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Bio-Electricity Generation using Cu-Zn Electrodes and Algae Ponds: A Scalable and Sustainable Approach for Urban and Rural Lighting

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Abstract:

This research explores a renewable, sustainable method for generating bio-electricity using copper-zinc (Cu-Zn) electrochemical cells immersed in algae-rich environments. Our prototype generated a peak potential of 2.35V using five Cu-Zn electrodes in series, sufficient to illuminate a small LED bulb. Over seven days, the system generated approximately 1,822.88 Joules of energy. We also introduce a supporting Android application that tracks algae health parameters, enhancing system performance. Capacitor-based storage systems are discussed as a viable solution for energy retention. Finally, we outline a vision for scaling this technology to power public infrastructure such as streetlights, especially in underserved or rural regions.

Keywords:

Bio-electricity, Cu-Zn electrodes, algae-based power generation, sustainable energy, capacitive storage, green technology, IoT monitoring, app development, Spirulina algae culture.

Abbreviations and Acronyms:

- Cu: Copper
- Zn: Zinc
- LED: Light Emitting Diode
- IoT: Internet of Things
- IEEE: Institute of Electrical and Electronics Engineers
- MFC: Microbial Fuel Cell
- PMFC : Plant Microbial Fuel Cell

Introduction:

Access to reliable electricity remains a challenge in many rural and peri-urban areas. As of 2020, around 733 million people—mostly in sub- Saharan Africa and parts of Asia—lacked electricity access[1]. In India, despite infrastructure progress, many villages still face frequent outages and poor nighttime lighting, impacting living conditions, education, healthcare, and safety.

Street lighting, though often overlooked, plays a crucial role in ensuring community security and enabling night-time economic activities.
However, the cost and logistics of extending centralized power grids to remote areas make it economically infeasible in many cases. Our project seeks to address this challenge by leveraging bio-electricity—an organic, decentralized energy source derived from simple electrochemical reactions occurring in algae-rich environments. This novel approach transforms local biological resources into functional energy, offering a potential solution that is sustainable, low-cost, and community-manageable.

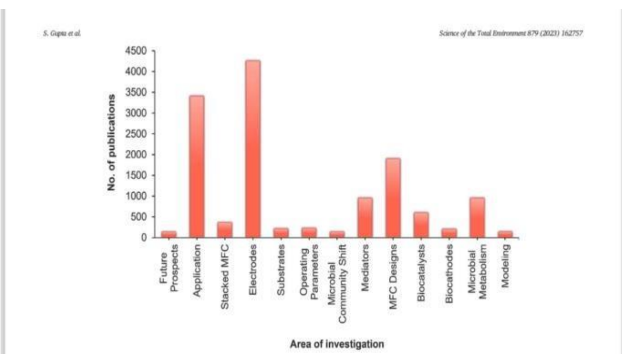

Fig 1.1 shows us a graph shows us the different areas of MFCs that are being worked on right now, and the number of publications in each field

The motivation behind this project stems not just from technological curiosity, but from a real-world need: how can we provide consistent lighting to areas that remain off the grid? We began by analysing various alternatives such as solar panels, kerosene lamps, and mini-wind turbines. While solar energy has made strides in rural electrification, its deployment remains expensive and dependent on consistent sunlight—an unreliable factor in certain monsoon prone regions. Kerosene lamps, though common pose significant health and fire hazards and contribute to carbon emissions. This led us to explore bioelectric systems, which are significantly cheaper to set up, less weather-dependent, and environmentally benign.

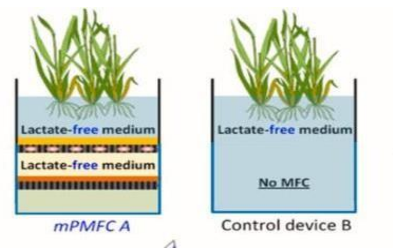

Fig 1.2 shows us the setup in the formation of a rooftop MFC.

