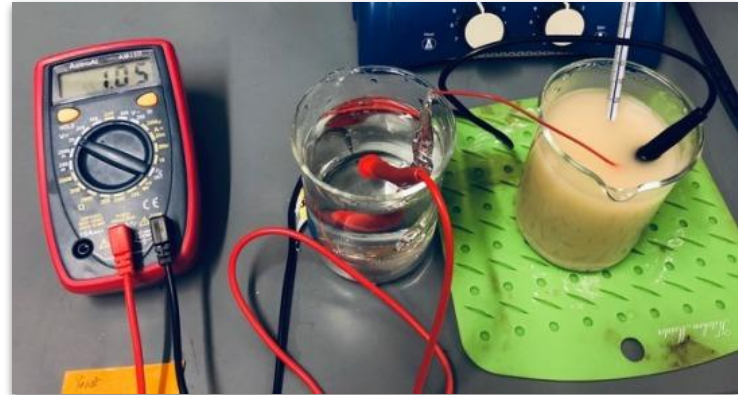


Sustainable Energy Microbial Fuel Cells

THE NEW SCHOOL

UNIVERSITY
SCIENCE LABS



Marcus Banks, *University Science Labs Manager, MFA DT Candidate*

Ryan Logan, *Product Design, BFA*

Katayoun Chamany, *University Science Labs Director, Mohn Family Professor in Natural Science and Mathematics, Eugene Lang College for Liberal Arts at TNS*

Jill Pelto (Artist/Scientist)

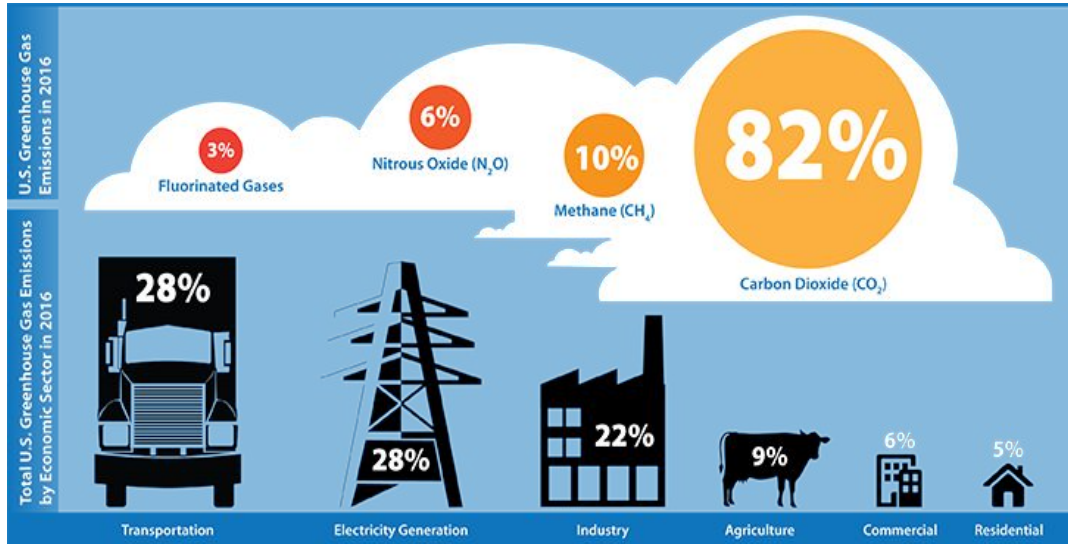
(Habitat Degradation: Ocean Acidification, Increasing Forest Fire Activity, Landscape of Change)



Why Sustainable Energy?

Greenhouse Gas Inventory Data Explorer [\(LINK\)](#)

- Collects data by sector, type of emission, and date

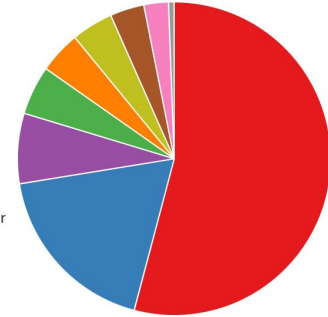


U.S. Greenhouse Gas Emissions from the Industrial Sector, 2016

Emissions in million metric tons of carbon dioxide equivalents

(Click to hide)

- Fossil fuel combustion: carbon dioxide (54.1%)
- Natural gas and petroleum systems (18.3%)
- Other industrial categories (7.2%)
- Chemical production and use (5.0%)
- Mineral products (4.3%)
- Coal mining (4.3%)
- Metal production (3.5%)
- Production and use of fluorinated gases (2.5%)
- Fossil fuel combustion: other greenhouse gases (0.6%)



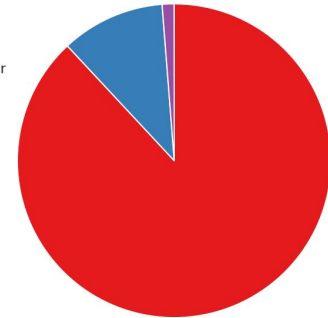
Source: U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016.
<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

U.S. Greenhouse Gas Emissions from the Residential Sector, 2016

Emissions in million metric tons of carbon dioxide equivalents

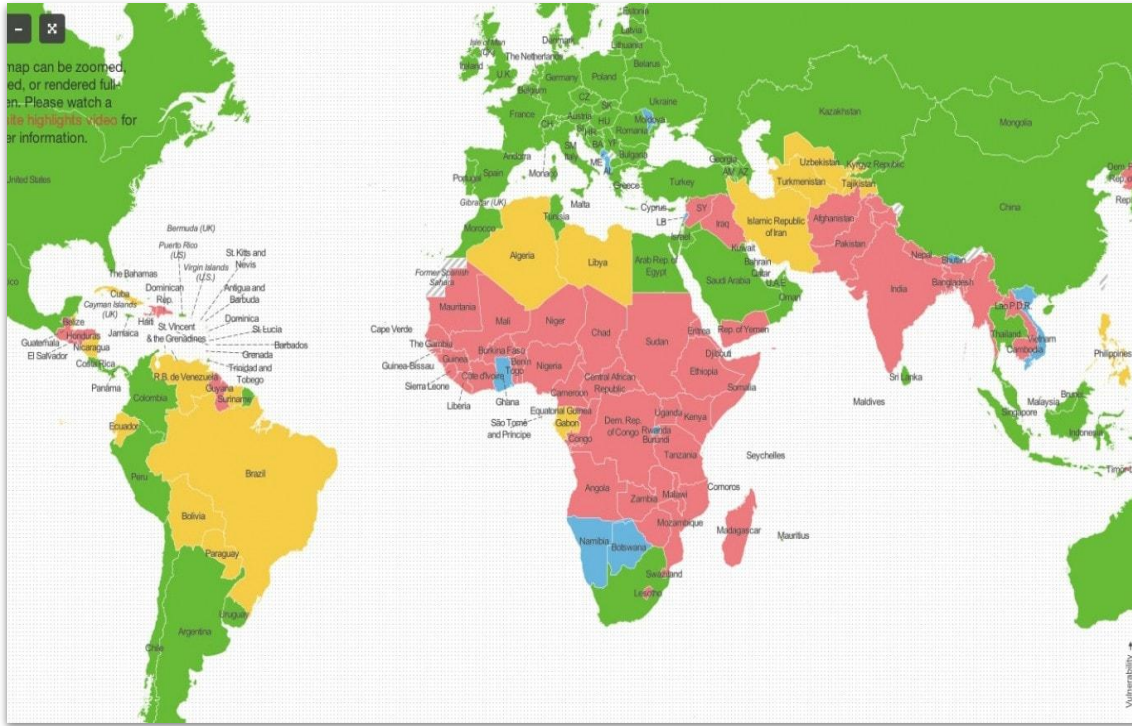
(Click to hide)

- Fossil fuel combustion: carbon dioxide (88.1%)
- Use of fluorinated gases (10.7%)
- Fossil fuel combustion: other greenhouse gases (1.2%)



Source: U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016.
<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

Climate Justice



Notre Dame Global Adaptation Index (ND-GAIN) Map indicating most (red)/least (green) vulnerable/equipped countries when dealing with effects of climate change. The group measures vulnerability by considering the potential impact of climate change on six areas: food, water, health, ecosystem service, human habitat and infrastructure. The readiness rank weights portions of the economy, governance and society that affect the speed and efficiency of adaptation projects. ([LINK](#))

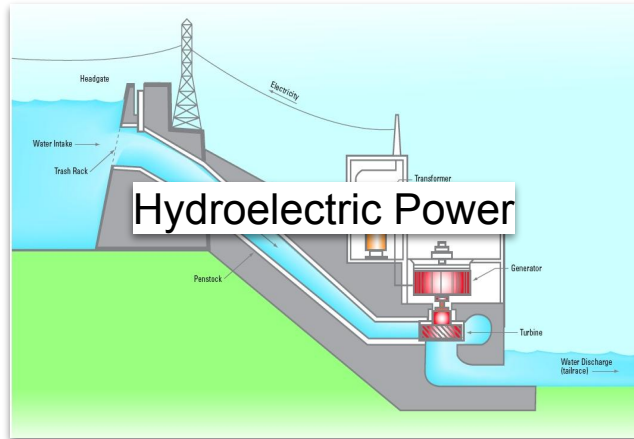
HIGH Emitting <i>Vulnerability Rank</i>	LOW Emitting <i>Vulnerability Rank</i>
1. China	1. Chad
2. U.S.	2. Burundi
3. E.U.	3. D.R.C.
4. India	4. Mali
5. Russia	5. Rwanda
6. Japan	6. Niger
7. Brasil	7. Uganda
8. Indonesia	8. Somalia
9. Canada	9. Ethiopia
10. Mexico	10. Burkina Faso

Sustainable Energy

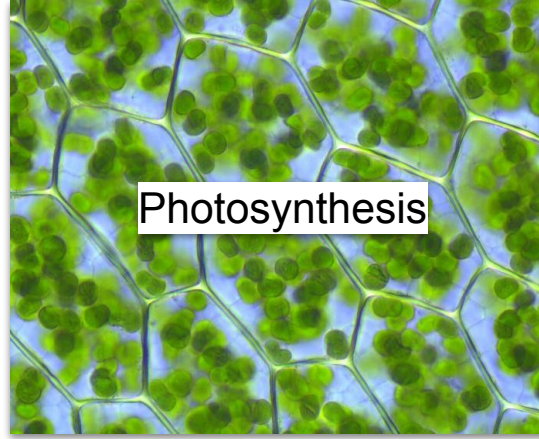
- Produce electric current through chemical reaction
 - PEMFC, Proton Exchange Membrane Fuel Cell
 - DMFC, Direct Methanol Fuel Cell
 - PAFC, Phosphoric Acid Fuel Cell
 - AFC, Alkaline Fuel Cell
 - MCFC, Molten Carbonate Fuel Cell
 - SOFC, Solid Oxide Fuel Cell
 - Microbial Fuel Cell
 - Solar Cell

Conservation of Energy

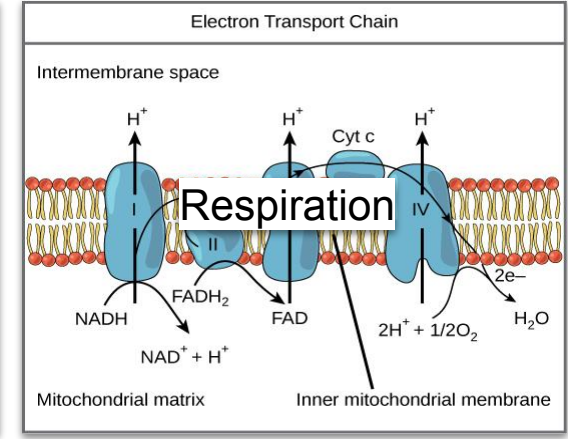
Energy is neither created nor destroyed it is converted from one form into another.



Mechanical $\longrightarrow$ Electrical



Light $\longrightarrow$ Chemical



Chemical/Sugar $\longrightarrow$ ATP

[New York Times Article.](#)

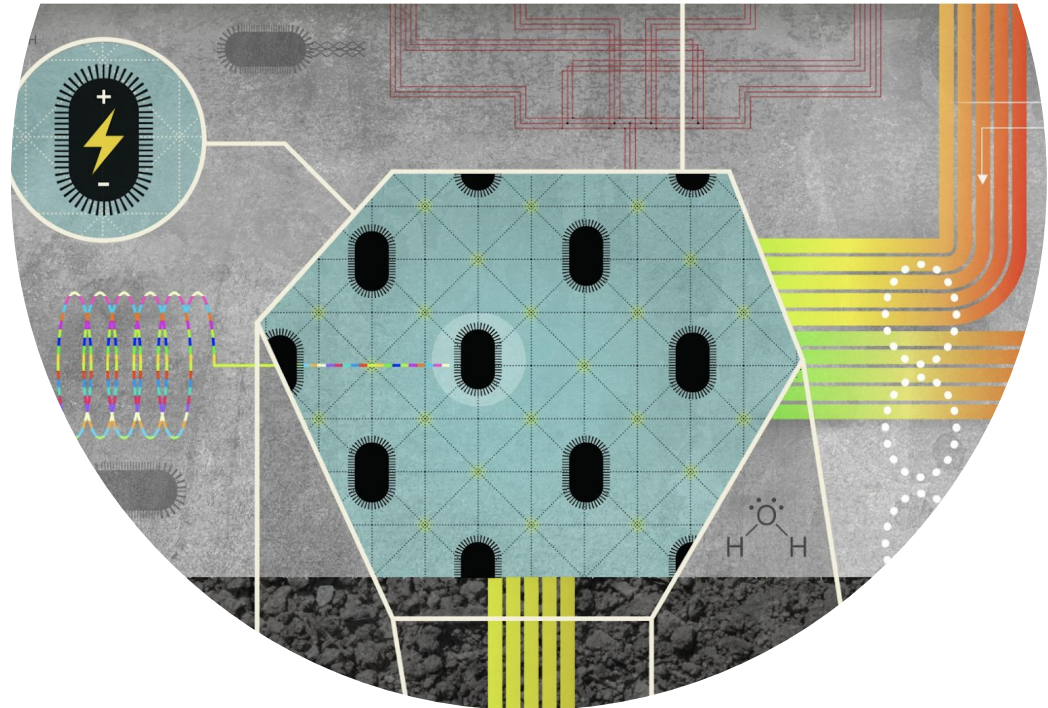
***Wired Bacteria Form Nature's
Power Grid:
'We Have an Electric Planet'
by Carl Zimmer***

"Not to sound too crazy, but we
have an electric planet,"

*John Stolz, Microbiologist,
Duquesne University*

Wired Bacteria Form Nature's Power Grid: 'We Have an Electric Planet'

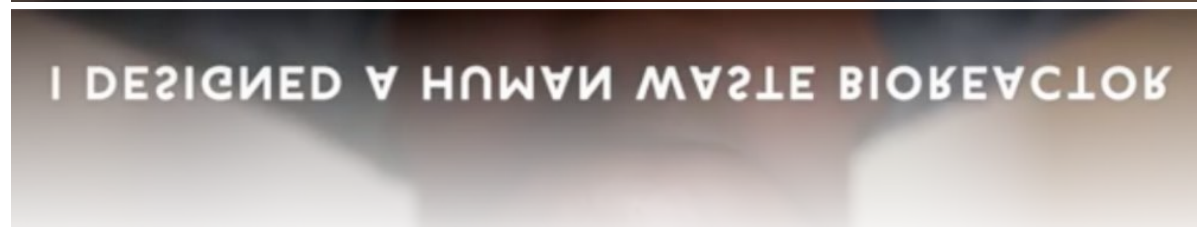
Electroactive bacteria were running current through "wires" long before humans learned the trick.



