

Novel Hybrid Microbial Electrochemical System for Efficient Hydrogen Generation from Biomass

Project ID: PD129

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Overview

Timeline

- Project Start Date: 02/01/16
- Project End Date: 01/31/19*
- * Project continuation and direction determined annually by DOE

Budget

- Total Project Budget: \$1,670K
 - Total Recipient Share: \$167K
 - Total Federal Share: \$1,500K

Barriers

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

Partners

- **Oregon State University**: project lead; cost-share funding
- **PNNL**: co-project lead
- **Oregon Nanoscience & Microtechnologies Institute**: cost-share funding

Relevance

Project Objective:

Develop a microbial electrochemical system for H₂ production from low-cost feedstock (lignocellulosic biomass and wastewater) at a cost less than \$2/kg H₂.

Approach/Strategy to Achieving DOE's target:

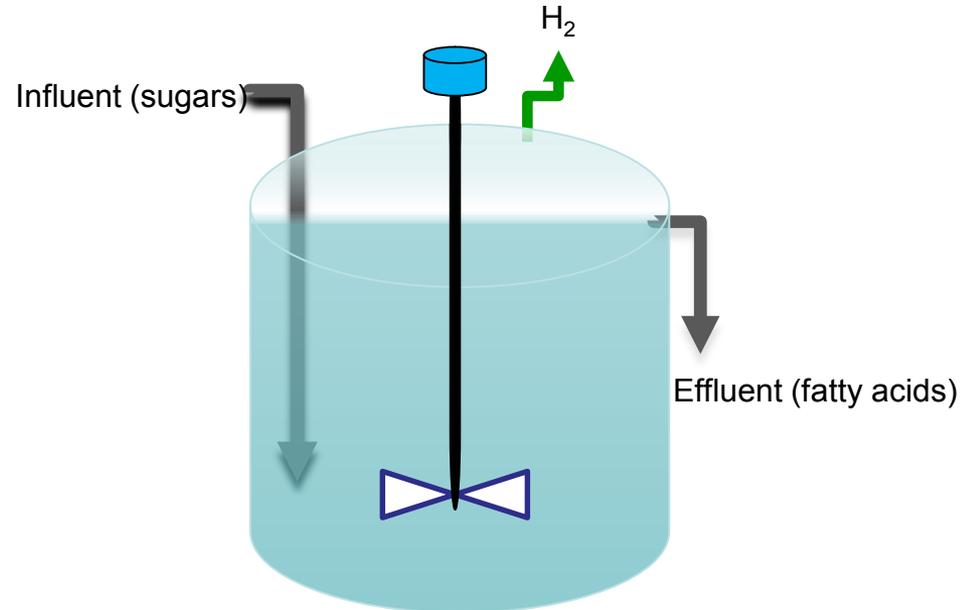
Characteristics	Units	Current Status	Project Target	Commercial Target
Feedstock		glucose	hydrolysate/wastewater	hydrolysate/wastewater
Feedstock cost contribution	\$/kg H ₂	8.2	2.0/0	1.2/0
Capital cost contribution	\$/kg H ₂	3.0	0.4/0.7	0.3/0.6
Electricity cost contribution	\$/kg H ₂	0.4	0.2	0.2
Other operational cost	\$/kg H ₂	0.3	0.3/0.6	0.3/0.6
Total cost	\$/kg H₂	11.9	2.9/1.6	2.0/1.5
Credits	\$/kg H ₂	0	0/-10	0/-10
Final cost	\$/kg H₂	11.9	2.9/-8.4	2.0/-8.5

* Using wastewater as feedstock can generate a credit as much as -\$1/kg glucose equivalent, or -\$10/kg H₂.

