Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass

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Project ID P129

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*: $1,500K

* As of 4/30/20

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.

Characteristics	Units	2020 Target	Commercial Target
Feedstock		hydrolysate/ wastewater	hydrolysate/ wastewater
Feedstock cost contribution	\$/kg H_2	1.30/0	1.30/0
Capital cost contribution	\$/kg H_2	0.69/1.47	0.30/0.75
Electricity cost + other operational cost	\$/kg H_2	1.25/1.25	0.72/0.76
Fixed O&M cost	\$/kg H_2	0.25/0.59	0.10/0.30
Total cost	**\$/kg H_2**	**3.50/3.33**	**2.42/1.81**
Credits	\$/kg H_2	0/-10	0/-10
Final cost	**\$/kg H_2**	**3.50/-6.67**	**2.42/-8.19**

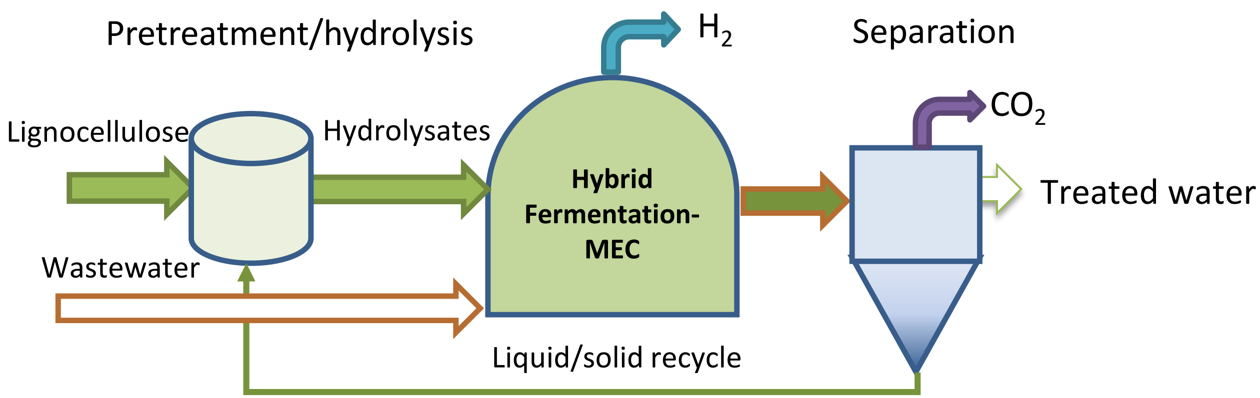
Using wastewater as feedstock can generate a credit as much as -\$10/kg H_2 assuming:

- 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:

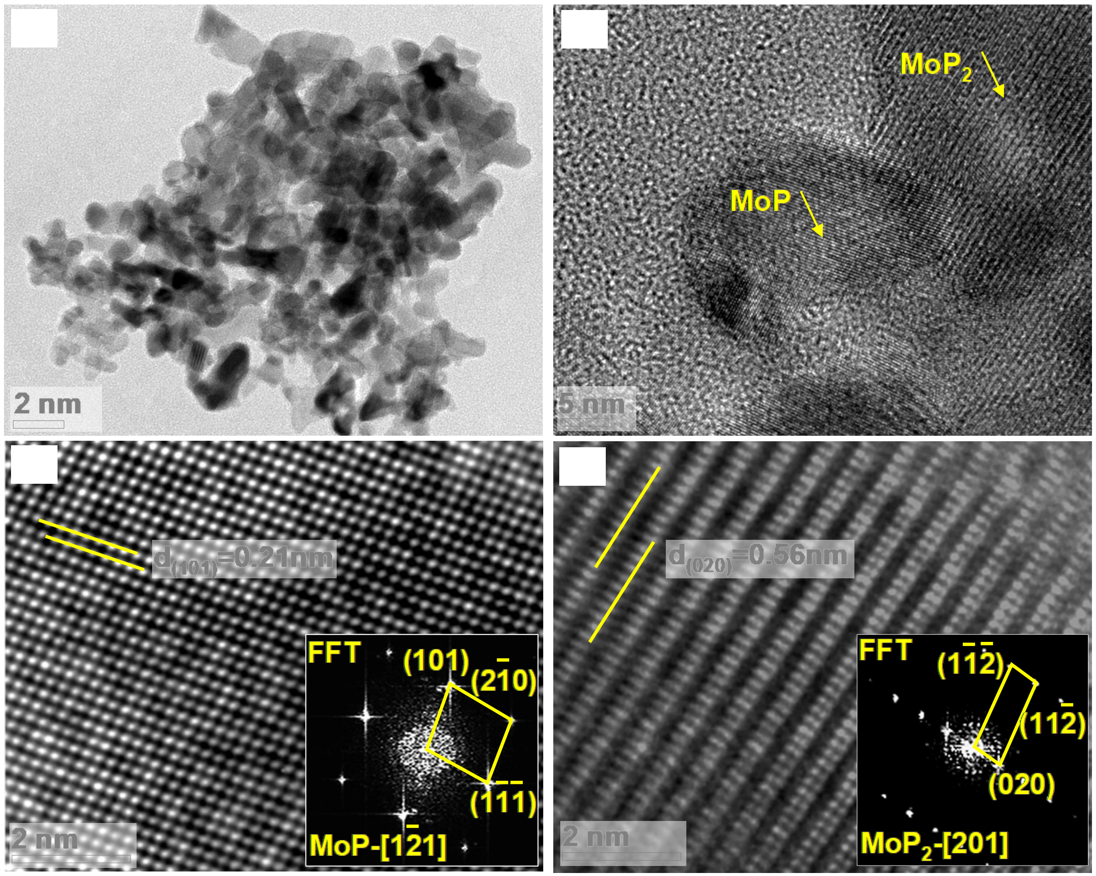
- Use low-cost feedstock
- Combine strengths of dark fermentation and MEC processes
- Reduce capital/operational costs with low-cost and low-overpotential cathodes
- Reduce operational cost with novel reactor design and operational conditions
- Apply cost performance model throughout the project to prioritize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

