Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass

PI: Hong Liu

Oregon State University

April 30, 2019

Project ID PD129

Overview

Timeline

- Project Start Date: 02/01/16
- Project End Date: 04/30/20

Barriers

- Low hydrogen molar yield (AX)
- High electrode (cathode) cost (AAA)
- Low hydrogen production rate (AAB)

Budget

- Total Project Budget: $1,670K
  - Total Recipient Share: $167K
  - Total Federal Share: $1,500K
  - Total DOE Funds Spent*: $1,217K

* As of 2/1/19

Partners

- **US DOE**: project sponsor and funding
- **OSU**: project lead; cost-share funding
- **PNNL**: co-project lead

Relevance

Project goal:

Develop a microbial electrochemical system for H_2 production from low-cost feedstock (lignocellulosic biomass and wastewater) at a cost close to or less than \$2/kg $H_{2.}$

Approach/Strategy to Achieving DOE's target:

Characteristics	Units	Current Status	Project Target	Commercial Target
Feedstock		hydrolysate/ wastewater	hydrolysate/ wastewater	hydrolysate/ wastewater
Feedstock cost contribution	\$/kg H_2	1.21/0	0.98/0	0.98/0
Capital cost contribution	\$/kg H_2	1.47/1.47	0.81/0.85	0.46/0.63
Electricity cost + other operational cost	\$/kg H_2	0.75/0.86	0.75/0.76	0.40/0.75
Fixed O&M cost	\$/kg H_2	0.38/0.38	0.31/0.33	0.17/0.25
Total cost	**\$/kg H_2**	**3.81/2.71**	**2.86/1.94**	**2.03/1.63**
Credits	\$/kg H_2	0/-10	0/-10	0/-10
Final cost	**\$/kg H_2**	**3.81/-7.29**	**2.86/-8.06**	**2.03/-8.46**

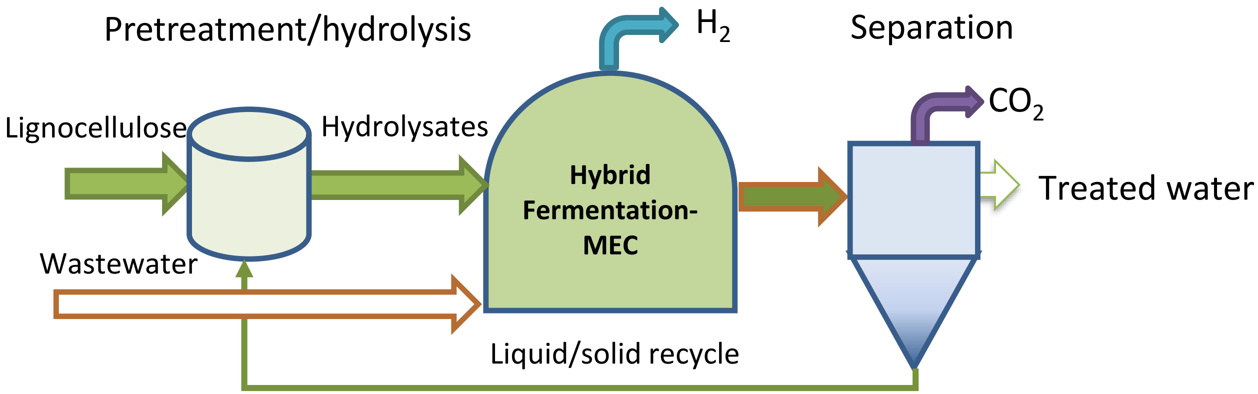
Using wastewater as feedstock can generate a credit as much as -\$10/kg H_2 assuming:

- A surcharge of \$0.6 per pound of BOD discharged
- Generating 1 kg H_2 corresponding to 17.6 pounds of BOD reduction
- Sewage system available on site

Approach

Overall approach:

Develop a hybrid fermentation and microbial electrolysis cell (F-MEC) system that can be integrated with lignocellulose pretreatment/hydrolysis or wastewater treatment processes for H_2 production.



