Microbial Electrochemical Technology (MxCs): Challenges and Opportunities

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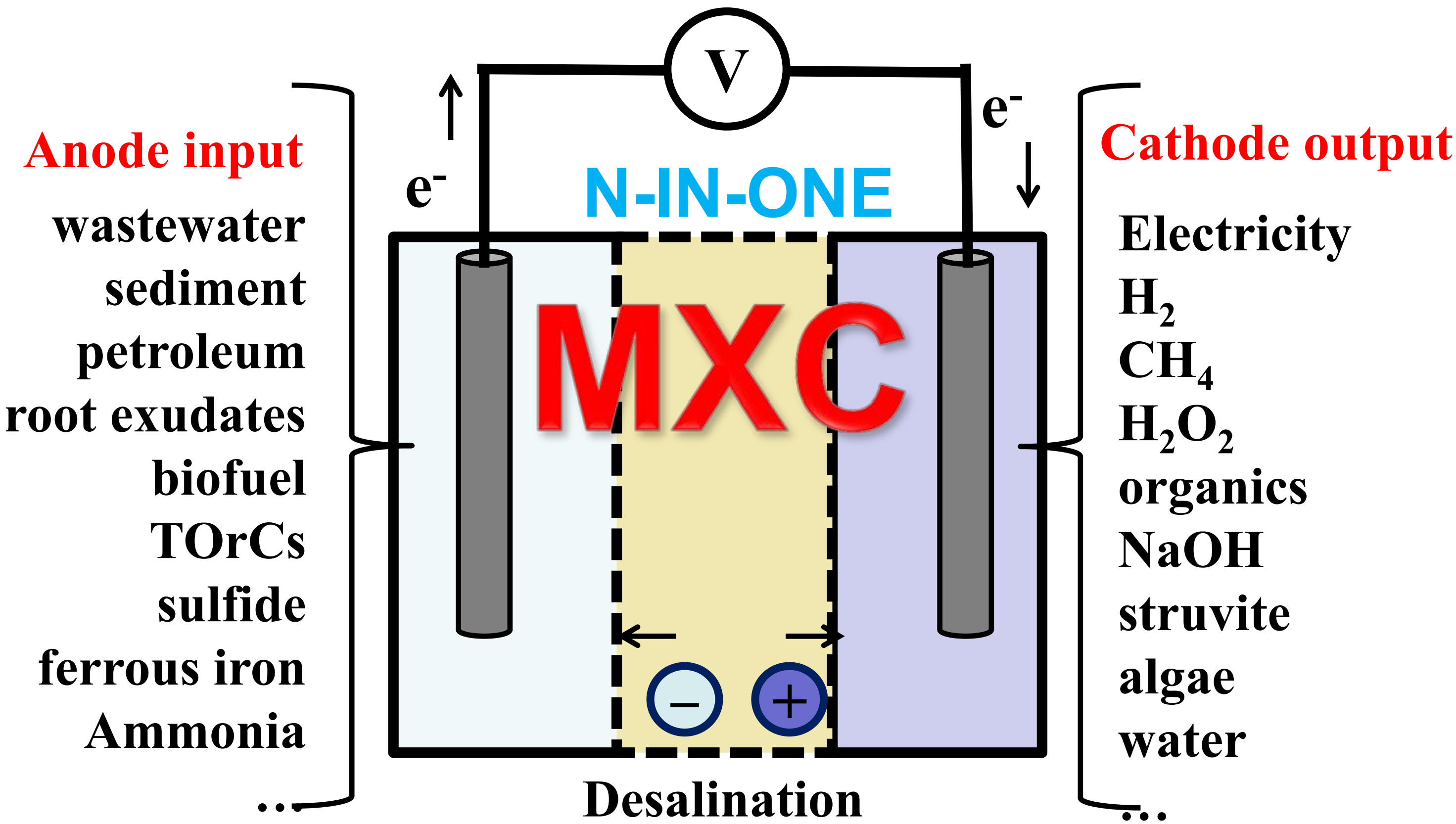
MxC is a platform technology that integrates microbiology, electrochemistry, materials science, engineering, and many related areas together

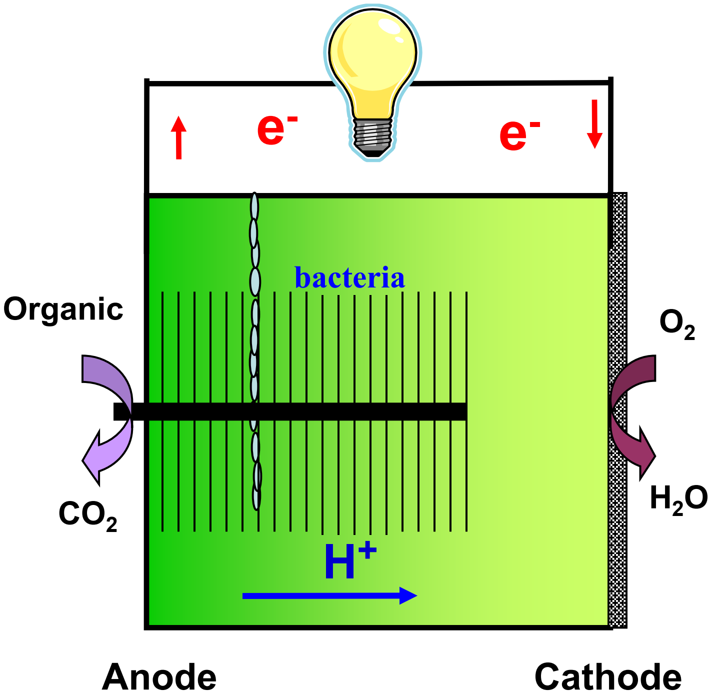


(Wang and Ren, Biotechnol. Adv. 2013,31,1796-1807)

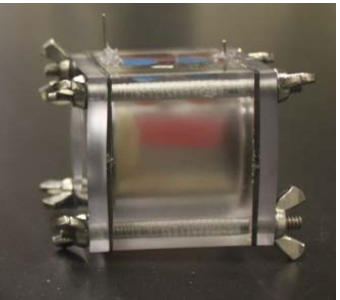
Using the electrons generated from biodegradable materials, many functions have been developed using the MxC platform