Microbial Fuel Cells

Makeshift, Youtube Video [LINK](#)

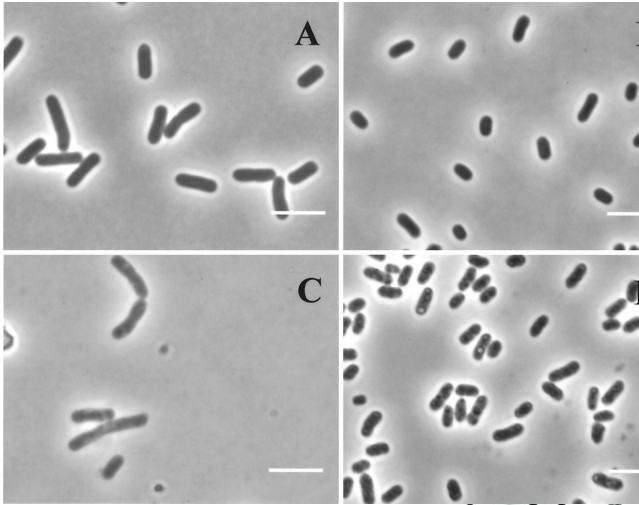
- Leroy Mwasaru and classmates
 - Designed Bioreactor/digestor
 - Uses human, organic waste
 - Food remains
 - Cow dung
 - Cut grass
 - Bacterial Methanogenesis
 - Byproduct of metabolism
 - 'Biogas'
- Can be used on larger scale
 - Most frequently on dairy farms
 - YouTube Video [LINK](#)



Cells (Self Contained Units)

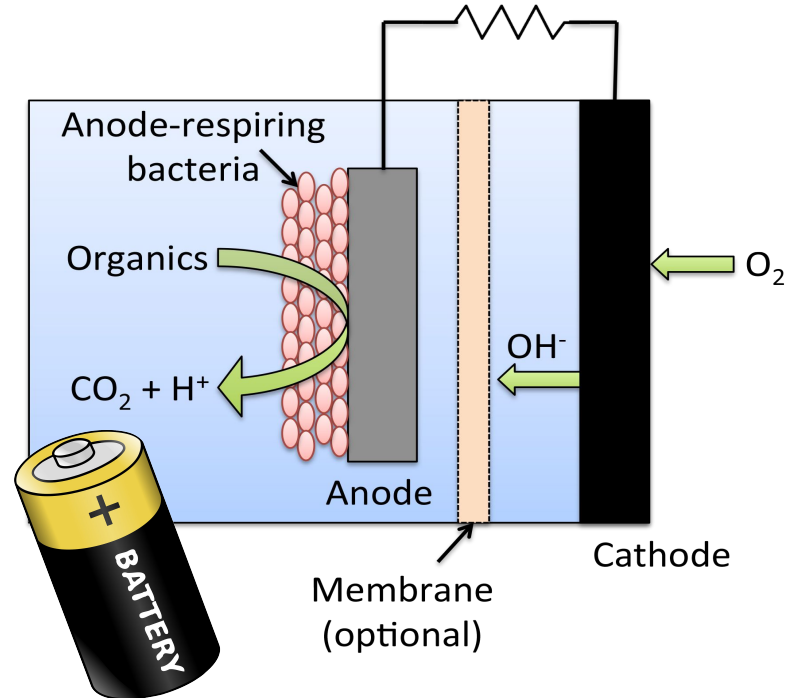
Bacterial Cell:

smallest living unit, organism



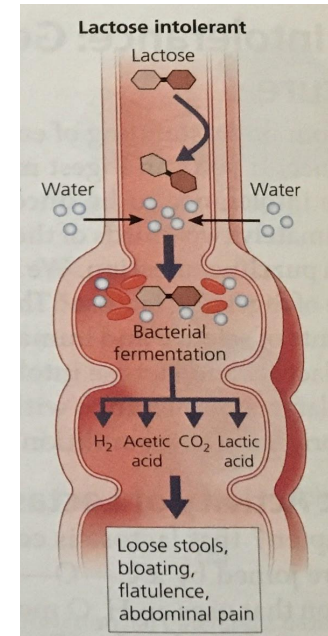
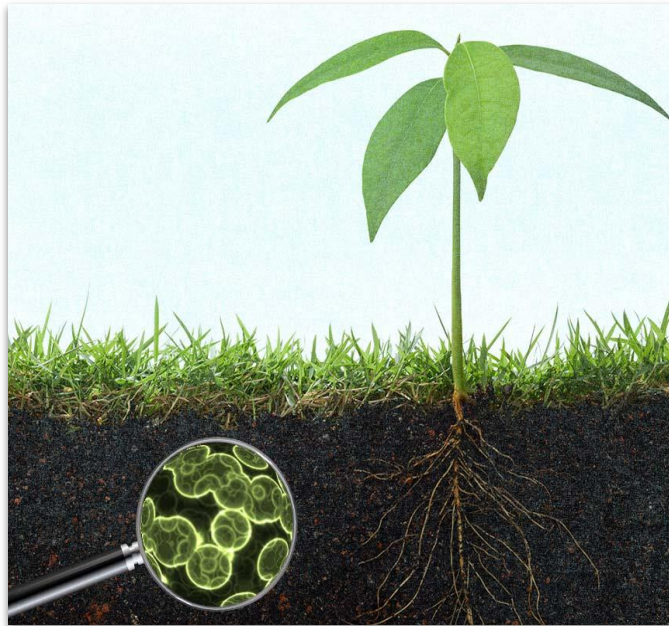
Fuel Cell:

energy producing unit



Where Do Microbes Reside?

- **Environmental Microbiome:** Present in soil, sediment, sludge, compost
- **Gut Microbiome:** Diverse Microbial Population
 - Aid in metabolism of sugars (e.g. lactose fermentation, susceptibility to obesity, etc.)
 - Bacteria are deposited from human gut into wastewater (human coliforms)



Credit: Jordan, T. *Molecules of Life* Ch. 14.

History of MFC

“The results of recent researches in electrophysiology have familiarised us with the view that any physiological process accompanied by chemical changes involves an associated electrical change.”

-M.C. Potter, Professor of Botany in the University of Durham. 1911

- 1911 Potter builds a MFC with yeast and shows voltage is affected by:
 - Concentration of yeast, Concentration of food/sugar, Temperature of reaction
- 1931 Barnett Cohen (Yale, Society of American bacteriologists)
 - Combines MFCs in series to create 35V
- 1980s M.J. Allen and H. Peter Bennetto (King's College, London)
 - Redesigns MFC into form used today
- 1990s B.H. Kim (Korean Institute of Science and Technology)
 - Shows organisms can donate electrons to anode without mediator molecule

Harnessing Microbial Energy

- Biodiverse Community is better for Microbial Fuel Cells (MFC)
- Isolated Pure Microbial Cultures
 - Algae: *Chlorella pyrenoidosa* 6030 mW/m²
 - Yeast: *Saccharomyces cerevisiae* 25.5 mW/m²
 - Cyanobacteria: *Spirulina* 6.5 mW/m²
 - γ- Proteobacteria
 - *E. coli* (human microbiome) first used in 1911 (Potter)→ 0.3V
 - *E. coli* (genetically modified) 1304 mW/m²
 - *Shewanella putrefaciens* (soil) 1024 mW/m²
 - *Shewanella oneidensis* (soil) 249 mW/m²
 - *Geobacter sulfurreducens* (soil) 3.9 W/m²

Cao, et al. 2019. *Electricigens in the anode of microbial fuel cells: pure cultures versus mixed communities* Microbial Cell Factories. [Link](#)

Electrogenic Bacteria

Why might bacteria evolved different mechanisms? Hint: Think about location!

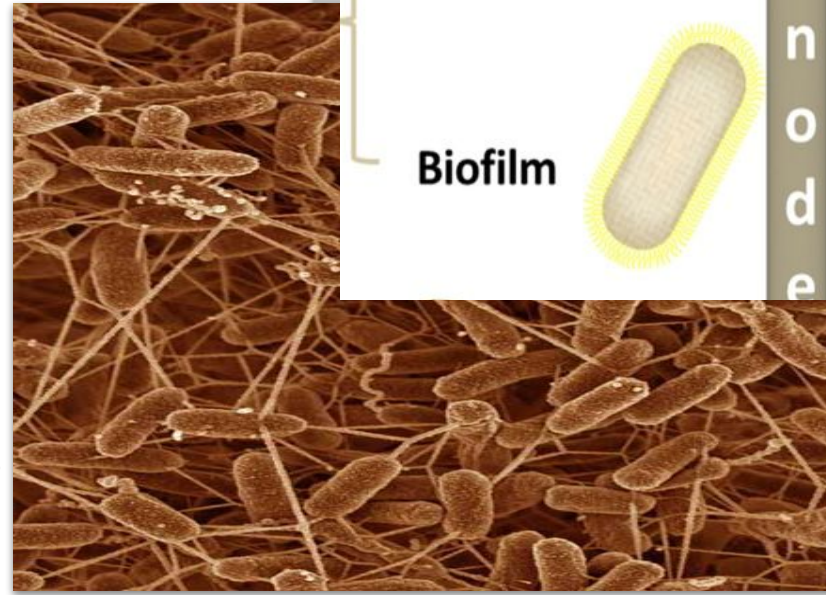
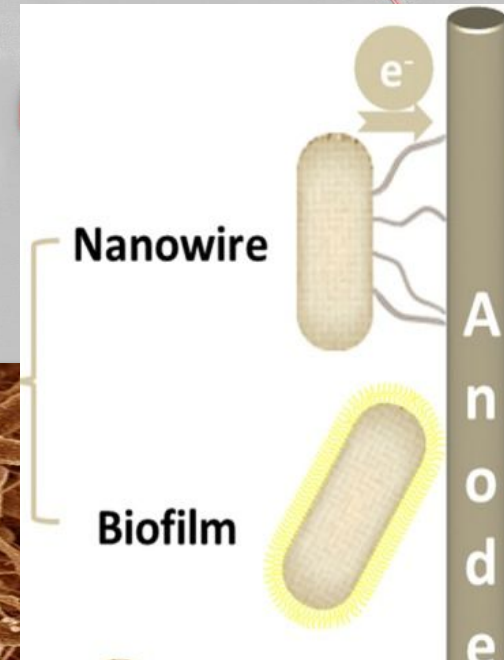
Nanowire length can be increased with environmental changes.

SOIL: Direct Electron Transfer (*Shewanella* & *Geobacter*)

- Highly Efficient
- Direct Contact with Anode
 - “Nanowires” are protein filaments, e-pili, and flagella
 - Biofilms are layers of bacteria colonizing the anode

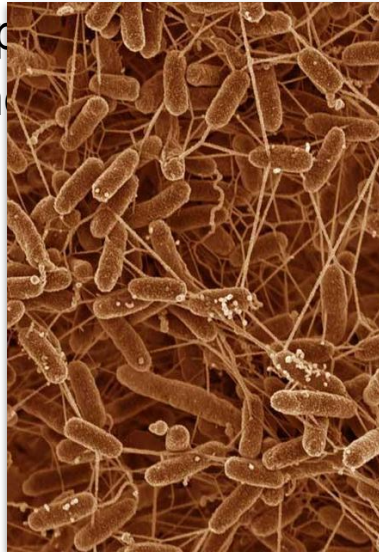
GUT: Indirect Electron Transfer (*E. coli*)

- Less Efficient
- Uses Oxidation-Reduction Endogenous Mediators
- Can be enhanced w/ chemicals; act as exogenous mediators
 - Expensive or toxic (Neutral Red, Methylene Blue)



Electrogenic Bacteria

- Electrogenic bacteria transfer electrons to extracellular electron acceptors
 - Have potential to power bioelectrochemical systems (BES).
- Have evolved in response to environments to be more electroactive
- DNA codes for proteins responsible for increased electroactivity
 - E-pilin Genes (encode for conductive pili)



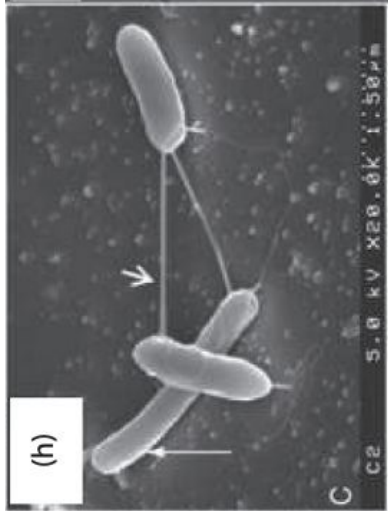
Widely Studied Electrogenic Bacteria:

Shewanella oneidensis

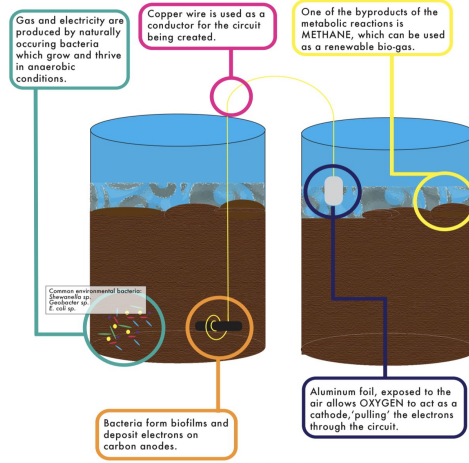
Geobacter sulfurreducens

Dietzia. sp.

