

MICROBIAL FUEL CELLS LAB RESOURCES



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Current energy systems rely heavily on fossil fuels such as petroleum/ crude oil, coal, and natural gas in order to generate power for people and industry. But the use of fossil fuels in energy and material production has contributed heavily to climate change and air pollution. Scientists and designers have discovered several useful and sustainable energy alternatives such as solar panels and wind turbines, but their implementation can be limited by economics, politics, and geography. Moreover, life cycle analyses associated with these approaches reveal that some of the processes are also not sustainable and/or produce negative outcomes.

Microbes have evolved to survive and carry out cellular functions, like **metabolism**, within wastewater and soil environments. Through these biochemical cellular processes, electrons are transferred (flow) from molecule to molecule, and ultimately energy is stored in the form of a molecule called ATP. Scientists can draw on/exploit this energy by designing a **circuit** that redirects this flow of electrons from the microbes to a filament (metal thread), thus producing a **microbial fuel cell** (MFC). As a result, MFCs are being developed as a form of alternative energy capable of 1) participating in a diverse, at-home energy grid; 2) treating wastewater; and 3) establishing energy autonomy in robotics. In this module we will research MFC activity as a means to explore electrical circuitry, sustainability, and microbial metabolism.

An MFC captures energy through redirection of the flow of electrons being transferred during metabolic processes known as **electron transport chains**. The electron transport chain uses redox (reduction and oxidation) reactions to drive the synthesis of ATP, a molecule which provides energy for cellular activity. By placing an **anode (electron acceptor)** in mud or soil, we provide a place for the naturally occurring, electrogenic bacteria to grow and donate electrons as they metabolize organic matter. We then install a **cathode (electron attractor)** and construct an electrical circuit between them with conductive wire, thus redirecting the flow of electrons. By connecting (or “stacking”) a series of such circuits (or “chambers”), the electric charge of the microbial fuel cell can be boosted. For this module, we create a 6-chamber MFC and use it to power a small device such as a calculator.

MFCs were first explored in the early 20th century by M.C. Potter, Ph.D. He experimented with both yeast and **bacteria** in liquid growth media (food) and successfully detected electrical activity as the organisms metabolized sugar. These findings were reproduced and expanded upon by Barnett Cohen in the 1930's. Cohen created a microbial fuel cell in series and measured potential energy of his circuit at 35 **volts**. For a long period after these discoveries, the MFC went underdeveloped and under researched. As NASA began to explore space more intensely in the 1960's, the MFC began to receive more attention as a possible way to produce energy through the recycling of human waste. In the 1980's and 1990's further developments were made in the functional construction and theory of the MFC.

Most recently, the genetic diversity of various bacteria has been studied to determine how some bacteria, known as **exoelectrogens**, are able to transfer electrons outward. Electroactivity in bacteria can be attributed to specific genetic sequences and proteins which have evolved over time to make them effective electrogens. In nature, exoelectrogenic bacteria form pili (nanowires) in order to donate electrons to other bacteria that have evolved to be electron acceptors. Since these electron acceptors also produce methane, capturing these electrons not only generates electricity but reduces methane (biogas) production as well.

Electroactivity in bacteria can be attributed to particular proteins coded for in their DNA. For example, *Geobacter sulfurreducens* secretes a c-type cytochrome electron shuttle protein into growth media making it available to other bacteria. *Geobacter* can also form biofilms and transfer electrons via protein filaments in E-pili (nanowires) to inanimate objects. *Shewanella oneidensis*, another widely studied **electroactive bacteria**, secretes proteins called flavins which act as electron shuttles. It is important to note that these bacteria have specific genetic sequences and proteins which have evolved to make them effective electrogens. Exploring these biodiverse ecosystems might shed light on solutions for those practices that are most energy draining in our society.