Main type of MxCs	Products
Microbial Fuel Cell (MFC)	Electricity
Microbial Electrolysis Cell (MEC)	H_2, H_2O_2, NaOH, Struvite, etc. – mainly inorganic chemicals
Microbial Electrosynthesis (MES)	CH_4, CH_3COOH, C_2H_5OH, lipid, etc. - mainly organic chemicals
Microbial Desalination Cell (MDC)	Desalinated water, in combination with other functions
MxC combined with other systems	
MxC + membrane bioreactor (MBR) MxC + capacitive deionization (CDI) MxC + photobioreactor (PBR) MxC + reverse electrodialysis (RED) MxC + forward osmosis/pressure retarded osmosis (FO/PRO) ……	

An MFC produces direct current from biodegradable materials



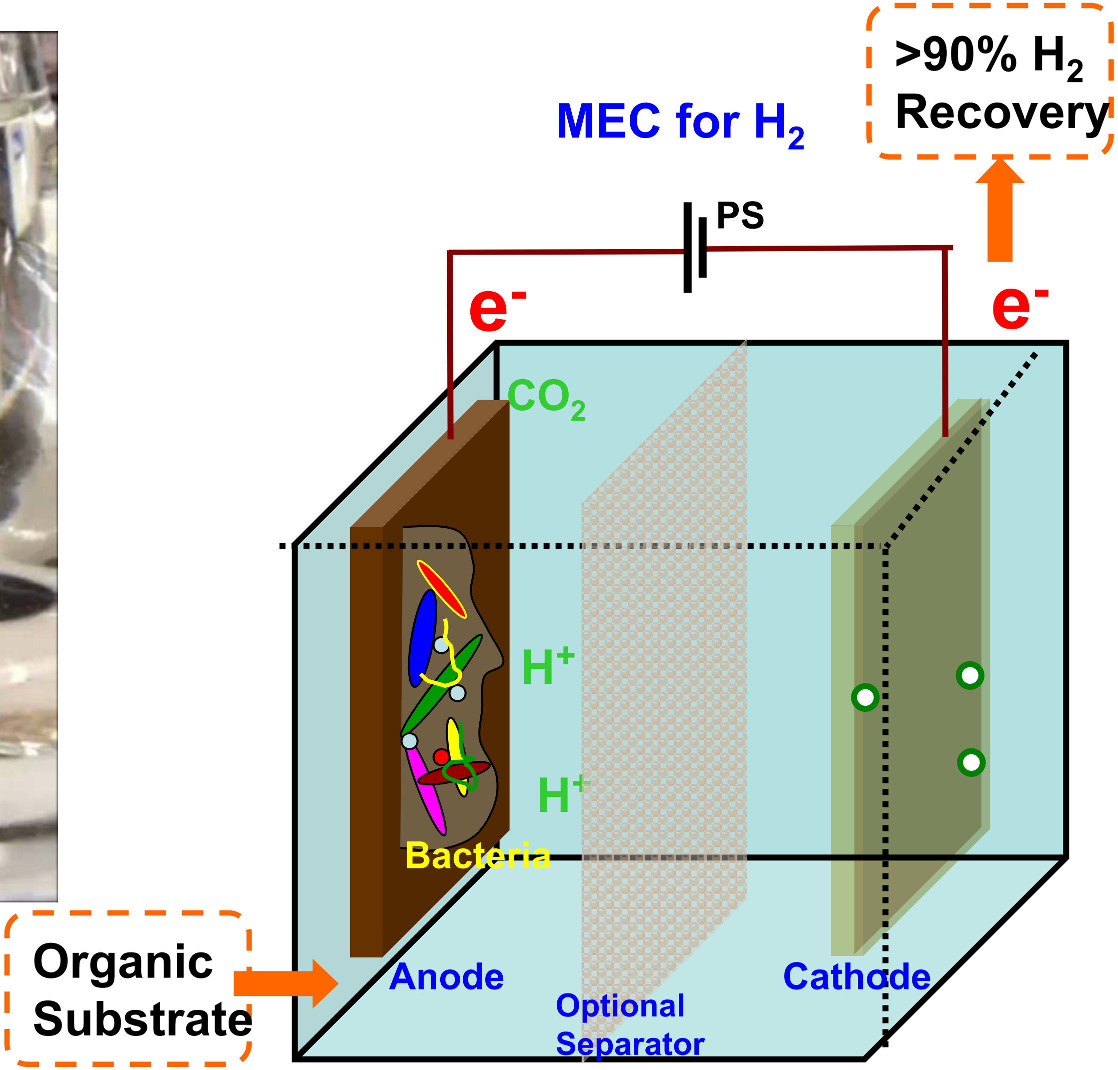
Single-Chamber,
Air-Cathode MFC



Video clip shows fan powered by an MFC

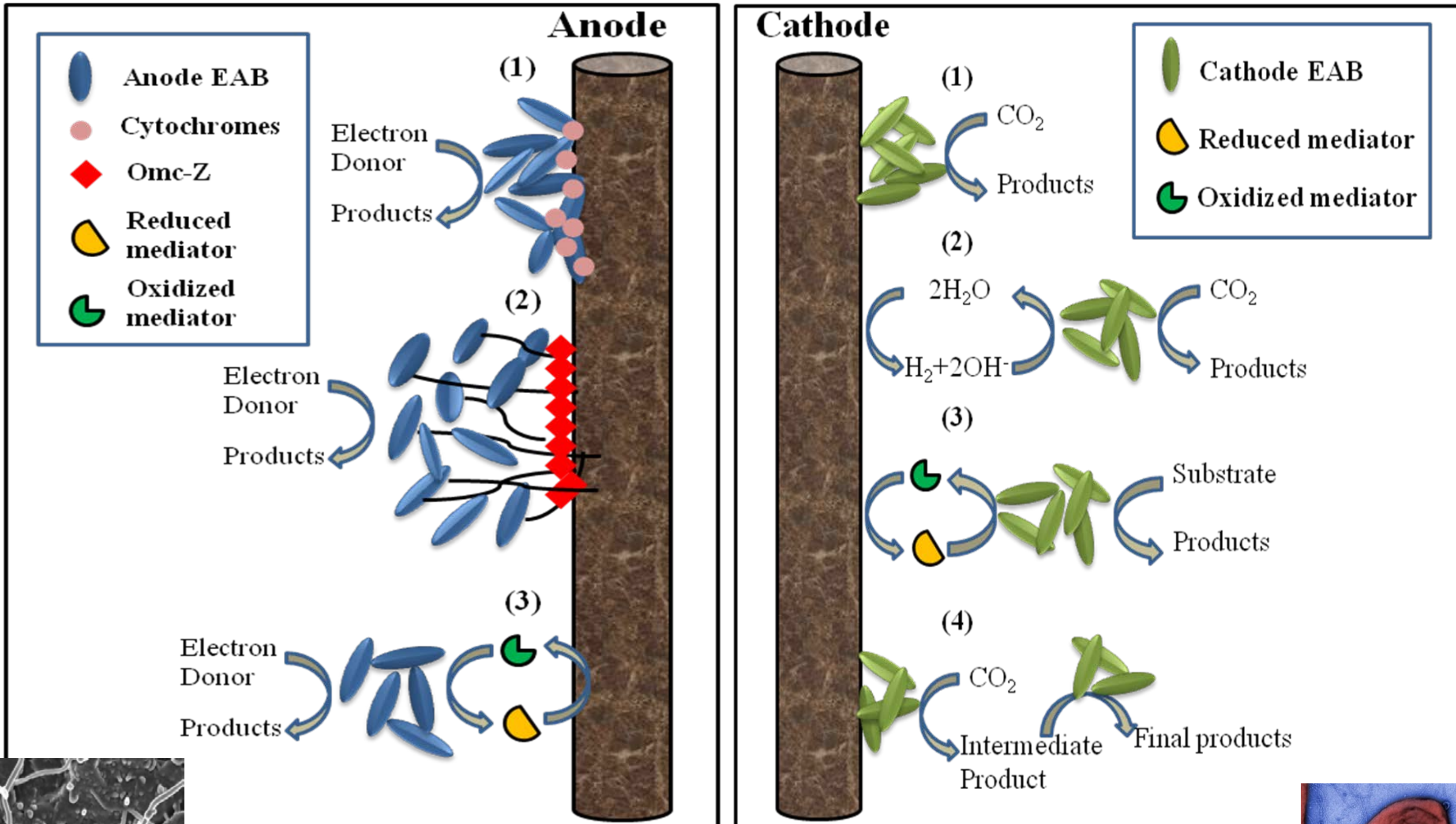
(Liu and Logan, 2005; Wang and Ren, 2013)

