Bio-electrochemical technologies for solving food-water-energy nexus challenges in upper great plain region- A case study on efficient wastewater reuse

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Introduction to Upper Great Plain Region:

- Upper great plain region (UGP) includes the regions of South Dakota, Iowa, Montana, Minnesota, Nebraska and North Dakota.
- UGP is a major exporter of food and energy and utilizing significant volumes of water and nutrient.[1]
- Food production, and water and energy consumption are interdependent processes.[2] For instance, conversion of grassland reduces ground water resources.
- The food-water-energy nexus in the UGP is currently influenced by the Bakken shale-oil boom, corn-ethanol production, coal mining, wind farms, and hydroelectric dams .
- It is important to balance the economics, technological innovation, and culture to sustain food-water-energy nexus in UGP.

Bakken Shale-oil Boom:

- Subsurface of the Williston Basin, underlying parts of Montana, North Dakota, Saskatchewan and Manitoba.[3]
- Bakken oil production increased from 150 thousand bbl/day in 2007 to 1350 thousand bbl/day in 2015.[4]
- Hydraulic fracturing and horizontal drilling is used for oil extraction from impermeable formations. This process generates significant amount of produced and flowback water.
- Flowback waters is characterized with high total dissolved solids (~200,000 mg/L) and chemical oxygen demand (1200 mg/L).

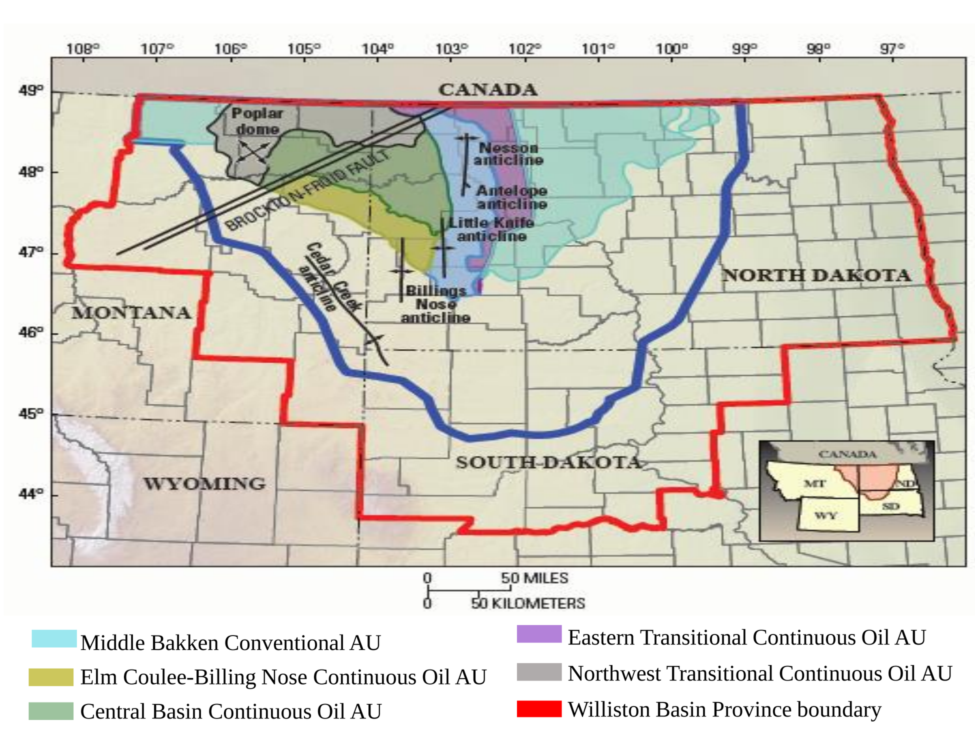


Figure 1. Williston basin province, Bakken total petroleum system (TPS). Adapted from Anna, L.O[5]

Problem statement:

- Existing technology for backflow water treatment like thermal or membrane processes coupled with pretreatment is prone to fouling, also expensive and energy consuming.

Approach

- A two stage treatment for backflow water based on electrochemical processes followed by biological treatment for Bakken's backflow water.

Bio-electrochemical technologies (BETs):

- The BETs uses specialized microbes called as anode respiring bacteria (ARB).[6]
- The ARBs can be used for simultaneous wastewater treatment, desalination, and electricity production.
- Examples of BETs are microbial fuel cells (MFCs), microbial electrolysis cells (MECs) , microbial desalination cells, MDCs.

