Electrogenic Biotransformation of Organic Substrates: A Bioanodic Approach to Decentralized Energy

EGSD012

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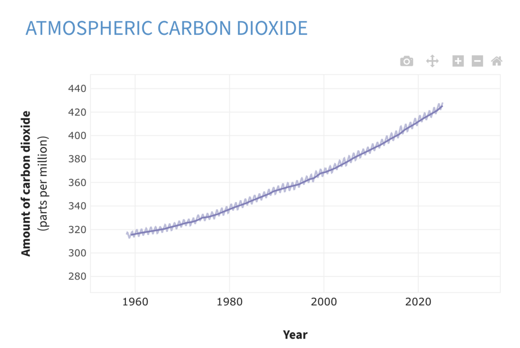
Introduction

- **CO_2 Increase:** From ~280 ppm to over 420 ppm since the late 1700s.
- **Food Waste:** Approximately 325 lbs/person annually
  Methane GWP: CH_4 has a GWP 28–30x that of CO_2 over 100 years.
- **Electrogenic Bacteria:** *Geobacter* and *Shewanella* facilitate EET.

Modern energy infrastructure is both centralized and carbon-intensive. Landfill-bound organic waste undergoes anaerobic decomposition, producing methane, an extremely potent greenhouse gas with a GWP over 25× that of CO_2. Compost presents a viable fuel source for bioelectrochemical systems such as MFCs. These devices generate electricity through EET, where electrogenic microbes metabolize substrates and release electrons.

MFCs are a renewable source capable of addressing both energy poverty and organic waste mismanagement.



Data compiled from multiple sources by World Bank – with minor processing by Our World in Data

Problem

The dual crises of climate change and energy poverty demand innovative solutions. Over1.2 billion people worldwide lack reliable access to electricity, disproportionately affecting rural and underserved communities. Traditional renewable technologies such as solar and wind, while effective, require substantial

Methane Emissions:
- Captures organic waste before landfill decomposition, reducing CH_4 output

Food Waste:
- Redirects a portion of the ~30–40% of U.S. food waste into energy generation

Energy Inaccessibility:
- Offers low-cost, renewable power for households in off-grid or resource-limited regions

Fossil Fuel Dependence:
- Produces clean energy with no combustion or fossil extraction

Biodegradable Battery Concept:
- Offers a renewable alternative to lithium-based power storage systems

Urban Sustainability:
- Aligns with circular economy goals, converting municipal compost into distributed energy

Climate Adaptation:
- Empowers localized climate solutions that don't depend on weather or central grids

Background

Microbial fuel cells (MFCs) are devices that use bacteria to convert organic matter into electricity. As microbes break down compounds in low-oxygen environments, they release electrons that travel through an external circuit, generating a current. This process is known as extracellular electron transfer (EET).

Early studies focused on wastewater-fed MFCs using pure cultures like *Geobacter sulfurreducens*. More recent research explores compost as a low-cost alternative, offering both a fuel source and a natural microbial community. However, power outputs in compost-based systems remain inconsistent due to changing conditions inside the biomass.

Research shows that system efficiency depends heavily on variables such as electrode material, oxygen availability, internal resistance, and microbial population density. Electrode spacing, container size, and compost age all influence these factors.

This project builds on that foundation, using compost as the substrate and optimizing conditions for stable power generation. It also integrates circuit components to store and boost low-voltage output, moving the MFC concept toward practical, everyday use.

Objective

This project investigates how compost can be transformed into a renewable source of electricity using a MFC. The goal is to engineer a small-scale system that converts biochemical energy from organic waste into electrical output sufficient to power an LED lamp.

Methodology

This project combined engineering experimentation with local data collection to evaluate the feasibility of household-scale MFC systems. A DIY microbial fuel cell was constructed and tested over the course of three months, and a regional survey was distributed to assess compost accessibility and community interest.