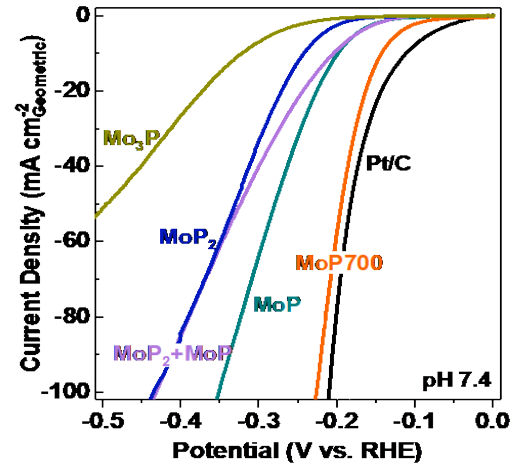
Approach/Milestone

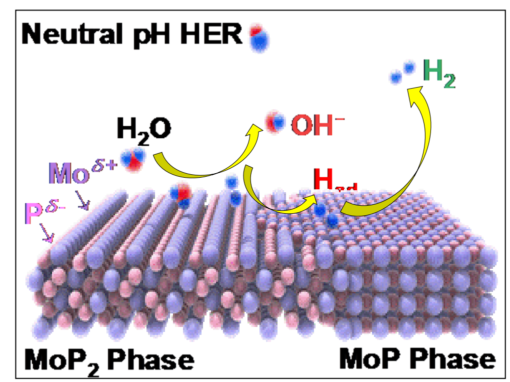
Phase I Fermentation and MEC optimization (FY 16-17)	Accomplished
Milestone 1: Identify a bacterial culture capable of producing H_2 from all major sugars with > 10% yield	100%
Milestone 2: The activity of hybrid nonprecious metal electrocatalyst higher than or equal to Pt.	100%
Milestone 3: H_2 production 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	**90%**
Milestone 2: Demonstrate progress towards reaching 80% of theoretical hydrogen yield with lignocellulosic hydrolysate	**100%**
Milestone 3: Demonstrate progress towards reaching 15 L H_2/L-reactor/day on average with wastewater feedstock	**95%**
Final deliverable: Evaluate the techno-economic feasibility of the proposed system	**100%**

