DOE Bioenergy Technologies Office (BETO)

Bioenergy 2015: Opportunities in a Changing Energy Landscape

Enhanced Anaerobic Digestion and Hydrocarbon Precursor Production from Sewage Sludge

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Project Objectives

- Ultimate Goal: Transform negative-value or low-value biosolids into high-energy-density, fungible hydrocarbon precursors
  - 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

Enhanced Anaerobic Digestion

Waste-to-Energy: Why Biogas?

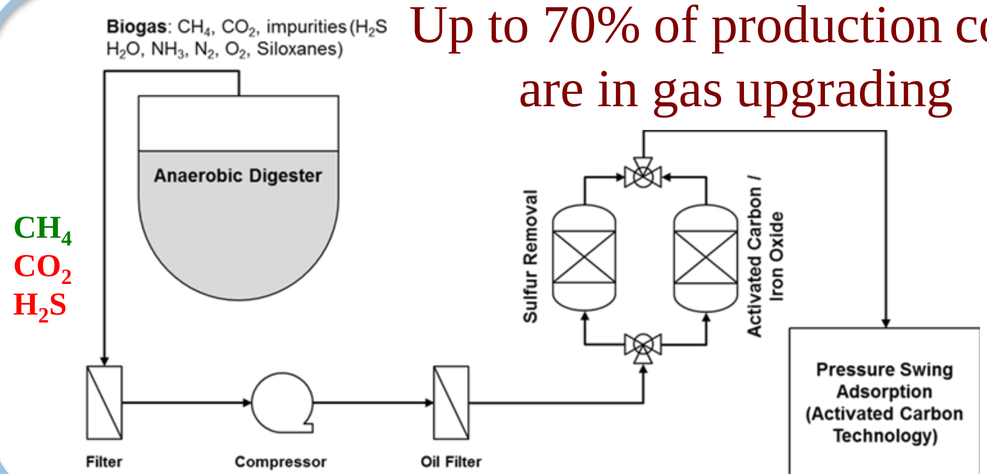
- Renewable sources for natural gas
  - Agricultural residues
  - Manure
  - Wastewater treatment
  - Landfill
  - Co-product in production of algal biofuels
- No competition with food and feed crops used for the production of other biofuels
- 7 days/24 hr production
- Low value materials
- It would displace the equivalent of 2.5 billion gallons of gasoline/year

Deer Island WWTP (Boston, MA)

Problem

- **Organic waste disposal**
  - Multiple, large volume sources; >$50 billion disposal costs
  - e.g. wastewater treatment plants, food and agricultural residues, manure →
- **Anaerobic digesters (AD) reduce waste volume and generate biogas**
  - Only 10% of WWTPs use biogas for energy; the rest is flared →
- **Expensive AD upgrading required for transportation-quality biogas**
  - Capital and energy costs too high
- **Biosolids**
  - Low-value require a tipping fee
  - Need to generate revenue

Up to 70% of production costs are in gas upgrading



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

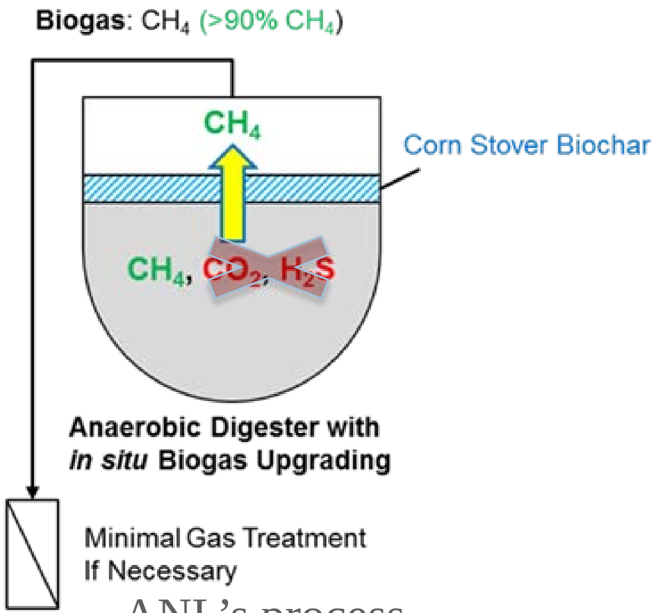
Pilot-scale testing
14 liter Bioflo Fermenter (FY15-16)