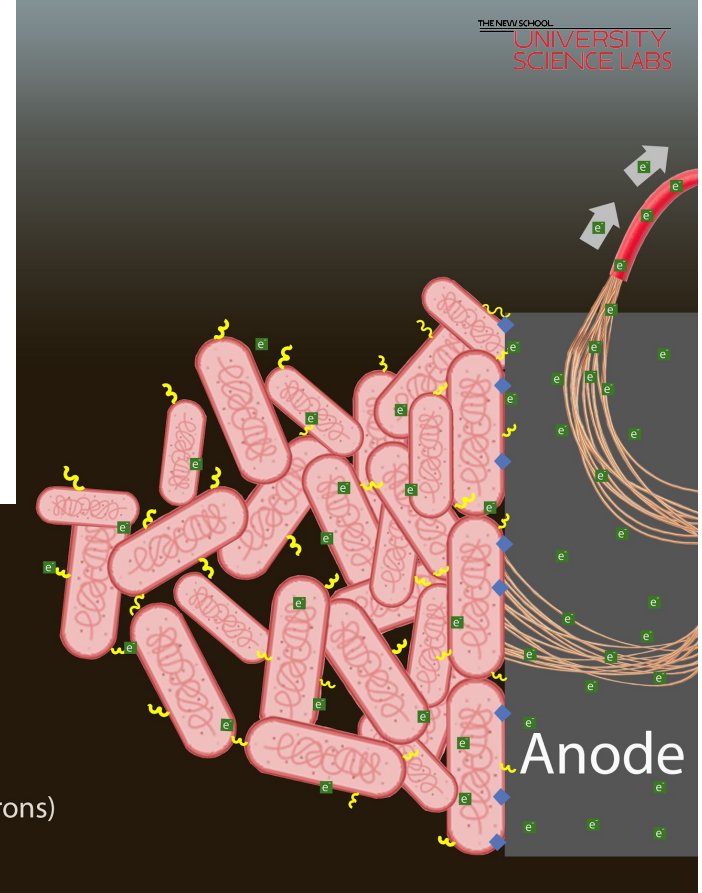
Design The System



Inside a Microbial Fuel System Using Human Sludge

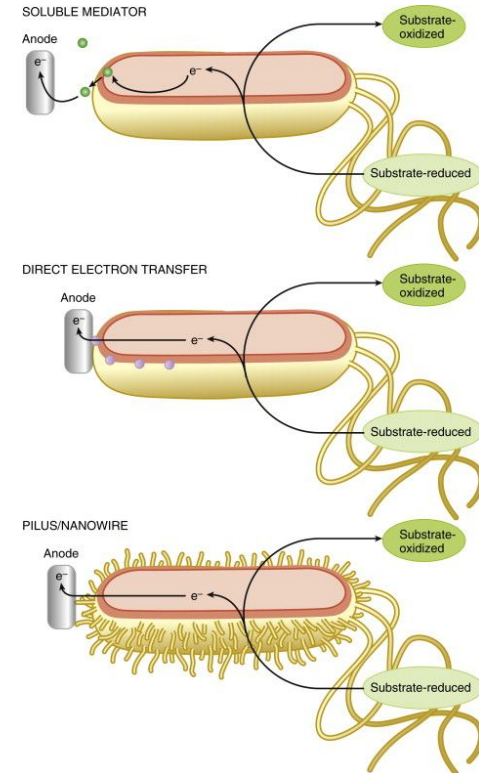


-  Conductive pili
-  Bacteria
-  Electron
-  Cytochrome (can directly transfer electrons)



Electron Flow Through A Microbial Fuel Cell

- Microbial Fuel Cell: Electrogenic Bacteria Transfer Electrons
- Metabolism: needs food source or substrate
 - Organic matter in soil or wastewater
 - Generating energy for cellular functions
 - Electrons transported into/through cell membrane
 - Electrons moved into circuit with conductor
 - Intercept electrons with anode
 - Bacteria/Biofilm deposit electrons onto anode
 - Conductor carries electrons toward cathode
 - Oxygen



Biosafety/Risk Group Level

Working with Microbes

BioSafety Level 1 Protocol: Lab grown non disease causing *E coli* K12 strain (MM294)

Wear LAB COATS and WEAR GOGGLES or EYE PROTECTION TO AVOID SPLASHES

USE GLOVES AT ALL TIMES- ONE SET FINE

DO NOT TOUCH FACE and EYES

MINIMIZE PHONE USE- ONLY FOR PHOTOGRAPHS/ WIPE with 70% ALCOHOL Before departure

USE ALCOHOL to CLEAN SPILLS

Note that alcohol is flammable; Use caution- demonstrated in lab

SDS Sheet on Safety Wall and Chemical Hygiene Plan in Prep Room 621

DISPOSE of GLOVES in BIOHAZARD WASTE BIN

WASH HANDS BEFORE LEAVING THE LAB

ALL BACTERIA ARE EXPOSED TO 10% BLEACH/ STERILIZED by Lab Staff

APPLYING THE SCIENTIFIC METHOD:

Student Handout

Observations: List prior knowledge, news, or science regarding traditional and alternative energy resources. What are some potential environmental impacts of each type? What do we already know about Microbial Fuel Cells that might inform our answers below?

Manipulating Variables: Considering the starting material at your lab bench (mud, glucose, heating element, water) what are some questions that you want the experiments today to answer? Consider which of these components you are interested in varying and why? What variables might increase the production of energy?

Research Question: What questions do you hope to answer with today's experimental design?

Hypothesis: Generate a hypothesis that is informed by your observations and your actions.

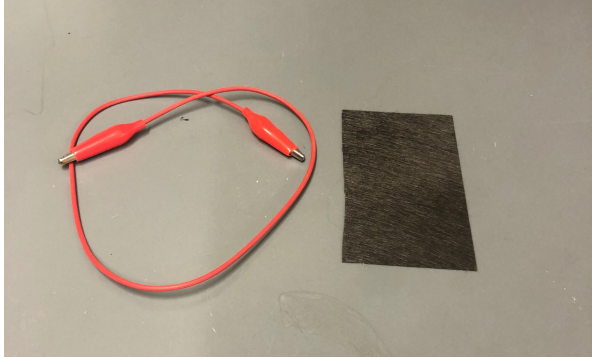
Think about the hypothesis like this

If ... (the action you will take; manipulating an independent variable)

Then ... (the result you expect to see; describing the dependent variables)

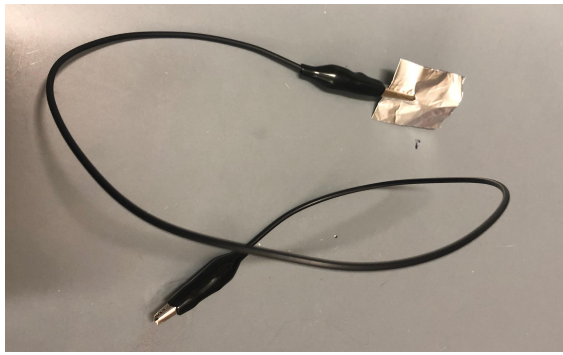
Because... (rationale for the prediction informed by prior knowledge, observations)

Creating Circuit Components



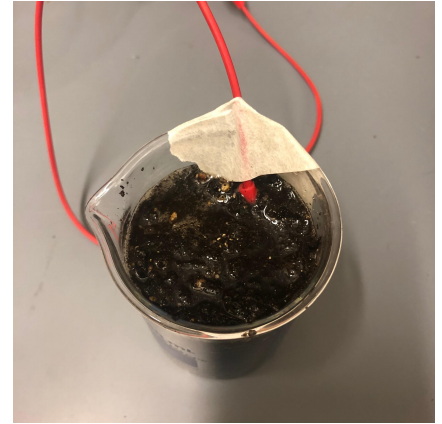
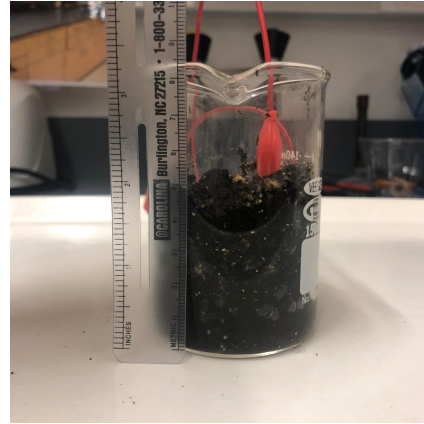
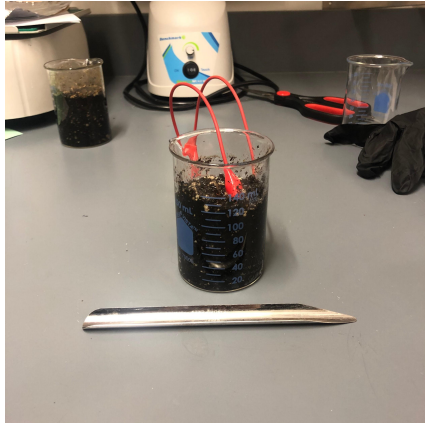
1. CREATE CIRCUIT COMPONENTS:

- a. ANODE: Fold graphite paper in half and attach one side of the red alligator clip



- b. CATHODE: Fold 3cm x 6cm aluminum foil in half and attach one side of the black alligator clip. (No difference if shiny or dull side is facing out)

Create Anaerobic Conditions



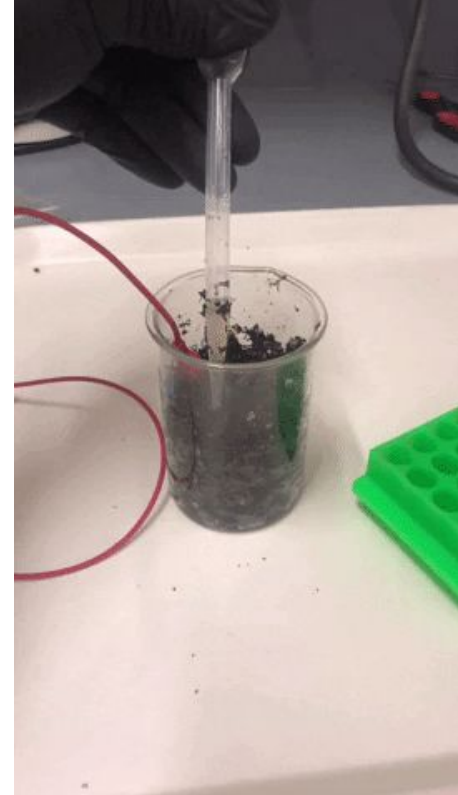
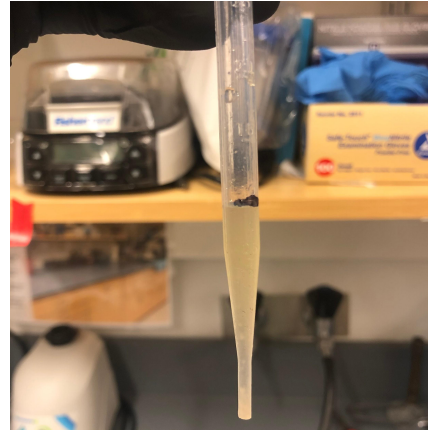
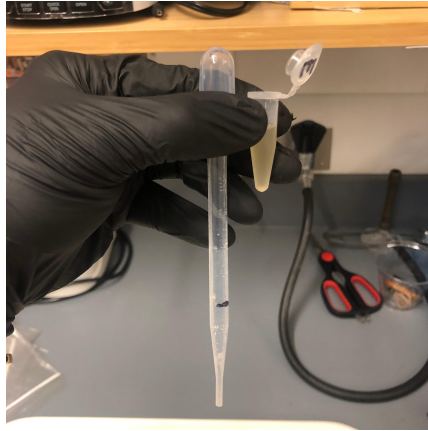
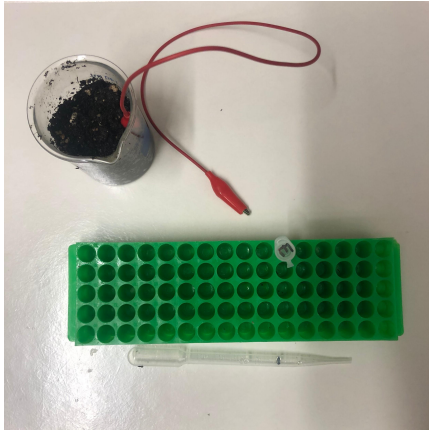
1. CREATE ANAEROBIC CONDITIONS

- a. PLACE graphite anode near bottom of anode chamber, using a metal spatula to move the soil. Try not touch the bottom of the beaker
- b. COMPRESS soil in all beakers using a gloved hand to about 5 cm (use a ruler to measure).

****If your Carbon Fiber Paper is loose/moving, tape the wire to the side of the beaker****

Add Microbes

ADD MICROBES. Using a plastic pipette to add 1 ml of live *E. coli* K-12 MM294 bacteria to anode beakers close to graphite as possible.



DETAILED INSTRUCTIONS:

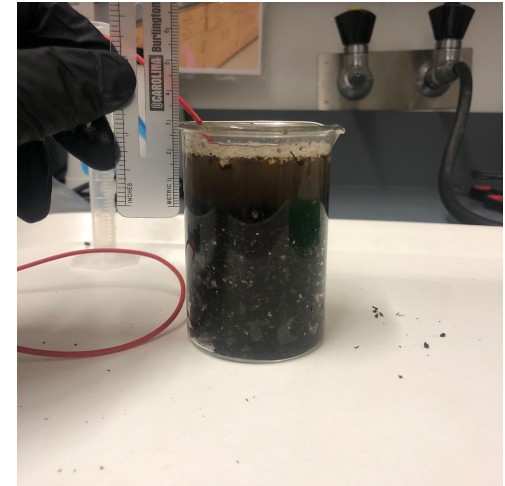
1. Located plastic pipette, eppendorf tube labeled "E," and anodic chamber
2. Add *E. coli* culture to the black mark on the pipette (1mL)
3. Insert the pipette into anodic chamber (close to bottom/near Carbon Graphite Paper)
4. Gently dispense *E. coli* sample by depressing the top of the pipette

Adding Sugar/Creating Anaerobic Conditions

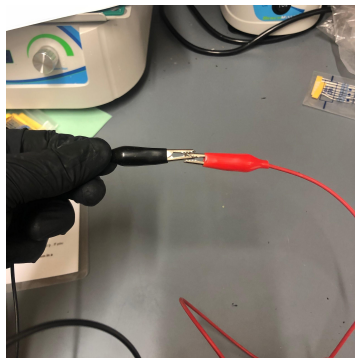
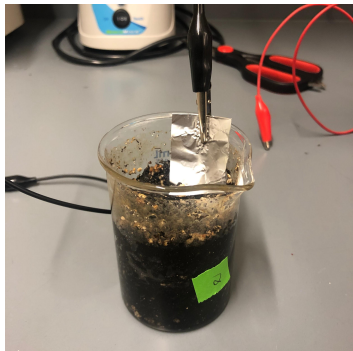
1. **ADD SUGAR:** Using a graduated cylinder slowly pour 10 ml of 5% glucose solution on top of the soil in the "+ Glucose" beaker.



1. **CREATE ANAEROBIC CONDITIONS**
 - a. DECANT WATER slowly into each beaker
 - b. CONTINUE to ADD UNTIL VISIBLE LAYER of 2-3 cm of water on top of the soil; the soil will soak up water
 - c. REMOVE SOIL: If needed, remove floating soil particles using a spatula from the water and place it in Tips Waste beaker.



Complete The Circuit

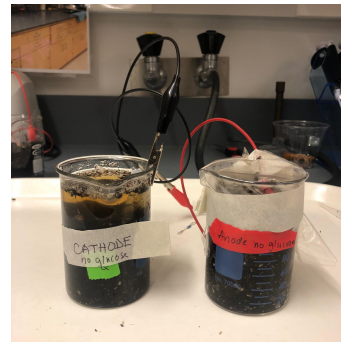
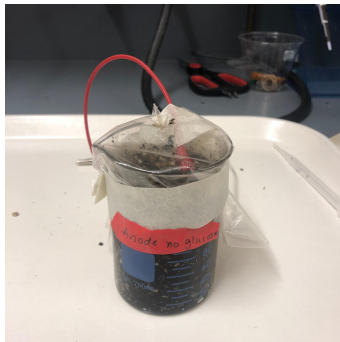


1. COMPLETE THE CIRCUIT

- PARTIALLY SUBMERGE CATHODE (aluminum foil) to expose it to air and water; do not let it touch the soil.
- SECURE the cathode to the side of the beaker with the alligator clip, and attach alligator clips to each other
- Cover both MFC beakers with plastic sheet and tape in place and ensure there is room to insert Multimeter probes. **Note: the plastic is cut to fit around the wire.**

2. PROVIDE TIME for METABOLIC REACTION

- Ensure you do not move your electrodes.
- Allow MFC to sit for 5-10 minutes while going over student handouts and watching videos.



Measure Voltage

1. MEASURE VOLTAGE

- a. SET MULTIMETER : set voltage reading at 20V
- b. PLACE PROBES JUST BELOW THE SURFACE of WATER: Red probe into anode beaker; Black probe into cathode beaker.
- c. MEASURE/ RECORD potential energy for each fuel cell in the chart



PPE Goggles, Gloves, and Lab Coats

1. LABEL THE SYSTEM

- Using a sharpie and labeling tape, label two beakers "Anode" (Red Tape) and two beakers "Cathode" (White Tape)
- Next, pair each Anode beaker with one Cathode beaker and write "+Glucose" for a pair and "No Glucose" for a pair.

2. CREATE CIRCUIT COMPONENTS:

- ANODE: Fold graphite paper in half and attach one side of the red alligator clip
- CATHODE: Fold 3cm x 6cm aluminum foil in half and attach one side of the black alligator clip. (No difference if shiny or dull side is facing out)

3. CREATE ANAEROBIC CONDITIONS

- PLACE graphite anode near bottom of anode chamber, using a metal spatula to move the soil. Try not touch the bottom of the beaker
- COMPRESS soil in all beakers using a gloved hand to about 5 cm (use a ruler to measure).

