NREL
NATIONAL RENEWABLE ENERGY LABORATORY

DOE Bioenergy Technologies Office 2019 Project Peer Review

Biomethanation to Upgrade Biogas to Pipeline Grade Methane (WBS 5.1.3.102)

Waste-to-Energy
Monday, March 4, 2019
3:45 – 4:15pm

CO_2 Utilization
Thursday, March 7, 2018
3:45 – 4:15pm

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Goal Statement

Goal

Develop and de-risk the biomethanation process to upgrade biogas sources to pipeline quality natural gas for long-duration energy storage and decarbonization of the transportation sector. **This is a new project under Biopower starting in April 2019**

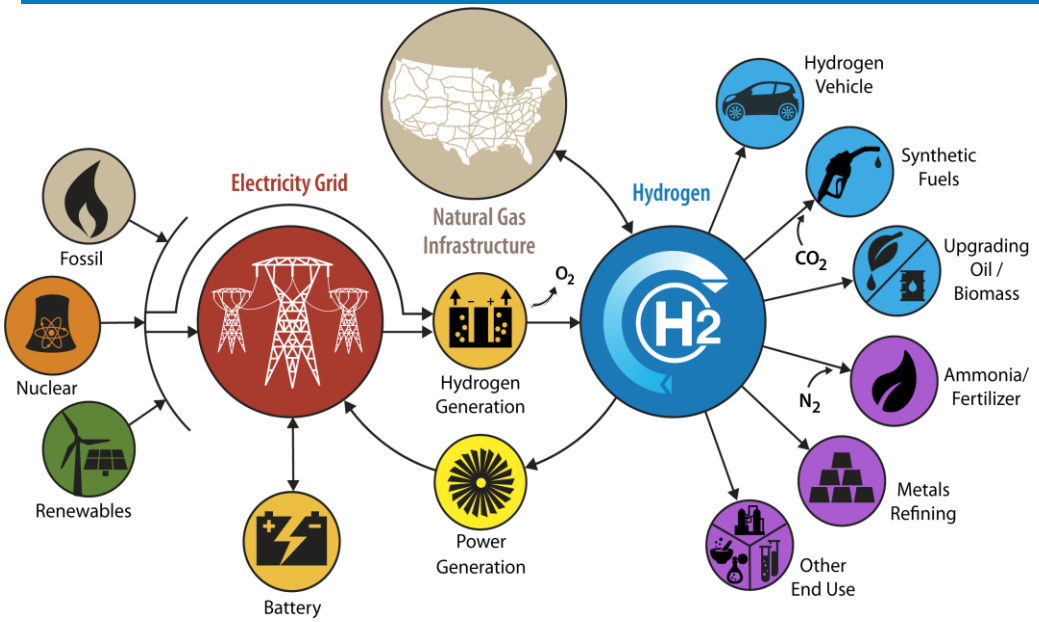
Outcomes

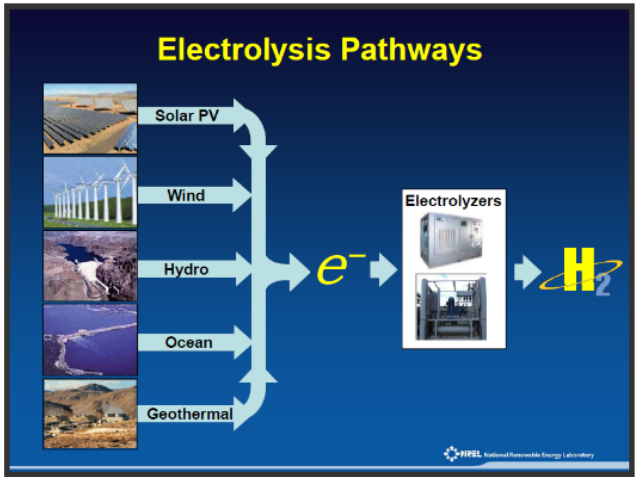
- Demonstrate biomethanation process at 700L scale to produce pipeline grade renewable natural gas from biogas
- Design and build of a mobile 30L system to accelerate process development on actual biogas feedstock in the field
- Develop scaling correlation factors between 30 and 700L systems using field and simulated biogas sources
- Model mass and energy flows to inform TEA and LCA for next generation MW-scale demonstration projects