Approach

Dark fermentative H₂ production

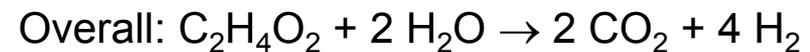
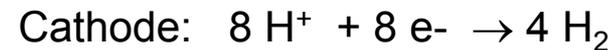
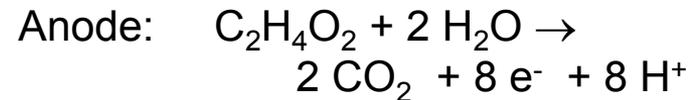
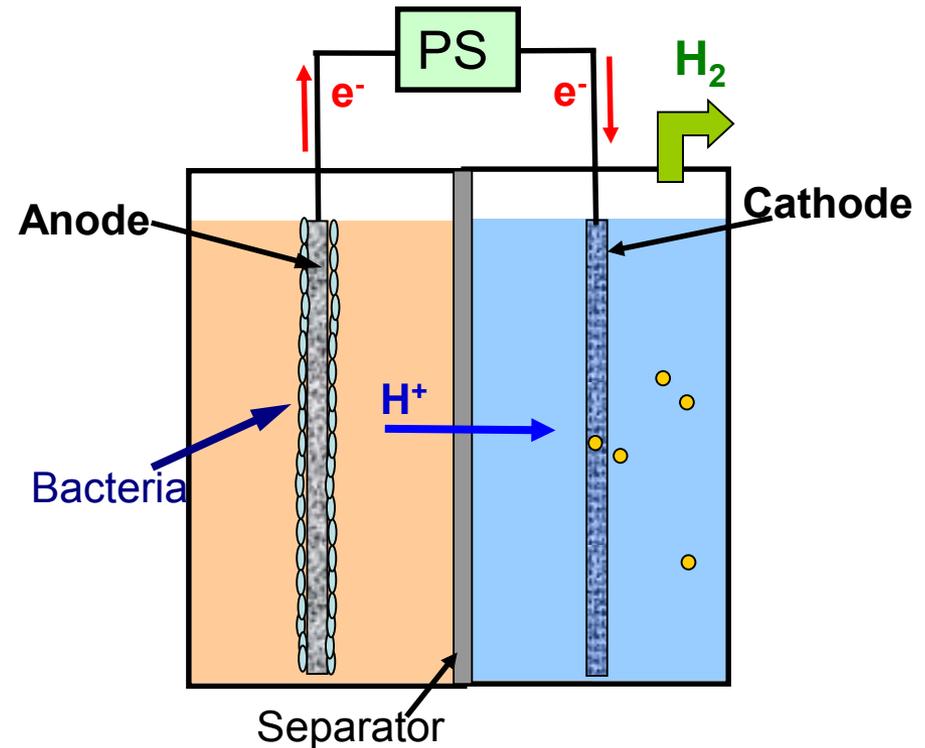
- Advantages
 - High hydrogen rate
 - Low energy input
- Challenge
 - low hydrogen yield (Fermentation Barrier):
 - Maximum 4 mol H₂/mol glucose
 - Most H₂ stored in liquid fermentation end products