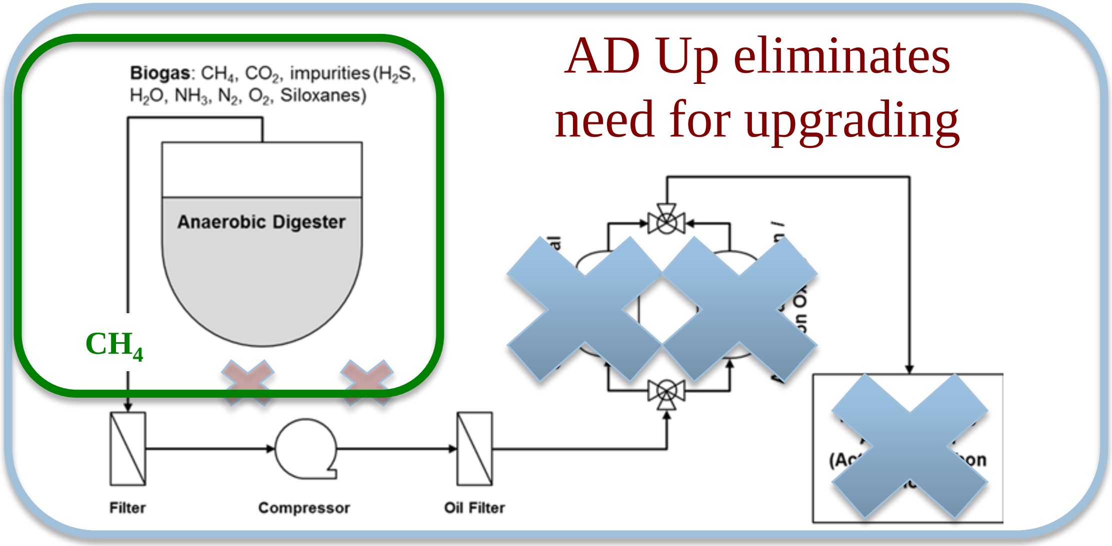
Biochemical Model TEA

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

Technology Deployment

AD Up Solution





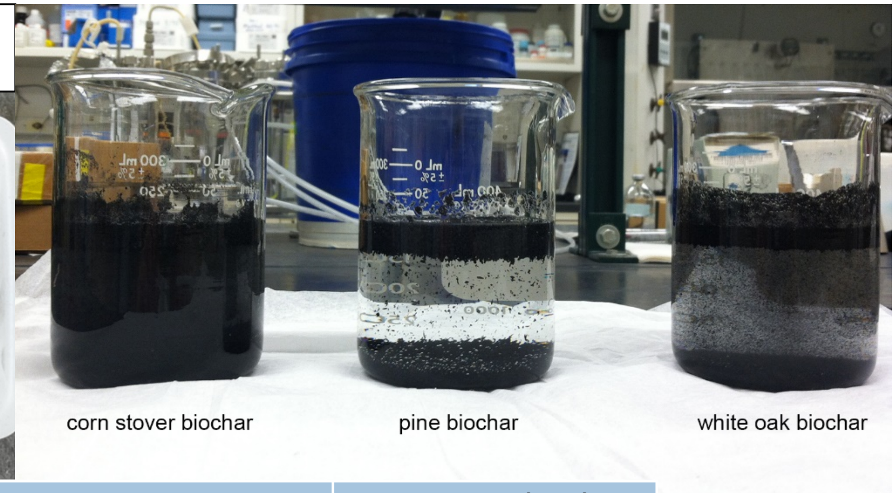
ANL's process
(U.S. Patent Serial No. 14/540,393)