Relevance

- Provide partners with operational performance of biocatalysts under varying pressure, flow and input gas
- Advance H2@Scale and electrons to molecules initiatives by storing renewable electricity in the NG network

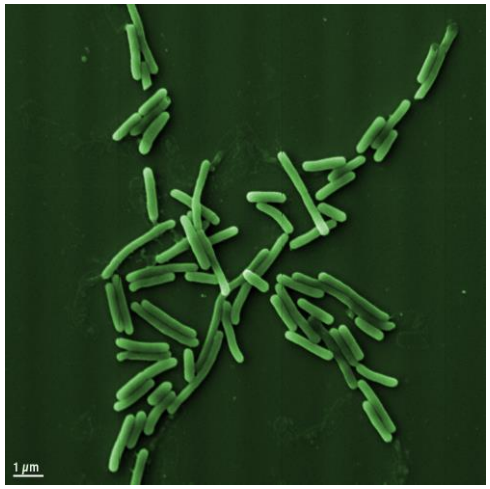
Project Concept





Rules of Thumb

- 50 – 55 kWh to make 1 kg of H_2
- 1MW$_e$ electrolyzer, 430 kg /day
- 10MW$_e$ of electrolysis feeding a bioreactor can recycle 7,500 tons of CO_2 per year



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$$CO_2 + 4\ H_2 \xrightarrow{\text{Biocatalyst}} CH_4 + 2\ H_2O + \text{Heat}$$

Methanothermobacter thermautotrophicus

Quad Chart Overview

Timeline

- New Project – 0% Complete
- Start: Q3 FY19
- Merit review cycle: FY2019 - 2021

(Dollars in 1000's)	FY19	FY20	FY21	Total Planned Funding (FY 19 – 21)
DOE Funded	$628	$500	$372	$1,500
Cost Share	$658	$53.3	$53.3	$765

Objective

Advance the science of scaling of the methanation of biogas CO_2 from different sources with nutrient and controls optimization to accommodate varying feedstock.

Barriers

Ct-H: Gas Fermentation Development

ADO-D: Technology Uncertainty of Integration and Scaling

Partners

Southern California Gas Company

Electrochaea GmbH

Biogas TEA/LCA groups at NREL and ANL

End of Project Goal

Demonstrate continuous operation of bioreactor at pressures up to 18 bar using biogas feedstock to produce a product gas composition of > 97% CH_4, < 3% CO_2, < 0.2% O_2 and < 4 ppm H_2S.

Project Overview

Project History

- SoCalGas & SETO
  - Power systems analysis
  - Design, safety, installation and commissioning
- SoCalGas & ESIF F&I – High Impact Project
  - System characterization
- BETO Biopower FOA to upgrade biogas to pipeline quality RNG
  - See next slides
- SoCalGas, BETO and FCTO CRADA
  - IP development
  - Electrolyzer/bioreactor integration at small and pilot scales

Benefits of Biomethanation

- Recycle and utilize CO_2 waste streams from;
  - Ethanol plants, dairies, wastewater and fossil
- Scale-able, non-toxic, self-replicating biocatalyst
- Easy separation and meets pipeline quality standards
- Provides long-duration energy storage of renewable electricity in the NG network
- Low temperature systems

