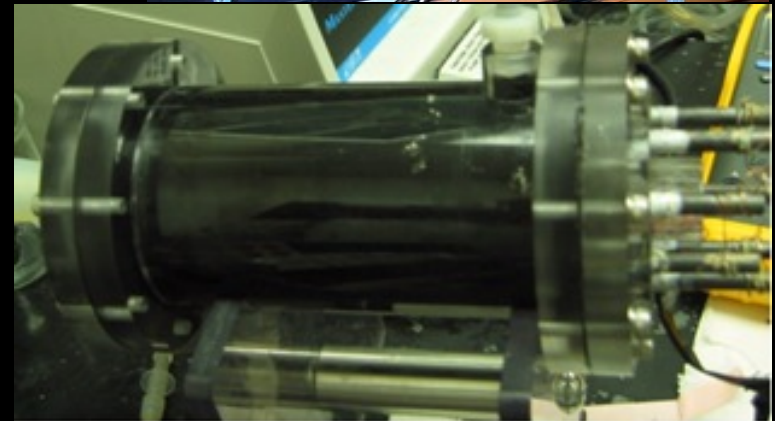
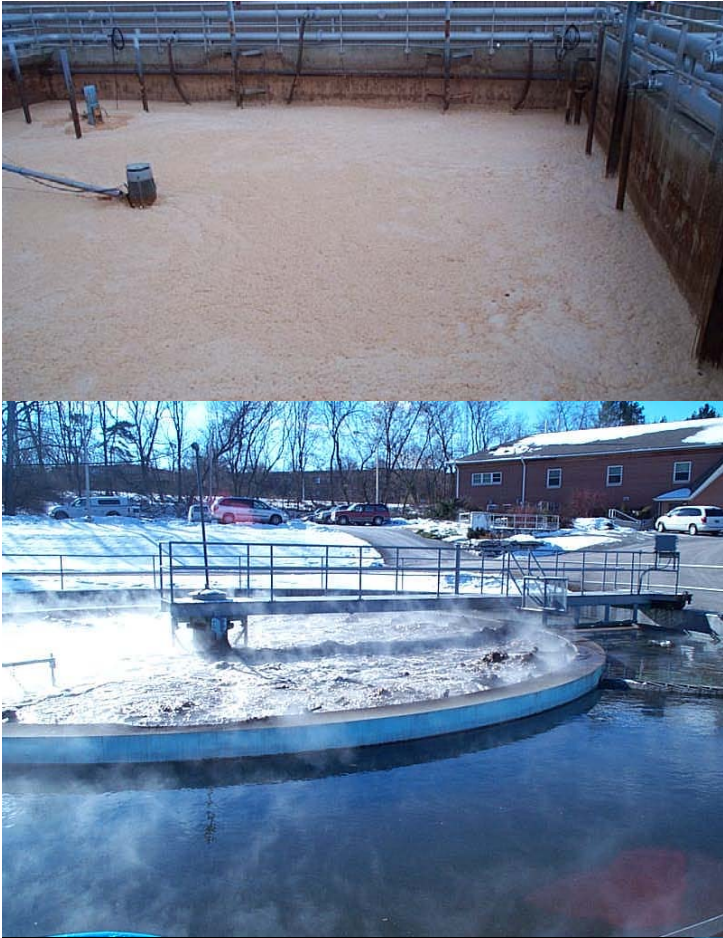


Harvesting Energy from Wastewater Treatment

Bruce Logan
Penn State University





Energy Costs?

5-7% of electricity
used in USA is for
water & wastewater

Global Energy & Health Issues

- 1 Billion people lack access to adequate sanitation— in part to costs for energy.
- Global industrial growth will increase the demand for fossil fuels and energy
 - US production of oil peaked 30 years ago
 - Global production of oil will peak sometime in the next 1 to 20 years
 - CO₂ emissions continue to increase causing climate change

“Energy is the single most critical challenge facing humanity”

- Nobel Laureate Richard Smalley

US electricity generation:	13 quad
5% used for W&WW:	0.6 quad

97 quad [quadrillion BTUs]= 28,400 terawatt hours

Energy content of Wastewaters

- Electricity “lost” to water and wastewater treatment= **0.6 quad**
- Potential sources of renewable energy in wastewater= **0.5 quad**
 - 0.1 quad of energy in domestic wastewater
 - 0.1 quad in food processing wastewater
 - 0.3 quad in animal wastes
- Toronto: wastewater has **9.3x** more energy than treatment consumes (Shizas & Bagley, Univ. Toronto)