AD Up's secret sauce is biochar

- Biochar is produced by pyrolysis of biomass and is high in multivalent minerals
- The minerals adsorb/react CO_2 and H_2S from the biogas and deposit them in the biosolids
- The minerals significantly increase the fertilizer value.
- Eliminate the need for gas upgrading unit operations

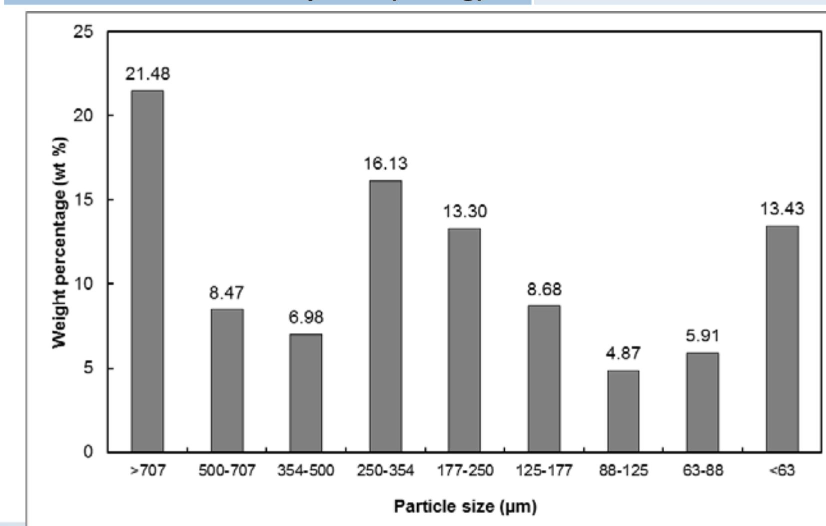
Not All Biochars are Equal!

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

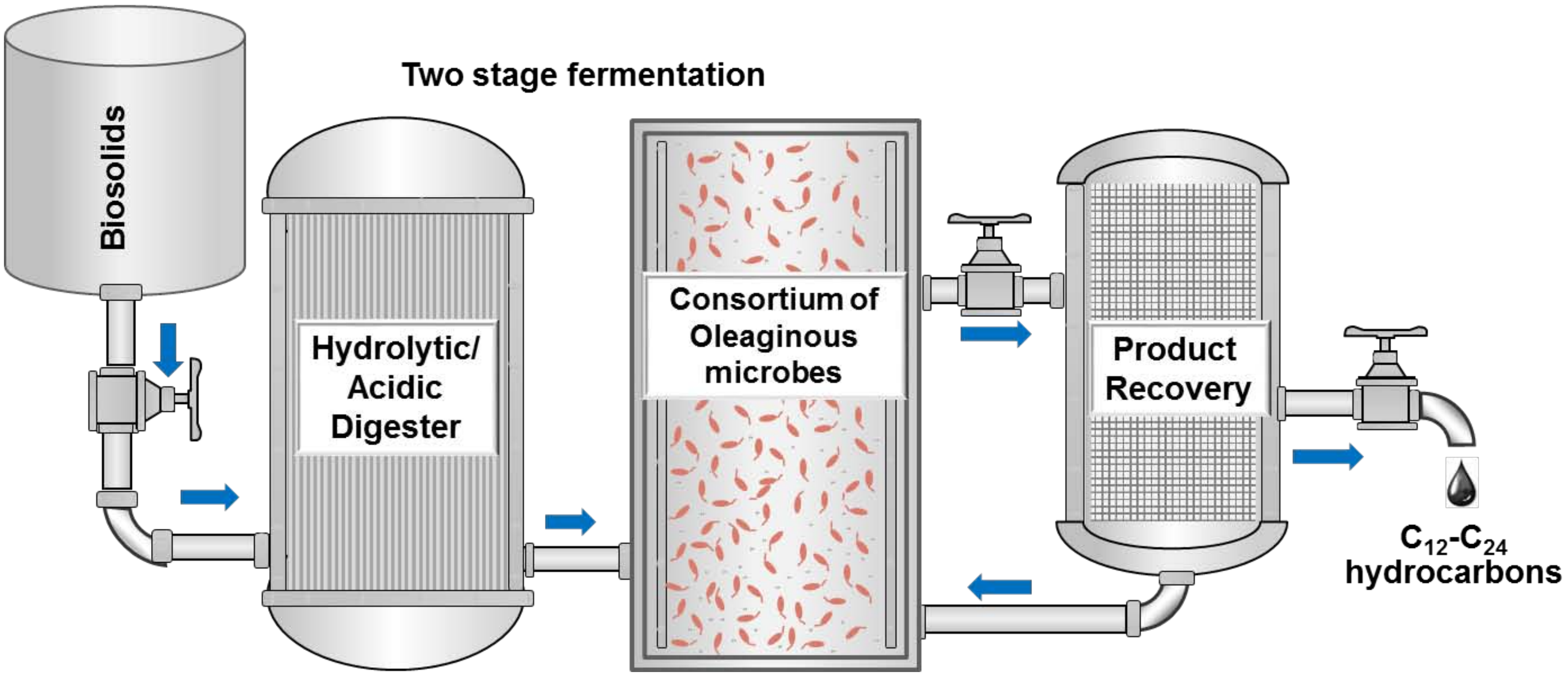
Property	Corn stover biochar
BET surface area (m^2/g)	105
Total volume of mesopores (cm^3/g)	0.02
Average diameter of mesopores (nm)	6.50
Total area of micropores (m^2/g)	315
Total volume of micropores (cm^3/g)	0.09