4. ADD MICROBES. Using a plastic pipette to add 1 ml of live E. coli K-12 MM294 bacteria to anode beakers close to graphite as possible.

STOP: Discuss why you are adding bacteria to these particular chambers.

5. ADD SUGAR: Using a graduated cylinder slowly pour 10 ml of 5% glucose solution on top of the soil in the "+ Glucose" beaker.

STOP: Discuss why you are adding glucose to this particular chamber.

6. CREATE ANAEROBIC CONDITIONS

- DECANT WATER slowly into each beaker
- CONTINUE to ADD UNTIL VISIBLE LAYER of 2-3 cm of water on top of the soil; the soil will soak up water
- REMOVE SOIL: If needed, remove floating soil particles using a spatula from the water and place it in Tips Waste beaker.

7. COMPLETE THE CIRCUIT

- PARTIALLY SUBMERGE CATHODE (aluminum foil) to expose it to air and water; do not let it touch the soil.
- SECURE the cathode to the side of the beaker with the alligator clip, and attach alligator clips to each other
- Cover both MFC beakers with plastic sheet and tape in place and ensure there is room to insert Multimeter probes

8. PROVIDE TIME for METABOLIC REACTION

- Ensure you do not move your electrodes.
- Allow MFC to sit for 5-10 minutes while going over student handouts and watching videos.

9. MEASURE VOLTAGE WITH AND WITHOUT RESISTANCE

- SET MULTIMETER : set voltage reading at 20V
- PLACE PROBES JUST BELOW THE SURFACE of WATER: Red probe into anode beaker; Black probe into cathode beaker.
- MEASURE/ RECORD potential energy for each fuel cell in the chart
- REPEAT STEPS A-C with the alligator clips attached to each end of a 100 ohm resistor
- DAY 2: Collect Second Set of Results-Data/Voltage:** Take a final reading with a multimeter-record in the chart.

10. GRAPH RESULTS: Using the data collected by the lab staff and the final reading collected in class, create a graph

[Spreadsheet for recording](#)

SUGAR/GLUCOSE

ELECTROGENIC BACTERIA

ANODE

"AIR" CATHODE

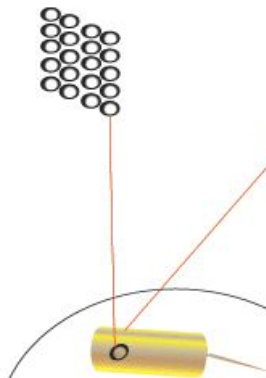


Oxygen in the air acts
as the final electron
receptor.

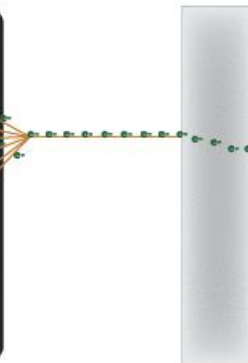
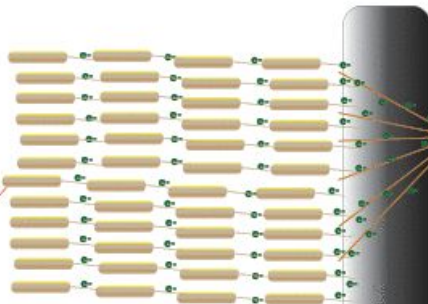


Oxygen accepts the
electron and reacts with
Hydrogen to create
a water molecule.

Flow of electrons

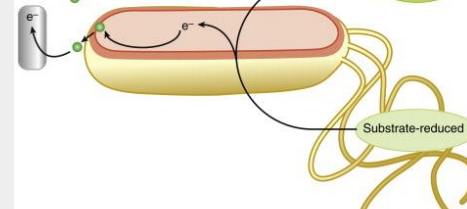


As *E. coli* metabolize (breakdown for energy) organic material, there is a shuffling or moving of **electrons (e^-)** from the organic material into the energy producing mechanism of the bacteria; the Electron Transport Chain.



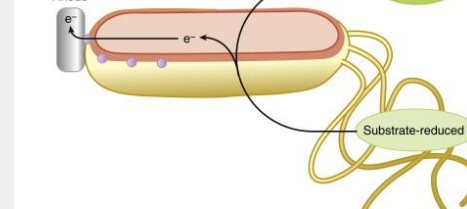
SOLUBLE MEDIATOR

Anode



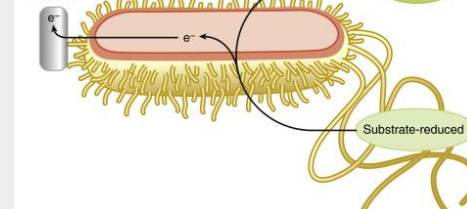
DIRECT ELECTRON TRANSFER

Anode



PILUS/NANOWIRE

Anode



Manipulating Energy Output

1. Which independent variables could be modified to increase energy output?
2. What could we do as a collective to power a calculator which needs 1.2V to produce enough power to work?
3. Reflecting back on the Makeshift Video, what is missing from our MFC, and why did we choose this approach as opposed to theirs for this proof of concept MFC?
4. How can a knowledge of biodiversity and evolution of microbes support improved MFC construction?

Energy Harvesting With Microbial Fuel Cell and Power Management System

Andrew Meehan, Hongwei Gao, *Senior Member, IEEE*, and Zbigniew Lewandowski

Abstract—This paper presents a system that can harvest energy in the water and use the harvested energy to power electronic devices deployed in the water. The system consists of a microbial fuel cell (MFC) and a power management system. The MFC uses electrochemical reactions and bacteria that exist in the water to harvest energy and generate electricity. The power management system consisting of a charge pump, a super capacitor, two solid-state switches, and a boost converter accumulates the energy harvested by the MFC, stores the energy in the super capacitor, and bursts power to the load. The power management system also boosts the voltage of the MFC to a sufficient level for the electronic devices. The presented energy-harvesting system is self-powered, sustainable, environment friendly, and maintenance-free. The system has been tested and proven through experimental work.

Index Terms—Boost converter, charge pump, hydrophone, microbial fuel cell (MFC), power management system.

I. INTRODUCTION

THERE are needs to harvest energy in the water and use the harvested energy to power electronic devices deployed in the water. For example, the U.S. Navy needs to detect and monitor sea turtle activities near naval bases so that the turtles are not endangered by naval ships. The navy uses electronic devices, so-called hydrophones, to do this. The hydrophones are anchored to the bottoms of the seas, and therefore, if they are powered by batteries, then the batteries have to be replaced frequently by diving teams, which is dangerous and expensive. The U.S. Navy considers using devices that can harvest energy from the water to power the hydrophones.

One type of devices that can harvest energy from the water is microbial fuel cells (MFCs). MFCs use bacteria that exist in the water and certain electrochemical reactions to generate electricity. They require no maintenance and have unlimited lifetime and are therefore more appealing than batteries for powering electronic devices deployed in the water. They can continue to produce electricity as long as the bacteria are alive

and active, and therefore, can make the systems powered by MFCs autonomous. They do not produce harmful waste and are therefore environment friendly.

Though MFCs are very attractive power sources, they present certain challenges for real applications—they produce very low voltage and current.

The voltage of an MFC is usually insufficient for the load. For example, an MFC usually produces a few hundred millivolts, while a hydrophone requires 3.3 V to operate. The voltage can be increased in the laboratory by stacking several MFCs in series like batteries, but this cannot be done in an open water system such as in the sea. This is explained with Fig. 1, which shows that two MFCs are deployed in a water aquifer and are connected in series. Unlike series-connected cells in a battery pack where all the cells are separated, the series-connected MFCs will be placed in a common water body. As a result, the overall voltage of the series-connected MFCs is the voltage between the two electrodes on the extreme ends of the series, which will be the voltage of a single MFC.

The current of an MFC is usually insufficient for the load too. For example, an MFC usually supplies less than 2-mA current, while the hydrophone requires around 29 mA. In addition, it is impractical to increase the current capacity of an MFC by increasing the surface area of the anode or cathode. This is

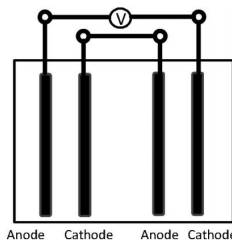
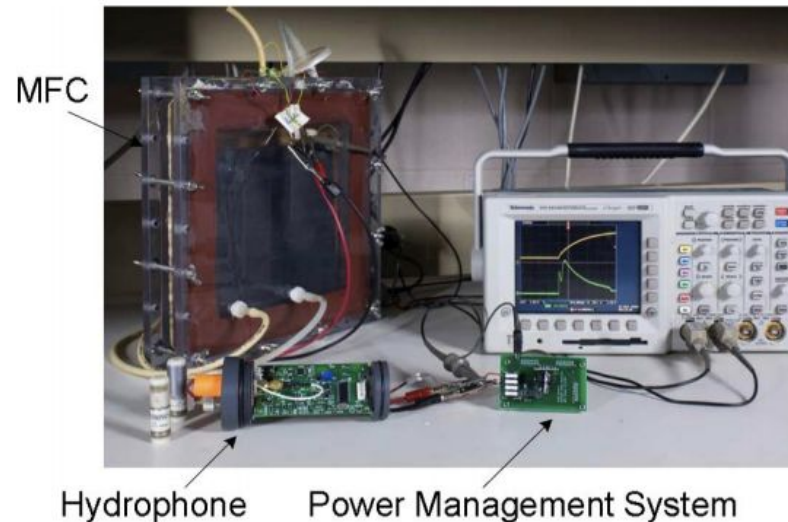


Fig. 1. Overall voltage of series-connected MFCs in an open water system.



[Link. Meehan, et al.](#)

Waste to real energy: the first MFC powered mobile phone

Ioannis A. Ieropoulos,^{*ab} Pablo Ledezma,^a Andrew Stinchcombe,^a
George Papaharalabos,^a Chris Melhuish^a and John Greenman^b

Cite this: *Phys. Chem. Chem. Phys.*, 2013, 15, 15312

Received 18th June 2013,
Accepted 10th July 2013

DOI: 10.1039/c3cp52889h

www.rsc.org/pccp

This communication reports for the first time the charging of a commercially available mobile phone, using Microbial Fuel Cells (MFCs) fed with real neat urine. The membrane-less MFCs were made out of ceramic material and employed plain carbon based electrodes.

Introduction

Microbial fuel cells are energy transducers that convert organic biomass directly into electricity through the metabolism of constituent microorganisms.¹ Electricity is generated as a by-product of anaerobic respiration, when the anode electrode found inside the negative half-cell is employed by the microbes as the end terminal electron acceptor.²

Over the last three decades, the technology has seen significant developments with a phenomenal improvement in performance, as reflected by the increasing number of scientific publications. Commercially, MFCs are yet to find their place in the market, despite the large number of patents filed by the scientific community. Reasons for the technology hold-up include bottlenecks in scale-up, low – compared to established technologies – power performance, expensive core parts and materials, and market acceptance. Although the latter is more related to each research group's exploitation strategy, the former scientific and technical challenges require deeper and more rigorous investigation.

Recently, it has been shown that small-scale MFCs are more energy dense than larger units,³ and that stacking of multiple small-scale MFCs is a viable approach to scale-up.⁴ Furthermore, it has also been reported that urine can serve as an excellent fuel for direct electricity generation. With the added

production of hydrogen from urine.⁷ Struvite, which consists of magnesium, ammonium, and phosphate, and precipitates naturally from urine, has also been reported as a promising avenue for useful phosphate recovery.⁸ All the aforementioned elements show great promise for material recycling from waste, and the MFC technology has been the ideal platform for validating these ground-breaking principles.

The aims of the current study are (i) to investigate whether ceramic MFCs can be assembled into stacks for practical implementation, at as low a cost as possible whilst being conducive to mass manufacture and (ii) to demonstrate the efficient utilisation of urine in various stacks and prove its superiority over other organic feedstocks. In the context of energy availability for emergency communications at remote locations in countries of the Developing World, the third aim of this study was (iii) to demonstrate the charging and powering of a commercially available mobile phone, with the energy produced by the MFC stacks when fed with real neat urine.

Materials and methods

Ceramic MFCs

Ceramic cylinders were purchased from International Biological Laboratories (Haryana, India) and were made from porous ceramic (earthenware) material. The average dimensions were 10.2 cm (length), 3.5 cm (outer diameter), 2.5 cm (inner diameter), with an approximate volume of 49 mL. The closed-ends of the cylinders were removed so that the 3D printed lids (air-gap adaptors – see below) could be introduced at both ends (see Fig. 1). The anode electrodes were made from 337.5 cm² of 20 g cm⁻² carbon fibre veil



Potential Uses

Wastewater treatment:

[TEDxYouth Talk: Link](#)

- High energy demand
- Wastewater = food for microbes
- Microbes would help produce
 - Energy for process
 - Clean water



Gastrobots:

- “Fed” sugar cubes
- Precursor to autonomous robots

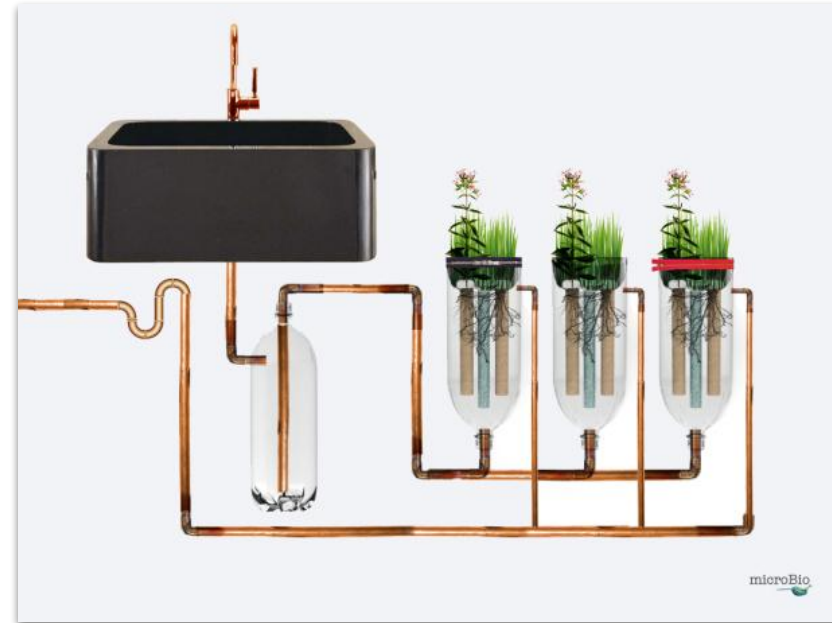
Pacemakers/glucose Sensors

- Glucose in blood feeds microbes continuously

Current Sustainability Iterations

Project Microbio

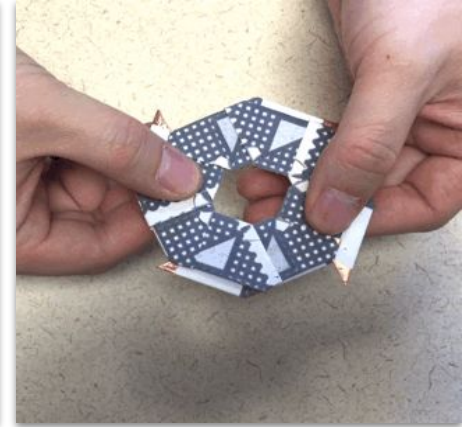
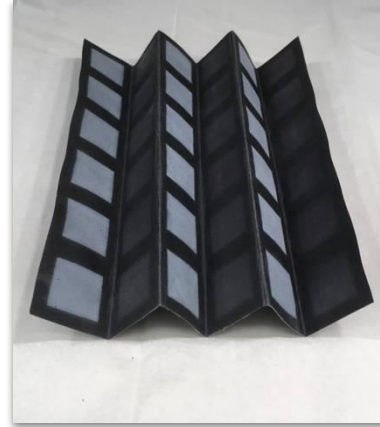
- Runs on Wastewater and energy from aquatic plants
 - Sweetgrass, cordgrass, rice, etc.
- Needs membrane to separate cathode/anode
- Is both a filtration unit (bottle 1)
 - Acts as a grease trap
- Combined Fuel Cell (bottle 2-4)
 - Microbes eat:
 - Organic material in water
 - Carbohydrates produced by plant roots



SUNY Binghamton Research

Seokheun "Sean" Choi, Yang Gao, et. al.

