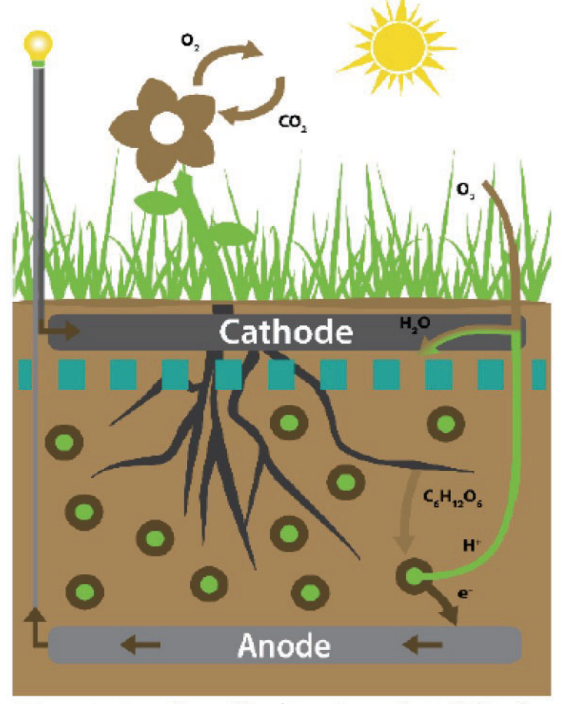
Optimizing *Plant Microbial Fuel Cell* Energy Output: The Effect of *Anodic Substance* and *Configuration*

Abstract

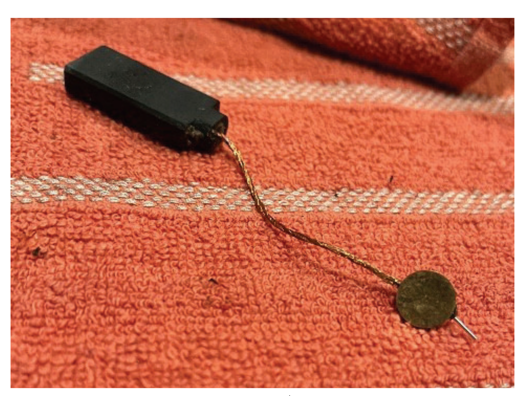
A **plant microbial fuel cell** (PMFC) is a novel technology that utilizes the oxidation of rhizodeposits released by the roots of plants to generate electricity. 12 PMFCs (3 per anodic configuration) were constructed, with the anode and cathode of each PMFC connected by a load resistor of 22 kΩ to complete the circuit. The voltage (in mV) of each PMFC was measured every 12 hours for the duration of the experimental period (168 hours). I hypothesized that the stainless-steel mesh + activated carbon anode would yield the greatest voltage output due to the high electrical conductivity of the stainless steel, the increased surface area (with the addition of activated carbon), and the beneficial bacterial bonding affinity with the carbon surface. However, my hypothesis was not supported as my results showed that the PMFC with the carbon copper brush electrode had a significantly greater output compared to the other anode configurations.

"Which conductive material serving as the anode would yield the greatest voltage output in a single-chambered Plant Microbial Fuel Cell?"



Visual 1: Concept of a Plant Microbial Fuel Cell (Visual Credit: Wageningen University)

