Studies on Corrosion and Fouling Detection and Prevention Using MicroElectrode Arrays

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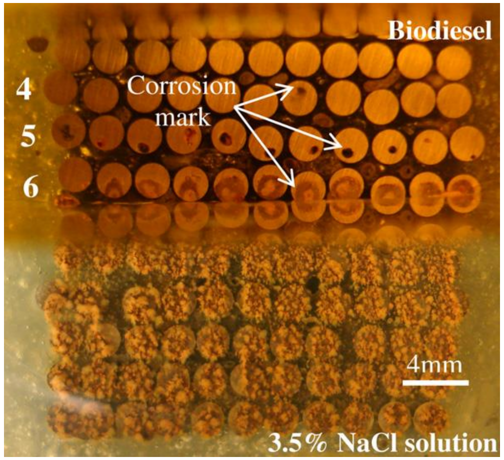


Our Research Background

We use microbial and electrochemical approaches to understand and develop technologies for energy and chemical production from biodegradable materials (wastewater, biomass, sediments, etc.)

Current Research Projects:

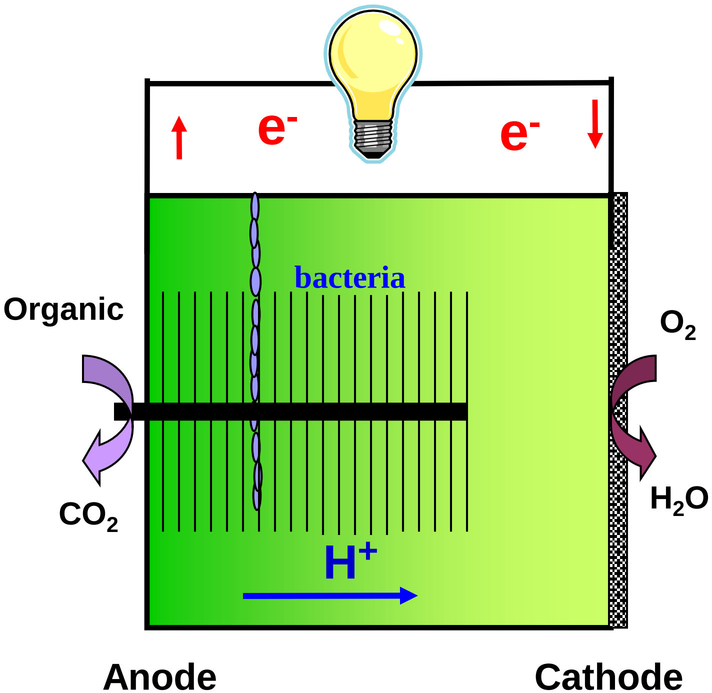
1. Develop Microbial Electrochemical Technology to recover energy and value-added chemicals during waste treatment *(NSF, Gates Foundation)*

2. Develop Microbial Capacitive Desalination systems for integrated organic degradation, salt removal, and energy production *(ONR, NSF)*

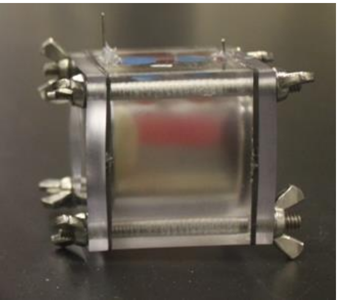
3. Develop new microbial electrochemical cell for *in situ* petroleum hydrocarbon remediation and electricity production *(Chevron)*

4. Understand and mitigate corrosion and biofouling associated with biofuel and microbial fuel cell systems *(ONR)*

The Microbial Electrochemical System (MES) Platform



Single-Chamber,
Air-Cathode MES



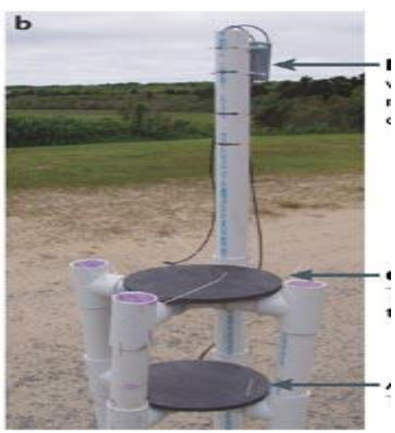
Video clip shows fan powered by a MES

MES Applications

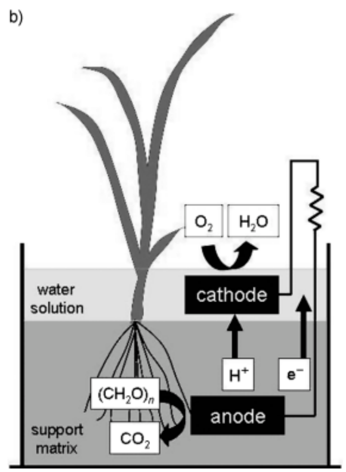
Anode Application:
Any biodegradable substrate can be removed by serving as the e- donor

- Biomass (wastewater, sediment, agri. waste, soil, etc.)
- Inorganic pollutants (ammonia, sulfide, etc.)
- Hydrocarbon (petroleum, biofuel, etc.)
- Other substrates

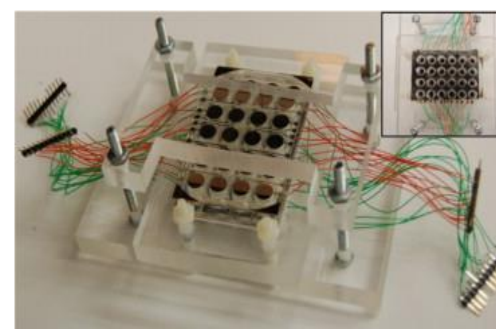
Pilot Wastewater MFC/BES, 10 m^3 Jin and Ren, 2012