- Can power point-of-contact diagnostics
- Potential to power small electronics for days
 - Biosensors
- Power is based on folding and configuration
 - 6x3 configuration 31.51 microwatts
 - 6x6 configuration 44.85 microwatts
 - Requires manual assembly



Wearable Technology

Textile-based microbial batteries

- SUNY researchers
- Same power as paper
- Potentially powered by sweat/microbiome



Unintended Consequences

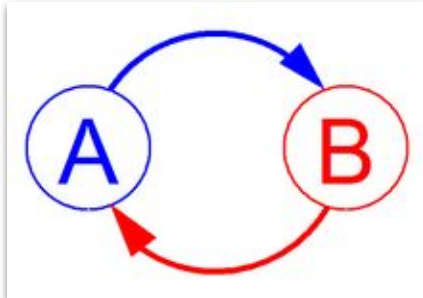
Microorganisms --> Methane Production

Yvon-Durocher, et. al. (Abstract [LINK](#))

[Full PDF Nature.com LINK](#) Free through EBSCOHost

Methane

- 20-25X warming potential of CO₂
- Emitted by Archaea in ecosystems
- Temperature dependent
- Contributes to positive feedback loop
- Burning produces CO₂ and H₂O



Science News

from research organizations

A more potent greenhouse gas than carbon dioxide, methane emissions will leap as Earth warms

Date: March 27, 2014

Source: Princeton University

Summary: New research indicates that for each degree that the Earth's temperature rises, the amount of methane entering the atmosphere from microorganisms dwelling in lake sediment and freshwater wetlands -- the primary sources of the gas -- will increase several times.

 **nature**
International journal of science

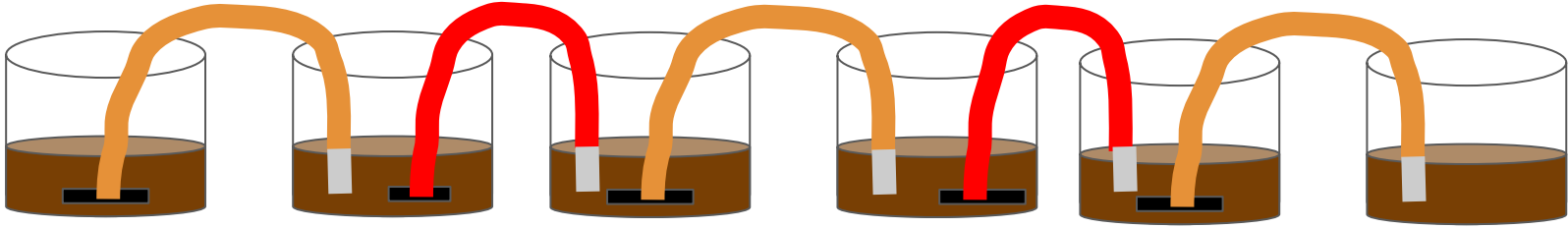
Letter | Published: 19 March 2014

Methane fluxes show consistent temperature dependence across microbial to ecosystem scales

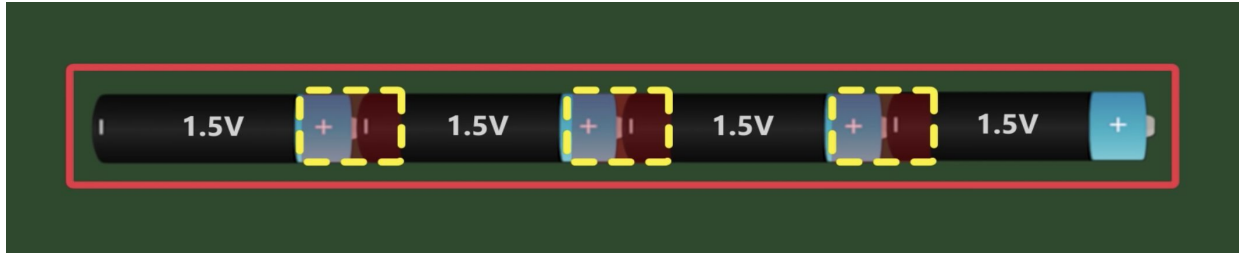
Gabriel Yvon-Durocher , Andrew P. Allen, David Bastviken, Ralf Conrad, Cristian Gudas, Annick St-Pierre, Nguyen Thanh-Duc & Paul A. del Giorgio

Nature **507**, 488–491 (27 March 2014) | [Download Citation](#) 

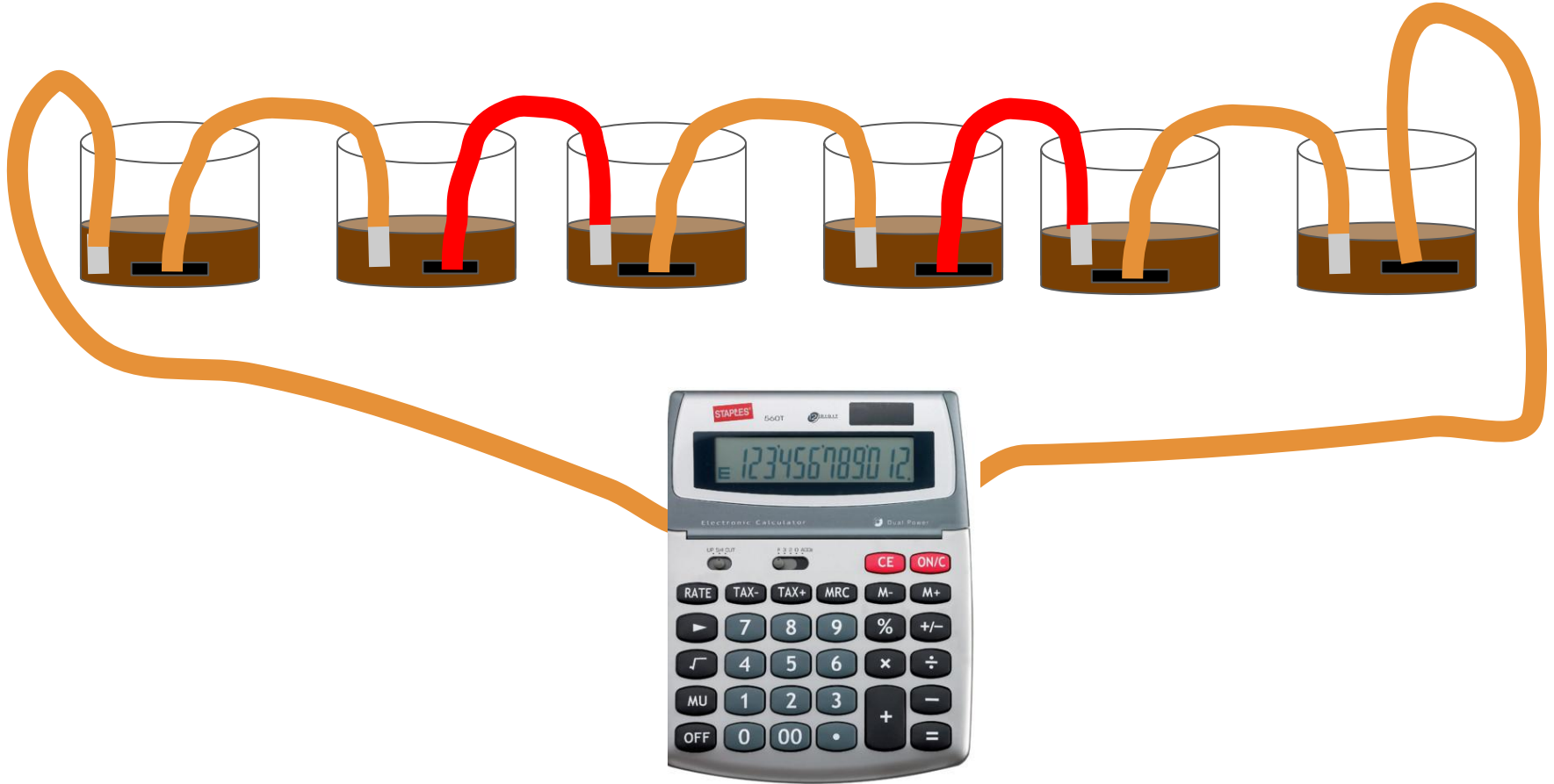
Connecting a Battery in Series



Youtube:
<https://www.youtube.com/watch?v=4GCvdcTxMN8>



Test your MFC

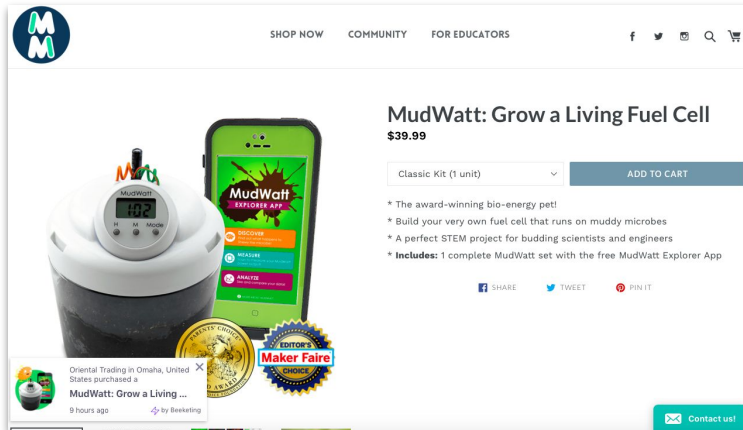


Thank you!

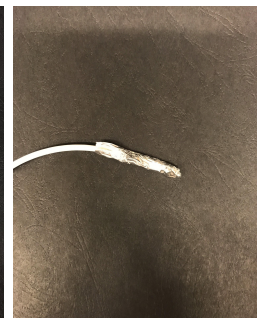
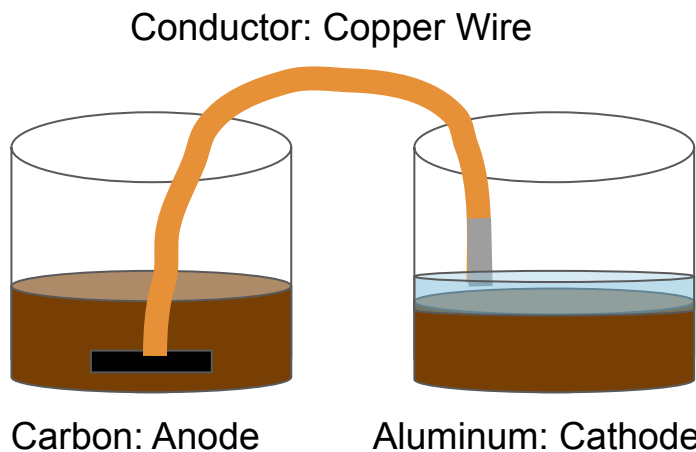
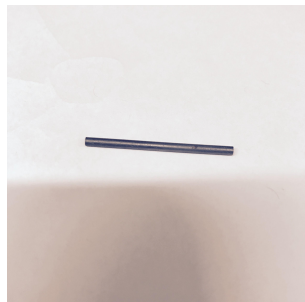
Assessment

Magical Microbes 'MudWatt'

- Powered by microbes in soil
- Produces enough energy to power:
 - LED light
 - Digital Clock
 - Thermometer
- Marketed and sold as educational tool ([LINK](#))
- App allows tracking of output and growth



Our MFC system setup:



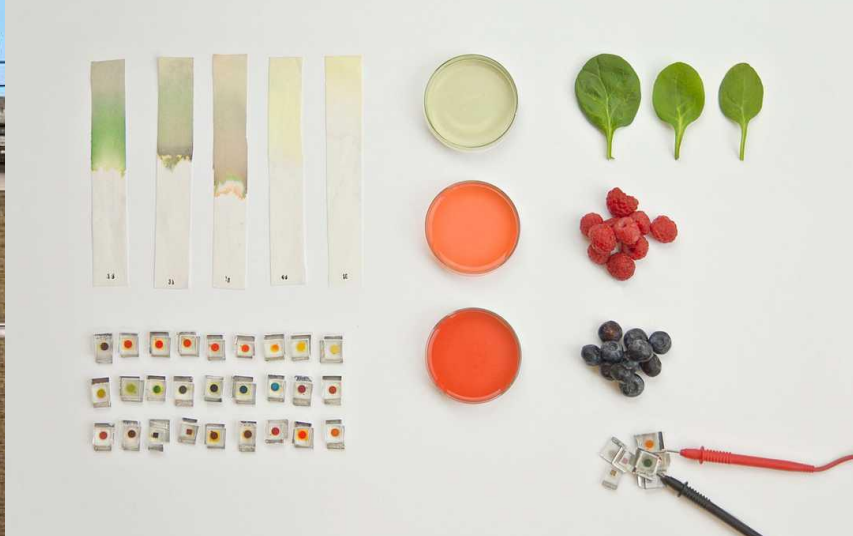
Prognosis

How Bill Gates Aims to Save \$233 Billion by Reinventing the Toilet

By [Jason Gale](#)

November 5, 2018, 9:00 PM EST

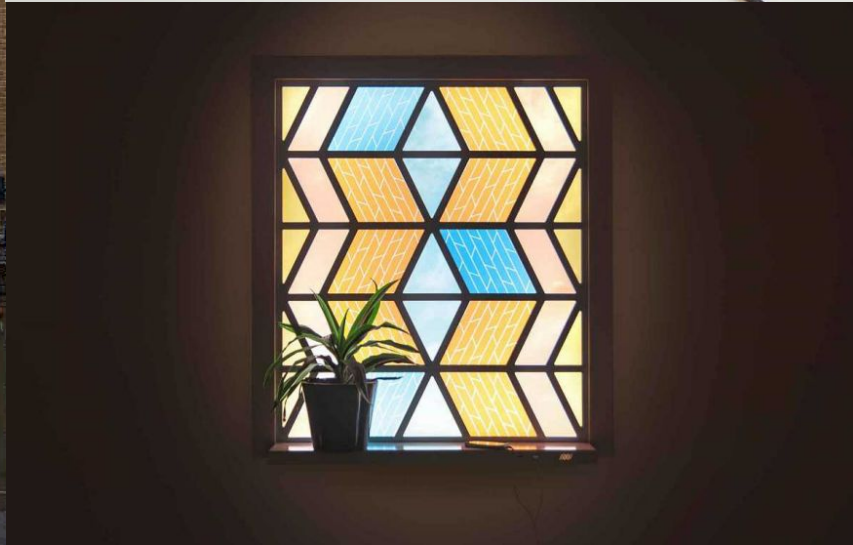




MARJAN VAN AUBEL

Video ([LINK](#))

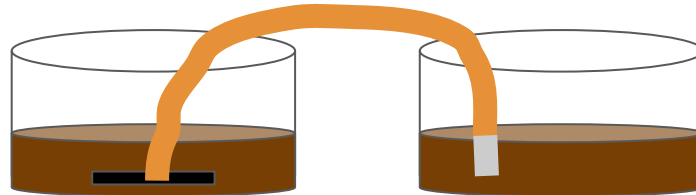
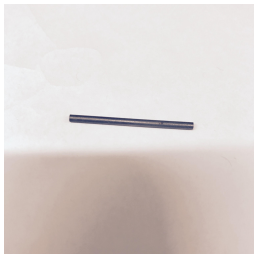
Current/Former Student led project:
Ana Remis



Create your MFC

PPE: Hot Hands, Goggles, Gloves, and Lab Coats

- 1.ADD ORGANIC MATTER: Fill both beakers with 400 ml of mud, label them beaker #1 and beaker #2
- 2.CREATE ANODE:
 - a. Wrap one end of of a 6 inch piece of copper wire around a small piece of Graphite
 - b. Wrap aluminum foil around the other end of conducting wire
- 3.CREATE ANAEROBIC CONDITIONS:
 - a. Fill both beakers with 100 to 200 ml of water
 - b. Fully submerge anode in the mud of one beaker.
 - c. Anode should be about $\frac{3}{4}$ the way down the beaker, with no contact with the water or oxygenated surface.
- 4.CREATE CATHODE: Place cathode (aluminum side) in the top layer of the water in beaker #2
- 5.LET SYSTEM SETTLE: Allow microbial fuel cell to sit for 2 mins and then take a reading with a multimeter.
- 6.ALLOW BACTERIA TIME TO COLONIZE/ METABOLIZE ORGANIC MATTER
- 7.TAKE VOLTAGE READINGS OVER TIME
- 8.GRAPH OUTPUT



But has it worked before?

