UNIVERSITY OF WOLLONGONG IN DUBAI

ECTE-250

DELIVERABLE -2

Detalied Design Report

PowerSrpout

IoT-Integrated Microbial Fuel Cell For Sustainable Electricity generation from Food Waste

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SUMMARY

This report analyzes the process of converting food waste into electricity using PowerSprout, an IoT-integrated Microbial Fuel Cell (MFC) system. The document outlines the microbiological mechanisms that enable waste breakdown and energy generation, including an in-depth examination of the monitoring systems that observe temperature, pH, gas output, and mass decrease during the conversion process.

The report provides numerical results on the efficiency of energy output, contrasting PowerSprout with traditional waste management methods. It records the benefits of the system's single-chamber design, offering technical specifications and performance data obtained from laboratory evaluations. Included are intricate circuit diagrams and sensor integration systems, along with data representation from the monitoring interface.

The analysis part assesses sustainability effects, measuring reductions in methane emissions and estimating possible energy recovery rates from different food waste sources. Implementation factors, economic viability assessment, and regulatory adherence elements are also discussed, backed by comparative case studies from analogous waste-to-energy projects.

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2. INTRODUCTION

Food waste is a major global issue, leading to economic losses, environmental harm, and resource mismanagement. In the UAE alone, food waste amounts to $1.63 billion annually, with each person generating an average of 224 kg of waste—almost double the amount in Europe and North America. The disposal of food waste in landfills contributes to harmful methane emissions, which are 25 times more potent than CO_2, exacerbating climate change.

To address this challenge, we have developed PowerSprout, an IoT-enabled Microbial Fuel Cell (MFC) that converts food waste into sustainable energy. Our system uses weight and pH sensors to monitor food breakdown, facilitating microbial activity that generates electricity. This electricity is stored in a supercapacitor, making it a viable and eco-friendly energy source. By integrating IoT technology, our solution enables real-time monitoring and optimization, ensuring maximum efficiency.

This innovation presents numerous benefits. Businesses and households can reduce waste management costs while simultaneously generating renewable energy. Additionally, municipalities can deploy our solution in food waste collection points to enhance sustainability efforts. Implementing these systems in restaurants, markets, and urban areas will significantly cut methane emissions and promote the circular economy.

Our team believes that tackling food waste through energy recovery will contribute to a greener future. By leveraging emerging technologies, we aim to drive sustainable waste management solutions and encourage widespread adoption of IoT-driven renewable energy innovations.

3. DESIGN

3.1 Working of the Product

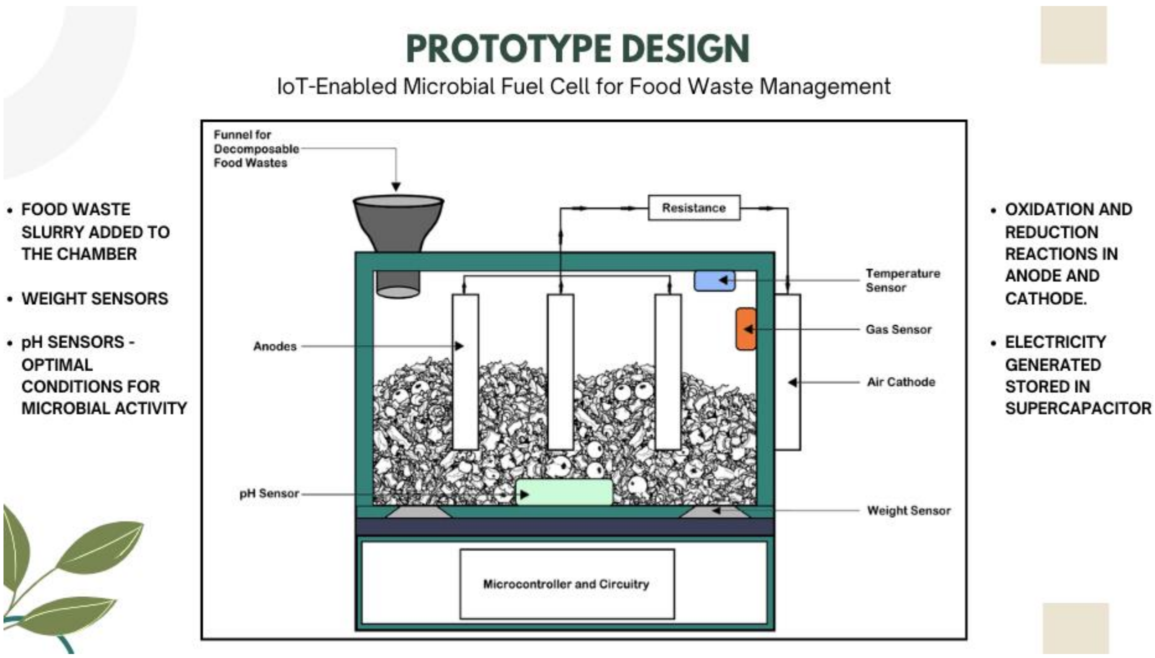

Figure 1. Prototype Design

The process starts with us adding the food waste slurry to the chamber through the funnel, then the weight sensors connected to an ESP32 microcontroller below the chamber will detect if the food waste is added or not .Once the food waste is detected by the sensors the ESP32 sends data to indicate the addition. Along with the weight sensors, pH and temperature sensors monitor the conditions within the chamber, ensuring that they remain within the ideal pH for MFCs that is between 6.5 and 7.5, and the temperature is kept between 25 to 40 degrees Celsius to support the growth of anaerobic respiring bacteria. If the pH level is too acidic or too basic , adjustments will be made by adding acid or alkali.

The microbial activity will occur at the anode chamber, where the anaerobic bacteria will break down the food waste and generate electrons. The organic matter will undergo oxidation, where the complex molecules are converted into simpler components like electrons and protons .the electrons transferred to the anode which acts like an electron collector .These electrons will flow from anode to cathode through an external circuit, passing through a resistor connected of small value between anode and cathode to control the current.

