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**Abstract**

The education of hydrogen production and storage is crucial to the potential future of the hydrogen economy. To accomplish the goal of hydrogen education, ERH2 proposes a hydrogen production and storage demonstrator consisting of a polymer electron membrane (PEM) electrolyzer and nickel mesh as well as material-based storage using graphitic carbon nitride. The cost of the system will be approximately $1800 and run at a maximum of 22.89 Amps producing 0.0142 grams of hydrogen per minute. The electrolysis unit will have a view to the internals in order to increase the educational value of the project. The discussed design also includes a clear portable reservoir containing the graphitic carbon nitride, allowing the storage method to be viewable to an audience. The proposed design is a safe and educational method to introduce students and the general public to hydrogen production and storage.

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# Nomenclature

|  |  |
| --- | --- |
| DTL | Design Team Lead |
| MBC | Microbial Biomass Conversion |
| PBS | Photobiological Systems |
| PEM | Proton Exchange Membrane |
| H2 | Hydrogen Gas |
| SMR | Steam-Methane Reforming |
| EyRIE | Energy Research and Interactive Experimentation |
| ERAU | Embry-Riddle Aeronautical University |
| CL | Catalyst Layer |
| LGDL | Liquid Gas Diffusion Layer |

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# System Overview

Purpose

The purpose of Embry-Riddle Hydrogen is to generate and store hydrogen to power the Embry-Riddle 1 Watt fuel cell to be as a demonstrator in the EyRIE (Energy Research and Interactive Experimentation) Lab to educate the population of Embry-Riddle Prescott about hydrogen as an alternative fuel source and hydrogen material storage.

Objectives

The system will successfully create enough hydrogen to run the ERAU 1-Watt fuel cell for 10 minutes. Hydrogen gas will be produced by the electrolysis of water using a polymer electron membrane (PEM) and nickel mesh anode and cathode. The material storage, graphitic carbon nitride, will absorb enough hydrogen to run the fuel cell for ten minutes at ambient conditions. The material will be heated using the extraction system and sealed chemistry flask to release the stored hydrogen to run the fuel cell for ten minutes. The system will safely inform and inspire the future engineers of Embry-Riddle Prescott about hydrogen as an exciting area of research.

Benefits

The design is affordable, innovative, and demonstrates the use and storage of hydrogen as a fuel. The design consists of an electrolysis machine and hydrogen material storage. Electrolysis is scalable to this smaller application, while still being effective in producing enough hydrogen to run the fuel cell for 10 minutes. The material storage is an exciting new way to store the hydrogen that does not require compression and is portable. Using this material is a great demonstrator because it is visible and safe for interaction with the public.

System Architecture

The ERH2 system is divided into six subsystems: electrolysis, material storage, system integration, heating, piping, and interactive user interface. These subsystems have specific components that can be seen in Figure 1 below.

Diagram

Description automatically generated

Figure 1: ERH2 System Architecture

Concept of Operations

The ERH2 concept consists of electrolysis of water to generate hydrogen gas, material storage to store the hydrogen, and an extraction process that heats the material storage to release the hydrogen. The overall system layout is depicted below in the process flow diagram, see figure 2. The electrolysis machine is filled with distilled water and uses DC power to charge two nickel mesh plates separated by a PEM with positive and negative charges to split the distilled water into oxygen and hydrogen. The oxygen gas is dispersed into the atmosphere and the hydrogen gas is channeled into the glass flask to be absorbed by the material storage, graphitic carbon nitride. After the sensor indicates at least 0.04 grams of hydrogen has entered the flask, the electrolysis machine is shut off and the flask is heated by the extraction system to 300 degrees Celsius to release the hydrogen. The released hydrogen is then channeled to the fuel cell to produce electrical power.

Diagram

Description automatically generated

Figure 2: Process Flow Diagram

# System Level Requirements

All System Level Requirements are listed in Appendix A.

### Requirements 1.1 and 1.1.1

Requirements 1.1 and 1.1.1 originate from the objective to run the Embry-Riddle 1-Watt fuel cell for 10 minutes as an educational demonstrator. To run the fuel cell, there needs to be hydrogen gas flow of 0.02 grams every minute. To verify that the electrolysis system is meeting these requirements, the production of hydrogen will be measured by a pressure gauge and the mass will be calculated by the ideal gas law. Trade studies were done to determine the best method of producing hydrogen, which can be seen in the table below. The SMR (Steam Methane Reforming) was the datum used to compare and biological hydrogen separation was compared with electrolysis.

