ME163 SENIOR DESIGN MICROBIAL FUEL CELLS

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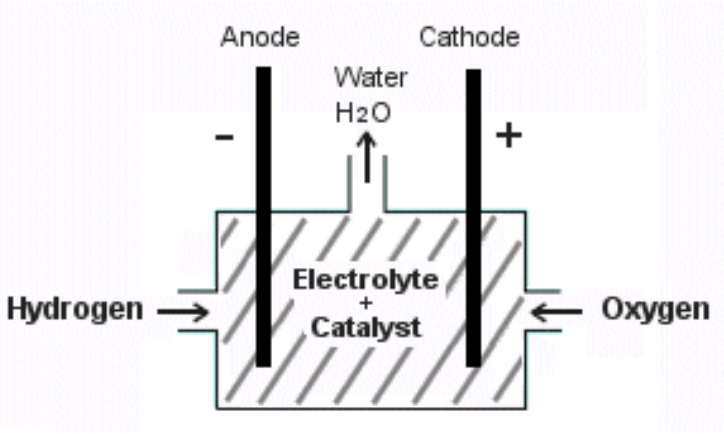
What is an MFC?

- What is a fuel cell?
  - A device that converts the chemical energy from a fuel into electricity through a chemical reaction
  - Requires a constant supply of fuel and oxidizing agent



http://hydroxene.net/images/fuel-cell.gif

What is an MFC?

Microbial fuel cells (MFCs) use biological processes to generate power by converting chemical energy in organic compounds into electrical energy

What are they good for?

- Applications:
  - Power source for low power devices
  - Sensors
  - Waste-water treatment
  - Gastrobots
- Benefits:
  - Energy can be derived from many different substrates
  - No harmful byproducts
  - Operate at neutral pH and room temp so harsh conditions are avoided

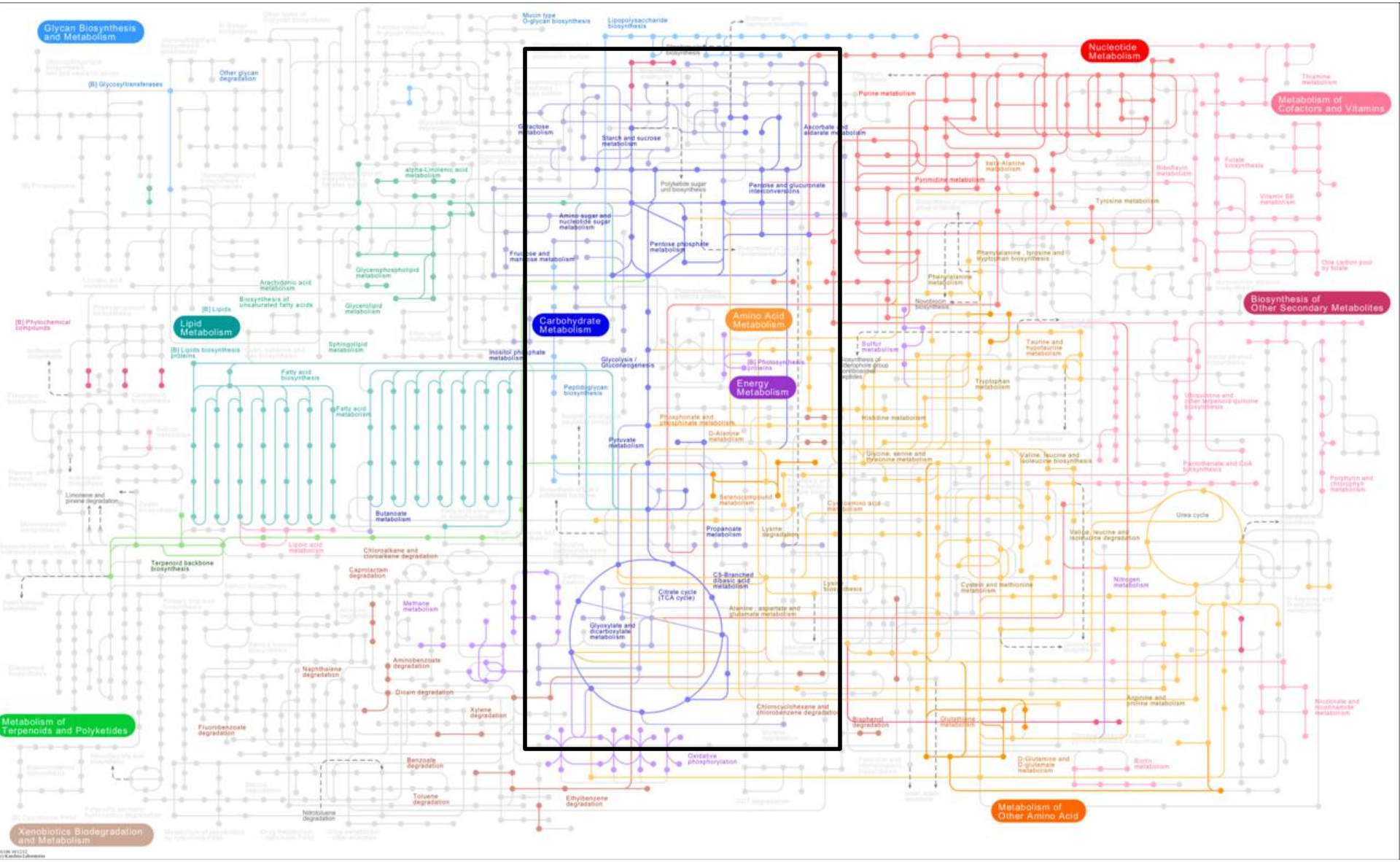
http://www.eng.usf.edu/~wilkinso/gastrobotics/index_files/image014.jpg