The electrical energy generated from this electron flow will then be stored in the supercapacitor, which is connected to the system, allowing the electricity generated to be stored and used for powering small devices or sensors. This process, using 800ml of food waste slurry will generate 0.196kWh of energy approx. as per our research and will take typically 3-7 days for the MFC to stabilize and produce consistent electricity as the microbial community adapts to the environment.

Using IoT technology we can continuously monitor the pH, temperature, and weight of the slurry added. The ESP32 microcontroller sends real-time data to provide us with valuable insights on the performance of the MFC. This is very helpful in easing our process of ensuring maximum efficiency in energy production.

Additionally, after the microbial process is completed, the remaining food waste slurry can be used as a biofertilizer making this system a sustainable solution. By integrating MFC with IoT monitoring we not only generate electricity but also recycle food waste into a valuable resource, supporting both energy generation and environmentally friendly waste management. Although it currently will generate small amount of electricity, the concept has significant potential for scaling up and being applied in smart cities or municipal waste management systems in the future.

3.2 Flowchart

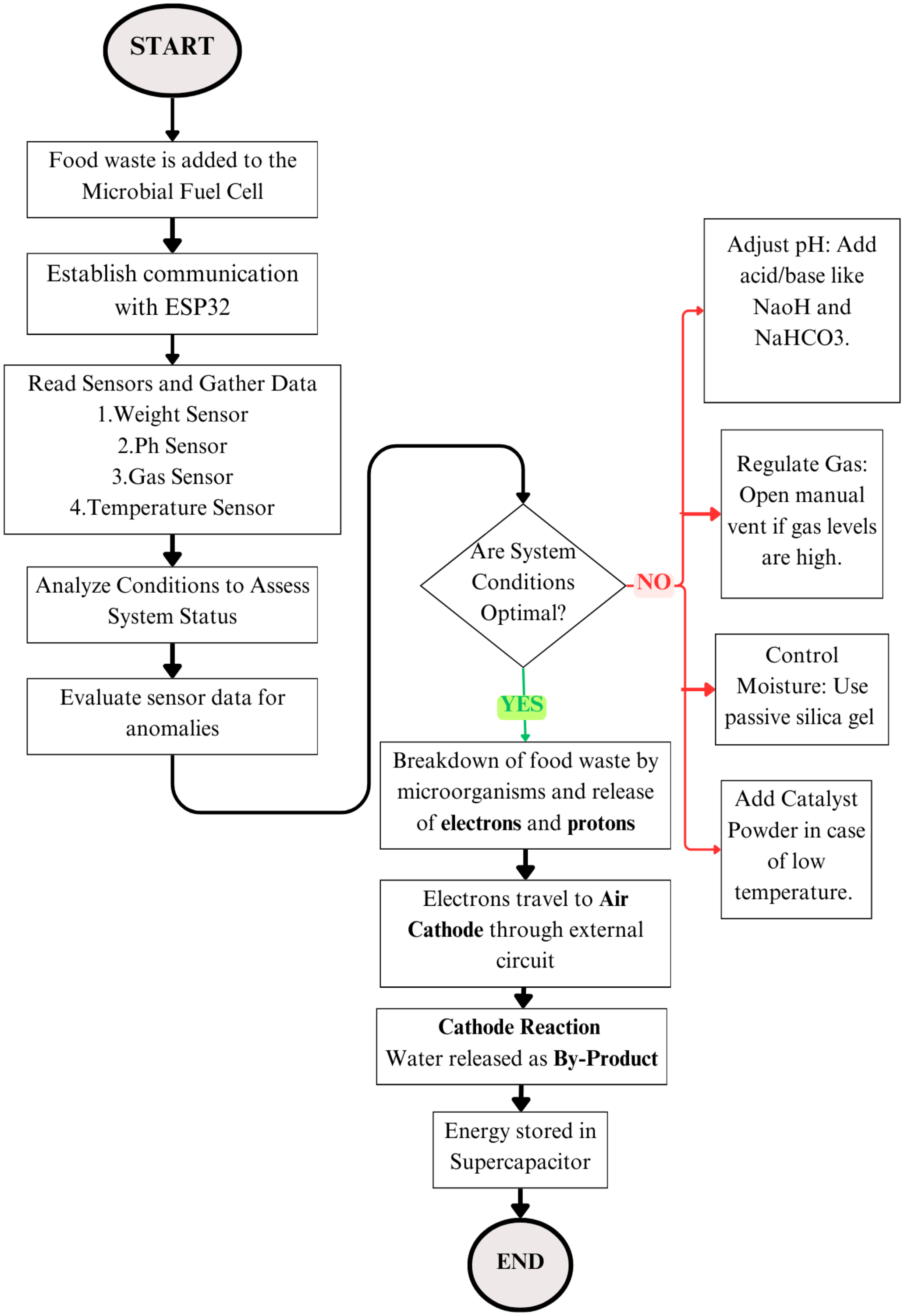

Figure 2. Design Flowchart

3.3 State Diagram

The state diagram illustrates the step by step progression of PowerSprout from the initialization state. It goes through ten states (S0–S9) and performs tasks like turning on sensors, data gathering, waste decomposition, energy balancing and power storage. The next action depends on input x while the system's status is reflected in output z. This structure leads to effective energy generation and storage.