Comparing Anodes/Hypothesis



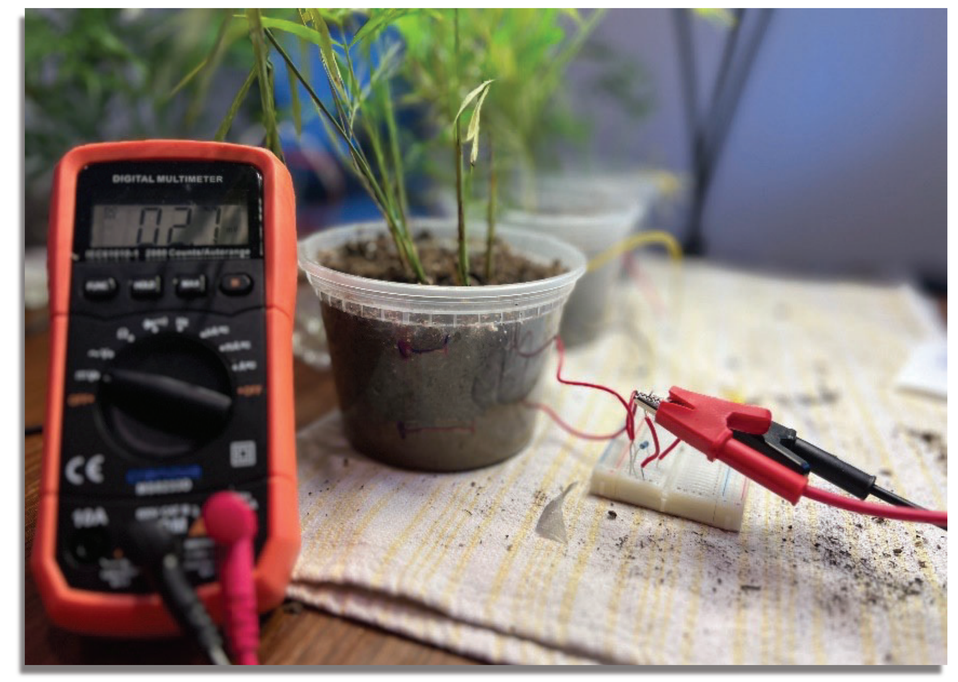
Carbon fiber ↑BA ↓EC

Stainless Steel + Activated Carbon ↑BA ↑EC

Stainless Steel ↓BA ↑EC

Graphite ↑BA ↓EC

- Rhizobium (plant root) bacteria tend to adhere to carbon due to molecular recognition, which is the interaction between the carbon surface and bacteria.
- Due to this biocompatibility, it is suggested that the formation of a biofilm around a neighboring anode should occur at a faster rate and be more proliferative around carbon-containing surfaces (high bacterial adherence **BA**).
- Additionally, it is known that stainless steel has a higher electrical conductivity (**EC**) compared to carbon.
- This led me to **hypothesize** that the stainless steel with activated carbon anode, compared to other anodic configurations, will yield the greatest energy output in a plant microbial fuel cell.



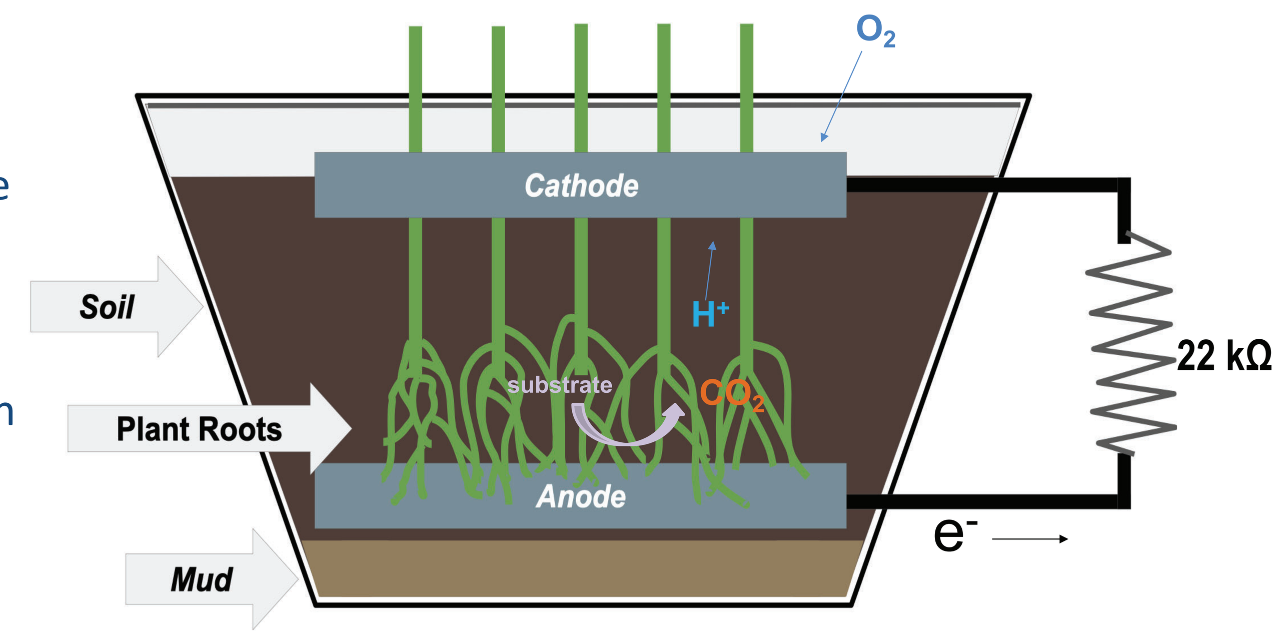
All photographs/visuals except visual 1 were taken/made by Maya Gandhi

