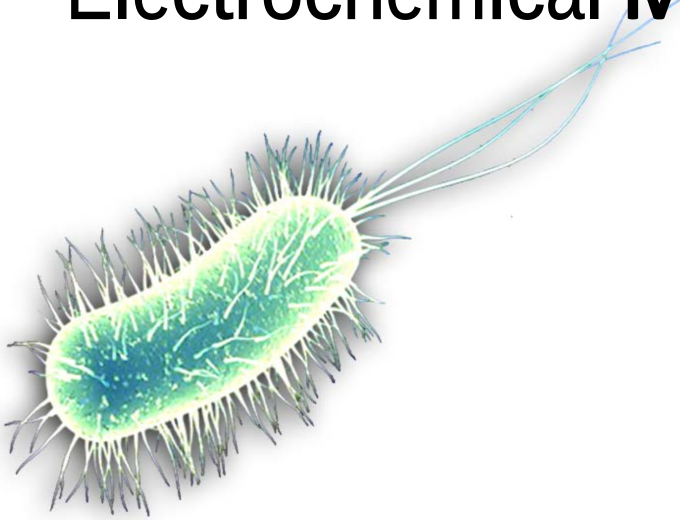
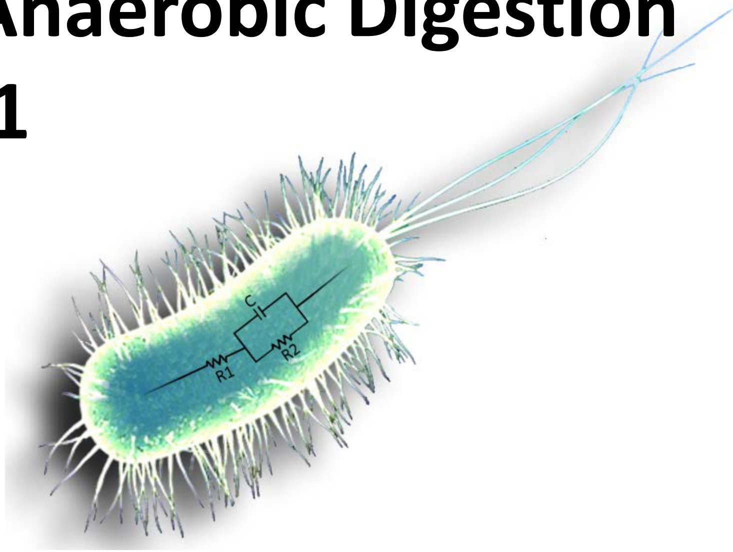
U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2017 Project Peer Review

Electrochemical **Monitoring of Anaerobic Digestion 2.5.2.100-101**





March 7, 2017
Waste to Energy

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Goal Statement

Goal: Design and develop sensors for real time, in-situ monitoring of bioprocesses for improved control, stability and efficiency at industrial scale applications.

Outcome: Technology to monitor bioreactor status in real time and prevent process upsets and failure. *More data and greater bioprocess efficiency at less cost.*

Relevance: Improvements to operational stability for increased success rates and thereby reduced investor and operator risk. Accelerate commercialization of waste to energy technologies.

