U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Bioenergy Technologies Office 2021 Peer Review

Organic Waste Conversion Session – Day 1

Beau Hoffman, 3/9/2021

Introductions – Peer Review Panel

Name	Affiliation	Previous Peer Review Experience
Jeanette Brown (lead reviewer)	Manhattan College	2019 Panel
Aaron Fisher	Ernest Maier	New this year
Alice Havill	Colorado Impact Fund	New this year
Phil Marrone	Leidos	Previous Lead Reviewer
Paige Novak	University of Minnesota	New this year

Jeanette

Aaron

Alice

Phil

Paige

What I talk about when I talk about organic waste (or wet waste)

- Municipal Sludge Residuals
- Animal Manure (mostly swine and dairy)
- Food Waste
- Inedible Fats/Oils/Greases

Wet Resources	Annual Beneficial Utilization (Current) Estimated Resource Availability (MM Dry Tons)	Inherent Energy Content (Trillion Btu)	Fuel Equivalent (MM GGE)[2]	Annual Potential Excess[1] Estimated Resource Availability (MM Dry Tons)	Inherent Energy Content (Trillion Btu)	Fuel Equivalent (MM GGE)[2]
Wastewater Residuals	7.12	107.6	927.0	7.70	130.0	1,119.6
Animal Waste	15.00	200.2	1,724.3	26.00	346.9	2,988.7
Food Waste	1.30	6.8	58.2	14.00	72.8	627.1
Fats, Oils, and Greases	4.10	147.4	1,269.3	1.95	66.9	576.6
Total	27.52	462.0	3,978.8	49.65	616.6	5,312.0

[1] Unused excess in this definition includes landfilled biosolids and other wet resources.

[2] 116,090 Btu/gal. This does not account for conversion efficiency.

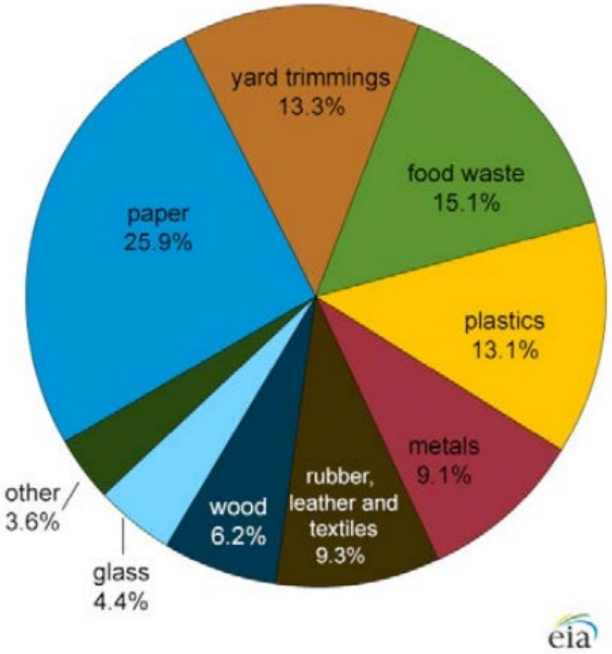
*Yet despite this logical start with wet wastes and derivative products, **BETO needs to expand its efforts in the WtE field to include more diverse types of waste**. Municipal solid waste (MSW), or at least the organic fraction of MSW, represents a much larger potential feedstock and source of carbon that is currently being underutilized.*

– 2019 Peer Review Report

See the Feedstock Technologies section for additional work on other MSW preprocessing, separations, and logistics R&D

See the Performance-Advantaged Bioproducts, Bioprocessing Separations, and Plastics Section for additional work on plastic waste R&D

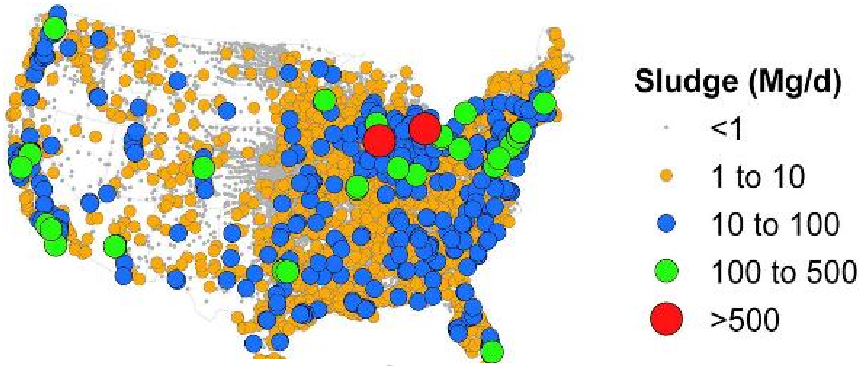
Total MSW generation in the United States by type of waste, 2015
Total = 262 million tons



