Scalable and Highly-Efficient Microbial Electrochemical Reactor for Hydrogen Generation from Lignocellulosic Biomass and Wastes

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Project ID P184

Overview

Timeline

- Project Start Date: 01/01/20
- Project End Date: 12/30/22

Barriers

- High electrode cost (AAA)
- Low hydrogen production rate (AAB)

Budget

- Total Project Budget: $1,277,145
  - Total Recipient Share: $277,239
  - Total Federal Share: $999,906
  - Total DOE Funds Spent*: $2,233

* As of 4/30/20

Partners

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

Relevance

Overall objective: develop a scalable hybrid microbial electrochemical reactor for hydrogen recovery from lignocellulosic biomass and wastewater at a cost close to or less than \$2/kg H_2.

Specific objective of this budget period: develop and evaluate low-cost and scalable electrode materials.

Strategy to Achieving DOE's target:

Characteristics	Units	Current Status	Project Target	Commercial Target
Feedstock		Hydrolysate/ wastewater	hydrolysate/ wastewater	hydrolysate/ wastewater
H_2 production rate	L_{H2}/L-d	20/20	35/25	35/25
Feedstock cost contribution	\$/kg H_2	1.3/0	1.0/0	1.0/0
Separator electrode assembly	\$/m^2	\$80#	\$40	\$20
Capital cost contribution	\$/kg H_2	1.6#/1.8#	0.8/1.1	0.4/0.5
Electricity cost contribution	\$/kg H_2	0.8	0.6	0.5
Other O&M cost	\$/kg H_2	0.4*/0.4*	0.2/0.3	0.1/0.2
Total cost	**\$/kg H_2**	**4.1/3.0**	**2.6/2.0**	**2.0/1.2**
Credits	\$/kg H_2	0/-10	0/-10	0/-10
Final cost	**\$/kg H_2**	**4.1/-7.0**	**2.6/-8.0**	**2.0/-8.8**

*H_2 separation/purification cost not included; #Estimated current collector cost included

Approach

- Develop low-cost CNT sponge electrodes
- Develop high-performing platinum group metal (PGM)–free cathodic catalyst
- Fabricate separator electrode assemblies (SEAs) with new electrode and catalyst materials
- Evaluate small reactors for hydrogen production from waste.

Uniqueness of the approach and impact:

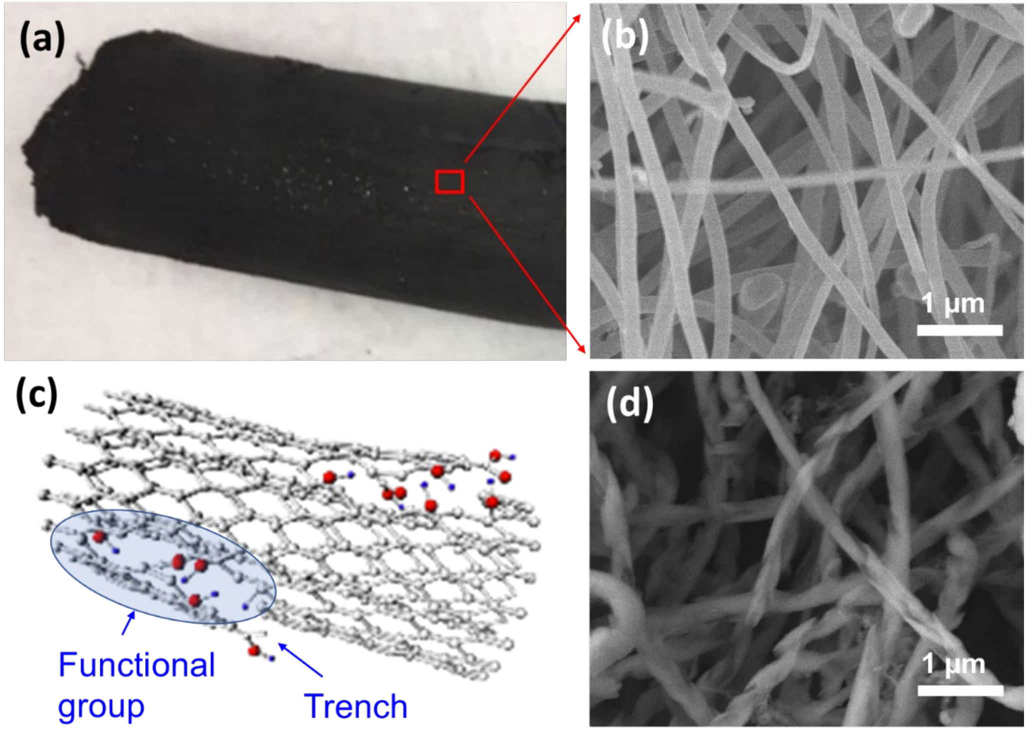
- Use low-cost feedstock
- Reduce capital/operational costs with low-cost electrode materials
- Reduce operational cost with novel reactor design and operational conditions
- Apply cost performance model throughout the project to prioritize development
- Formulate new designs and processing parameters for generating H_2 from other biomass feedstocks
- Increase environmental sustainability through simultaneous waste treatment during H_2 production process