Table 1: Generation Pugh Matrix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **GENERATION** | **Weighting** | **SMR (Datum)** | **Biological** | **Electrolysis** |
| Cost | 1 | - | -1 | 1 |
| Production rate | 2 | - | -1 | -1 |
| System efficiency | 3 | - | -1 | 1 |
| Total |  | - | -5 | 2 |

Based on the results from table 1, the best option for hydrogen production was using electrolysis.

### Requirement 1.2

The material storage must store 0.04 grams of hydrogen. This requirement came from the need to run the fuel cell for 10 minutes separately from the electrolysis system and to capture the excess hydrogen being produced. Since physical storage methods were ruled out in the early design phase due to the complexity and costs, material storage was the best fit for the system. The material must store 0.04 grams of hydrogen gas because the fuel cell takes 0.02 grams of hydrogen every 10 minutes; therefore, the material storage should hold double for losseRs. To verify that the material can hold 0.04 grams of hydrogen, experiments will be run on the material before implementing it into the system. While it is in the system, the material will be weighed before the hydrogen is introduced and after to do simple calculations to find how much hydrogen the material absorbed.

### Requirement 1.3

This requirement states that the system must run on DC power to be able to switch from battery power to alternative energy sources. For this system to succeed as an alternative energy demonstrator in EyRIE to inform and inspire the viewers, it needs to be operatable by other alternative energy systems. For the sake of consistent testing and demonstrating everywhere, it also needs to be operable by battery power, which is DC. To verify this requirement is met, the electrolysis will be designed and tested using a DC power source. Trade studies will be done to determine what type of DC source will work best.

### Requirement 2.1

The system will not have any leaks that occur from start to finish while producing hydrogen gas. This is important because the system should not have any hydrogen gas to escape and cause a risk to campus property or personnel. For verification that the system is leak free, a test known as the “Bubble Test” will be conducted. The bubble test is performed by spraying soapy water on components that aren’t allowed to leak, and supplying air through those components. If bubbles form, then leaks are present and the requirement is failed.

### Requirement 2.2

Requirement 2.2 states that the ERH2 system is to follow Embry-Riddle Prescott Campus’ safety requirements. The team’s objective to safely inform the future engineers of Embry-Riddle is achieved through this requirement. This will be verified via inspection from the Director of Campus Safety & Security, Michael Brady.

### Requirement 3.1 and 3.1.1

The third and fourth system requirements are to serve as an educational demonstrator to ERAU students by making the internal components of the system visible. To fulfill the objective of informing and inspiring ERAU students, the system needs to be an educational demonstrator. The best way to achieve this is to make the internal components visible. The internal system components of the electrolysis system should be visible to educate the viewers of the demonstrator. When the viewer can see the internal components, there is more opportunity for instruction and learning, which is the purpose of the ERH2 system. To verify that the internal components are visible, an outside source will be brought in to point out the internal components. Trade studies on materials will be done to ensure that the transparent material can withstand the stresses of the system.

### Requirement 3.1.2.1

The electrolysis system must detect the production of hydrogen to prove to the viewer that hydrogen is being created, determine the rate of hydrogen being produced, and ensure the system is operating properly. To verify that the system will detect the production of hydrogen, pressure experimentation will be done on the completed electrolysis system with the chosen indicator, and hydrogen should be detected. Trade studies on flow meters and pressure gauges will be done to determine the best method of detecting the hydrogen leaving the electrolysis system.

### Requirement 3.1.2.2

Similar to requirement 3.1.2.1, since hydrogen gas is not visible to the human eye, the system must have a readout for how much hydrogen gas is being stored to ensure that the storage system is operating properly. This requirement will be verified by the implementation of a display. To ensure the solution best meets the requirement, ERH2 will compare display options and styles to select the best setup for the system.

### Requirement 3.1.3

To build off the production, storage, and usage demonstration of our system, our design must include a learning feature about the hydrogen economy and where hydrogen can be used. This will give students a better understanding of the possible uses of hydrogen past our singular demonstrator. To verify that this requirement is met, ERH2 will conduct a focus group to verify the effectiveness of the learning feature that is integrated into our design. ERH2 will conduct a trade study to find the most effective learning feature that can efficiently convey the hydrogen economy.

### Requirement 3.1.4

The system must display all values for demonstration purposes in English units. This requirement originates from our target audience of Americans, and the dominant unit system for this audience being English units. To verify this requirement all displayed data will be reviewed to ensure English units are used.

### Requirement 4.1

The material must have an efficiency, hydrogen into the material to hydrogen out of the material, of 50%. The origin of this requirement is to ensure that the hydrogen produced by the electrolysis is not wasted. To verify that the efficiency is 50%, there will be a pressure gauge measuring the amount of hydrogen entering the vessel with the material and timing how long the fuel cell can run to measure the output hydrogen.