Sediment MFC, Lovley, 2006



Plant MFC, Deng, 2012



MFC micro array, Hou, 2009

MES Applications

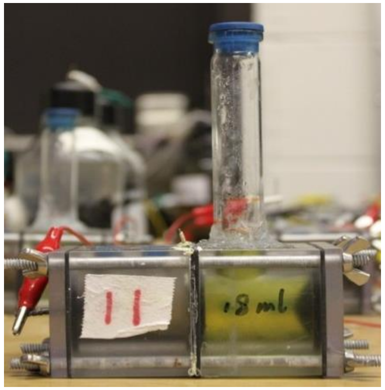
Cathode Application:
Any reduction reaction that can get e- from the electrode

- Electricity production
- Chemical production

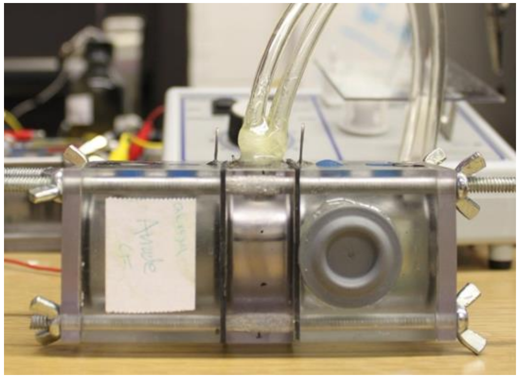
(H_2, CH_4, H_2O_2, Cu, NaOH, Liquid Fuels, Organics)

- CO_2 sequestration
- Removal of e- a- type pollutants

(chlorinated solvents, perchlorate, uranium, AMD, etc.)



MEC for H_2 production, Luo, 2010

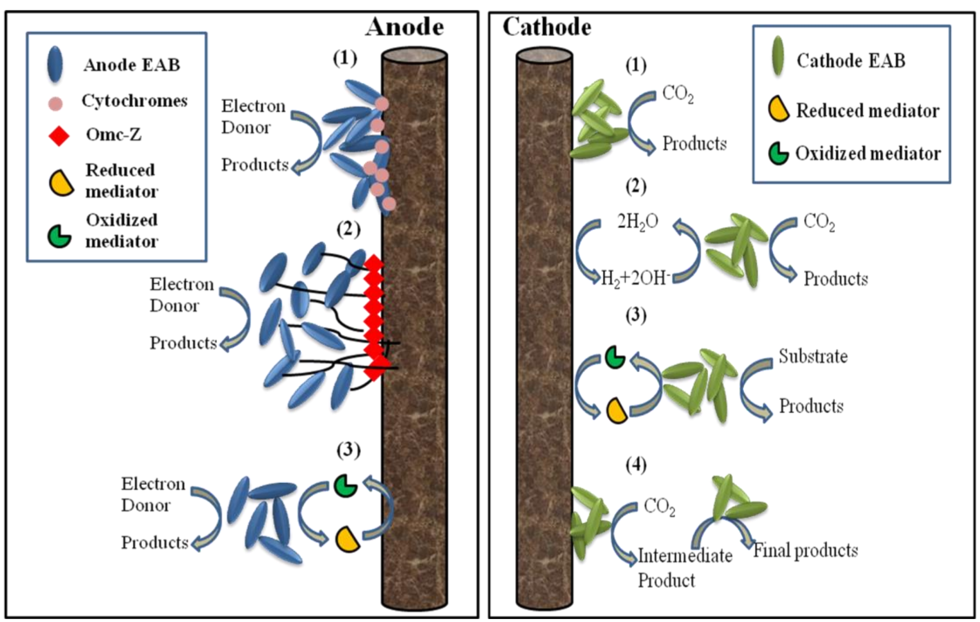


MDC for desalination, Forrestal, 2012

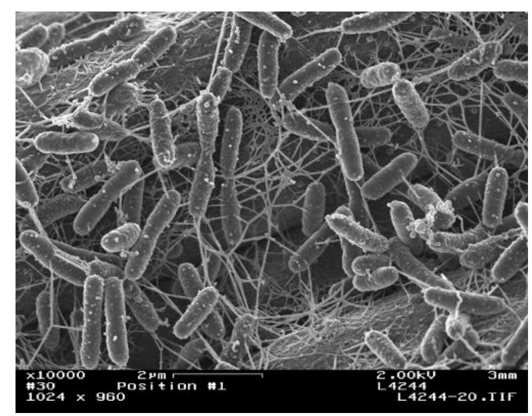
Reactor for
TCE reduction, UCD, 2009
CO2 reduction, UCD, 2012

Microbial Extracellular Electron Transfer in MESs

- Exoelectrogens *(Geobacter, Shewanella, Pseudomonas, etc.)* are microbes capable transferring electrons outside cell membrane to insoluble metals *(Fe, Mn, etc.)* in natural environment or electrodes in MESs.
- Possible mechanisms for electron transfer: use electron shuttles *(mediators)*, or direct contact *(microbial nanowires, cytochromes, etc.)*