Microbial Metabolism

- Complex chain of reactions lead to the conversion of glucose to energy:

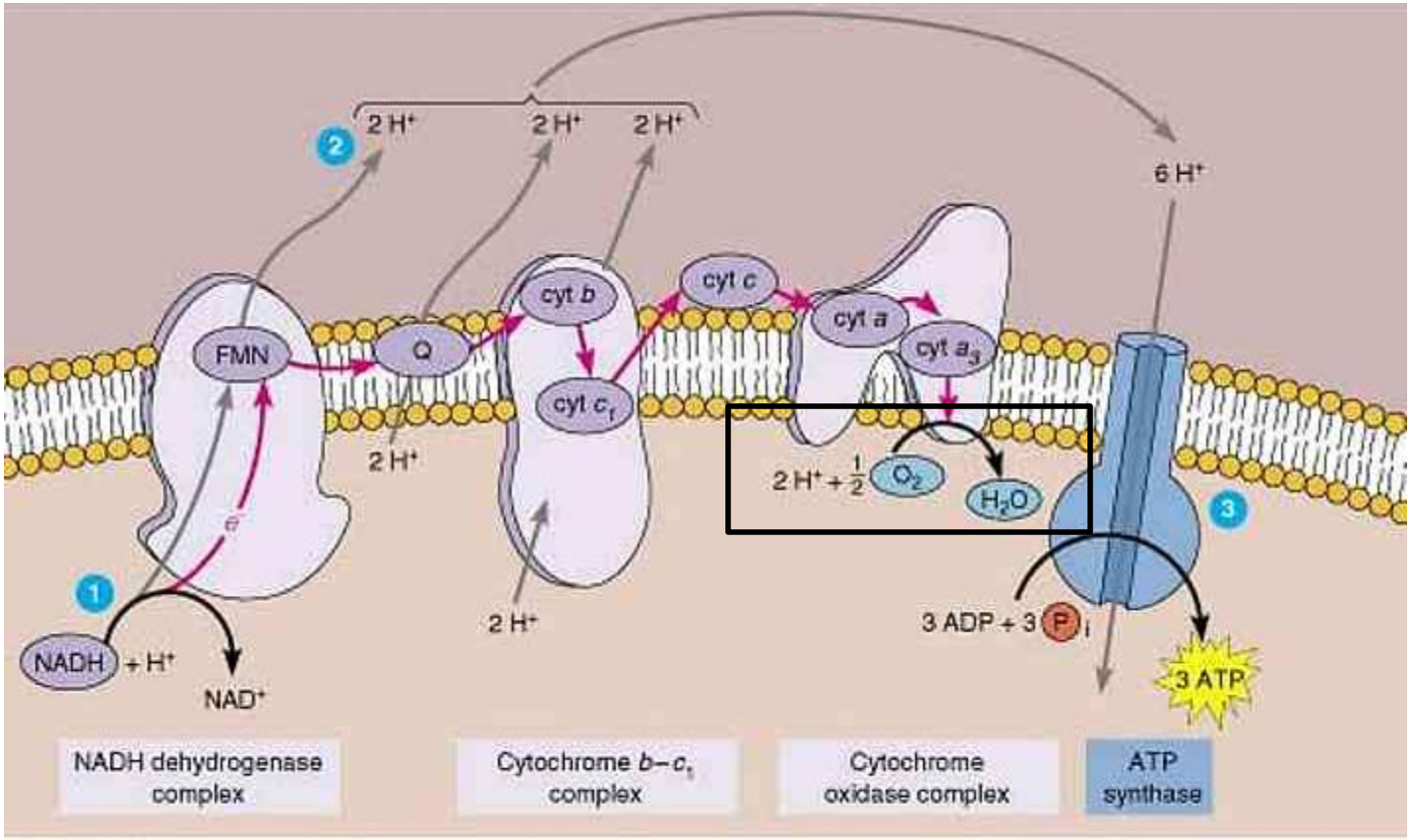
$$\mathbf{C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + energy}$$