Renewable Energy Production Using Wastewaters

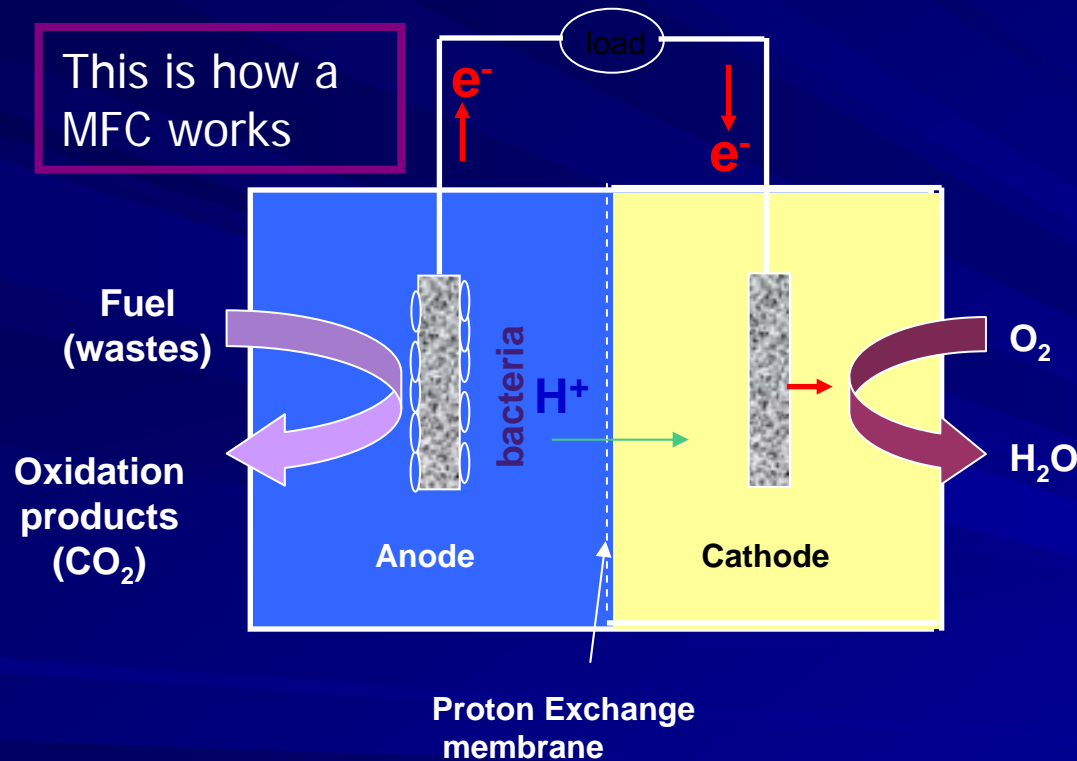
- Electricity production using microbial fuel cells
- Hydrogen production from biomass
- Economic considerations

MFC developed for demonstrations

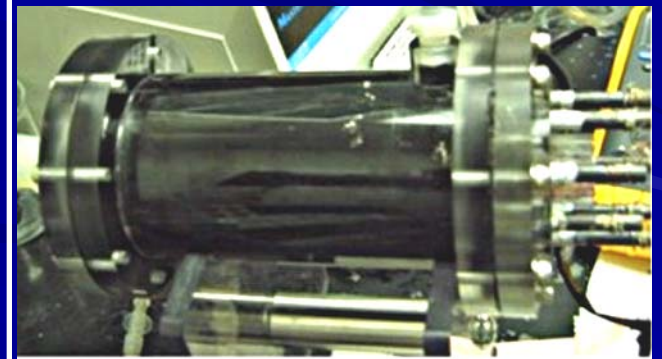


Electricity Production in a Microbial Fuel Cell

A MFC is a device that use bacteria to oxidize organic matter and produce electricity. The bacteria (attached to the anode) produce electrons that travel to the cathode (current).

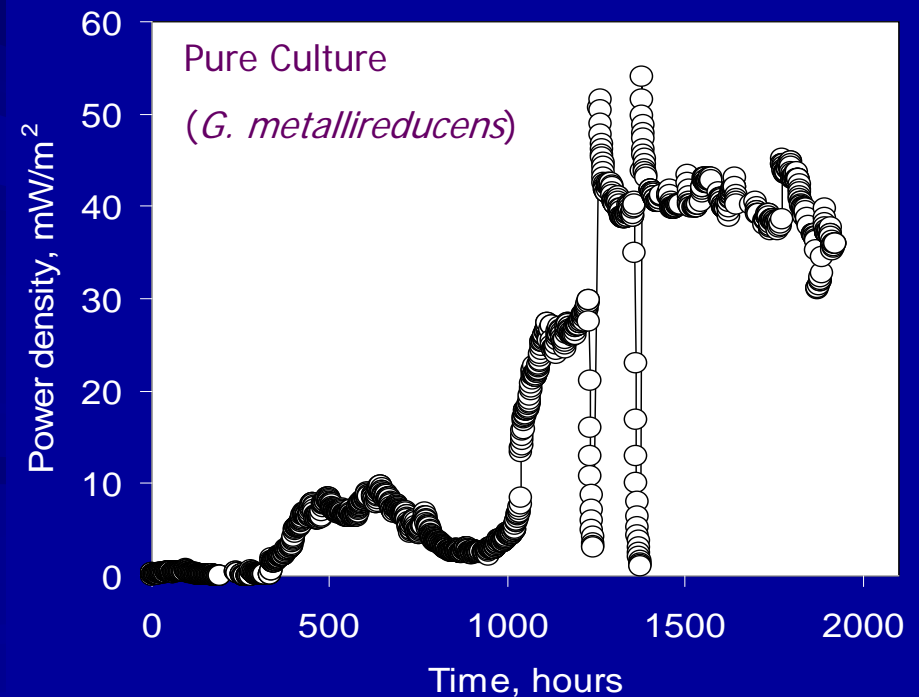
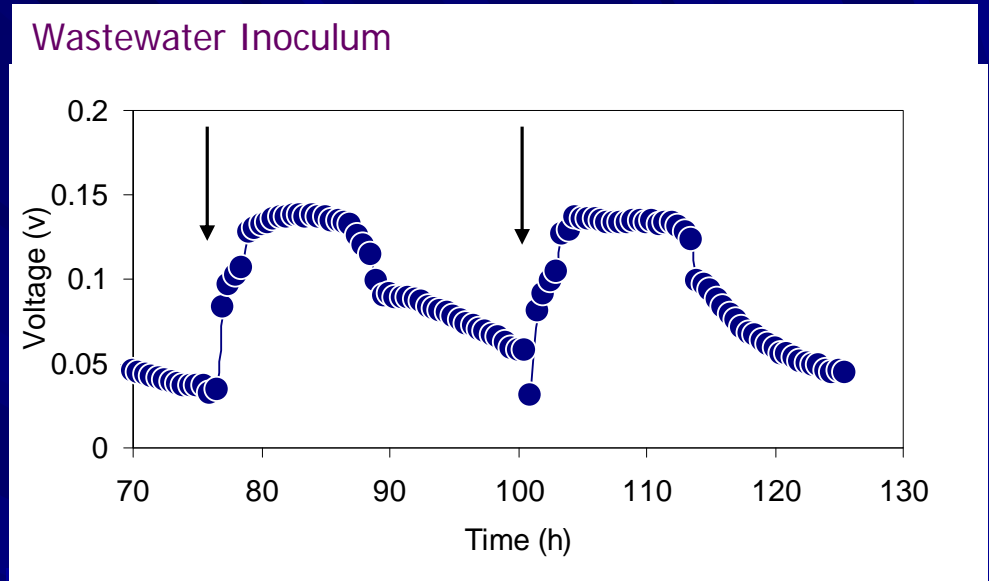


