DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Enhanced Anaerobic Digestion and Hydrocarbon Precursor Production

March 24, 2015
Biochemical Conversion Area Review

Meltem Urgun-Demirtas, Ph. D.
Argonne National Laboratory

Goal Statement

- Ultimate Goal: Transform negative-value or low-value biosolids into high-energy-density, fungible hydrocarbon precursors through targeted research, development and demonstration.
  - Enhance anaerobic digestion of biosolids to produce biogas with ~90% methane content and hydrogen sulfide at nondetectable level (Task 1)
  - Develop a Comprehensive Waste Utilization System (CWUS) for production of hydrocarbon precursors from the anaerobic digestion of biosolids (Task 2)
- Enables sustainable production of biogas that is considered as a cellulosic biofuel under new RFS2 (EPA, July 2014)
  - Biogas competes with conventional natural gas
  - Reduce greenhouse gas emissions relative to petroleum-derived fuels
  - Reduce U.S. dependence on foreign oil
  - Over 99% of D3 RINs generated from biogas
- Addresses DOE's goals of development of cost-competitive and sustainable biofuels by advancing efficient production strategies for drop-in biofuels

Quad Chart Overview

Timeline

- Project start date: February 2014 (Task 1) and October 2014 (Task2)
- Project end date: Sep 2017
- Percent complete: On Schedule

Budget

	Total Costs FY 10 – FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	N/A	N/A	$250,000	$750,000
Project Cost Share (Comp.)*	N/A	N/A	N/A	N/A

*If there are multiple cost-share partners, separate rows should be used.

Barriers

- Task 1:
  - Cleanup/Separation (Bt-H)
  - Product Acceptability and Performance (Bt-K)
  - Overall Integration and Scale-Up (Ft-J)
  - **Cost of Production** (Im-E)
- Task 2:
  - Biomass and Feedstock Recalcitrance (Bt-B)
  - Pretreatment Processing and Selectivity (Bt-D)
  - Biological Conversion Process Integration (Bt-J)
  - **Cost of Production** (Im-E)

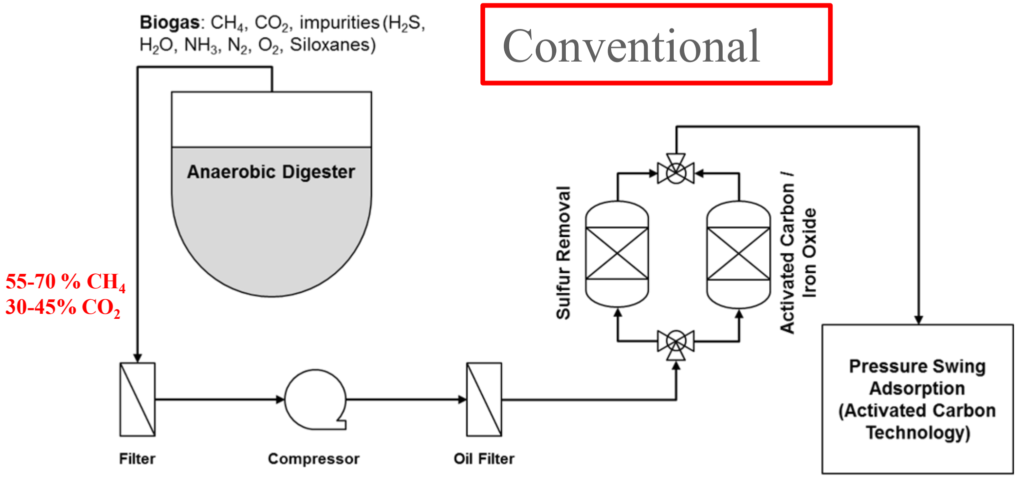
Partners

- Metropolitan Water Reclamation District of Chicago, DuPage County WWTP (IL)
- California Energy Commission
- Sacramento Municipal Utility District
- Iowa State University

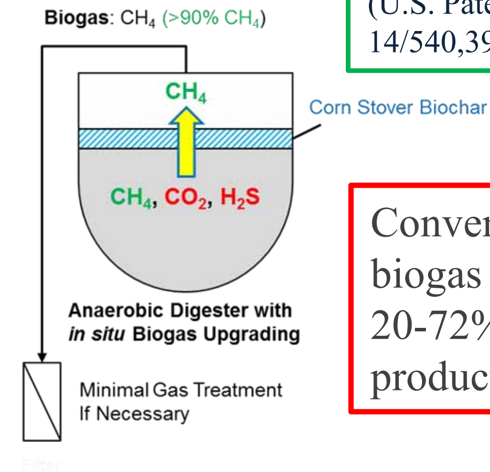
1 - Project Overview

- Development and deployment of a novel AD process to produce biogas to qualify for D3 RINs (Task 1)