Uniqueness of the approach:

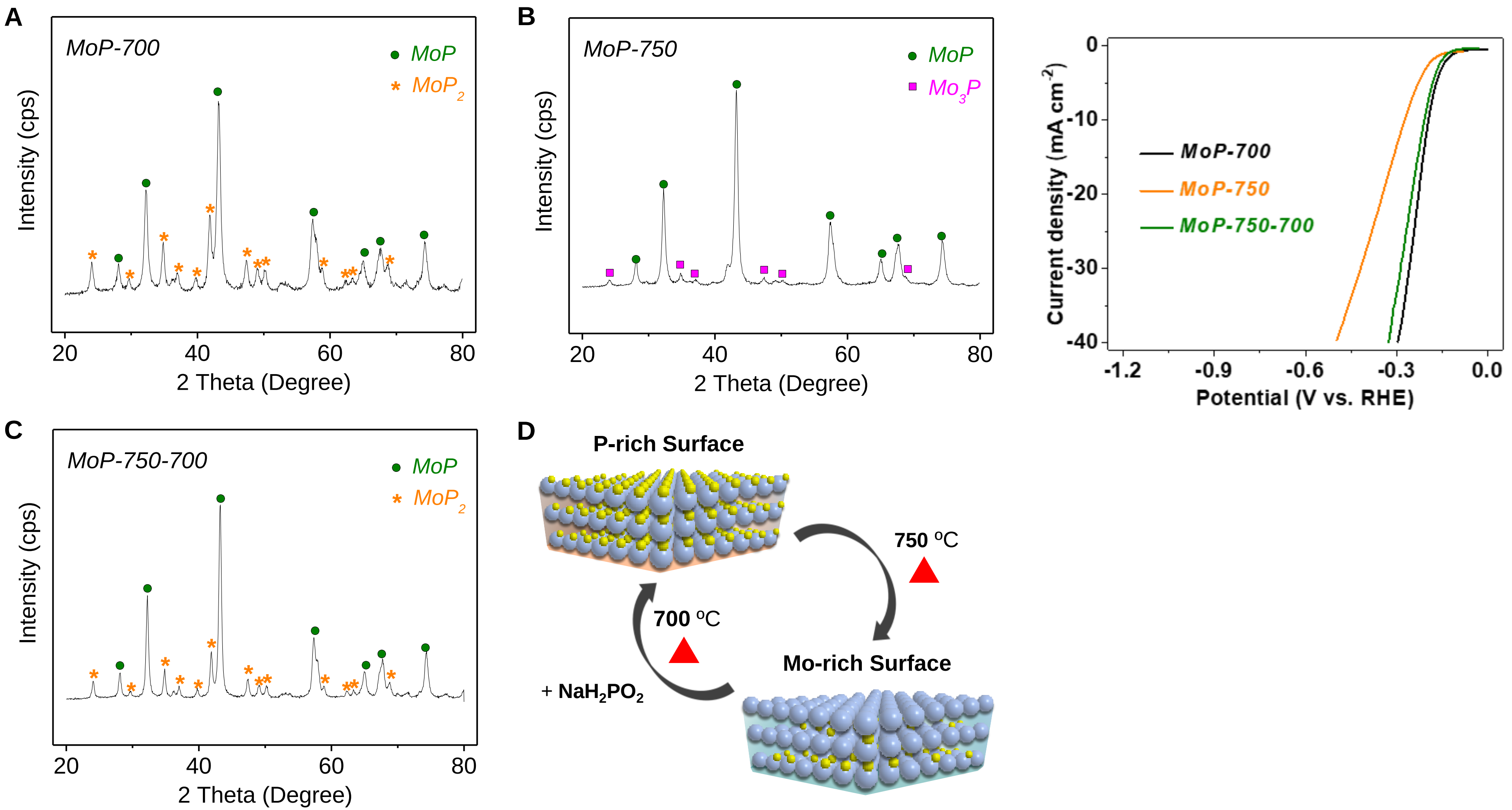
- Use low-cost feedstock
- Combine strengths of dark fermentation and MEC processes
- Reduce capital/operational costs with low-cost and low-overpotential cathode
- Reduce operational cost with novel reactor design and operational conditions
- Apply cost performance model throughout the project to prioritize development