Tested Variables

Category	Values
Compost Age	<12 Months, 12-18 Months, 18< Months
Electrode Spacing	1 cm, 3 cm, 5 cm
Electrode Material	Carbon Cloth, Graphite, Aluminum Mesh
Container Volume	500 mL, 1 L, 2 L

To assess scalability and local application, a survey was distributed in the surrounding community. It focused on compost habits, organic waste production, and openness to participating in a waste-to-energy system.

Survey Questions Included:
- What was the total weight of your compost over 1 week? (in lbs)
- How many people do you have in your family total?
- How many kids do you have in your family? (if any)
- Do you typically compost?
- What is your average monthly energy bill (optional)

An MFC was constructed using sealed Tupperware containers. → One variable was tested per trial. → Voltage output was measured every 30 mins using a voltmeter. → Trials were repeated over 3 months → Data was averaged to determine the best configuration.

Engineering Process


Figure 1: Basic MFC Testing setup *Kyla Fallis, 2025*

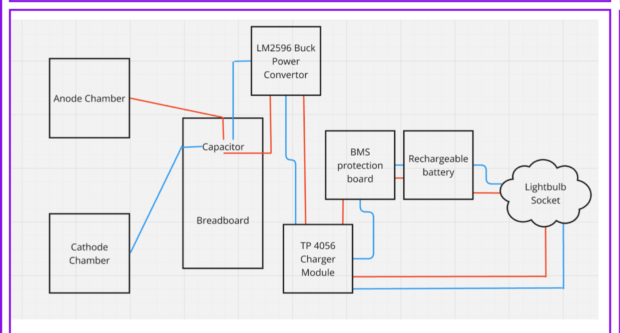
Test 1: Basic MFC Setup
- Single-chambered Tupperware unit
- Compostwith one embedded electrode pair
- Limited airflow control; voltage dips

Test 2: Dual-Chamber System
- Two connected Tupperware containers: one anode, one cathode
- Salt bridge and controlled oxygen exposure
- Increased voltage consistency over time
- Supported testing of new electrode materials


Figure 2: Dual-Chamber System *Kyla Fallis, 2025*

Data-Driven Design Adjustments
After testing over 3 months, I adjusted my setup based on:
- Voltage drop during peak microbial activity
- Failures caused by power spikes or circuit discharge
- Electrode corrosion and wiring issues
- LED failure when unregulated current hit 3V+

Each redesign was based on logged multimeter readings and tracked environmental variables.



Iteration 1 – LM2596-Based
- Capacitor + buck converter + TP4056
- Output unstable

Figure 3: Iteration 1 *Kyla Fallis, 2025*

Iteration 2 – Dual 9V Battery Assist
- MT3608 step-up + TP1500 controller
- Higher boost achieved but batteries dominated the load

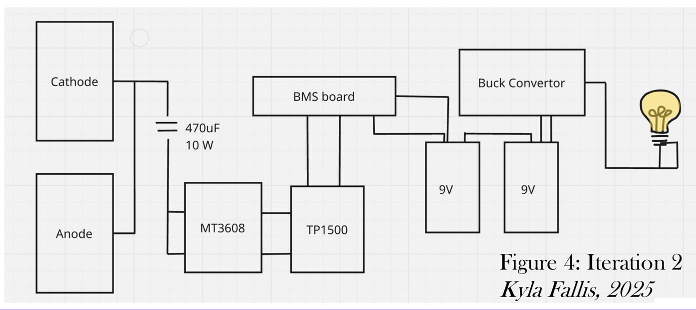


Figure 4: Iteration 2 *Kyla Fallis, 2025*

LYKA v1.0 (Prototype)
- Single vertical housing, no internal divisions
- Wires exited from ends, no cable routing
- Circuitry was loose inside the shell; no bracket or containment
- No airflow, venting, or heat escape design
- Light socket loosely fitted at top without locking mechanism
- Hard to disassemble without removing wires
- LED flickered due to unstable current and poor protection