Currently, waste water treatment centers tap 5% of the nation's energy budget. In NYC, the DEP is the third largest energy user, operating 14 wastewater treatment plants that clean and disinfect 1.3B gallons of wastewater in an effort to comply with the federal Clean Water Act. At the plants, wastewater undergoes five major physical and biological processes that closely duplicate how water is purified in nature. Though DEP has employed solar panels, and **exhaust capture** of the naturally occurring methane (biogas) created by decomposing waste, they have not yet looked to MFC as another means to be more sustainable. Yet, these centers contain sewage that is abundant with diverse bacteria and the organic matter to feed them. Therefore, a search for bacteria capable of withstanding the high phosphate in wastewater environments is also underway. *Geobacter sulferrans* has been identified as one such bacterial species (Bruce Logan's work).

Given the burden that increased urbanization is playing on waste streams, many are seeking creative means to address the energy and public health threats through innovations that exploit bacterial diversity. [Nurul Mohdreza](#), a high school student, has proposed a microbial fuel cell that is highly efficient and uses an electron acceptor (potassium ferrocyanide) that is nontoxic. Unfortunately, this fuel cell requires a chemical reaction utilizing hydrogen cyanide, a very poisonous chemical compound. In 2011, funded by [New York State Energy and Research Development Agency \(NYSERDA\)](#), commercial companies (WERF) teamed up with researchers at the University of Connecticut to pilot a MFC project that used municipal effluent from Johnstown, NY as the source of bacteria to power 16L reactors using continuous flow. This was the first time an anaerobic MFC was used in situ, or at the site of effluent production.

We are using this module within the context of sustainability and alternative energy production. There are ways to contextualize this module for water treatment, farming practices, physical computing, and basic chemistry/physics involving **the first law of thermodynamics**- which states that energy must be conserved. In our system we are **converting chemical energy (the energy stored in chemical bonds of sugar) into electrical energy (electrons to power a calculator)**

Below are resources and the current slide set to help guide your understanding of energy production and to inform you of the current developments in microbial fuel cells. Included in these resources are news articles, videos, and research papers. Please take a look through some of the materials we have provided. We highly recommend you watch the 6 minute Bill Nye The Science Guy video on Electricity and read the Zimmer NY Times article about electrogenic bacteria

[Vocabulary List](#)

[Student Lab WorkSheet](#)

[Slide Set Link](#)

Resources Best for Workshops and Students on Next Page :

Resources

Resources in **green** are used by lab staff in lab sessions

Resources in **yellow** may be used by faculty or attendees to further their learning.

What is a MFC?:

1. **Electricity Video:** PopUpComputerRepair. "Electricity - Bill Nye the Science Guy." *YouTube*. YouTube, 05 Apr. 2012. Web. 27 Jan. 2017. [Link](#)
2. **Video MFC Pili:** "The Microbial Fuel Cell." Sebastian De Bruin. *YouTube*. April 2013. [Link](#).
3. **MFC Wastewater Treatment Video:** TEDx Youth. "Turning Wastewater into Energy: Nurul Mohdreza." *YouTube*. May 14, 2014. [Link](#)
4. **Research/Paper Battery:** SUNY, Research Foundation for. "Binghamton University engineer creates origami battery." Binghamton-Origami Battery - RF for SUNY. [Link](#)
5. **News Article:** Miller, L. Jan. 2017. Paper battery powered by bacteria: Observer, Santa Monica. "Bacteria-powered Battery Is a Single Sheet of Paper." *Santa Monica Observer*. 27. [Link](#)
6. **News:** Chinmayi, T.S. Fuel Cell Electricity from Landfill Waste. Research Matters Mumbai [Link](#)
7. **Video.** Makeshift. 17-Year-Old Kenyan Creates Energy From Human Waste. *Youtube*, Feb 23, 2015. [Link](#)
8. **News:** Chu, J. Jan 11, 2019. Technique Identifies Electricity-Producing Bacteria. *MIT News*. [Link](#)
9. **News:** Zimmer, C. July 1, 2019. Wired Bacteria Form Nature's Power Grid: "We Have an Electric Planet". *The New York Times*. [Link](#)
10. **Reference Chapter:** Azuma M. and Ojima Y. No 5, 2018. Catalyst Development of Microbial Fuel Cells for Renewable-Energy Production. *In Current Topics and Biochemical Engineering Edited by Naofumi Shiomi. (20 pages)* [Link](#)

