

Unraveling the effects of ion exchange membranes on the performance of real wastewater treatment in microbial fuel cells



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INTRODUCTION & AIM

Microbial fuel cells (MFCs) are bioelectrochemical systems that harness the metabolic activity of microorganisms to convert organic matter in wastewater into electricity. The separation of anodic and cathodic chambers by an ion-exchange membrane is crucial for sustaining charge balance, pH stability, and ionic transport.

Different membrane types: cation exchange (CEM), anion exchange (AEM), and bipolar (BPM) govern ion migration in distinct ways, influencing redox potential, nutrient transformation, and energy recovery. While synthetic wastewater studies have revealed general trends, real municipal wastewater introduces complex interactions among organic load, ionic strength, and microbial community behavior, often resulting in variable performance.

This study investigates how these membranes affect organic removal, nutrient balance, and electrochemical response under real-world conditions to identify the most suitable configuration for sustainable water-energy recovery.

METHOD

- Three dual-chamber microbial fuel cells were built from plexiglass reactors separated by interchangeable ion-exchange membranes (CEM, AEM, BPM). The anode received municipal wastewater, while the cathode contained deionized water for oxygen reduction.
- Carbon-felt electrodes (5×10×3 cm) were linked through a 1 kΩ resistor and monitored using a digital multimeter.
- Key parameters: COD, TN, TP, ammonia, pH, EC, TDS, salinity, and DO were analyzed for each setup, and membrane performance was assessed through removal efficiency, Coulombic efficiency, and electrochemical stability.