Project Overview

Project Summary

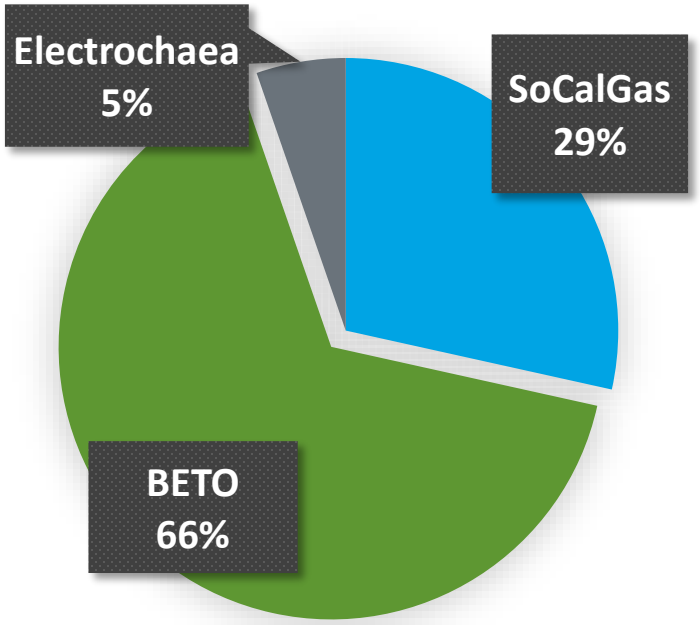
Create synthetic and actual biogas from field sites to produce pipeline grade RNG containing; > 97% CH_4, < 3% CO_2, < 0.2% O_2 and < 4 ppm H_2S

- Real biogas will be run in the small-scale mobile bioreactor designed and built for this project
- Synthetic biogas will be run in the 700L bioreactor by feeding back product gas from the output and blending in H_2S from cylinders
- Quantify improvements in H_2 mass transfer and biocatalyst performance
- TEA and LCA on the biomethanation process will be completed through the Biochemical Analysis Project between NREL and ANL

Project Objectives

- Biogas characterization
- Biocatalyst analytical development
- Design and build of mobile electrolyzer/bioreactor R&D platform and field site demonstrations
- Develop science of scaling integrated systems to/from 30L and 700L pressurized bioreactor with biogas

Approach - Management



(k dollars)	SoCalGas	BETO	Electrochaea
FY19	$602	$628	$57
FY20	$22	$500	$32
FY21	$22	$372	$32
Contributions	**$645**	**$1,500**	**$120**