This is single-chambered MFC treats wastewater and produces electricity

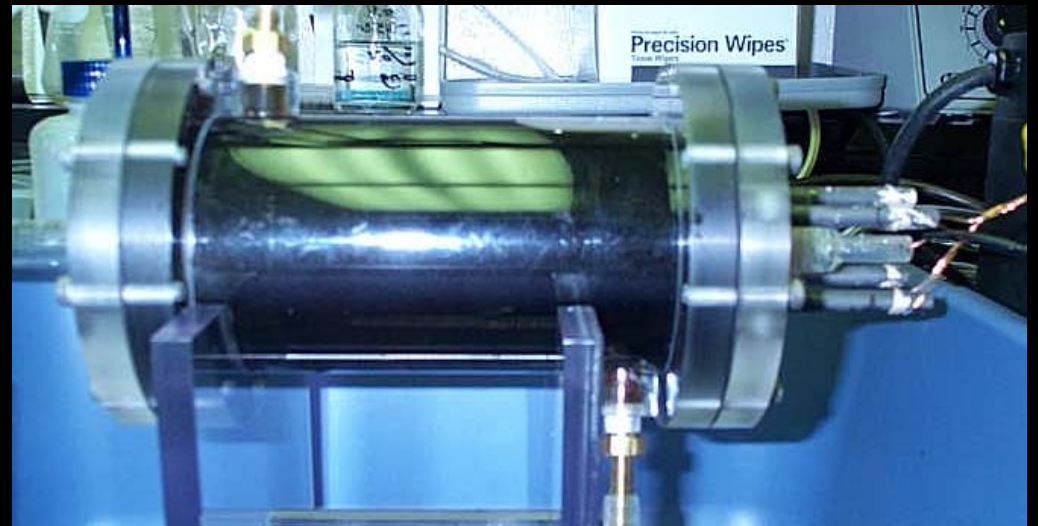
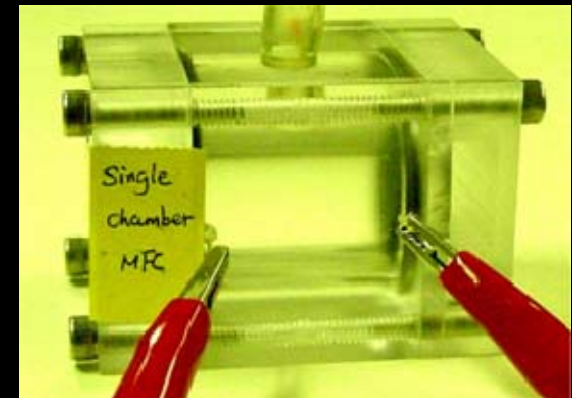
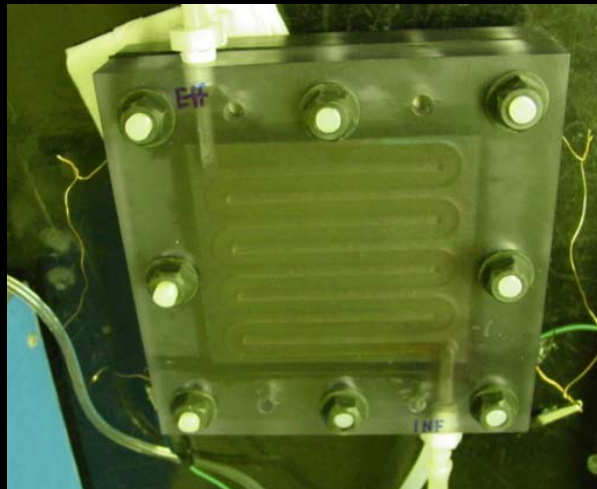
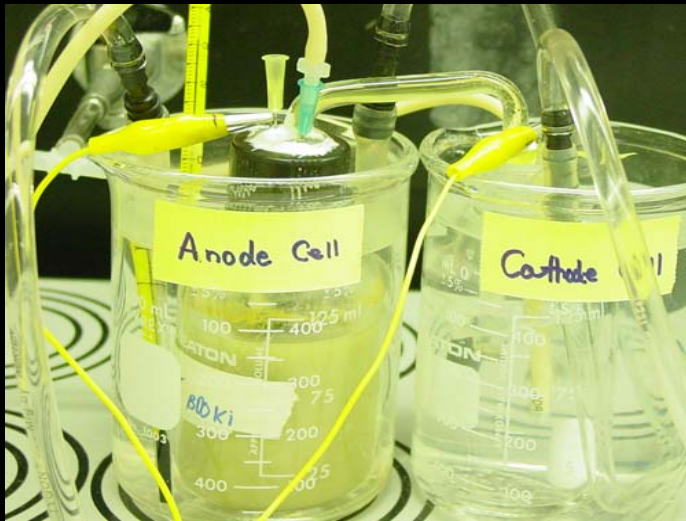


