

# The Heartbreakers - MSE 2

## Glucose Biofuel Cell Hybrid System

### for Extended Pacemaker Battery Life

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**MATERIALS SCIENCE  
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## Problem Definition

### Motivation

**The Core Problem:** Pacemaker batteries last 5-10 years, requiring risky and expensive replacement surgeries.

**The Medical Risk:** Surgeries always have risk, especially for elderly patients who are the primary users.

**The Demographic Trend:** As life expectancy increases, the number of patients requiring \*multiple\* replacement surgeries in their lifetime is growing.

**Objective:** How can we extend the life of the \*existing\* batteries to reduce the frequency of these surgeries?

### Our Solution: The Hybrid "Load Reduction" System

- Glucose Biofuel Cells:** Their job is to generate a small, continuous current from the body's glucose in a cathode-anode system
- The current that is generated charges a **supercapacitor**, which acts as an **energy buffer**
- This charged buffer then works in parallel with the main **battery** to power the **pacemaker**.



### Prior Research

**Glucose Biofuel Cell (G-BFC):** G-BFCs remain conceptually valid but are limited by inadequate power output & insufficient operational lifespan.

Type of G-BFC	Open Circuit Voltage	Current Density/Power Density	Stability
Single G-BFC	0.47 V	0.83 mA/m <sup>2</sup>	Short-lived power supply
Nanozymatic G-BFC	0.70 V	2.3 μW/cm <sup>2</sup>	30 days
Nanozymatic G-BFC	—	5.1 mA/cm <sup>2</sup>	90 days with 0.8% decay per day
Double-Chambered Enzymatic G-BFC	0.575 V	4 μW/cm <sup>2</sup>	150 days
Enzymatic G-BFC	—	7.52 – 24.4 mW/mL	Initially 11 days; with polytetrafluoroethylene insertion up to 3 months
Enzymatic G-BFC	0.52 V	1.9 μW/mL	1 week

Typical Pacemaker Current Drain and Cell Potential ranges from 10uA-20uA and 2.8-3.2 V

### Glucose Biofuel Cell

#### Anode:

- Rayon Graphite Felt coated with:
  - 5 mg Carbon Black
  - 2 mg Glucose Oxidase (GOx) enzyme
  - 50 μL Nafion Binder (5wt% solution)
  - 100 μL Ethanol
  - 50 μL Nafion Binder (5wt% solution)
- Carbon Black ensures electrical conductivity. At the same time, the Nafion solution acts as a proton-conductive binder to immobilize the GOx enzyme onto the high-surface-area Carbon Felt substrate.

#### Cathode:

- Rayon Graphite Felt coated with:
  - 5 mg 20% Pt/C (Platinum on Carbon)
  - 50 μL Nafion Binder (5wt% solution)
  - 100 μL Ethanol

### H-Cell Design

#### Dimensions:

- Cell:**
  - Internal Diameter 30mm
  - Internal Height 35mm
  - Total Height 40mm
  - Wall Thickness 5mm
- Bridge:**
  - Total Length 14mm
    - (5mm thick flange)
  - Internal Diameter 15mm

#### Materials:

- Filament:**
  - PEEK VESTAKEEP i4 3DF
- Components:**
  - Stainless Steel 316
    - Nuts
    - Screws
    - Washers
  - Membrane**
    - PFSA D170-U Proton Exchange Membrane
  - O-Rings**
    - Fluoroelastomer for chemical resistance and leak-proofing

### Electronics

#### Boost Converter:

- Steps up lower voltages into higher voltages to match the voltage of the battery