Approach

Microbial electrolytic H₂ production

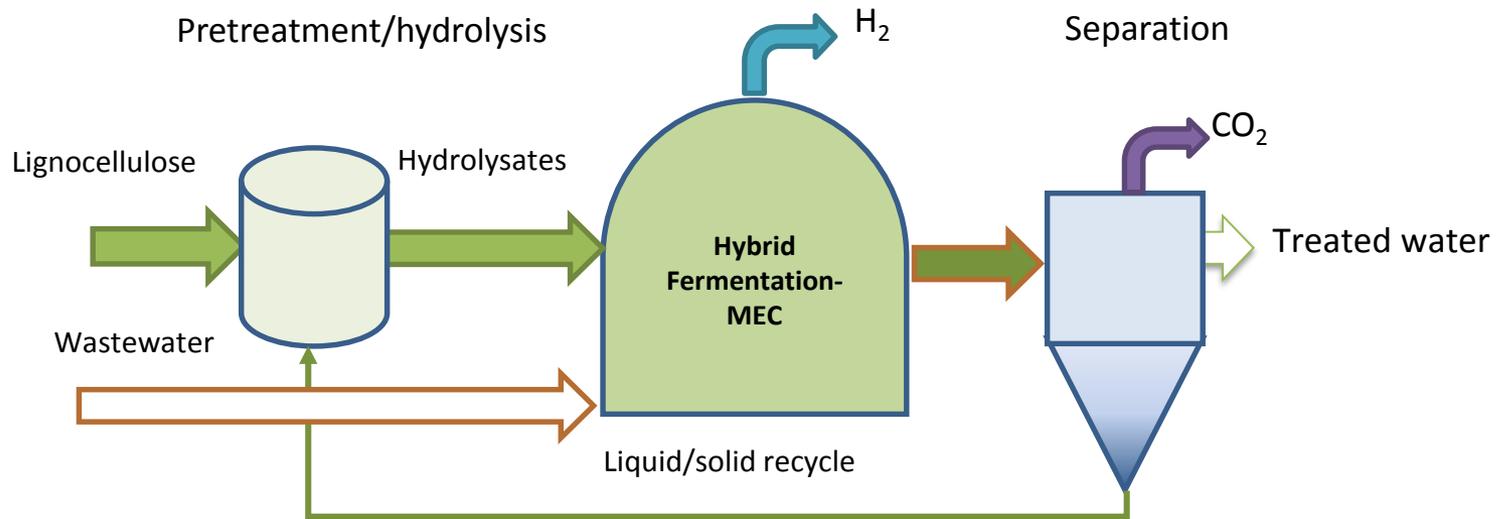
- **Advantages:**
 - Overcoming the “Fermentation Barrier”
 - High H₂ yield
- **Challenges**
 - Incapable/inefficient in directly utilizing biomass or biomass components
 - Low H₂ production rate/high energy input
 - High costs for electrode and separator materials



Approach

Overall approach of this project:

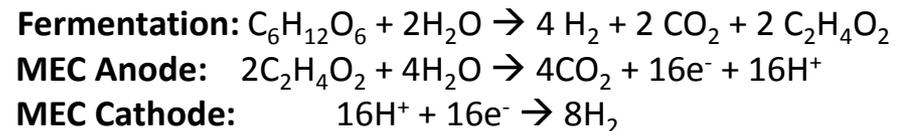
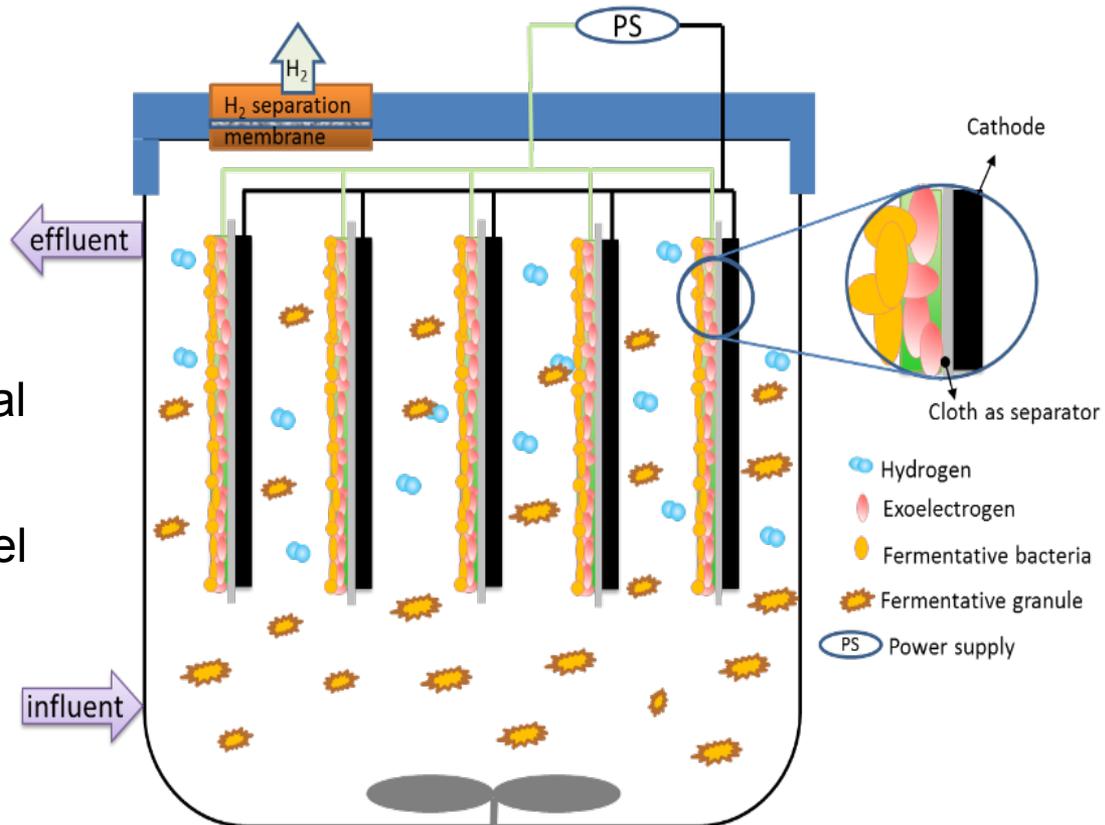
Develop a hybrid fermentation and microbial electrolysis cell (F-MEC) system that can be integrated with lignocellulose pretreatment/hydrolysis or wastewater treatment processes for H₂ production.



