The Novel Implementation of Biochar Cathodes in Microbial Fuel Cells

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Microbial fuel cells (MFCs) have the potential to contribute to the increasing demand for sustainable energy.

**Operation:** First, electrons are removed from organic matter, which is known as oxidation. Electrons travel through a series of respiratory enzymes in the cell and make energy for the cell in the form of ATP. The second step is the transfer of these electrons to an electron acceptor, a process known as reduction.

**Benefits of MFCs:**
- Operate at low and ambient temperatures, robust
- Do not require gas treatment or aeration
- Currently being used to treat wastewater since it contains organic matter that can be used to generate electricity

Anodic reaction: $\text{CH}_3\text{COO}^- + 2\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 7\text{H}^+ + 8\text{e}^-$

Cathodic reaction: $\text{O}_2 + 4\text{e}^- + 4\text{H}^+ \rightarrow 2\text{H}_2\text{O}$
The design and cost of the cathode is one of the greatest challenges for MFCs.

Currently, the platinum cathode makes up 60% of the cost of MFCs. Platinum is a precious metal. Energy-intensive to mine.

Performance limited by the cathode because the reduction of oxygen to water that takes place at the cathode is not very efficient naturally.

U.S. Department of Energy has proposed the goal of reducing platinum usage in cathodes by a factor of 20 or replacing it all together.

The challenge is to find a cheap, efficient, sustainable, and scalable material. The feasibility of microbial fuel cells is potentially dependent on discovering a cheaper and environmentally friendly cathode.

The goal of this research was to determine whether a functioning, feasible, and environmentally friendly cathode could be made from biochar.
Biochar is pyrolized organic material and a method of carbon sequestration, generally used as a soil amendment and for bioremediation.

Biochar has properties that make it suitable for cathode development

- High surface area
- Porous structure to allow gas transport, water dissipation, good proton/electron conductivity
- Beginnings of the formation of graphene sheets
To design and test a feasible and sustainable cathode for a microbial fuel cell using biochar
Biochar Preparation

- Obtained various biochar samples
  - Pyrolyzed at 670°C: Mixed wood chips, Douglas fir, yellow pine from the International Tech Corp
  - Pyrolyzed at 1100°C: Arundo Donax, Douglas fir, brewer’s grain, digested plant fiber from the Environmental Protection Agency
- Crushed to < 63μm particle size using a coffee grinder and sieves to maximize surface area
Development of catalyst

- Identifying ratio of biochar powder to binders (ethanol, PTFE) and ideal heating/stirring time to create a tensile, water resistant, uniform polymer
- Conscious selection of feasible materials (stainless steel mesh vs. carbon cloth, PTFE and ethanol vs. Nafion)
Cathode Assembly and Evaluation

1. Crush biochar to uniform particle size (<63um)
2. Place 0.48g of biochar in vial w/ PTFE and ethanol.
3. Place vial on a stirring and heating plate. Stir for 1 hour on highest setting.
4. Cut 5cm x 4cm piece from stainless steel mesh
5. Spread catalyst polymer evenly across mesh using a spatula
6. Cut out a circle from the mesh with an area of .7cm²
7. Place cathode in designated chamber with catalyst facing down
8. Place and seal a rubber washer on top of the cathode
9. Fill the cell with the electrolyte
10. Open Potentiostat program on computer
11. Set the voltage to -0.3V to 0.3V
12. Begin experiment and collect data after 3 hours

Cathode performance in MFC is determined.
Photographs
Data

Biochar Cathode Performance: 670°C Pyrolysis

- Mixed wood chips
- Yellow pine
- Douglas Fir
- Pt control

Biochar Cathode Performance: 1100°C Pyrolysis

- Douglas fir
- Digested Plant Fiber
- Brewer's grain
- Arundo Donax
- Pt control
## Data

<table>
<thead>
<tr>
<th>Cathode material</th>
<th>Current Density Range (A/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed wood chips (670)</td>
<td>0.07 - 0.27</td>
</tr>
<tr>
<td>Yellow pine (670)</td>
<td>0.1 - 0.17</td>
</tr>
<tr>
<td>Douglas fir (670)</td>
<td>0.4 - 1.17</td>
</tr>
<tr>
<td>Douglas fir (1100)</td>
<td>2.02 - 4.9</td>
</tr>
<tr>
<td>Digested plant fiber (1100)</td>
<td>0.35 - 1.9</td>
</tr>
<tr>
<td>Brewer's grain (1100)</td>
<td>0.28 - 0.98</td>
</tr>
<tr>
<td>Arundo Donax (1100)</td>
<td>0.88 - 4.0</td>
</tr>
<tr>
<td>Platinum control</td>
<td>5.3 - 12.0</td>
</tr>
</tbody>
</table>