E. Coli Metabolic Pathways



http://www.genome.jp/kegg-bin/show_pathway?org_name=ecj&mapno=01100&mapscale=0.35&show_description=hide

Electron Transport Chain

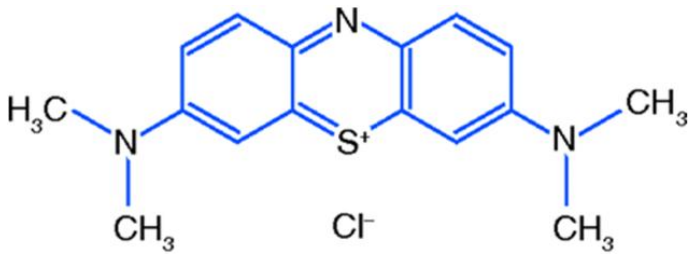


Microbial Metabolism

- Complex chain of reactions lead to the conversion of ADP to ATP

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

- Under anaerobic conditions, O_2 can be substituted for another molecule, like methylene blue



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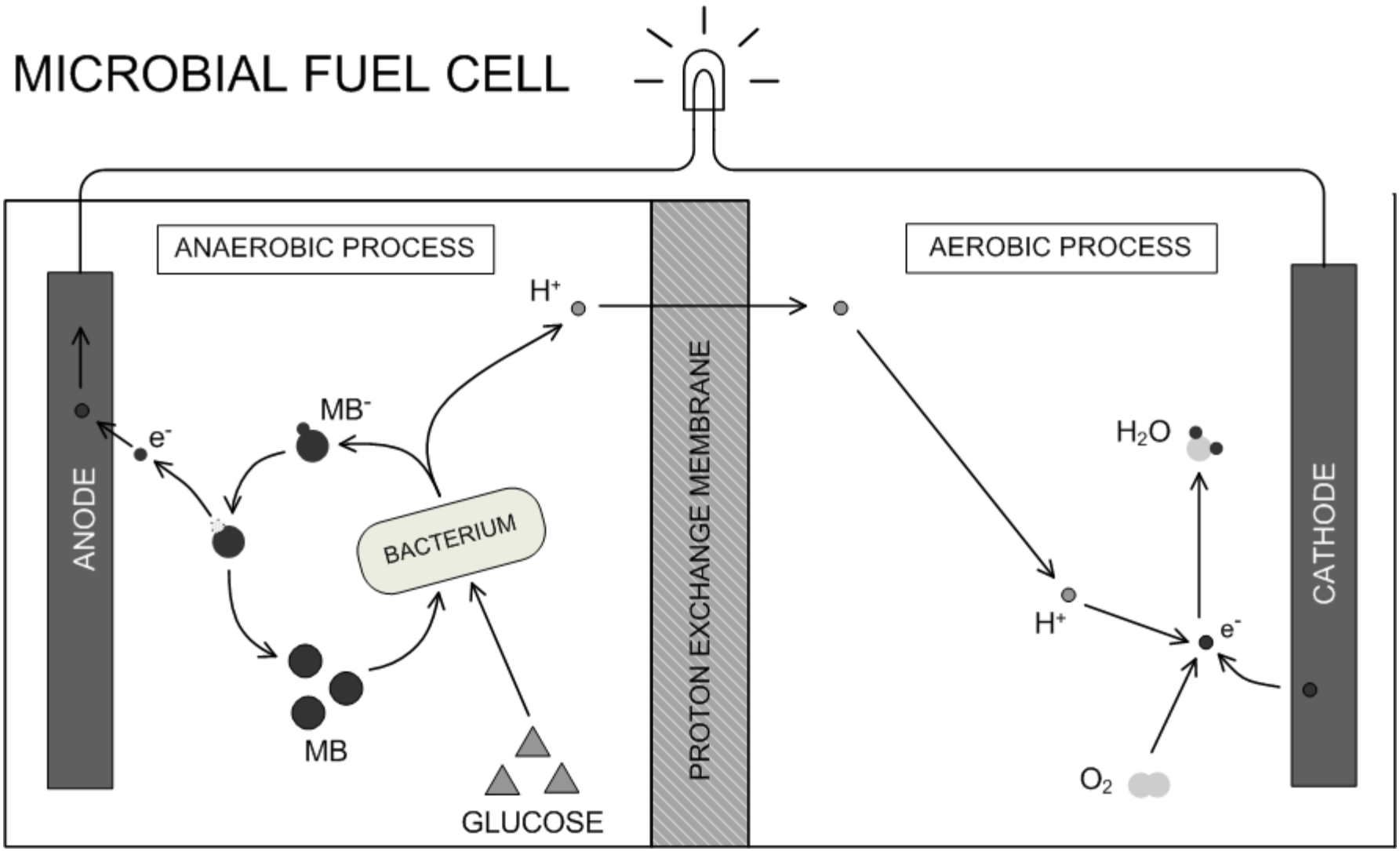