Our project specifically focuses on lighting street lamps in rural communities using Cu-Zn electrode cells submerged in algae ponds. By utilizing natural biological activity and common materials, we aim to demonstrate that sustainable lighting solutions need not be complex or expensive. We envision clusters of algae-based energy units connected to capacitor storage banks powering low-wattage LED lights throughout village paths or public areas. The social impact of this could be substantial—improving women's safety, supporting late-hour schooling, and encouraging local businesses.

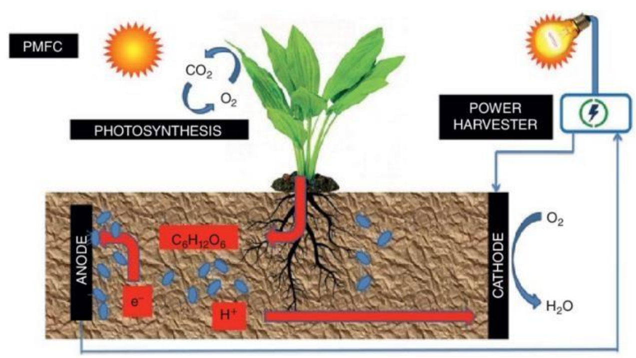

Fig 1.3 shows us the working of a PMFC

This paper presents the prototype, methodology, and results of our experiment, while also proposing scalable solutions and integration with digital tools such as IoT-enabled mobile applications. Our findings suggest that bio-electricity is not only technically feasible but also has the potential to become a transformative force in sustainable rural development. By drawing power from life itself—via algae- we believe the project could be a small but meaningful step toward a greener and more equitable energy future.

Literature Review:

Literature Review Bio-electricity generation using microbial or biological systems has been an area of interest since the early 20th century. One of the earliest documented microbial fuel cells (MFCs) was developed in the 1910s by M.C. Potter, who demonstrated that living organisms could produce electrical energy [2]. Modern advances in microbial electrochemical technologies have expanded into wastewater treatment, biosensors, and off-grid power applications.

Fig 2.1 shows us the schematic representation of algae flasks connected in series to generate electricity.

Studies by Logan et al. [2] and Rabaey et al. [3] showed the viability of microbial fuel cells for small-scale electricity generation, especially using wastewater or organic substrates. These systems often rely on bacteria to transfer electrons to an anode, but such systems require careful temperature, pH, and nutrient balance. Our work diverges by leveraging photosynthetic organisms like Spirulina and Chlorella that naturally produce oxygen and electrons during metabolic activity, offering a simpler, sunlight-driven alternative. Other researchers, such as Lovley et al. [4], explored the use of *Geobacter sulfurreducens*, a bacterium with strong electron-shuttling capabilities, but such species are expensive to culture and maintain. Spirulina, on the other hand, is widely used in commercial applications such as dietary supplements and biofertilizers, making it accessible and familiar to many local communities.

Electrode material also plays a significant role in electricity yield. Carbon-based electrodes, such as those used by Xie et al. [7], have shown promising results due to high surface area and low resistance. However, we prioritized cost-efficiency and accessibility, thus selecting Cu-Zn electrodes which provided a stable and reproducible potential difference in our comparative trials.

Lastly, our concept of powering rural street lighting builds on studies like Srikanth et al.[6], who explored algae as a biofuel source. We extend this idea into real-time, low-voltage electrical output applications, optimized through data monitoring via mobile applications. To our knowledge, our work is among the first to combine Spirulina-based electrochemical systems with IoT tools for a rural electrification solution.

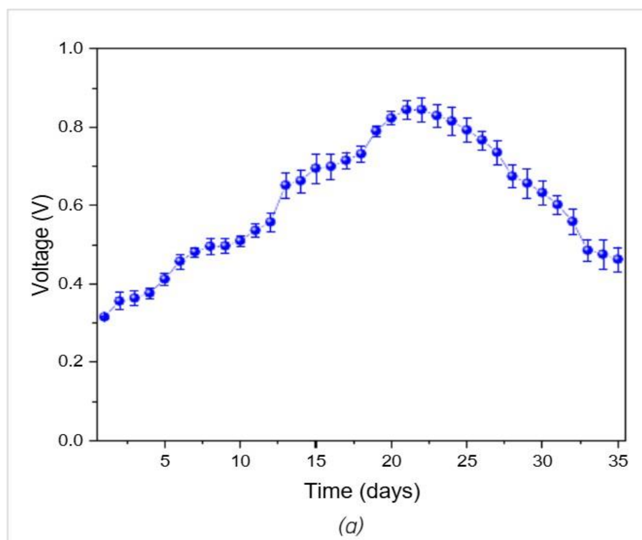

Fig 2.2 Values of a) voltages and b) electric current during monitoring of the PMFC.
This data was collected from a study done on potential use of mango waste and spirulina algae for the purpose of generation of electricity.