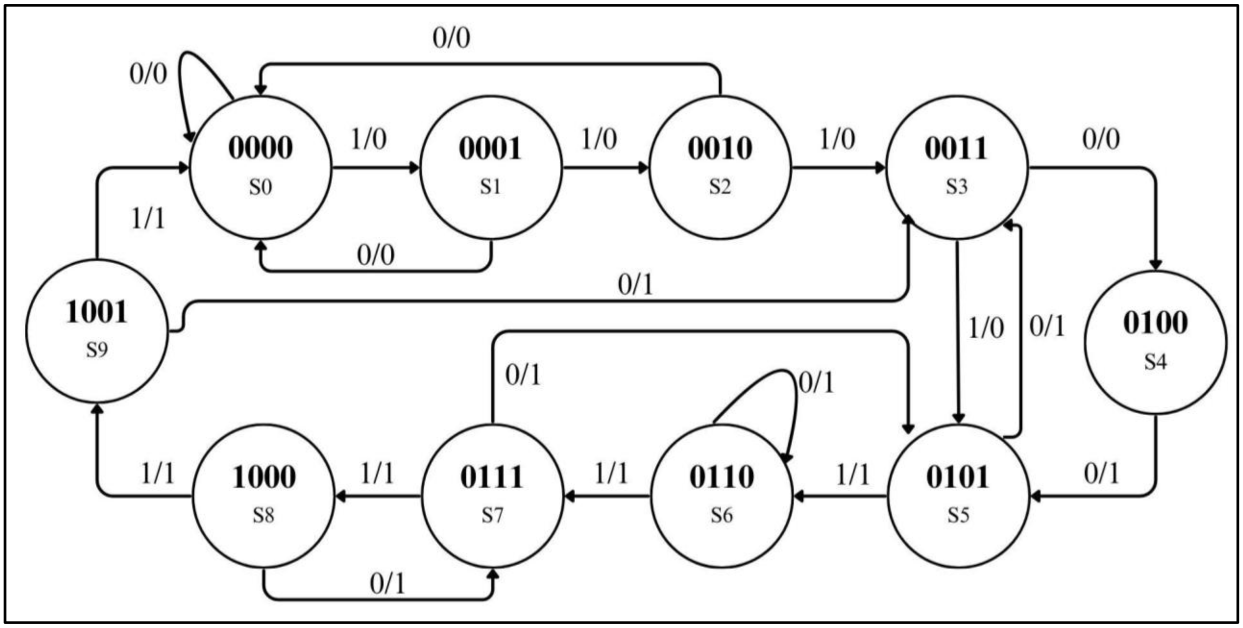

Figure 3. Design State Diagram

3.3.1 State Descriptions

- S0 (Initialize System):
    - Start the system and initialize sensors.
- S1 (Connect to Wi-Fi):
    - Establish a network connection for data logging.
- S2 (Read Sensors & Gather Data):
    - Collect readings from weight, temperature, pH, and gas sensors.
- S3 (Analyze Conditions):
    - Check sensor data for anomalies or missing inputs.
- S4 (Adjust Settings If Needed):
    - Modify pH, temperature, or microbial conditions if required.
- S5 (Microbial Decomposition & Electron Transfer):
    - Breakdown of food waste releases electrons that flow in a circuit.
- S6 (Cathode Reaction):
    - Electrons complete the circuit, producing a water by-product at the cathode.

- S7 (Energy Output Evaluation):
    - Verify if the system is generating energy.
- S8 (Store in Supercapacitor):
    - Store the produced energy in a supercapacitor.
- S9 (End):
    - Complete the process and prepare for shutdown or next set of foodwaste.

3.3.2 Overview of the Inputs and Outputs:

The state machine operates by taking an input signal **X** and producing an output signal **Z** which directs the system's action. The state diagram follows the **X/Z notation**, where **X** represents the input that controls state transitions, and **Z** represents the output reflecting the system's status. The input x regulates state shifts; the system advances to the next stage at **X=1** but stays current at **X=0**. This allows for a controlled flow from initialization to energy storage, thus ensuring each step is executed in sequence.

The output z is a function of the system's present activity. During the first five states (S0–S4), the system is primarily engaged in preparation, measurement, and evaluation of data which means it does not produce energy so **Z** equals 0. The microbial decomposition process starts in state S5, leading to electron transfer and energy production. Starting from state S5 through state S9, **Z** equals 1, indicating energy production and storage are in action. This well-organized input-output interaction helps for better supervision, right use of energy and proper handling of the microbial fuel cell system.

3.3.3 State Transitions

The state diagram describes the sequential functioning of the microbial fuel cell system. It starts at S0 (Initialize System), where sensors are configured before progressing to S1 (Connect to Wi-Fi) for network connectivity. After establishing a connection, the system moves to S2 (Read Sensors & Gather Data) to obtain readings from weight, temperature, pH, and gas sensors. If valid data is obtained, it moves to S3 (Analyze Conditions) to look for anomalies; if not, it returns to S2. Should modifications be necessary, the system transitions to S4 (Adjust Settings If Needed) to enhance microbial and environmental conditions.

Subsequently, S5 (Microbial Decomposition & Electron Transfer) starts the disintegration of food waste, producing electrons that travel to S6 (Cathode Reaction), where the circuit concludes. In S7 (Energy Output Assessment), the system checks energy generation—if deemed inadequate, it might modify settings prior to continuing. After energy is verified, it moves to S8 (Store in Supercapacitor) to accumulate the produced energy. Ultimately, the system arrives at S9 (End), signifying completion and getting ready for the next cycle. The transitions guarantee an effective, regulated procedure for energy production.

3.3.4 State Table

States	Current State (S0 - S9)				Input	Next State				Output
	A	B	C	D	X	A’	B’	C’	D’	Z
S0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	1	0	0	0	1	0
S1	0	0	0	1	0	0	0	0	0	0
	0	0	0	1	1	0	0	1	0	0
S2	0	0	1	0	0	0	0	0	0	0
	0	0	1	0	1	0	0	1	1	0
S3	0	0	1	1	0	0	1	0	0	0
	0	0	1	1	1	0	1	0	1	0
S4	0	1	0	0	0	X	X	X	X	0
	0	1	0	0	1	0	1	0	1	0
S5	0	1	0	1	0	0	0	1	1	1
	0	1	0	1	1	0	1	1	0	1
S6	0	1	1	0	0	0	1	1	0	1
	0	1	1	0	1	0	1	1	1	1
S7	0	1	1	1	0	0	1	0	1	1
	0	1	1	1	1	1	0	0	0	1
S8	1	0	0	0	0	0	1	1	1	1
	1	0	0	0	1	1	0	0	1	1
S9	1	0	0	1	0	0	0	1	1	1
	1	0	0	1	1	0	0	0	0	1