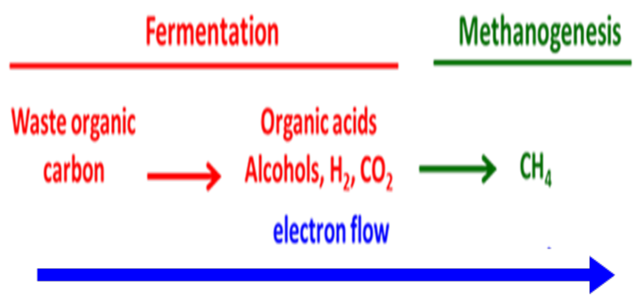
Balanced Conditions

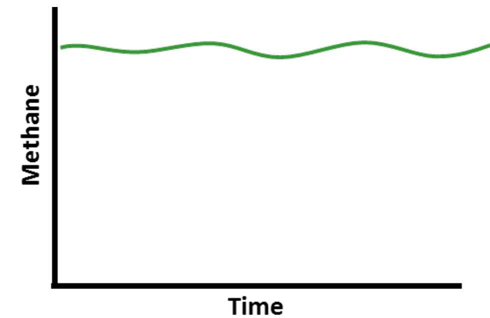
Unperturbed metabolic activity

Consistent methane production

Desired condition

<u>*Consistent electron flow*</u>





Imbalanced Conditions

Inhibitors present

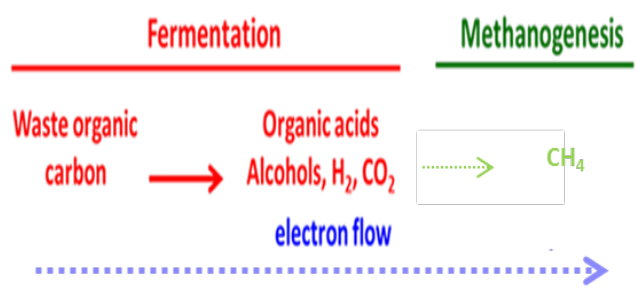
Perturbed metabolic activity

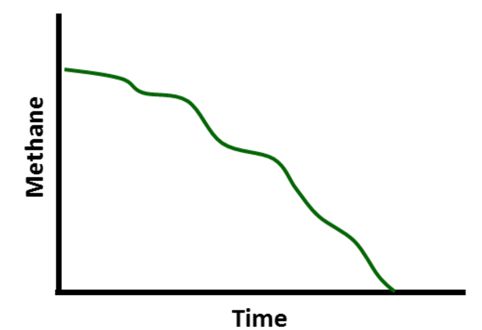
Decreased or no CH_4 production

Undesired condition

<u>*Interrupted electron flow*</u>

<u>*Process failure!!!*</u>





Quad Chart Overview

Timeline

- Project start date – 10/1/2017
- Project end date – 9/30/2020
- Percent complete ~ 16%

Budget

	Total Costs FY 12 –FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17-Project End Date)
DOE Funded	N/A	N/A	N/A	$1175K ($90K to date)
Project Cost Share (Comp.)*	N/A	N/A	N/A	N/A

Barriers

- Im-B: High risk of large capital investments
- Im-H: Lack of Acceptance and Awareness of Biofuels as a Viable Alternative
- Im-E: Cost of Production
- Ct-N: Reactor Design and Optimization

Partners

- ANL – (2.5.2.101) –31.4%
- Other interactions/collaborations
  - University of South Carolina – 21.3%
  - Savannah River Consulting – 4%

1 - Project Overview

Challenge

Real time determination of the stability of anaerobic digesters for waste to methane.

Question

Can the flow of electrons in a microbial consortium during methanogenesis be monitored and linked to the physiological status of the consortium?

Overall Objectives.

Electrochemically define microbial activity leading to balanced methanogenesis and differentiate between imbalanced conditions.

Technical Objectives

- . Electrochemically define microbial activity leading to methane production.
- Determine electrochemical responses to various inocula and loading rates.
- Compare electrochemical monitoring to conventional methods.

2 – Approach (Management)

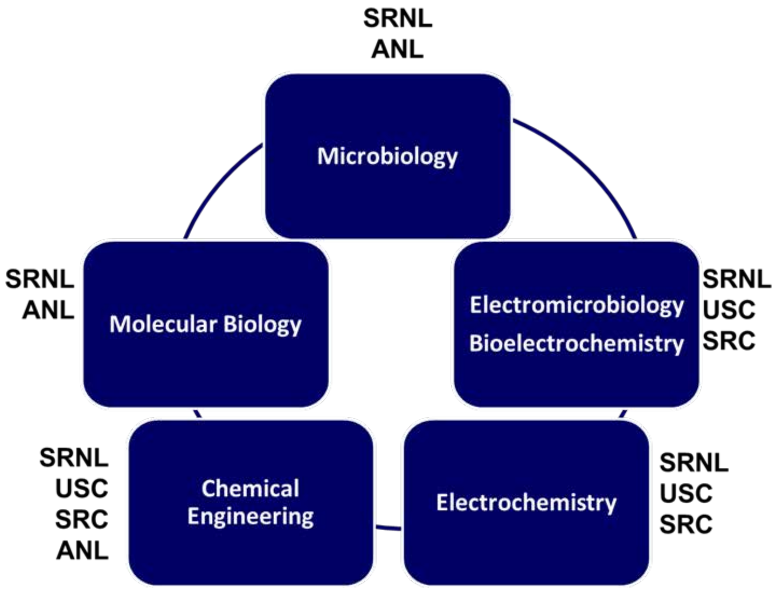
The team will correlate microbial activity measurements and molecular analyses to electrochemical phenomena. All information pertaining this project has been shared by team members and results communicated weekly or biweekly via teleconferences. Spending is being tracked monthly. Results will be compiled and communicated to BETO quarterly.

SRNL – 1. Responsible for project management and coordinate the activities among team members. 2. Conduct electrochemical, biochemical and molecular analyses.

ANL - This work will be linked with ongoing bioprocess development activities and molecular analyses of community structure and dynamics. Scale-up studies to be conducted at ANL.

USC - EC analysis and modeling. They will also supervise graduate and post-graduate activities related to this work.