#### Schottky Diode:

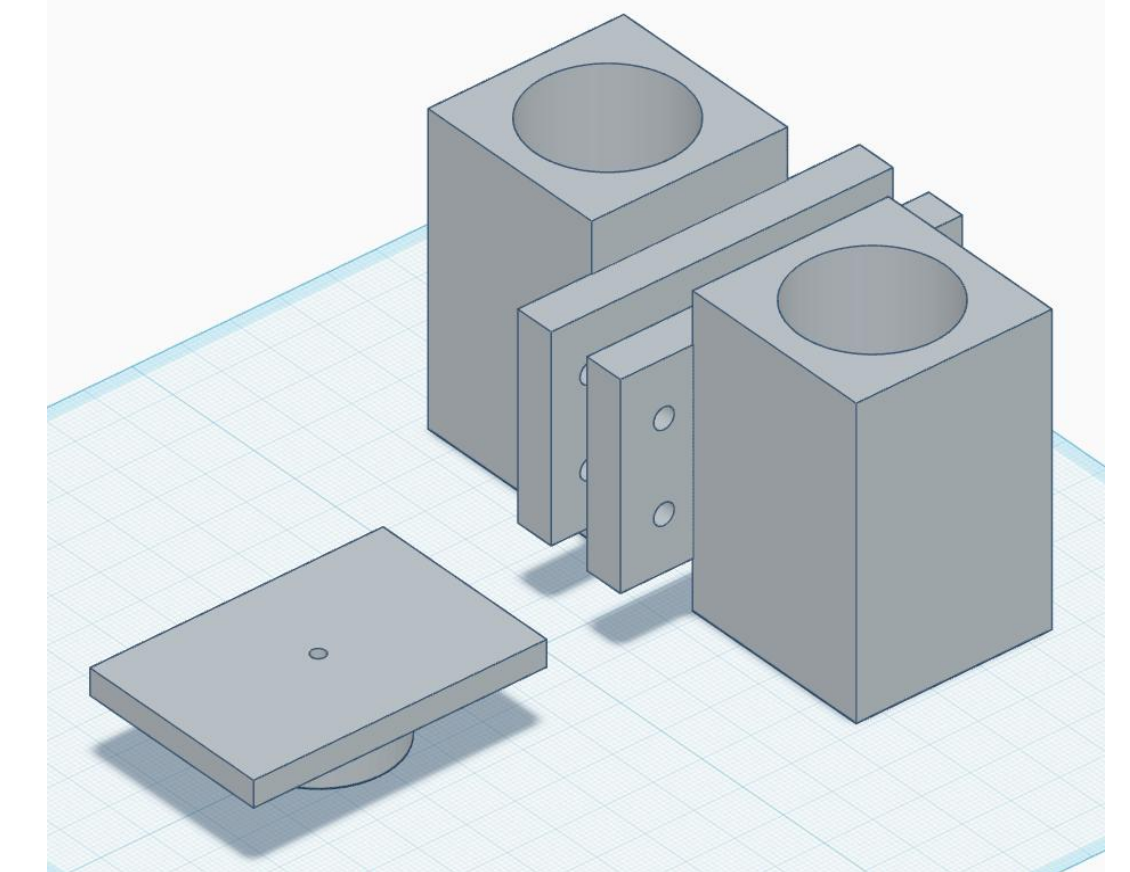
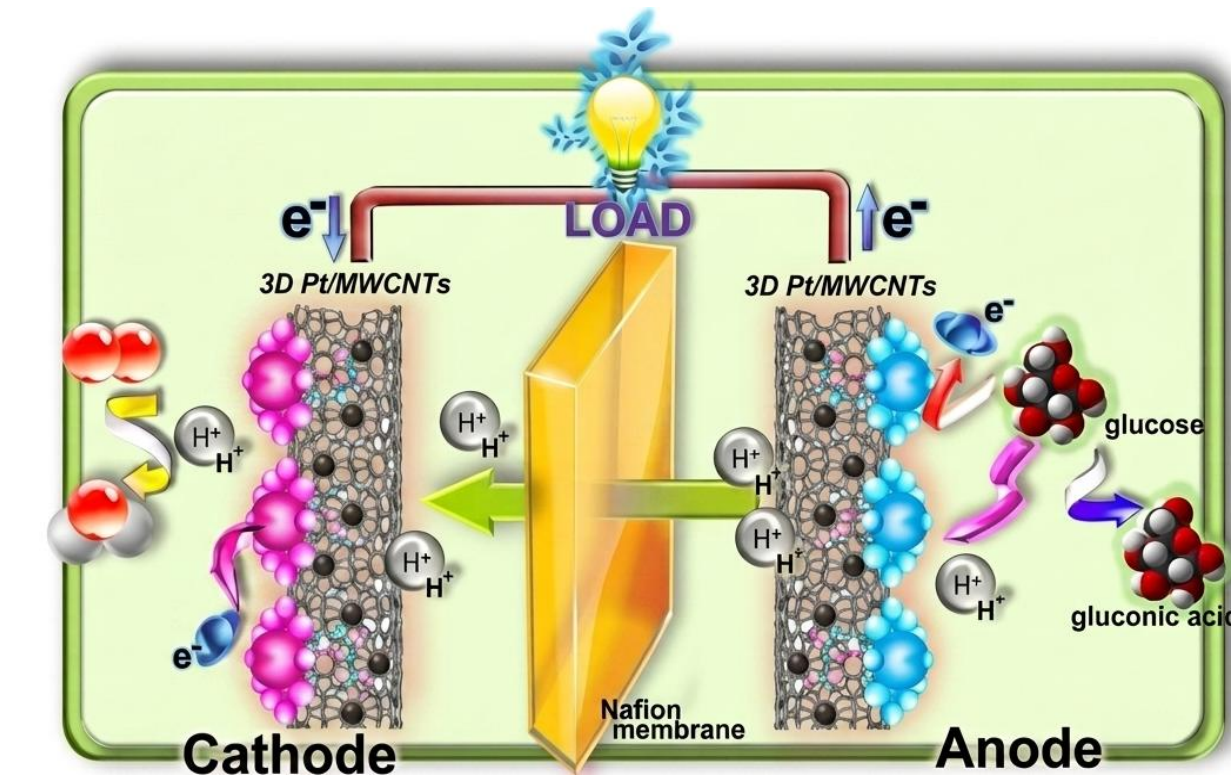
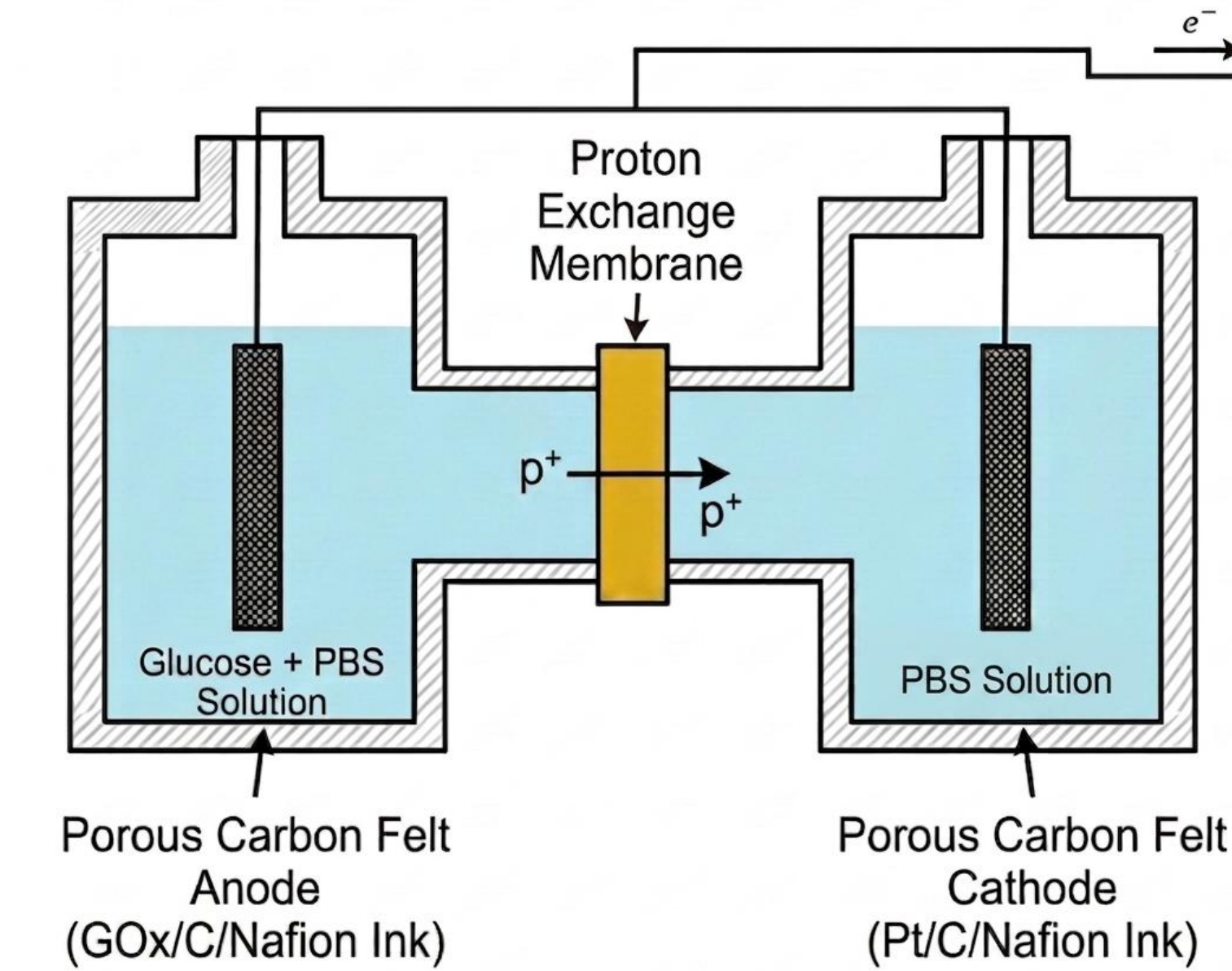
- Prevents higher battery voltage from forcing current back into the G-BFC, ensuring the BFC does not charge the battery and acting as a regulator for the supercapacitor's energy reservoir.

