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1. Details of the Team

1.1 Group Name

Team Spectro

1.2 Group Leader's Name

Sithija Vihanga Ranaraja

1.3 Group Members' Information

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1.4 External Support

- Udeni Jayalal
  Professor at Sabaragamuwa University of Sri Lanka, Belihuloya 70140, SRI LANKA linkedin profile

2. Problem Description

2.1 Primary Area of Development

Power generation and efficiency

2.2 Other Supporting Areas of Development

Environmental conservation and preservation

2.3 Problem Statement

The energy crisis in Sri Lanka has resulted in frequent power cuts over the past months, primarily due to ineffective utilization of available energy sources. Being an island surrounded by the ocean, abundant with tidal power, and a country with abundant solar energy throughout the year, the high cost of solar panels and tidal power plants makes them unaffordable for developing countries like Sri Lanka to supply the increasing demand. The current reliance on imported fuels such as coal for energy generation is costly, unsustainable, and contributes to environmental pollution.

Additionally, there is a need for an efficient energy storage method to account for times when energy generation is not possible, such as plant errors or fuel shortages, which result in power shortages all over the country. For example, in hydropower plants in rainy seasons, the abundant source provides energy. However, in dry seasons, the plants malfunction due to a lack of an energy source. If the abundant source in the rainy seasons is utilized properly to store energy, the power supply of the country could be more stabilized.

Therefore, the necessity of proper management of a low-cost and sustainable method for electricity generation and energy storage arises.

The problem has been validated through a number of sources including,
Data analysis: The government of Sri Lanka declared a state of emergency due to the energy crisis in the past year. The news articles and the frequent power cuts faced support this claim.
Stakeholder interviews: Conducting interviews with citizens and industrial professionals to gather experiences on the energy crisis, its causes, and its consequences.
Cost analysis: Evaluating the costs associated with solar power, tidal power, and imported oil and assessing their affordability and feasibility in the context of the national power supply in Sri Lanka.
Environmental impact assessment: Examining the environmental consequences of current energy generation methods, including carbon emissions and their contribution to global warming.

The mentioned problem affects all user segments in Sri Lanka, including:
Households: Everyday consumers facing the consequences of power cuts, high electricity expenses amidst the economic crisis, and an unreliable energy supply (Ex: - Disrupts for educational activities of children).
Businesses: Many small-scale businesses were affected due to the power cuts and high expense of electricity.
Hospitals: Frequent power cuts have caused the interrupts in medical procedures, causing life-threatening situations.

The problem described has several impacts:

Power cuts: Frequent power cuts disrupt daily life, affecting businesses, households, education, healthcare, and overall productivity.
High electricity expenses: The reliance on expensive imported fuel drives up electricity costs, burdening consumers and hindering economic growth.
Environmental pollution: Current energy generation methods, particularly using fossil fuels, contribute to pollution and climate change, harming the environment and public health.
Unsustainable energy system: ineffective utilization of available energy sources, lack of storage options, and reliance on imported oil make the energy system unsustainable in the long run.

2.4 How does finding a solution to our problem impact the causes of climate change?

A solution for the aforementioned problem will directly impact the causes of climate change, mainly due to reduced reliance on fossil fuels.
Fossil fuels are a major contributor to greenhouse gas emissions that drive climate change, primarily carbon dioxide (CO_2). In 2020, global CO_2 emissions from fossil fuel combustion and industrial processes were approximately 31.5 gigatons (Gt) of CO_2 (source: Global Carbon Project). The impacts of CO_2 on climate change include rising global temperatures, sea-level rise due to the melting of glaciers and ice sheets, extreme weather events including heatwaves, hurricanes, droughts, and heavy rainfalls, and ocean acidification due to the absorption of excess CO_2 by the oceans, leading to harm to marine ecosystems.
By shifting to cleaner and more sustainable energy sources, the direct emissions associated with energy generation can be significantly reduced.