Savannah River Consulting - direct the design and implementation of experimental protocols to link bioreactors and microbial processes



2 – Approach (Technical)

- Problem - Methane bioprocess failure or abandonment as high as 50% due to technical difficulties and/or cost of monitoring and maintenance

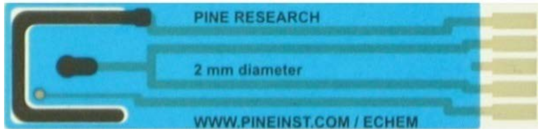
- Approach – Develop sensors to monitor reactors in-situ for inexpensive real-time data.
  - In-situ monitoring - Use of common electrochemical hardware and software and correlate to microbiology, biochemistry and molecular biology. There will be enough technical overlap to link data for a complete picture.

- Potential challenges -
  - Low data resolution – Overcome through increased signal strength or reconfigured electrode design.
  - Electrode fouling – overcome through rapid voltammetric cycling.
  - Data complexity – Refine data enough to simplify analyses / results for end user / computer feedback control.

- Critical success factors -
  - Ability to define imbalanced conditions in real time cheaper and more timely than conventional methods.

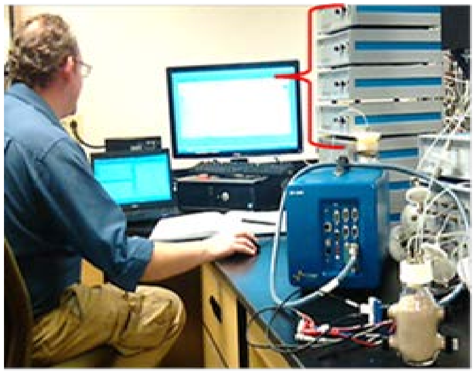
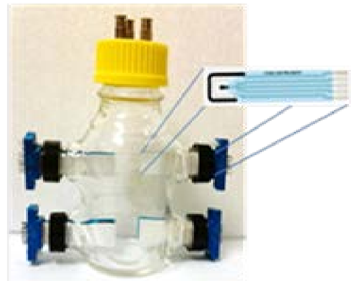
3 – Technical Accomplishments/ Progress/Results

- Coordination of key personnel, responsibilities, analytical equipment, software, communication and protocols among project partners.
- Methanogenic rumen fluid consortium established in 100 ml reactors with cellobiose as carbon source. Methane production (measured with GC) remains stable.
- Graphite electrode design and configuration established.

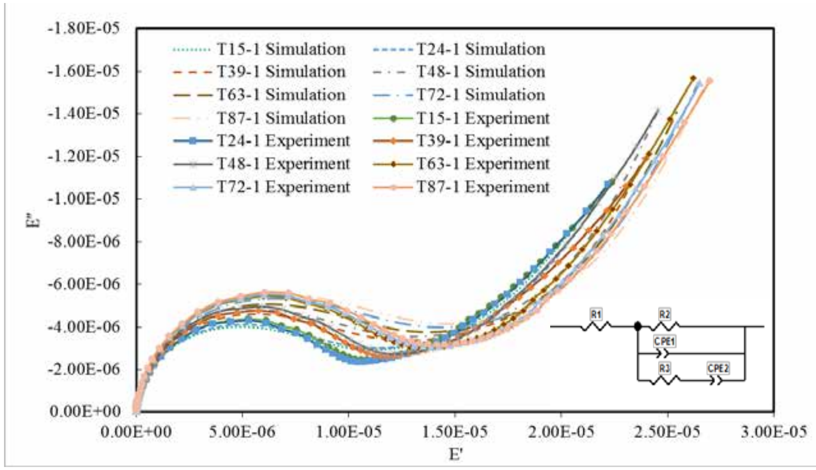


- Electrochemical analysis on preliminary data.
- Key milestone status - Completed experimental setup with collection and analysis of baseline data of microbial growth ahead of schedule.
- On track with 2nd milestone - Electrochemically define balanced methane production by a mixed rumen fluid culture.

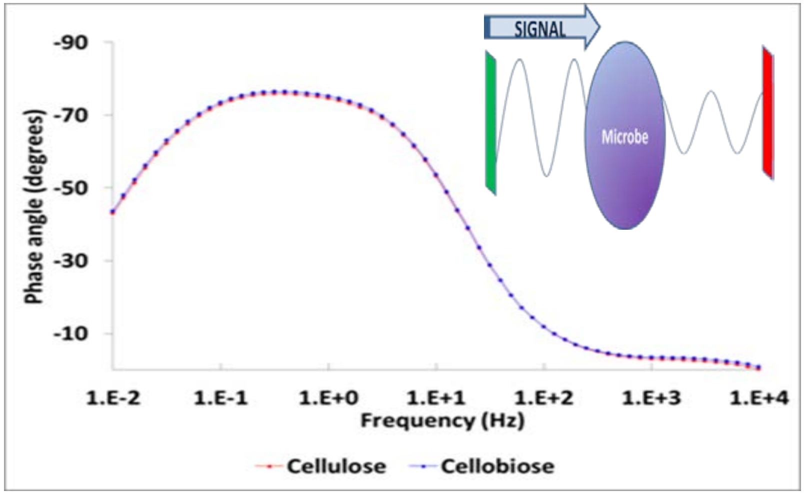
3 –Technical Accomplishments/ Progress/Results (cont'd)