### Requirement 4.2

Requirement 4.2 is that the system must weigh less than 25 pounds dry. The entire system must be movable in order to transport it to demonstrating areas, so it must be easy to carry. The easier the system is to move, the more demonstrations the system can do in a shorter period. To verify that the system weighs less than 25 pounds dry, the system will be weighed on a scale with no water in the electrolysis subsystem.

### Requirement 4.3

The material storage to fuel cell system must be able to run for 10 minutes. This requirement achieves the system objective to run the fuel cell with hydrogen gas extracted from material storage. To verify this, hydrogen gas will be extracted from storage and ran through the fuel cell. Electrical current, detected by a multimeter over the course of 10 minutes, will satisfy this requirement.

### Requirement 4.4

All subsystem interfaces should have a proper connection. This is important because our system will not function if hydrogen gas cannot properly be transferred from one subsystem to another. All interface connections shall be airtight and sealed with a gasket or adhesive sealant. For testing proper seals, a test consisting of spraying interfacing spots with soapy water and supplying air through the internal sub-systems. If bubbles form, then the seals have failed.

### Requirement 5.1

Requirement 5.1 requires the system to be operated in a room with a fire/smoke alarm whenever it is operated indoors. This helps meet the system objective of conducting all operations safely. To verify that this requirement is satisfied, the operator must verify with a qualified health safety officer that the room is equipped with the required safety equipment.

### Requirement 5.2

Requirement 5.2 is for the system to be easily operable by users. Simple operation increases system safety by limiting complicated procedures which can be missed. This requirement will be met by implementing a simple on/off switch to operate the electrolysis unit and utilizing a storage material which is operable at room temperature and pressure. To verify this requirement, ERH2 will conduct a small focus group to gather feedback on usability of the demonstrator to ensure that the system is easily operable.

The system is defined by other requirements that can be divided into six subsystem categories: electrolysis, material storage, extraction, system housing, plumbing, and interactive user interface. These subsystem requirements are discussed in detail below.

# Electrolysis Requirements

The electrolysis system can be broken down into three smaller components: production, housing, and power.

## Production Requirements

Related System Requirements:

1.1 The system must produce hydrogen gas.

1.1.1 The system must produce 0.02 grams of hydrogen gas every 10 minutes.

2.2 The system must follow Embry-Riddle Prescott Campus’ safety requirements. https://myerauedu.sharepoint.com/teams/APPM/section-2/Pages/2-4-policy.aspx

### Production Component Requirements

6.1 The operating temperature of the electrolysis system must not exceed 94 degrees Celsius.

6.2 The operating pressure of the electrolysis system must be less than or equal to 0.29psi gauge pressure.

6.3 The hydrogen and oxygen produced in the electrolysis system must not mix.

### Requirement 6.1

The operating temperature of the electrolysis system must not exceed 100 degrees Celsius because at that temperature, water begins to boil. If water boils within the system, steam could mix with the hydrogen output and damage the fuel cell or the material storage and could decrease the rate of the production of hydrogen. To verify that the operating temperature does not exceed 100 degrees Celsius, a temperature gauge will be placed inside the system to monitor the temperature. Trade studies on temperature gauges will be done to determine the most effective way to measure the temperature in the system.

### Requirement 6.2

The operating pressure of the electrolysis system must be less than or equal to 0.29psi to ensure that hydrogen gas, when flowed directly into the fuel cell, will not exceed the maximum operating pressure of the fuel cell resulting in damage. This requirement will be verified by experimentation and a pressure gauge in the hydrogen output.

### Requirement 6.3

Requirement 6.3 states that the hydrogen and oxygen produced in the electrolysis system must not mix. Mixing the hydrogen and oxygen in the system would be extremely flammable and degrade the fuel cell. To verify that the two gasses do not mix, gaskets around the PEM will be installed and pressure tests will be conducted to ensure that oxygen cannot pass through to the hydrogen side. Trade studies on gaskets and sealing materials will be conducted to determine the best sealing method.

## Housing

Related System Requirements:

3.1.1 The internal system components should be visible for educational purposes.

4.2 The system must weigh less than 25 pounds dry.

2.2 The system must follow Embry-Riddle Prescott Campus’ safety requirements. https://myerauedu.sharepoint.com/teams/APPM/section-2/Pages/2-4-policy.aspx

### Housing Component Requirements

6.4 The electrolysis system housing layers must be replaceable.

6.5 The electrolysis system housing must be resealable.

6.6 The electrolysis system housing must not be electrically conductive.

### Requirement 6.4

Requirement 6.4 states that the electrolysis system housing layers must be replaceable, this is applicable in the event of any damage occurs during the production of hydrogen gas to the membrane or other layers. To keep using the system and creating hydrogen, the layers need to be easily and quickly replaced. To verify that the layers can be replaced, slots in the housing will be added to easily slide the layers in and out and then bubble tests will be run to make sure they are sealed.