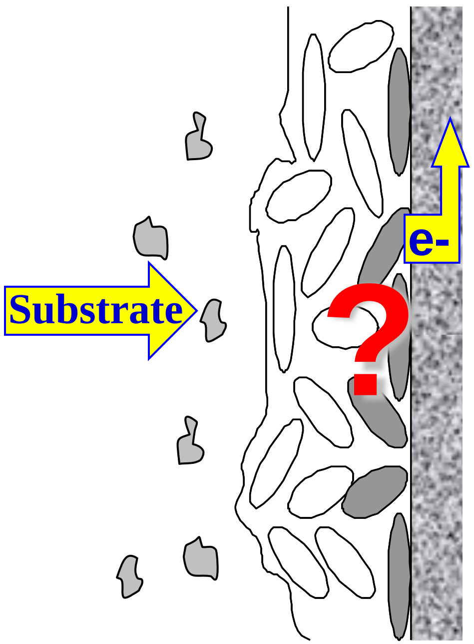


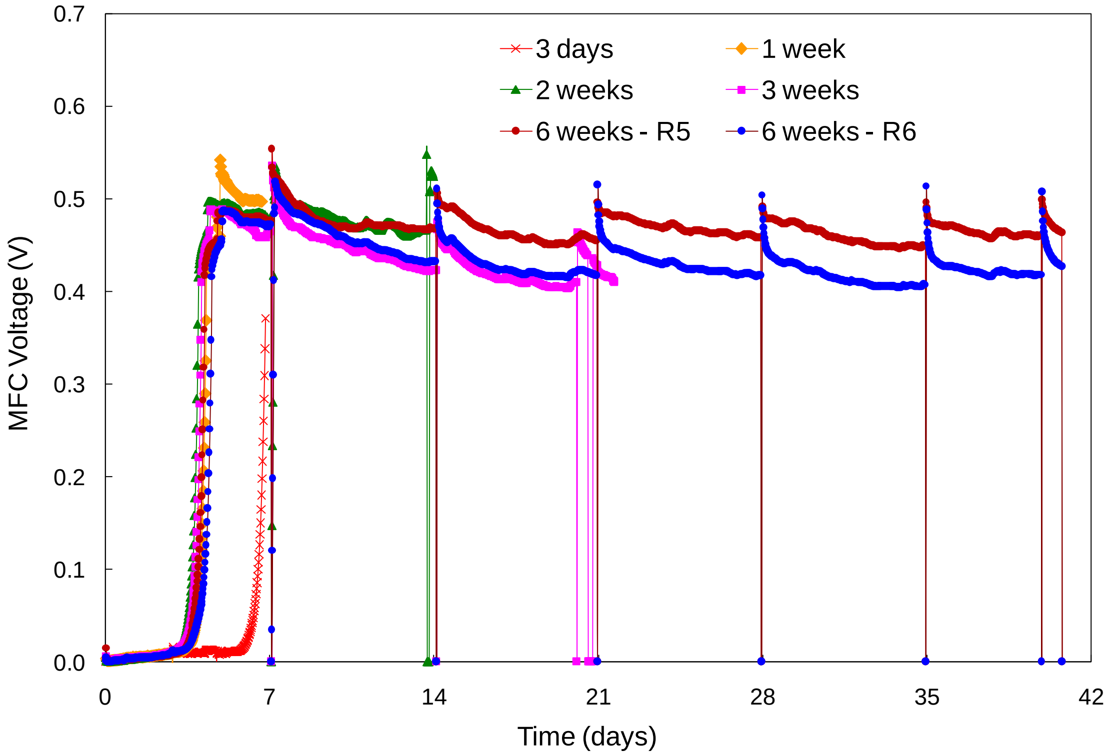
(Ren, Principles and Applications of BES, 2013)



(Gorby et al, PNAS, 2007)

Time-course correlation of cell (biocatalyst) density and electrochemical activity