Approach/Milestone

Phase I Fermentation and MEC optimization (FY 16-17)	Accomplished
Milestone 1: Identify a bacterial culture capable of producing H_2 from all major sugars with > 10% yield	100%
Milestone 2: The activity of hybrid nonprecious metal electrocatalyst higher than or equal to Pt.	100%
Milestone 3: H_2 production rate >0.2 m^3 H_2/m^2 cathode/day using a cathode surface area of >20 cm^2	100%
Go/NoGo: Reaching a fermentative hydrogen production rate of 8 L $H_2/L_{reactor}$/day	**Met**
Phase II Hybrid F-MFC system design/fabrication (FY 17-18)	**Accomplished**
Milestone 1: H_2 production rate >0.3 m^3 H_2/m^2cathode/day using a cathode surface are of > 100 cm^2	100%
Milestone 2: The stability of hybrid nonprecious metal electrocatalyst higher than or equal to Pt	100%
Milestone 3: Finish the design of the 10 L hybrid reactor	100%
Go/NoGo: Finish the fabrication of the reactor and demonstrate or show significant progress towards reaching an overall hydrogen production rate of 24 L $H_2/L_{reactor}$/day	**Met**
Phase III Hybrid F-MFC system evaluation (FY 18-19)	
Millstone 1: Demonstrate progress towards reaching 30 L H_2/L-reactor/day on average from lignocellulosic hydrolysate feedstock	**50%**
Milestone 2: Demonstrate progress towards reaching 80% of theoretical hydrogen yield with lignocellulosic hydrolysate	**90%**
Milestone 3: Demonstrate progress towards reaching 15 L H_2/L-reactor/day on average with wastewater feedstock	**90%**
Final deliverable: Demonstrate the techno-economic feasibility of the proposed system	**50%**

Accomplishments and Progress

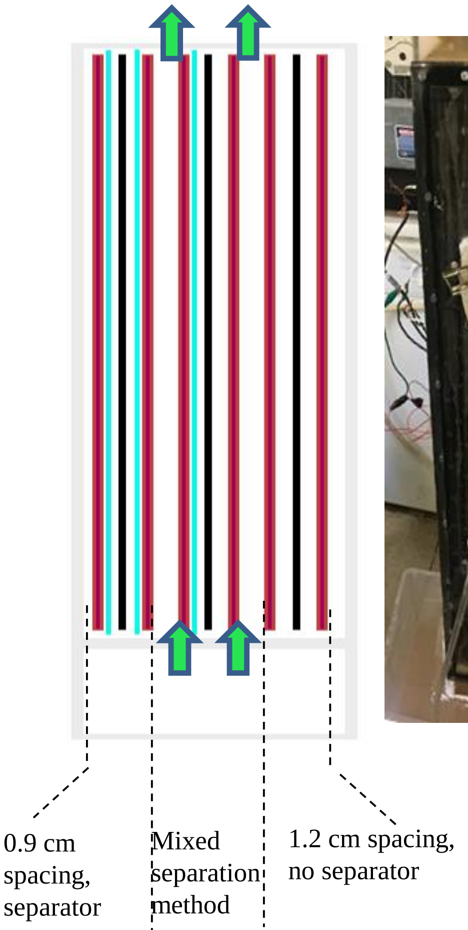
Develop a scalable, cost effective method for production of P-rich MoP

