Sustainable Energy Transition: Photolysis-Driven Bioelectricity

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Abstract - *The potential of photolysis-driven bioelectricity generation using algae and succulents, offering a novel, sustainable, and scalable approach to renewable energy production. Through bio-electrochemical systems, algae and succulents exhibit high photolysis efficiency, generating potential electricity outputs. The main objective of this study is to explore how Microbial Fuel Cells (MFCs) present in algae and succulents can be utilized to generate electricity. Optimized photolysis conditions and electrode materials further enhance electricity generation, providing a viable alternative to fossil fuels and reducing greenhouse gas emissions. This study emphasizes to show the enhanced power density and stability, paving the way for further research and development of scalable bioelectricity systems. A preliminary cost analysis indicates the economic viability of bioelectricity production. Key findings highlight the potential for large-scale implementation, underscoring the significance of bio-photolysis electricity generation in the pursuit of a low-carbon economy.*

Key Words: **Sustainability, Electrolysis, Renewable energy, MFCs, Electricity, Amplification.**

1.INTRODUCTION

The global energy consumption is anticipated to increase 36% by 2030, which will cause a massive global shortage of conventional fuel in the near future. Therefore, the shift to renewable energy is imperative to mitigate the unprecedented energy crisis driven by escalating demands, depleting fossil fuels and climate change. The relevance of leveraging local resources to generate clean energy is a predominant factor for sustainable development. Algae and succulents particularly, abundant, fast growing and rich in organic matter has the potential to harness electricity. The study focuses on the electrochemical conversion of algae and succulents into electricity, utilizing their photosynthetic properties to generate power.

While previous research has demonstrated that algae-based photolysis can generate power densities ranging from 10-500 microwatts/cm^2 and aloe vera could produce 200-800 microwatts per plant, this research aims to optimize these conditions to a higher efficiency.

Under ideal conditions, the raw materials of 10^3 algae culture and 2,000 aloe vera plants could generate 1 W of power. To make this bio electricity viable for practical applications, amplifiers can be used to enhance the output. Although this is an ongoing study and the concept is yet to be fully validated through experimental trials, such that the main objective is to develop an efficient system that can contribute to a low-carbon economy.

Algae are photosynthetic organisms capable of converting sunlight into chemical energy. With over 40,000 known algal species, selecting the optimal variety is crucial for efficient energy harvesting. Various types of algae and their potential for harnessing electricity, particularly through electrolysis are summarized in table 1.

Succulents, with their Crassulacean Acid Metabolism (CAM) produces a photosynthetic pathway which allows it to perform gas exchange and store organic acids such as malate at night that potentially generates electrons during both light and dark phases could provide a more consistent bioelectric output compared to other plants. Succulents, adapted to arid environments, store water in their leaves, stems, or roots. This water storage capacity enhances their electrochemical properties, making them ideal for bio-electrochemical energy harvesting.

Evaluating the electrochemical properties, water storage capacities, and harvesting complexities of Aloe vera, Echeveria elegans, Crassula ovata, and Kalanchoe daigremontianin etc., it is found that Aloe vera could be the most suitable species for bio-electrochemical energy harvesting due to its high electrochemical activity, robust water storage, and ease of electrolysis.

Table -1: Types of Algae and Potential to Produce Electricity

Type of algae	Characteristics	Potential for Electricity generation	Ease of harvesting energy via electrolysis
Green Algae	High growth rate, rich in chlorophyll	Can produce biofuels; used in bio-electrochemical systems	Moderate; easier to culture but may require optimization for efficiency
Brown Algae	Contains alginates; often found in marine environments	Can be converted into biofuels; some species show promise in microbial fuel cells	Moderate; harvesting can be labour-intensive, but species are abundant
Red Algae	Contains phycoerythrin; often found in warmer waters	Limited direct use in electricity generation; potential in bioprocessing	Low; typically, not optimized for electrolysis but can be used in biochemical pathways
Cyanobacteria	Photosynthetic bacteria; fast-growing	Can generate hydrogen through photo-fermentation	High; efficient hydrogen production, relatively easy to culture
Diatoms	Silica cell walls; diverse species	Potential for biofuel production and bioprocessing	Moderate; extraction of oils can be challenging, but effective in some systems

2. LITERATURE REVIEW

The review [15] outlines the principles of algae mediated bioelectricity in MFCs, emphasizing the photosynthetic electron generation via water splitting in Photosystem II. It provides a theoretical basis for algae bio-photovoltaics (BPVs) and supports the sustainability narratives of the system. The study highlights the power densities in the bacteria-algae coupled systems underscoring the challenges like how power output and electrode efficiency, relevant to optimizing the algae system.