MICROBIAL FUEL CELL
ANAEROBIC PROCESS
AEROBIC PROCESS
ANODE
CATHODE
PROTON EXCHANGE MEMBRANE
BACTERIUM
H+
e-
MB-
MB
GLUCOSE
H2O
O2

Characterization

- Goal: Maximize power density

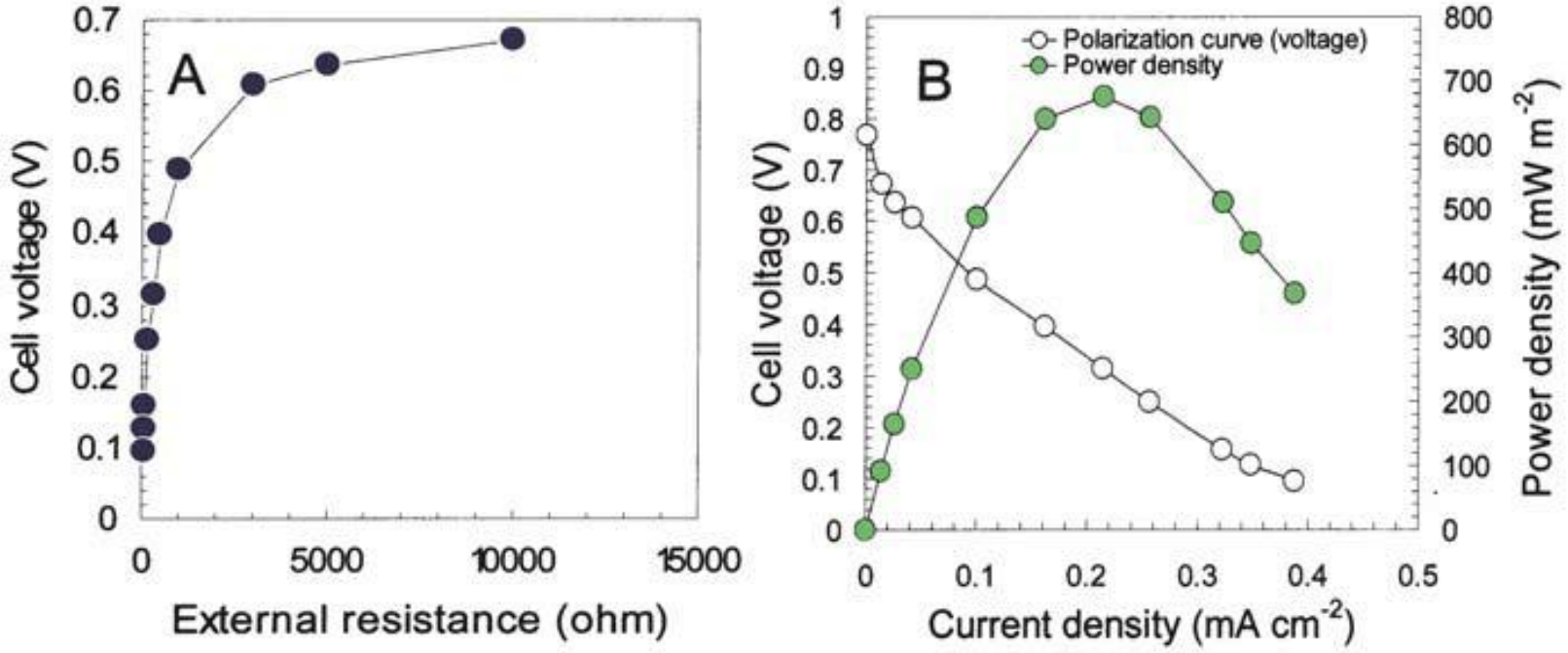


Image taken from Microbial Fuel Cells By Bruce E. Logan

Polarization Curves

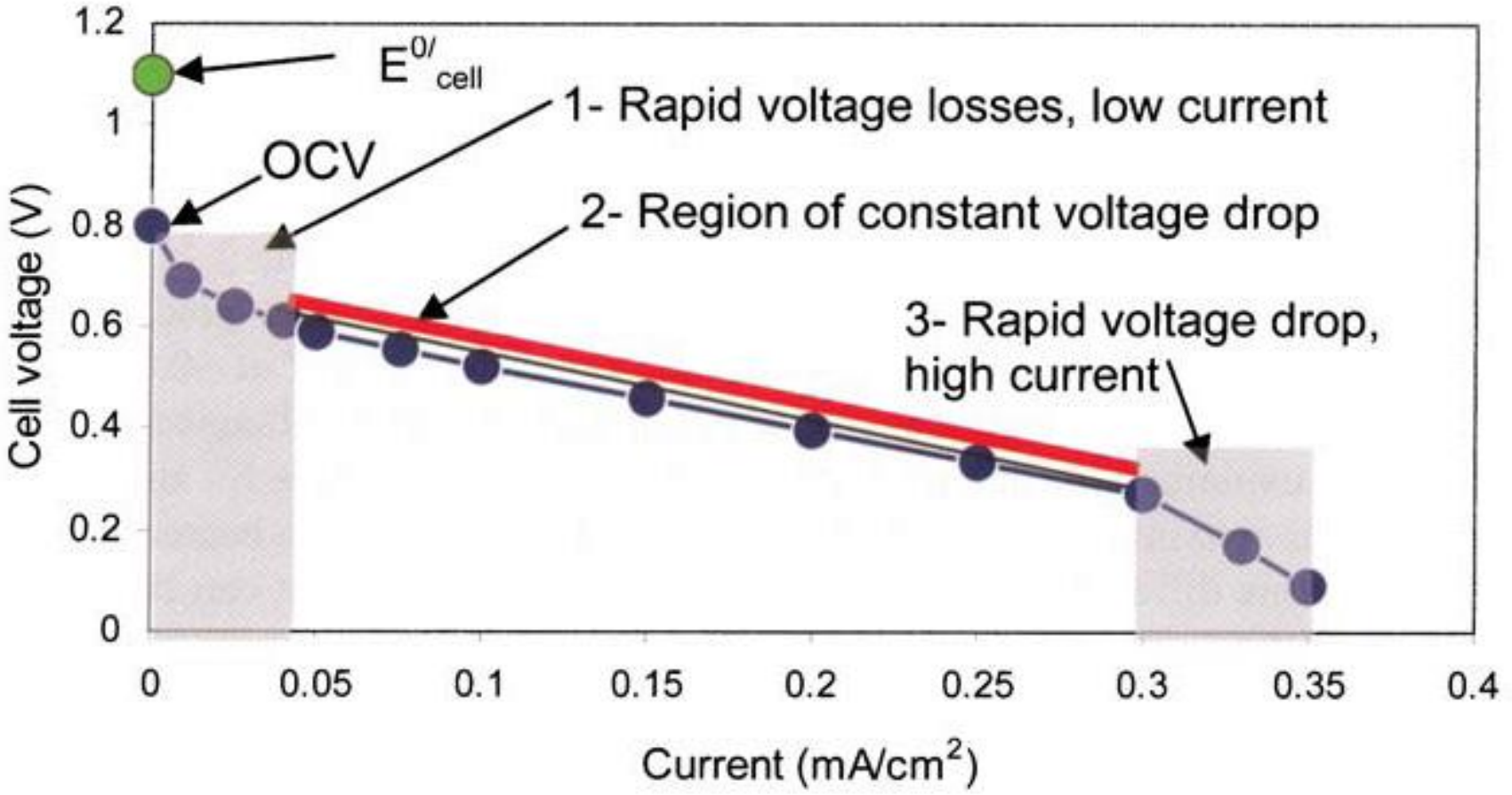


Image taken from Microbial Fuel Cells By Bruce E. Logan

Limitations

1. Poorly understanding of biological mechanisms
2. Research lacks uniform standard procedures or characterization methods
3. Materials can be costly
4. Power densities are too low for most applications

Project Goals

1. Open-Source Educational Kit
   - Designed for high school students
   - Multidisciplinary
   - Accompanied with procedures, labs and challenges

2. Implantable µMFC
   - Application of MFCs
   - Based on a previous design
   - Focus on manufacturing processes rather than biocompatibility

Educational MFC Kit

- Design for safety, simplicity, reusability, cost

- Microbe: Yeast
- Mediator Molecule: Methylene Blue
- Interchangeable electrodes:
  - Carbon Foam
  - Carbon Fabric
  - Graphite