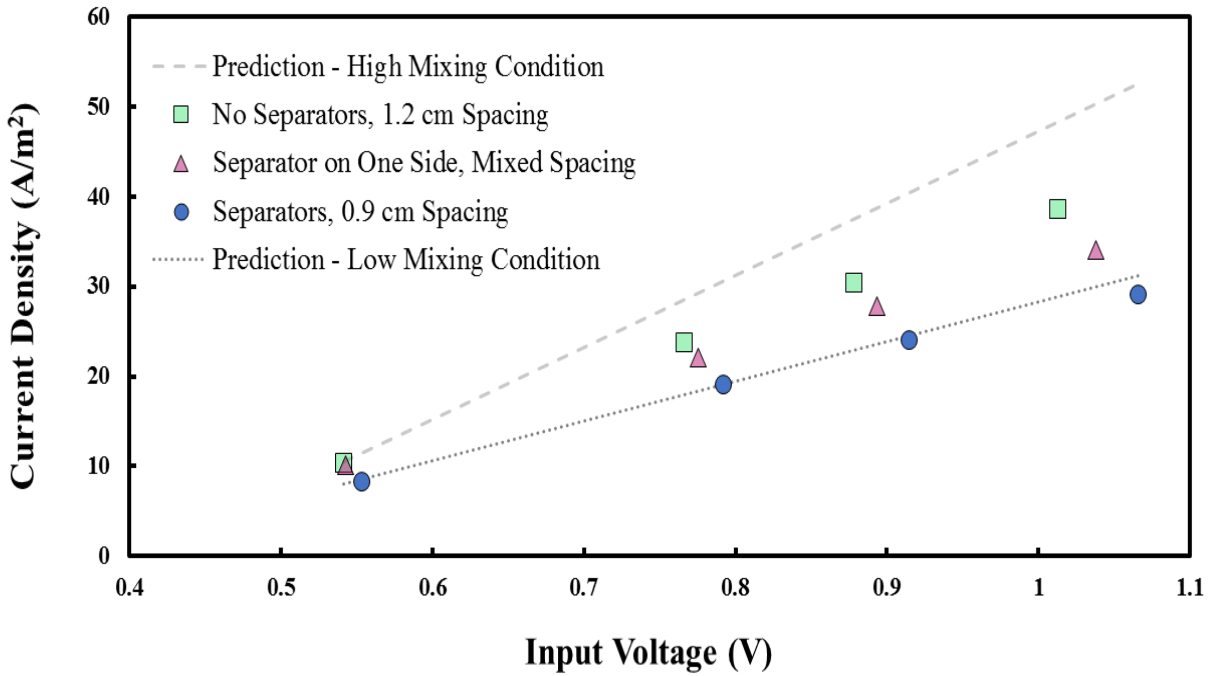


Reversible transformation of MoP structure indicates that a proper post-treatment of commercial MoP may achieve desired surface structure that enables high performance.

Accomplishments and Progress (con.)