Conventional

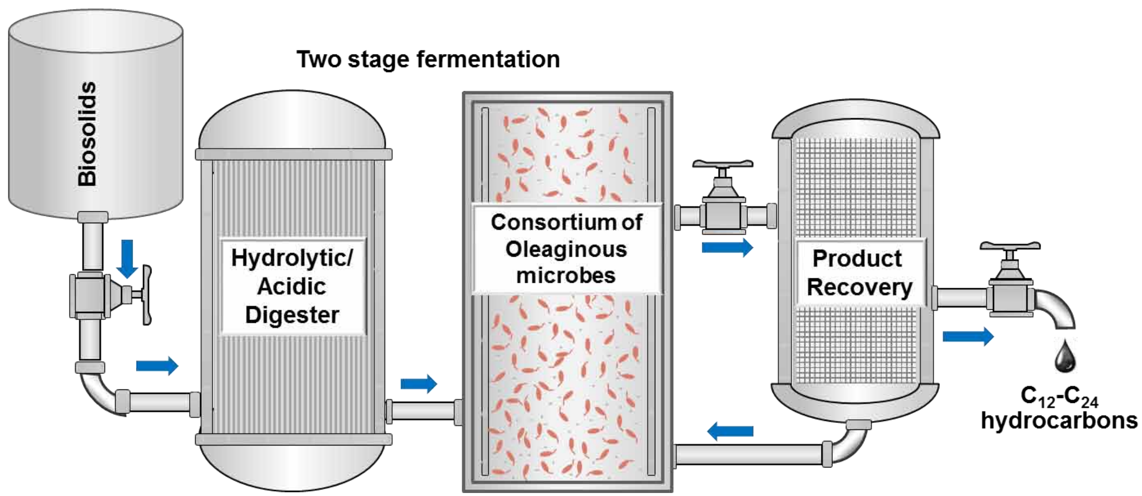


ANL's process (U.S. Patent Serial No. 14/540,393)



Conventional biogas upgrading: 20-72% of overall production cost

- Development of a low-cost process to produce hydrocarbon fuels (Task 2)



2 - Technical Approach

ANL's Patented Process
(US 8,247,009)
Accelerated weathering
Ca/Mg rich rock
sequester CO2 into carbonates

Bench-scale Testing
Serum bottles (FY14-15)

Biochemical Model
TEA

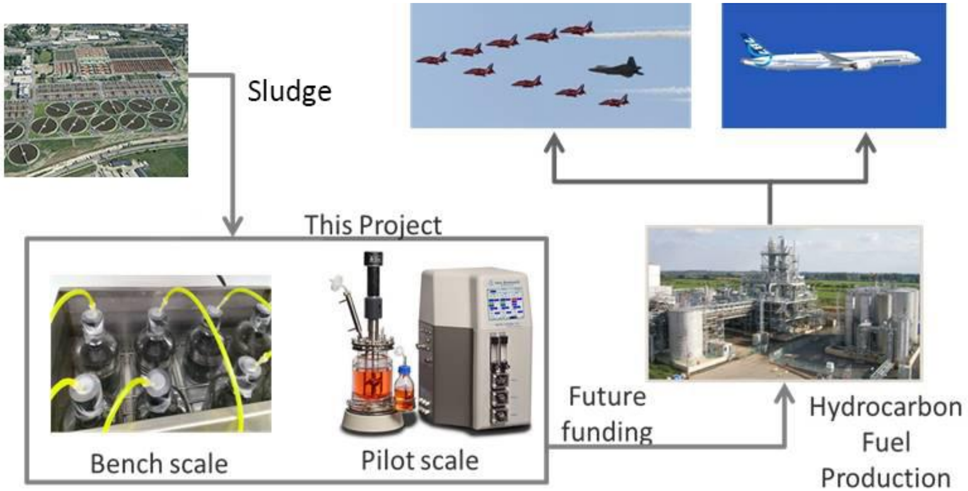
Pilot-scale testing
14 liter Bioflo Fermenter (FY15-16)

Biochemical Model
TEA

Field-scale technology demonstration
Test at the field-scale digester (FY17)

Technology Deployment

Task 1



(FY15) (FY17)

Task 2

Metrics:

- Target:
  - Produce biogas (>90% CH_4) to qualify for D3 RINs (Task 1)
  - Demonstrate hydrocarbon precursors production with the CWUS process
- Go/No-go Decision Points:
  - FY15 – >90% CH_4 biogas (3/31/2015) (Task 1)
  - FY15 – Produce 30 g/L of cells with 50% (w/w) lipid content (Task 2)

2 – Approach (Technical) (FY 2014-2016)

- *Task: 1*
  - **Assess availability of the feedstock resources**
  - **Conduct bench-scale anaerobic digestion experiments with**
    - Different biochar types (corn stover, oak and pine), operating temperature (mesophilic and thermophilic) and different biochar/organic loading rates
    - Different digester configurations and operating modes
    - Determine community structure and composition in the digester
  - **Perform techno-economic analysis**
  - **Scale up the process to 14 liter digester**
- *Task: 2*
  - **Conduct bench-scale experiments**
    - Determine required operating conditions to increase digestability of sludge
    - Examine the needs of oleaginous microorganisms at the process level
    - Determine community structure and composition in the bioreactor
  - **Develop a mathematical model to understand complexities in the bioreactor**
- **Potential challenges**
  - Accumulation of metals and other inert material in the digester due to biochar addition (Task 1)
  - Lack of reduced sugar in the feedstocks (Task 2)

