

ENGINEERING BIOLOGY FOR SUSTAINABLE POWER GENERATION

Context

Reliable, long-duration power remains a constraint for distributed sensing systems, particularly when deployed in environments in which battery replacement is impractical. Power sources such as lithium batteries, solar panels or harvesting from ambient energy each have limitations relating to endurance, maintenance or environmental dependence. Therefore, there is strong motivation to explore bio-derived, self-sustaining power systems in which naturally occurring or engineered microorganisms generate electricity directly from soil or organic matter.

Relevance

Sustainable power that requires minimal maintenance confers a strategic advantage when operating in remote or denied environments. A viable engineering-biology power source would support:

- Autonomous sensor networks in locations where routine maintenance is impractical, maximising intelligence coverage through continuous, uninterrupted operation.
- Sustainable and biodegradable power systems that align with environmental, logistical, and resilience considerations.
- Edge-computing and power autonomy, enabling sensor nodes with extended operational lifetimes that are independent of grid- or weather-dependent energy.

Problem

Microbial fuel cells (MFCs) and soil microbial fuel cells (SMFCs) harness the metabolic activity of electrogenic bacteria, passing released electrons through an external circuit to generate electricity, and proof-of-concept systems have been field-demonstrated (e.g. powering water purification [1]).

However, significant barriers prevent their use as a deployable power source: low power

density, variable and unstable output under field conditions, and the difficulty of interfacing low/variable bio-electrical output with IoT electronics and power-management systems. No current engineering-biology system reliably powers IoT devices under real-world, uncontrolled conditions.

Solution

Develop and field-test engineering-biology power systems — based on MFC/SMFC architectures — capable of sustainably powering IoT devices under realistic operating conditions. The solution integrates three disciplines: engineering biology (to improve and stabilise current generation), materials science (to optimise electron transfer and durability), and power electronics (to condition and manage variable low-voltage output) — culminating in a deployed demonstrator that proves operational feasibility.

Example Approaches

- **Microbial / biological engineering [2]** — identify, engineer, or enrich electrogenic microorganisms (e.g. *Geobacter*, *Clostridiaceae*) for higher current output, stability in variable environments, and compatibility with low-nutrient or waste substrates.
- **Electrode and materials engineering [3]** — develop novel electrode materials (bio-char, biomass-derived activated carbon, carbon-felt/stainless-steel composites) and architectures (spacing, surface area, stack configuration) to optimise electron transfer and durability.
- **Power harvesting and electronics integration** — design or adapt low-voltage, low-current energy-harvesting and power-management circuits matched to MFC output characteristics, suitable for sensor nodes, data logging, and wireless comms.
- **Field deployment and sustainability assessment** — test systems under realistic/tactical conditions (variable soils, temperatures), evaluating long-term performance, maintenance needs, environmental impact, and lifecycle

sustainability; explore cell stacking and modular design [5] to scale output and improve robustness.

- **Application demonstration** — implement an IoT demonstrator node powered by a microbial battery and measure operational lifetime, reliability, and feasibility in a resource-constrained scenario.

References

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3. Mutuma, B, “*Valorization of biodigester plant waste in electrodes for supercapacitors and microbial fuel cells*” Chemical Physics (2021).
4. Hess-Dunlop, A, “*Towards Deep Learning for Predicting Microbial Fuel Cell Energy Output*” Electrical Engineering and Systems Science (2024).
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