Organic Waste in the United States

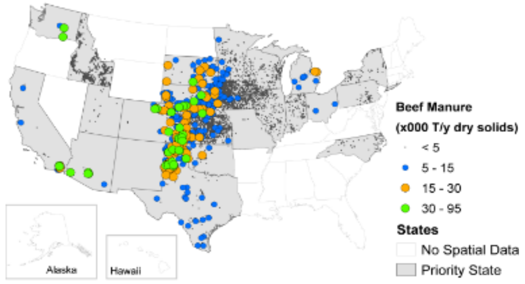
First site-specific inventory of untreated sludge production at >15,000 WWTPs in the US (14.8 M dry tons)

- 0.24 quad. btu or 2 billion gallons of gasoline equiv.

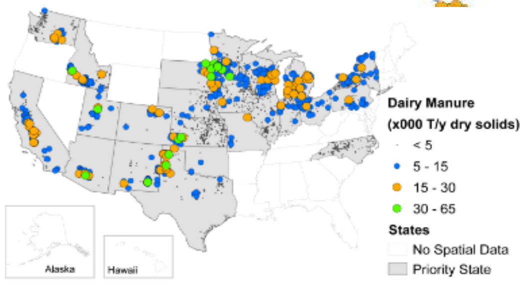


Inventory of confined manure production at >32,000 beef, dairy, and market swine operations (41 M dry tons)

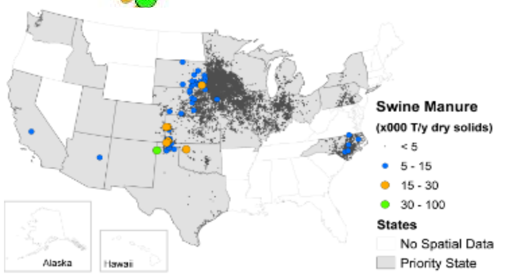
- 0.55 quads or 4.7B gge



Feedlot Beef



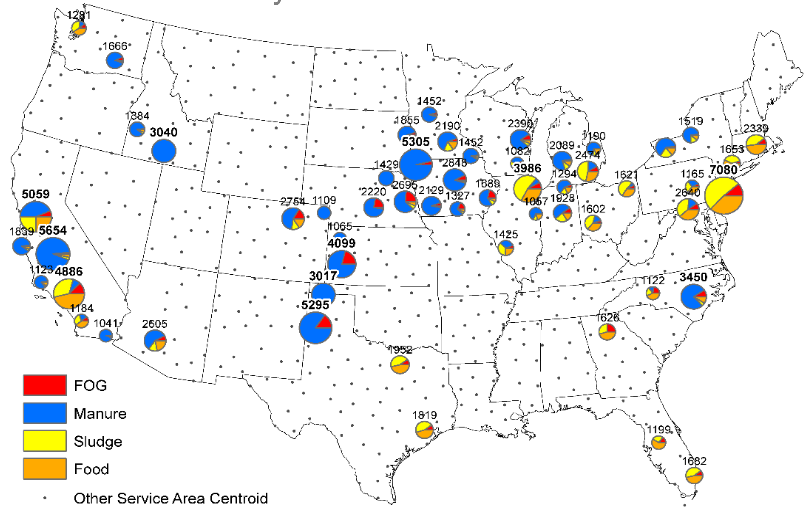
Dairy



Market Swine

67% of organic waste feedstocks are within 50 miles of blending hotspots (>1000 T/d dry)