Metrics for Task 1 and Task 2

Performance measurement
- ✓ Product titer
- ✓ Product yield
- ✓ Robustness of AD community

2 – Approach (Management)

Critical success factors:

- Cost effectiveness of pipeline quality methane production
- Identify technology users
- Engagement with WWTPs and digester technology users
- Identify customers (not technology users)
- Identify appropriate technology provider model
- Value of fertilizers (Task 1)

Potential challenges:

- Acceptance of new technology by utilities (Task 1)
- Identify biochar provider partnership
- Cost effectiveness of CWUS- lack of reduced sugar (Task 2)

Use of milestones for monitoring progress:

- Product titer and yield
- Feedstock resource assessment
- Techno-economic assessment of the process from bench-, pilot- and field-scale

3 - Technical Accomplishments/ Progress/Results- Task 1 (Feb 2014-Feb 2015)

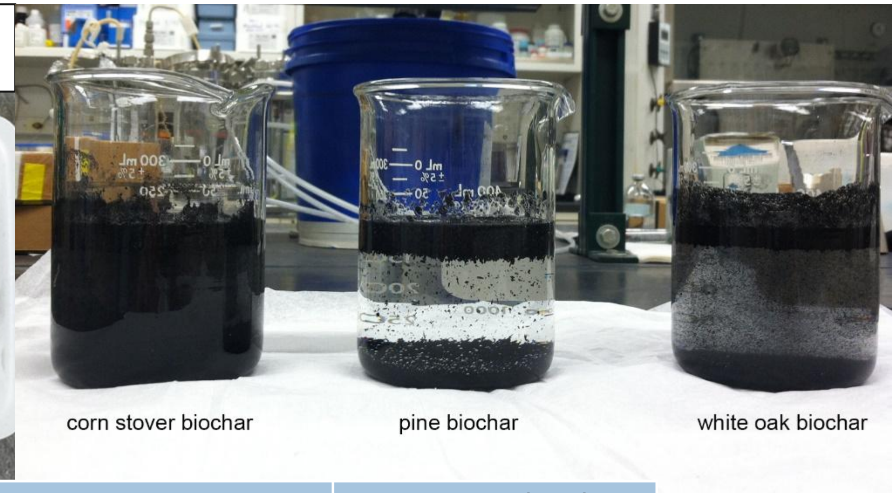
- Task 1.1 Completed resource assessment at WWTPs and determined challenges and opportunities towards energy-neutral WWTPs
- Task 1.2 Conducted bench-scale experiments
  - Three different biochar types (corn stover, oak and pine)
  - Two different operating temperature (mesophilic and thermophilic)
  - Different biochar/organic loading rates
  - One stage and two-stage digesters
  - Batch and semi-continuous operating mode (semi-continues mode operation ongoing)

❖ Milestone: Produced a gas composition with at least >90% CH_4 (batch mode).

- Task 1. 3 Microbial Community Analysis- Ongoing
- Task 1. 4 Techno-economic assessment-Ongoing

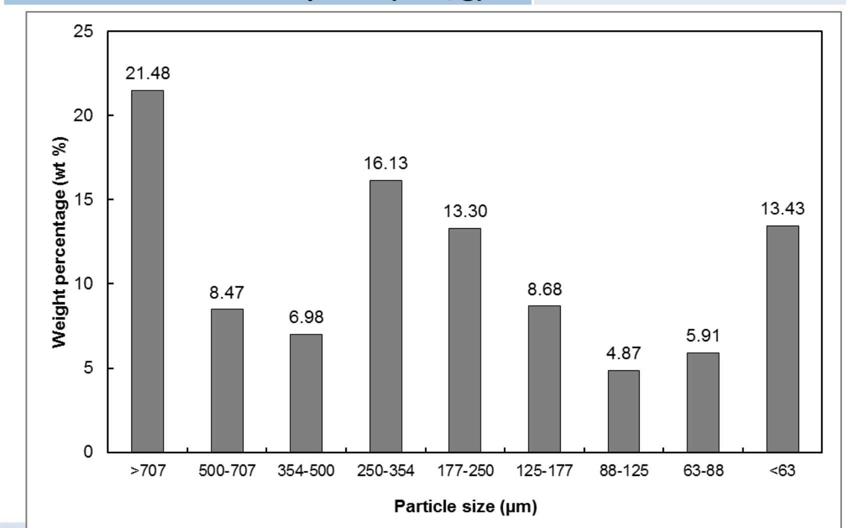
Not All Biochars are Equal!