Yes, and in this lab!



ASSESSMENT

Please See your Email or Canvas

Complete Now Please

<https://forms.gle/UUYFSVjoJNUcrKqJ9>

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Mondays, Feb. 3rd & 10th
(5-6:30 pm)



Sustainable Plastics: Biopolymers

A two-session exploration of the science of polymers, design strategies to detect oceanic plastic & the interdisciplinary approach used to address the challenge of creating sustainable biopolymers.



Thursdays, Feb. 20th & 27th
(4-5:30pm)

Fridays, Feb. 21st & 28th
(10-11:30am)

Monday, March 9th
(12:10-2:50pm)



Sustainable Dyes: Microbial Pigments

A two-session painting & printing experience exploring environmental control of microbial diversity and color.

Thursdays, Feb. 13th & 20th
(12:10-1:40 pm)



Sustainable Cities: Sewage & Water

A two-session experimental analysis of climate change, urban design & health.

Fri. Mar.27 & April 3rd (10-11:30 am)
Thur. April 9th & 16th (4-5:30pm)
Fri. April 10th & 17th (10-11:30 am)



FREE

Please
RSVP

<http://tinyurl.com/z4n45ja>

or email

tnsscienceclubs@newschool.edu

LOCATION

The University Center
63 Fifth Avenue
Room 618

Sponsored by The Department of Natural Sciences & Mathematics,
The Provost Office, and Eugene Lang College for Liberal Arts at The New School.

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COURSES

Spring

LSCI 2040 Genes Environment and Behavior

LSCI 3055 Microbiome of Urban Spaces (prereq:Microbial Ecologies

LSCI 2XXX Science and Politics of Infectious Diseases

PSDS 6720 Biodesign Challenge Studio (undergrads by proposal-spring)

ULEC 2XXX Waste

LSCI 2700 Energy and Sustainability (spring 2021)

Fall

LSCI 2500 Chemistry of the Environment

LSCI 2320 Microbial Ecologies

PSDS 2640 Honeybee Colonies

ULEC 2764 Plastics!

LSCI 2034 Imagine Science Film Festival Course (fall)

Thank you!

END OF PRESENTATION

Conductor

- Conductor: easily gives up or allows electrons to pass along its atoms
 - Copper is often used as a conductor for electricity
 - Copper: Made up of Copper atoms
 - Copper atoms easily lose the electron on their outermost shell
 - The electrons would normally be randomly moving between Copper atoms
 - When a potential charge gradient is established, electrons can move in a singular direction creating a current of electricity

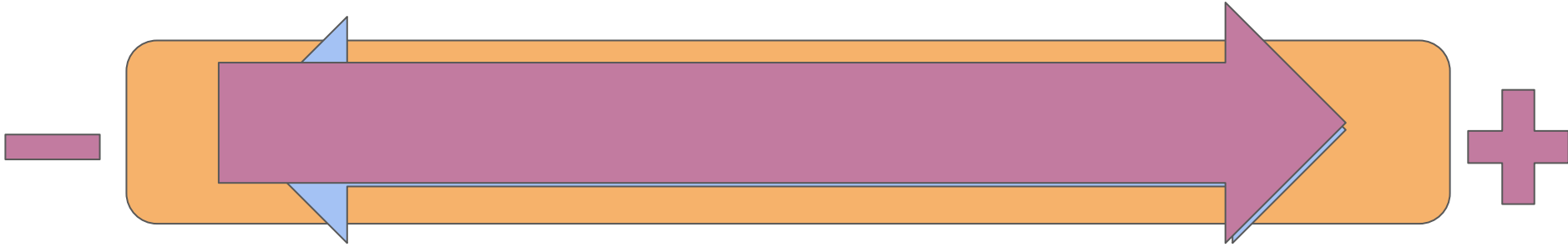


Cathode in a series

- When creating a series (several MFC combined) the cathode may change
- Aluminum will establish an energy gradient with copper
 - Aluminum can act as the cathode
- To create our cathode in a series, we will wrap our copper wire in aluminum on one end



Conductor



- Copper wire: made up of copper atoms
- Without potential energy gradient, electrons will move randomly between copper atoms
- When a gradient is established, electrons will move directionally

Electron Transport Chain

- Cellular Protein Complexes

- Complexes are capable of performing redox reactions
- Transfer electrons during creation of biochemical energy
- INcorporate DNA/Living organisms/protein evolution for transfer of catalysts for transferring electrons pilli

- RedOx Reactions:

- **Red**uction: Gains Electrons
 - In ETC, Oxygen or other organic molecule will accept electrons
- **O**xidation: Loses Electrons
 - In ETC, a molecule (NADH) or organic compound is oxidized

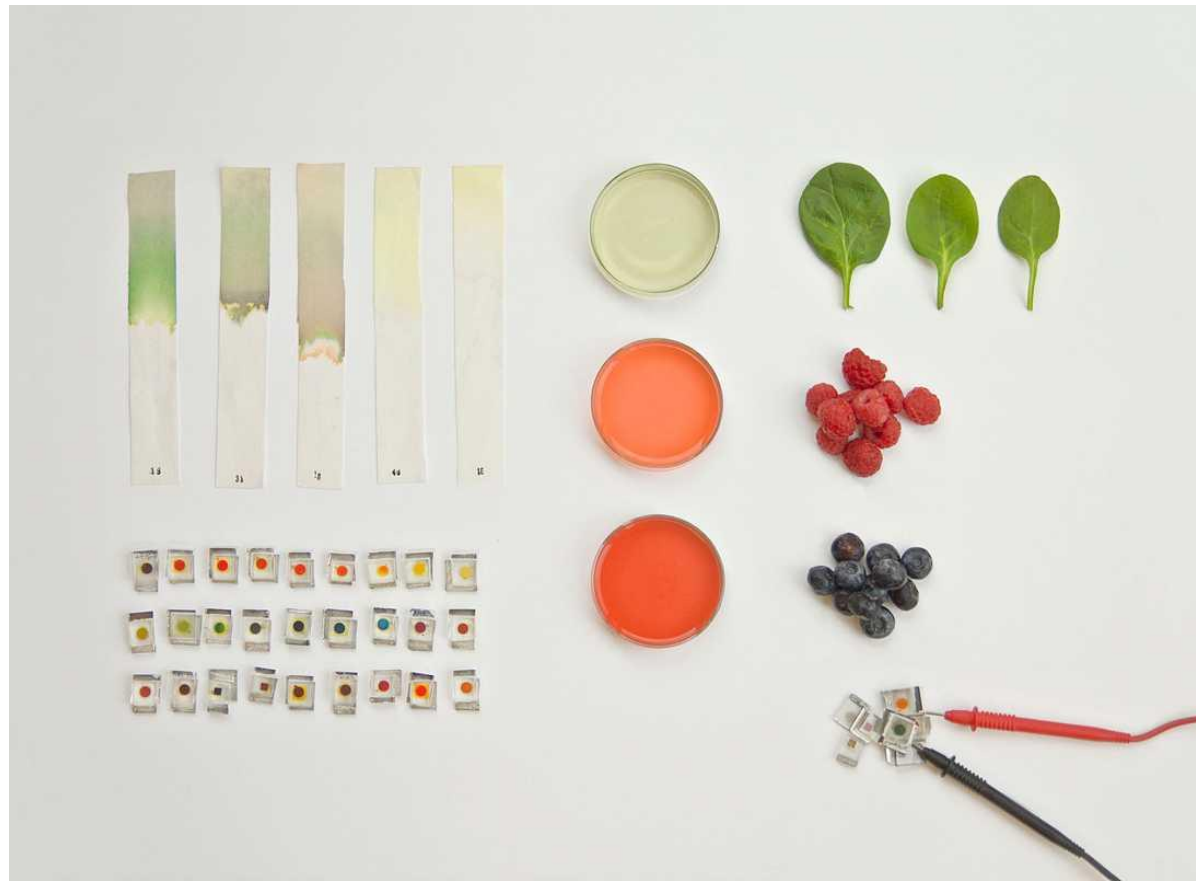
Anode

- Anode:
 - Electrons are intercepted after *anaerobic*/aerobic respiration
 - In our system the anode is Carbon (graphite)
 - Bacteria are growing on the anode



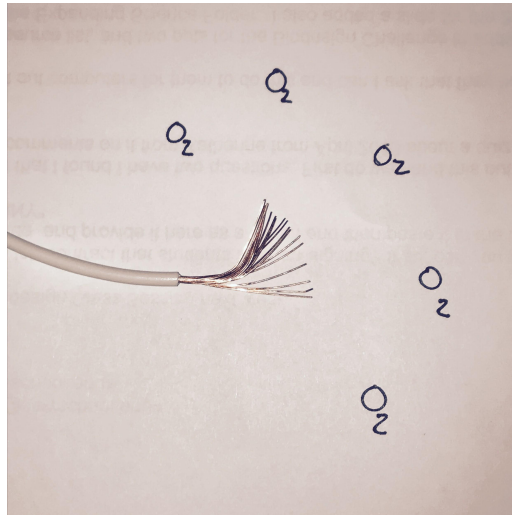
More work by Marjan Van Aubel

<https://vimeo.com/142252856>



Cathode

- Cathode:
 - Copper conductor is exposed to Oxygen (air), which is the final electron acceptor

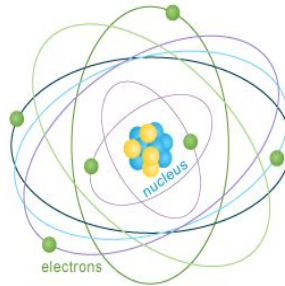


Contents

- Introduction to Microbial Fuel Cells
 - What is a Fuel Cell/MFC?
 - How does it generate electricity?
 - Where and how are they being developed?
 - What is their potential?
- Understanding electricity
 - Electrons
 - Creating electric current
 - Conductors
- Electrons in the MFC
 - How are electrons being produced in the MFC
 - Components of the MFC

What is electricity?

To understand electricity you have to first understand the atom and its parts.



What is electricity?

- Electric current: movement of electrons from atom to atom across potential energy gradient
 - moving from high energy potential to low energy potential “downhill”
 - as electrons move they create electric force with each new atom
 - A conductor allows for electrons to be placed in a circuit
 - the directed movement of this electric force is electric current

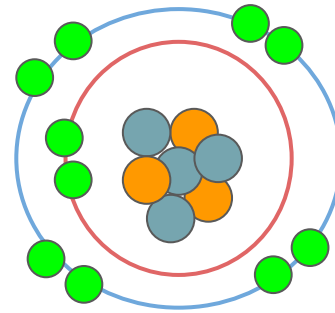
What is electricity?

Nucleus:

- Protons (positively charged)
- Neutrons (no net charge)

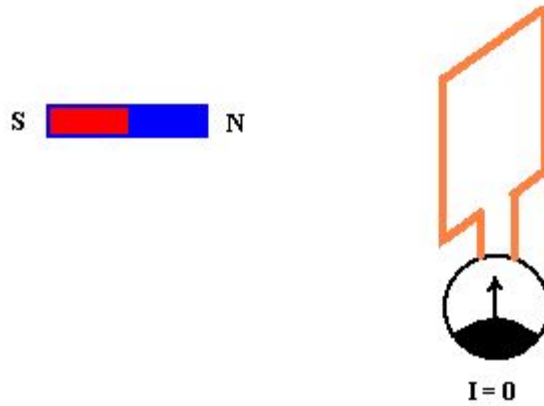
“Cloud”

- Electrons (negatively charged)
 - Orbit the nucleus on different shells
- Can move from atom to atom



ATOM

Electromagnetic induction



How do we get power/heat/electricity?

Fuels (oil, gas) are to create mechanical energy

This mechanical energy is often used to power a process called
ELECTROMAGNETIC INDUCTION

Electrical current is created through magnetic flux

This process can also be powered by sustainable sources:

- Dams
- Windmills



Electricity and Electric Current

- A conductor can be directed in a circuit to harness the flow of electrons.
 - A circuit runs from high energy potential to low energy potential
 - The flow of electrons from high energy potential to low energy potential produces energy which can be used to do work
- When connected to a filament, the electric current produces heat and light.



What do we know so far?

- Electric current is produced by the movement of electrons
- We can harness and induce directional movement of electrons to create useable energy
- In biology there are processes which are accompanied by the movement of electrons

- Electricity: the interaction of electrons and protons
 - Protons and electrons are attracted to each other due to opposite charges
 - Atoms will more easily give up unpaired, outer shell electrons which have less attractive force acting on them
 - the directed movement of this electric force is electric current

Studies on Microbial life in soil and farming

Organic Farming/Fertilizers

Natural Dye-Sensitized Solar Cells (NDSC)

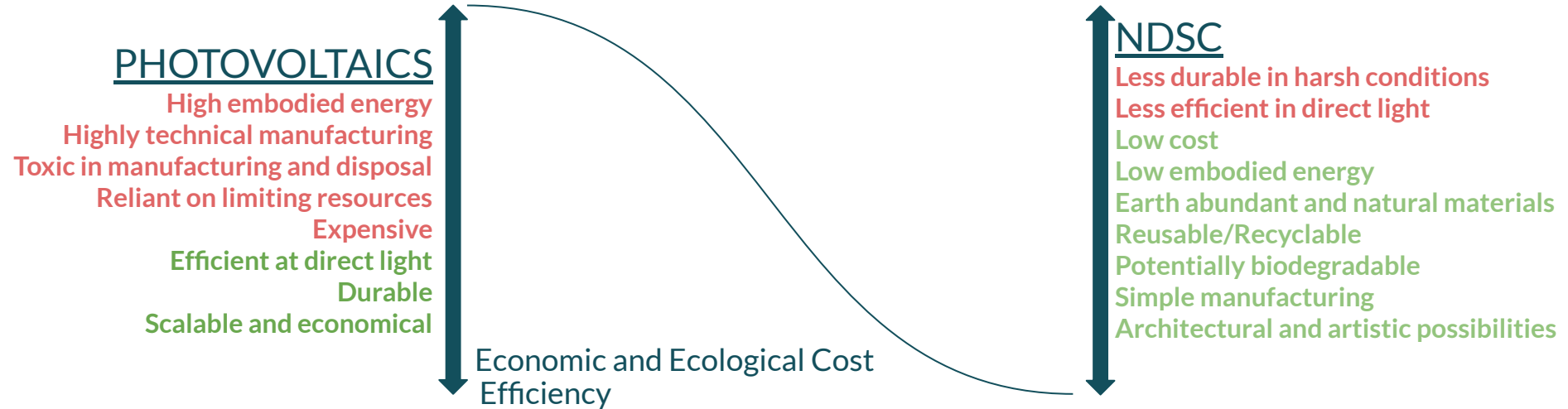
Student Solar Cell Team:

Sasha Hodson, Environmental Studies

Jozef Soloff, Environmental Studies Graduate

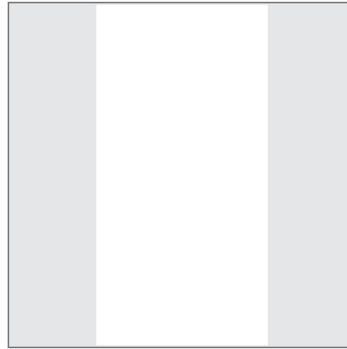
Ana Remis, BAFA Environmental Studies & Design Technology

Why have alternative solar technology?