### Requirement 6.5

The electrolysis system housing must be resealable in order to regularly do maintenance and to ensure that the hydrogen does not leak out of the system. If the hydrogen leaks out of the system, the rate of hydrogen flow decreases which could affect the fuel cell run time. To verify that the system is resealable, bubble tests will be performed on the system housing to ensure that no gases can escape. Trade studies on sealing materials will be done to determine the best way to seal and reseal the housing.

### Requirement 6.6

Requirement 6.6 states that the electrolysis system housing must not be electrically conductive. This requirement ensures the safety of the system to the operators and viewers. Because there is high amperage going into the electrolysis system, the housing material cannot be conductive or else it will shock anyone who touches the housing when it is in use. To verify that the electrolysis housing is not conductive, the resistance of the material will be found and tested using an ohmmeter. Trade studies on resistive materials will be done to find the best material for the ERH2 application.

## Power

Related System Requirements:

1.3 The system must use DC power to be able to use both alternative energy sources and battery power.

2.2 The system must follow Embry-Riddle Prescott Campus’ safety requirements. https://myerauedu.sharepoint.com/teams/APPM/section-2/Pages/2-4-policy.aspx

### Power Component Requirements

6.7 All wires must be insulated and sized according to the National Electrical Code.

6.8 The amperage applied to the electrolysis system must not exceed 22.89 amps.

6.9 The electrolysis system must have an emergency stop function.

### Requirement 6.7

All wires going into the electrolysis system must be insulated and sized according to the National Electrical Code. Because there is high amperage running the system, it is important to ensure that all wiring is insulated and sized correctly for safety. To verify this requirement, the National Electrical Code table will be referenced and used when selecting wire.

### Requirement 6.8

The amperage applied to the electrolysis system must not exceed 22.89 amps because the nickel mesh plates begin to melt at 25 amps. When the nickel mesh plates are damaged, hydrogen cannot be produced, and the demonstrator cannot operate. To verify that the amperage applied to the system does not exceed 22.89 amps, a circuit breaker will be added to cut off power at 22.89 amps. Trade studies on circuit breaker methods will be done to determine the best method of cutting off power to the system.

### Requirement 6.9

The electrolysis system must have an emergency stop function to ensure the safety of the viewers, operators, and the system. The emergency stop function is needed if the amps get too high, the pressure increases, or the hydrogen is escaping. To verify that there is an effective emergency stop function, tests will be run to ensure that when the switch is hit, power is cut.

# Material Storage Requirements

Related 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%.

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

## Subsystem Requirements

7.1 Material storage must release hydrogen at 0.02 grams every 10 minutes.

7.2 Material must store hydrogen with at least 2% weight of Hydrogen.

7.3 Must produce at least 0.4 grams of material storage.

### Requirement 7.1

The material storage must release hydrogen at 0.02 grams every 10 minutes because that is the required rate to run the fuel cell for 10 minutes to fulfill requirement 4.3. This requirement will be verified by heating the material with the extraction subsystem and running the fuel cell successfully for 10 minutes. The fuel cell will light up a LED light, so the light must be on for 10 minutes.

### Requirement 7.2

The maximum storage capacity of graphitic carbon nitride is 10% of its weight of hydrogen so the minimum amount of capacity for the storage is 2%. If the material has a capacity of less than 2% weight percentage of hydrogen, too much material will need to be used and it will not be effective. This requirement will help fulfill requirement 1.2 by storing the required amount of hydrogen. To verify this requirement is satisfied, experimentation will be done on the material and the weight will be taken before and after to determine the mass of hydrogen. Trade studies on other potential storage materials found that metal hydrides, intermetallic hydrides, and chemical hydrides performed poorly in storage capacity. According to table 2 with the datum being the traditional physical hydrogen storage in tanks, graphitic carbon nitride excelled in capacity and cost. This proved that carbon nitride was the best material for this application.

Table 2: Pugh Matrix on Storage Materials

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **STORAGE** | **Weighting** | **Physical (Datum)** | **Metal Hydride** | **Intermetallic Hydride** | **Chemical Hydride** | **Carbon Nitride** |
| Cost | 2 | - | 1 | 1 | 1 | 1 |
| Capacity | 3 | - | -1 | -1 | -1 | 1 |
| Discharge rate | 1 | - | -1 | 1 | 1 | -1 |
| Total |  | - | -2 | 0 | 0 | 4 |

### Requirement 7.3

The ERH2 team must create at least 0.4 grams of the material storage. The maximum storage capacity of graphitic carbon nitride is 10% weight hydrogen, so the minimum amount of material needed is 0.4 grams to hold 0.04 grams of hydrogen. To verify that requirement 7.1 is fulfilled, calculations of yields will be done to ensure that enough raw material is purchased and after the material is created, it will be weighed to ensure that it is at least 0.4 grams.