Corn stover Pine White oak

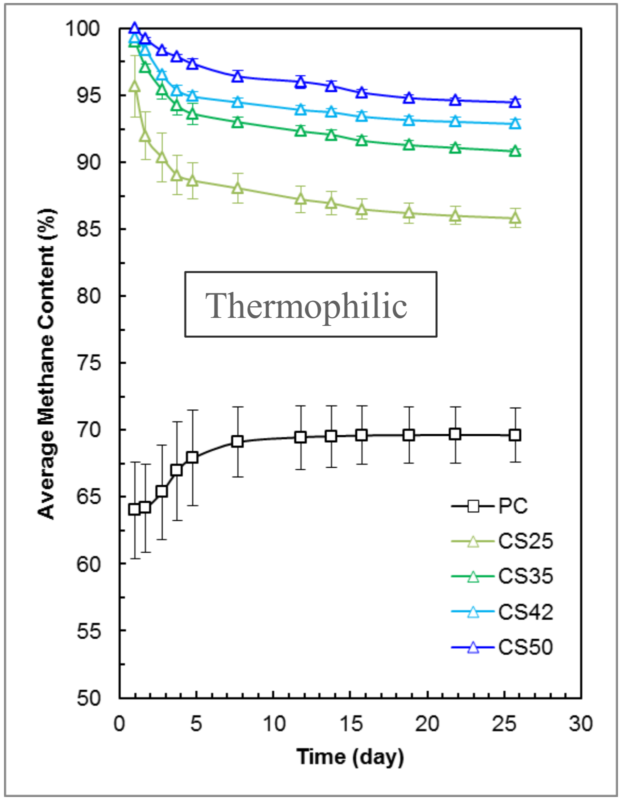


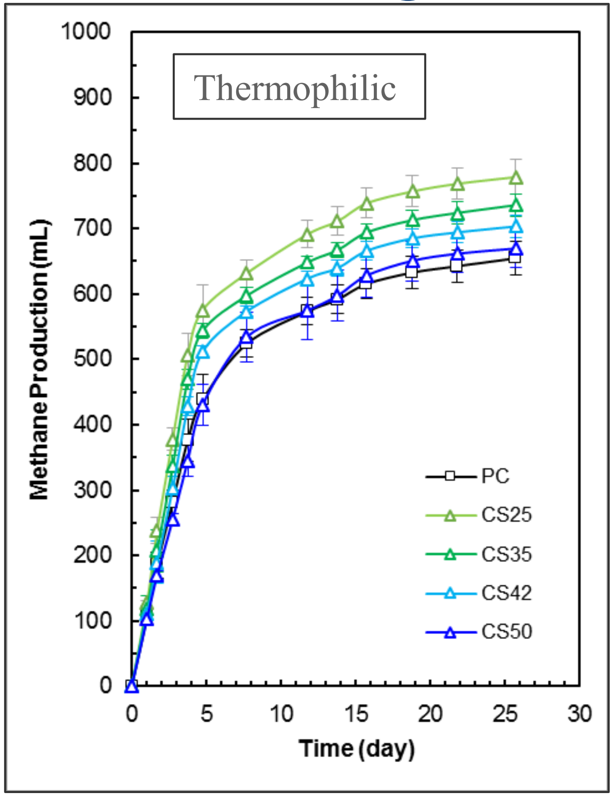
Analysis	Content	Concentration
Proximate Analysis	Moisture	0.97 ± 0.05
	Ash	45.18 ± 0.40
	VM	7.18 ± 0.58
	FC	46.66 ± 086
Elemental Analysis of Ash	SiO_2	60.58 ± 0.58
	Al_2O_3	5.65 ± 0.10
	TiO_2	0.27 ± 0.01
	Fe_2O_3	1.93 ± 0.05
	CaO	3.87 ± 0.11
	MgO	4.23 ± 0.13
	Na_2O	0.74 ± 0.03
	K_2O	14.17 ± 0.15
	P_2O_5	2.19 ± 0.12
	SO_3	0.22 ± 0.06
	Cl	1.01 ± 0.02
	CO_2	1.17 ± 0.13

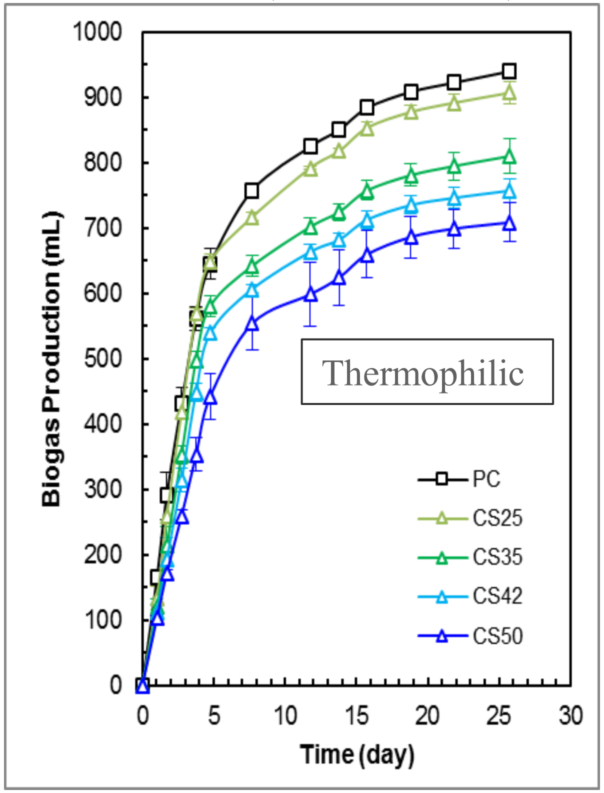
Property	Corn stover biochar
BET surface area (m^2/g)	105
Total volume of mesopores (cm^3/g)	0.02
Average diameter of mesopores (nm)	6.50
Total area of micropores (m^2/g)	315
Total volume of micropores (cm^3/g)	0.09