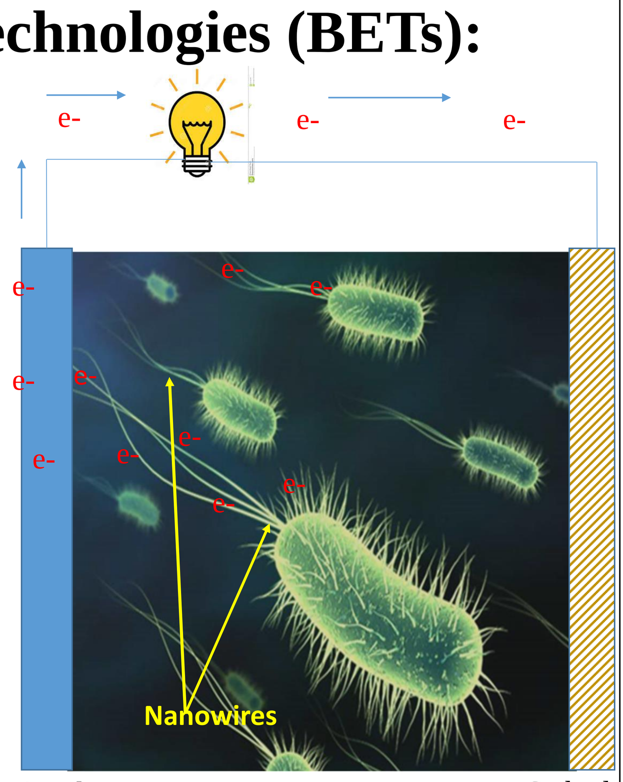


Figure 2: Microbial nanowires transferring electrons[7]

A Case Study of Bio-electrochemical Technologies for Wastewater Reuse in Powerplant:

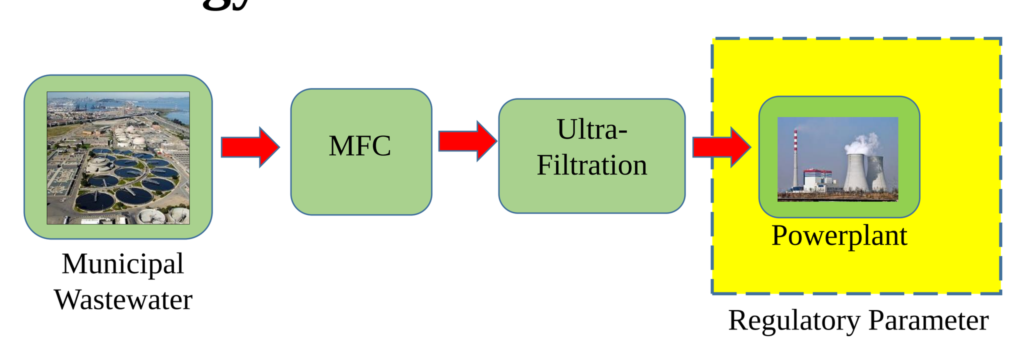
Water Energy Nexus:

- Power plants in the US consume ~40% of total freshwater withdrawals.
- Wastewater Treatment:
  - ❑ Energy: 0.5–2.0 kWh/m3
  - ❑ Sludge Disposal: 60% of total operating cost
- Energy-intensive wastewater treatment plants annually spends 4480 MW to treat wastewater.

Goals:

- Evaluate the municipal wastewater as the electron donor in the anode of MFCs.
- Examine the viability of MFCs/membranes to enable wastewater reuse (power plants).

Methodology:



Measurement Analysis:

- pH : pH meter.
- Conductivity :Conductivity meter.
- Chemical Oxygen Demand : Using spectrophotometer based on standard methods.[8]
- Ion measurement: Using atomic absorption spectrometer based on Standard methods.[8]
- Cyclic Voltametry : Using Potentiostat.
- Electrochemical Impedance analysis: Using Potentiostat.

Results:

- Chemical Oxygen Demand (COD) Removal:

❑ We achieved 90% COD removal in the Rapid City's wastewater.

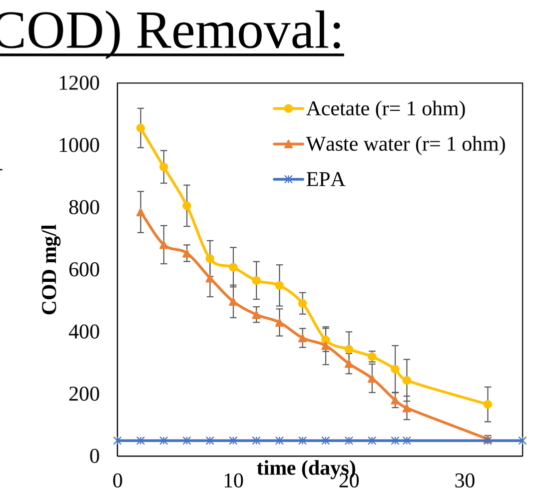


Figure 3: COD removal in MFC

- Element Removal:

❑ Minimal elemental removal Tested for Fe, Al, Cu, Zn and Ca.