An MEC produces H_2 or other chemicals with the assistance of a small external voltage

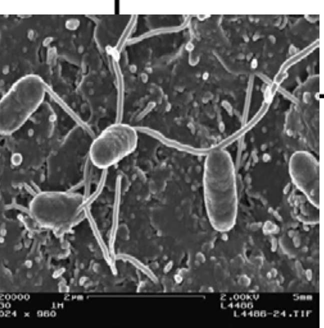


(Lu and Ren, 2015)

Microbial Interactions with the MxC Electrodes

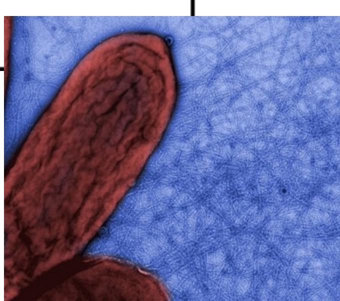


(Ren, book chapter, Biofuels, 2013)



(Gorby et al, PNAS, 2011)

(Lovley, Nature reviews, 2008)

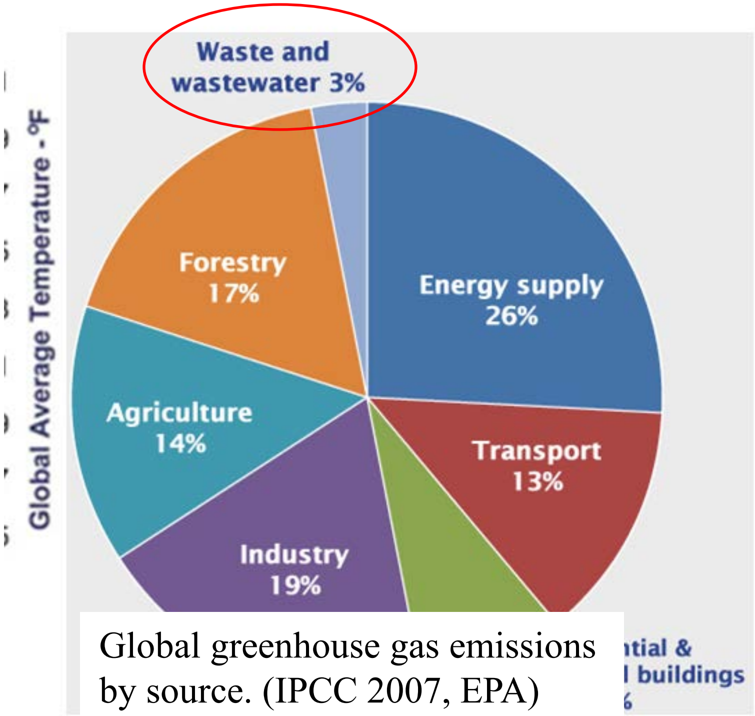


Current Wastewater Treatment Process is Energy Intensive and Carbon Positive

Current Wastewater Industry consumes high energy and emits net CO_2

-Consumes 22 Terawatt hour of electricity every year, ~ 3% of the total U.S. electrical energy load (= ~ 2.2 million household annual use)

-Emits 0.75 GigaTonnes of CO_2-equivalent, ~ 1.5% of the global greenhouse gas emissions (= ~ 260 million tonnes of coal burn)

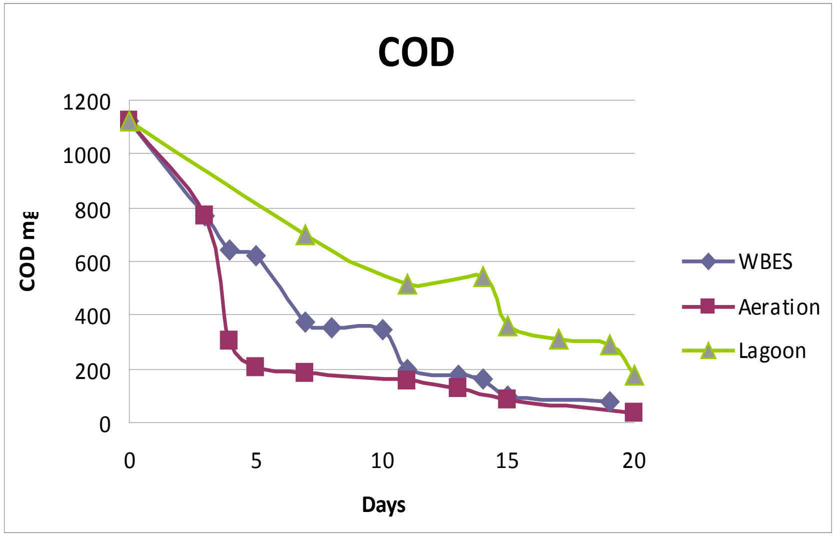


Global greenhouse gas emissions by source. (IPCC 2007, EPA)