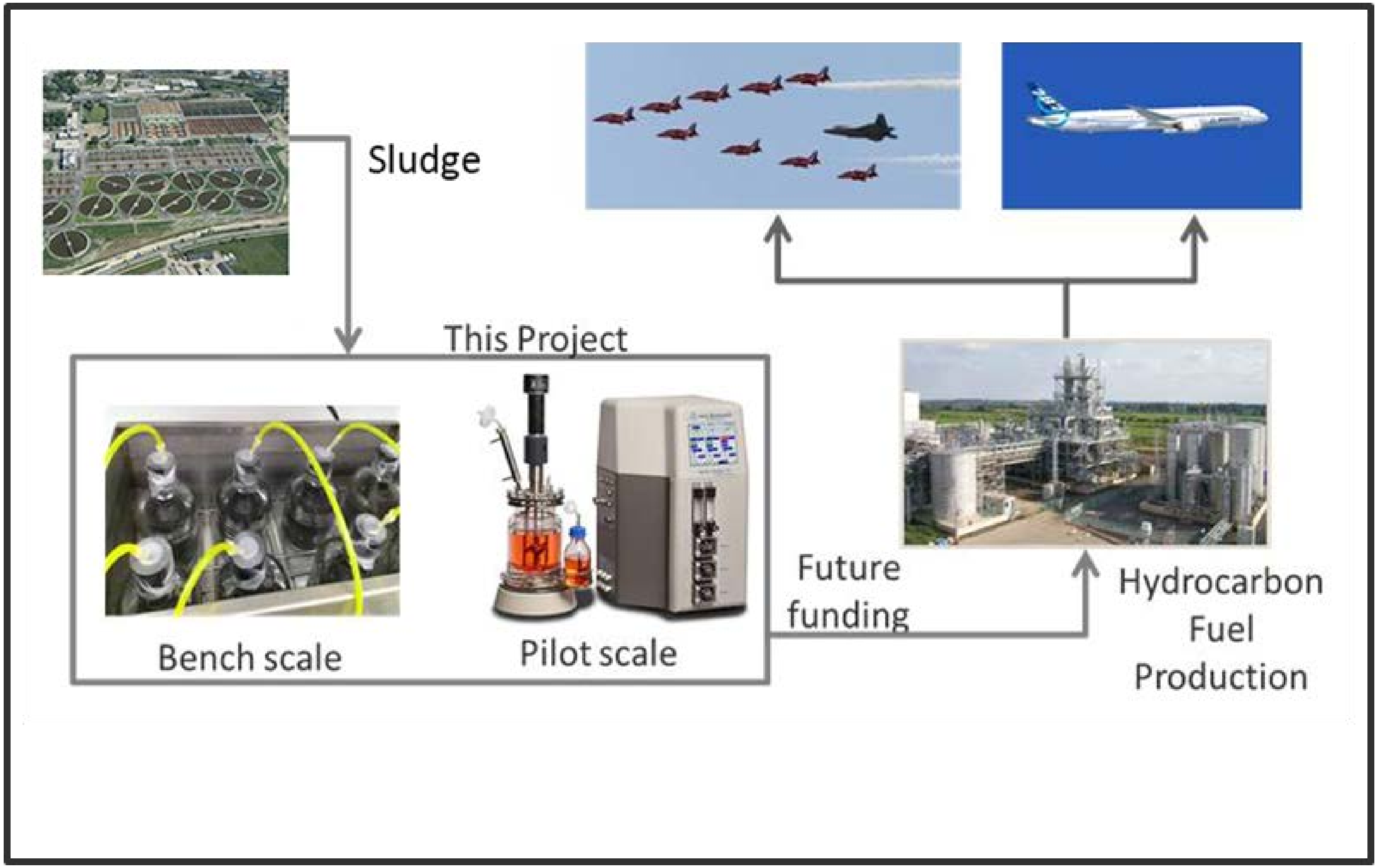
Hydrocarbon Precursor Production

Project Overview

- Development of a low-cost process to produce hydrocarbon fuels



Technical Approach

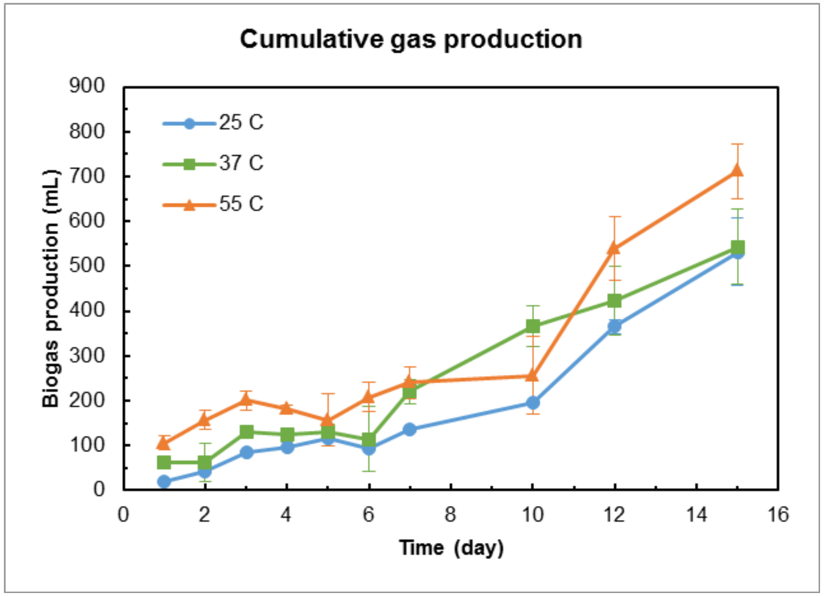


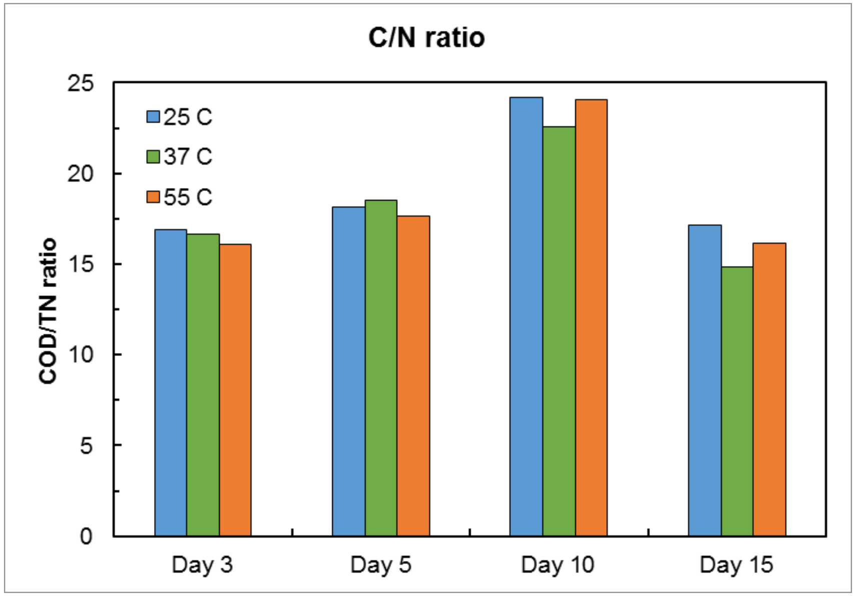
Results

- 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 (yeast)** ***Trichosporon oleaginosus* ATCC20509 (yeast)**	20°C to 25°C
***Lipomyces starkeyi* ATCC58680 (yeast)**	25.0°C
***Mortierella isabellina* ATCC38063 (fungus)**	24.0°C
***Mucor