MFC Bacteria

- Bacteria that can produce electricity in a MFC are abundant in wastewater
- “Acclimation” can take as little as 76 h with bacteria in wastewater vs. 1200 h with pure culture



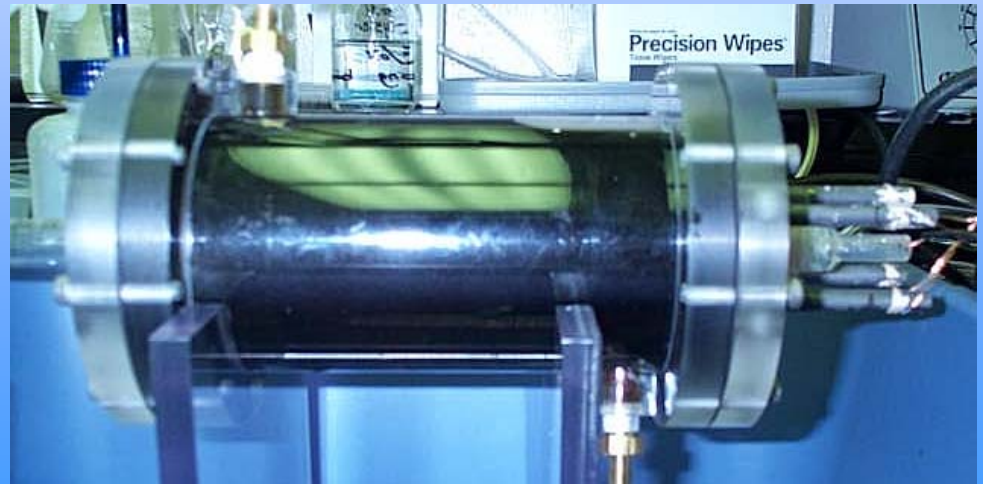
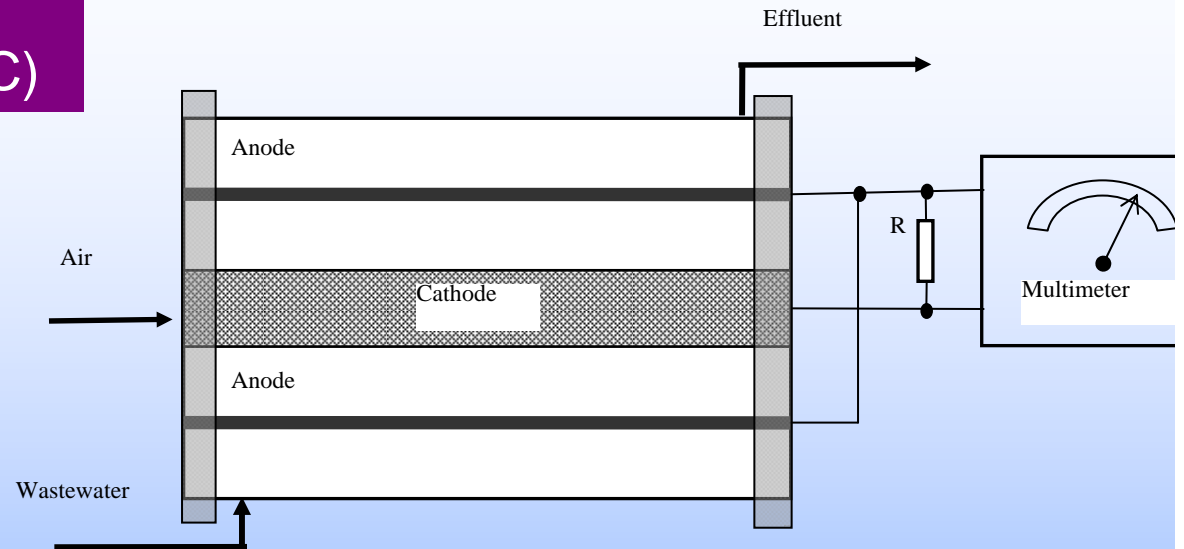
MFC Reactors used in our laboratory



MFC- Air cathode systems

Large, single compartment continuous flow MFC (SCMFC)

- Developed for high particle wastewaters
 - Six graphite rod anodes
 - One central air-cathode
- Open flow structure allows continuous flow through the reactor
- 20 m²/m³ surface area



Source: Liu et al., *Environ. Sci. Technol.*, (2004)