3.4 Multisim circuit explanation

A′ : A' = $\bar{A}$ B C D + A $\bar{B}$ $\bar{C}$ D

AB/CDX	000	001	011	010	100	101	111	110
00	0	0	0	0	0	0	0	0
01	X	0	0	0	0	0	1	0
11	X	X	X	X	X	X	X	X
10	0	1	0	0	X	X	X	X

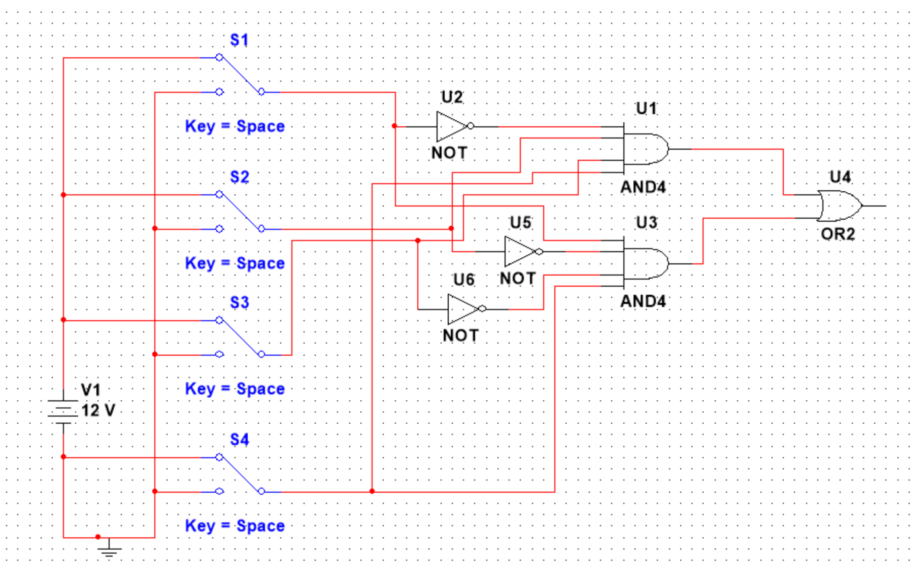

Figure 4. A' Circuit

B′ : $B' = \bar{A}\,\bar{B}\,C\,D + \bar{A}\,B\,(C + D) + A\,\bar{B}\,\bar{C}\,\bar{D}$

AB/CDX	000	001	011	010	100	101	111	110
00	0	0	0	0	0	0	1	1
01	X	1	1	0	1	1	0	1
11	X	X	X	X	X	X	X	X
10	1	0	0	0	X	X	X	X

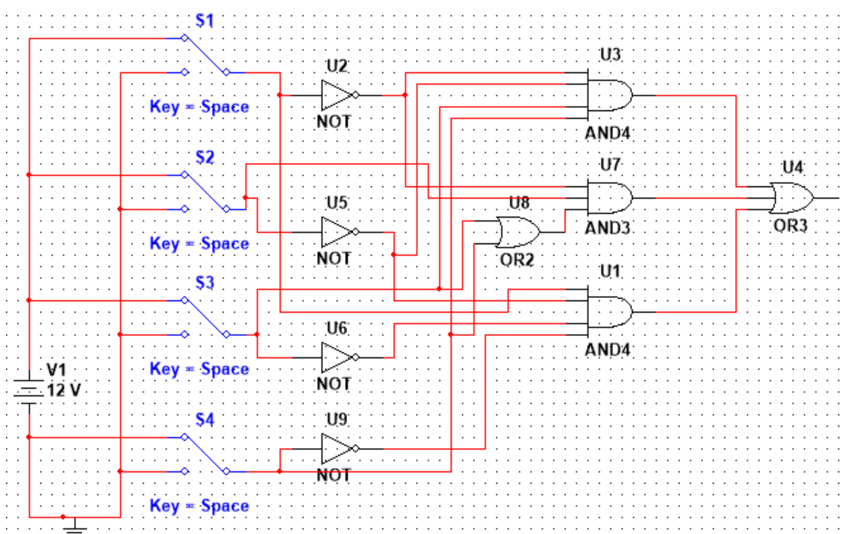

Figure 5. B' Circuit

C′ : $C' = \bar{A}\,\bar{B}\,\bar{C}\,D + \bar{A}\,B\,C + \bar{D}(B \oplus A)$

AB/CDX	000	001	011	010	100	101	111	110
00	0	0	1	0	0	1	0	0
01	X	0	1	1	1	1	0	0
11	X	X	X	X	X	X	X	X
10	1	0	0	1	X	X	X	X

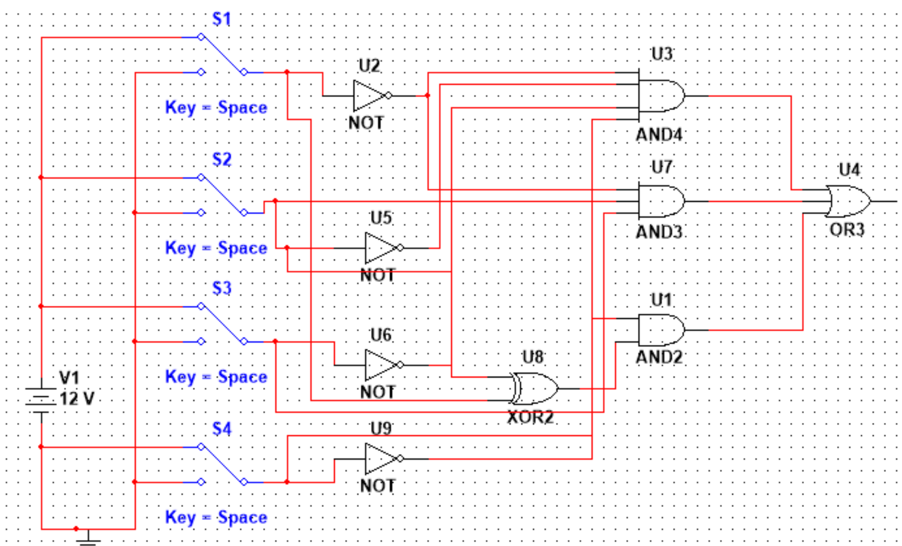

Figure 6. C' Circuit

D′ : D' = $\bar{A}\,C\,\bar{B} + \bar{A}\,C\,B\,D + A\,\bar{B}\,\bar{D}$

AB/CDX	**000**	**001**	**011**	**010**	**100**	**101**	**111**	**110**
00	0	1	0	0	0	1	1	0
01	X	1	0	1	0	1	0	1
11	X	X	X	X	X	X	X	X
10	1	1	0	1	X	X	X	X