Procedure: Constructing the PMFCs

1) **Fill** vessel ⅓ way with mud
2) **Place** anode on top of mud in the vessel
3) **Plant** 5 Neanthe Bella Palms branches in the soil so the roots are making contact with the anode
4) **Fill** the vessel with enriched soil mixture (1 cup water, 2 cups soil) until vessel is ⅔ of the way filled.
5) **Place** the cathode (circular-shaped stainless steel mesh electrode) on top of the soil and partly cover with soil (cathode should be slightly exposed to oxygen)
6) **Connect** both electrode wires to the breadboard
7) **Insert** a resistor of 22 kΩ across the electrode wires to complete the circuit.

- PMFCs were placed under LED plant lights for 8 hours daily. Temperature and moisture were kept stable. pH level of the soil was found to be consistent through all PMFCs
- A voltmeter was used to measure voltage across the resistor twice daily (every 12 hours) for total of 168 hours

All previous steps were repeated three times for each anodic configuration (stainless-steel, stainless-steel w/ activated carbon, graphite, and carbon copper brush electrodes) for a total of 12 PMFCs

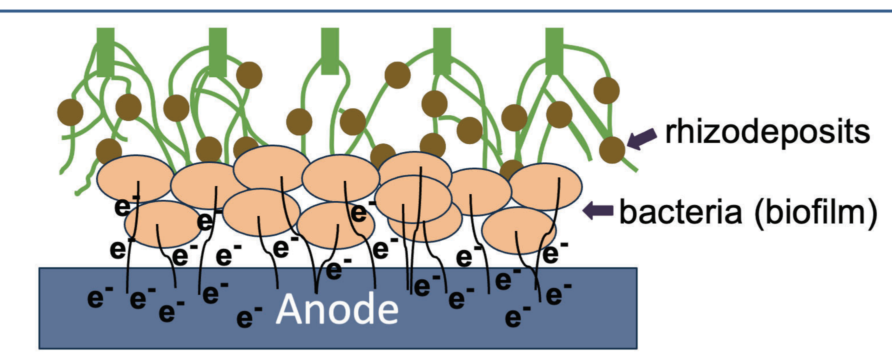


Example reaction at ***anode*** -- exoelectrogenic bacteria use organic compounds (e.g. sugars such as glucose) as substrate to produce electrons:

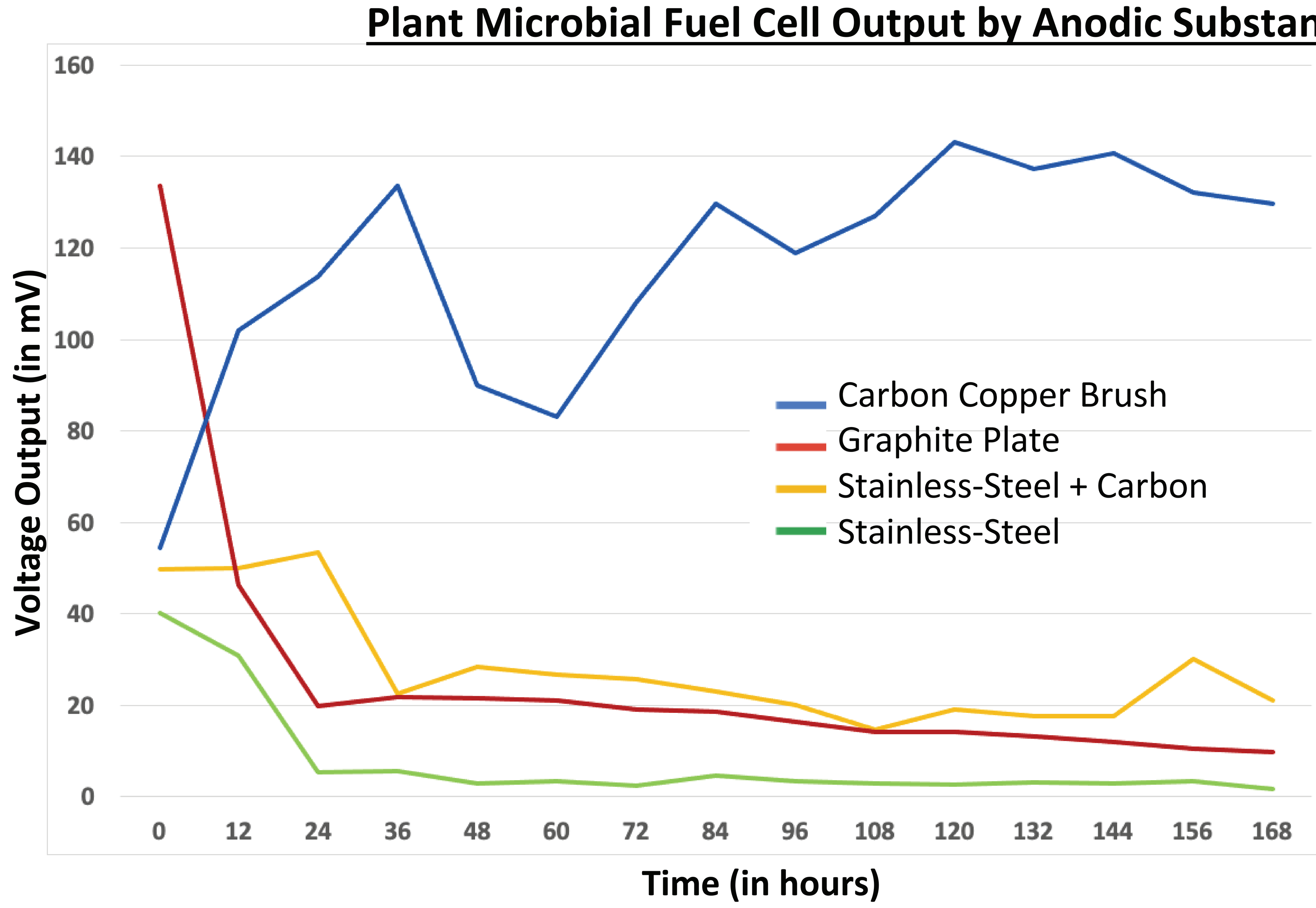
$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + \mathbf{24e^-}$$

Example reaction at ***cathode*** – exposure to O2 is needed:

$$6O_2 + 24H^+ + \mathbf{24e^-} \rightarrow 12H_2O$$



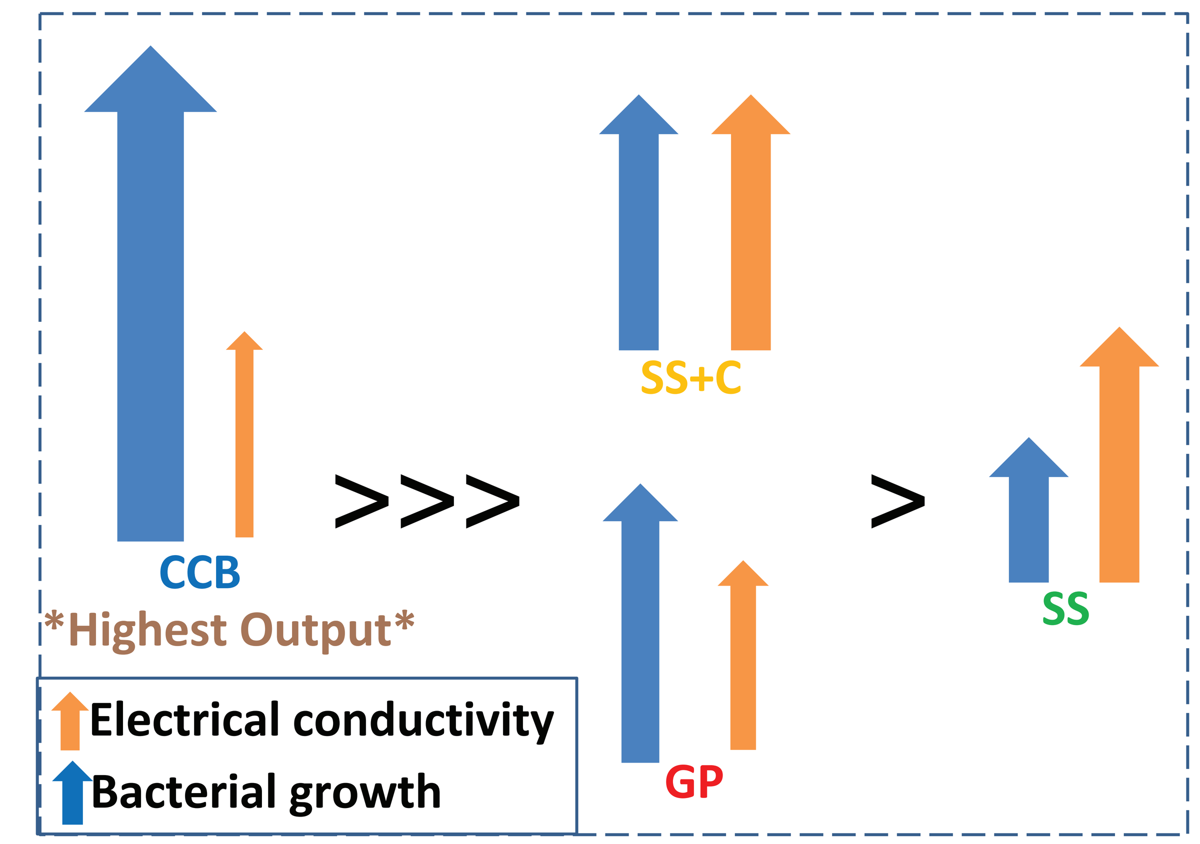
Plant Microbial Fuel Cell Output by Anodic Substance (in mV)