Task1- Accomplishments/ Progress/Results (cont'd)

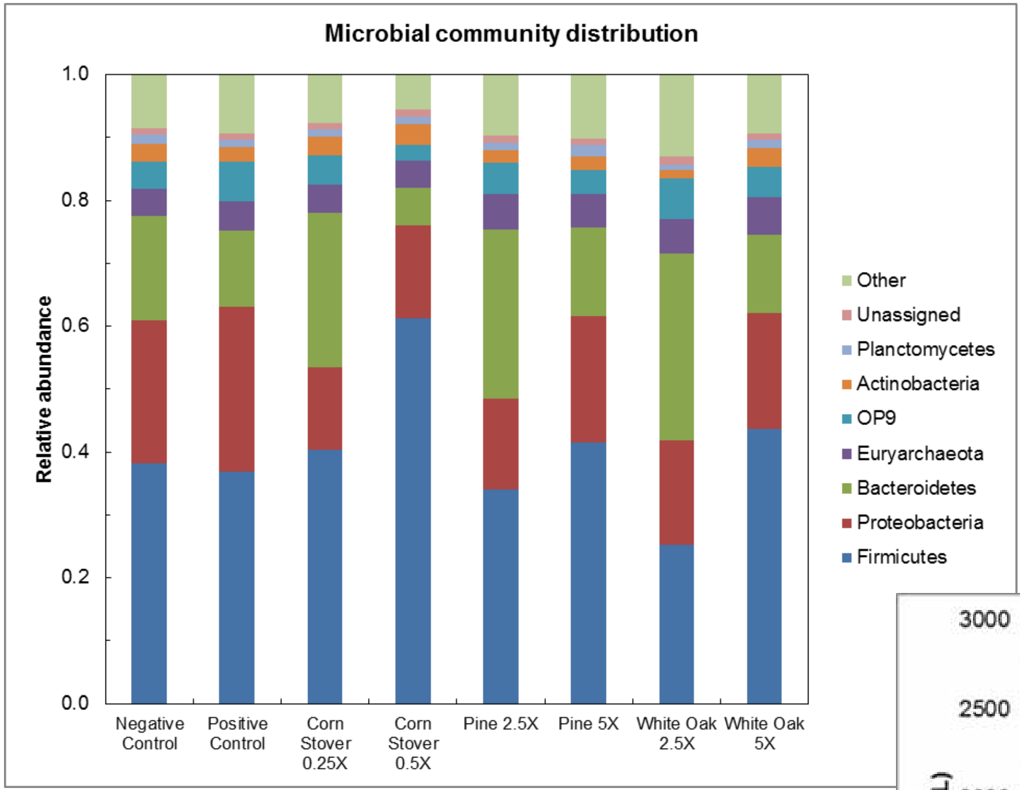






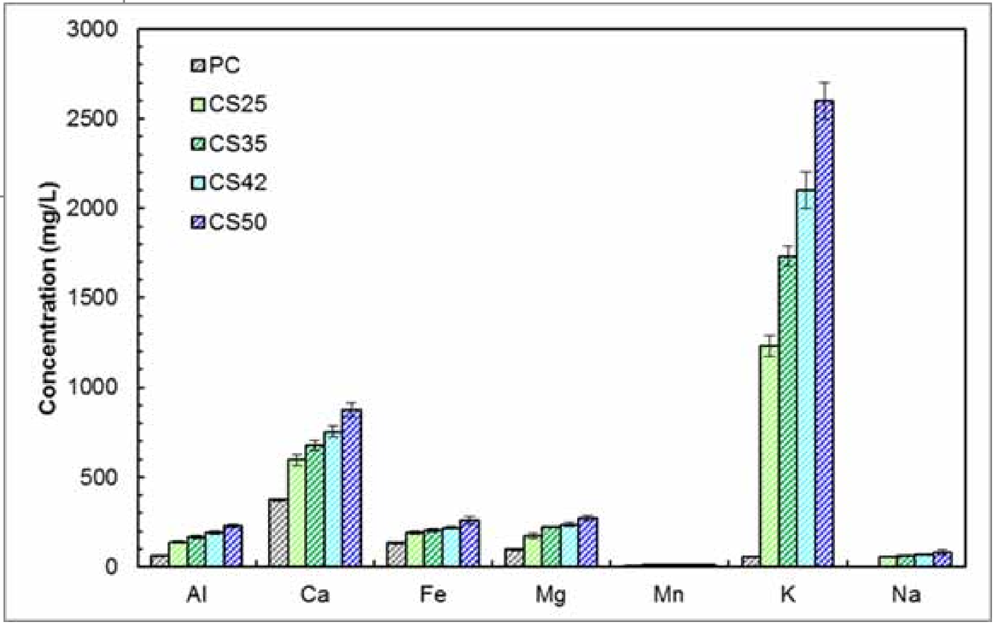
- Testing of three different biochars at bench-scale (0.5 liter) thermophilic/mesophilic digesters results in
  - Pipeline quality renewable methane production (> 90% CH_4 and <5ppbvH_2S)
  - CO_2 sequestration by up to 86%
  - Enhanced maximum methane production rate by up to 27.6%