Scalability of the reactor design

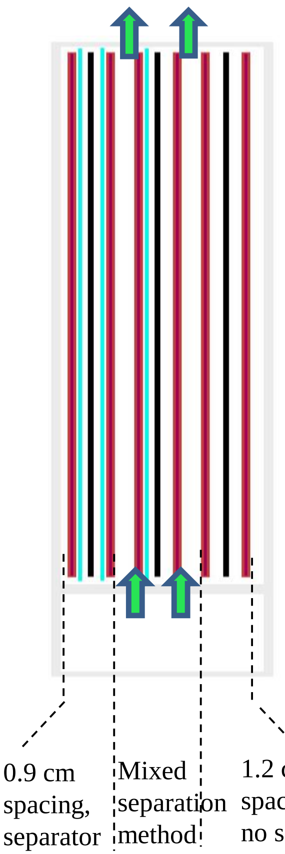


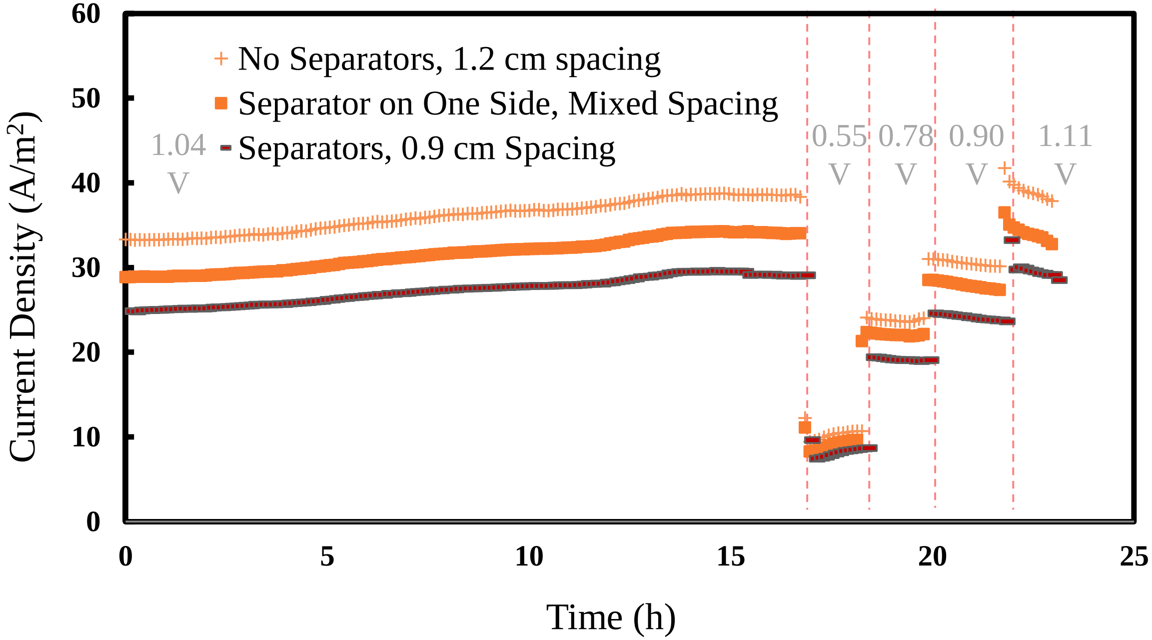


The current densities achieved in the larger MECs fall within the range of predicted values between the two mixing conditions based on the performance of small-scale MECs (0.15 L volume), suggesting the scalability of the reactor design.

Accomplishments and Progress (con.)