# System Integration Requirements

Related System Requirements:

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

4.4 All subsystem interfaces should have a proper connection.

## Subsystem Requirements

8.1 All interfaces at the electrolyzer will be properly accounted for and sized.

8.2 All interfaces at the pressure gauge interface will be properly accounted for and sized.

8.3 All interfaces at the material storage interface will be properly accounted for and sized.

### Requirement 8.1

Requirements 8.1 will reference all mass flow interfaces occurring at the electrolyzer. 8.1.1 focuses on the water entering the electrolyzer. 8.1.1.1 will dictate that all interfaces with a liquid flowing through it shall be leak resistant. 8.1.1.2 will dictate that the fittings at the water supply interface shall be corrosive resistant. 8.1.2 focuses on the interface from the electrolyzer with the piping. 8.1.2.1 requires that the interface fittings must be airtight and must not leak. 8.1.2.2 requires that the interface fittings must be secure with either threaded connections or a form of fasteners to the electrolyzer. 8.1.2.2.1 if the connection is threaded, the male insert must be on the piping side and the female end must be on the electrolyzer. 8.1.2.2.2 any connectors used must not directly damage the piping and electrolyzer casing either through welding, machining, or epoxy tearing.

### Requirement 8.2

Requirements 8.2 will reference all hydrogen gas flows through the piping and the pressure gauge under the user interface requirements. 8.2.1 requires that the fittings must be allow for easy connection from the meter into the piping. 8.2.1.1 the connection point will be threaded allowing the meter to be “screwed into place”. 8.2.1.2 the threaded connection will be paired with a gasket insert to prevent any hydrogen gas leaks from the connection. 8.2.1.3 the threaded machine components will be made out of a metal material and adhesively applied to any non-metal interface. 8.2.2 the connection point for the meter will not interfere with most of the flow of hydrogen gas from the electrolyzer to the material storage. 8.2.2.1 at a minimum 80% of the hydrogen gas produced from the electrolyzer should flow freely through the connection point of the interface. 8.2.3 any adhesive used at this interface will leave an airtight connection once hardened.

### Requirement 8.3

Requirements 8.3 will reference all hydrogen gas flows entering and exiting the material storage from the piping. 8.3.1 a T-fitting with a ball valve or damper will be used to control the direction of the flow of hydrogen gas once it has reached the material storage. 8.3.1.1 requires that the valve is properly marked to dictate if the material storage is either “open” or “closed” from the electrolyzer. 8.3.2 requires that the T-fitting must have a rubber stopper component to it. 8.3.2.1 requires that the rubber stopper must be an airtight fit on the material storage flask. 8.3.2.2 requires that if the rubber stopper is to be permanently cemented, an epoxy or rubber cement will be used to prevent leakage.

# Heating Requirements

Related 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.

## Subsystem Requirements

9.1 The heating system must be able to cause the material storage to off-gas hydrogen at a rate which yields a gauge pressure less than 2000pa gauge or 0.29psi gauge.

9.2 The heating system must be able to heat the storage material to 300°C and must not exceed 350°C.

### Requirement 9.1

Heating requirement 9.1 ensures the system will be able to cause the material storage to off-gas hydrogen at a rate which yields a gauge pressure less than 2000pa gauge or 0.29psi gauge. This requirement protects the fuel cell by keeping hydrogen gas input pressure within the permitted operating pressure and fulfills. Verification of this requirement will be performed by testing.

### Requirement 9.2

Heating requirement 9.2 sets temperature bounds on the heating system of 300°C minimum and 350°C maximum. The 300°C minimum exists to meet the minimum required temperature to cause the release of hydrogen gas from the material storage. The 350°C maximum protects other systems, particularly the piping system, by ensuring system components do not degrade and melt. The melting of a component would result in hydrogen gas leaks which causes the system to fail requirement 2.1.

# Piping Requirements

Related 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.

## Subsystem Requirements

10.1 The subsystem must transport hydrogen gas from the electrolyzer to the fuel cell.

10.2 The subsystem must withstand internal pressures up to 0.29psi gauge without leaking.

10.3 The subsystem must withstand temperatures up to 350°C without leaking.

### Requirement 10.1

To satisfy requirement 4.3, there must be a method of transporting hydrogen gas throughout the system. Specifically, that means moving hydrogen gas from the electrolyzer to the T-fitting and from the T-fitting to the fuel cell. To verify hydrogen gas is moving from electrolyzer to T-fitting, the mass of the material storage will be measured, set the system to store hydrogen gas produced by electrolysis in material storage, and measure the mass of the material storage after electrolysis. A difference in mass will indicate hydrogen gas has been stored. A trade study will be preformed regarding material types and sizes to determine the most effective solution.