Approach

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

Budget period 1 (FY 2016-2017)

- Fermentation optimization
- MEC cathode development

Budget period 2 (FY 2017-2018)

- MEC process optimization
- Hybrid system design/fabrication

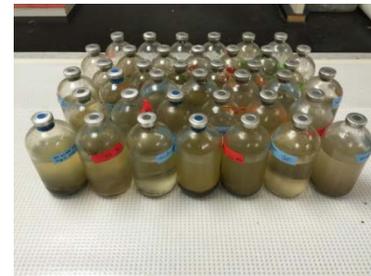
Budget period 3. (FY 2018-2019)

- Hybrid system evaluation
- Cost performance model

Approach

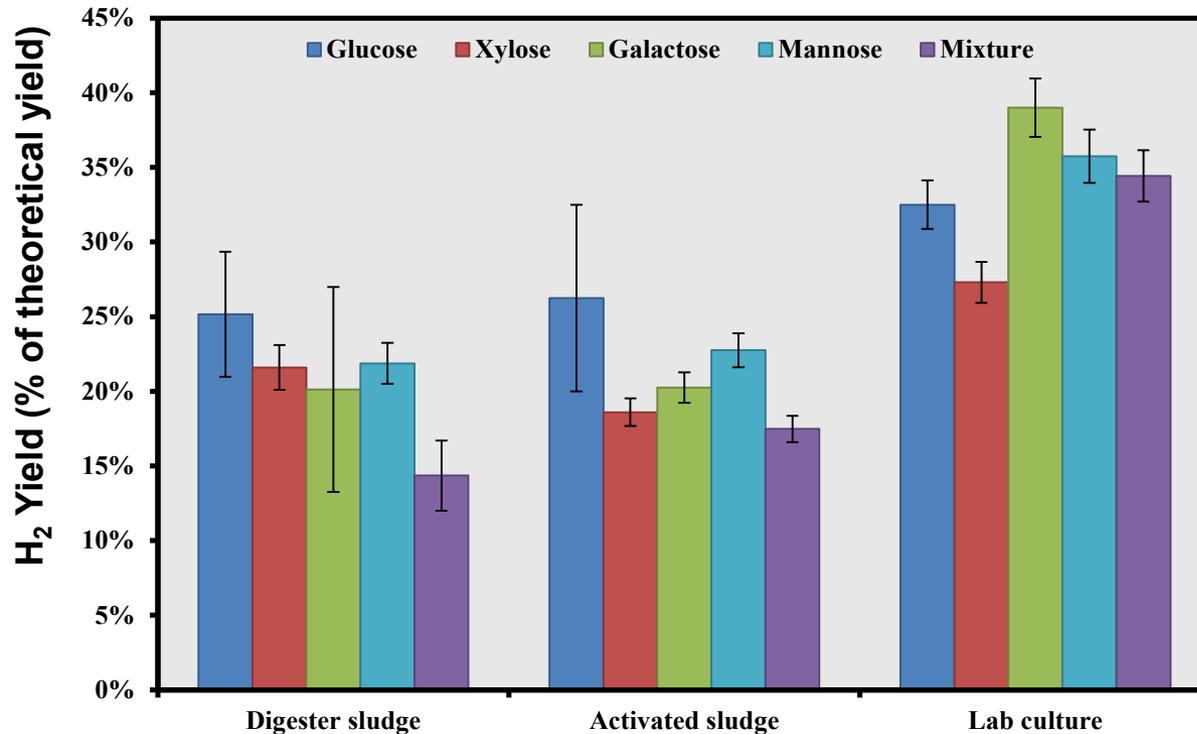
This reporting period (Feb 2016 – April 2016)