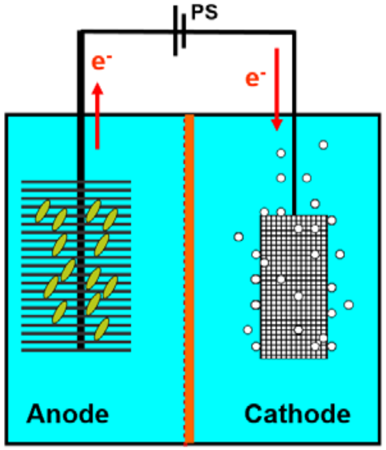
WERF, 2014

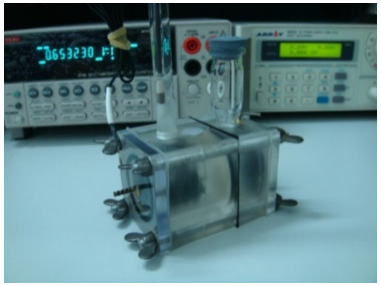
MxCs for energy-neutral or energy-positive wastewater treatment (examples)

1. MFC accomplished similar COD removal as aeration (>95%) and higher removal than lagoon using municipal wastewater.
2. For the same COD removal, MFC saved 100% aeration energy and produced ~10% more energy.
3. MFC reduced sludge production by 80% (0.11 V.S. 0.42 gVSS/gCOD).



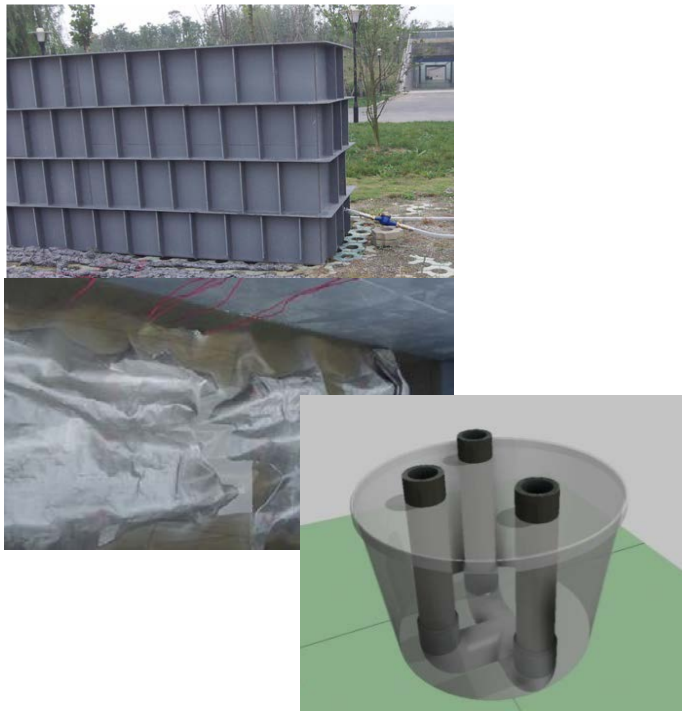
1. MEC obtained a H_2 production rate 2.27 m^3 $H_2/m^3/d$, with H_2 recovery of 91% from industrial wastewater.
2. Energy efficiency relative to the electrical input was 251%.
3. COD removal was higher than 85%.

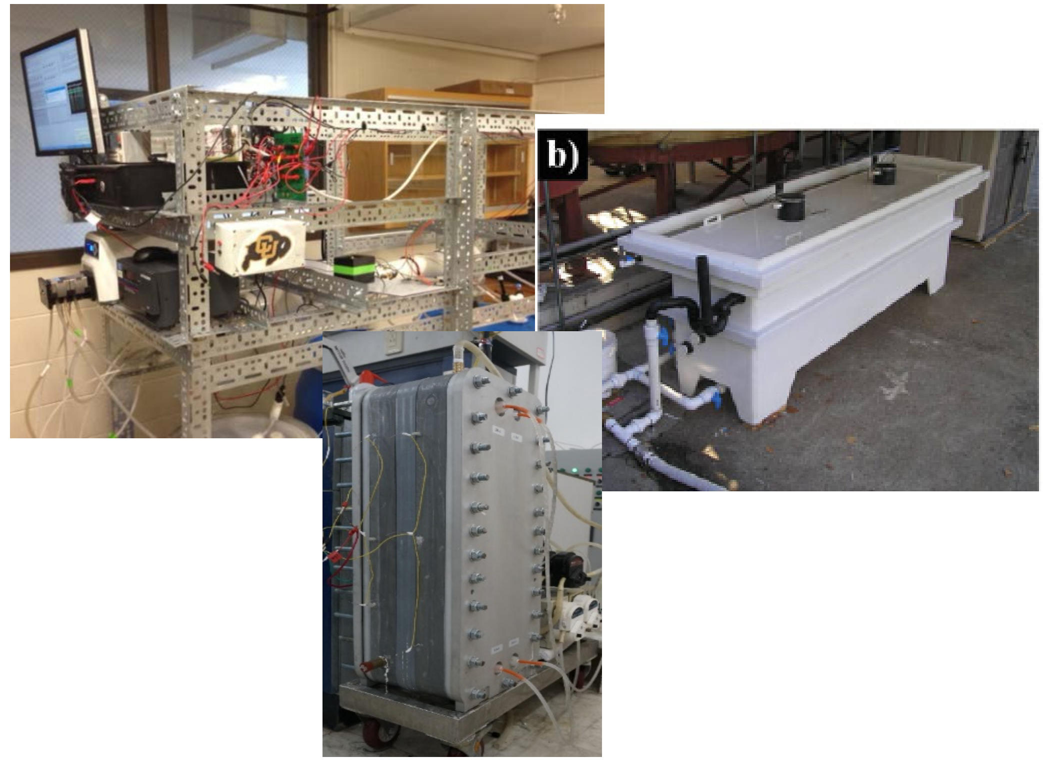




(Huggins et al,, *J Microb Biochem Technol*, 2013, Lu et al, 2015)

Two ways of scaling up MxCs – integrate into the tanks or modular device development





1. MFC in 10 m³ aeration tank, Jin & Ren, 2012
2. Pluggable MFC for Septic tank retrofit, Yazdi et al, Bioresour. Technol. 2015

1. Spiral wound MCDC (0.5 gpm) for oil/gas wastewater; Haeger, et al, 2014
2. Modular MEC (1 m³) for winery wastewater; Cusick, et al, 2011
3. Frame-n-plate MDC (60 L) for municipal wastewater; Liang et al, 2015