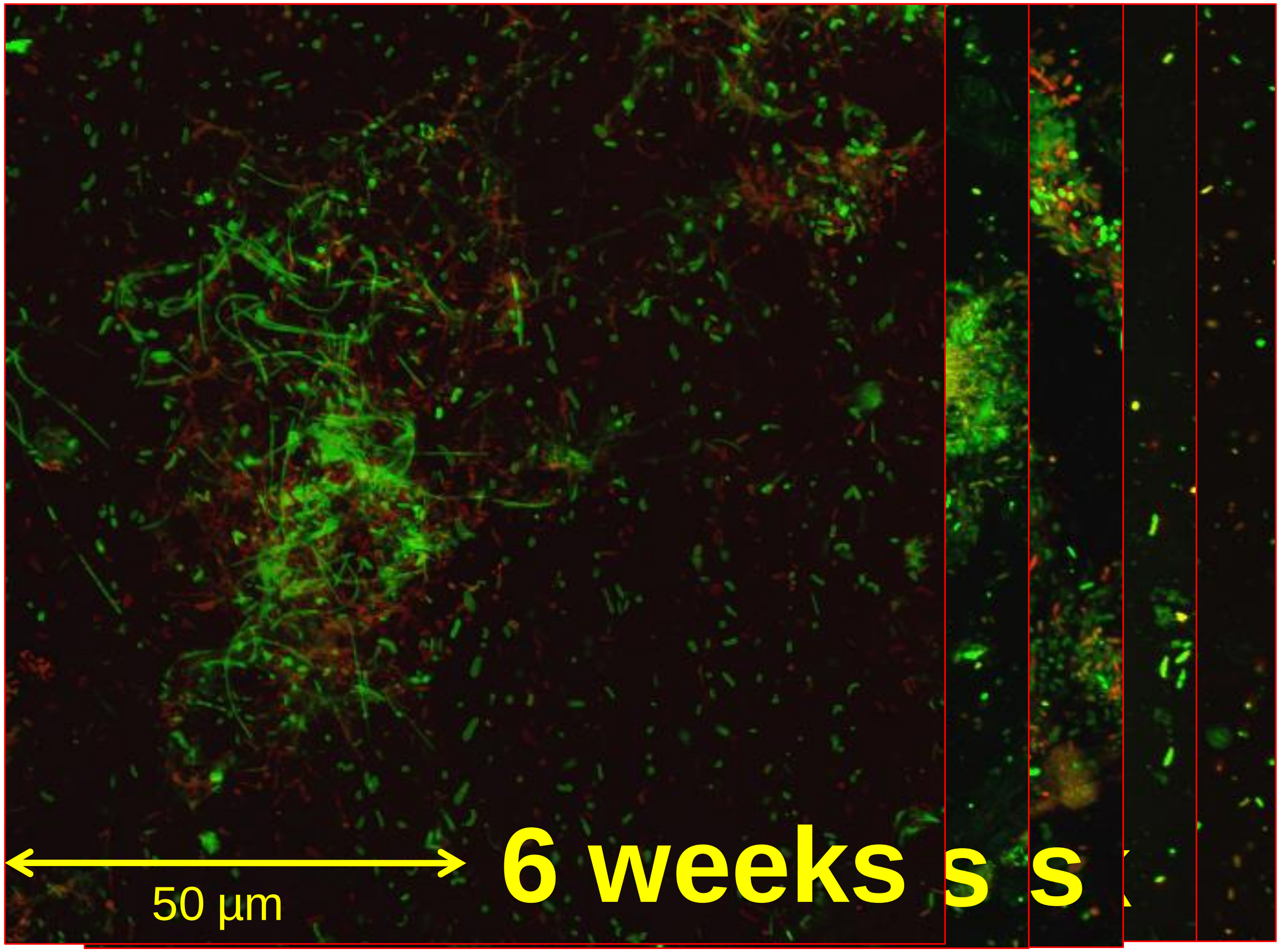




Voltage (power density) was stabilized in 4 days, while biofilm continued growing.

(Ren et al., Bioresour. Technol., 2011)

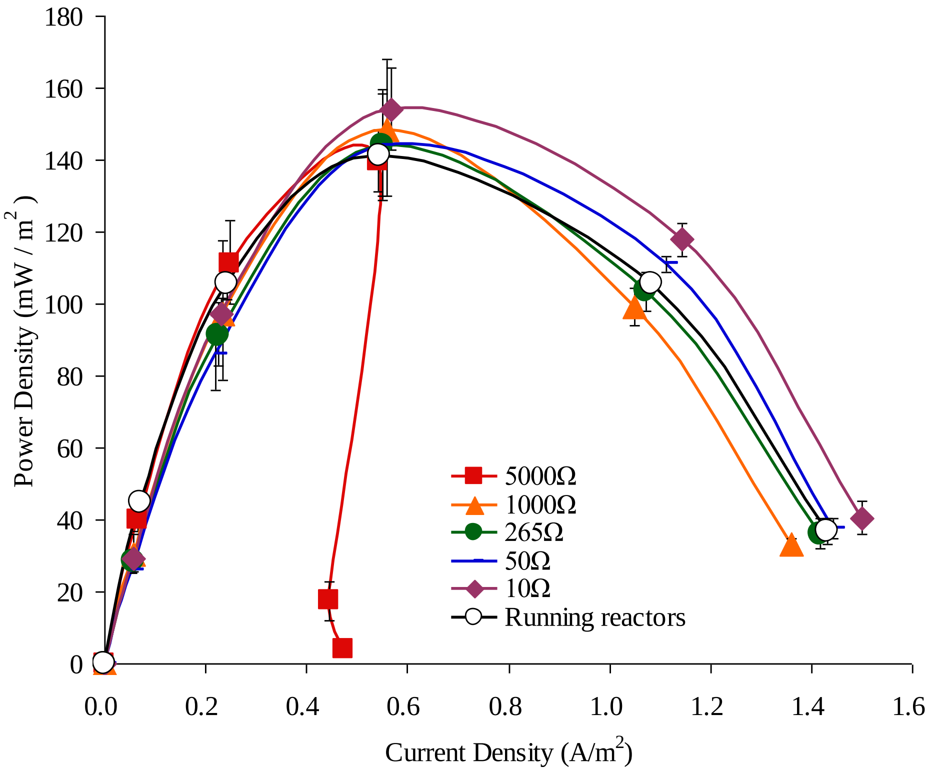
Evolution of anode biofilm at steady state power output



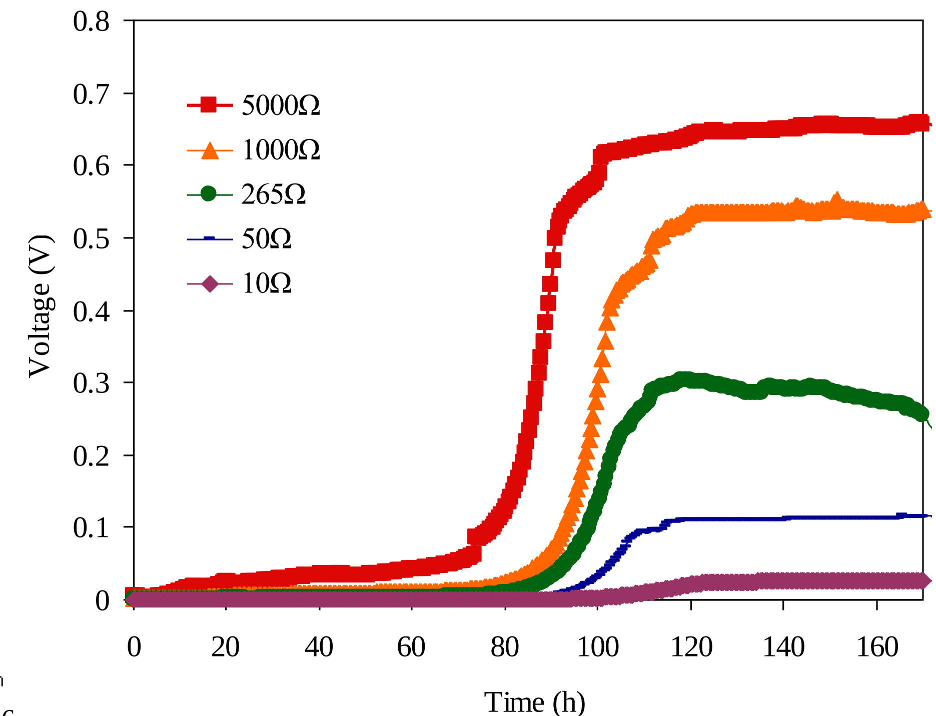
The biofilm architecture shifted from rod-shaped, dispersed cells to more filamentous structures.