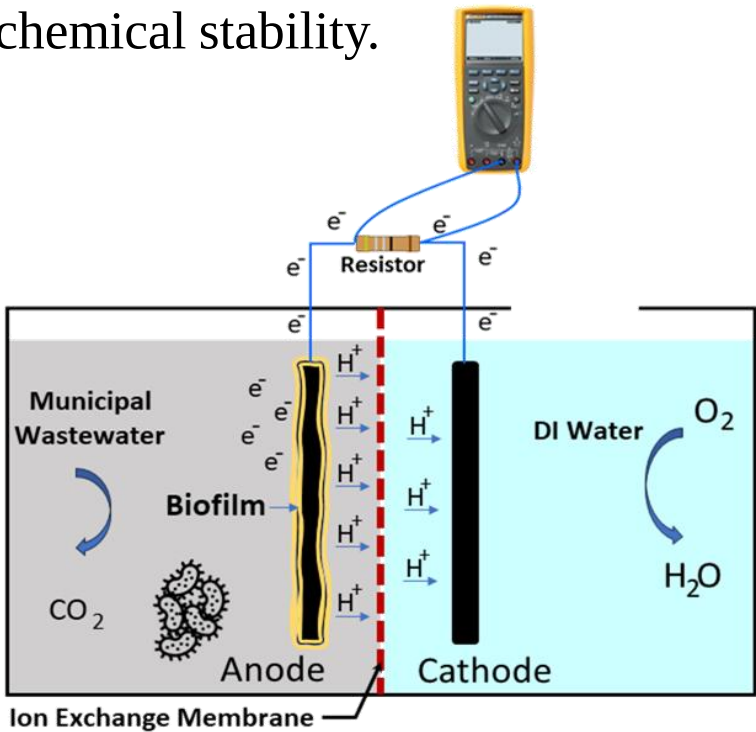


Fig 1. Schematic of Dual-chamber Microbial Fuel Cells

RESULTS

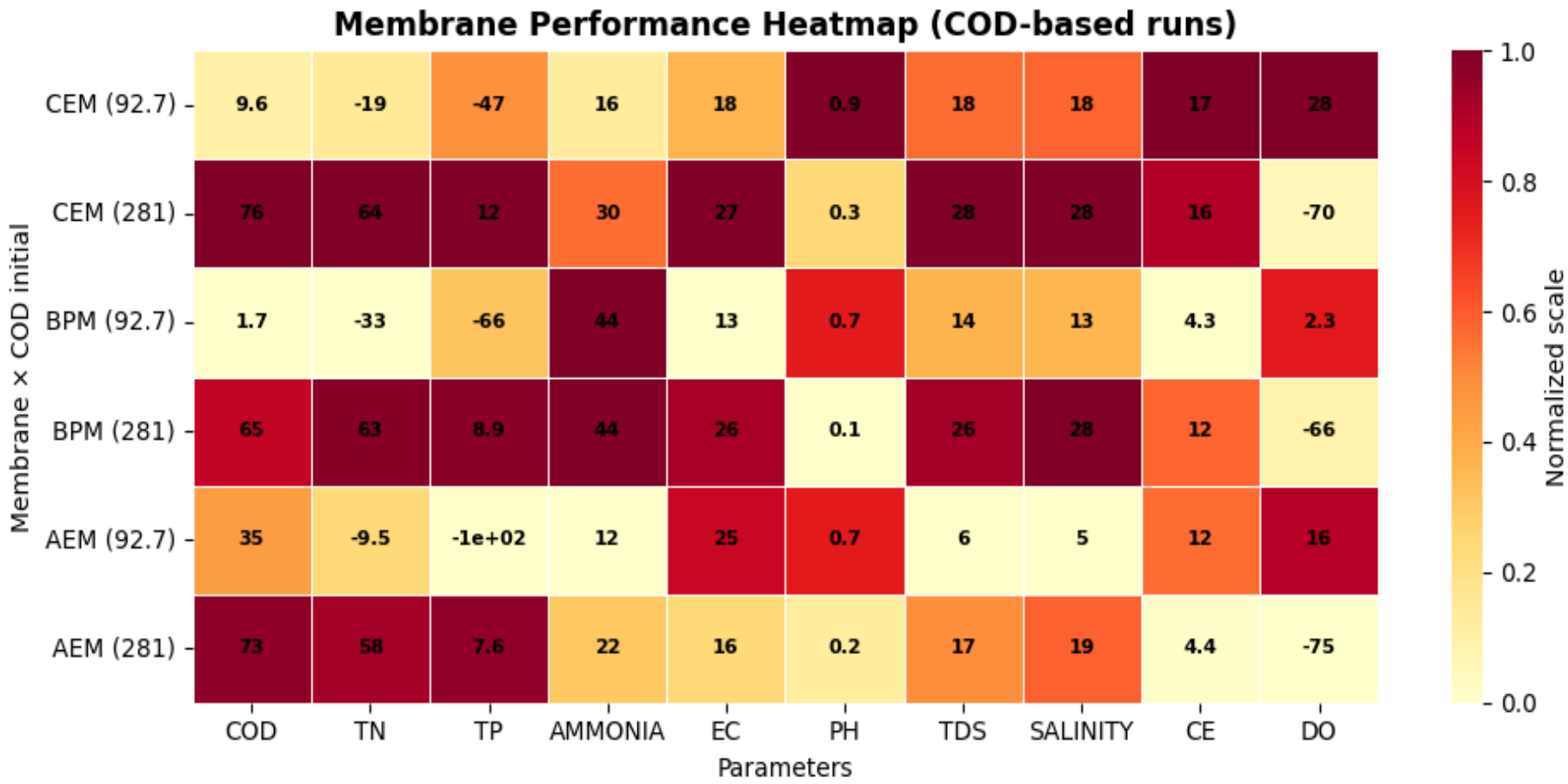


Fig 2. Normalized membrane performance heatmap illustrating parameter responses across CEM, BPM, and AEM under low & high COD loadings

Table 1: Summary of membrane behavior under contrasting COD loadings

Membrane type	High Initial COD (~300 mg/L)	Low Initial COD (~100 mg/L)
CEM	Strong COD, TN, and ammonia removal with major DO decline, indicating vigorous oxidation and high electron recovery. Highest CE and power due to efficient proton transfer.	Moderate removal and CE; minimal DO change under limited substrate.
AEM	Excellent phosphorus and COD removal but lower N/NH ₃ removal; restricted proton transport caused low CE and DO fluctuations.	Variable removal; DO stable, weak electrochemical activity.
BPM	Balanced organic and nutrient removal; internal water-splitting stabilized pH but increased resistance, giving intermediate CE and power.	Stable but lower removal; diffusion-limited at low load.