MxC Challenges	Development Opportunities
Treatment Challenges - Reduced performance in high/low BOD wastewater - May not meet BOD/SS discharge standard alone - Slower rate than aerobic treatment	- Combine with other processes as pre- or post treatment to deal with different influent and effluent quality needs
Energy/Product Generation Challenges - Low and unstable energy output from real wastewater - Difficult to stack and scale - Best usage of the products	- Develop energy harvesting systems to stabilize and modularize energy harvesting - Conduct quantitative studies to understand application niche of MxCs
COST - Reactor architecture - Materials - Microbial community - Product harvesting, storage, and utilization	- Product driven development - Cost driven development - Market driven development - Sustainability driven development

Low and unstable energy output from real wastewater due to wastewater intrinsic characteristics

Low conductivity and buffer capacity of WW

Limits ion transfer in MFC, resulting low power output and pH imbalance

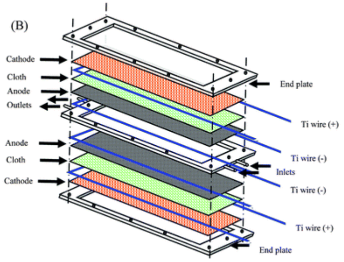
Power from the same reactor

Acetate w/ buffer – 68 W/m^3 (20 mS/cm)

WW w/o buffer – 5.1 W/m^3 (1-2 mS/cm)

Two-chamber spacer / sandwich design to improve ion transfer and reduce internal resistance

– too many parts, imbalanced surface area, and short circuiting



pH without buffer addition

Anode pH – drops from ~7 to ~5

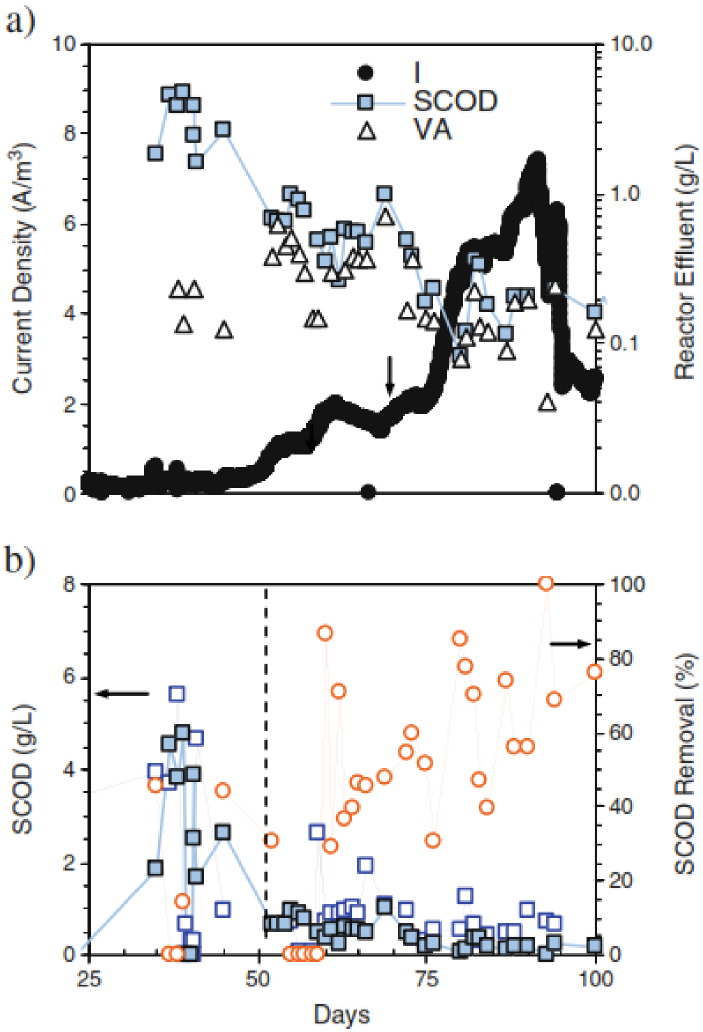
Cathode pH – increases from ~7 to ~11

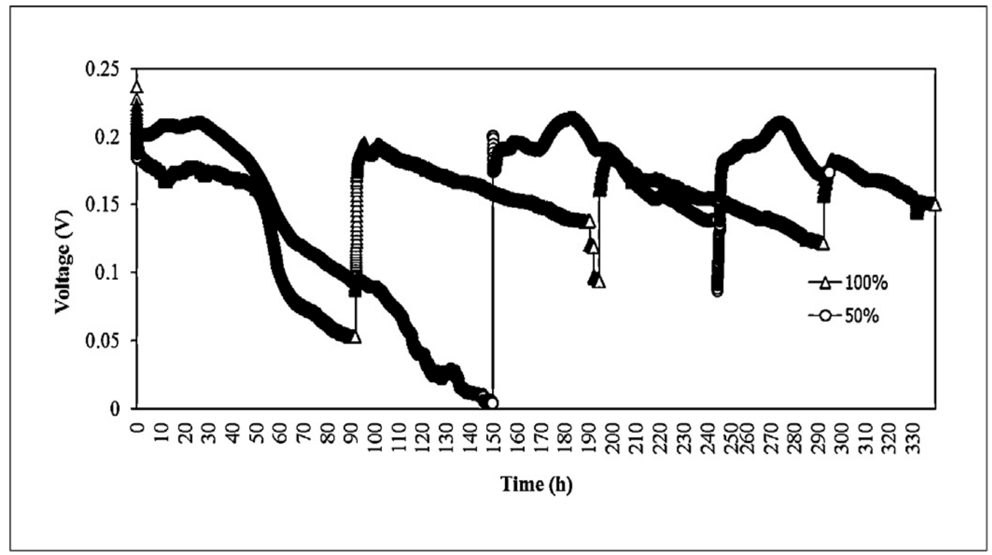
Single-chamber air cathode to minimize pH imbalance and reduce cost

– Difficult and expensive to make, leaking as a major problem

Fan et al, 2012; Rabaey et al, 2008

Low and unstable energy output from real wastewater due to wastewater intrinsic characteristics