circinelloides* ATCC1216B (fungus)**	24.0°C
***Rhodosporidium toruloides* ATCC10788 (yeast)**	25.0°C
***Rhodotorula glutinis* ATCC204091 (yeast)**	25°C to 30°C
***Yarrowia lipolytica* ATCC20460 (yeast)**	20°C to 25°C
***Rhodococcus wratislaviensis* (bacteria)**	28^0 C
***Pseudomonas aeruginosa* (bacteria)**	37^0 C
***Rhodococcus opacus MITXM-61* (bacteria)**	28^0 C

Results





- 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.

Summary

Renewable Methane Production

- We 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 (< 5 ppb), and boosted average CH_4 content in biogas by up to 30.1%
  - Enhance methane production rates ~28%
  - Bolt on to existing systems

Hydrocarbon Precursor Production

- Establish the links between feedstock characteristics, microbe community structure and environmental and economic impact on fuel production
- Evaluate pathways to piloting and scale up the process.

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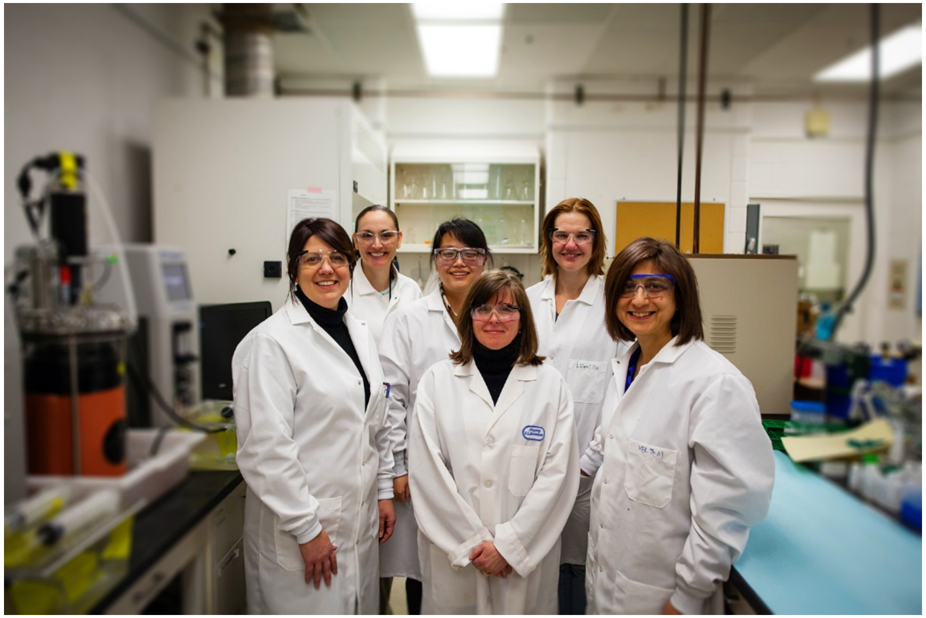

ANL Waste-to-Energy Group