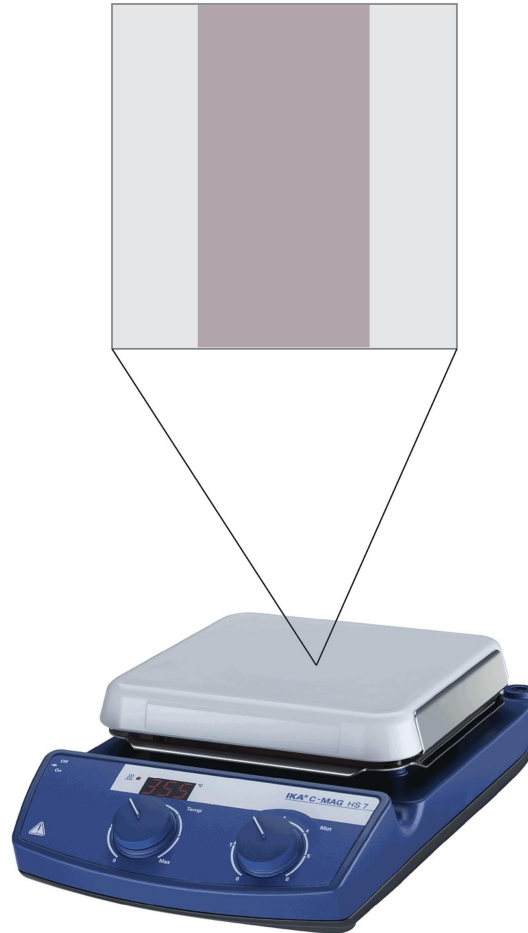




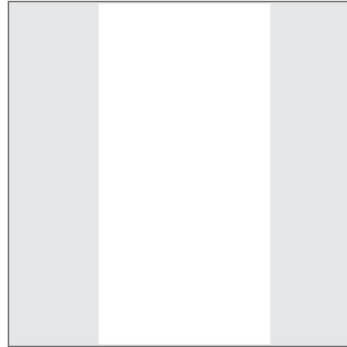
Begin with a
conductive
glass slide



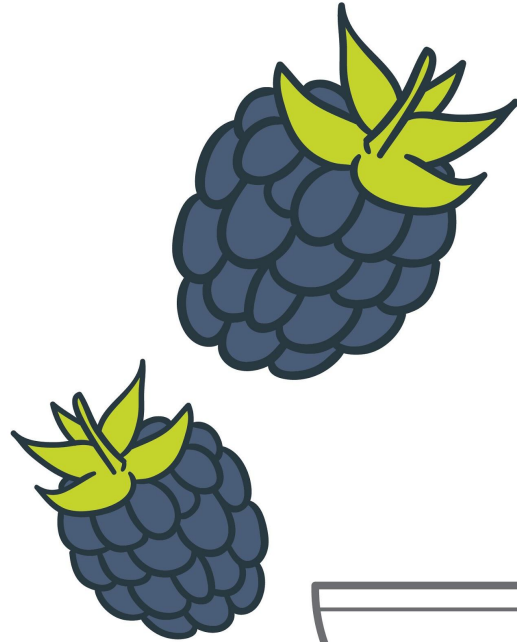
Apply titanium
dioxide paste



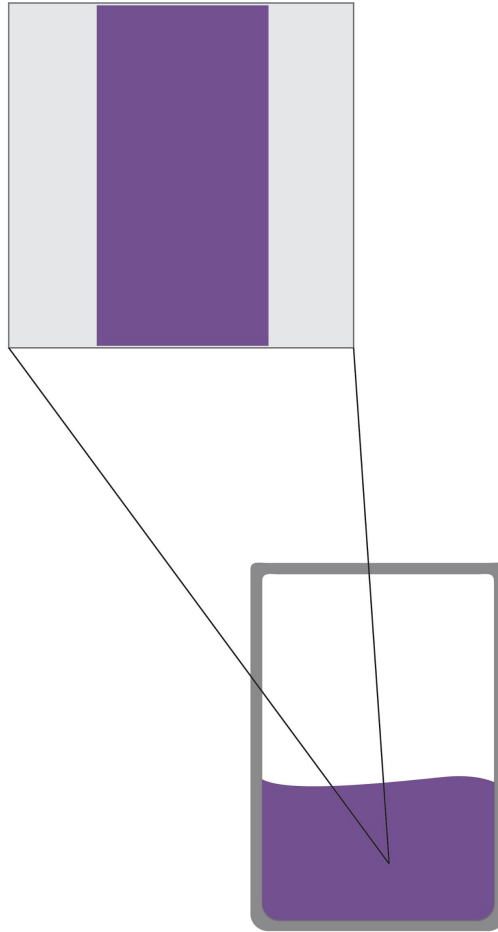
Cook at
350-400
degrees F for
30 minutes



The result, a
conductive
glass slide with
baked titanium
dioxide paste

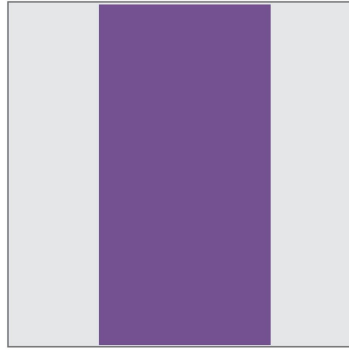


Mash berries
and add water



Dip slides in
berry mash for
5 minutes

Rinse slides
and let dry



Distilled
Water

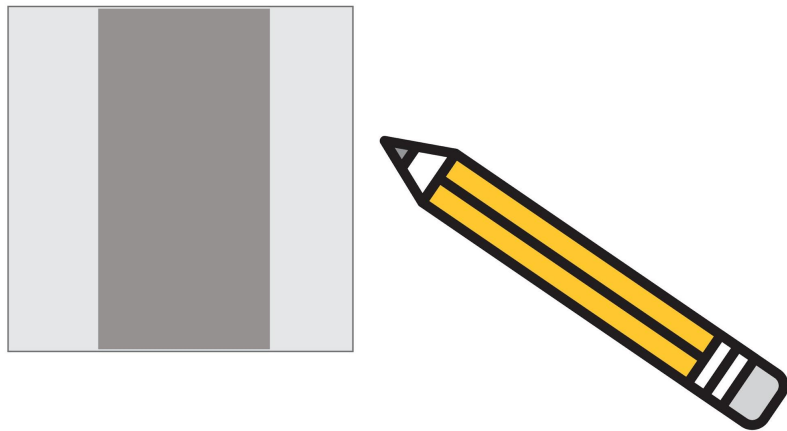


Ethanol

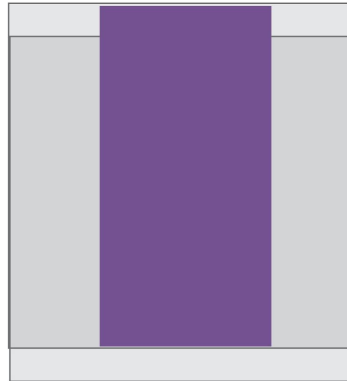
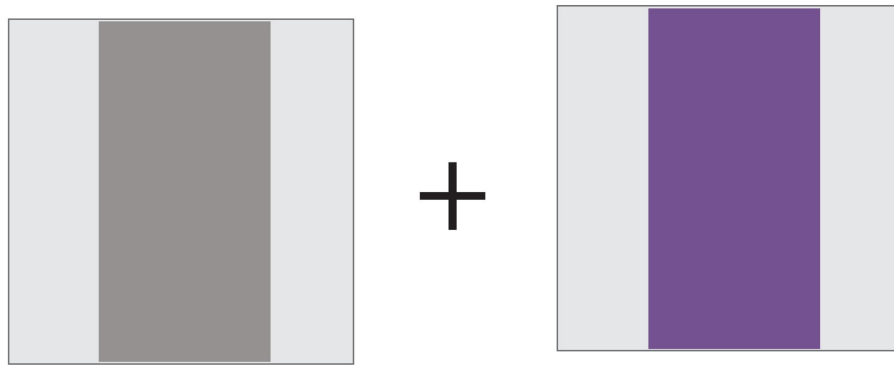


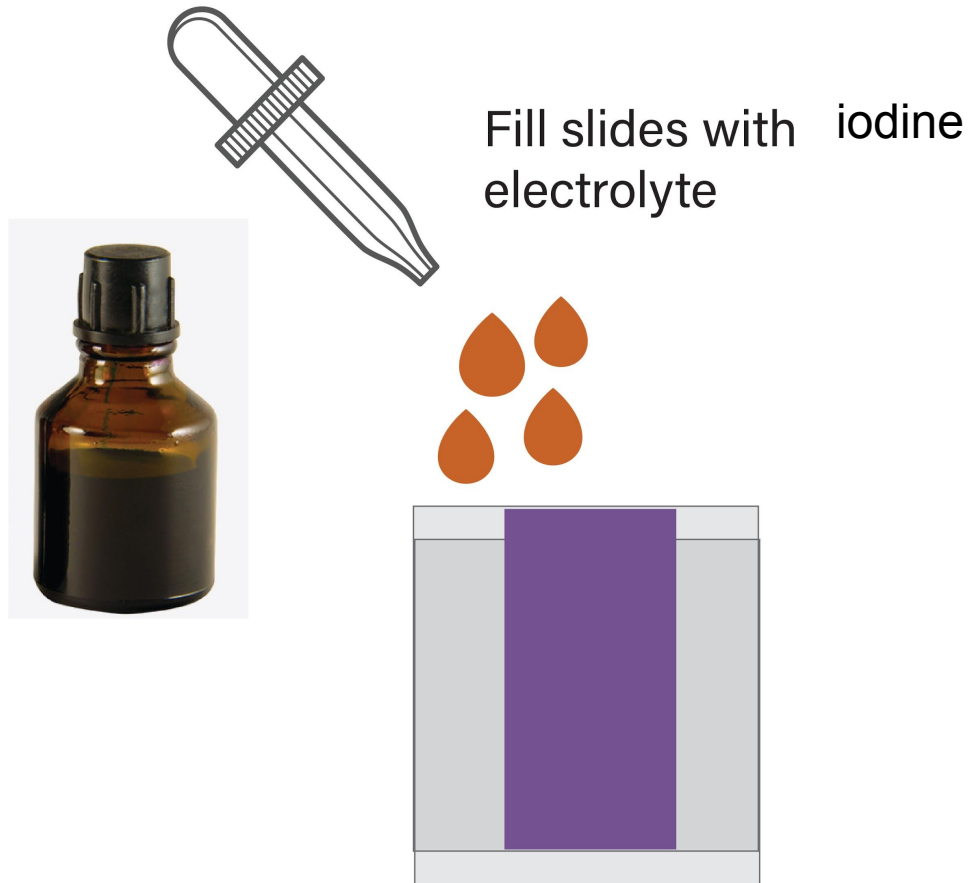


Prepare another
conductive glass
slide



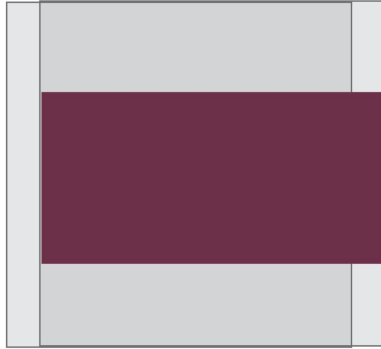
To make counter electrode, coat surface of another conductive glass slide with graphite







The cell is ready
to be tested with
a multimeter



Sources for Natural Dye



Betalain



Anthocyanin

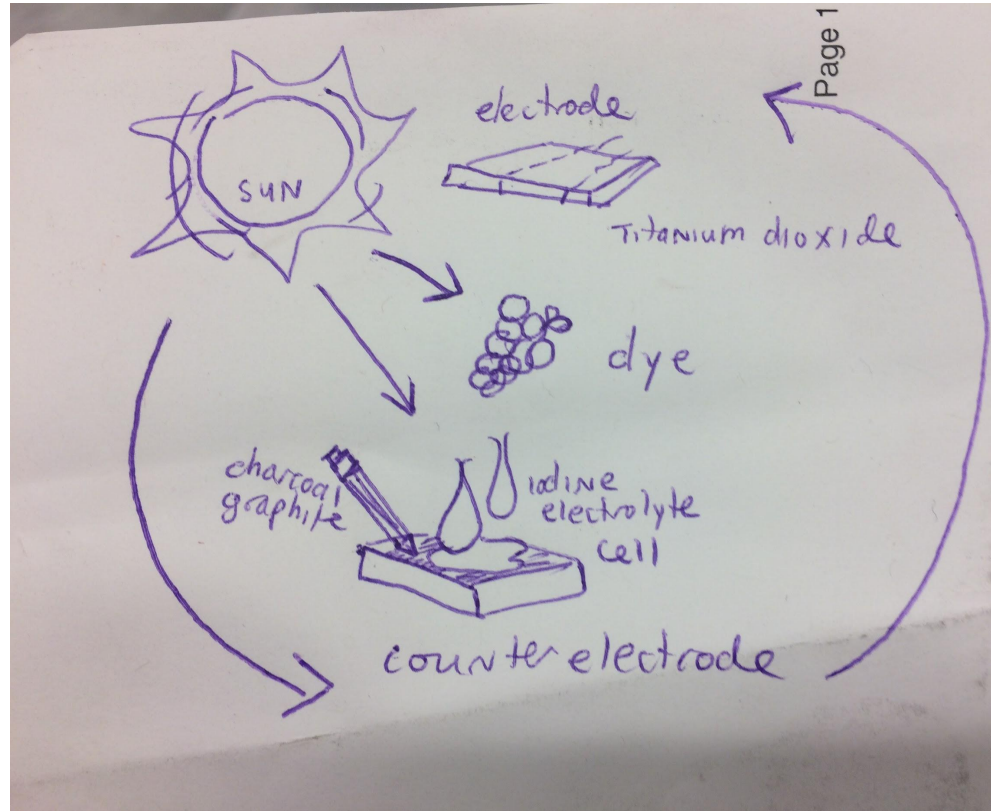


Chlorophyll

Carotenoid



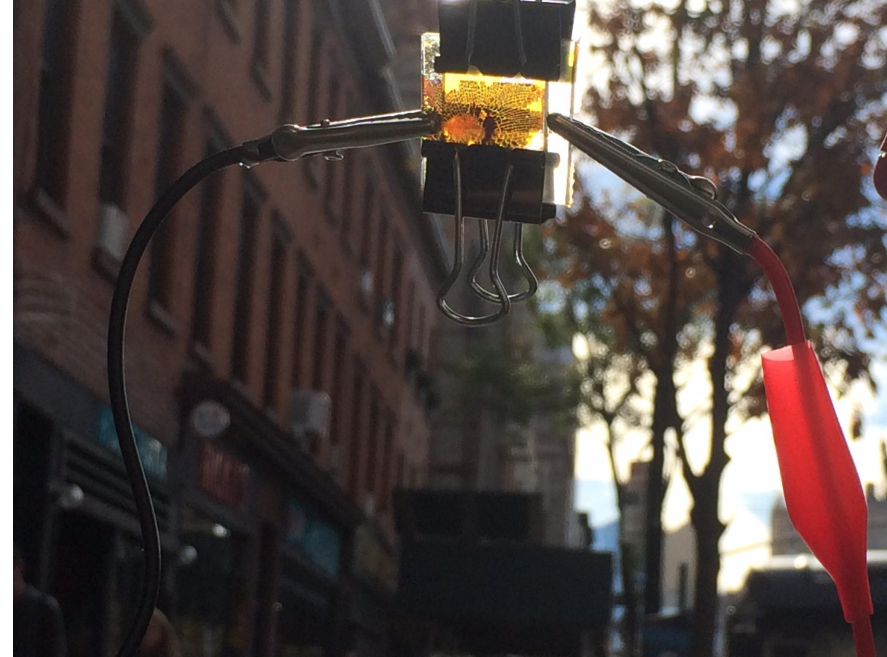
How does the cell work?