µMFC

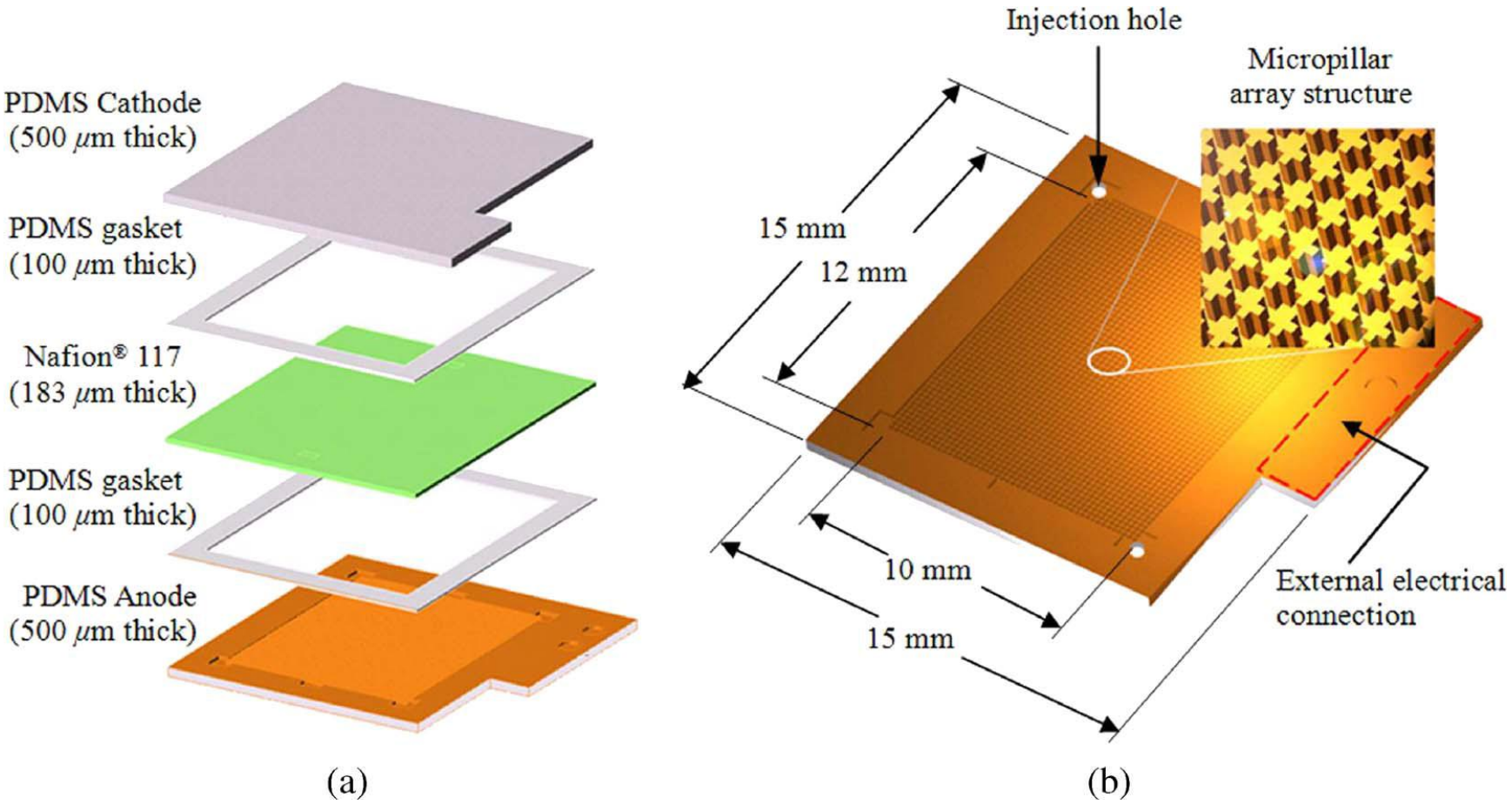
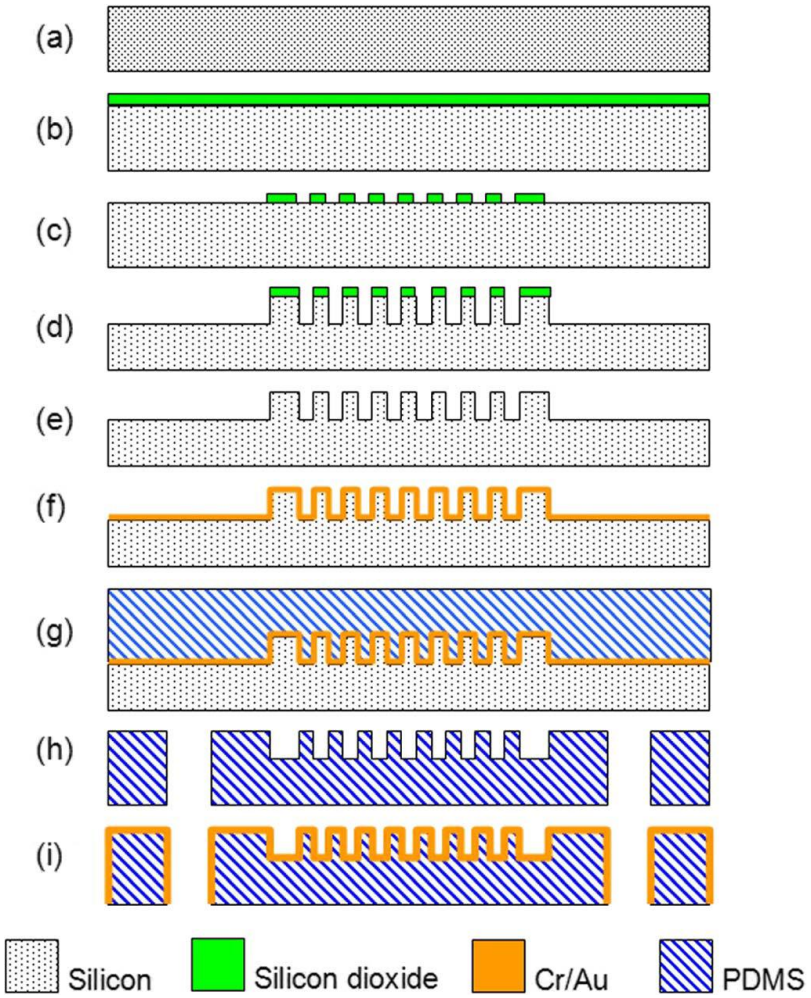