Approach/Milestone

Phase I Electrode material development and evaluation (FY 20-21)	
Milestone 1.1: Synthesize low-cost CNT electrodes capable of producing an anodic current density > 20 A/m^2 in MECs and fabricate roll-to-roll setup	100%
Milestone 1.2: Optimize the synthesis conditions and fabricate low-cost CNT sponge electrodes capable of producing an anodic current density > 30 A/m2 in MECs	70%
Milestone 1.3: Fabricate functionalized CNT sponge electrodes capable of producing an anodic current density of 40 A/m^2 in MECs feedstock	Started
Milestone 2.1: Synthesize HER catalyst that can deliver > 40 A/m^2 in MECs	Started
Milestone 3.1: Fabricate small MECs (~0.5L) using the developed electrodes and HER catalyst with an electrode area with reactor volume ratio ranging from 20-100.	Not started
Go/NoGo: Demonstration of continuous production of 30 L-H2/L/day for 48 hours either using wastewater or biomass hydrolysate in ~0.5 L reactors.	Not started
Phase II Scaled-up reactor fabrication and evaluation (**FY 21-22**)	
Milestone 1.4: Fabricate 2 m^2 optimized CNT sponge electrode for the large reactor	Not started
Milestone 2.2: Synthesize HER catalyst enough for 1 m^2 CNT-supported cathode for the large reactor	Not started
Milestone 4.1: Fabricate a 10-L large reactor with the total anode and cathode areas of at least 1 m^2 and the liquid volume of at least 6 liters.	Not started
Milestone 6.1: Develop cost performance model	Not started
Milestone 5.1: Demonstrate the large reactor is capable of 35 L H_2/L/day continuous production for 72 hours with lignocellulose hydrolysates or wastewater.	Not started
Final deliverable: Demonstrate the techno-economic feasibility of the proposed system based on the cost performance modeling, and define a pathway for this system to achieve the FCTO cost goal of <$2/gge.	Not started

Accomplishments and Progress

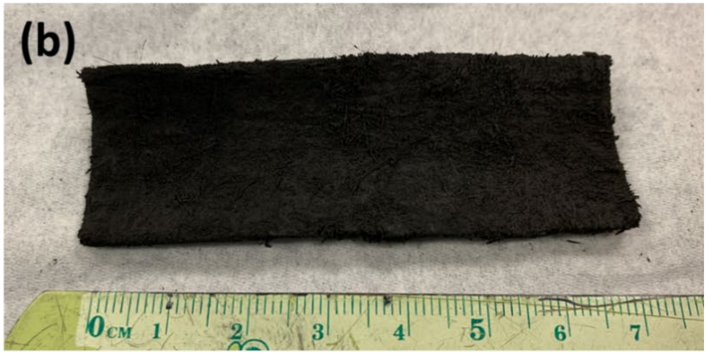
Synthesize cylindrical porous CNT



The cylindrical CNT was synthesized using a chemical vapor deposition (CVD) method (a) and composed of inter-connected multi-walled CNTs whose diameters range from 50 nm to 200 nm (b). The surface of CNT was further modified by partially unzipping the multi-walls and grafting the functional groups on the surface (c), showing spiral trenches on CNT (d).

Accomplishments and Progress (con.)

