overall Hazard Rating
Overall System	Explosion	Hydrogen Leak, normal operation	Sealant	Likely	4A
Electrolysis	Electrocution	Short Circuit	Insulator	Seldom	2C
Electrolysis	Fire	Excess Oxygen	Planned Dispersion	Likely	4B
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

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Risk Matrix – After Mitigation

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

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

Item	Cost
Shirts	$150.00
Urea	$20.00
lithium Chloride 30grams	$17.90
Plexiglass	$84.56
Pressure gauge	$35.65
Mesh X 2	$22.00
PTFE Tubing x 25ft	$62.25
F-F Thread Adapter x2	$19.12
Bolts	$7.60
Copper Pipe (2ft)	$5.49
Barbed T fitting x 2	$24.28
Barbed Fitting x3	9.02
Graduated Bottle	91.64
Nichrome Wire 20gauge x 50ft	$12.00
Solder	$30
Rubber Plug	$10.42
Rubber Tape (25ft)	18.37
Diverting Valve	123.84
Epoxy's	$30
nuts	$2.20
Other Plastic	$88.04
Power Supply	$289.99
Total	
$1,154.37	

Schedule

ERH2

Embry-Riddle Hydrogen

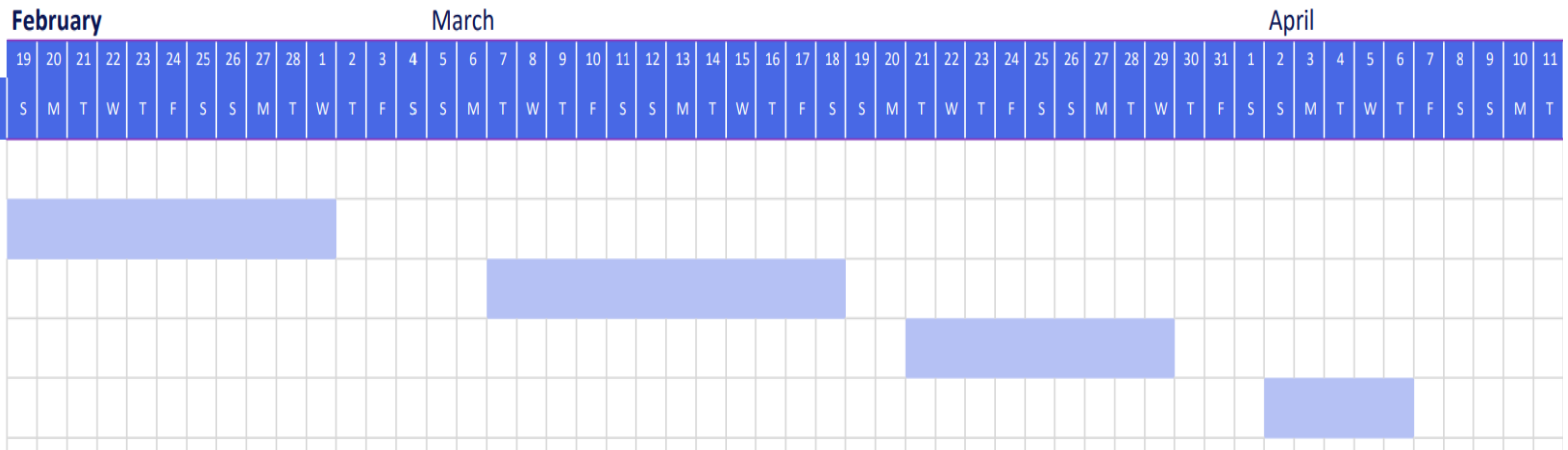
Detail

Project start date: 1/10/2023

Milestone marker: 1

Scrolling increment: 40

Milestone description	Assigned to	Progress	Start	Days
Build				
Electrolysis		0%	2/13/2023	18
Plumbing		0%	3/6/2023	14
Valves and Seals		0%	3/20/2023	11
Control Elements		0%	4/1/2023	7



ERH2

Acknowledgements

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- Dr. David Lanning
- AXFAB Staff
- Taylor Spiller

Questions?