The research [16] demonstrates a BPV system specifically designed Cladophora sp. with POME, achieving a high-power density of 619.1 mW/m². It explains electron transfer from algal photolysis to carbon electrodes and 90% Chemical Oxygen Demand (COD) removal, unveiling dual energy and environmental benefits. The study focuses on combining energy generation with wastewater treatment, guiding another sustainable way of generating electricity.

The comprehensive research [17] explores bio-electrochemical systems that focus on harnessing electricity from plant rhizospheres and photosynthetic tissues. It reports a power density of 10-100 mW/m² for plant MFCs and discusses their role in pollutant removal and sustainable energy. The paper provides a framework for extrapolating bioelectricity from photosynthetic plants.

The study [18] reviews CMOS-based power amplifiers for low-power applications including IoT devices and biosensing. The paper supports the feasibility of using amplifiers for high input impedance and low-noise characteristics suitable for amplifying small biological signals.

3. METHODOLOGY

3.1 Harnessing the Energy of Algae

Harnessing electricity from algae is an exciting avenue for sustainable energy. Algae-based photolysis for electricity generation involves several key steps. Fig 1. shows the process by which simple electrolysis takes place to produce the power. It generates electricity by harnessing light energy to split water molecules into hydrogen ions, electrons, and oxygen gas. The electrons flow through an external circuit, producing electricity, while oxygen is released.

During the process, initial measurements shows that an open-circuit voltage of up to 993 millivolts and a peak power of 175.37 microwatts. The electrochemical reactions in algae-based photolysis require efficient electrodes to facilitate electron transfer. Anode (oxidation) electrodes, such as graphite, carbon nanotube (CNT), titanium dioxide (TiO2), and tungsten oxide (WO3), offer high conductivity, stability, and electrocatalytic activity. Cathode (reduction) electrodes, including platinum (Pt), palladium (Pd), silver (Ag), and nickel (Ni), provide high electrocatalytic activity, conductivity, and corrosion resistance. Additionally, biocompatible electrodes like conductive polymers, bio-inspired electrodes, and nanoporous gold could be used for their sustainability and biodegradability.

The process involves a series of electrochemical reactions. Initially, algae absorb light energy, triggering the photolysis reaction [6]:

$$6H_2O + \text{light energy} \rightarrow 6H^+ 6e^- + 3O_2$$

At the anode, water oxidation occurs:

$$2H_2O \rightarrow 4H^+ 4e^- + O_2$$

At the cathode, hydrogen ions and electrons combine:

$$2H^+ 2e^- \rightarrow H_2$$

Overall reaction:

$$\text{Algae} + \text{light energy} + 6H_2O \rightarrow 6H_2 + 3O_2 + \text{biomass}$$

The electrolyte solution plays a crucial role in facilitating ion transport between the anode and cathode. Common electrolyte solutions include phosphate buffer solution (PBS), sodium chloride (NaCl) solution, potassium chloride (KCl) solution, algae growth medium, and natural seawater. The ideal electrolyte solution should have high ionic conductivity, pH buffering capacity, compatibility with algae and microorganisms, low toxicity, and cost-effectiveness.

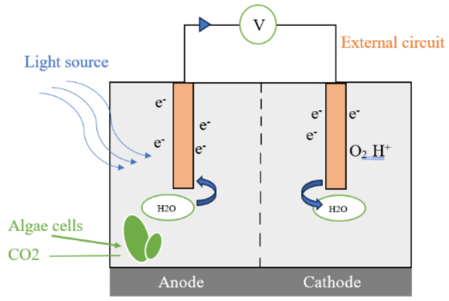

Fig -1: Photolysis Process Using Algae

3.2 Harnessing the Energy of Succulents

Among wide varieties of succulents, aloe vera has a unique combination of properties that could make it an ideal candidate for bioelectricity generation. With a water content of 95-98% and a rich composition of electrolytes, polysaccharides, and glycoproteins, it can promote efficient electrolysis. Due to its abundant availability, low cost, ease of cultivation, and non-toxic nature makes aloe vera an appealing option for bio-electrochemical energy harvesting.