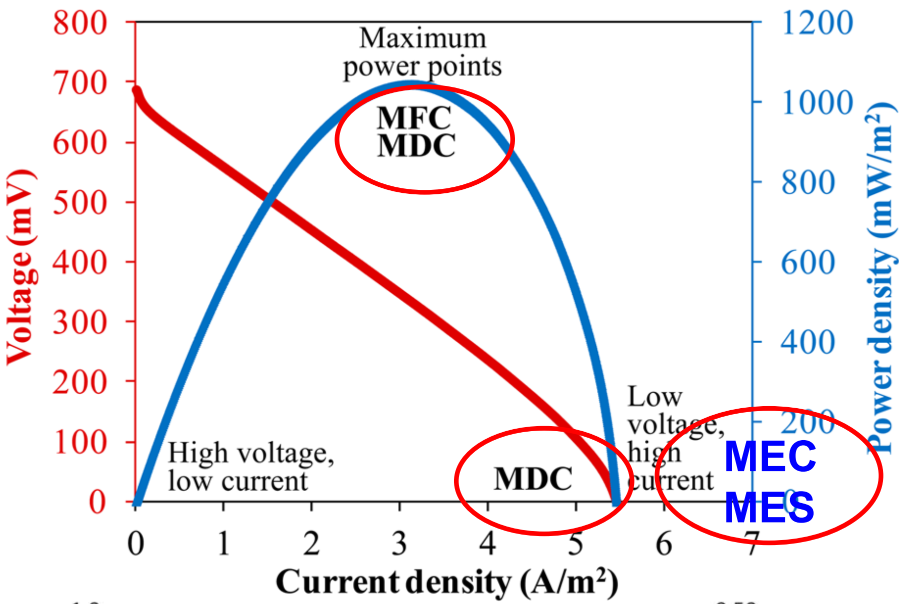


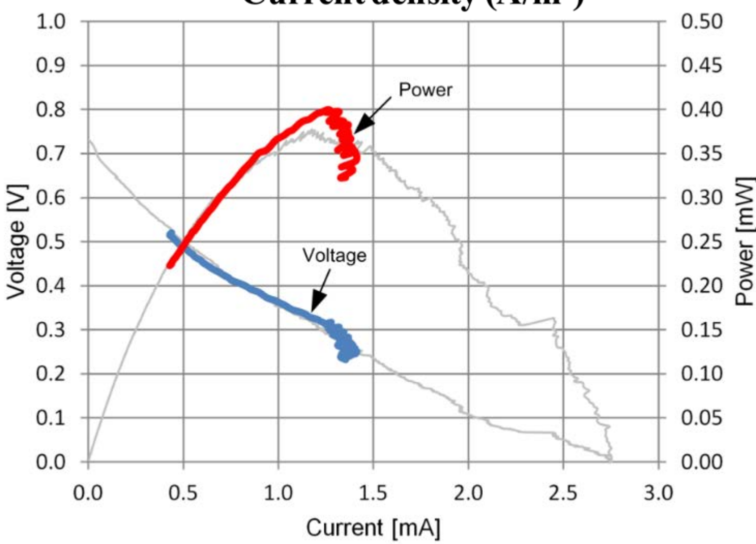


Product or electricity outputs can fluctuate significantly due to the changes of environmental conditions (pH, Temp, loading, toxicity, etc.)

(Cusick et al, 2011; Chookaew et al, 2013)

Electrical Energy Harvesting System Increases MxCs Performance and Simplifies Engineering Scale-ups





Rather than passively receiving electrons from bacteria on the anode, active energy harvesting can

1. Track real-time anode capability and maximize energy extraction – preliminary results showed 20 times increase in energy production.

2. Stacking simple electrical circuits rather than bulky MFC units can prevent voltage reversal – a major problem in MxCs.

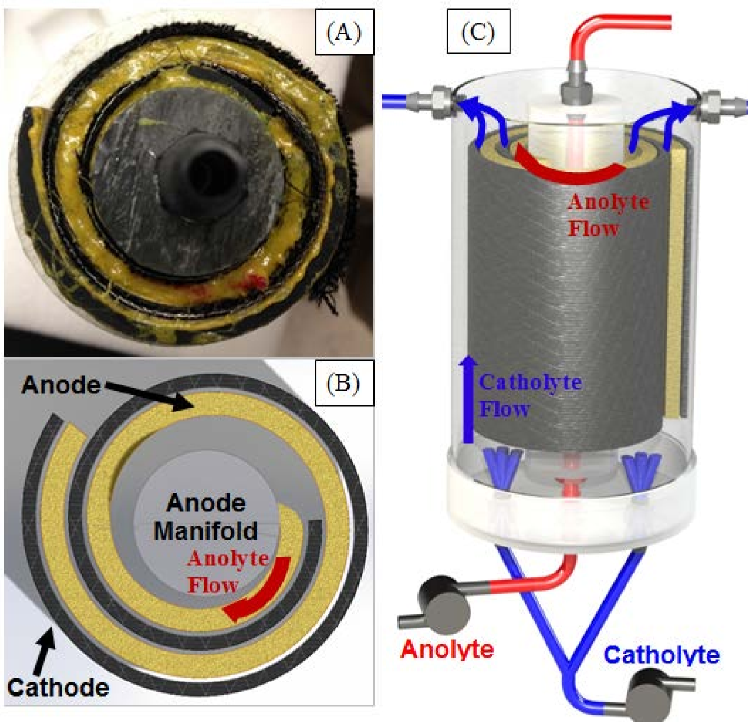
3. Using circuits to control current harvesting can stabilize MxCs output for stable energy and product generation.

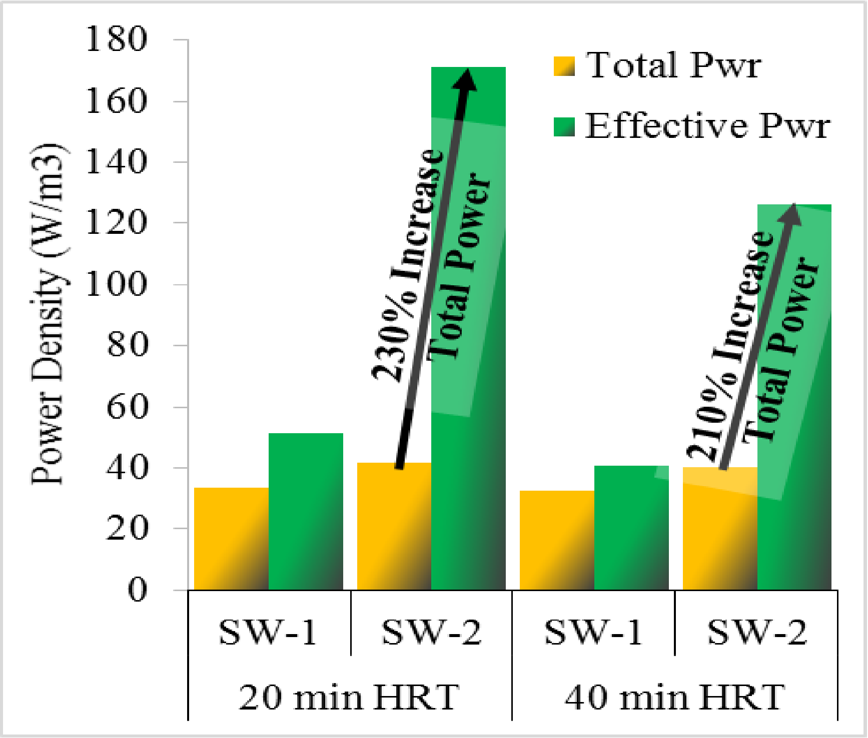
4. The active harvesting approach also posts a selective pressure for more efficient electron transfer and community structure.