Overall Project Total $2.265M

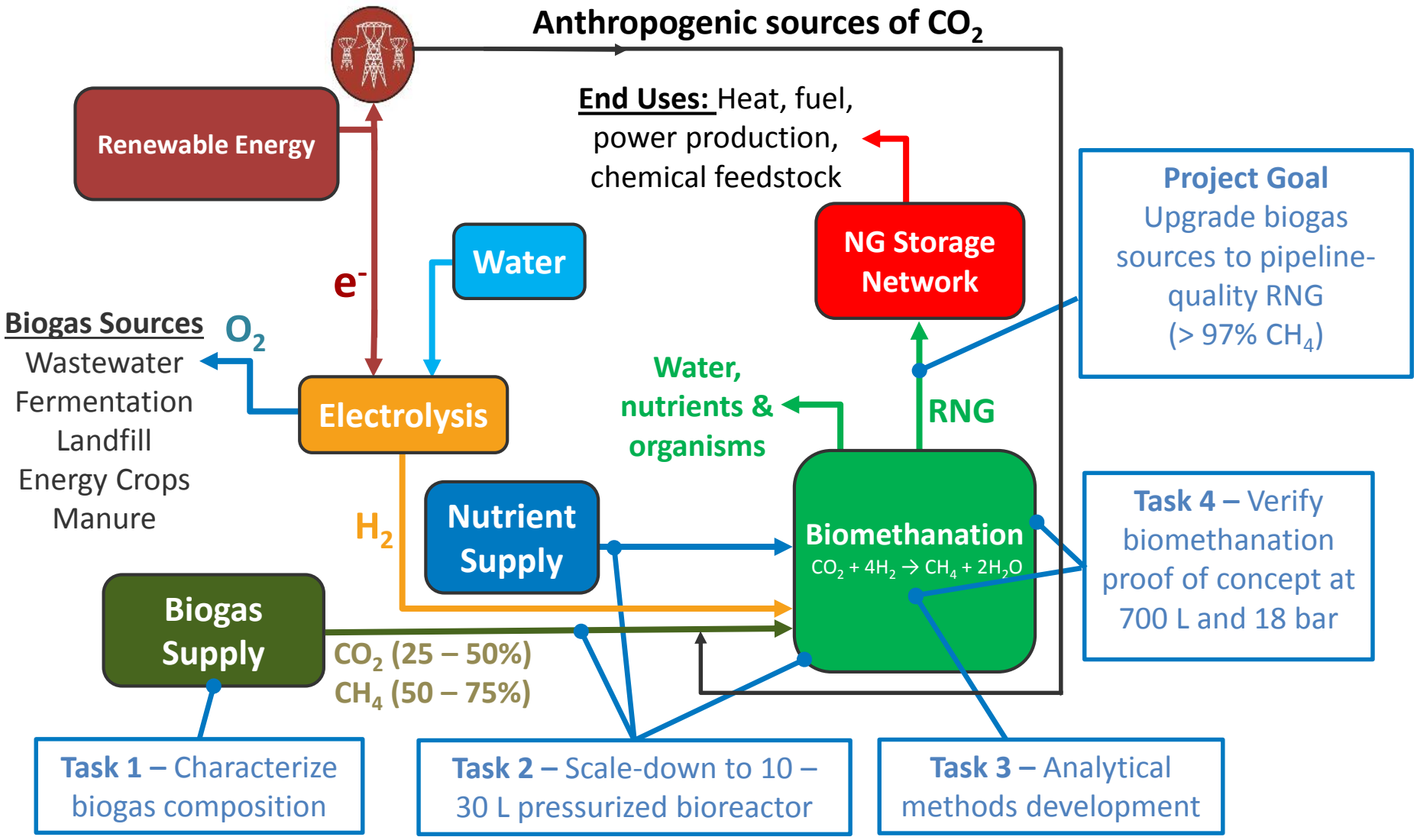
- $580K bioreactor (out of $2M+ cost to SoCalGas)
- $25K Licensing Fee for the organism

Project Management

- Standing weekly calls
- Periodic on-site visits from team members for critical project reviews

- Project managed and schedule by PIs at NREL
- SoCalGas provides guidance for market and commercial deployment
- Electrochaea provides design, process development and operational support leveraging their experience at BioCat

Approach - Technical



Approach – Technical
Task 1: Biogas Characterization

Capital/Resource needs:	Year 1: $90k; Year 2: $90k; No activity in Year 3
Outcome for BETO:	Years 1 & 2: Gain an understanding of the compositional differences between regional biogas sources and variability in time (hours to season) through site visits and existing databases.

Goal: Investigate the time and spatial composition differences of biogas sources from field sites across the country. Understand the early market opportunities for MW-scale demonstrations.

Challenge: Understand feedstock variability to inform process controls and operation.

Approach: Coalescing data from various sources like;

- Michigan State University's Anaerobic Digestion Research and Education Center (ARDEC)
- NREL's internal WTE projects
- NYC wastewater treatment facilities
- Duke University's Pratt School of Engineering
- Electrochaea's BioCat project

Approach – Technical
Task 2: Pressurized Bioreactor Scale-Down

Capital/Resource needs:	Year 1: $390k; Year 2: $290k; Year 3: $120k
Outcome for BETO:	Year 1: NREL will design and build a mobile pressurized 30 L lab-scale bioreactor as a R&D platform for gas fermentation Year 2: Show benefit of using high pressure to improve H_2 mass transfer, which will improve biocatalyst productivity. Utilize lab-scale operations to select conditions worth testing at the 700 L scale. Year 3: Demonstrate feasibility of upgrading real biogas to pipeline grade methane at select field locations.