Effect of cloth separator and electrode spacing

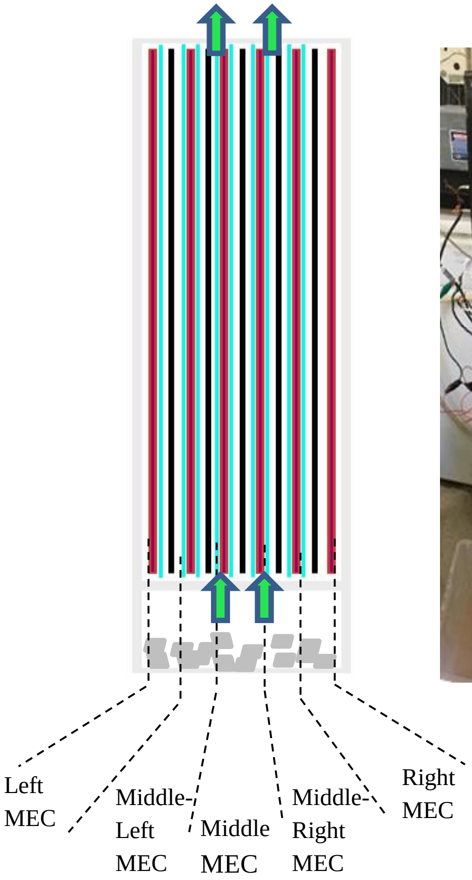


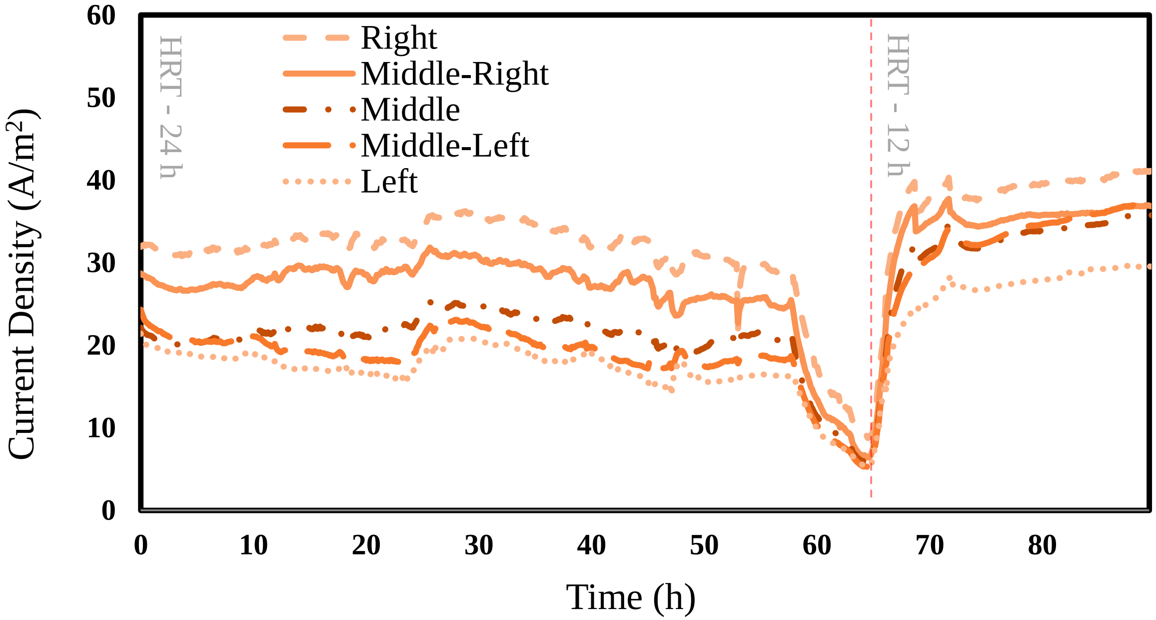


Lack of separator and wider electrode spacing increase the current density. However, the chance of short circuit also increases.

Accomplishments and Progress (con.)