	SS+C	SS	GP	CCB
Hour 0	49.7	40.1	133.6	54.3
Hour 12	50.1	30.8	46.3	102.1
Hour 24	53.3	5.3	19.9	113.7
Hour 36	22.4	5.6	21.9	133.7
Hour 48	28.5	3	21.5	89.9
Hour 60	26.6	3.4	21.1	83
Hour 72	25.8	2.4	19.1	108
Hour 84	23	4.5	18.5	129.7
Hour 96	20	3.3	16.5	118.9
Hour 108	14.6	2.9	14.2	126.9
Hour 120	19.1	2.6	14.3	143.2
Hour 132	17.7	3.1	13.2	137.4
Hour 144	17.5	2.8	11.9	140.8
Hour 156	30	3.3	10.6	132.2
Hour 168	21.1	1.6	9.8	129.6

Data Analysis/Conclusion

- The carbon copper brush anode yielded the highest overall voltage output, while the stainless-steel mesh + activated carbon anode had the 2nd highest output.
- In the end, **my hypothesis was not supported**: The addition of activated carbon to the stainless-steel mesh anode increased the overall voltage output of the system. This was likely due to a more favorable environment created for electrogenic bacteria to flourish with the addition of the activated carbon.
- **The carbon fiber brush electrode, however, yielded the greatest output of all the anodes by a factor of 10. This was likely due to:**
  - Bacterial adherence directly to carbon itself as opposed to indirectly in the stainless steel + activated carbon environment
  - More overall bacterial growth on the carbon copper brush electrode due to increased microscopic surface area compared to other anodes – **this probably outweighed any lack of conductivity of the carbon itself**
- Likely, the growth of bacteria on the carbon copper brush electrode was much greater and overcame the effect of the lesser electrical conductivity of carbon. This may have been due to a much greater microscopic surface area compared to other anodes.



Potential sources of error: At some points, there were some variations in voltage output between the trials of the same anode configuration.

- This may have been due to minor fluctuations in the soil and oxygen environment as well as moisture levels causing greater electron flow in certain PMFCs compared to others.

Improvements: To decrease the variability in measured voltage output, I could consider:

- using an enriched soil mixture to allow for greater and more consistent bacterial growth
- improving the seal around the anodal environment to ensure it stays anaerobic (as oxygen is an electron sink)

Next Steps:

- Improve the durability and decrease the sensitivity of these fuel cells
- Quantify bacterial growth (biofilm) production on the different anodal surfaces

Application:

- We are presented with the possibility of producing green energy from plants using plant microbial fuel cells. This type of fuel cell could be an important and widely scalable source of completely green renewable energy for the future.