Goal: Develop scientifically based scaling functions using a scaled-down bioreactor that can operate at pressures up to 18 bar, temperatures up to 70°C, and capable of upgrading gas mixtures containing CO_2, H_2, H_2S and CH_4 in order to understand the effect on the organism's productivity, composition and by-product formation before operating the 700 L bioreactor (Task 4).

Challenge: Off-the-shelf equipment have set designs, not flexible and are costly.

Approach: Utilize low-cost (e.g., 316L SS) materials in the design & build process of a scaled-down 30 L pressurized mobile bioreactor system for field demonstrations at biogas sites. Design will be informed by the 700 L SoCalGas system and Electrochaea's experience in the design of their lab-scale pressurized bioreactor.

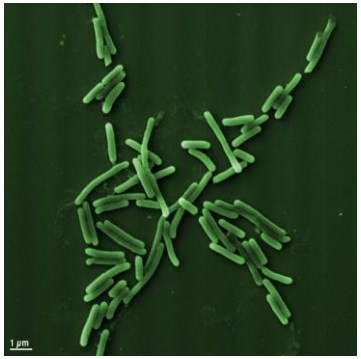
Approach – Technical
Task 3: Analytical Methods Development

Capital/Resource needs:	Year 1: $120k; Year 2: $120k; Year 3: $50k
Outcome for BETO:	Year 1 – 2: Working with Electrochaea to develop an expanded set of laboratory analytical procedures for characterizing the biomethanation process under varying biogas feedstock. Year 3: Perform and model accurate mass and energy balances on the fermentation process to strengthen TEA and LCA.

Goal: Develop analytical methods for mass balances (e.g., carbon, nitrogen, sulfur, hydrogen, phosphorus), guide nutrient additions, and look for potential co-products produced by the methanogens under varying process conditions.

Challenge: Leveraging methods from other biological systems may not transfer.

Approach: Build from NREL's analytical capabilities previously developed in the areas of algae biomass characterization, waste-to-energy and the biochemical platform; utilizing existing analytical equipment (e.g., LC, GC, LC/MS, GC/MS, NMR, ICP).



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Approach – Technical
Task 4: Process Scale-Up

Capital/Resource needs:	Year 3: $230k
Outcome for BETO:	Year 3: Demonstrate simulated (CH_4, CO_2 ,H_2S mixture) biogas upgrading and feasibility of producing pipeline grade biomethane to > 97% CH_4, < 3% CO_2 , < 0.2% O_2 and less than 4 ppm H_2S.

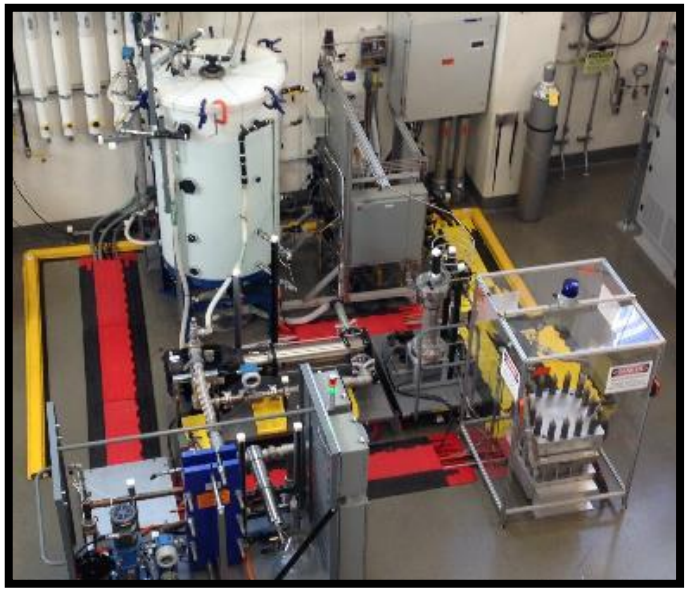
Goal: Based on the process development and scaling results using the 30 L lab-scale bioreactor at biogas sites containing H_2S, perform operations on the 700 L reactor at 18 bar using simulated biogas (CH_4, CO_2, H_2S).