(Ren et al., Bioresour. Technol., 2011)

Correlation of cell density and electrochemical activity at different anode potential or R_{ex}



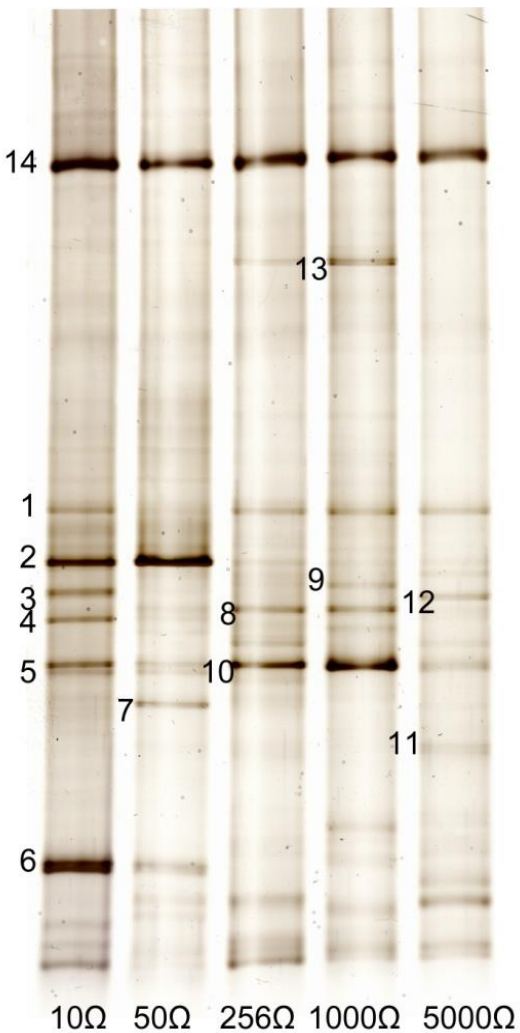
Power density curves at different Rex showed comparable profiles, but the anode biofilm architectures and communities varied considerably.

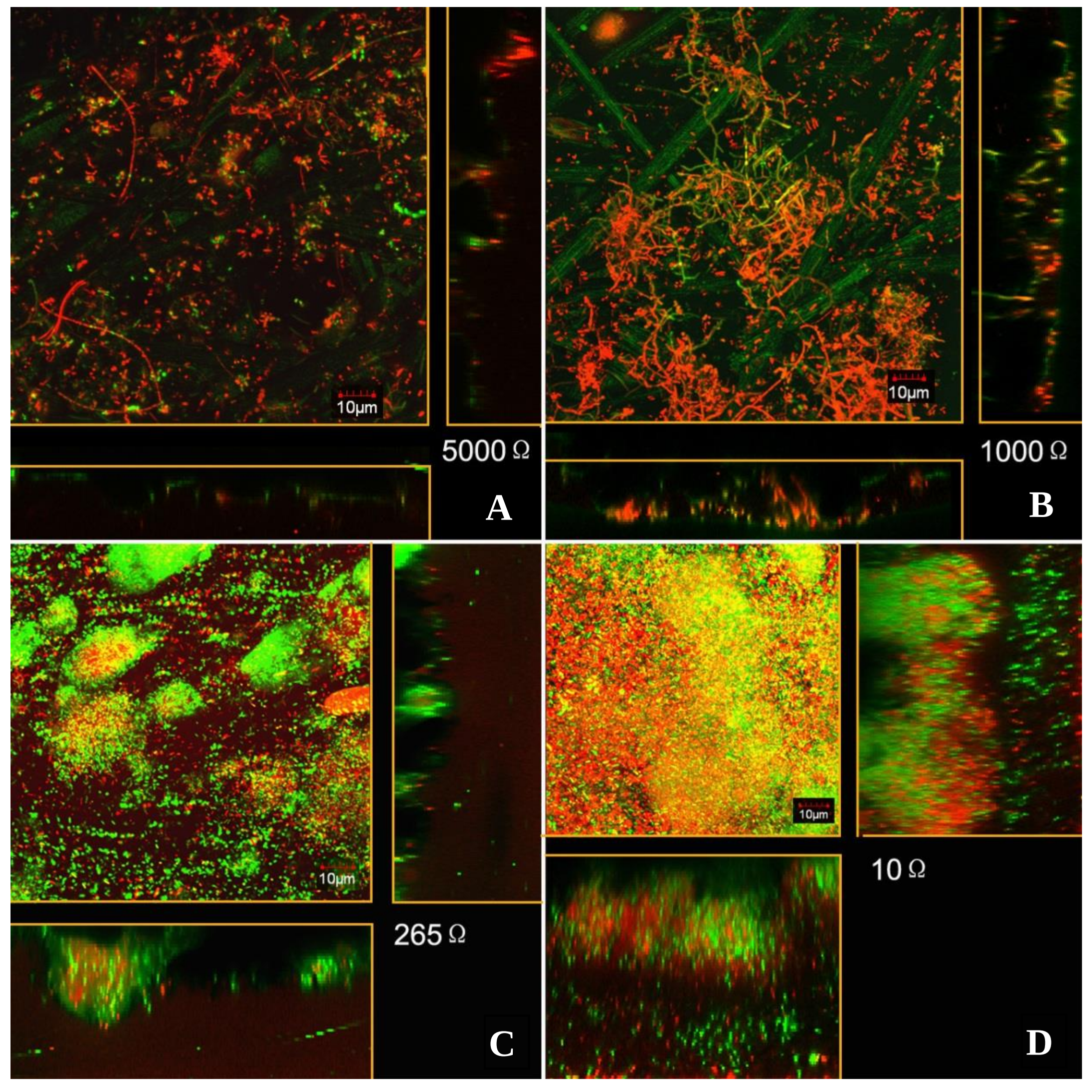


High Rex provides quicker biofilm acclimation and voltage generation, while low Rex provides higher currents. Such feature may be used to develop tailored treatment/energy systems.