Task1- Accomplishments/ Progress/Results (cont'd)



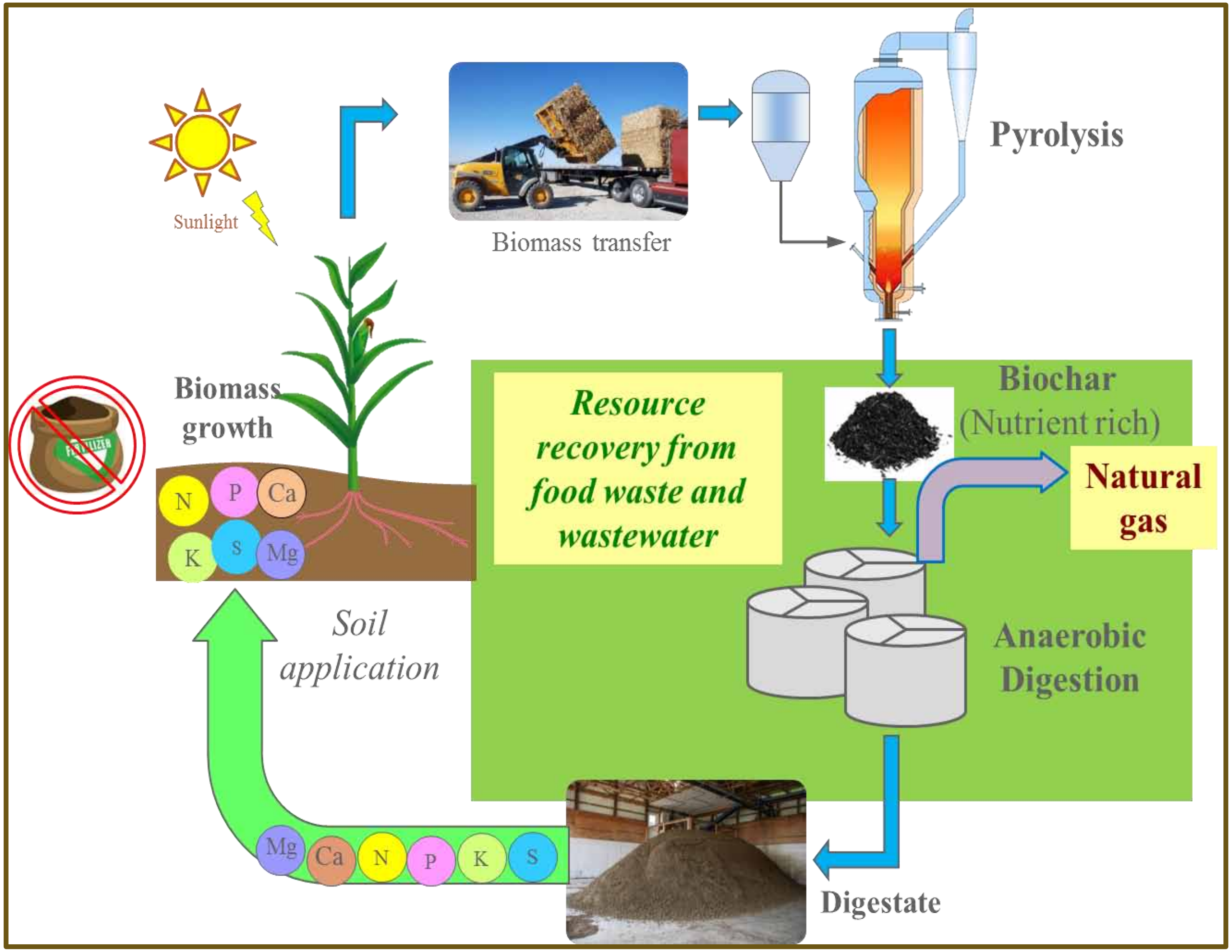
16S-rRNA-based microbial community analysis over biochar addition

Phylum level identification



Digestate w/ high fertilizer value

Task1- Accomplishments/ Progress/Results (cont'd)