3. Solution Description

3.1 Arriving at our solution

Arriving at our solution first led us to find a sustainable energy source that facilitates electricity generation and convenient storage, and various options were explored. While renewable energy sources like solar and tidal power are effective for electricity generation, they present challenges when it comes to energy storage. Consequently, we decided to adopt hydrogen gas as our energy storage mechanism due to its high energy content and its potential for clean and sustainable utilization. Following are some advantages of using hydrogen gas for our solution:

1. Energy Content: High energy-to-weight ratio, making it an efficient fuel source.
2. Versatility: Hydrogen can be used in a variety of applications. It can be burned directly as a fuel in internal combustion engines or used in fuel cells to generate electricity.
3. Environmental Impact: A clean energy source when produced from renewable resources or through processes that capture and store carbon emissions. When burned, hydrogen only produces water vapour as a by-product, making it a potentially carbon-neutral energy carrier.

Methods of hydrogen production in the industry includes,

1. Steam Methane Reforming (SMR): Most common method of hydrogen production, accounting for the majority of current industrial production. However, this process currently relies on fossil fuels and contributes to carbon emissions which defies the purpose of using hydrogen for sustainable energy generation.
2. Electrolysis: Can be powered by various energy sources, including renewable electricity from sources like solar or wind. However, the cost of the electrolysing process is very high.
3. Coal Gasification: This method involves Coal, which is a carbon-intensive fossil fuel and produces CO_2 as a by-product contributing to the greenhouse effect and climate change.

In the current industry, majority of hydrogen production methods rely on fossil fuels, resulting in carbon emissions. To fully harness the environmental benefits of hydrogen as an energy source, it is crucial to adopt sustainable production methods that align with the goal of reducing carbon emissions.

An alternative solution of sustainable hydrogen production in the research stage is water electrolysis using solar generated electricity or photovoltaic electrolysis. Solar panels convert sunlight into electricity, which can then be used to power the electrolysis process. This method is referred to as solar electrolysis or photovoltaic electrolysis. However, the efficiency of the produced hydrogen does not account for the solar power used to generate the hydrogen. And also, the cost of the solar panels required to generate enough hydrogen is very high. Hence this method is also not viable.

This led to us finding a hydrogen production method using biochemical processes of Green Algae.

There are two main methods to generate hydrogen using green algae.

- **Direct photolysis -**Process in which algae use sunlight to split water molecules into hydrogen gas and oxygen gas. This process occurs in the chloroplasts of the algae, and it is catalysed by a protein complex called photosystem II. This is a promising technology for the production of hydrogen gas, but it is not yet commercially viable. One challenge is that the yield of hydrogen gas from direct photolysis is relatively low. Another challenge is that the algae that carry out direct photolysis are sensitive to light and temperature.

- **Indirect photolysis** – This is also known as two stage method. As name suggest there are two stage in the hydrogen generation process.

1. **Photosynthesis -** In the first stage, algae use sunlight to convert carbon dioxide and water into organic matter. This process is catalysed by a protein complex called photosystem I.
2. **Fermentation -** In the second stage, the organic matter is fermented to produce hydrogen gas. This process is catalysed by a group of enzymes called hydrogenases.

During the initial stages of the design development, a panel design was proposed for installation on rooftops in urban areas to capture high CO2 emissions. However, various challenges were encountered during the process:

1. Maintaining the temperature of the algae culture within a specific range was crucial for optimal hydrogen production. However, this posed a significant challenge in the initial design, as temperature regulation complicated the system and increased its energy consumption.
2. The supply of necessary nutrients for the algae culture required external containers, which added bulk to the panel design intended for urban deployment.
3. Due to space limitations, the generated gas had to be compressed for storage purposes.
4. To prevent the precipitation of green algae and ensure proper mixing of the culture, external motors were required. This added complexity to the design and increased its power consumption.

Considering these challenges, the design was modified for utilization in an oceanic environment. The revised design includes three transparent panels and a container with 2 layers, made with an opaque material capable of storing liquid. In this design, hydrogen production occurs through a two-stage method, which is more efficient compared to direct photolysis. Indirect photolysis yields a higher quantity of hydrogen gas, and the algae involved in this process exhibit reduced sensitivity to light and temperature.