Bioelectricity on aloe vera is generated through photolysis during photosynthesis, where light energy splits the water molecules in Photosystem II to produce electrons, which are transferred to electrodes. CAM metabolism may also contribute electrons via organic acid breakdown in dark phase. In bio electrochemical system with aloe vera, anode and cathode electrodes are inserted into the plant creating a plant-based microbial fuel cell (PMFC) or BPV like system. The processes involve the oxidation of polysaccharides and glycoproteins at the anode, oxygen reduction at the cathode with aloe vera gel itself acts as a natural electrolyte due to its high amount of water content and ionic compounds like potassium, magnesium and organic acids. However, Phosphate Buffer Solution could be used as an external electrolyte solution to enhance the conductivity and electron transfer at the electrode-tissue interface. Reduced Graphene Oxide or a simple bamboo charcoal can be used as electrodes as they balance efficiency and practicality. In a microbial fuel cell using aloe vera, the main chemical reactions involve [6]:

a) Glucose breakdown at the anode:
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 2e^- + 4H$

b) Reduction at the cathode:
$O_2 + 4e^- + 4\ H \rightarrow 2H_2O$

c) The overall reaction can be represented as:
$C_6H_{12}O_6 + O_2 \rightarrow C_2H_5OH + 2H_2O$

These reactions depict the conversion of glucose to ethanol and carbon dioxide while generating electrons for electricity.

4. AMPLIFICATION TECHNIQUES

Amplification methods are used to increase the intensity or signal strength of a weak signal. In the field of bio-electrochemistry, amplification techniques are mainly used to enhance the electrical signals generated by the algae and succulents. Below are the methods/techniques that can be used to amplify the electrical output from the sources:

4.1 Instrumentation Amplifier

Instrumentation amplifiers (in-amps) are designed for applications requiring high input impedance, which is critical when dealing with low current, high-impedence biological sources like algae and succulents. This along with the common-mode rejection of the circuit makes it effective in capturing low-level signals from plants.

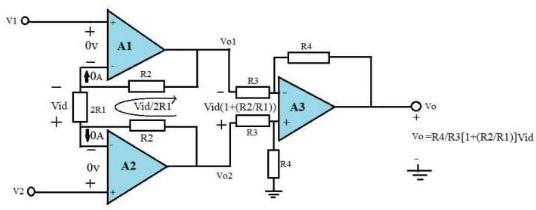

Fig -2: StandardOp-Amp based InstrumentationAmplifier [13]

An instrumentation amplifier is a specific type of differential amplifier engineered to boost low-level signals while effectively minimizing noise and interference. It comprises three operational amplifiers that deliver high input impedance, reducing the load on high-impedance sources. The amplifier emphasizes the difference between two input signals and provides excellent common-mode rejection, essential for preserving signal integrity. Its design also allows for easy gain adjustments with external resistors, making it adaptable for a range of applications [14]. AD620 and INA128 are widely used precision instrumentation amplifier which are suitable for low power applications and ease of integration in prototype circuits.

An instrumentation amplifier can be used to sum up and amplify the electrical output from algae and aloe vera by capturing the small voltage signals generated from Current-Voltage Converter connected to the electrodes [14]. Connecting these signals to the input terminals of the Op-Amp instrumentation amplifier, which is designed to provide high input impedance and excellent common-mode rejection, could be crucial for accurately measuring low-level signals.

A Current-to-Voltage (I-V) converter transforms the small current generated by algae and the succulent into a measurable voltage signal. These converters amplify the current while minimizing noise and ensuring high accuracy.

4.2 Operational-Amplifier

An operational amplifier is a high gain electronic amplifier, widely used in analog electronics for signal amplification. The amplifier consists of resistors and capacitors, which work together to provide high gain, low noise, and high input impedance [12]. The Op-Amp can be classified as inverting, non-inverting, or differential amplifiers in accordance with the application. With the high gain and low noise, Op-Amps are ideal for amplifying weak signals, making them a fundamental component in many electronic systems [12].

Op-Amp could be used to amplify the weak electrical signals generated by both algae and aloe vera, combining the signals to increase their strength and stability. Op-amps also facilitate power conversion, transforming the electrical signals into a format suitable for electricity generation. Furthermore, they enable monitoring and control of the electricity generation process, allowing for real-time adjustments to optimize energy output. By leveraging the capabilities of op-amps, the electrical potential of algae and succulents can be harnessed, that might pave the way for innovative and sustainable energy solutions.

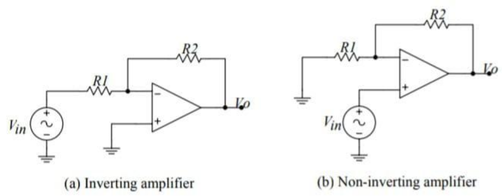

Fig -3: Basic feedback Operational-Amplifier Configurations [12]

5. PRELIMINARY COST ANALYSIS

The cost analysis of harnessing electricity from algae and succulents reveals a promising economic viability. The initial investment for setting up these systems is significant, but operational costs are substantially lower. Maintenance costs are also minimal, making these systems an attractive alternative to traditional renewable energy sources. As research and development continue to advance, costs are expected to decrease further, making algae and succulent-based electricity generation a cost-effective and sustainable solution. The capital expenditures (CAPEX) for establishing an algae and succulent-based electricity generation system, includes electrodes, power conversion systems, and electrical connections. Ongoing operating expenditures (OPEX) are expected to be relatively low, comprising algae/succulent maintenance, water and nutrient supply, labour and training. The initial investment costs that include the equipment costs, land acquisition costs, labour costs etc is the CAPEX. The ongoing operating costs can be the maintenance costs, energy costs, etc. is the OPEX, also the break-even analysis for a system is to be considered. Further, there could be opportunities to earn carbon credits or other incentives, which can also enhance the revenue streams. Therefore, for a good production yield of output and collaborating with the various industries, it is mandatory to ensure the cost dependency.