Challenge: Develop pilot-scale H_2S blending hardware capability at NREL with very limited space on existing research pad outdoors.

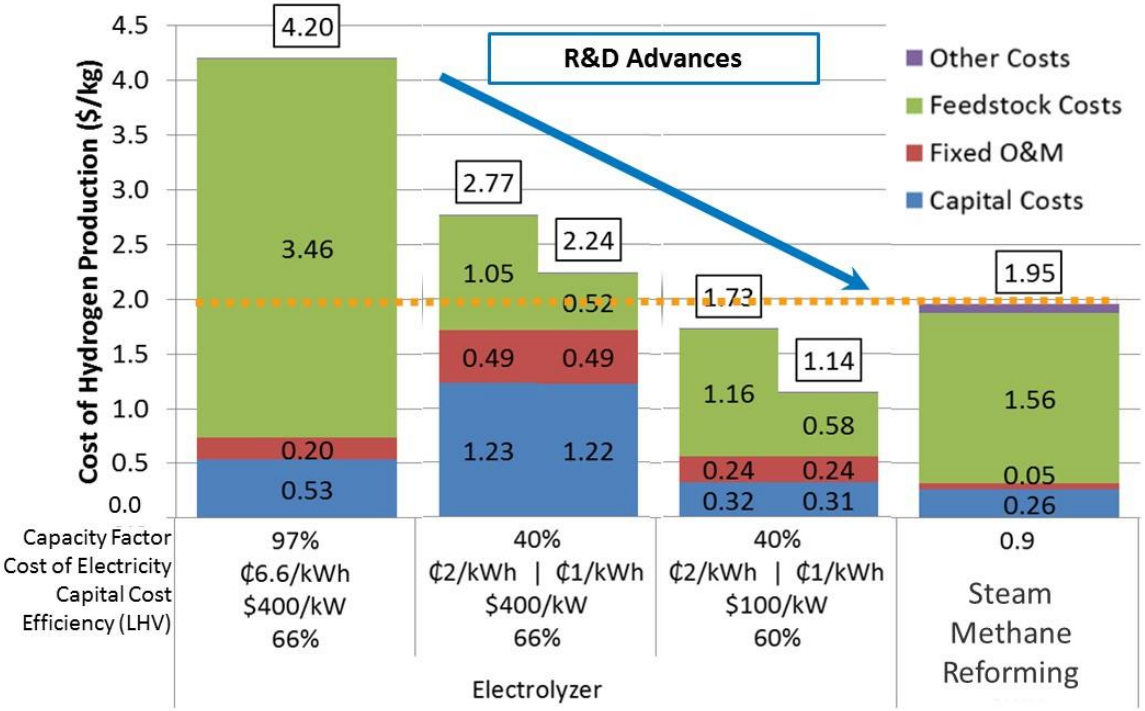
Approach: The on-board GC will have to be modified to monitor the input gas stream, which will vary in its composition. Capturing information from all 3 (input, raw and output gases) locations will guide the nutrient additions of the Na_2S as a function of the H_2S input and head space concentration to achieve > 97% CH_4.

Accomplishments – Pre-Project

NREL Electrolyzer System



Reducing the cost of LTE H_2 Production



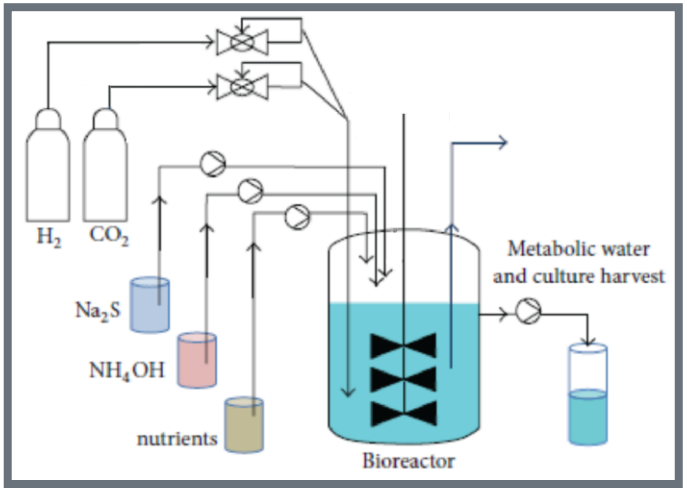
System Specifications

- 20 – 70 bar differential pressure
- 4000 A_{dc} at 250 V_{dc} (1 MW DC)
- < 5 ppm_v H_2O_v
- 5 kg H_2 / hr w/ 250 kW PEM stack