In this approach, the initial step involves reducing the concentration of oxygen in the algae culture. This is achieved through a method known as **Aerobic-anaerobic batch culture**. Initially, the algae culture is grown in an aerobic environment where oxygen is present. Once the culture reaches a specific density, it is then transferred to an anaerobic environment where oxygen is removed. This transition to an oxygen-free environment reduces the oxygen concentration in the culture and promotes the production of hydrogen gas. The growth of algae culture takes place within the transparent panels, each with a capacity of 450 litres.

The design of these panels is intended for cultivating green algae until the culture becomes oxygen free. Once a portion of the algae culture is transferred to the hydrogen generation container, the vacant space in the panels is filled with fresh seawater. To facilitate this, the panels are equipped with a nozzle system that allows water to be supplied to the panels without allowing the green algae culture to spill out. The panels are constructed with an etched structure along the edges, which serves to retain seawater on top of the panels. This design feature enables the regulation of temperature without exceeding the required ranges. This overcomes another challenge we came across in our first design. Inside of the panels are designed in a special curved shape to utilise gravitational force to move algae from panels to the hydrogen generation container, minimising the need for additional power consumption.

When the concentration of algae in the container reaches the suitable level (low oxygen conditions) the algae liquid is transferred to the container at the center of the panels to start Fermentation process. Here, in order to start the hydrogen production, the sulphur concentration in the culture should be reduced. There are several methods that can be used to remove sulphate ions from solutions, among which precipitation method is used for our design. By Adding a suitable reagent such as calcium, barium or lead salts to the solution, insoluble sulphates precipitate, which can be removed by filtration or sedimentation. We have chosen BaCl2 to be added for the removal of sulphate ions from the solution as Barium sulphate (BaSO4) has several uses across various industries, including Medical Imaging as a contrast agent for X-ray and CT scans, in Oil and Gas Industry, etc.

Our design maximizes sustainability by utilizing the by-products without releasing them into the environment. Once the sulphur is removed from the culture, the container initiates hydrogen gas production under dark conditions. This specific section of the container has a capacity of 810 litres. Meanwhile, the remaining algae in the panels continue to grow through photosynthesis.

The central container consists of two compartments. The upper half serves as a storage space for the algae involved in the fermentation process, which produces hydrogen gas along with dimethyl sulphide as a by-product which can be used to reduce the climate change. After 5 days the hydrogen generation will stop and the algae is transferred to the bottom half of the container. This part is a storage that collects the wastage of algae and squeezes the mixture by a special compression method. The proposed capacity of this part is 200 litres. After reaching the maximum capacity of this container the control system detects it and wastage removal can be carried on. According to the space available in the second part of the container, we can perform 6 iterations of the process or more without removing the wastage. Meaning, we need to remove this container after 30 or more days. The accumulated waste can be utilized to generate biodiesel, as algae serve as an excellent source for this purpose.

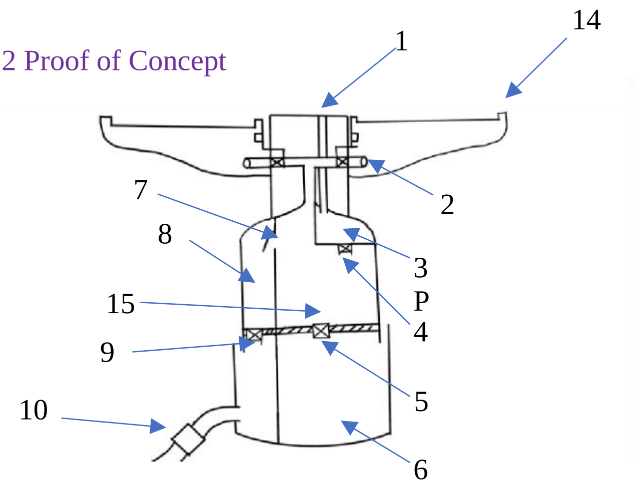
To facilitate the efficient transfer of generated gas, a nozzle system is incorporated in the first part of the container. This system allows the gas to be extracted and transported to the mainland through a pipeline powered by tidal energy. This approach takes advantage of the natural tidal power, eliminating the need for external motors and addressing a challenge encountered in the initial design.