6. STORAGE

Specific storage conditions are necessary for algae and succulents to preserve their electrochemical characteristics. Like this, to guarantee a steady supply of energy, the produced electricity needs to be stored effectively. For algae, storage methods include refrigeration at 4°C to 10°C with 80% humidity, freeze-drying for extended preservation, and lyophilization to remove water content and enhance stability. In order to preserve their water content, succulents need to be kept in controlled conditions with temperatures between 15°C and 25°C and humidity levels between 50% and 70%. Lead-acid, lithium-ion, or flow batteries provide effective energy storage, while supercapacitors allow for quick charging and discharging of the produced electricity. Bio-electrochemical energy harvesting can develop into a reliable and effective renewable energy source by implementing these storage options into practice.

7. TRANSPORTATION

Transportation plays a vital role in the generation of electricity using algae and succulents. The different transportation techniques of algae and succulents for electricity generation requires careful consideration to ensure the maintenance of their viability and integrity. The transportation of these organisms from cultivation sites to power generation facilities can significantly impact the overall cost and efficiency of the process. For algae, photobioreactors or closed systems can be used to transport the microorganisms while maintaining optimal growing conditions. These systems can be designed to regulate temperature, pH, and light exposure, thereby minimizing stress on the algae. For succulents, transportation techniques focus on maintaining the plant's water balance and preventing the physical damage. This can be achieved by using specialized containers or packaging materials that retain moisture and provide cushioning. Succulents can also be transported in a dormant state, which can help reduce water loss and improve their survival rate during transportation. Various transportation methods such as road, rail, and pipeline transport can be employed, each with its own advantages and challenges. Also, the use of refrigerated transportation or insulated containers can help regulate temperature and humidity levels, further reducing stress on the succulents.

Overall, the choice of transportation technique will depend on factors such as the distance and duration of transport, the type and quantity of algae or succulents being transported, and the specific requirements for maintaining their viability. Maintaining optimal temperature conditions during transportation is crucial for preserving the viability of algae and succulents. Additionally, ensuring the safe and secure transportation of these organisms is essential to prevent contamination and maintain their integrity. As the industry continues to grow, developing specialized transportation infrastructure, integrating with existing transportation networks, and investing in new transportation technologies will be essential for improving efficiency, reducing costs, and scaling up the production of electricity from algae and succulents. Overall, a reliable and efficient transportation system is crucial for the successful generation of electricity from algae and succulents.

8. CONCLUSIONS

The study demonstrates the feasibility of producing electricity from algae and succulents through electrolysis, providing a novel and sustainable renewable energy solution. The high electrochemical property of these organisms and the importance of efficient storage solutions are predominant factors. Future research should focus on scaling up electrolysis systems, genetic engineering, and use of novel electrode materials. This technology has significant implications for addressing the global energy crisis, promoting rural energy development, and ensuring energy independence. This approach not only harnesses natural resources but also supports biodiversity and carbon capture, underscoring its potential significance in the transition to a greener economy. With further collaboration and development, bio-electrochemical energy harvesting from algae and succulents can become a viable and sustainable energy source for the future.

9. OPPORTUNITIES & WAY AHEAD

Harnessing the electricity from algae and succulents unfolds a vast array of opportunities and avenues for future exploration. As research and development continue to advance, we can anticipate significant breakthroughs in efficiency, scalability, and cost-effectiveness. One of the most promising opportunities lies in integrating these systems with existing renewable energy infrastructure. By combining algae or succulent-based power generation with solar, wind, or hydroelectric power, which can create hybrid systems that optimize energy production and reduce reliance on fossil fuels. Algae and succulent-based systems can be designed for off-grid applications, providing energy access to remote communities and underserved population. This can have a transformative impact on socio-economic development, enabling communities to power their homes, schools, and businesses sustainably. As part of the future initiatives, integrating the bioelectricity that is generated from algae and succulents can be used for the recharging purpose in the batteries at industries. Also maximising the output current that is generated as a huge amount can be used to power or run the machines for commercial and industrial purposes.

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