Electronic supplementary information (ESI)

Significant increases in power output from soil microbial fuel cells under dynamic temperature profiles

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Section 1: Liquid MFCs construction

Liquid MFC: Figure S1 shows a typical liquid MFC consisting of an anode chamber and cathode chamber constructed using two 150 mL bottles and a glass bridge connector (Adams and Chittenden Scientific Glass, NY). The growth medium and *G. sulfurreducens* in the anode chamber were necessary to generate electrons in an anaerobic environment. The ferricyanide solution in the cathode chamber was chosen as an electron acceptor to ensure that the reduction reaction at the cathode was not rate limiting. A 19.6 cm^2 CEM membrane (CMI - 7000S, Membrane International Inc., NJ, USA) was used to connect the anode chamber and cathode chamber in the bridge connector positions. The two electrodes were made using standard graphite plate electrodes (GraphiteStore, USA) with dimensions of 25 mm × 25 mm × 3 mm and were connected by an electric wire passing through the 8 mm diameter port of the chamber to the external resistor (1.0 kΩ) and a development board (Arduino Mega 2560).[1]

To normalize power density, we used the geometric surface area of all sides of the anode, which was $A_{anode(geo)} = 2 \times 2.5 \text{ cm} \times 2.5 \text{ cm} + 4 \times 25 \text{ cm} \times 3 \text{ cm} = 15.5 \text{ cm}^2$.

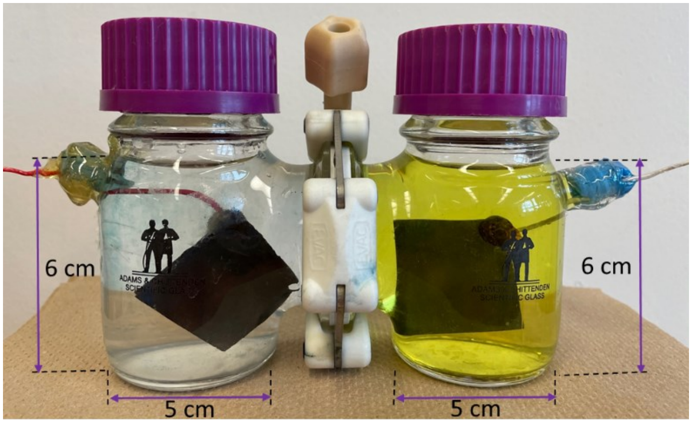

Figure S1. H-cell liquid MFC used in this study with dimensions showing electrical connections to square graphite plates in anolyte and catholyte chambers (left and right, respectively).

Section 2: Polarization test raw data

Polarization tests were run by switching between open circuit voltage (R_{ext}=infinity) and finite electrode potentials corresponding to external resistor values between R_{ext}=16 kΩ and R_{ext}=2 kΩ. From this raw data, polarization curves and power density curves were created.

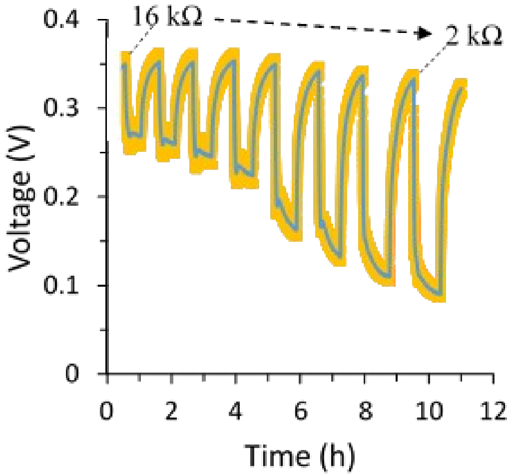

Figure S2. Example of a voltage versus time curve for a MFC under different external resistors (16.0, 13.0, 10.0, 7.0, 4.0, 3.0, 2.5, and 2.0 kΩ). The times of switching to 16 and 2 kΩ external resistors are indicated. Error bands indicate the standard deviation results from 3 separate measurements at 25 days.

Section 3: Temperature cycling applied to liquid MFCs

As shown in Figures S3a and S3b, no voltage spikes were observed when cycling the temperature for liquid MFCs.