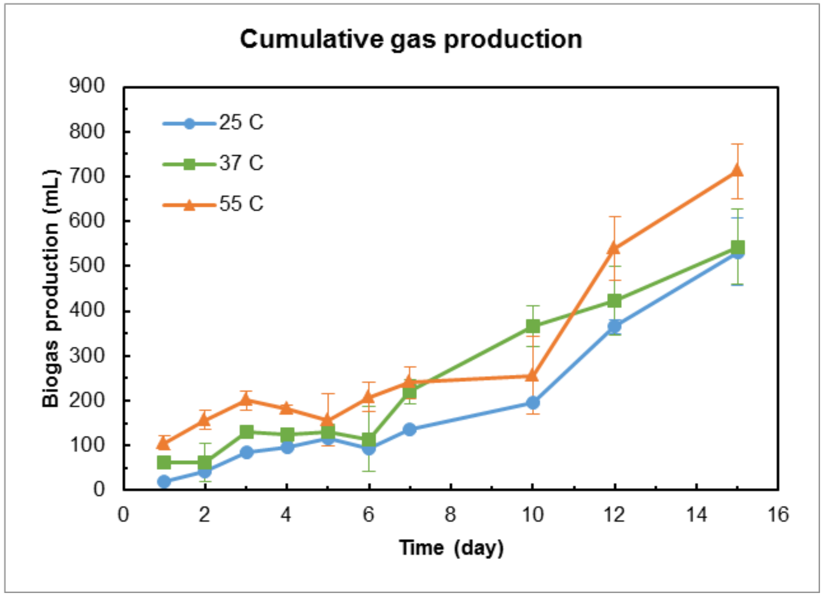
ANL's Patent Pending Process (U.S. Serial No. 14/540,393)

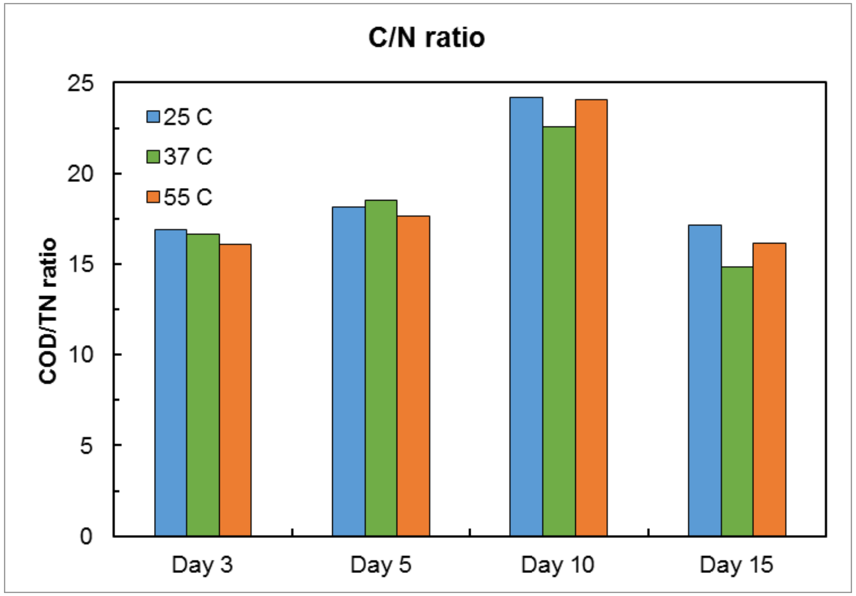
3 – Technical Accomplishments/ Progress/Results- Task 2 (Oct 2014-Feb 2015)

- Identified and obtained most promising oleaginous microorganisms
- Completed initial short AD screening experiments
- Developed analytical methods for VFA (GC/FID) and FAME (GC/MS)
- Started testing of oleaginous microorganisms growth on digestate permeate

Strain	Growth temp.
***Apiotrichum curvatum* ATCC20509** ***Trichosporon oleaginosus* ATCC20509**	20 C to 25 C
***Lipomyces starkeyi* ATCC58680**	25.0 C
***Mortierella isabellina* ATCC38063**	24.0 C
Mucor circinelloides ATCC1216B	24.0 C
***Rhodosporidium toruloides* ATCC10788**	25.0 C
***Rhodotorula glutinis* ATCC204091**	25 C to 30 C
***Yarrowia lipolytica* ATCC20460**	20 C to 25 C
Rhodococcus wratislaviensis	28 C
***Pseudomonas aeruginosa* (ATCC10145)**	37 C
***Rhodococcus opacus* PD630**	28 C

3 - Technical Accomplishments/ Progress/Results- Task 2 (Oct 2014-Feb 2015)





- First trial experiments showed that short AD operation should be less than 10 days.
  - Biogas productions starts to ramp up after 7 days
  - C/N ratio decreases after 10 days
- Second trial experiments needs to be conducted up to 7 days to minimize the biogas production.