### Biochar Cathode Performance Comparison

The chart illustrates the performance comparison of various cathode materials across different potentials. Each line represents a different material, with the platinum control being the black line at the top. The x-axis represents potential (volts), ranging from -0.4 to 0.4, and the y-axis represents current density (A/m²), with values ranging from -25 to 0.

- **Mixed wood chips (670)**
- **Yellow pine (670)**
- **Douglas fir (670)**
- **Douglas fir (1100)**
- **Digested plant fiber (1100)**
- **Brewer's grain (1100)**
- **Arundo Donax (1100)**
- **Platinum control**
## Cost Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Price</th>
<th>Cost $/m²</th>
<th>Replacement material</th>
<th>Unit Price</th>
<th>Cost $/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pt-based lab MFC cathode</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>20% Pt</td>
<td>$35/g</td>
<td>875</td>
<td>Biochar</td>
<td>$0.001/g</td>
<td>0.25</td>
</tr>
<tr>
<td>5% Nafion solution</td>
<td>$1500/L</td>
<td>250</td>
<td>Ethanol</td>
<td>$10/L</td>
<td>3</td>
</tr>
<tr>
<td>Carbon powder</td>
<td>$1/g</td>
<td>25</td>
<td>Commercial PTFE</td>
<td>$10/L</td>
<td>1</td>
</tr>
<tr>
<td>PTFE</td>
<td>$300/L</td>
<td>100</td>
<td>Commercial stainless steel</td>
<td>$10-30/m²</td>
<td>10 to 30</td>
</tr>
<tr>
<td>Carbon cloth</td>
<td>$200/m²</td>
<td>200</td>
<td>Fabrication cost</td>
<td>$10/m²</td>
<td>10</td>
</tr>
<tr>
<td>Fabrication cost</td>
<td>$50/m²</td>
<td>50</td>
<td></td>
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<td></td>
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<tr>
<td><strong>Total cost</strong></td>
<td><strong>1500</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>Projected total cost</strong></td>
</tr>
</tbody>
</table>
Summary of Results

• Biochar can function as an inexpensive and environmentally friendly cathode.

• Cathodes made with biochar pyrolyzed at 1100°C had higher current densities than cathodes made with biochar pyrolyzed at 670°C.

• Feedstock of the biochar affects the current densities produced.

• The cathode made out of Douglas fir pyrolyzed at 1100°C was 41% as efficient as a traditional platinum cathode (current density of 2.02 – 4.9A/m² compared to platinum, 5.3 – 12A/m²).

• The cathode made out of yellow pine biochar pyrolyzed at 670°C had the lowest current density from 0.1 – 0.17 A/m².

• The biochar cathode that was designed is approximately 50 times cheaper than the traditional platinum cathodes. It costs $24-44 per square meter in comparison to the cost of the platinum cathode at $1500 per square meter.
Limitations

- Limited feedstock variation and limited temperatures of pyrolysis of biochars tested
- One possible design tested
- Tested in electrochemical test cell with Potentiostat

Potential Sources of Error

- Cathode performance is influenced by how uniformly the catalyst polymer is spread. Using the spatula, it was difficult to evenly coat the stainless steel cathode surface while filling the 20cm² area. It is likely that there were minor variations in thickness in many of the cathodes. The extent to which this affected the results is unknown.
Future Research and Applications

Future Research
- It can be seen that feedstock does affect cathode performance, and therefore, a broader variety of feedstock need to be investigated in order to optimize this factor.
- Tests need to be done to assess the durability and reusability of biochar cathodes.
- Also, the engineering of a biochar-carbon nanoparticle hybrid catalyst to optimize both performance and cost will be pursued.
- Goal is to optimize both cost and performance

Applications
- Biochar cathodes may have applications in different types of fuel cells
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- Bill Petrich- International Tech Corp

- Family
References


Thank you so much for listening and for the opportunity to be here!