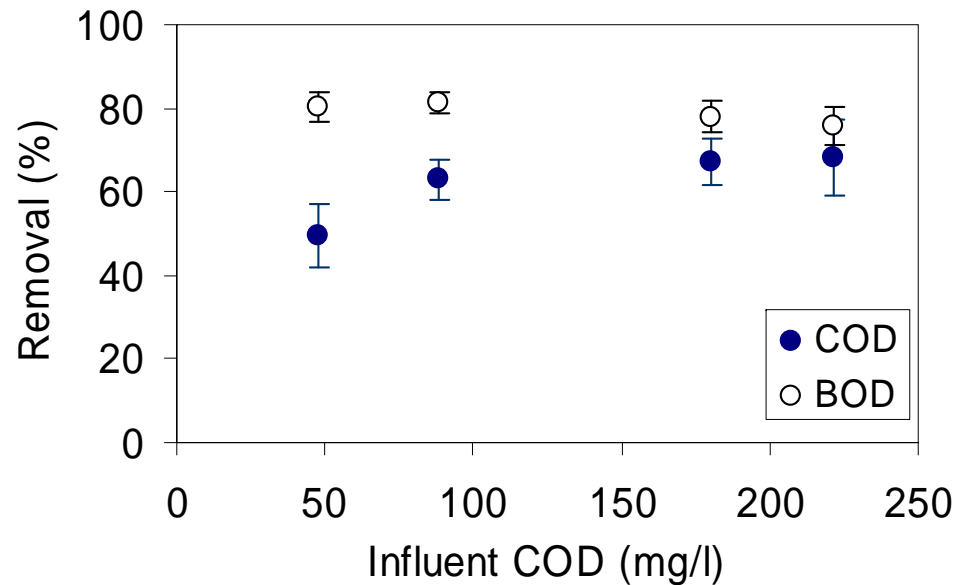
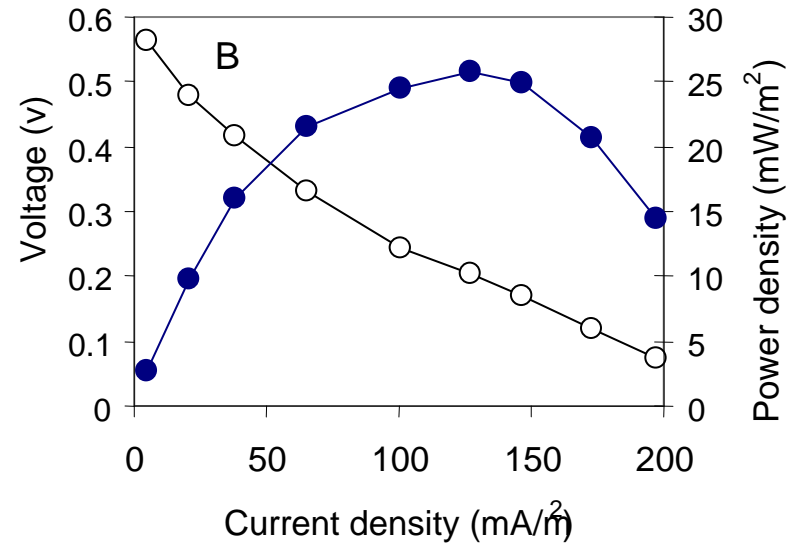
MFC- Electricity Production

Domestic wastewater

Single compartment
MFC (SCMFC)

Power: 26 mW/m²

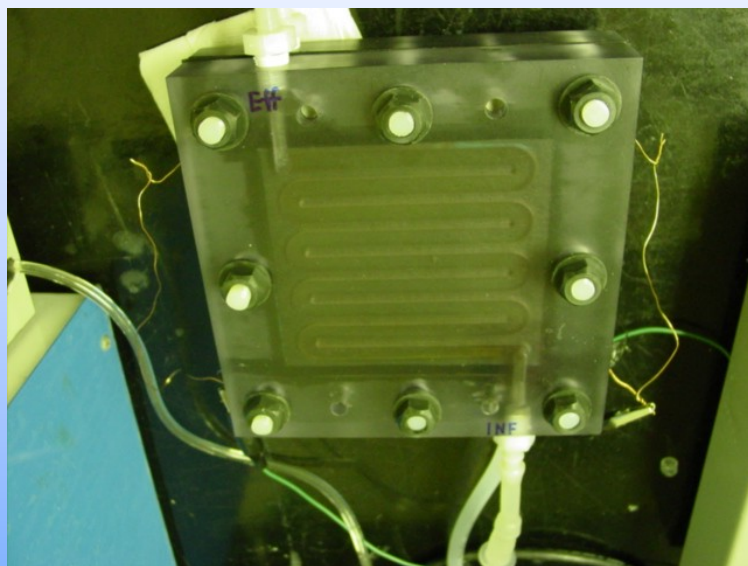
Up to 80% BOD removal
and 75% COD removal



Source: Liu et al., *Environ. Sci. Technol.* (2004)

MFC- Air cathode systems

Flat Plate, continuous flow MFC (FP MFC)