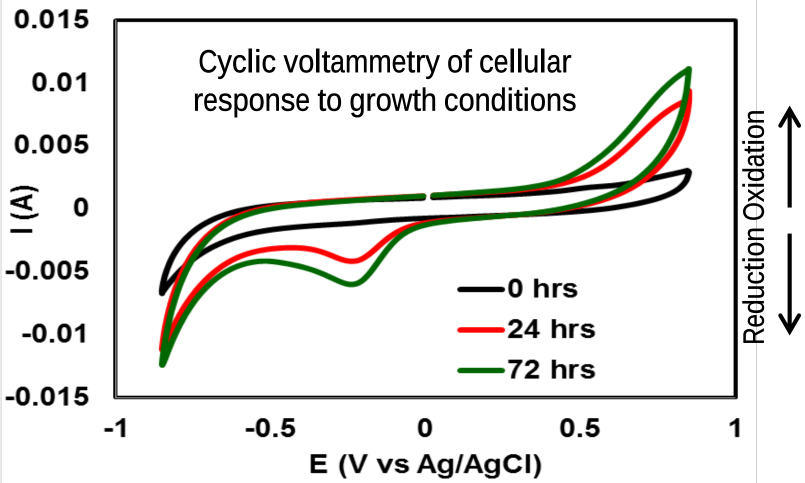
Electrochemical instrumentation coupled to bioreactor and respirometer.



Cole-Cole plots of *Clostridium phytofermentans* grown on cellobiose. Freq. range: 10^{-2} to 10^{5} Hz



Electrode configuration demonstrates high level of precision.



Starvation induced reduction in a methanogenic consortium.

4 – Relevance

Statement of Relevance to BETO: Develop sensors for improved control, stability and efficiency at industrial scale waste to methane. This will improve process reliability and efficiency in order to "accelerate commercialization of WTE technologies through development of real time sensors for anaerobic processes"[1,2].

Linkage Goals: Expected to help DOE/EERE meet 2022 goals for GHG emissions reduction of 50% or more compared to petroleum-derived fuel[1].

Potential for near market integration and accelerate commercialization of wet waste technologies of biomass conversion to methane:

Potential of 2.5 billion gasoline gallon equivalent[2]
Reduced stakeholder risk[1]
Operational cost reductions[1-3]
Improved energy efficiency[1-3]
Bioprocess control and reliability[1-4]

Tech transfer/marketability: Regular interaction with potential industry end-users to provide guidance for practical applications of the technology.

1. BETO. WTE Workshop. 2015
2. BETO:MYPP 2016
3. Bioresource Technol. 2008, 7928
4. Bioresource Technol. 2014, 491

5 – Future Work

- Next 18 months - Correlate balanced and imbalanced methane production to biochemical, microbial, genomic and electrochemical data.

- Upcoming key milestones –
  – Define balanced and imbalanced methanogenesis in terms of electrochemistry.
  – Electrochemistry data - differentiate (>90% confidence) balanced vs. imbalanced conditions.
  – Evaluate five inocula from industrial/municipal methanogenic bioreactors and report conventional data related to system electrochemistry and metagenomics.
  – Correlate (>90%) electrochemistry data to conventional monitoring techniques.

- Go/No-Go Specific electrochemical parameters (i.e. $\Delta\varepsilon'_{\Gamma}$, $\Delta\sigma''$, $\Delta\varphi$, I_p) will correlate consistently with microbial activity related to methane production. Mitigation: revise equivalent circuit model or increase monitoring intervals. Parameters with low correlation will not be followed throughout.

- **Budget.** Current remaining funding will be put toward defining balanced methanogenesis as an electrochemical phenomenon.

Summary

1. **Overview** – Develop real time, in-situ sensors for monitoring the physiological status of mixed methanogenic cultures.

2. **Approach** – Use electrochemical methods to monitor microbial physiology and digester health.

3. **Technical Accomplishments/Progress/Results.** - Multi-disciplinary team has been established. Cultures, instrumentation, software, methods and modeling approaches in place.

4. **Relevance** - "Development of real time sensors for anaerobic processes" to accelerate commercialization of WTE technologies and optimize existing facilities.

5. **Future work.** - Define balanced and imbalanced biomass conversion to methane in terms of electrochemistry and use results to forecast potential digester failure.