### Requirements 10.2 and 10.3

To satisfy requirement 2.1, the piping subsystem must withstand the conditions created by the other subsystems without leaking. The maximum pressure and temperature in the system will be produced by the heating subsystem, and they are 0.29psig and 350°C, respectively. The piping must not leak under these conditions. To verify this subsystem passes requirements, the Bubble Test will be performed as described in Requirement 2.1.

# Interactive User Interface Requirements

The Interactive User Interface (IUI) requirements cover all requirements that deal with a label or graphic that the viewers of the demonstrator would see. This includes most of the 3.0 Education requirements, and its sub requirements.

Related System Requirements:

3.1 The system must serve as an educational demonstrator or lab device for the student body of Embry Riddle Prescott campus.

3.1.2.1 The system must detect the production of hydrogen gas.

3.1.2.2 The system must display the approximate amount of hydrogen gas stored.

3.1.3 The system must have a learning feature about the hydrogen economy and where it could go in the future.

3.1.4 The system must display all values used for demonstration purposes in English units.

## Subsystem Requirements

11.1 The system must include a pressure gauge integrated in the hydrogen piping directly after the electrolysis.

11.2 The system must include a scale to mass the material storage subsystem.

11.3 The IUI must have an infographic detailing the hydrogen production methods, storage methods, and uses.

11.4 The IUI must have digital displays to indicate all measured values.

11.5 The IUI displays must display values with English units.

### Requirement 11.1

To satisfy system requirement 3.1.2.1, the amount of hydrogen being produced must be measured. To do this, there must be a pressure gauge integrated in the hydrogen piping directly after the electrolysis unit. The viability of this method of measurement will be verified to make sure that it is accurate by conducting a pressure test of our system at known levels to verify the instrument and the related algorithm to convert pressure to mass of hydrogen. Trade studies on pressure gauges will be done to determine the best pressure gauge for the ERH2 system.

### Requirement 11.2

In order to satisfy system requirement 3.1.2.2, the IUI system must include a scale to mass the material storage subsystem before and after hydrogen is produced and stored. This requirement will be verified by inspection of the scale. A trade study must be conducted to verify that a mass difference is the most efficient way to measure the stored hydrogen in the system.

### Requirement 11.3

To satisfy system requirement 3.1.3, the IUI must have an infographic that explains the various hydrogen production methods, storage methods, and uses. To verify the effectiveness of the infographic, students without any previous knowledge will be surveyed to ensure that the infographic is detailed and informative to those with no background knowledge.

### Requirement 11.4

In order to satisfy 3.1.2.1 and 3.1.2.2, values must be displayed to the viewers. To do this effectively, requirement 11.4 requires that the IUI has digital displays to show all measured values to the viewer. Other options will be researched to determine the most effective way for information to be displayed.

### Requirement 11.5

To satisfy system requirement 3.1.4 the IUI will display all values in English units. This allows most students and the public to easily understand the demonstrator with very little previous knowledge. To verify this requirement is met, an outside reviewer will check the correct usage of units.

# Conclusion

Our design prioritizes all the listed requirements that have been requested. ERH2 will use an electrolysis unit to demonstrate and educate on the process of hydrogen generation because of its wide industry adoption and the ease of viewing the generation process. Our design also includes material hydrogen storage, a revolutionary method of hydrogen storage that will benefit both the educational possibilities as well as the overall system efficiency. Therefore, our hydrogen generation and storage design is the best suited for the provided requirements, exceeding the minimum educational, efficiency, and safety requirements providing the best possible product for your application.

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# Appendix

## Appendix A: Requirements

**1.0 Function**

1.1 The system must produce hydrogen gas.

1.1.1 The system must produce 0.02 grams of hydrogen gas to run the fuel cell for 10 minutes at 1 watt.

1.2 The system must store 0.04 grams of hydrogen gas.

1.3 The system must use DC power to be able to use both alternative energy sources and battery power.

**2.0 Safety**

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

2.2 The system must follow Embry-Riddle Prescott Campus’ safety requirements. https://myerauedu.sharepoint.com/teams/APPM/section-2/Pages/2-4-policy.aspx

**3.0 Educational**

3.1 The system must serve as an educational demonstrator or lab device for the student body of Embry Riddle Prescott campus.