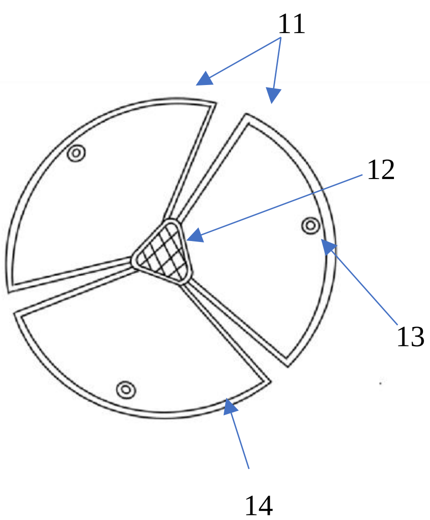
in-order to mix the contained algae culture to increase the efficiency, tidal power is utilised without any external motors which overcomes a challenge encountered in the first design. As the panels and the container are floating on the water, the design has capability to absorb the tides of the ocean since the parts are moving with controlled degree of freedom. This process mixes the culture as required.

The design is connected to the sea bottom using 3 cables connected to the center compartment of the design allowing the panels to remain stationary while still maintaining their freedom of movement in all directions.

In order to regulate the process and manage key functions, such as removing accumulated sulphur in the top compartment and controlling the flow of algae between the panels and the compartments, a nozzle system is essential. Additionally, the detection of when the bottom container reaches its full capacity is crucial. To accomplish these tasks, an electronic control system is implemented, powered by a solar panel located on the main structure.

3.2 Proof of Concept





1 - Inlet to restock BaCl2
2 - Openings controlled electronically allowing algae culture grown in panels into the Hydrogen producing chamber 3 - BaCl2 storage
4 - Valve to insert BaCl2 into the algae mixture to deprive the Sulphur concentration. This opening is controlled by the electronic control system allowing only the required amount to be added
5 - One-way valve allowing the algae after Hydrogen production into the storage compartment

6 - Telescopic storage chamber allowing excess water to be passed out. Three one-way valves are placed, lined with a filter to stop the algae from leaking out. Compressed bio-mass is stored until the collection is done 7 - One-way valve allowing the produced gas into storage
8 - Stores the produced gas
9 – Electronically controlled valve allowing stored gas to be passed into the pump system
10 - Pump-system transfers the gas using tidal energy
11 - Transparent panels with the algae culture
12 - Solar panel providing the power for the electronic control system
13 - One-way inlet allowing fresh sea water to be added to algae culture
14 - Etched structure along the edge to retain sea water above the panels allowing temperature regulation 15 - Compartment storing the sulphur deprived algae culture for Hydrogen production

Algae Efficiency:

There are several kinds of algae available for generate hydrogen in sea water. Some of these are, **Chaetomorpha sp**, **Scenedesmus obliquus**, **Chlorella vulgaris**. By considering the efficiency of generating hydrogen and the conditions that need to grow, we selected Chlorella vulgaris for our application.

Chlorella vulgaris

These algae can grow in sea water with high salt concentration.
References :

- Enhancement of growth and biohydrogen production potential of Chlorella vulgaris MSU-AGM 14 by utilizing seaweed aqueous extract of Valoniopsis pachynema
- Bio-hydrogen production by Chlorella vulgaris under diverse photoperiods

Conditions

- 100 ml of medium containing 5 mg Ca(NO3)24H2O, 10 mg KNO3, 5 mg NaNO3, 5 mg Na2SO4, 5 mg MgCl26H2O, 10 mg b-Na2 glycerophosphate, 0.5 mg Na2EDTA, 0.5 mg FeCl36H2O, 0.5 mg MnCl24H2O, 0.05 mg ZnCl2, 0.5 mg CoCl26H2O, 0.08 mg Na2- MoO42H2O, 2 mg H3BO3, 50 mg.
- pH of 8.6 adjusted with 0.1 MNaOH.
- Cells were cultivated in a glass reactor with an inner diameter of 7 cm and working volume of 1 liter.
- Cells were illuminated by cool fluorescent light (120 l mole/ m2 /s at 27 C)
- d bubbled with sterile air containing 5% (v/v) CO2 at a rate of 0.3 vvm
- Two stage method
- Sulfur containing medium utilized for photosynthetic cell growth (Stage 1) was replaced with sulfur-deficient medium with an initial pH of 8.6. The medium was prepared by replacing the Na2SO4 in growth medium with 5 mg of NaCl.
- The medium was flushed with N2 for 10 min, and the bottle was sealed with a rubber stopper with an aluminum rim and tightly fitted with a syringe for monitoring the volume of water replaced by gas.
- The bottles were incubated at 37 C with shaking at 150 rpm.