MEMBRANE SURFACE CHARACTERIZATION AND FOULING ANALYSIS

Fourier Transform Infrared (FTIR) Spectral Analysis

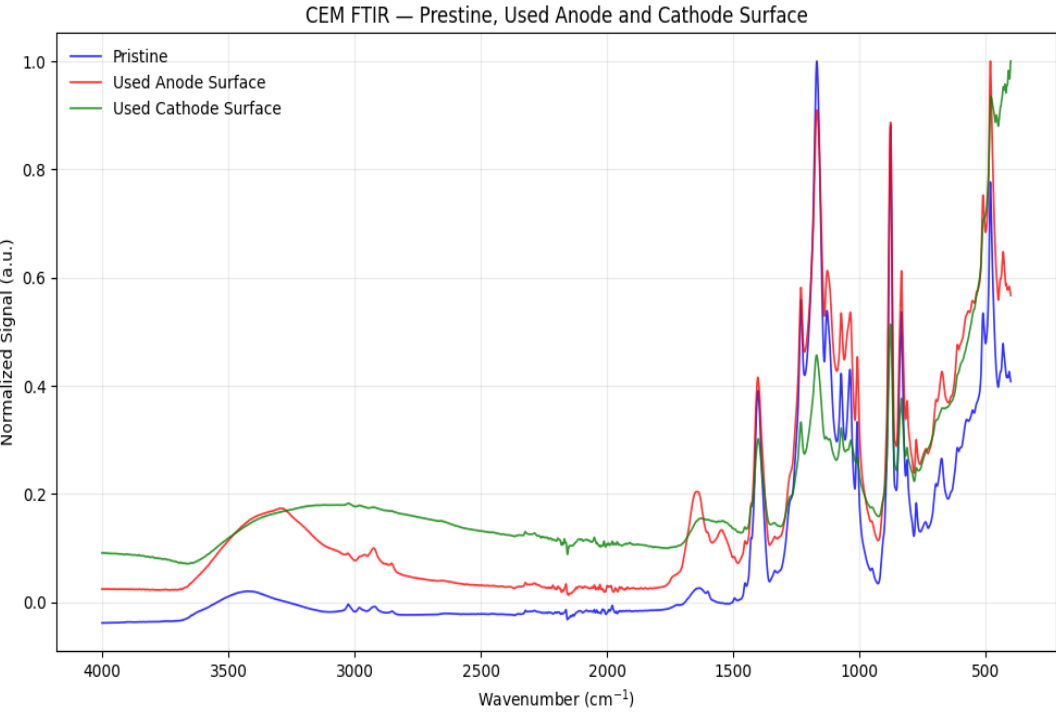


Fig 3A : Pristine & Used CEM anode & cathode surface

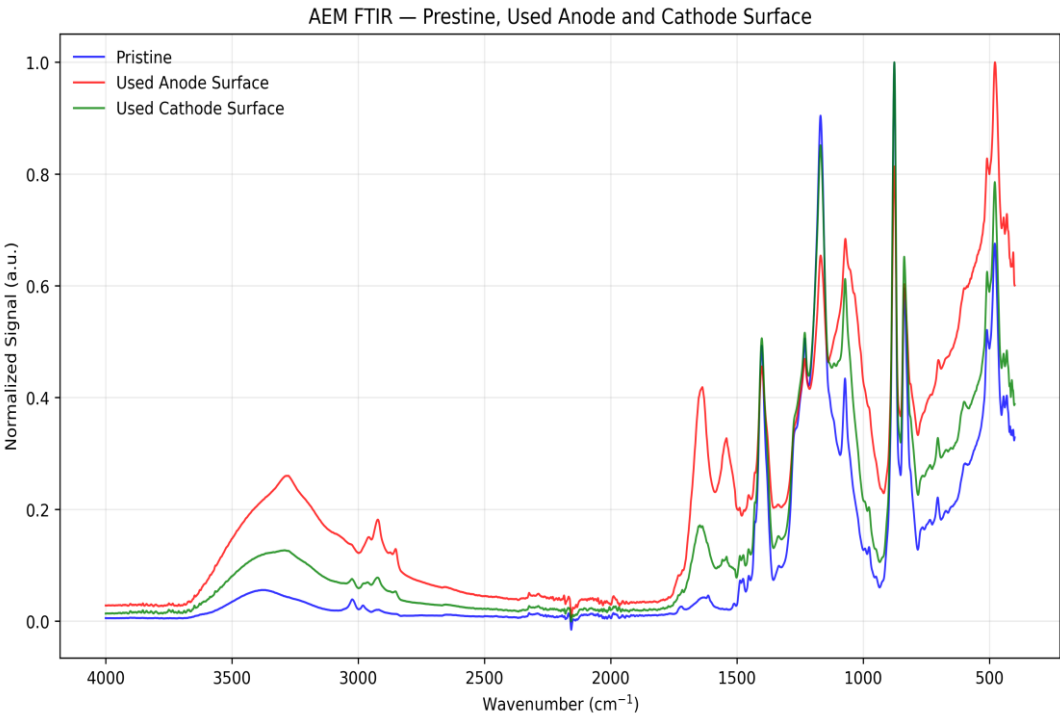


Fig 3B : Pristine & Used AEM anode & cathode surface

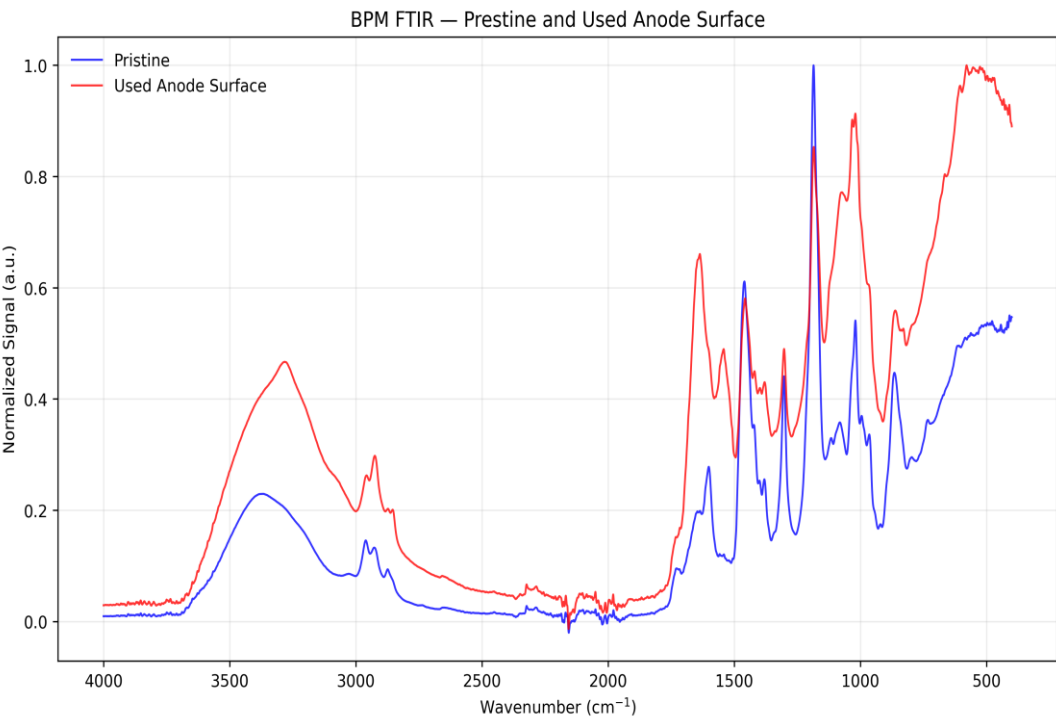


Fig 3C : Pristine & Used BPM anode surface

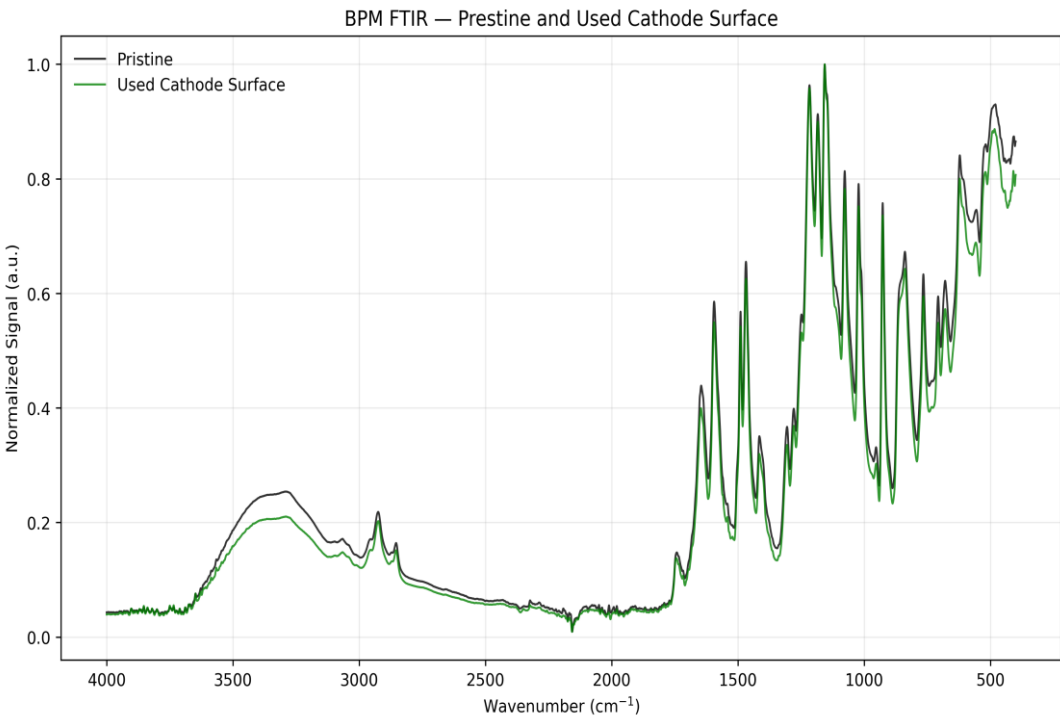