(Ren et al., Environ. Sci. Technol., 2011)

DGGE profile and anode biofilm confocal images at different Rex





(Ren et al., Environ. Sci. Technol., 2011)

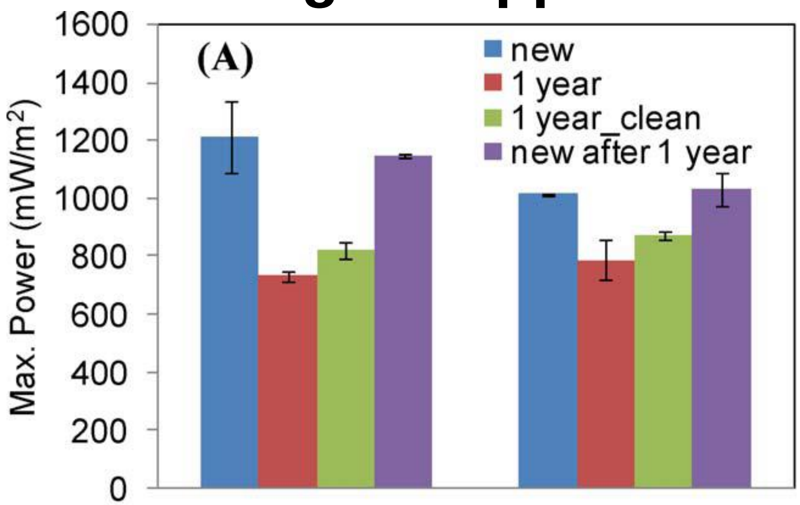
The MES performance drop due to biofouling is a main challenge in application

Anode Biofilm After 6-month operation

Cathode Biofilm After 6-month operation under different external resistors

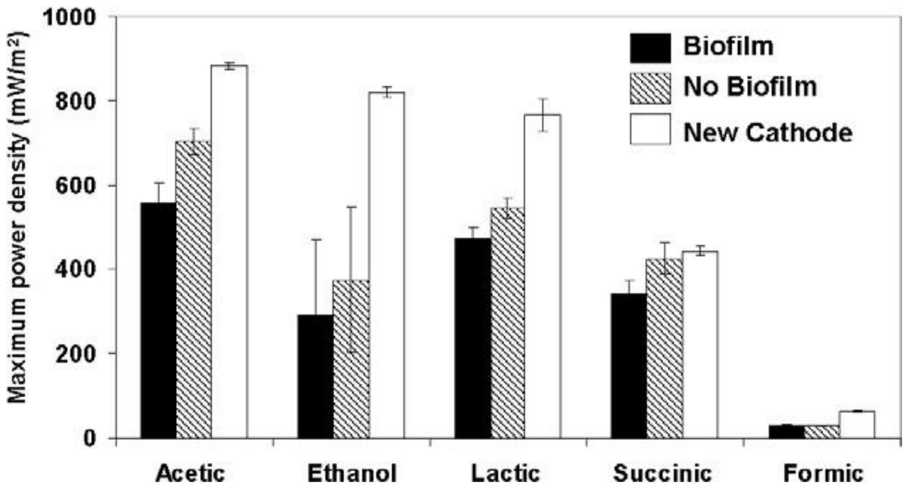
(thick biofilm was observed)

MFC performance drop due to biofouling is a main challenge in application



Zhang, et al., Biosen. Bioelectron., 2011

Cubic MES/MFC performance dropped by 30%-65% after a year due to biofilm accumulation on the electrodes.



Kiely et al, Bioresour. Technol. 2011)

The need of anti-fouling/anti-corrosion is universal in many areas

- The microbial activity related electron transfer mechanisms are similar

- The anti-fouling and anti-corrosion understanding and technologies can be transferable across different areas

- Linking to Naval applications

Photo Credit: Drs. Callow, U of Birmingham

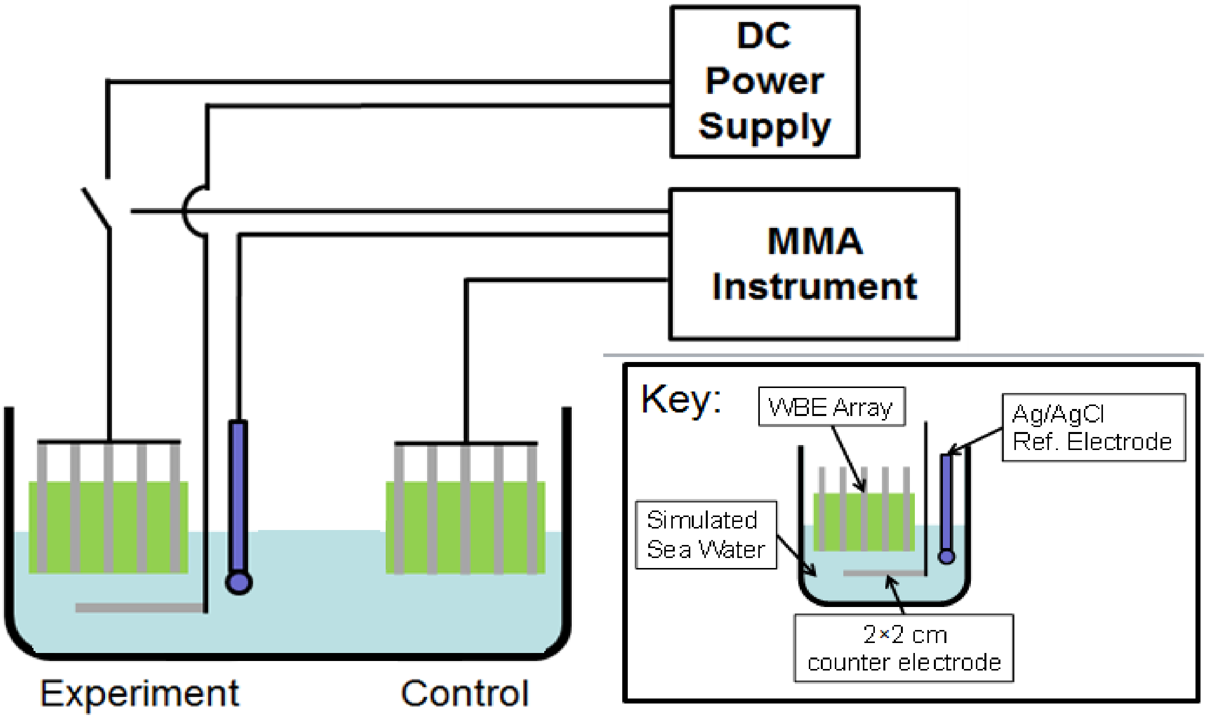
Policastro, 2011

The Hypothesis of Using Electrochemical Approach for Corrosion and Fouling Detection and Control
- Microelectrode Array (Wire Beam Electrode) Method