Additional Slides

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

Requirements Matrix

Requirements		Design Elements			
	Function 1.0	Electrolysis Device	Material-based Storage	Fuel Cell	Laws
	1.1	■			
	1.1.1	■			
	1.2		■		
	1.3	■			
	Safety 2.0				
	2.1	■	■		■
	2.2				■
	Education 3.0				
	3.1	■	■	■	
	3.1.1	■	■		
	3.1.2.1	■			
	3.1.2.2		■		
	3.1.3	■	■	■	
	3.1.4	■	■	■	
	Performance 4.0				
	4.1	■			
	4.1.1	■			
	4.2				■
	4.2.1	■	■	■	
	4.3	■			
	Human Factor 5.0				
	5.1				■
	5.2				■

Generation - Natural Gas

Methane Resource

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

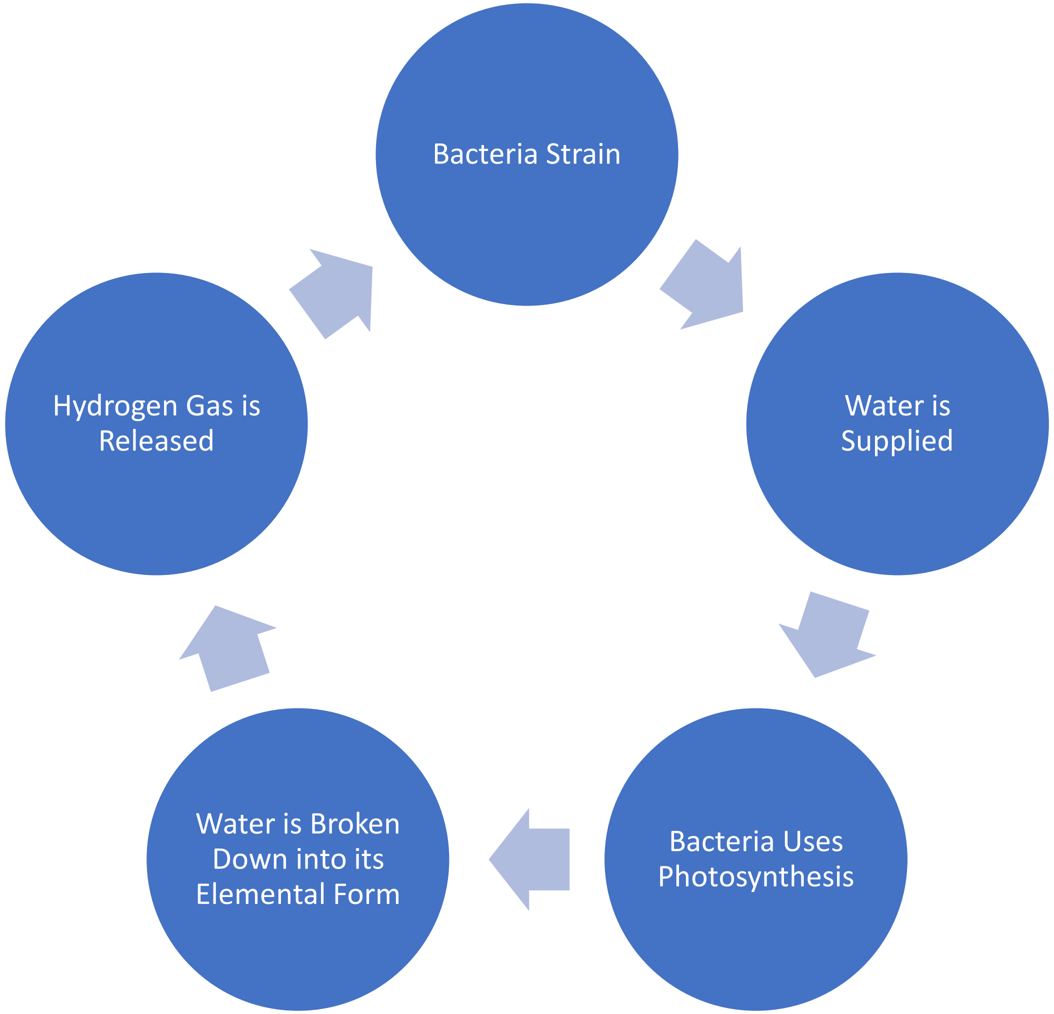
Steam-Methane Reforming

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

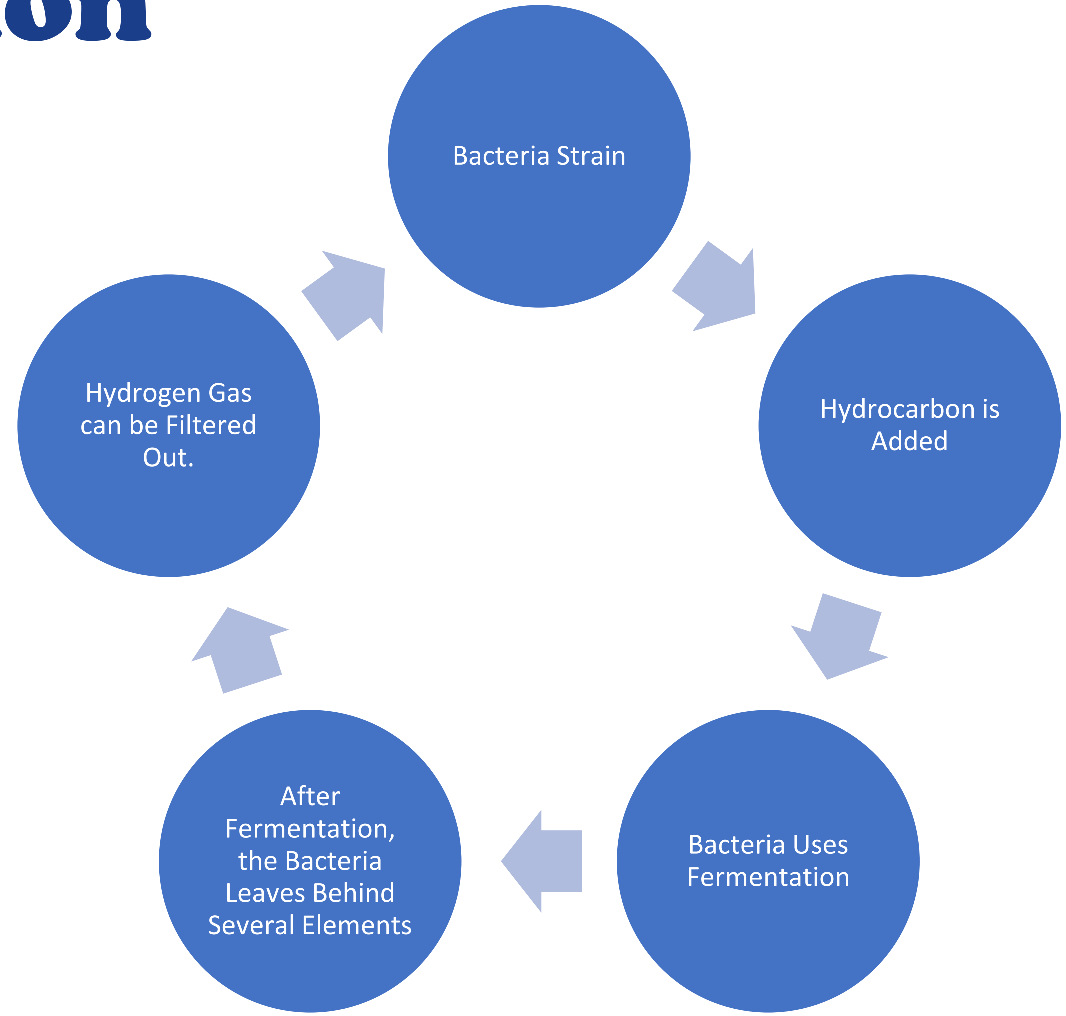
Hydrogen Extraction

- 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 H2 at -252.2 °C

Solid H2 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

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

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

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

Misc. Interfacing Table

Type of Interface	Name	Price	Interface Point
Plastic Epoxy	Plastic Epoxy Putty	$5.83 per 2 ounces	Electrolyzer to piping connection
Electrical Epoxy	Fire Barrier Sealant	$11.28 per 10.3 ounces	Electrical Epoxy for Electrolyzer
Gasket Tape	NEMA 12	$15.55 per 10 feet	Internal Electrolyzer Interfaces
Pipe Gasket	Gasket	$0.79 each	Threaded Connections
Plastic Epoxy	J-B Weld	$9.76 per 2 ounces	Electrolyzer Water Storage Casing
Threaded Connections	Made Inhouse	1/2 inch Aluminum Stock	To be Decided

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