(Wang, Park, and Ren, Environ. Sci. Technol. 2012, 2015)
(Park and Ren, J. Power Sources., 2012, 2012, 2013)

Spiral Wound Configuration MxC

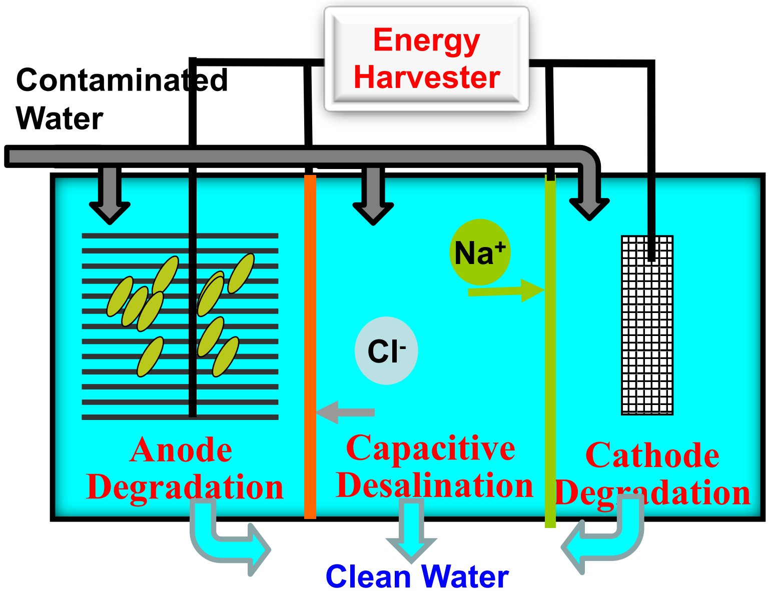
- Compact and modular design flexible for different scales
- High and matched surface areas between anode and cathode (350-700 m^2/m^3) provides high power output without using catalysts
- Reduces leaking problems faced by cubic and tubular designs
- Easily adaptable by current manufacturing infrastructure

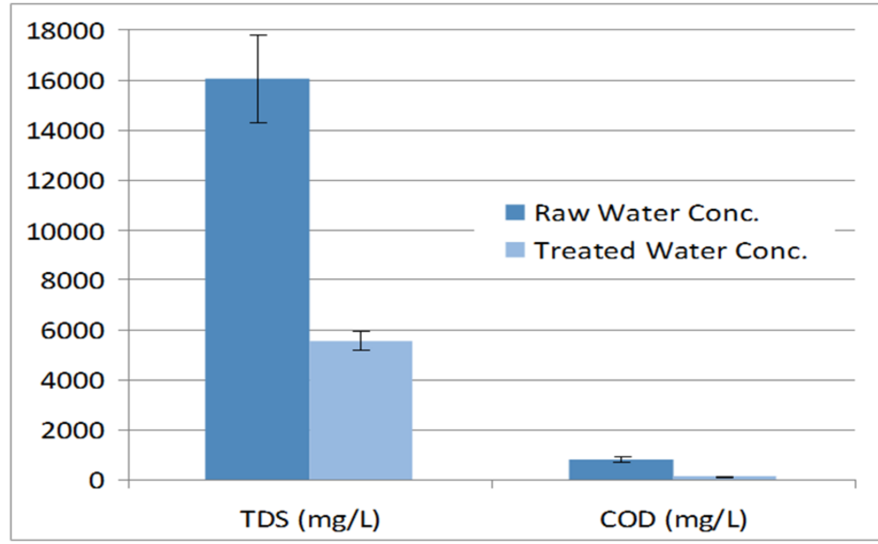




Haeger, et al, Bioresour. Technol., 2014

Microbial capacitive desalination kills 3 birds with 1 stone
- Organic removal, Salt removal, Energy/Chemical production



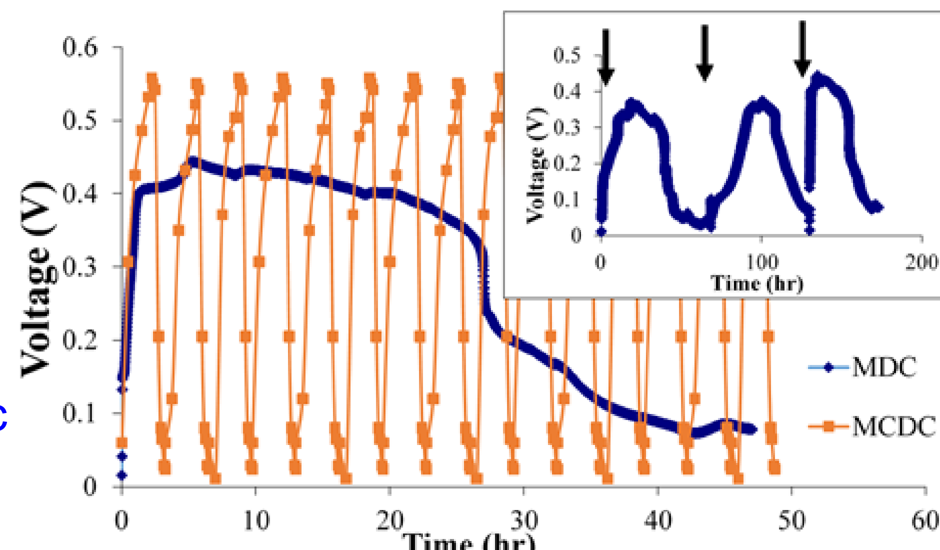


ALL simultaneously

Treat and Reuse
- Flowback and Produced Water

Remove:
-Hydrocarbons
-Metals
-Salts and Ions

Produce:
- Electricity
- Biogas (or)
- Chemicals



MCD increased rates by >10x for organic removal, salt removal, and energy production.