Accomplishments and Progress

High performance PGM-free HER catalyst: MoP







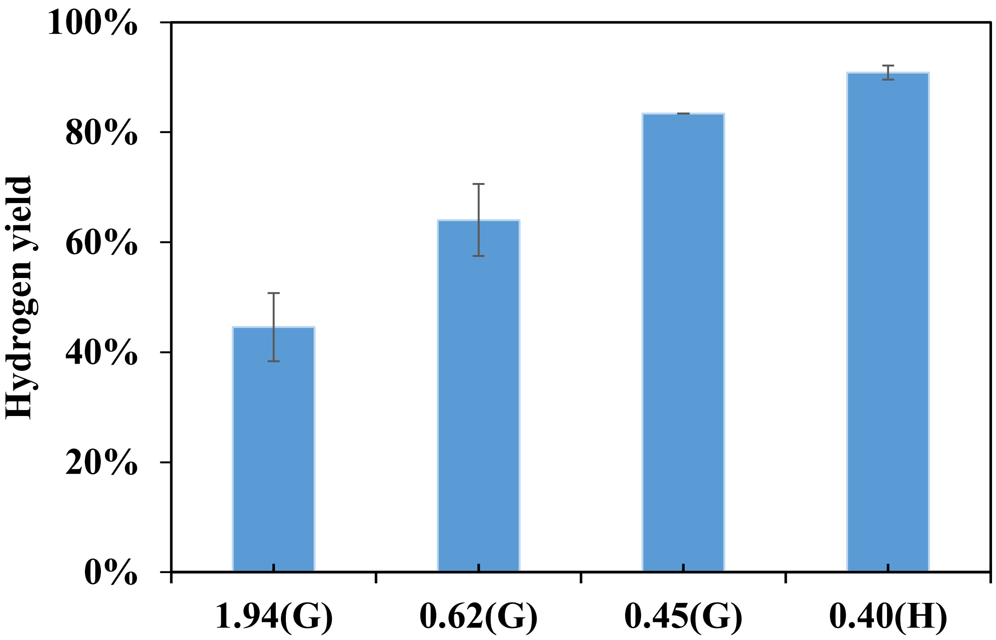
P: Pink Mo: Purple

The two phase synergy (MoP2 and MoP) has been identified as the main mechanism for enhanced HER activity in neutral pH solution: MoP2 for water dissociation and MoP for H_{ads} recombination.

Shao, et al., *ACS Catal.* 2019, 9, 9, 8712–8718

Accomplishments and Progress (con.)

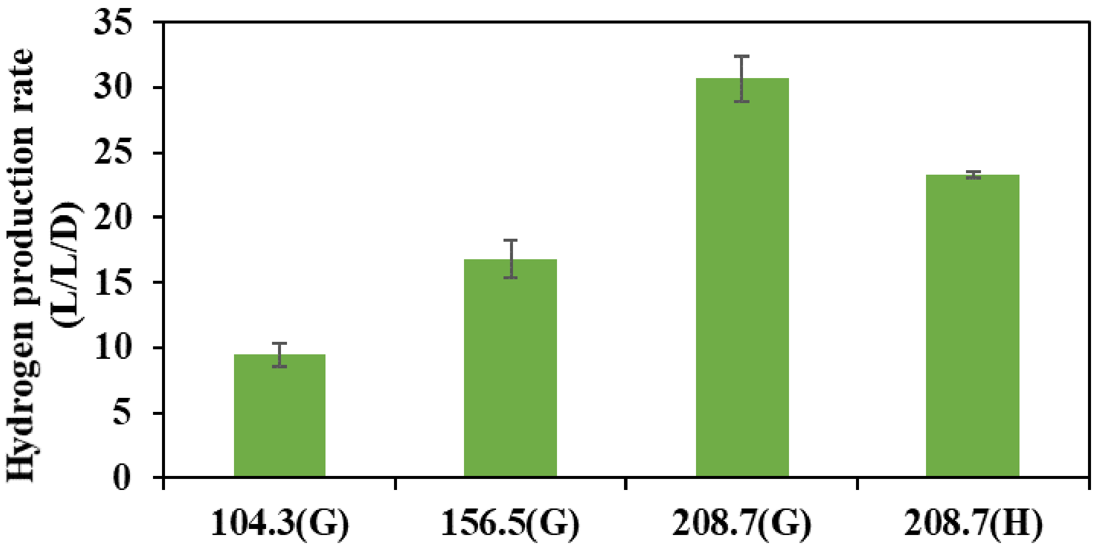
Hydrogen yield in the 10-L reactor



Hydrogen yield increased with the decease of organic lading rate and reached over 80% with 0.45 g/day of glucose (G) and 90% with 0.4 g/day of lignocellulosic hydrolysate (H).

Accomplishments and Progress (con.)