#### Supercapacitor:

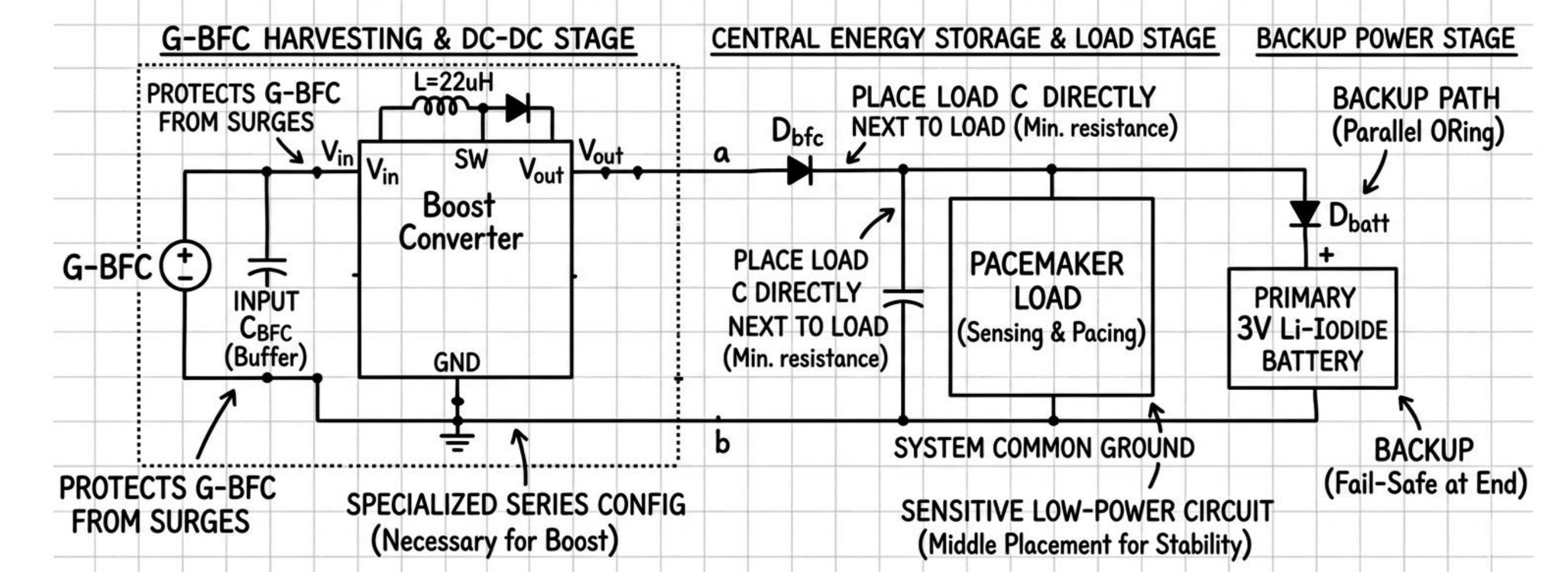
- Allows the system to capture all the available energy from the G-BFC, acting as a bucket that collects every droplet of water and helps act as a dampening system to prevent shorts