3.1.1 The internal system components should be visible for educational purposes.

3.1.2.1 The system must detect the production of hydrogen gas.

3.1.2.2 The system must display the approximate amount of hydrogen gas stored.

3.1.3 The system must have a learning feature about the hydrogen economy and where it could go in the future.

3.1.4 The system must display all values used for demonstration purposes in English units.

**4.0 Performance**

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

4.2 The system must weight less than 25 pounds dry.

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

4.4 All subsystem interfaces should have a proper connection.

**5.0 Human Factor**

5.1 The system must operate in a room that has a fire/smoke alarm system if working indoors.

5.2 The system should be easy to operate by authorized users.

## Appendix B: Requirements Verification Matrix

Table 3: Requirements Verification Matrix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Requirement** | | | **Design Metric** | **Verification Method** |
| **Number** | **Title** | **Description** |
| 1.0 | Function |  |  |  |
| 1.1 |  | The system must produce hydrogen gas | Alkaline Selection | Test |
| 1.1.1 |  | The system must produce 0.02 grams of hydrogen gas to run the fuel cell for 10 minutes at 1 watt. | Electrolysis Design | Test |
| 1.2 |  | The system must store 0.04 grams of hydrogen gas. | Material Volume | Test |
| 1.3 |  | The system must use DC power to be able to use both alternative energy sources and battery power. | System Design | Test |
| 2.0 | Safety |  |  |  |
| 2.1 |  | The system must allow for safe extraction of hydrogen gas without risk of major leaks. | Sealant | Test |
| 2.2 |  | The system must follow Embry-Riddle Prescott Campus’ safety requirements. https://myerauedu.sharepoint.com/teams/APPM/section-2/Pages/2-4-policy.aspx | System Design | Inspection |
| 3.0 | Educational |  |  |  |
| 3.1 |  | The system must serve as an educational demonstrator or lab device for the student body of Embry Riddle Prescott campus. | System Design | Inspection |
| 3.1.1 |  | The internal system components should be visible for educational purposes. | System Design | Inspection |
| 3.1.2.1 |  | The system must detect the production of hydrogen gas. | System Design | Inspection |
| 3.1.2.2 |  | The system must display the approximate amount of hydrogen gas stored. | System Design | Inspection |
| 3.1.3 |  | The system must have a learning feature about the hydrogen economy and where it could go in the future. | System Design | Inspection |
| 3.1.4 |  | The system must display all values used for demonstration purposes in English units. | System Design | Inspection |
| 4.0 | Performance |  |  |  |
| 4.1 |  | The material storage efficiency (hydrogen in vs. Hydrogen out) must be at least 50%. | Material Volume | Test |
| 4.2 |  | The system must weight less than 25 pounds dry. | System Design | Inspection |
| 4.3 |  | The material storage to fuel cell system must be able to run for 10 minutes. | Material Volume | Test |
| 4.4 |  | All subsystem interfaces should have a proper connection. | User Interface | Inspection |
| 5.0 | Human Factor |  |  |  |
| 5.1 |  | The system must operate in a room that has a fire/smoke alarm system if working indoors. | System Location | Inspection |
| 5.2 |  | The system should be easy to operate by authorized users. | User Interface | Inspection |
| **Subsystem Requirements** | | | | |
| 6.0 | Electrolysis |  |  |  |
| 6.1 |  | The operating temperature of the electrolysis system must not exceed 100 degrees Celsius. | Applied Power | Analysis; Test |
| 6.2 |  | The operating pressure of the electrolysis system must be less than or equal to 1 atmosphere gauge pressure. | Applied Power | Analysis; Test |
| 6.3 |  | The hydrogen and oxygen produced in the electrolysis system must not mix. | Membrane Design | Test |
| 6.4 |  | The electrolysis system housing layers must be replaceable. | System Design | Demonstration |
| 6.5 |  | The electrolysis system housing must be resealable. | System Design | Demonstration |
| 6.6 |  | The electrolysis system housing must not be conductive. | Material Selection | Analysis; Test |
| 6.7 |  | All wires must be insulated and sized according to the National Electrical Code. | System Design | Inspection |
| 6.8 |  | The amperage applied to the electrolysis system must not exceed 20 amps. | Applied Power | Analysis; Test |
| 6.9 |  | The electrolysis system must have an emergency kill switch. | System Design | Inspection; Demonstration |
| 7.0 | Material Storage |  |  |  |
| 7.1 |  | Material storage must release hydrogen at 0.02 grams every 10 minutes. | Steady state Temperature | Test |
| 7.2 |  | Material must store hydrogen with at least 2% weight of Hydrogen. | Material Composition | Test |
| 7.3 |  | Must produce at least 0.4 grams of material storage. | Material Volume | Test |
| 8.0 | System Integration |  |  |  |
| 8.1 |  | All interfaces at the electrolyzer will be properly accounted for and sized. | Sealant | Test |
| 8.2 |  | All interfaces at the pressure gauge interface will be properly accounted for and sized. | Sealant | Test |
| 8.3 |  | All interfaces at the material storage interface will be properly accounted for and sized. | Sealant | Test |
| 9.0 | Extraction |  |  |  |
| 9.1 |  | The heating system must be able to cause the material storage to off-gas hydrogen at a rate which yields a gauge pressure less than 2000pa or 0.29psi. | Steady state Temperature | Test |
| 9.2 |  | The heating system must be able to heat the storage material to 300°c and must not exceed 350°c. | Applied Power | Test |
| 10.0 | Piping |  |  |  |
| 10.1 |  | The subsystem must transport hydrogen gas from the electrolyzer to the T-fitting, and from the T-fitting to the fuel cell. | System Design | Test |
| 10.2 |  | The subsystem must withstand internal pressures up to 0.29psi gauge without leaking. | Material Choice | Test |
| 10.3 |  | The subsystem must withstand temperatures up to 350°C without leaking. | Material Choice | Test |
| 11.0 | Interactive User Interface |  |  |  |
| 11.1 |  | The system must include a pressure gauge integrated in the hydrogen piping directly after the electrolysis. | System Design | Inspection |
| 11.2 |  | The system must include a scale to mass the material storage subsystem. | System Design | Inspection |
| 11.3 |  | The IUI must have an infographic detailing the hydrogen production methods, storage methods, and uses. | System Design | Inspection |
| 11.4 |  | The IUI must have digital displays to indicate all measured values. | System Design | Inspection |
| 11.5 |  | The IUI displays must display values with English units. | System Design | Inspection |