Figure 5: LYKA 1.0 Rendering *Kyla Fallis, 2025*

Iteration 3 – Final Circuit

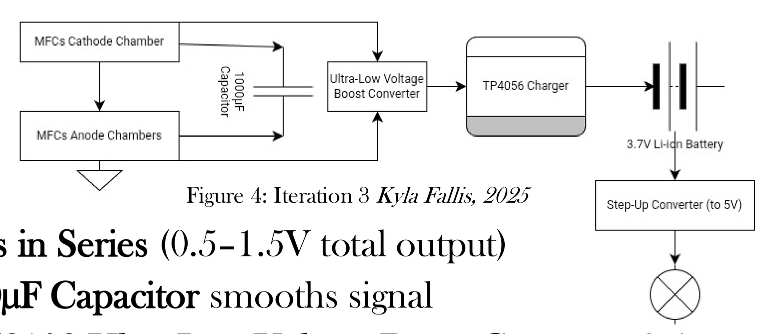


Figure 4: Iteration 3 *Kyla Fallis, 2025*

- **MFCs in Series** (0.5–1.5V total output)
- **1000µF Capacitor** smooths signal
- **LTC3108 Ultra-Low Voltage Boost Converter** brings output to 3.3–5V
- **TP4056 Module** charges a 3.7V Li-ion battery
- **Step-Up Converter (MT3608)** raises battery output to match LED load
- **LED Bulb** powered by stored, boosted energy


Figure 6: LYKA 2.0 Rendering *Kyla Fallis, 2025*

LYKA v2.0 (Final Design)
- Three-part body to isolate the battery, circuit, and LED
- Integrated cable slots and internal compartments for clean wire routing
- Cylindrical housing redesigned to accommodate the MT3608 and TP4056 boards
- Internal supports added to secure the 3.7V battery
- Fully sealed system to protect against compost gas or moisture intrusion
- Enlarged internal volume for improved airflow

Results

Compost from a family can power **3–9 MFCs** week
Average sustained output: **925.26 Wh/year per family**
Estimated savings: **$3.26/week** or **$169.75/year**
Highest performing family (5 members, 8.9 lbs compost/week) saved **$312.42 annually** through generated electricity

Figure 13: LYKA Cost *Kyla Fallis, 2025*

LYKA cost				
Material	Bulk Cost	Units needed	units	unit price
Carbon Cloth	$ 550.00	50.00	21600	$ 1.27
Copper Wire	$ 9.76	200.00	792	$ 2.46
Graphite powder	$ 40.37	1.00	3628.72	$ 0.01
Agar Powder	$ 100.00	1.00	500	$ 0.20
Salt	$ 108.00	1.00	24947	$ 0.00
Cotton Rope	$ 69.00	60.00	6000	$ 0.69
Hot Glue	$ 59.00	0.25	50	$ 0.30
lightbulb	$ 12.91	1	12	$ 1.08
lightbulb socket	$ 17.81	1	9	$ 1.98
LM 2596 Buck	$ 8.99	1	3	$ 3.00
TP 4056 power convertor	$ 7.79	1	10	$ 0.78
Rechargeable battery	$ 15.00	1	4	$ 3.75
perfboard	$ 14.00	1	24	$ 0.58
capacitor	$ 166.00	1	1000	$ 0.17
pins	$ 2.00	10	40	$ 0.50
			Total	$ 16.77

Total unit cost: $16.77

Major costs: Carbon cloth ($1.27/unit), battery ($3.75), step-up converter, and TP4056

Built using affordable, bulk-sourced materials; scalable at low cost for classrooms or rural households