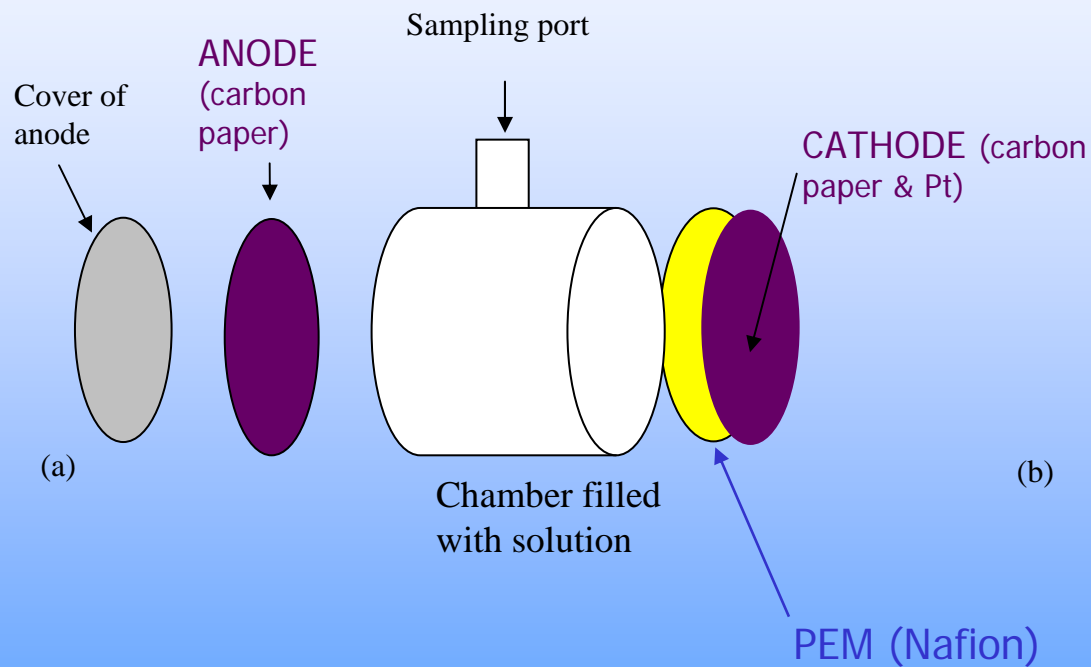


Substrate	Power (mW/m ²)
Wastewater	76
Glucose	150
Dextran	212
Starch	242
Butyrate	230
Acetate	286

All samples at 1 g/L except WW=0.3 g/L

MFC- Air cathode systems

Small, batch system for optimizing cathode/membrane system



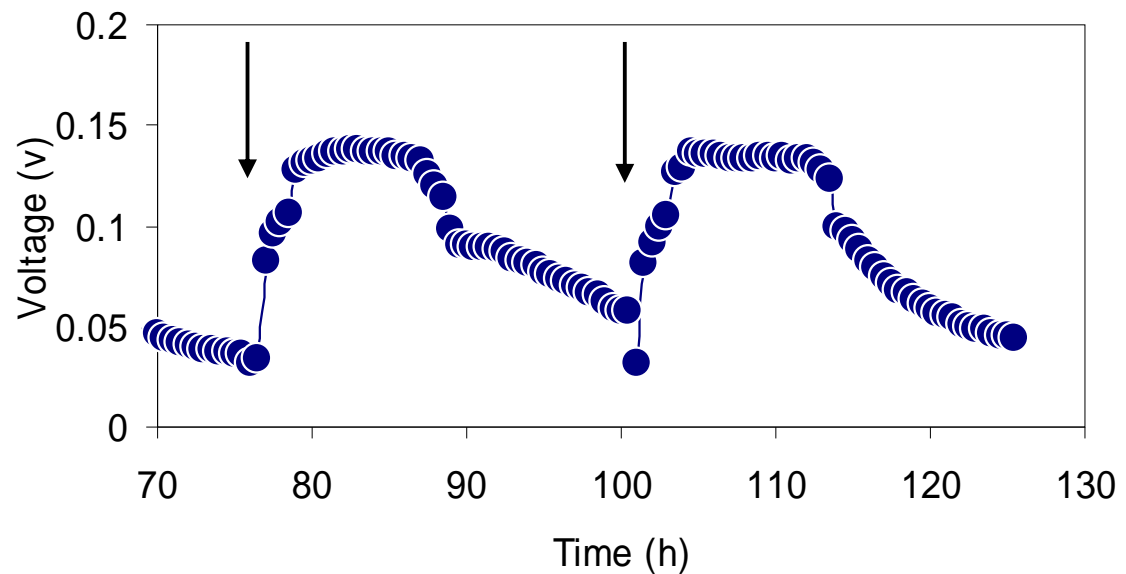
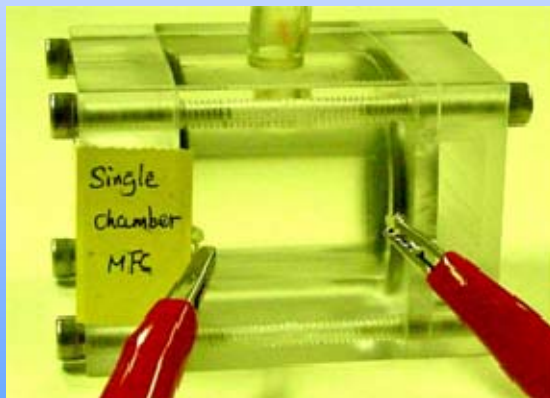
The PEM can be omitted, increasing power generation

MFC- Electricity Production

Small, batch system for optimizing cathode/membrane system

Domestic wastewater
(primary clarifier effluent)

$P = 28 \text{ mW/m}^2$ (PEM/Nafion)
 $= 146 \text{ mW/m}^2$ (No PEM)