Fig 3D : Pristine & Used BPM cathode surface

Table 2: Summary table of FTIR analysis

Type	Major Functional Groups (FTIR)	Dominant Fouling Type	Performance Trend
CEM	S=O (sulfonate), C–O–C (polysaccharides)	Organic + microbial film	High COD & TN removal; strong CE; moderate fouling
AEM	P=O (phosphate), C=O (carboxylate)	Inorganic + organic complexation	Excellent P removal; low CE; severe anionic fouling
BPM	O–H, C–O stretching	Biofilm polysaccharide layer	Stable redox; moderate CE; mild fouling

Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectrometry (EDX) analysis

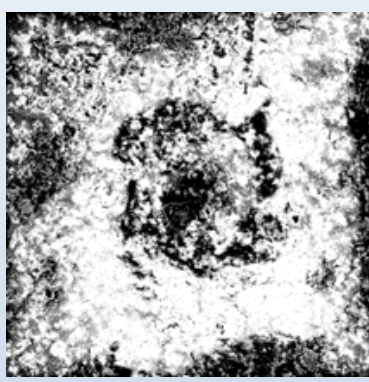
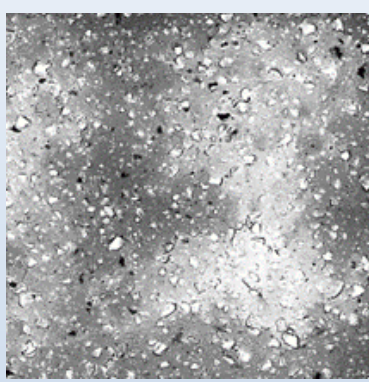


Fig 4A&B: CEM Anode-Pristine (Left) & Used (right)

CEM Anode: Pristine		
Element	Atomic	Weight
Symbol	Conc.	Conc.
F	43.06	52.45
C	50.46	38.86
O	4.36	4.48
S	1.05	2.15
K	0.47	1.18
Na	0.60	0.88