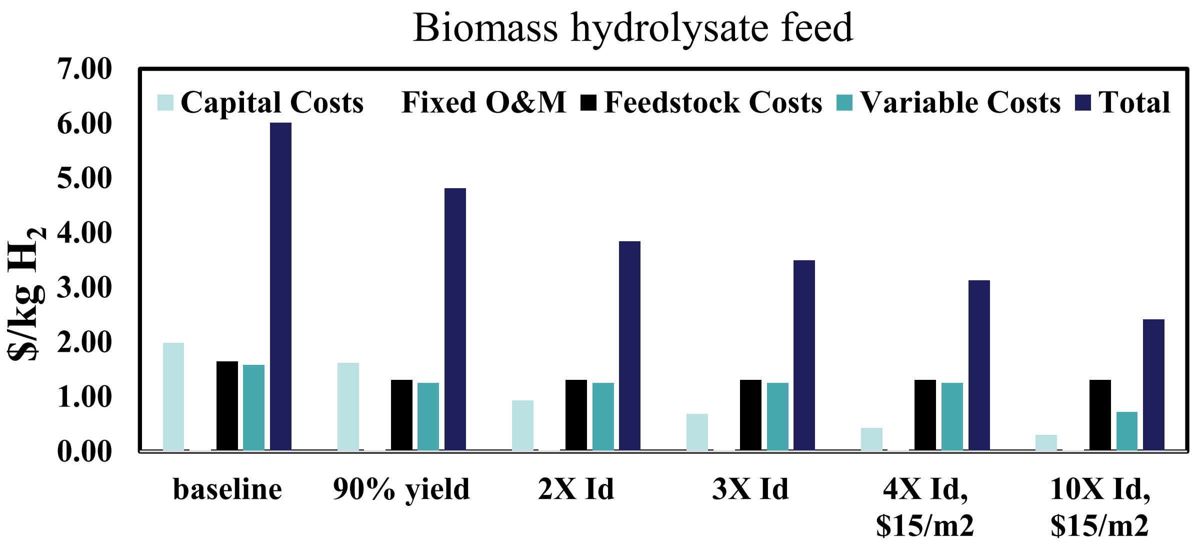
Hydrogen production rate in the 10-L reactor



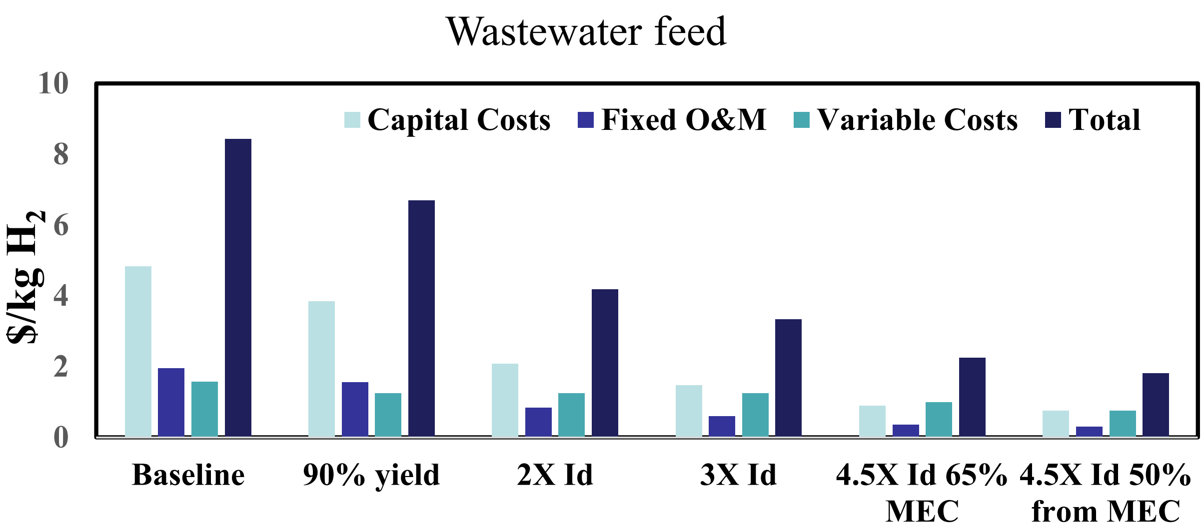
Hydrogen production rate increased with the organic lading rate and reached over 30 L/L/day with 208 g/day of glucose (G) and 23 L/L/day with lignocellulosic hydrolysate at the same loading rate.

Accomplishments and Progress (con.)

Cost Performance Modeling based on the larger reactor's operation and performance



Using biomass hydrolysate as feedstock, further improvement in performance and reduction in electrode and feedstock costs are needed to met the target H_2 production cost.



Using wastewater as feedstock, the target H_2 production cost can be met if wastewater treatment credit is included.

Note: Wastewater treatment credit (~$10/kg H_2) is not included in this figure.

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

Summary - progress and accomplishment

- The two phase synergy (MoP2 and MoP) has been identified as the main mechanism for enhanced HER activity in neutral pH solution: MoP2 for water dissociation and MoP for H_{ads} recombination.
- Hydrogen yield increases with the decease of organic lading rate and can reached 90% with lignocellulosic hydrolysate.
- Hydrogen production rate increases with the organic lading rate and can reach over 30 L/L/day with glucose and 23 L/L/day with lignocellulosic hydrolysate.
- Using biomass hydrolysate feedstock, further improvement in performance and reduction in electrode and feedstock costs are needed to met the target H_2 production cost.
- Using wastewater as feedstock, the target H_2 production cost can be met if the wastewater treatment credit is included.
- Overall, MEC is the limiting factor affecting the current F-MEC performance.