Family Average Energy Savings								
Compost Figures	1 cup	Volume(in^3)	Weight	Maintained	Energy Averages	Watts	Wh/week	Wh/year
	1.980833333	4.23	8.38	8.00		1.08803108	183.8772525	9561.617129
	Family members	Weight in compost	MFCs powered/1 week	Sustained MFCs at peak	Wh/week	Wh/year	$/week saved	$/year saved
Family 1	5	9.70	1.16	9.26	1702.95	88553.30	$6.01	$312.42
Family 2	2	4.40	0.53	4.20	772.47	40168.51	$2.73	$141.71
Family 3	4	4.80	0.57	4.58	842.70	43820.19	$2.97	$154.60
Family 4	4	6.20	0.74	5.92	1088.48	56601.08	$3.84	$199.69
Family 5	6	3.43	0.41	3.27	602.18	31313.18	$2.12	$110.47
Family 6	3	6.47	0.77	6.18	1135.88	59065.97	$4.01	$208.38
Family 7	4	3.32	0.40	3.17	582.86	30308.97	$2.06	$106.93
Family 8	4	5.23	0.62	4.99	918.19	47745.75	$3.24	$168.45
Family 9	5	8.90	1.06	8.50	1562.50	81249.94	$5.51	$286.65
Family 10	4	7.20	0.86	6.87	44.43	2310.49	$0.16	$8.15
AVERAGES	Per 1 persom	1.45	0.17	1.39	225.67	11735.06	$0.80	$41.40
	Per US family	4.52	0.54	4.32	701.85	36496.03	$2.48	$128.76
	Per sample family	5.97	0.71	5.70	925.26	48113.74	$3.26	$169.75

Figure 11: Family Energy Savings *Kyla Fallis, 2025*

- **Best-performing setup** used 12–18 month compost, carbon cloth, 1 cm spacing, and 1L containers
- This configuration yielded the highest wattage: **1.73 W**, with an average output of **1360 mV** and **127 mA**
- Carbon cloth outperformed all other materials despite aluminum's conductivity, due to higher microbial compatibility

Average Outputs	mV	mA	W
Compost Age			
<12 Months	1122.29792	94.49329	1.060496
12-18 Months	1360.1115	127.2409	1.730618
>18 Months	538.41412	46.9412	0.252738
Container Size			
500 mL	923.57028	63.13379	0.583085
1 L	1131.7708	74.54939	0.843728
2 L	923.5703	63.13379	0.583085
Electrode Material			
Aluminum Mesh	1053.8436	63.10145	0.664991
Graphite	1122.55131	69.9228309	0.78492
Carbon Cloth	1165.49743	80.6994717	0.94055
Electrode Spacing			
1 cm	1325.6401	63.15647	0.837227
3 cm	1079.9289	70.02099	0.756177
5 cm	1048.3493	80.69871	0.846004