In-depth resources dealing with fuel cells, research, and current iterations:

1. **Journal Publication:** Boghani, H. et al. "Reducing the burden of food processing washdown wastewaters using microbial fuel cells." *Biochemical Engineering Journal* 117 (2017): 210-17. [Link](#)
2. **News Article:** MacDonald, F. "Scientists Have Built a Microbial Fuel Cell That Runs Without External Power." *ScienceAlert*. Web. 27 Jan. 2017. [Link](#)
3. **Informational Website:** "Types of Fuel Cells." *Types of Fuel Cells | Department of Energy*. Web. 27 Jan. 2017. [Link](#)
4. **Video:** KeegoTech. "MudWatt Microbial Fuel Cell - How It Works." *YouTube*. YouTube, 03 Oct. 2010.. [Link](#)
5. **Video: Benthic MFC:** USNRL. "Using Microbes to Generate Electricity." *YouTube*. YouTube, 07 Feb. 2013. [Link](#)
6. **Video Electrifying Wastewater:** Lilaznschoii. "Electrifying Wastewater: Using Microbial Fuel Cells to Generate Electricity." *YouTube*. YouTube, 29 Oct. 2013. Web. 27 Jan. 2017. [Link](#)

7. **Video: NPR Science Friday:** BarkaMack. "FUEL CELLS Clean Energy for the Future." *YouTube*. YouTube, 12 Feb. 2013. Web. 27 Jan. 2017. [Link](#)
8. **Research Paper:** Sacco N. et al. 2017. Isolation and Characterization of a Novel Electrogenic Bacterium, *Dietzia* sp. RNV-4. *PLoS ONE* 12(2). [Link](#)

Resources on Climate Change and Energy Resources

1. Pelto, Jill. *Landscape of Change*. Oil on canvas.
2. StileEducation. The Greenhouse Effect, Explained. *YouTube*, YouTube, 8 Aug. 2017, [Link](#)
3. Greenhouse Gas Inventory Data Explorer. *EPA*, Environmental Protection Agency. [Link](#)
4. Wallace, Tim. Oceans Are Absorbing Almost All of the Globe's Excess Heat. *The New York Times*, 12 Sept. 2016, [Link](#)
5. Japan heatwave declared natural disaster as death toll mounts. *BBC News*, July, 24. 2018, [Link](#)
6. Japan heat wave death toll soars amid record temperatures. *DW*, DW.com, 23 July. 2018 [Link](#).
7. Anderson, Christina and Cowell, Alan. "Heat Wave Scorches Sweden as Wildfires Rage in the Arctic Circle". *The New York Times*, The New York Times. 19 July, 2018. [Link](#)
8. Global Climate Report - June 2018. *NOAA*, National Centers for Environmental Information. [Link](#)
9. Friedrich, J. et al. This Interactive Chart Explains World's Top 10 Emitters, and How They've Changed. *WRI*, World Resources Institute. 11 April, 2017. [Link](#)
10. Paris Agreement Ratification Tracker. *Climate Analytics*. 13 July 2018. [Link](#)
11. Mildenberger, Matto et al. Partisan Climate Opinion Maps 2016. Yale Program on Climate Change Communication. [Link](#)
12. Least CO2 Emitting Countries per Capita. *The Shift Project Data Portal*, Browse Energy and Climate Data. [Link](#)
13. Swanson, Ana. "The countries most vulnerable to climate change, in 3 maps". *The Washington Post*, The Washington Post. 3 February, 2015. [Link](#)
14. The Carbon Map. [Link](#)
15. Van Aubel, Margan. "Caventou". *Vimeo*, Vimeo. 13 October, 2015. [Link](#)
16. Princeton University. A more potent greenhouse gas than carbon dioxide, methane emissions will leap as Earth warms. *ScienceDaily*, ScienceDaily. 27 March 2014. [Link](#)
17. Yvon-Durocher, Gabriel et al. Methane fluxes show consistent temperature dependence across microbial to ecosystem scales. *Nature* 507, 488-491. 27 March, 2014. [Link](#)