## Final Design

### H-Type Glucose Biofuel Cell (G-BFC) Assembly



### REFINED PACEMAKER POWER HARVESTING & STORAGE CIRCUIT 2.0



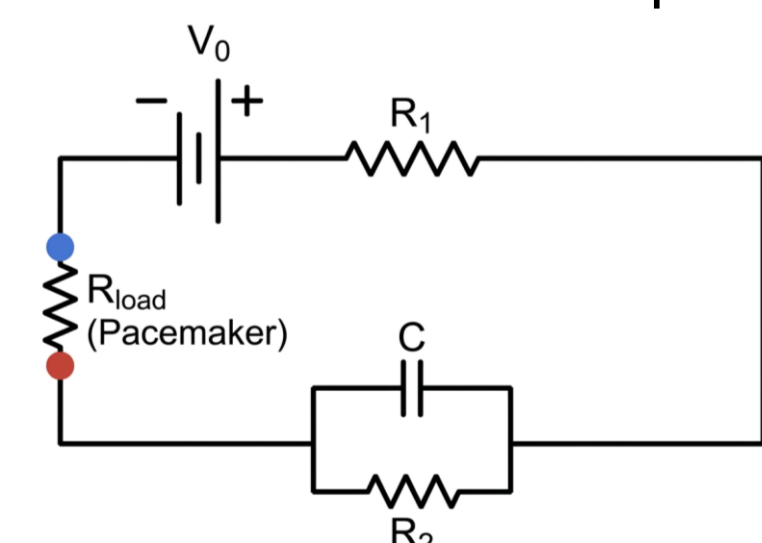
## Design Calculations

The time-dependent voltage for the **G-BFC** battery is shown below, where  $V_0$  equals the open circuit voltage, the term with **R1** being the Ohmic resistance (internal friction of the wires, membranes, and electrode felt), and the term with **R2** being the Faradaic/polarization resistance, with **C** being the natural capacitance of the battery. The voltage was also limited by a series of diffusion steps from how much  $O_2$  enters the system, to the rate of glucose breakdown.

$$V(t) = V_0 - IR_1 - IR_2 \left(1 - e^{-\frac{t}{R_2 C}}\right)$$

### Equivalent Circuit Model

The voltage over time equation is based on an equivalent circuit model (**ECM**) to simplify the many factors that could serve as impedance to the **G-BFC**, confined to few parameters. Note that  $V(t)$  is being evaluated at the resistor nodes of the pacemaker resistor.



**Red Point:**  $V(t)$  going into the pacemaker load after it first took internal losses ( $R_1, R_2$ ).

**Blue Point:** The total external voltage drop of the pacemaker circuit,  $V(t)$  drop and the external drop

$$R_2(t) = R_{total}(t) - R_1$$

$$R_1 = \frac{OCV - V_R}{I_{inst}}$$

$$R_{total}(t) = \frac{V_{OCV} - V_{cell}(t)}{I(t)}$$

$$J = D \cdot \frac{\Delta C}{L}$$

Glucose Flux

$$\dot{n}_{gtu} = JA$$

Molar Delivery Rate

$$I_{max} = (24) F \dot{n}_{gtu}$$

Theoretical Max Current

### Glucose Kinetics

- When implemented in the body, the glucose biofuel cell will be fueled by naturally produced glucose.
- To reach the cell, there is a multistep transport system. The glucose concentration in blood plasma diffuses through capillary walls into the surrounding **interstitial fluid (ISF)**. This glucose-rich **ISF** is what "delivers" glucose molecules to the biofuel cell, where they then diffuse into the anode region.
- The glucose flux can be calculated using **Fick's law**, where the diffusion distance  $L$  is the thickness of the **G-BFC**. This flux can further be used to calculate the theoretical maximum current produced by using the molar delivery rate

## Prototype & Test Results/Analysis



### Prototype Design Modifications H-Cell

- To make our design easier to construct with our available resources, we scaled up the dimensions of the **H-cell** by **10% on average**
- We used **PETG** instead of **VESTAKEEP** for cost purposes. **PETG** isn't **watertight**, but we applied an **epoxy resin coating** to preserve the containment of our reactants

### Circuit

- Due to the **unknown voltage output** of the G-BFC, we could not procure a DCDC boost converter in time to test the complete hybrid circuit
- Instead, we simplified the circuit to test the output of the **G-BFC in series with the simulated pacemaker load** (a resistor) and used **ECM** to help measure the **performance over time**

G-BFC Data & Open Current Voltage (OCV)	Inst. Voltage ( $V_0$ )	Steady State $V_{cell}$ (V)	Current ( $\mu A$ )	Power ( $\mu W$ )	R1 ( $k\Omega$ )	R2 at 10 min ( $k\Omega$ )
100 kΩ Resistor 1 OCV: 0.31V	0.230	10 min: 0.239	10 min: 2.15	0.514	34.78	-1.76
100 kΩ Resistor 2 OCV: 0.21V	0.205	10 min: 0.21	5-10 min: 2.3	0.483	2.43	-2.43
50 kΩ Resistor OCV: 0.23V	0.180	5 min: 0.144 10 min: 0.2	5 mins: 6.6 10 mins: 9.3	1.86	13.88	-10.65

Test results for the electrical measurements of the **G-BFC** are shown. Key factors to voltage attenuation included mass-transport limitations of glucose and oxygen interacting with each other.

- Theoretically, **R1** and **R2** were supposed to bring the voltage down. In practice, although **R1** yielded a positive number, **R2** yielded a negative number, implying that the faradaic resistance increased the voltage.
- Potential causes include failure to establish an **effective contact resistance** at the leads and/or **Faradaic impedance**, due to **increasing enzyme activation**.
- Additionally, the current did not stay constant like the ECM equation displayed, yielding more factors that need to be accounted for in further studies, e.g., **heating of the cell, build-up of reaction byproducts, and varying oxygen flow conditions**