CEM Anode : Used		
Element	Atomic	Weight
Symbol	Conc.	Conc.
F	33.42	38.44
C	41.61	30.25
O	20.93	20.27
Ca	1.21	2.93
P	1.15	2.15
Zr	0.38	2.08
Te	0.27	2.06
S	0.55	1.06
Mg	0.36	0.52

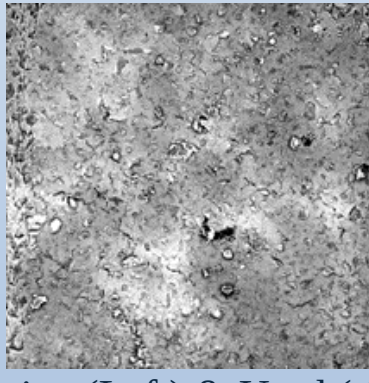
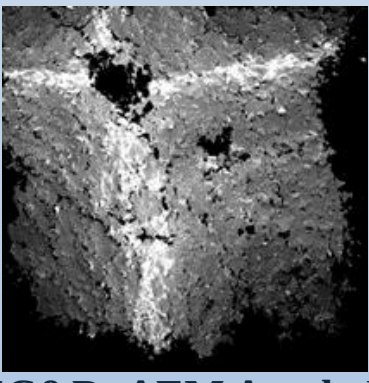


Fig 4C&D: AEM Anode-Pristine (Left) & Used (right)

AEM Anode: Pristine		
Element	Atomic	Weight
Symbol	Conc.	Conc.
C	60.15	49.28
F	35.26	45.70
O	4.59	5.01

AEM Anode : Used		
Element	Atomic	Weight
Symbol	Conc.	Conc.
F	35.78	45.26
C	51.18	40.92
O	7.38	7.86
N	5.07	4.73
P	0.39	0.80

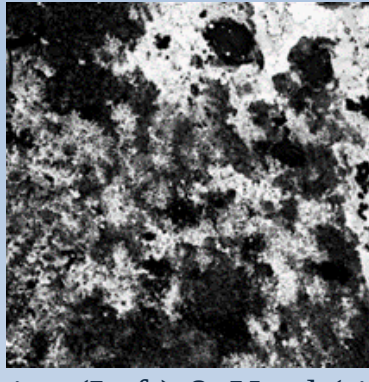
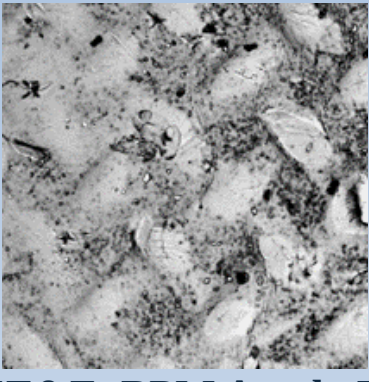


Fig 4E&F: BPM Anode-Pristine (Left) & Used (right)

BPM Anode: Pristine		
Element	Atomic	Weight
Symbol	Conc.	Conc.
C	79.79	65.33
O	16.56	18.07
Br	2.71	14.76
Si	0.69	1.32
P	0.25	0.52

BPM Anode : Used		
Element	Atomic	Weight
Symbol	Conc.	Conc.
K	15.27	20.86
O	30.90	17.28
C	39.54	16.59
Zr	2.19	6.97
P	6.40	6.93
Br	0.91	2.53
S	0.88	0.99
Si	0.72	0.70

CONCLUSION

Membrane behavior strongly influenced both treatment efficiency and electrochemical performance. Tailoring selection: CEM for higher power output, AEM for nutrient polishing, and BPM for balanced operation offers a practical approach to optimize pollutant removal and energy recovery in real wastewater applications.

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- Hernández-Flores, G., Poggi-Varaldo, H. M., & Solorza-Feria, O. (2016). Comparison of alternative membranes to replace high cost Nafion ones in microbial fuel cells. *International journal of hydrogen energy*, 41(48), 23354-23362.