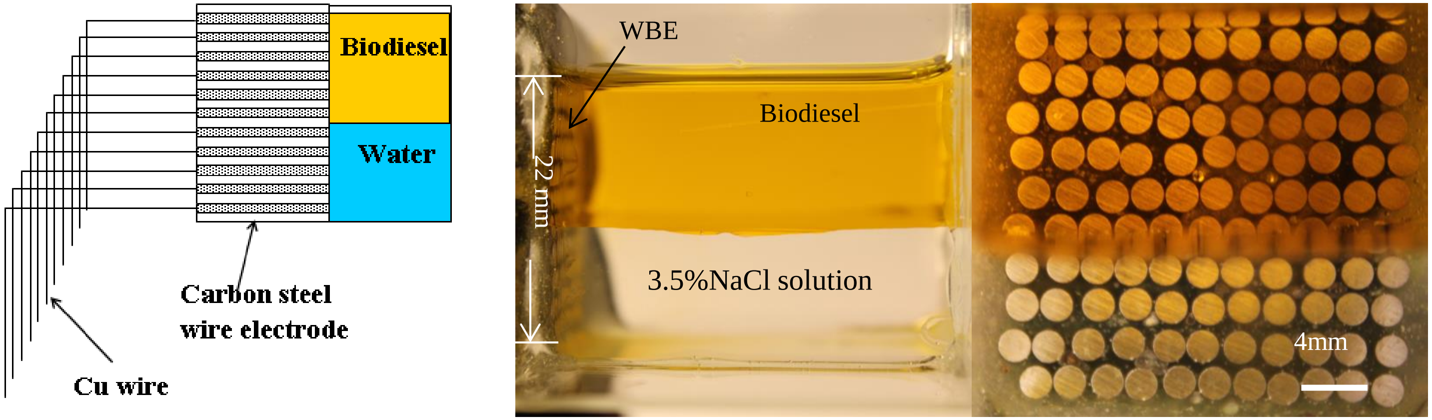
- **Detects corrosion in real time and applies localized reverse current/potential for active cathode protection**

- **The current pulse acts as electrochemical disinfection, which inhibits biofouling**

- **This approach may reduce or eliminate the expensive or toxic anticorrosion and antifouling paintings and extend vessel's service life.**

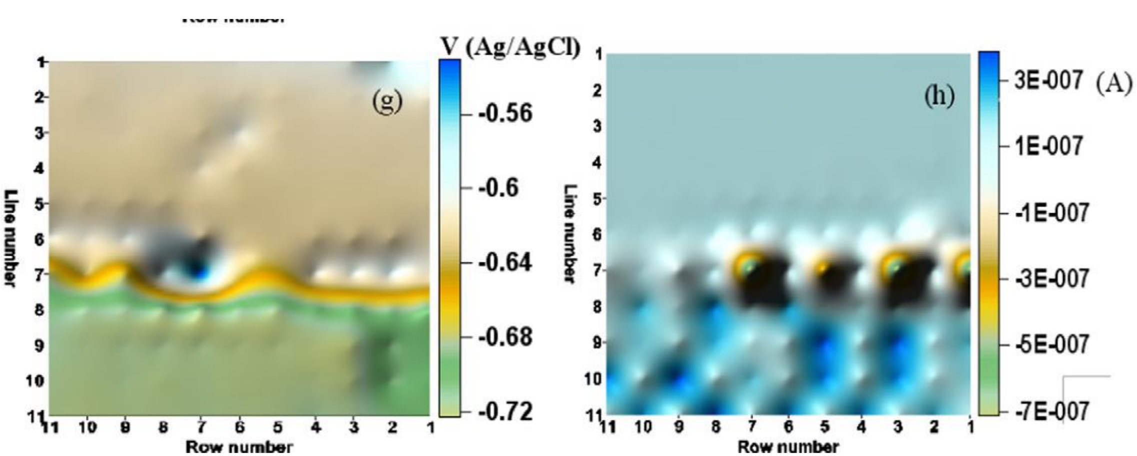


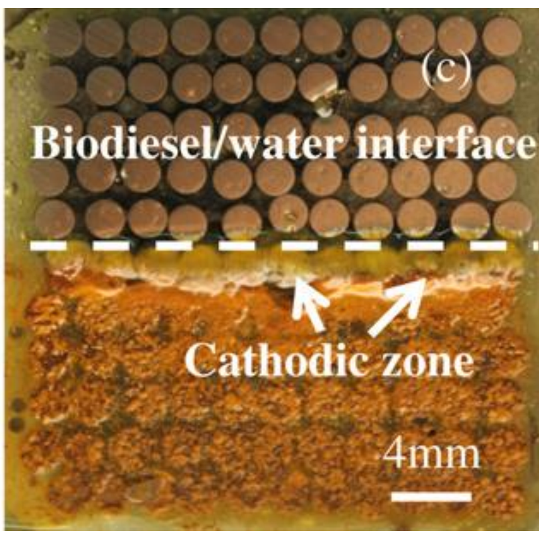
The Microelectrode Array was able to detect real time corrosion behavior in biodiesel storage tanks – earlier than optical observation