Effect of MEC assembly location within reactor

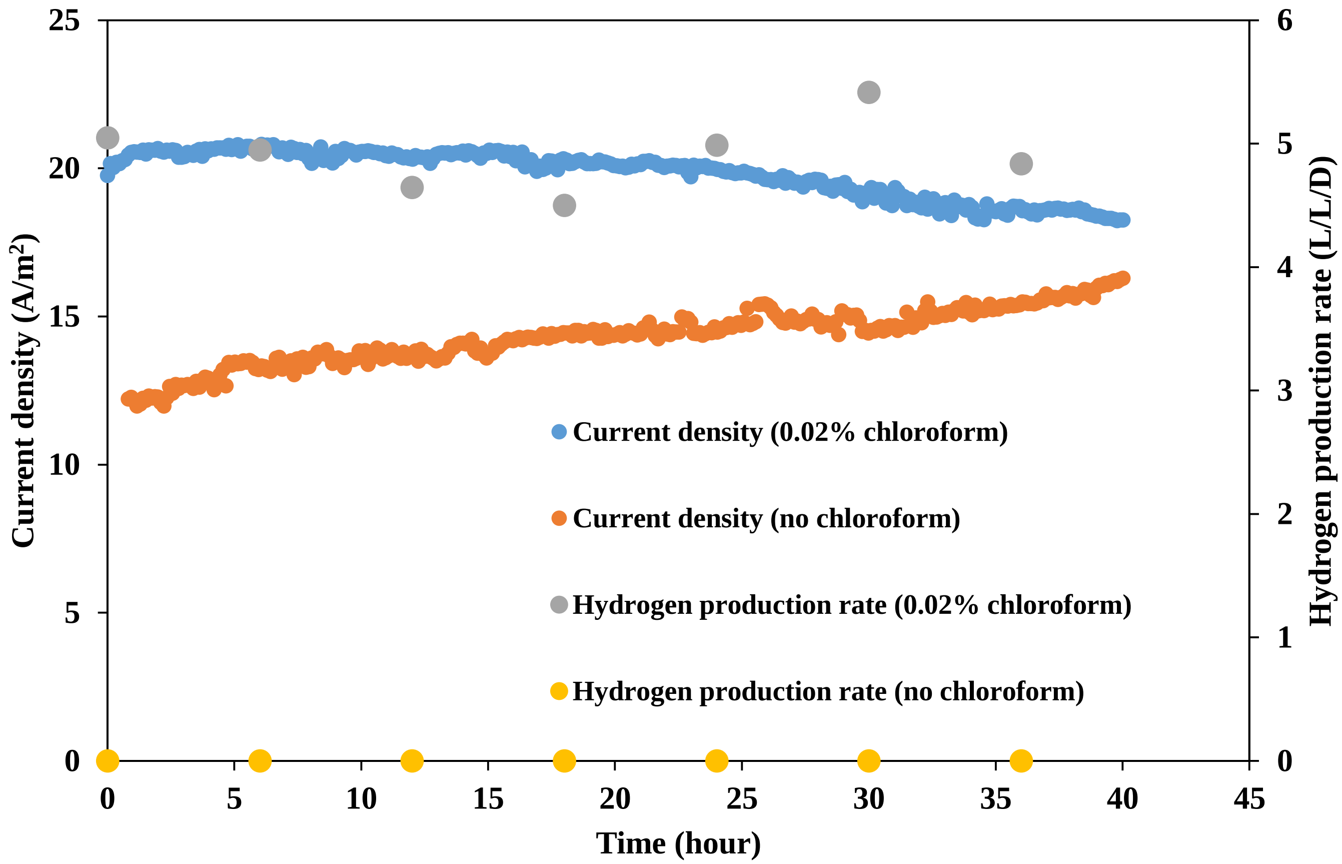




Shortening hydraulic retention reduces the performance difference among the MEC cathodes.

Accomplishments and Progress (con.)

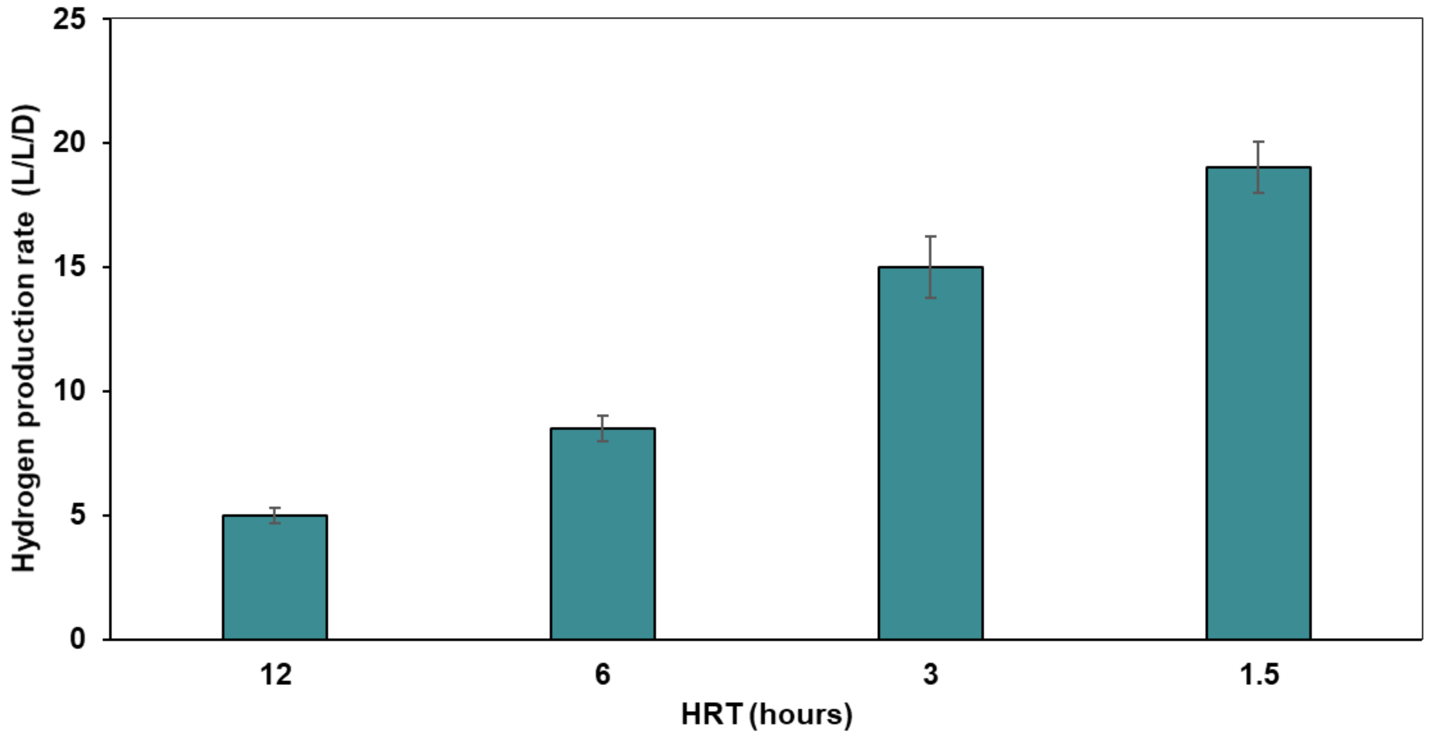
Reducing hydrogen uptake by homoacetogens and methanogens