Electrolyzer systems are flexible electrical loads that can help stabilize the electricity grid and enable higher penetrations of renewable electricity.

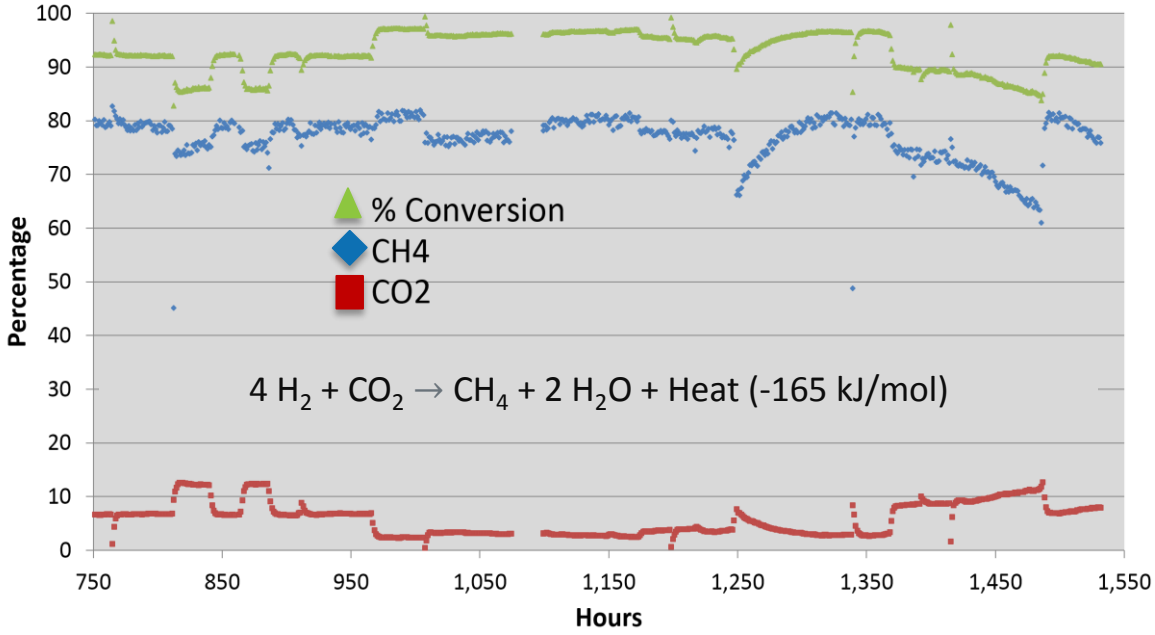
Accomplishments – Pre-Project

5L bioreactor growing the biomethanation biocatalyst – archaea *Methanothermobacter thermautotrophicus*