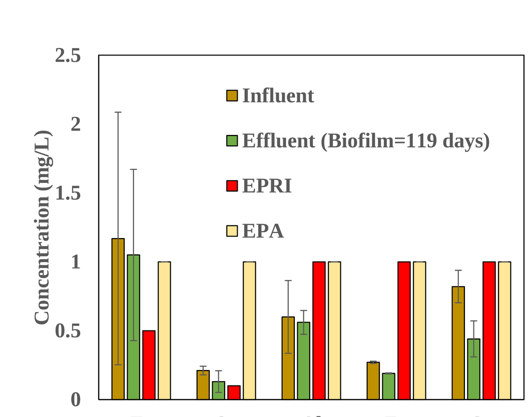


Figure 4: Element removal in MFC

- Cyclicvoltametry:

❑ Higher electrochemical current in acetate than wastewater.

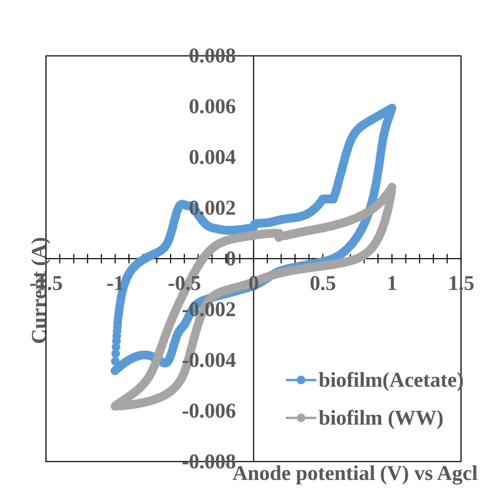


Figure 5: Cyclic voltammogram

- Electrochemical Impedance:

❑ High impedance in wastewater (~6.7 $k\Omega.cm^2$) than in acetate (~0.28 $k\Omega.cm^2$).

❑ Power production using wastewater (325 mW/m^2) less than acetate (150 mW/m^2).

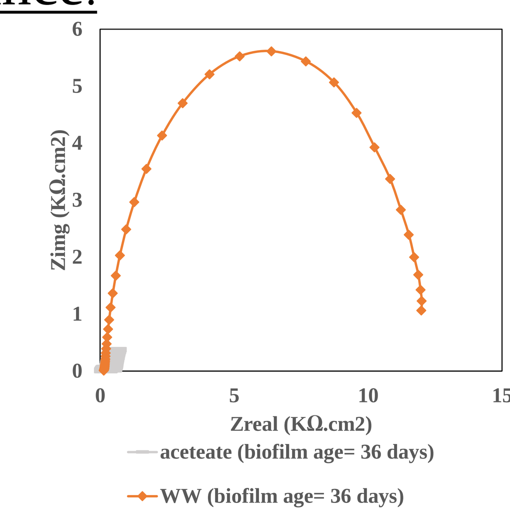


Figure 4: Impedance in MFC

Conclusion:

- ❑ This research presents inexpensive option to achieve high-quality wastewater effluent as cooling water in power plants.
- ❑ Effluent from MFC was further treated with ultrafiltration membrane to eliminate the residual COD, particulate matter, metals and salt.
- ❑ Metal removal efficiency can be enhanced by optimizing electrochemical parameters and solution chemistry.

Bioelectrochemical desalination:

BETs have been previously used for the desalination and simultaneous COD removal from shale gas exploration produced water at rate of 2760 mg/l TDS per hour and COD at the rate to 170 mg/l per hour.[9]

Some of the BET desalination configuration used are :[10]

1) Air cathode Microbial desalination (MDC).

2) Stack structure alternating anion exchange membrane and cation exchange membrane.

3) Recirculation MDC.

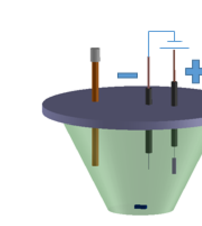
4) Capacitive MDC.

5) Upflow MDC.

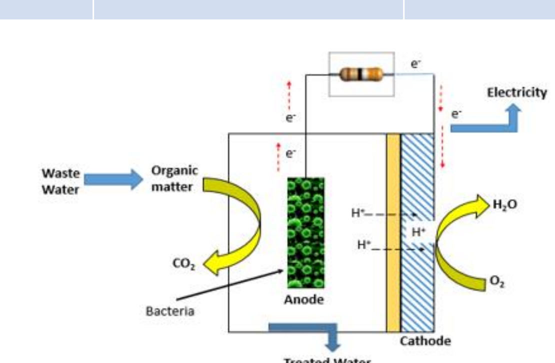
6) Decoupled MDC.

Experimental Plan:

#	Electron Donor	Electron Acceptor	Media
MFC1	Bakken Backflow water	Oxygen	100 mM
Control1	Artificial Salt water	Oxygen	100 mM
Control2	None	Oxygen	100 mM



Stage 1
(Electrochemical treatment in 3 electrode Cell)



Stage 2
(Biological treatment in Microbial fuel Cell)

Summary:

- Bio-electrochemical technologies viable alternative for solving food-water-energy nexus challenges in upper great plain region.
- Use of two stage approach to deal with high salinity in the Bakken backflow water.

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