The effectiveness of chloroform as an inhibitor to both methanogens and homoactogens is confirmed in the 10-L F-MEC operated in continuous flow mode using glucose.

Accomplishments and Progress (con.)

Hydrogen production from brewery wastewater



More than to 15 L/L/day H_2 production can be achieved in the 10L reactor under continuous flow mode using brewery wastewater (COD: 20-60 g/L).

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year.

Collaborations

Partner	Project Roles
Oregon State University Prof. Liu research group Prof. Murthy's group Center for Genome Research and Biocomputing	Project lead, management and coordination Bioreactor design and operation Lignocellulosic feedstock selection and treatment Microbial community characterization
Pacific Northwest National Laboratory Dr. Shao's group Dr. Viswanathan group	Cathode catalyst and catalyst layer coating Cost performance modeling

Remaining Challenges and Barriers

- Current density decreased over time and affected hydrogen yield
- Environmental impact of using the low-cost chemical as an inhibitor to both methanogens and homoactogens needs to be further evaluated.
- Simultaneously achieving both high H_2 yield and production rate would require:
  - Further increase the current density of MECs
  - Reducing the fermentative sludge yield

Proposed Future Work

- Determine the key reason causing the decrease of the current density in the large F-MEC

- Optimization of reactor performance by
  - Adjusting the brewery wastewater biomass hydrolysate concentrations
  - Adjusting the recirculation rate
  - Adjusting the hydraulic retention time
  - Adjusting the ratio of fermentation zone to MEC zone

- Update the cost performance modeling

Any proposed future work is subject to change based on funding levels

Summary - progress and accomplishment

- Reversible transformation of MoP structure indicates that a proper post-treatment of commercial MoP may achieve desired surface structure that enables high performance.
- Initial current densities achieved in the larger MECs fall within the range of predicted values of small-scale MECs, suggesting the scalability of the design.
- Electrode separator, spacing, and location did not affect the performance of the reactor significantly.
- Effectiveness of the identified low-cost chemical as an inhibitor to both methanogens and homoactogens is confirmed in the larger reactor operated in continuous flow mode.
- About 20 L/L/day H_2 production can be achieved in the larger reactor using both glucose and brewery wastewater.
- Current collector material and its connection with electrodes significantly affect the current output, indicating the importance of electrode conductivity for future reactor design.
- Overall, MEC is the limiting factor affecting the current F-MEC performance.