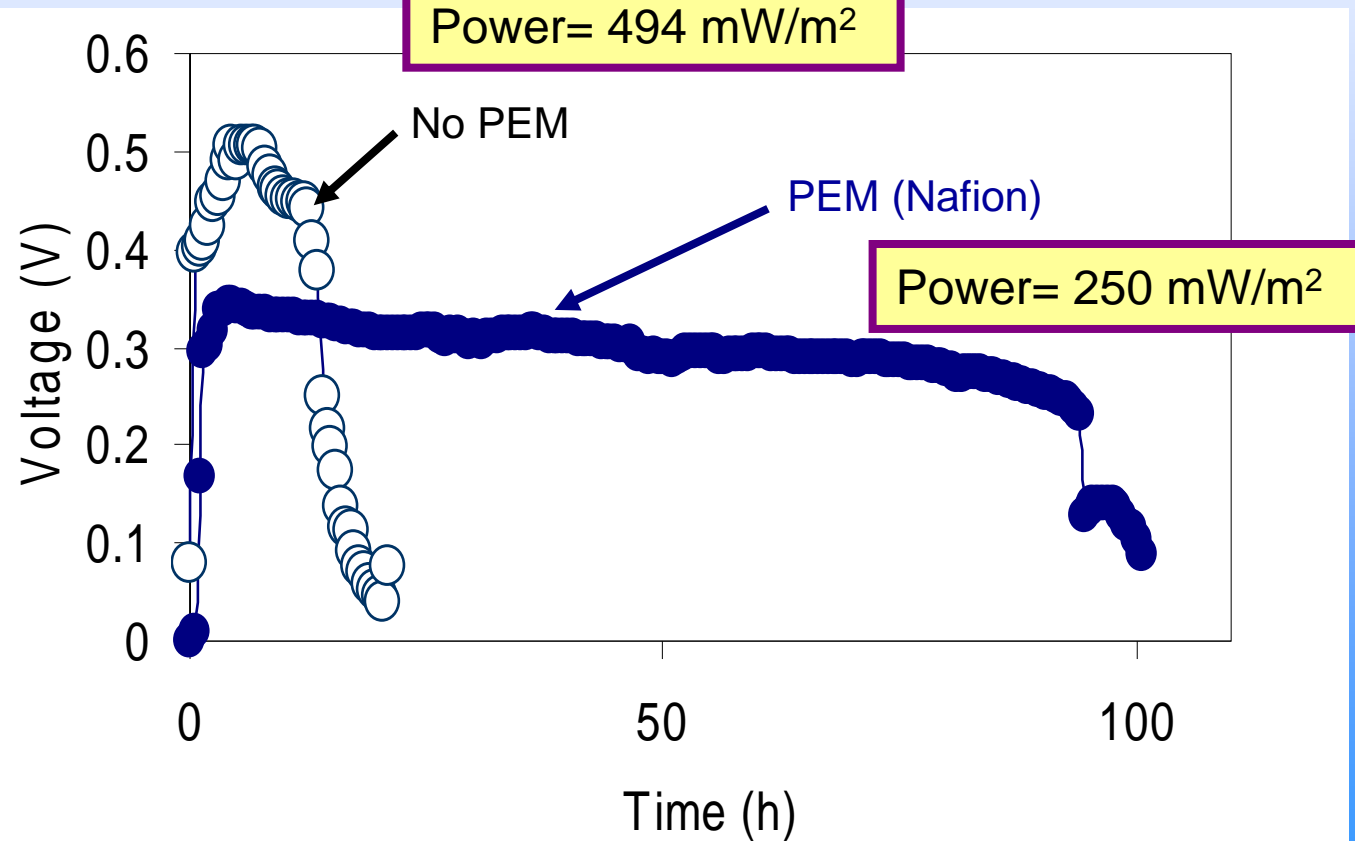
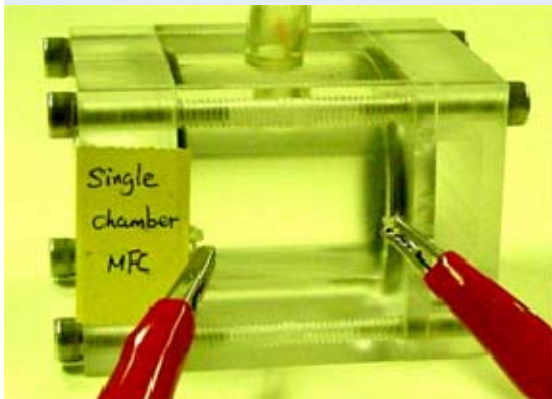


Arrows indicate wastewater addition

MFC- Electricity Production

Small, batch system for optimizing cathode/membrane system

Glucose



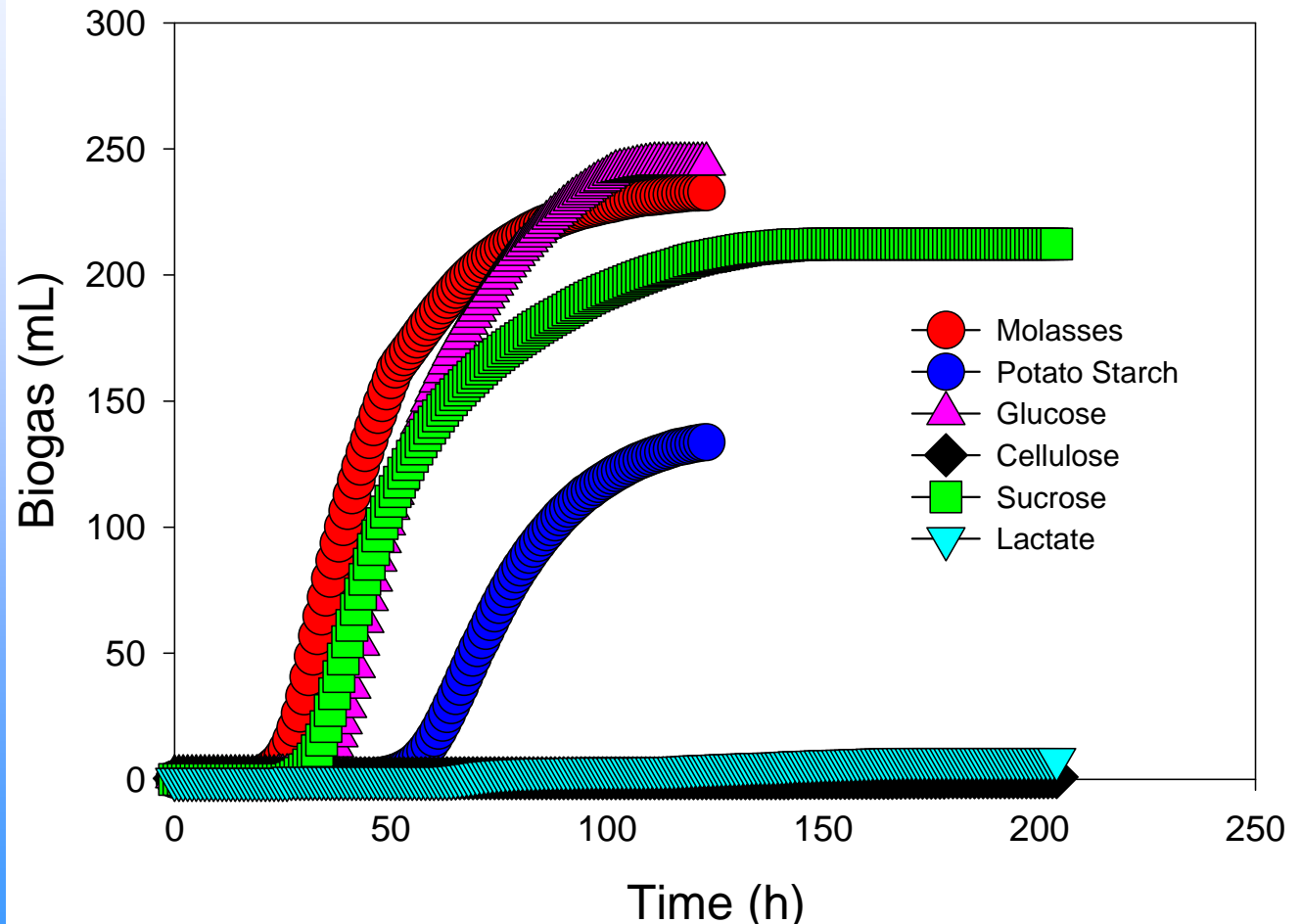
Renewable Energy Production Using Wastewaters