Image from Siu et al. 2008

µMFC Manufacturing



Clean Si Wafer

SiO_2 growth

RIE Etching

XeF_2 Etching

BOE Etching

Gold Electron Beam Evaporation

Mold

PDMS casting

PDMS detachment

Gold Electron Beam Evaporation

Electrode

Manufacturing Simplifications

- Laser cut PDMS mold out of plastic
- Raster micropilli structure into the mold

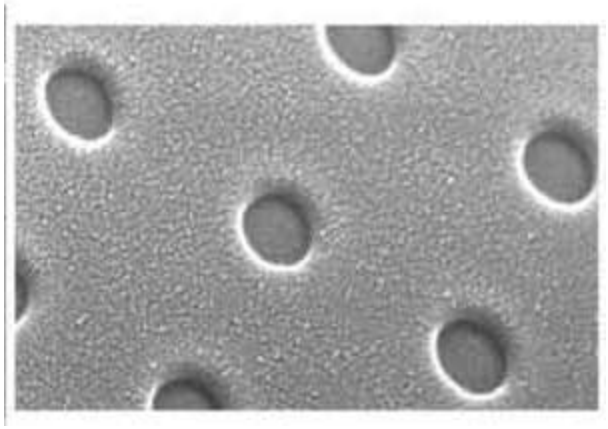
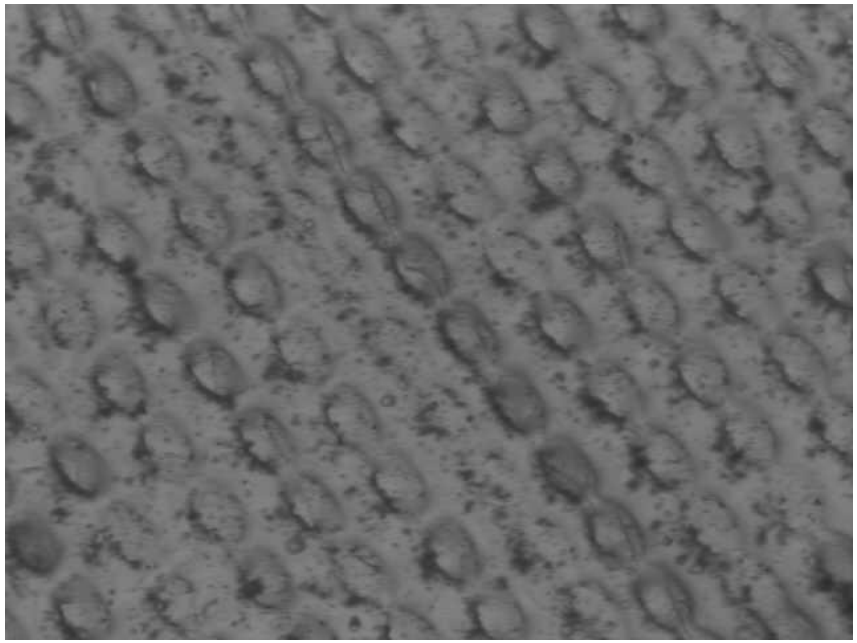