- **Identify a fermentative bacterial culture capable of producing H₂ from all major sugars in lignocellulose hydrolysates and wastewater**
 - ***Mixed culture***
 - Higher robustness and adaptability
 - Easier to grow at large scales
 - More economical to build and operate
 - Relatively simple to manage
 - Suited for using wastewater and complex biomass hydrolysates
 - ***Batch reactors***
 - Types of bacterial culture
 - Types of sugars
 - Biogas
 - Liquid products
- **Developing MEC cathode catalysts**
- **Cost performance modeling**



Accomplishments and Progress

Identification of a bacterial culture capable of producing hydrogen from all major sugars



*n= 3, error bars represent standard deviation
Theoretical yield: maximum for known metabolic pathways

Summary: All three tested cultures are capable of producing hydrogen from all tested sugars. The lab culture enriched with glucose demonstrated the highest hydrogen yield.

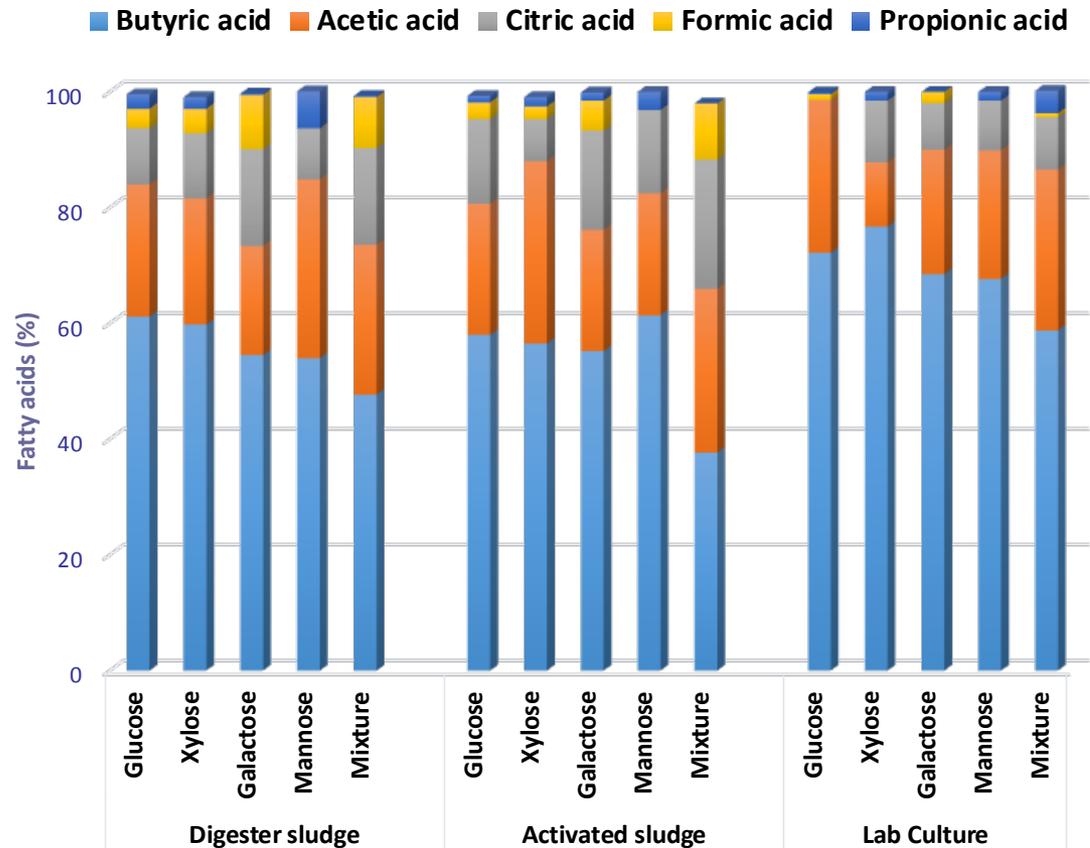
Accomplishments and Progress

Liquid fermentation products

- Provide information for MEC process design
 - Types of carbon source for exoelectrogens
 - Relative production rate

Summary:

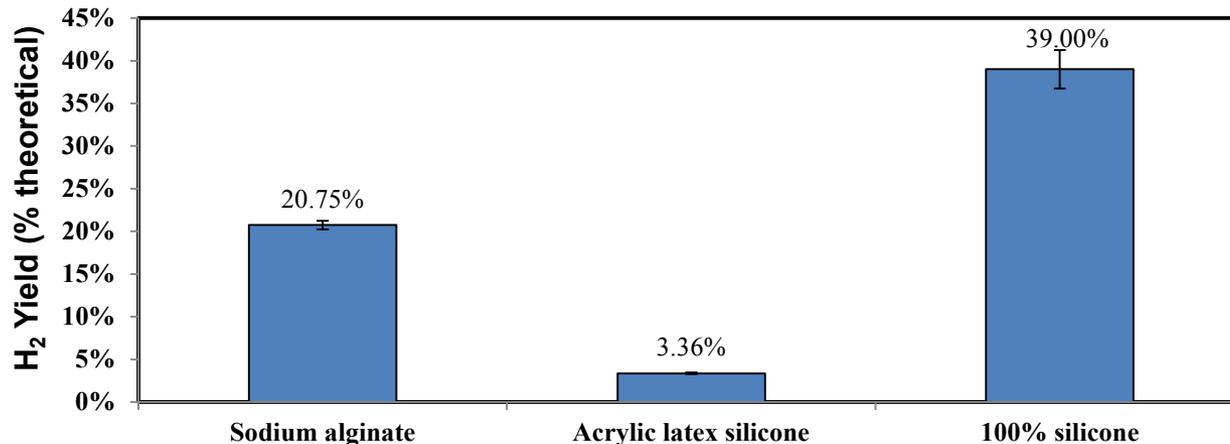
Butyrate and acetate are the dominant fermentation liquid products for all sugars and all three cultures.



Accomplishments and Progress

Immobilization of hydrogen-producing culture

- To increase bacterial cell density in continuous-flow reactors
- To increase volumetric hydrogen production rate



*n= 3, error bars represent standard deviation;
Theoretical yield: maximum for known metabolic pathways

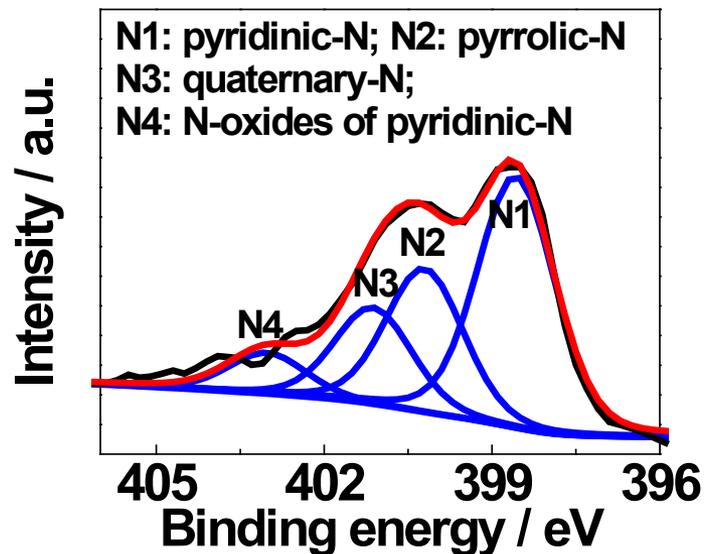
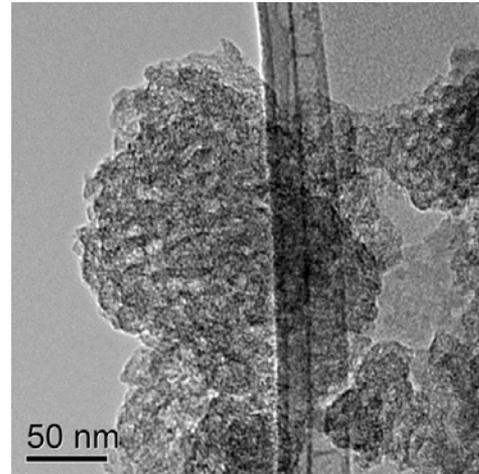