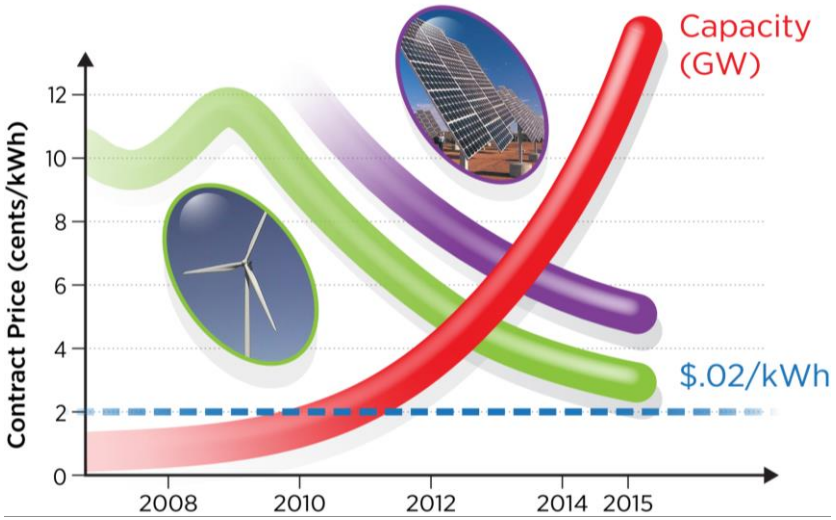
LAB SCALE BIOMETHANATION DATA

- 66 days of continuous operation
- Ambient pressure and 60°C
- 13 g / L Dry Cell Weight
- 90 – 95% conversion efficiency



Relevance

BIG Picture: Enable higher penetrations of solar- and wind-generated electricity sources, leveraging FE, NE and EERE Program initiatives like H_2@Scale, to advance the concept of electrons-to-molecules by recycling carbon and using RNG as a long-duration energy storage option



Source: (Arun Majumdar) 1. DOE EERE Sunshot Q1'15 Report, 2. DOE EERE Wind Report, 2015

Biopower Goal: Demonstrate biogas upgrading to pipeline RNG standards by developing scientifically-based scaling functions using small- and pilot-scale systems under simulated and real-world conditions. Enable MW-scale biogas upgrading through systems integration and improved biocatalyst performance.

BETO Goals: Accelerate the deployment by improving the economics of WTE technologies using biogas sources.

- Advancing the SOT: Reducing capital costs by incorporating low-cost bioreactor materials of construction. Improving the biocatalyst productivity through improve H_2 mass transfer using high pressure and innovative systems integration
- Pure CO_2 and biogas sources can be utilized in this biomethanation process

Future Work

Starting work on Tasks 1 – 4 presented on Slides 8 - 11

First 18 months

- Design and start fabrication of the mobile scaled-down pressurized bioreactor system
- Coalesce time and spatial composition data from biogas data repositories to inform experimental campaign and process control
- Develop an expanded set of laboratory analytical procedures for characterizing the biomethanation process under varying biogas feedstock

Near-term Key Milestones

- Design scaled-down pressurized reactor for 10 - 30L , up to 20 bar pressure, and up to 80^{o}C
- Target 2 – 4 biogas compositions for development industry input and site visits, determine what compositions could be early market targets in California for biological upgrading

Go/No-Go

- Achieve 4.5 g/L-hr CH_4 productivity (10x baseline) and at least 91% biomethane concentration using the pressurized lab scale bioreactor

Summary

New Project starting in April 2019

1. Overview

Advance the science of scaling of the biomethanation process to utilize CO_2 from biogas sources to produce pipeline quality RNG.

2. Approach

Through the science of scaling, the research program will scale-down the biomethanation process to inform pilot-scale biogas optimization and accelerate next-generation system design. Leverage existing time and spatial biogas composition data and analytical methods to guide experimental and process control.

3. Progress

Project is currently waiting for DOE approval and T & Cs negotiations with partners.

4. Relevance

Enable higher penetrations of solar- and wind-generated electricity sources, leveraging FE, NE and EERE Program initiatives like H_2@Scale, to advance the concept of electrons-to-molecules by recycling CO_2 and storing RNG as a long-duration energy storage.

5. Future Work

Design and start fabrication of the mobile scaled-down pressurized bioreactor system. Coalesce time and spatial composition data from biogas data repositories to inform experimental campaign and process control.

Thank You

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Collaboration/Partners

Formal Partners

- SoCalGas
- Electrochaea GmbH

Potential Biogas Field Demo Sites

- SoCalGas
- Duke University
- Michigan State University
- Vermont
- National Grid - NYC