CNT grown on carbon veil



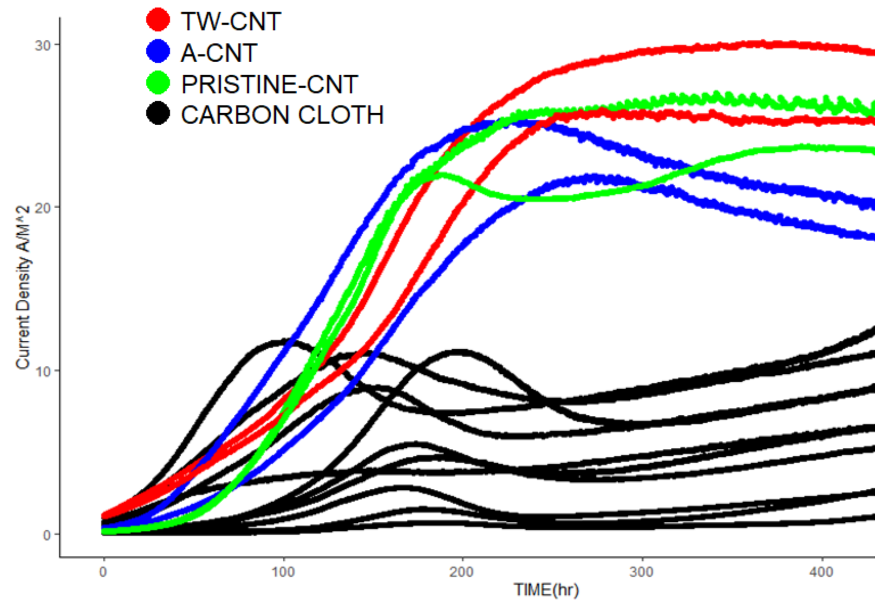
Carbon veil

CNT grown on carbon veil

Successfully grew CNTs on the carbon veil (commercially available and inexpensive) with a thickness of ~1 mm. The thickness can be readily increased or decreased depending on the reaction time.

Accomplishments and Progress (con.)

Evaluation of the fabricated CNT electrodes



An MEC reactor was designed and fabricated to evaluate multiple (16) electrodes simultaneously. The anodic current density of all three CNT materials (TW-CNT, A-CNT, Pristine CNT) surpassed that of the carbon cloth. These observations indicate a significant advantage of the CNT material over standard carbon cloth material as an MEC anode.

Responses to Previous Year Reviewers' Comments

- This project just started this year.

Collaborations

Partner	Project Roles
Oregon State University Prof. Liu's Lab Prof. Murthy's Lab	Project lead, management and coordination Bioreactor design and operation Lignocellulosic feedstock treatment
Texas A&M University Prof. Yu's lab	Carbon nanotube electrode material fabrication and characterization
Pacific Northwest National Laboratory Dr. Shao's group Dr. Viswanathan group	Cathode catalyst development Cost performance modeling

Remaining Challenges and Barriers

- **Increase the repeatability of the electrode evaluation results**
  - Standardize the testing procedure
- **Increase productivity in synthesizing CNT electrodes**
  - Optimize synthesis conditions in a larger scale furnace

Proposed Future Work

Remainder of the current budget period:

- Optimize the synthesis conditions and fabricate low-cost CNT sponge electrodes
- Fabricate functionalized CNT sponge electrodes
- Synthesize HER catalyst
- Fabricate small MECs (0.5 L) using the developed electrodes and HER catalyst
- Evaluate the small MECs using wastewater

FY 2021-2022:

- Fabricate 2 m^2 CNT electrode material
- Synthesize HER catalyst for 1 m^2 CNT-supported cathode
- Design and fabricate 10-L reactor
- Evaluate the 10-L reactor
- 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 carbon nanotube electrode material development
  - IP related to scalable HER catalyst development
  - Identify industry partners for commercialization

- **Plans for future funding**
  - Responding to DOE STTR opportunities
  - Seeking support from industry partners

Summary

Objective: Develop a scalable hybrid microbial electrochemical reactor for hydrogen recovery from lignocellulosic biomass and wastewater.

Relevance: Provide a green and renewable approach for H_2 production at a cost close to or less than $2/kg

Approach: Reduce the capital and operating costs by: 1) developing low cost and highly-conductive CNT electrode; 2) synthesizing high performing PGM–free cathodic catalyst; 3) Designing novel bioreactors with developed electrode and catalyst materials; 4) Producing H_2 from low-cost and negative value feedstocks.

Accomplishment: Synthesized and characterized cylindrical porous CNT; Modified CNT surface by grafting functional groups on the surface; Evaluated three CNT materials and the anodic current density of all three surpassed that of the carbon cloth.

Collaborations: A team comprised of two universities (OSU, TAM) and a national lab (PNNL).