The immobilized cells were allowed to grow in growth medium for 3 days in the light (Stage 1). Hydrogen production (Stage 2) was initiated by decanting the growth medium and replacing it with sulfur-deficient medium. Light or darkness was then provided in four different ways: 72 h of continuous light, 72 h of continuous darkness, 24 h of darkness followed by 48 h of light, and 24 h of light followed by 48 h of darkness. Once Stage 2 was completed, the sulfur-deficient medium was replaced with fresh growth medium and the cells were allowed to grow again for 3 days in the light. The description of light and dark patterns administered during the experiment has been presented in **Table 1**.(Reference - Bio-hydrogen production by Chlorella vulgaris under diverse photoperiods)

Table 1
Description of light and dark patterns administered during the experiment.

Pattern	First 24 h	After 24 h
Fully light	Light	Light
Fully dark	Dark	Dark
Partial dark	Dark	Light
Partial light	Light	Dark

Along with these patterns the recorded gas production rates are,

Table 2
Hydrogen production in different conditions.

Condition	Fully dark	Partial dark	Fully light	Partial light
Rate (ml/h/l)	19.4	28.7	28.5	34.8
H_2 volume (Max)	348	448	496	530
Starting time for H_2 (h)	23–24	24–25	21–22	21.5–22
Total time of H_2 production (h)	45	59	47	52

In our application we are having partially light conditions in hydrogen generation chamber(dark) and in growing panels(light). Due to which, we consider our hydrogen generation rate is 34.8 ml/h/l. In our design generated hydrogen is removed, so that the hydrogen generation can be continued up to 52 hours.

<u>Calculation</u>
With practical factors we can assume hydrogen generating rate is 50% of recorded experiment values. Also, in this experiment the gas measurements were measured by gas chromatography (GC-17A, Shimazdu) with a column packed and molecular sieve 5A column (Alltech), using argon as a carrier gas. The packed column was maintained at 80 C and the thermal conductivity detector was set at 120 C. The volume of hydrogen gas produced was calculated from it's volumetric content, multiplied by the total volume of collected gas. Generated hydrogen gas volume per day - 417.6 ml/day/l.
Number of generated hydrogen moles – 0.0187 mol/day/l
For 810 liters – 15.1 mol
The theoretical maximum amount of energy that can be generated is 242 kJ per mole of hydrogen gas. However, the actual amount of energy that can be generated is typically much lower due to inefficiencies in the fuel cell.
So theoretical energy – 3654.37 kJ per day
Amount of Petrol that gives equivalent energy = 3654.37 kJ / 32,000 kJ/L
This is equivalent to 0.1142 liters of petrol, and a typical solar panel that generates 3654.37 kJ kJ per day would be around 1 square meters in size. This is based on the assumption that the solar panel has an efficiency of 15% and that it is exposed to full sunlight for 8 hours per day.

<u>BaCl2 Calculation:</u>
To calculate the concentration of barium chloride ($BaCl_2$) needed to precipitate sulfate ions (SO_4^{2-}) from seawater, we need to consider the stoichiometry of the reaction between barium chloride and sulfate ions. The balanced chemical equation for the reaction is:

$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$
The molar ratio between barium chloride and sulfate ions is 1:1.

Let's assume we want to precipitate the sulfate ions from seawater with an **average sulfate concentration of 2.800 g/L (or 0.0291 mol/L).** The concentration of **barium chloride needed to react with the sulfate ions would also be 0.0291 mol/L.** Therefore, to precipitate sulfate ions from seawater with the given concentration, we will need a barium chloride solution with a concentration of approximately 0.0291 mol/L.