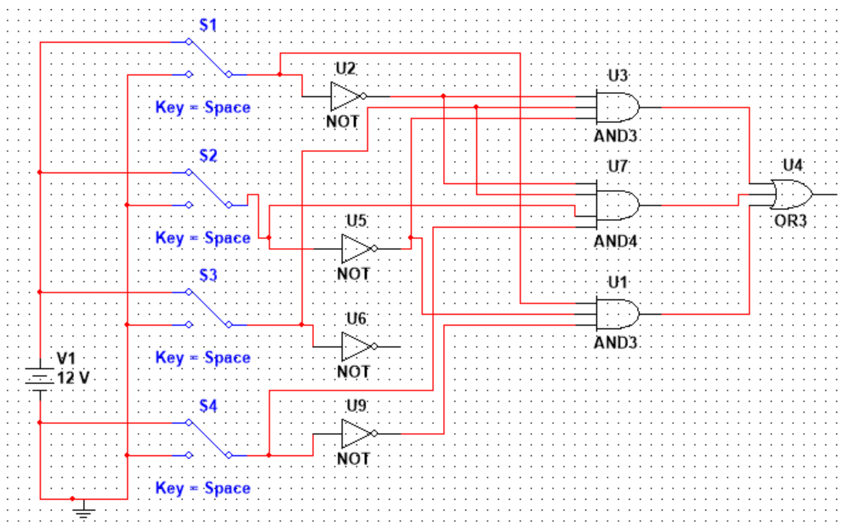

Figure 7. D' Circuit

Z : Z = B ⊕ A

AB/CDX	**000**	**001**	**011**	**010**	**100**	**101**	**111**	**110**
00	0	0	0	0	0	0	0	0
01	0	0	1	1	1	1	1	1
11	X	X	X	X	X	X	X	X
10	1	1	1	1	X	X	X	X

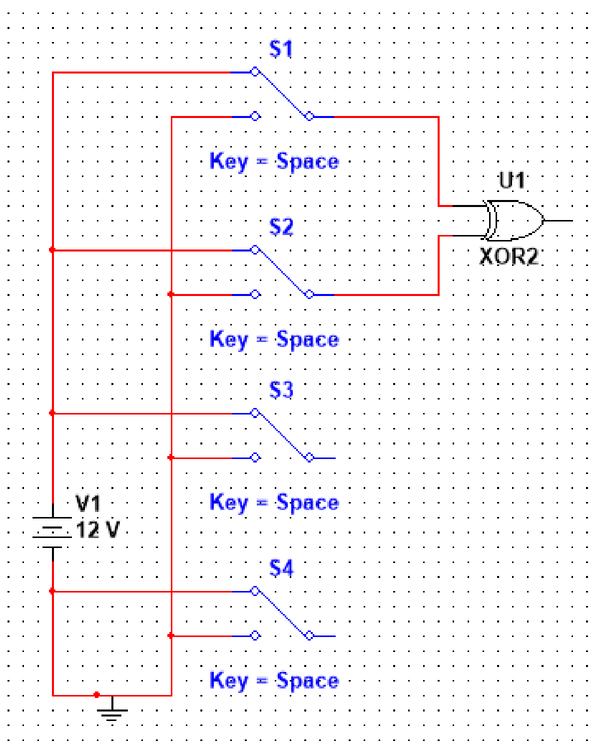

Figure 8. Z Circuit

3.5 Block Diagram

The diagram represents a system that utilizes a Microbial Fuel Cell (MFC) to generate energy from food waste through biological processes involving an anode and air cathode. The generated energy is stored in a supercapacitor and monitored by an ESP32 microcontroller, which collects data from various sensors, including pH, gas, temperature, and weight sensors. This setup enables real-time monitoring of the MFC's performance and environmental conditions, making it useful for bioenergy applications and waste management.