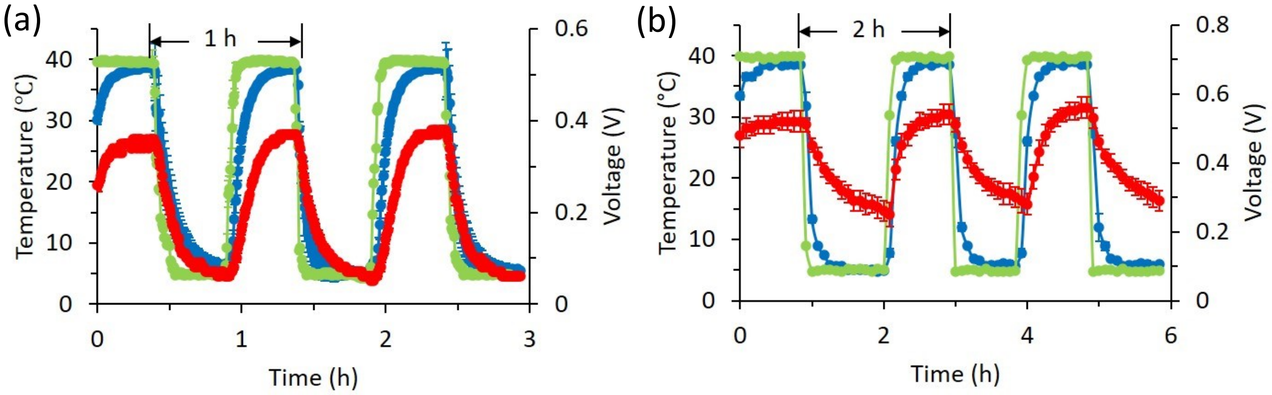

Figure S3. Dynamic experiment for liquid MFC. The temperature and voltage were recorded versus time during dynamic temperature changes with 1-hour temperature cycling time (a) and 2-hour temperature cycling time (b).

Section 4: Dynamic electrochemical impedance spectroscopy

Electrochemical impedance spectroscopy (EIS) was conducted on an inactive soil MFC during temperature cycling in a 2-electrode EIS format using a 5 mV AC amplitude. Although caution should be applied in interpreting the result because the system was never in equilibrium during the measurement, we conducted these measurements at a relatively slow cycle time (2 hr) compared to the measurement time (5 min), such that the system change was limited during the sampling. In any case, the results are interpreted qualitatively in this work. The EIS raw data (not shown) were fit using an accepted equivalence circuit for soil MFCs and are plotted in Figure S6.[2] The data show the changing resistance elements from the hydrated soil and at the electrodes. The results display an inverse correlation between R_S and temperature, as expected. An anti-correlation between electrode resistance ($R_{electrode}$) and temperature is also observed as expected for carbon graphite in this range of temperatures. Somewhat unexpected in both cases was the observation that the resistance did not change linearly with temperature at high temperatures, whereas these changes tracked with better proportionality at low temperatures. Similar experiments were conducted on live soil MFCs but were not successful, with the Nyquist plots showing mostly noise (not shown).

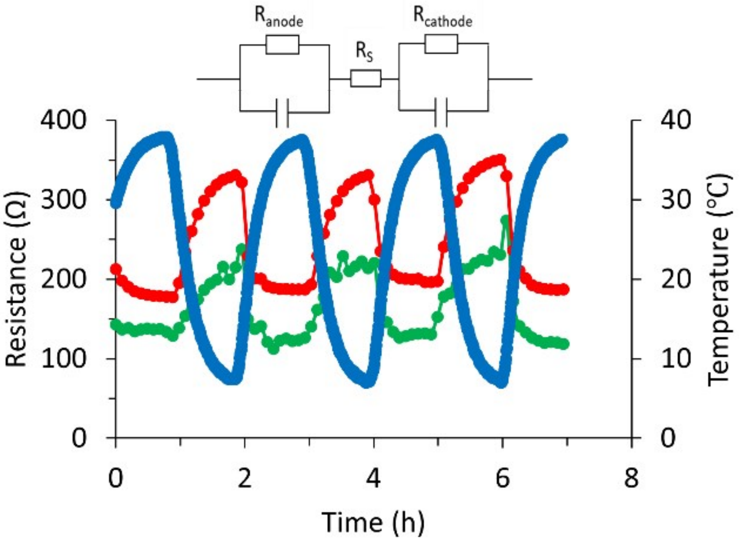

Figure S4. Fitting results from EIS measurement from one soil MFC during temperature cycling. The temperature inside the soil MFC (blue), fitting results of electrode resistance ($R_{electrode}=R_{cathode} + R_{anode}$, green), and hydrated soil phase resistance (R_S, red) were recorded with 2-hour cycling time. The inset shows the equivalence circuit consisting of resistances for the anode, cathode and soil phase (R_{anode}, $R_{cathode}$, R_S) and capacitances (C_{anode} and $C_{cathode}$).

Section 5: References

1. M. Abbaszadeh Amirdehi, S. Saem, M. P. Zarabadi, J. M. Moran-Mirabal and J. Greener, *Advanced Materials Interfaces*, 2018, **5**.

2. X. Li, X. Wang, Q. Zhao, Y. Zhang, Q. Zhou, *Sensors*, 2016, **16**.