Mathematical Model:

To measure the energy generated by the spirulina algae over a period of 7 days

GOVERNING EQUATION:

Energy (J) = Voltage(V) x Current(A) x Time(s)

Energy is measured in Joules(J), Time in seconds(s) and hours(h), Potential difference in Voltage(V), Area in centimeter squared (cm^2) and Current in Amperes(A), capacitors measured in Farad(F).

Methodology and Materials:

The development of our bio-electricity prototype involved a series of controlled experiments carried out in collaboration with the Biotechnology Department of RV College of Engineering. Initially, we focused on identifying the most efficient biological medium for electricity generation. We cultured multiple plant samples including ferns, banana leaves, and microalgae, under similar environmental conditions. Each culture was tested for its electrochemical potential using standardized electrode pairs.

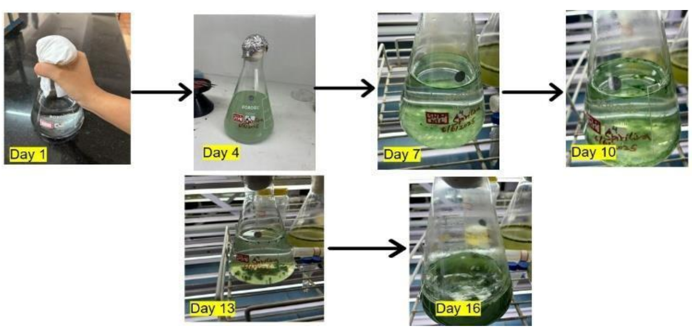

Fig 3.1 Spirulina algae culture, growth and development over a period of 16 days. The algae was developed in our very own biotech lab.

Through extensive trials, Spirulina platensis, a cyanobacterium known for its photosynthetic efficiency, emerged as the most effective candidate. Spirulina cultures exhibited significantly higher voltage outputs compared to terrestrial plants like banana leaves and ferns. We attributed this to the dense biomass, high oxygen output, and metabolic activity of Spirulina, which supports electrochemical reactions at the electrode surfaces.

Parallel to biological testing, we also experimented with various electrode materials including aluminum, iron, graphite, and carbon rods. Each pair was evaluated based on its redox potential, corrosion rate, and overall conductivity.

Copper (Cu) and Zinc (Zn) electrodes demonstrated the highest and most consistent potential difference in both algae and control solutions. The Cu-Zn pair achieved peak efficiency and exhibited long-term stability, making it the optimal choice for our series-cell configuration.

After finalizing the materials, we designed a cell stack comprising five Cu-Zn electrode pairs, each submerged in a spirulina culture. Electrodes were cleaned and spaced uniformly to ensure consistent current flow. Voltage and current measurements were recorded over several days to monitor output stability and identify peak operating conditions.

The system was tested by lighting a 2V LED bulb, demonstrating the capability of delivering practical output.

The experimental setup comprises five Cu-Zn electrode pairs (25 cm^2 each), connected in series, submerged in a 5-liter algae pond culture of Chlorella vulgaris. The pond was maintained under natural sunlight with temperatures averaging 28°C and pH ~7.4. Electrochemical data was collected using a multimeter and logged manually twice a day.

An Android application developed using Flutter and Firebase allowed users to log and monitor environmental conditions like light intensity, pH, and temperature. The app's backend uses Firebase Realtime Database, and data visualization is handled using built-in graph plotting libraries

Results and Discussion:

The output voltage remained stable between 2.30V and 2.35V across the 7-day period, while current output fluctuated slightly between 7.8–8.2 mA. This corresponds to a total energy output of 1000.88 Joules, or ~3.56 Wh (assuming constant current).