4 - Relevance

Barriers addressed

Task 1:

- Bt-H: Cleanup CO2 and H2S from Biogas
- Bt-K: Pipeline quality methane production (90% CH4)
- Ft-J: Scaling up process from batch to semi-continuous digesters (bench-scale)

Task 2:

- Bt-B: Determining operating conditions to improve digestability of sludge

Project is relevant to:

- DOE and BETO: Supports BETO's work to develop renewable and cost-competitive biofuels from non-food biomass feedstocks (waste)
- Contributes to fulfilling BETO goal of developing commercially viable technologies for converting feedstocks via biological routes into energy-dense, fungible, liquid transportation fuels and chemicals.
- BETO actively pursues R&D in Waste-to Energy technology
- Over 99% of D3 RINs generated from biogas (August-December, 2014)
- Conversion of biosolids to hydrocarbon precursors would be
  - capable of displacing the equivalent of ~ 450 million gallons of gasoline per year
  - reduce US dependence on foreign oil, increasing energy security, and mitigating climate change.

5 - Future Work

- Task 1:
  - Determine impacts of biochar addition on digester microbial community structure and composition
  - Develop the mathematical model to understand the complexities in the digester environment
  - Complete techno-economic assessment of the process
  - Scale up the process up to 14 liters.
- Task 2:
  - Establish the links between feedstock characteristics, microbe community structure and environmental and economic impact on fuel production
  - Develop the mathematical model to understand the complexities in the bioreactor environment
  - Evaluate pathways to piloting and scale up the process.
  - Complete techno-economic assessment of the process

Summary

- Developed a novel process using biochar for producing biomethane at pipeline quality (>90% CH_4)
- A new paradigm of efficient and economical biomethane production for the AD industry
  - Both methane production and *in situ* sequestration of carbon dioxide and hydrogen sulfide take place in the same reactor
  - Facilitated CO_2 sequestration by up to 86.3% and H_2S removal (< 5ppb), and boosted average CH_4 content in biogas by up to 30.1%
  - Enhanced AD performance
    - Methane yield, biomethanation rate and maximum methane production rate increased by up to 7.0%, 8% and 28%, respectively.
    - Increased alkalinity and mitigated ammonia inhibition, hence providing sustainable process stability
  - Increased fertilizer value of digestate
    - K, Ca, Fe and Mg in the biochar-amended digesters increased by 2000-4400% (corn stover), 122-273%, 60-134%, 43-95%, and 82-183%, respectively.
- Engaged with WWTPs and digester technology users

Summary (cont'd)

- Started techno-economic assessment of novel process producing pipeline quality methane
- Such an integrated assessment and technology R&D project generating hydrocarbon precursors using CWUS has not been investigated before by BETO-DOE.
- Completed initial short AD screening experiments to determine operating conditions that will boost growth of oleaginous microorganisms
- Test growth of oleaginous microorganisms on digestate permeate (ongoing)

Additional Slides

Publications, Patents, Presentations, Awards, and Commercialization

- Patent Application: Method For Generating Methane From A Carbonaceous Feedstock, U.S. Serial No. 14/540,393 (pending)
- *Journal Papers*
  1. An overview of biogas production and utilization at full-scale wastewater treatment plants (WWTPs) in the United States: challenges and opportunities towards energy-neutral WWTPs *(under review)*
  2. Producing pipeline-quality biomethane via anaerobic digestion of sludge amended with corn stover biochar with in-situ CO_2 sequestration (*under review)*
- *Conference and Workshop Papers*
  1. "Bringing It All Back Home: The Next Generation in Anaerobic Digestion using Biochar, Presented at the Food, Energy, Water Nexus Initiative, San Diego CA, February 2015
  2. Enhanced Anaerobic Digestion and Hydrocarbon Precursor Production. DOE-BETO Workshop on Hydrogen, Hydrocarbons, and Bioproduct Precursors from Wastewaters, Washington, DC, March 18-19, 2015
  3. Current Biogas Production and Utilization at U.S. Wastewater Treatment Plants: It's All About Co-Digestion. *Water-Energy Conference, WEF, Washington, DC June 2015 (accepted)*

Publications, Patents, Presentations, Awards, and Commercialization (cont'd)

– *Conference and Workshop Papers (cont'd)*

4. Are we there yet to achieve energy self-sufficiency at U.S. Wastewater Treatment Plants (WWTPs)? Is biogas derived renewable fuel production enough to meet renewable volume obligations? (*under review*, WEFTEC 2015)
5. Producing pipeline-quality biogas in situ by anaerobic digestion of sewage sludge with biochar amendment (*under review*, WEFTEC 2015)

– *Journal Papers in Preparation*

1. Accelerated weathering process for producing pipeline-quality biogas
2. High performance porous biochars for CO_2 uptake

Abbreviations and Acronyms

AD: Anaerobic Digestion

C/N: Carbon to Nitrogen Ratio

CWUS: Comprehensive Waste Utilization System

FAME: Fatty Acid Methyl Ester

RIN: Renewable Identification Number

RFS: Renewable Fuel Standard

VFA: Volatile Fatty Acid

WWTP: Wastewater Treatment Plant