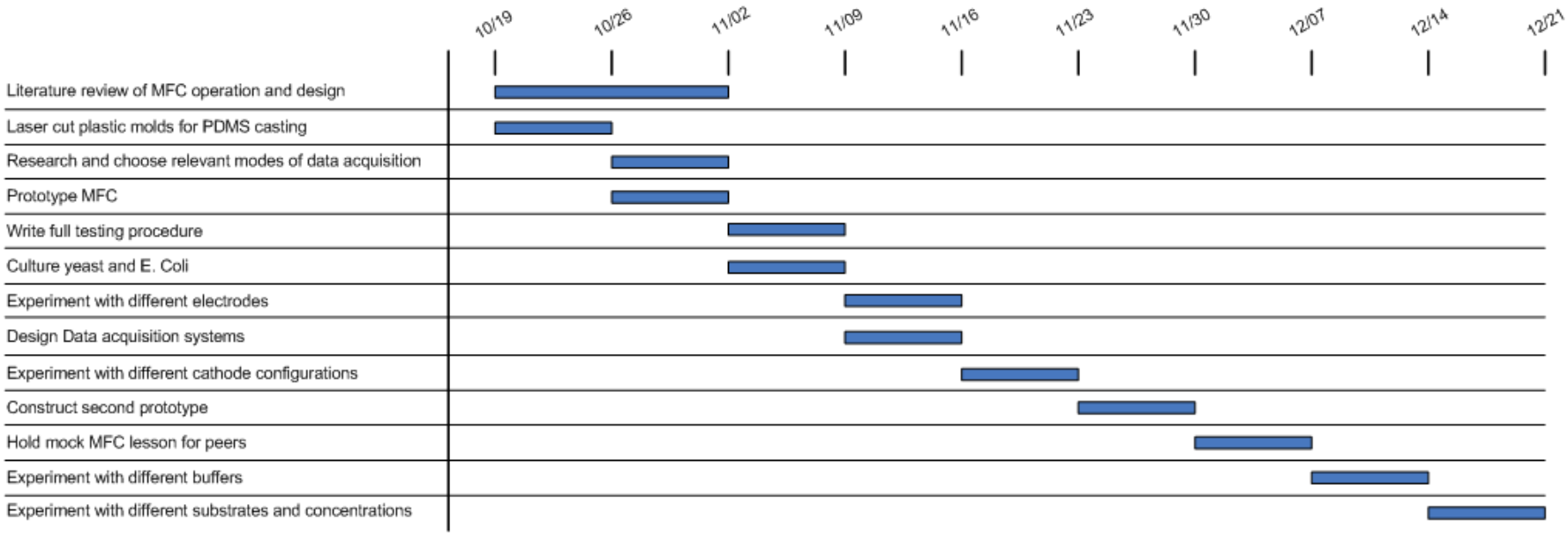
Image from Qin et al. 2010



Challenges

- Create micropilli by:
  - Focusing laser better
  - Experimenting with different materials
  - Using microabrasion/sandpaper
  - Create bigger features
- Quantify surface area, visible surface areas, surface roughness

Gantt Chart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10/26
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11/23
11/30
12/07
12/14
12/21
Literature review of MFC operation and design
Laser cut plastic molds for PDMS casting
Research and choose relevant modes of data acquisition
Prototype MFC
Write full testing procedure
Culture yeast and E. Coli
Experiment with different electrodes
Design Data acquisition systems
Experiment with different cathode configurations
Construct second prototype
Hold mock MFC lesson for peers
Experiment with different buffers
Experiment with different substrates and concentrations

Thanks!

We'd like to thank our advisors, Prof. Cumberbatch, Prof. Kymissis, and Prof. Lima for their guidance. We'd also like to thank David Tan for helping us with the laser cutter, and Dionne Lutz for her expertise in the Kanbar Lab. Finally we'd like to thank all of our friends who have given us their input and suggestions on our senior project.

References

- Logan, B. E. *"Microbial Fuel Cells."* Wiley, 2008.
- Siu C., Chiao M. "A Microfabricated PDMS Microbial Fuel Cell." *Journal of Microelectromechanical Systems*; Vol. 17, No. 6. December 2008.
- Qin D., Xia Y., Whitesides G.M. *"Soft lithography for micro and nanoscale patterning."* Nature Protocols; Vol. 5, No. 3, 2012.

Specs for µMFC (from Siu et al. 2008)

- Power Density = 4 mW/m^2
- Volumetric Power = 2 W/m^3
- Max Current Density = 300 mA/m^2
- Max Open Circuit Voltage = 500mV