Our Work



Our Work





The Greenhouse Effect

[Video Link](#)

Stile Education. "The Greenhouse Effect, Explained."

- Greenhouse Effect
 - Naturally occurring event
 - Greenhouse Gases (CO₂, CH₄, N₂O, water vapor) in atmosphere
 - Oceans/Land absorb energy from sun and re-emit as heat
 - Appropriate greenhouse gas levels allow heat to eventually escape into space
 - Keeps Earth a habitable temperature
- Greenhouse effect *in relation to climate change*
 - Increase of greenhouse gases in atmosphere due to human activity
 - Transportation, industry, agriculture
 - Greenhouse gas molecules collide with and absorb heat (energy) radiating back into space
 - Absorbed heat is then emitted from greenhouse gas in a random direction
 - Can collide with other greenhouse gases in atmosphere
 - Can be absorbed by land and oceans
 - Keeps heat trapped close to the Earth's surface
 - Average temperature of Earth increases

Ocean Temperatures

- **Excess heat absorbed by Oceans**

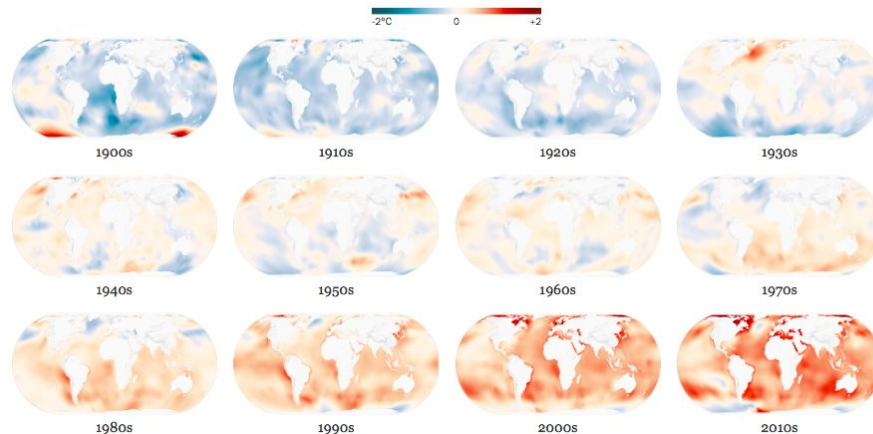
- Consistently rising temp. for at least three decades
- Temp. trends consistent with human-caused warming
- Oceans absorb over 90% of excess heat since 1955
 - Large capacity to store heat
 - Expansion/Sea level rises
- Warmer ocean temp. increases destructive potential of extreme weather, like cyclones and hurricanes.

New York Times Article:

Wallace, Tim. "Oceans Are Absorbing Almost All of the Globe's Excess Heat." *The New York Times*, The New York Times, 12 Sept. 2016,

www.nytimes.com/interactive/2016/09/12/science/earth/ocean-warming-climate-change.html

Where the Oceans Have Been Colder and Hotter Than Average



Average temperatures from each decade compared with the 20th-century average.

In fact, the effects of warmer waters are already widespread.



Josh Haner/The New York Times

Ice Melt and Sea Level Rise

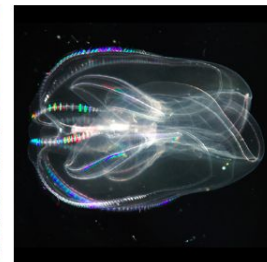
The Greenland ice sheet is studded with meltwater streams, rivers and lakes. The rate of melt is alarming many scientists. Both ice melt and thermal expansion are causing a significant rise in global sea levels.



Agence France-Presse — Getty Images

Marine Species Are at Risk

Warmer temperatures are threatening some marine animal and plant species, like these bleached coral on the Great Barrier Reef. Scientists also predict that some birds, like the black-legged kittiwakes in Norway, may soon die off in warmer waters.



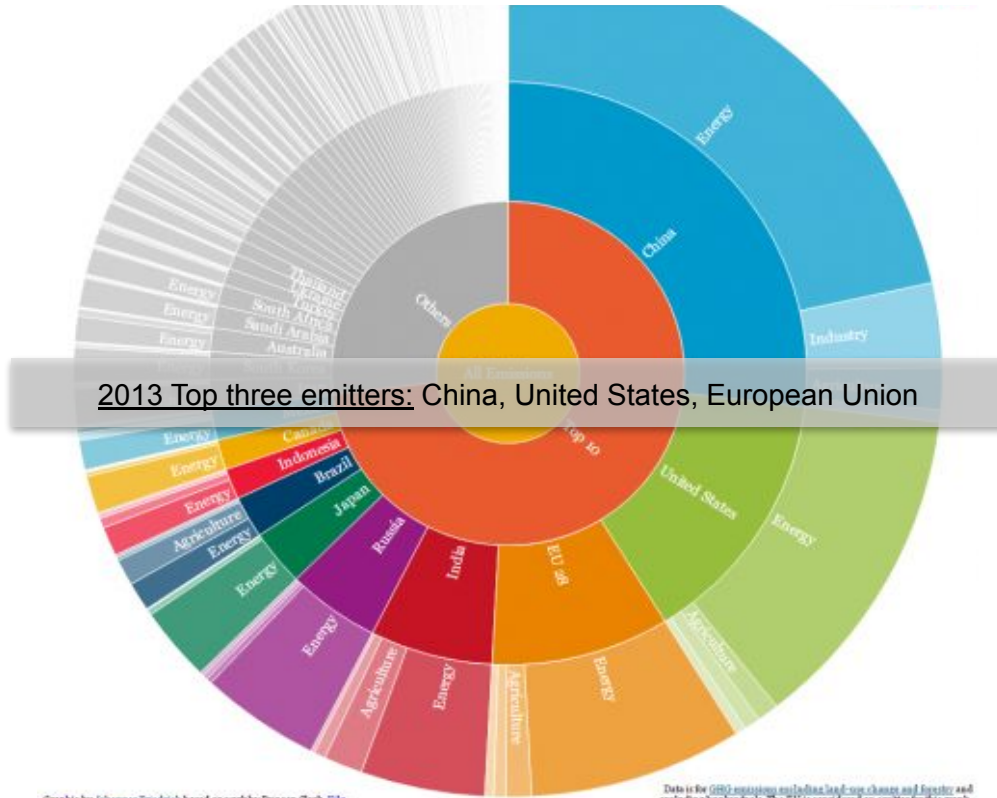
Bruno C. Velutini

Habitats Are Changing

The warmer conditions have allowed some jellyfish, like the comb jellyfish, pictured above, in Narragansett Bay, to have longer seasons. Others have expanded their territory. In some cases, United States fisheries have shifted north to cooler waters.

Emissions Data, Visualized

World Resources Institute: CAIT Interactive data visualization ([LINK](#)) Data from 2013



Graphic by [Johannes Fendrich](#) based on work by Duncan Clark, [Mike Romet](#) and [James Crotty](#). Thanks also to Jamie Cote.

Data is for GHG emissions excluding land use change and forestry and excluding 5 nuclear theft. The EU is considered an emitter for this graph. For more information, visit our [WRI blog](#).

Emissions Rank
1. China
2. U.S.
3. E.U.
4. India
5. Russia
6. Japan
7. Brasil
8. Indonesia
9. Canada
10. Mexico

Global Climate Anomalies: Climate Report 2018

- **Extreme temperatures Globally in June 2018**
 - European Heat Wave
 - Contributing to droughts, wildfires
- **Japanese Heat Wave** ([BBC article LINK](#))
 - Declared a 'natural disaster' with at least 65 deaths in one week
 - Over 22,000 people taken to hospital with heat stroke
 - Almost half were elderly
 - Kumagaya, Japan reported a temperature of 41.1C (106F)
 - Highest ever recorded in Japan.



National/Global Climate Reports



NOAA NATIONAL CENTERS FOR
ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

- June 2018 Global Climate Report ([LINK](#))
 - Provides climate data with historical context
 - Compiled by over 450 scientists from over 60 countries
 - Antarctic Ice Extent: 8th smallest on record
 - Arctic Ice Extent: 4th smallest on record (1979)
 - 6th Warmest in North America in 1910
 - 4th Warmest in Africa since 1910

Documentaries as recommended viewing:

- *Chasing Ice*, 2012 ([Trailer](#), [Dailymotion Full Link](#))
- *Chasing Coral*, 2017 ([Trailer](#), [Dailymotion Full Link](#))

Selected Significant Climate Anomalies and Events June 2018

GLOBAL AVERAGE TEMPERATURE
June 2018 average global land and ocean temperature was the fifth highest for June since records began in 1880.

ARCTIC SEA ICE EXTENT
June 2018 sea ice extent was 9.0 percent below the 1981–2010 average—the fourth smallest June sea ice extent since satellite records began in 1979.

ASIA
Record warm temperatures were observed across much of central Russia. Overall, Asia had its seventh highest June temperature on record.

NORTH AMERICA
June 2018 ranked as the sixth warmest June since continental records began in 1910. The contiguous U.S. had its third highest June temperature since national records began in 1895.

HURRICANE BUD
(June 9–15, 2018)
Maximum winds—215 km/h.
The second major hurricane in the Eastern North Pacific Hurricane basin in 2018. Bud brought heavy rain and floods to northern Mexico and parts of the southwestern contiguous U.S.

EUROPE
Europe had its highest June temperature since 2003. Several European countries had a June temperature that ranked among the six warmest Junes on record.

AFRICA
Africa had its fourth highest June temperature since 1910.

OMAN
Oman recorded its highest minimum temperature on June 26 when temperatures only dropped to 42.6°C (108.7°F) in Qurayt.

SOUTH AMERICA
Warmer-than-average temperatures were present in the northern half of South America, while southern South America had near-to-cooler-than-average conditions during June 2018. Averaged as a whole, South America had its smallest June temperature departure from average since 2008.

ANTARCTIC SEA ICE EXTENT
June 2018 sea ice extent was 3.8 percent below the 1981–2010 average—the eighth smallest June sea ice extent on record.

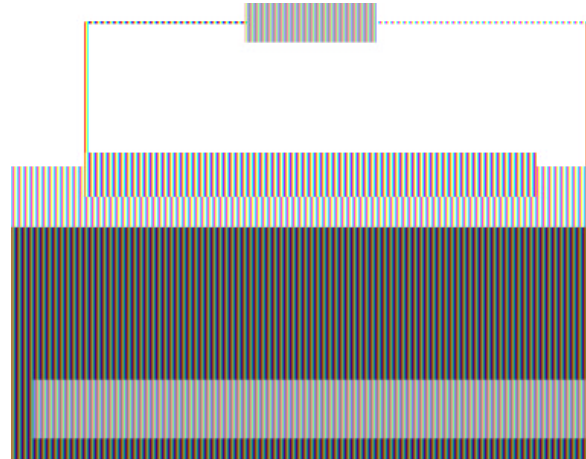
AUSTRALIA
Drier-than-average conditions were present across much of Australia. Regionally, Northern Territory had the most notable precipitation deficit at 90% below average.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit <http://www.noaa.gov/state>



MFC and the Electron Transport chain

- ETC:
 - Results in the movement of free electrons from oxidized molecules
- How can we use this?
 - We intercept the electrons with an anode
 - Bacteria deposit electrons onto anode
 - Copper wire carries electrons toward cathode (Oxygen)



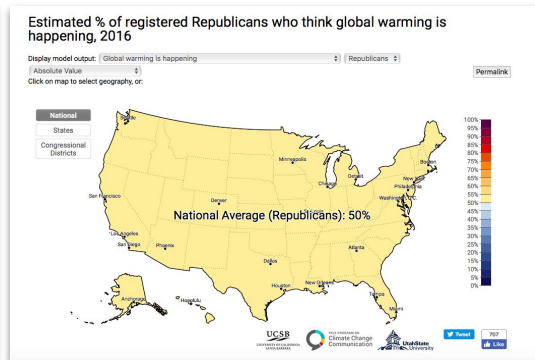
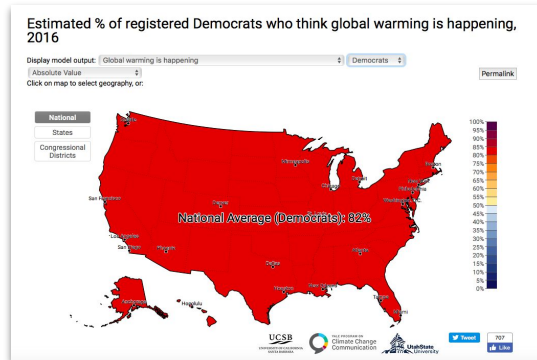
U.S. Climate Change Politics

Paris Agreement (2015):

- Seeks to limit global carbon emissions
- Goal is to limit long term warming to 1.5°C
- Ratified by 170 countries since 2015
 - Not legally binding unless ratified
- U.S. Political Controversy ([source LINK](#))

2016 Public Opinion by Party

- Yale Program on Climate Change Communication ([LINK](#))
- 82%(D)/50%(R) think global warming is happening



US withdrawal from the Paris Agreement

On 1 June 2017, the American President Donald Trump announced his intent to withdraw the United States from the Paris Agreement, stating that “as of today, the United States will cease all implementation of the non-binding Paris Accord ... this includes ending the implementation of the nationally determined contribution”.

Article 28 of the Paris Agreement permits a Party to withdraw by giving written notification to the Secretary-General of the United Nations, which notification may only be provided “after three years from the date on which [the Paris Agreement] entered into force for a Party.” Withdrawal then takes effect upon expiry of one year from the date of receipt. The Paris Agreement entered into force for the US on **4 Nov 2016**. Hence the earliest the US could give written notice is three years later, **4 Nov 2019**, and the earliest the US could leave the Paris Agreement is **4 Nov 2020**.

Until this time the US will remain a Party to the Paris Agreement and is obliged under international law not to frustrate or obstruct its implementation. Until such time as the US legally withdraws from the Paris Agreement, the US will be listed in our ratification tracker.