## Appendix C: Organization Chart

Timeline

Description automatically generated

Figure 3: Organization Chart

## Appendix D: Budget

Review table 1 for the core-component and sub-system budget. For individual costs, refer to the team finances excel document.

Table 4: Team Budget

|  |  |  |
| --- | --- | --- |
| **INCOME** |  |  |
|  | Base | $1,300.00 |
|  | **TOTAL INCOME** | $1,300.00 |
| **EXPENSES** |  |  |
|  | Electrolysis | $675.00 |
|  | Material Storage | $230.00 |
|  | Charge/Discharge | $87.00 |
|  | Plumbing | $24.00 |
|  | Instrumentation | $400.00 |
|  | Valves | $80.00 |
|  | Sealant | $30.00 |
|  | Electrical | $30.00 |
|  | Team Shirts | $80.00 |
|  | **TOTAL EXPENSES** | $1,636.00 |
| **TOTAL** |  | $(336.00) |

Currently the system is $336 overbudget. This is because extremely conservative estimates were used for all our expenses and set aside money for systems that will likely be provided by Embry-Riddle. The team plans to apply for a $1000 grant through Embry-Riddle to further support the project.

## Appendix E: Schedule

Table 5: Team Schedule

|  |  |  |
| --- | --- | --- |
| **Task** | **Start Date** | **End Date** |
| Build Electrolysis | 2/13/2023 | 3/3/2023 |
| Assemble Plumbing | 3/6/2023 | 3/20/2023 |
| Valves and Seals | 3/20/2023 | 3/31/2023 |
| Final Report | 2/15/2023 | 4/28/2023 |

It is expected to take around 6 weeks to build the system. To complete the electrolysis machine, it will take three weeks, the piping of the system will take 2 weeks, and checking the valves and seals will take 1 week. Throughout the process, the team will be documenting the progress and writing the report due the 28th of April. All Gantt charts for fall and spring can be found in appendix D.

Once the system is complete, it will be an installment into the EyRIE Lab. Since the EyRIE Lab is not built yet, the system will go into the care of the college of Engineering. The system will be compact enough to be easily stored in a closet or put on display in an engineering building until the EyRIE Lab is complete. The overseer of the system will be the chair of the college of engineering and/or the chair of the energy department within the college of engineering.

## Appendix F: Acknowledgements

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Dr. Hillary Eaton

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Dr. Istemi Ozsoy

Dr. David Lanning

Dr. Robert Murray-Smith

AXFAB Staff

## Appendix G: Equations

Maximum Theoretical Current Requirement for Electrolyzer:

Rate of Hydrogen Production in Electrolyzer:

Rate of Oxygen Production in Electrolyzer:

Area of Mesh in Electrolyzer:

Hydrogen Required to Run the Fuel Cell for 10 Minutes at 1 Watt:

## Appendix H: Gantt Chart

Graphical user interface

Description automatically generated

Figure 4: Schedule for August-October

Chart

Description automatically generated

Figure 5: Schedule for November

Timeline

Description automatically generated

Figure 6: Schedule for build