Figure 12: Average Outputs *Kyla Fallis, 2025*

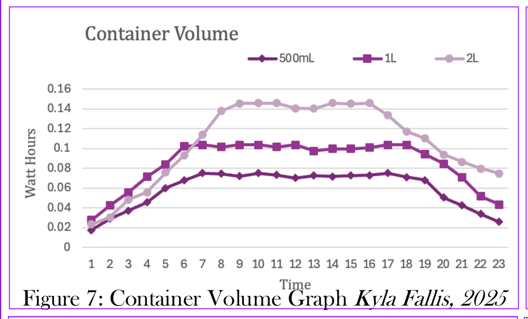


Figure 7: Container Volume Graph *Kyla Fallis, 2025*

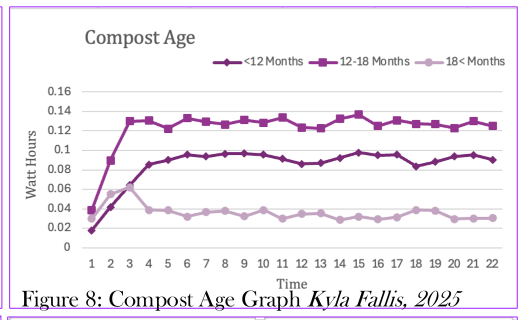


Figure 8: Compost Age Graph *Kyla Fallis, 2025*

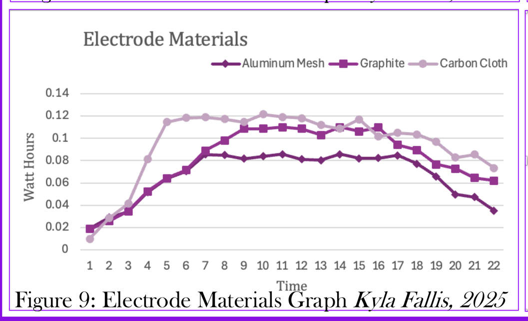


Figure 9: Electrode Materials Graph *Kyla Fallis, 2025*

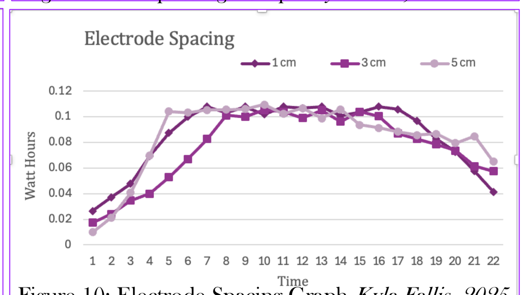


Figure 10: Electrode Spacing Graph *Kyla Fallis, 2025*

Conclusions

Each MFC-powered lamp produced **~6.2 kWh/year** of stored, usable energy per family on average

A single LYKA lamp costs **$16.77** to build and saves **$169.75/year** in energy over 10 years = **$1,596.84 net savings**

Battery charge time: ~12 hrs

Run time: ~2.4 hrs per charge

Fully rechargeable with compost-powered energy and no input

Figure 14: LYKA Lamp *Kyla Fallis, 2025*

LYKA Lamp					
	Battery Capacity	Battery Charge Time	Energy Required	Run Time	LYKA Cost
	11.7	11.9482	4.91197	2.43246	$ 16.77
	Family Members	Energy Produced	$/year saved	Cost	Net Savings(10 years)
Per 1 Person	1	1.51137	$41.40	$ 16.77	$397.24
Per Average US Fam	3.11	4.70035	$128.76	$ 67.07	$1,220.51
Per Sample Size Ave	4.1	6.1966	$169.75	$100.61	$1,596.84

This study demonstrated that compost-fed microbial fuel cells (MFCs) can provide clean, affordable power for small-scale applications. After extensive testing and redesign, the LYKA system successfully powered an LED lamp using only compost and microbial energy.

Category	Result
Top Performing Setup	12–18 month compost, carbon cloth, 1 cm spacing, 1 L container
Peak Output	1.73 W (enough to charge a 3.7V battery and run a 2.2V LED)
LYKA Lamp Savings	$169.75/year per family → $1,596.84 over 10 years
Best Family Sample	$312.42 saved/year with 8.9 lbs compost
National Potential	Up to $8.1 billion saved/year if adopted by 50% of U.S. households
CO_2 Offset	~2 trillion kg CO_2 avoided annually (equal to powering Disneyland 14x)

This project reimagines waste as energy and households as micro power plants. With further optimization, MFC systems like LYKA could be used in off-grid homes, classrooms, and disaster relief zones, where energy is needed most.

Applications

If just **33% of U.S. households** adopted compost-powered MFCs:
- Over **153 billion kWh** could be generated
- **9.3 billion kg CO_2** could be offset
- That's equivalent to powering **Disneyland nine times over**

Large-Scale Implementation							
Averages per 1 person	Weight in compost	MFCs powered/1 week	Sustained MFCs at peak	Wh/week	Energy produced yearly	$/week saved	$/year saved
	1.45	0.17	1.39	225.67	11735.06	0.80	41.40
Figures	US population	CO2 Emissions/kWh	$/kWh	Disney World			
	392,500,000	0.86	$0.13	14,000,000			
	Percentage of US population	kWh	$/year	CO2 emissions	Disneyland		
Applications	50%	2303005088685	8.125E+09	1.98058E+12	14.01785714		
	100%	4606010177370	1.625E+10	3.96117E+12	28.03571429		
	33%	1535183192118	5.416E+09	1.32026E+12	9.344303571		

Figure 15: Family Energy Savings *Kyla Fallis, 2025*

Households: Compost-integrated lighting, emergency kits, and energy savings

Agriculture: Power from manure and wastewater, reducing methane

Disaster Relief: Portable MFC kits for off-grid energy in crises

Industry: Future designs may use graphene electrodes and stacked arrays for higher outputs

Citations

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