Summary: Immobilization of the lab culture using silicone demonstrates the highest hydrogen yield.

Accomplishments and Progress

Cathode catalysts

- Synthesized nitrogen doped porous carbon (N-C), surface area tunable between 1000-2500 m²/g. Metal catalysts will be applied onto N-C.
- Identified metal catalyst candidates (NiMo, NiCo, NiCoMo) from literature research.



*Black line: original data; Red line: fitted data

Accomplishments and Progress

Cost performance modeling

- Test driving DOE H2A model for hydrogen production
- Successfully ran the model with mock input values
 - Received suggestions from NREL experts
 - Conducted preliminary cost estimation of feedstock, yield and required reactor size
- Working on implementing the model for this work

Responses to Previous Year Reviewers' Comments

- This project just started this year.

Collaborations

- **Oregon State University (OSU)**
 - Liu group (Lead): biohydrogen production
 - Murthy group: feedstock treatment
 - Center for Genome Research and Biocomputing (CGRB): microbial community characterization
- **Pacific Northwest National Lab (PNNL)**
 - Shao group: cathode development
 - Viswanathan group: cost performance modeling
- **Oregon Nanoscience and Microtechnologies Institute (ONAMI)**
 - Supplemental funding to support a graduate student to work on this project

Remaining Challenges and Barriers

- **Butyrate utilization rate by exoelectrogens may be slower than that of acetate in MEC**
 - Enrich butyrate-utilizing exoelectrogens
 - Addition of butyrate-utilizing pure cultures
- **Methane production may occur during long term operation**
 - Apply low-cost methane inhibitors to inhibit methanogens
- **Cathode performance may deteriorate over time**
 - Evaluate/modify the cathode catalyst to enhance stability

Proposed Future Work

Remainder of the year:

- Characterize the microbial community
- Optimization of fermentative H₂ production in continuous-flow reactors
- Develop hybrid nonprecious metal electrocatalysts for MEC cathode
- Evaluate MEC H₂ production rate from fermentation liquid products
- Cost performance modeling

FY 2017-2018:

- MEC development
 - Integrate the cathode materials developed
- Hybrid system design/fabrication
- Evaluation of the hybrid system with glucose
- Cost performance modeling

Technology Transfer Activities

- **Technology-to-market or technology transfer plans or strategies**
 - IP related to reactor design and operation
 - IP related to cathode catalyst/material
 - Scale up the system
 - Identify industry partners for commercialization
- **Plans for future funding**
 - Responding to NSF PFI opportunities
 - Seeking support from industry partners

Summary

Objective: Demonstrate a novel microbial system for efficient H₂ production from low-cost biomass

Relevance: Provide a green and renewable approach for H₂ production at a cost less than \$2/kg

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 H₂ production.

Accomplishment: Identified a microbial community that is capable of producing hydrogen from all major sugars in lignocellulosic biomass hydrolysates; Synthesized nitrogen doped porous carbon for loading the non-precious metal catalyst

Collaborations: A team comprised of a university (OSU), a national lab (PNNL), and a state signature center (ONAMI).