- Electricity production using microbial fuel cells
- Hydrogen production from biomass
- Economic considerations

Hydrogen production results primarily from carbohydrates

Biogas:

- 60% H₂
- 40% CO₂



H₂ from industrial wastewaters such as food processing wastewaters

	Apple	Potato	Conf-A	Conf-B
Flow rate (m ³ /h)	26	15	13	0.24
COD (mg/L)	8,900	20,400	---	20,100
Glucose	6,000	2,800	1,100	20,000
H₂ Yield (mL/L-ww)	800	2500	100	200

Hydrogen is a high-value gas

- Wastewater treatment can be made more economical through H₂ production
 - \$6/kg-H₂
 - \$0.43/kg-CH₄
- Practical COD removals as H₂ are ~15%
- Link H₂ production to a second process
 - Methane Production
 - Microbial Fuel Cells (MFCs)

Renewable Energy Production Using Wastewaters

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Domestic Wastewater: Electricity

	Current	Goal	Max
Power- mW/m ²	146	1000	---
Power- MW	0.19	0.50	2.3
No. houses	130	330	1500
\$0.151 /kWh	\$250,000	\$1,700,000	\$3,000,000
\$0.44 /kWh	\$750,000	\$5,000,000	\$8,900,000

Assumes: 100,000 people = 16.4×10^9 L/y

Industrial Wastewater: Electricity

	H ₂ &CH ₄ *	Elec. Only**	H ₂ & Elec
Basis	\$6/kg H ₂	\$0.151/kWh	
H ₂ (/yr)	\$350,000	---	\$350,000
CH ₄ (/yr)	\$264,000	---	---
Elec (/yr)	---	\$1,031,000	\$1,031,000
TOTAL (/yr)	\$614,000	\$1,031,000	\$1,381,000

**\$4.6 million
(\$0.44 /kWh)**

*Assumes 2 mol-H₂/mol-glucose

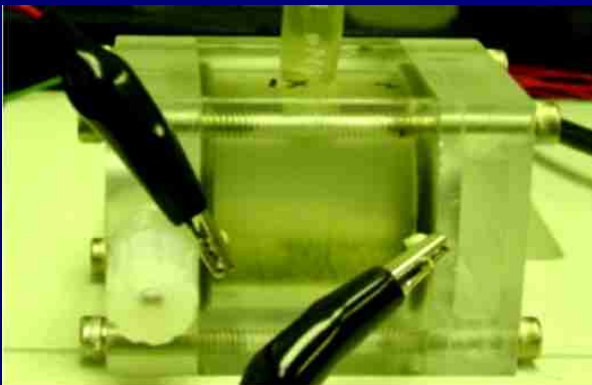
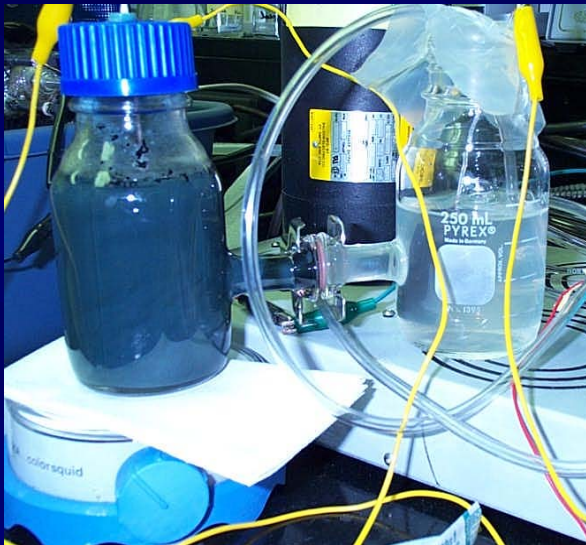
**Assumes 100% Coulombic efficiency

What will a wastewater MFC treatment plant of the future look like?



Physical Configuration of the MFC?

Laboratory Devices



New systems more likely to resemble trickling filter media



Acknowledgements

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- Stan and Flora Kappe Endowment at Penn State University
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