To find the number of moles needed for 810 L of seawater with the given sulfate concentration, we can use the concentration of sulfate ions, which is 0.0291 mol/L.
Number of moles = Concentration x Volume
Number of liters for a cell = 270L
Number of days for $BaCl_2$ treatment for month = 6 (once in 5 days)
Number of moles = 0.0291 mol/L x 270 L
Number of moles = 7.857 moles (per one cycle)
Total number of moles per one maintenance period = 7.857 x 6 x (1 month)
Therefore, approximately 47.142 moles of barium chloride would be needed to precipitate sulfate ions from (810 x 6 x 1 L) of seawater with the given concentration for 1 months.

Molar mass of $BaCl_2$ = (1 × Ba) + (2 × Cl) = (1 × 137.33) + (2 × 35.45) = 208.23 g/mol
Number of moles = Mass / Molar mass
Number of moles = 1000 g / 208.23 g/mol Number
of moles ≈ 4.8 moles
Therefore, approximately 4.8 moles of barium chloride are present in 1 kilogram of barium chloride powder.

If the price for 1 kilogram (1 kg) of barium chloride powder is 60 Indian Rupees (INR), we can calculate the cost per mole using the molar mass of barium chloride (208.23 g/mol) as determined earlier.

Cost per mole = Cost per kilogram / Molar mass

Cost per mole = 60 INR / 208.23 g/mol

Cost per mole ≈ 0.2877 INR/mol

Total cost per one maintenance period = 47.142 x 0.2877 = INR 13.563

= LKR 50.09

Above calculated value is the theoretical maximum. Due to Sulphuric usage by green algae during its growth and biomass production, required barium chloride quantity can further be reduced by using experimental data.

3.3 Sustainability

Our solution aligns strongly with two Sustainable Development Goals (SDGs): Goal 7 - Affordable and Clean Energy, and Goal 13 - Climate Action and SPARK's Mission statement.

Goal 7: Affordable and Clean Energy

By utilizing green algae for hydrogen production, we promote the use of a clean and sustainable energy source. Hydrogen gas, when produced from renewable resources like green algae, can provide a clean alternative to fossil fuels for electricity generation and various other applications.

Goal 13: Climate Action

By replacing conventional hydrogen production methods that rely on fossil fuels, our solution significantly reduces greenhouse gas emissions, including carbon dioxide (CO_2), a major contributor to climate change. This helps in mitigating the impacts of climate change and achieving emission reduction targets. Our solution also embraces sustainable practices by utilizing green algae, a renewable resource, for hydrogen production. Also, by minimizing water consumption, utilizing byproducts, and reducing waste generation, we promote resource efficiency and sustainable production methods.

Addressing this problem and actively working towards the development of affordable and clean energy solutions, by utilizing the knowledge we obtain as electronic engineering undergraduates, we strongly believe that we are setting a positive example and making a lasting impact for future generations.

4. Social and Environmental Impact Assessment

Social Impact:

- Reliable Power Supply: By providing a low-cost and sustainable method of power generation, our solution addresses the energy crisis faced by Sri Lanka and many such developing countries. It ensures a more reliable power supply, improving the quality of life for people.
- Job Creation: The development and implementation of our solution can create employment opportunities in areas such as algae cultivation, system installation and maintenance.
- Technological Advancement: By introducing innovative renewable energy solutions, our project contributes to the technological advancement of Sri Lanka and fosters a culture of sustainable energy practices.

Environmental impact:

- Carbon Emission Reduction: The use of green algae to produce hydrogen eliminates the carbon emissions associated with conventional hydrogen production methods reliant on fossil fuels. This contributes to reducing climate change and the carbon footprint.
- Clean Energy Source: Hydrogen, when burned or used in fuel cells, produces only water vapor as a byproduct, making it a clean energy source. By promoting the adoption of hydrogen, our solution helps reduce air pollution.
- Preservation of Natural Resources: By utilizing renewable energy sources like solar power for system control and tidal energy for the mechanical processes in the design, our solution reduces the dependence on finite fossil fuel resources.
- Marine Ecosystem Preservation: The floating panel design minimizes disturbance to marine ecosystems as it utilizes ocean spaces effectively without causing significant harm to marine life. Additionally, the cultivation of green algae can contribute to water purification by absorbing excess nutrients and improving water quality.