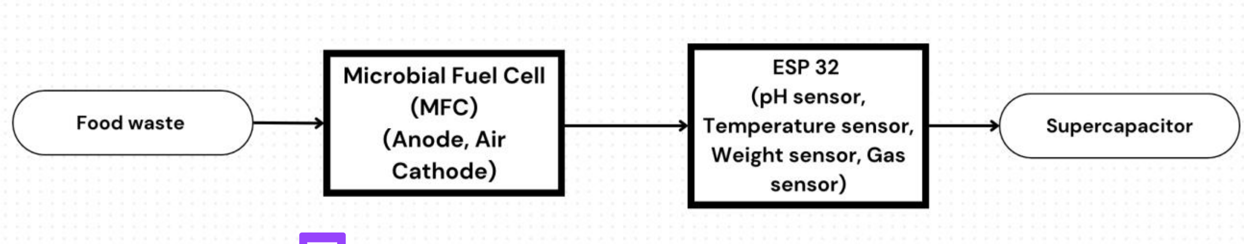

Figure 9.a Block Diagram

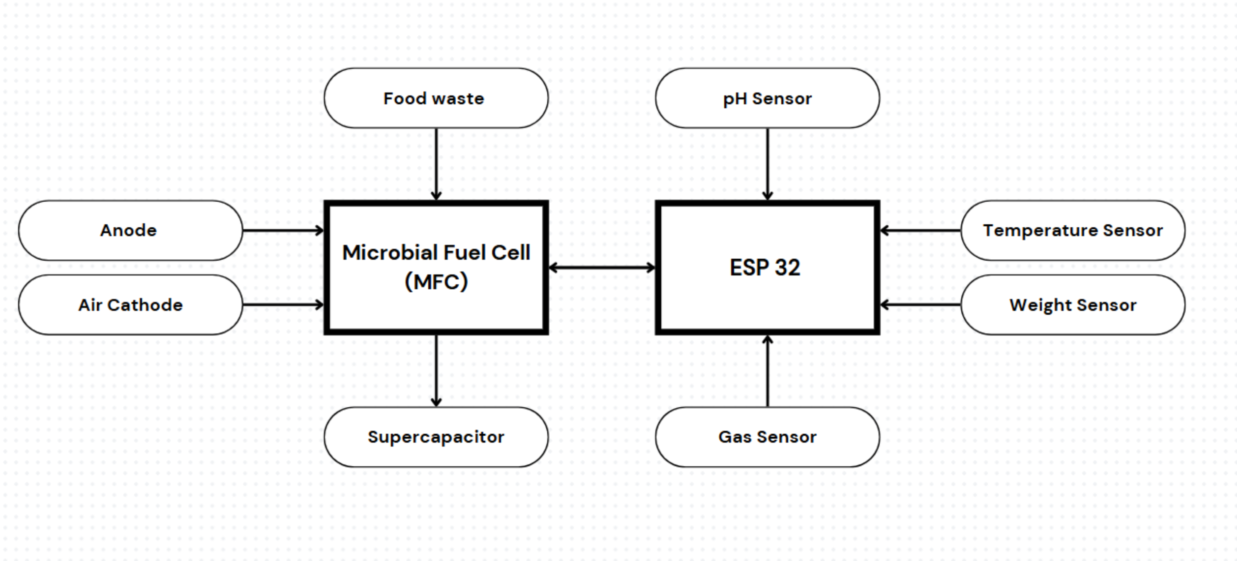

Figure 9. b Block Diagram

4. ALIGNMENT

Our single-chamber microbial fuel cell (MFC) design combines both sustainable waste management and advanced IoT applications. The project not only utilizes food waste to generate sustainable electricity but it also incorporates modern IoT technologies to monitor, control, and optimize the system in real time. Here's how the design aligns with key themes and requirements:

4.1 Integration with IoT Applications

1.Sensor Network:

The system employs a network of sensors that feed data into a central control unit. This setup is visualized using a state diagram, which maps out the various operational states and transitions based on sensor inputs. Such integration enables:

•Real-time Monitoring: Continuous tracking of parameters like voltage, temperature , and ph levels.

•Remote Access: Using the ESP32, the system benefits from enhanced connectivity options (WiFi and Bluetooth), allowing remote monitoring and control—key aspects of modern IoT applications.

4.2 Alignment with the 3Rs

Our single-chamber MFC directly supports the principles of Reduce, Reuse, and Recycle, making it a sustainable energy solution:

•Reduce: By converting food waste into electricity, our system decreases organic waste disposal and reduces methane emissions from landfills.

•Reuse: Instead of discarding food waste, the MFC repurposes it as a bio-energy source, extending its utility in a circular economy model.

•Recycle: The process transforms organic matter into electricity, biogas, and biofertilizer, ensuring waste materials are continuously converted into valuable resources.

Through this approach, our MFC promotes green behavior and aligns with sustainable energy goals by turning waste into a renewable power source.

4.3 Design Improvements and System Innovations

1.Single-Chamber MFC:

Our choice to use a single-chamber design simplifies the architecture while maintaining efficiency. This approach reduces system complexity and costs while facilitating easier maintenance and scalability.

2.Funnel:

•Funnel Design: The integrated funnel directs food waste efficiently into the MFC, ensuring a steady substrate supply for microbial activity.

3.Sensor Placement and Energy Management:

•Sensor Placement Constraints: Proper sensor placement is crucial to accurately capture environmental and operational parameters. While this remains a challenge, careful design planning is aimed at mitigating these issues.

•Energy Utilization: Efficiently harnessing the energy stored in supercapacitors is another constraint that we are addressing through iterative testing. The real-world performance data will guide further refinements in power management strategies.

In summary, the single-chamber MFC is a prime example of how IoT technologies can be integrated with sustainable energy solutions. By converting food waste into electricity, the system adheres to the 3Rs—reducing waste, reusing resources, and recycling organic matter while also incorporating a proper sensor-actuator network and advanced connectivity via the ESP32. Although challenges such as sensor placement and energy management in supercapacitors persist, the design meets most of the project requirements. Further testing will provide the necessary insights to refine power consumption analysis and enhance overall system performance.

5. TESTING

The testing of PowerSprout will be conducted in phases, evaluating individual components before integrating them into a fully functional system. Each module will be tested to ensure accuracy, efficiency, and reliability before system-wide validation.

5.1 Microbial Fuel Cell (MFC) Testing

The microbial fuel cell will be tested to confirm its ability to break down food waste and generate electricity. Parameters such as microbial activity, voltage output, and power efficiency will be monitored. Consistent energy production will be verified by measuring current and voltage over time.

5.2 Weight Sensor Testing

The weight sensor will be tested to ensure it correctly detects and logs the amount of food waste input into the system. The sensor data must be accurately transmitted to the website for real-time tracking.

5.3 pH Sensor Testing

The pH sensor will be tested and calibrated to monitor acidity levels, ensuring optimal conditions for microbial activity. The data collected will be used to analyze the efficiency of the breakdown process and energy generation.

5.4 IoT and Website Integration Testing

The IoT system will be tested to verify real-time data collection and transmission to the PowerSprout website. This includes ensuring that weight, pH, and energy generation metrics are accurately displayed and updated. The website's interface will be tested for user accessibility, responsiveness, and data visualization.