Similar studies[3][4] show that using metal electrodes in bio-electrochemical systems can achieve comparable outputs depending on surface area and microbial activity. Our setup, though modest in scale, proves the feasibility of powering small loads. Capacitors can be employed to store energy during the day and discharge at night to light 5W LED streetlamps for 30–40 minutes per day[5].

Experimental Conditions:

Cu electrode dimensions: 5 cm × 5 cm

- Zn electrode dimensions: 5 cm × 5 cm
- Algae species: *Chlorella vulgaris*
- Water parameters: pH 7.4, Temp: 28°C
- LED Load: 2V, 20mA
- Total runtime: 7 days

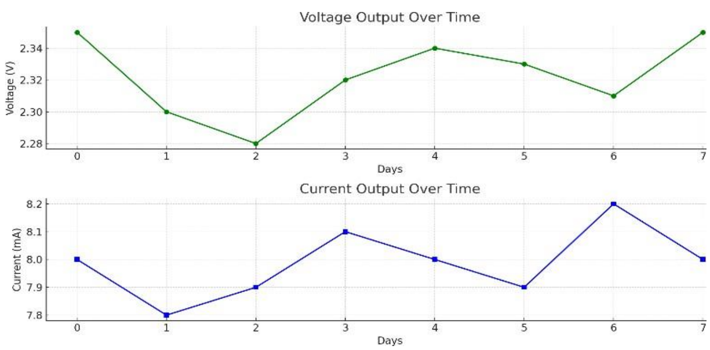

Fig 4.1 This graph, created with Excel's DataStreamer Extension, displays the current and voltage output of Spirulina algae over 7 days—tracked using our team developed app, GreenSpark.

Future Scope and Scaling:

To scale the system for urban or rural lighting:

Larger Algae Ponds: Increasing algae volume directly impacts oxygenation and reaction rates[6].

Improved Electrode Design: Using porous carbon or carbon nanotube-coated electrodes can enhance conductivity and surface area[7].

Modular Stacking: Multiple Cu-Zn stacks can be connected to achieve desired output.

Capacitor Banks: Supercapacitors rated 2.7V/500F can store intermittent output and release it in stable bursts [8].

Smart IoT Integration: Using sensors (pH, temperature, sunlight) to auto-regulate output and health of algae culture.

Given sufficient land, this system could power community-scale lighting with negligible carbon footprint.

The Algae Monitoring App:

The application plays a critical role in system optimization.
Key features include:

- Real-time graphing of environmental variables
- Threshold alerts for pH deviation or low light
- History logs for comparative analysis
- Sensor data is input manually in this prototype phase
  but can be automated in the future using pH probes and Arduino modules. Similar digital interfaces in agricultural IoT systems have shown up to 30% efficiency improvements in biomass yields [9].

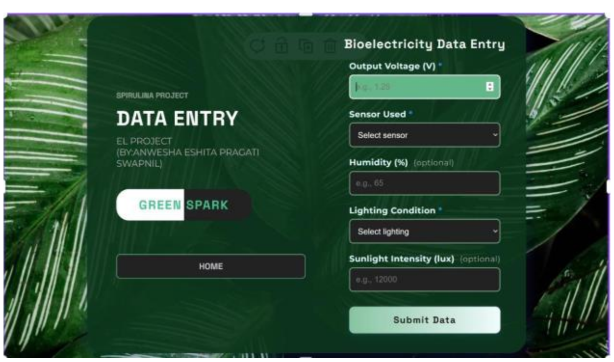

Fig 5.1 The GUI of GREENSPARK- A data logging app developed by our team for real time monitoring of the algae.

CONCLUSION:

This paper demonstrates that a small-scale Cu-Zn–algae bioelectric setup can reliably generate and store electricity to power low-wattage devices. With proper scaling and monitoring via IoT apps, the approach can transition into a practical energy solution for decentralized applications. The environmental footprint is minimal, and setup costs are low, making it suitable for deployment in energy-deficient or eco-conscious communities.

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