5. Logistics

5.1 Task Breakdown and Time Frame

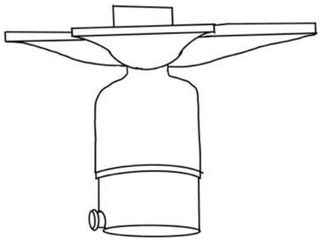
Sithija Ranaraja	Research on Hydrogen production and Sulphur removal technique
Ishara Dilshan	Research on Algae varieties and Efficiency calculation
Nisala Yapa	Research on Solid waste removal mechanism and filters
Ranuka Ranasinghe	Research on Air filtration and pumping mechanism
Thisari Amarasekara	Research on Nutrient intake and level detection of Algae culture

September 2022 – Initial phase of our project involved outlining the problem statement in accordance with the Sustainable Development Goals (SDGs)
December 2022 – Research on Hydrogen production mechanisms centered around water electrolysis
January 2023 – Research efforts shifted towards investigating the potential of algae-based hydrogen production **March 2023** – Experimental session on Hydrogen production from Algae obtained from Sabaragamuwa University and Integrating research outcomes to conceptualize a practical and efficient system for hydrogen production **April 2023** – Final conceptual design related to the Ocean environment

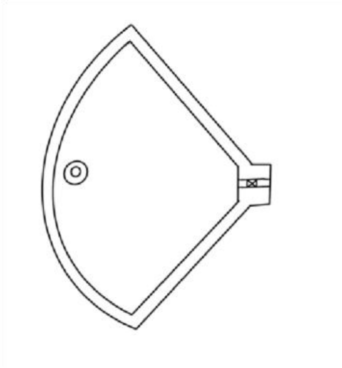
6. References

- Hydrogen Production. Green Algae as a Source of Energy
- https://scialert.net/fulltext/?doi=biotech.2012.258.262
- Biohydrogen production by Chlorella vulgaris and Scenedesmus obliquus immobilized cultivated in artificial wastewater under different light quality
- Bio-hydrogen production by Chlorella vulgaris under diverse photoperiods
- Fermentative hydrogen production using pretreated microalgal biomass as feedstock
- Two-step method of hydrogen production by biologically photolyzing water using ocean green algae
- How can having too much algae cause an oxygen depletion
- Influence of dimethyl sulfide on the carbon cycle and biological production
- Using copper sulfate to control algae in water supply impoundment
- Recovery of Nutrients From Wastewaters Using Microalgae
- Sulfate Removal From Waste Chemicals By Precipitation
- The mechanism of photosystem-II inactivation during sulphur deprivation-induced H2 production in Chlamydomonas reinhardtii
- Role of Sulfur for Algae: Acquisition, Metabolism, Ecology and Evolution
- Eco-chemical mechanisms govern phytoplankton emissions of dimethylsulfide in global surface waters

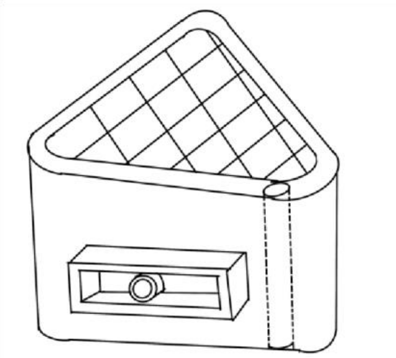
7. Appendix



Design – Side View

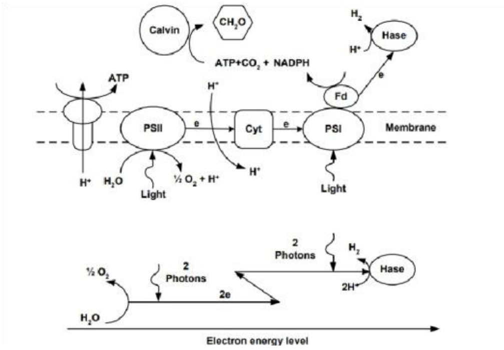


Panel – Top View



Electronic Control System with Solar Panel

Panel – Cross section



Hydrogen production mechanism in Green algae