5.5 Simulation Testing

Electronic components and control logic will be simulated using Multisim and Tinkercad before physical implementation. This will validate circuit design, power flow, and sensor interactions. Since website connectivity cannot be fully simulated, it will be tested in the prototype phase.

5.6 Prototype Testing

During the prototype phase, all components will be assembled and tested together. Breadboard/perfboard testing will verify the state machine's operation, sensor accuracy, and energy storage performance. The website's functionality will also be evaluated to ensure seamless communication with the hardware, accurate data logging, and real-time monitoring.

6. PLAN

6.1 Deliverables

The project execution strategy has been structured into multiple deliverables to ensure systematic development and timely completion of all deliverables. Each deliverable has specific objectives and milestones aligned with the course requirements.

Deliverable 1 focused on developing two unique IoT-based project proposals. During this phase, the team conducted market research, estimated costs and created preliminary designs. The two proposals that were presented in Winter Week 3 were – **"Smart IOT based Planter"** and **"Food Waste to Electricity Generating MFC**". A panel evaluated and selected one project for further development which was **"Food Waste to Electricity Generating MFC**".

Deliverable 2 – The Detailed Design Phase commenced after the proposal selection and resulted in a comprehensive design report due in Winter Week 6. This phase involves creating detailed technical specifications, implementation strategies, and demonstrating preliminary state machine simulations. Feedback received during the proposal stage will be accommodated.

Deliverable 3, 4 & 5 – The Development and Testing Phase encompasses three critical deliverables. First, the team will complete design simulations and submit the report by Winter Week 9 (Deliverable 3). Following this, we will develop a TinkerCAD prototype to validate our design concepts (Deliverable 4). The phase concludes with the construction of a working breadboard prototype, including thorough testing and documentation of all procedures and results (Deliverable 5).

Deliverable 6 & 7 – The Final Documentation Phase will be a comprehensive design report to be submitted by Spring Week 9, involving the entire development process, technical specifications, testing results, and any design modifications made during implementation (Deliverable 6). A final presentation will showcase our completed project and its achievements (Deliverable 7).

Deliverable 8 – The project concludes with the Innovation Fair, where the project will be demonstrated as a working prototype at the innovation fair. This phase focuses on effective project presentation and marketing, competing for recognition among peer projects.

Throughout all phases, the team will adhere to the 900 AED budget constraint (including the 250 AED arduino kit) and ensure compliance with laboratory safety protocols. Regular team meetings will be conducted, with detailed documentation maintained via the Moodle discussion board. Each team member will maintain active involvement in the design process while rotating through management roles every five weeks as specified in the project requirements.