(a) (b) (c)

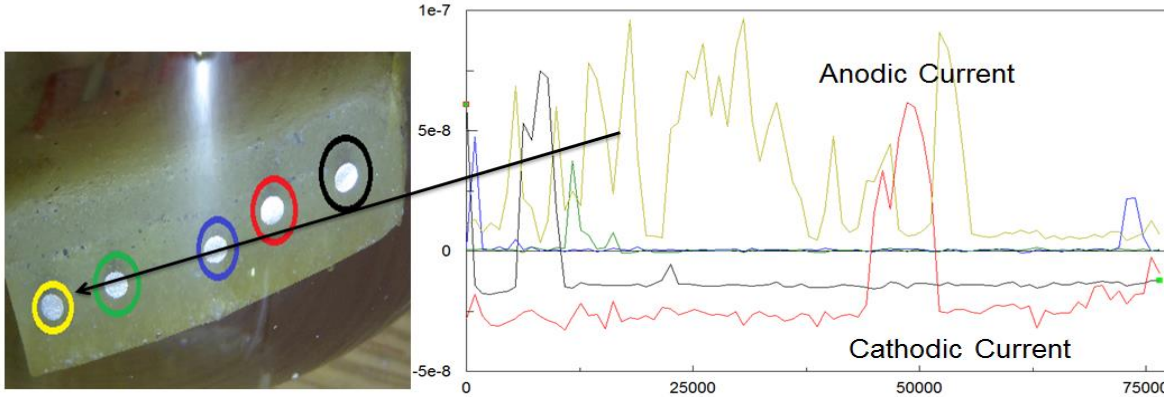
In situ current measurement of corrosion pattern





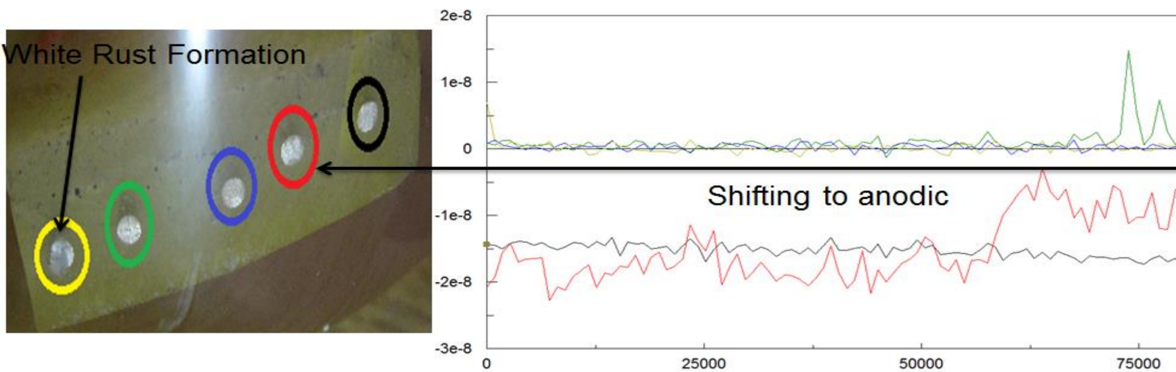
(Wang et al., Corrosion Sci. 2012)

Apply Reverse Potential for Corrosion Control



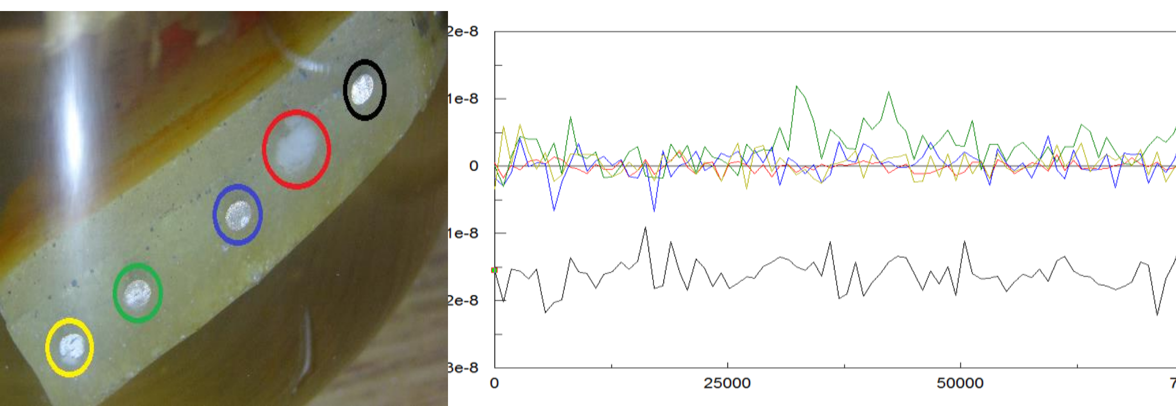
Day 1: 5 x 1 electrode array submerged in seawater

- **Yellow electrode shows anodic current, while other electrodes were either neutral or cathodic**



Day 3, white deposit occurred on Yellow cell

- **A 0.5V reverse potential was applied on Yellow cell for 24 hours**
- **Yellow cell became neutral, but then Red cell became more anodic**



Day 5, White deposit occurred on Red cell

- **A 0.5V reverse potential was applied on Red cell for 24 hours**
- **Red cell became neutral, while Yellow kept neutral**

Next Steps

1. Continue the reverse potential application and test the hypothesis of electrochemical corrosion control

2. Apply similar strategy on biofouling prevention and control

3. Develop control systems for larger scale testing and applications

4. Find partnerships in corrosion and biofouling research

Acknowledgements (The Ren Lab)

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Sponsors:

- National Science Foundation
- Office of Naval Research
- Bill & Melinda Gates Foundation
- Private Industrial Sponsors

Collaborators:

- National Renewable Energy Lab
- Naval Research Lab
- Colorado School of Mines
- University of Colorado