Forrestal et al, Environ. Sci. Water Res. Technol. 2015

MCD was a Market Driven Research – received industry supports

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By MICHAEL CASEY / CBS NEWS / March 2, 2015, 12:48 PM

Microbes could help clean up after fracking

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Energy positive treatment for fracking water

5 November 2014 Elisabeth Bowley

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$5 billion (£3 billion) is the estimated annual cost for disposing of contaminated water produced during shale gas extraction. Now, researchers in the US have developed a new technology that could reduce the cost of dealing with this water by 30–40%.

Hydraulic fracturing, the process used to extract oil and gas from underground rock formations, produces over 20 billion barrels of contaminated water every year. Current methods, such as underground injection, to dispose of these vast quantities of contaminated water have risks, including a chance of initiating earthquakes. Reuse of this water avoids disposal issues, but requires multiple treatment processes to

March 6, 2015

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University of Colorado researching microbe treatments for fracking wastewater

06 Mar 15 | Author James Perkins | Research, Trends & Technology

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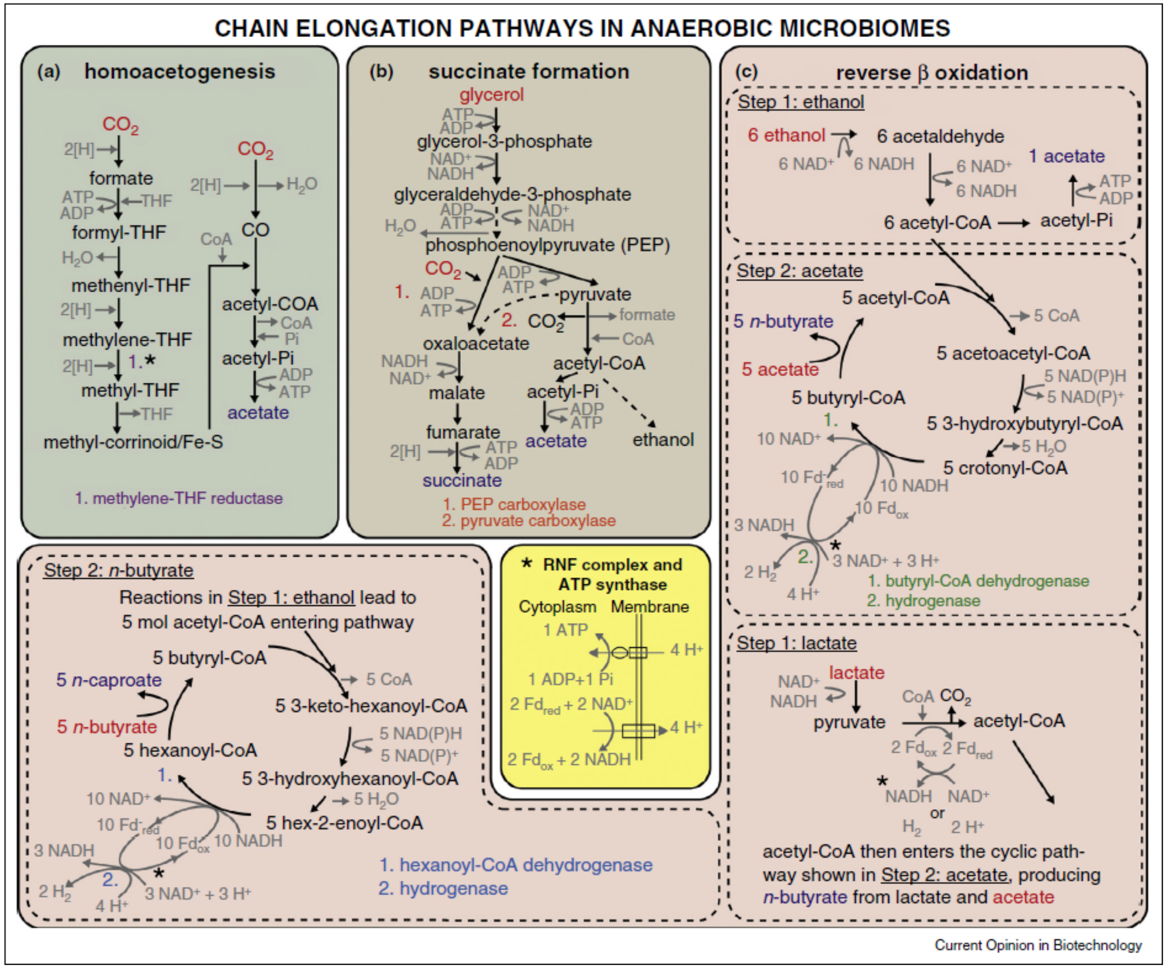
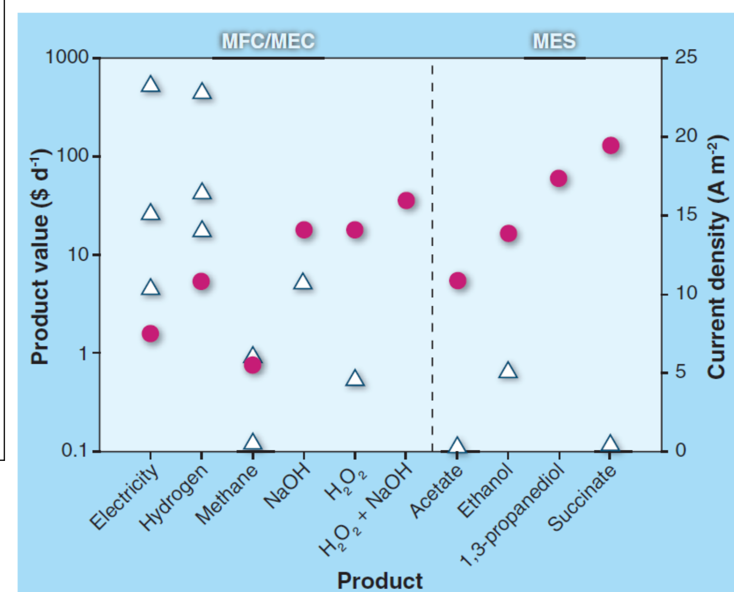
University of Colorado scientists are developing a microbe based solution to remove salt and organic contaminants from fracking wastewater

BioElectric

- A University of Colorado Spin-off Cleantech Company

MES can produce 1-2 carbon organics but more research are needed on longer-chain hydrocarbons





(Logan and Rabaey, 2012, Spirito et al, 2014)

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