6.2 Plan Workflow

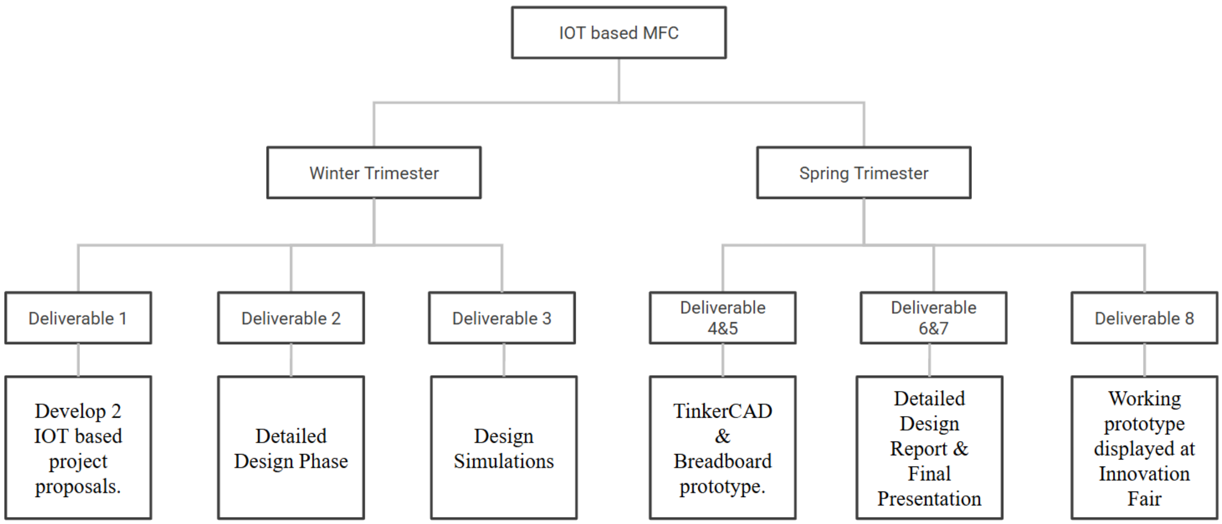

Figure 10. Plan Workflow

6.3 Gantt Chart

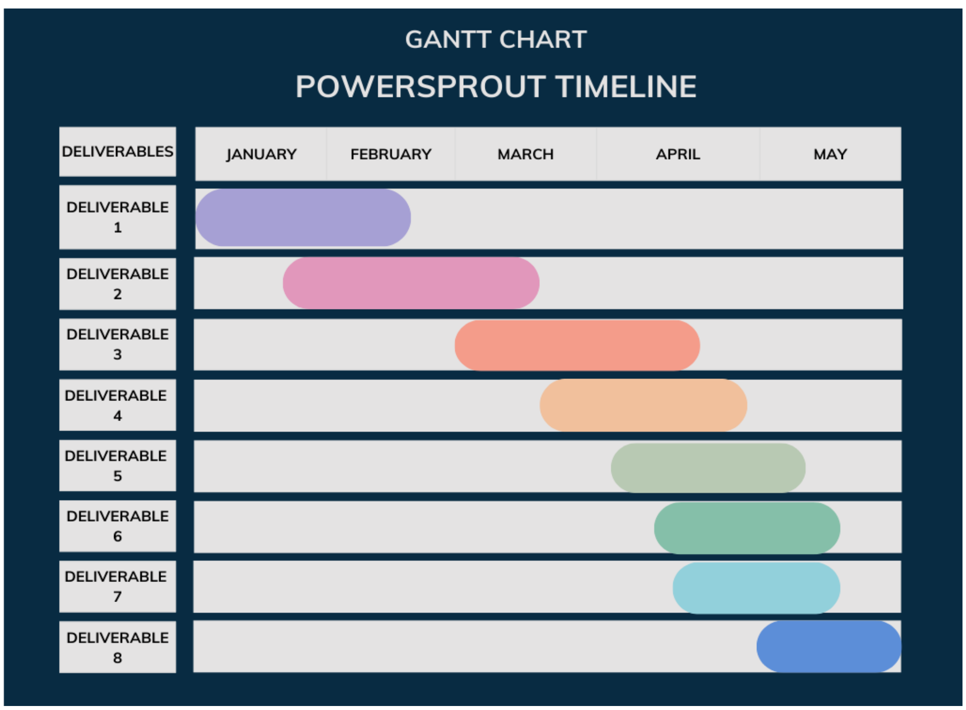

Figure 11. Gantt Chart

6.4 Potential Risks

There are several potential risks associated with the preparation of our Microbial Fuel Cell (MFC) project. One of the primary concerns is the handling of electrical components, which poses the risk of shocks or short circuits. This can be mitigated by ensuring proper insulation, using low-voltage circuits, and wearing appropriate safety gear while working with wiring and connections. Soldering is another potential hazard, as improper handling can lead to burns or inhalation of harmful fumes. To prevent this, safety measures such as working in a well-ventilated area, using protective gloves, and handling the soldering iron with care should be followed. Another risk involves exposure to bacteria and organic waste, which could lead to health hazards if not handled properly. To minimize this risk, gloves should be worn, and proper hygiene practices should be followed when working with food waste and microbial cultures. Additionally, technical issues may arise in the operation of the MFC, such as inefficiencies in power generation or connectivity problems with monitoring systems. These can be anticipated and addressed by thoroughly testing the system, ensuring stable connections, and troubleshooting any faults before final implementation. By taking these precautions, we can ensure the safe and efficient development of our MFC project.

7. BUDGET

Following is a structured table with the budget breakdown:

Item	Quantity	Unit cost (AED)	Total cost (AED)
Arduino kit	1	250	250
Weight sensor	1	70	70
Gas sensor	1	25	25
Catalyst powder alternative	1	20	20
Copper mesh(small roll/piece)	1	39	39
Catalyst powder alternative	1	50	50
Graphite paper/strips	1	25	25
Graphite rods	1	30	30
Conductive copper wire	1	25	25

Digital multimeter	1	50	50
Supercapacitor (small capacity)	1	32	32
Basic funnel	1	25	25
Silicon funnel	1	30	30
Weatherproof plastic container	1	20	20
Ph sensor	1	100	100
Total estimated cost			**AED 791**

This table organizes all the components with their respective costs and total budget allocation.

8. MARKETING APPROACH

This section of the report outlines the team's approach to revolutionize waste-to-energy conversion through IoT-based Microbial Fuel Cell(MFC) technology. The team will follow a dual-phase implementation strategy, beginning with household-level integration and expanding to industrial-scale applications, positioning the solution as a cornerstone of sustainable energy generation in the UAE and beyond.

8.1 Strategic Overview

The team will address two critical challenges: waste management and sustainable energy generation. With approximately 40% of household food ending up as waste, there is a significant opportunity to transform this environmental challenge into an energy resource. Through advanced MFC technology enhanced with IoT capabilities, the team aims to transform organic waste processing while contributing significantly to clean energy production.

8.2 Phase 1: Household Integration (2025-2030)

8.2.1 Market Penetration Target

The team has established an ambitious target of 40% market penetration across UAE households, approximately 950,000 residential units, within a four-year timespan. This target is strategically aligned with the current household food waste rate of 40%, presenting a significant opportunity for immediate impact. This initiative aligns with the UAE's commitment to sustainability and clean energy initiatives.

8.2.2 Implementation Strategy

8.2.2.1 Strategic Partnerships

- Collaboration with leading home appliance manufacturers and smart home technology providers.
- Integration of MFC technology into existing kitchen infrastructure.
- Development of smart home ecosystem compatibility.

8.2.2.2 Government Engagement

- Strategic alignment with UAE Waste Department initiatives
- Development of policy frameworks supporting residential MFC adoption
- Implementation of incentive programs and subsidies to accelerate adoption

8.2.2.3 Market Development

- Comprehensive digital marketing campaign focusing on sustainability benefits.
- Engagement with environmental influencers and technology advocates
- Educational initiatives highlighting the economic and environmental impact

8.3 Phase 2: Industrial Scale Implementation

8.3.1 Expansion Strategy

8.3.1.1 Municipal Infrastructure

- Development of large-scale MFC processing facilities
- Integration with existing waste management infrastructure
- Implementation of city-wide organic waste collection systems

8.3.1.2 Commercial Partnerships

- Deployment of high-capacity MFC systems in:
    - Hotel chains and hospitality sector
    - Food processing facilities
    - Large-scale retail operations
    - Commercial districts

8.3.1.3 Technical Infrastructure

- Development of smart grid integration protocols
- Implementation of advanced energy storage solutions
- Establishment of distributed energy management systems

8.4 Expected Outcomes

The team's strategic initiative will transform organic waste management while establishing a new paradigm in sustainable energy generation. The dual-phase approach ensures:

1. Immediate impact through household-level waste reduction, targeting the 40% of food currently being wasted
2. Long-term sustainability through industrial-scale implementation
3. Significant contribution to UAE's clean energy objectives
4. Creation of a scalable model for global implementation

8.5 Conclusion

The team's strategic vision represents a comprehensive approach to addressing waste management and energy generation challenges. By targeting the substantial 40% household food waste rate, the solution addresses a critical environmental issue while creating value. Through innovative technology deployment and strategic partnerships, the team is positioned to create substantial environmental and economic impact, while establishing a new standard in sustainable energy generation.

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