- Blending of organic wastes is feasible



Organic waste landfill bans are being implemented

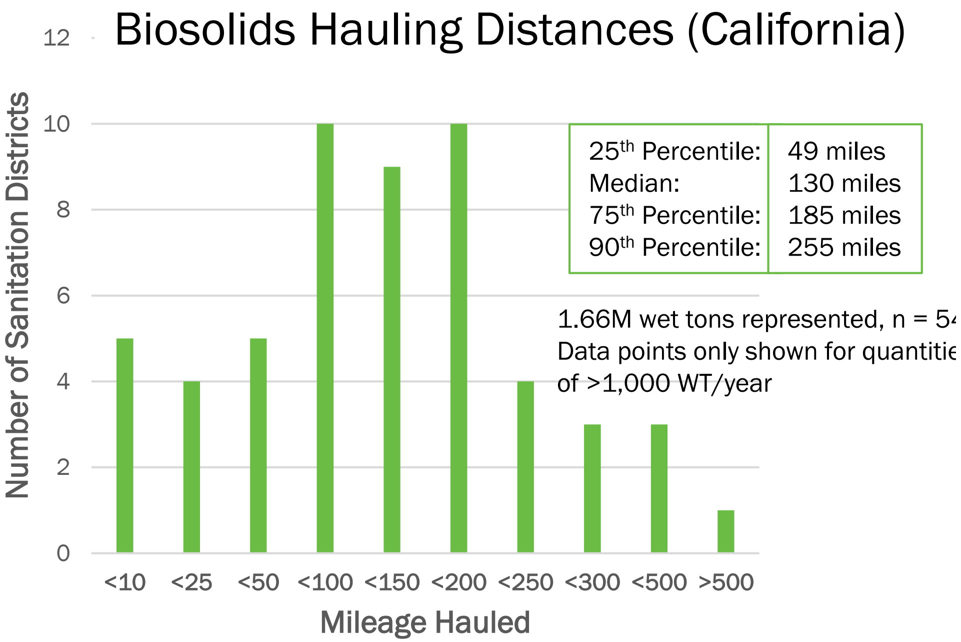
- The economic and environmental value proposition is large, and growing

Organic Waste is a Sustainability Liability

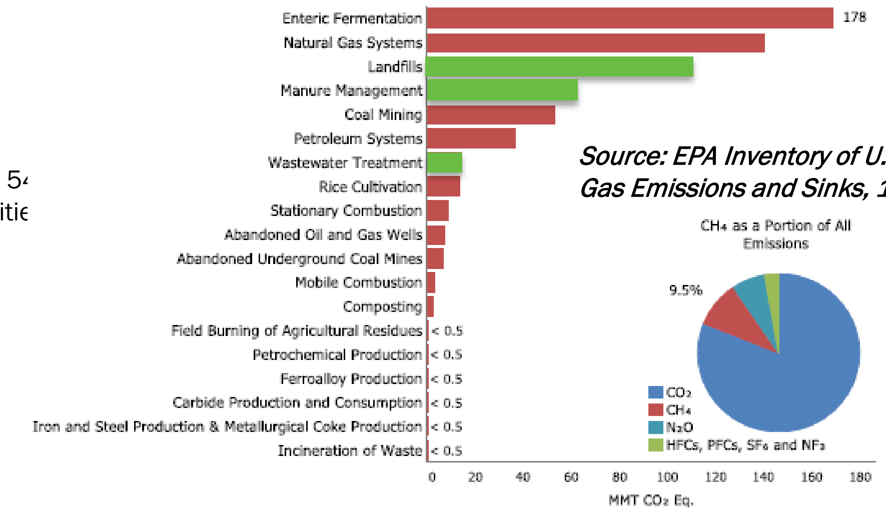
- "it is estimated that 40% of a wastewater treatment facility's total annual operating cost is spent on solids management[1]"
- Biosolids management comprised $11M of DC Water's Annual Operating budget in 2015 and 2016[2]
- "…for all five facilities (Calgary, Vancouver, Orlando, Santa Rosa, and Tohopekaliga) , sludge is ultimately shipped off-site at a cost ranging between $21-102/wet ton or $121-645/dry ton…Thus, there is the potential for significant cost savings if the volume of solids requiring disposal (and associated preparation work) can be reduced)"[3]

The wastewater industry spends >$3.3B/yr disposing of their residual waste:

Dewatering/drying
Sterilization/treatment
Transportation
Tipping fees at landfills/compost facilities



Sources: BACWA 2016 Biosolids Trends Survey
2016 SCAP Biosolids Trends Survey

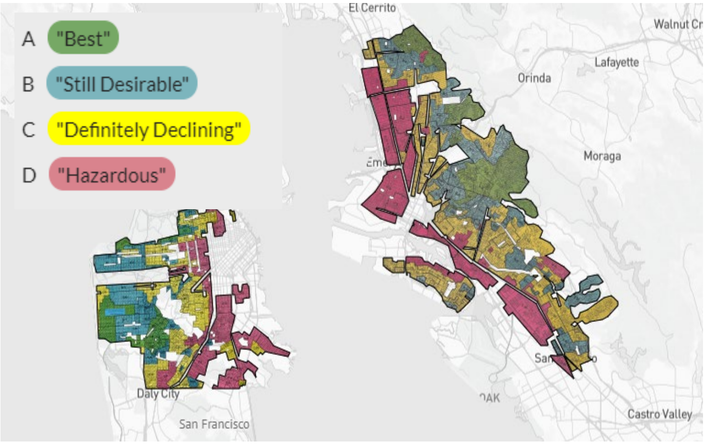


Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2018

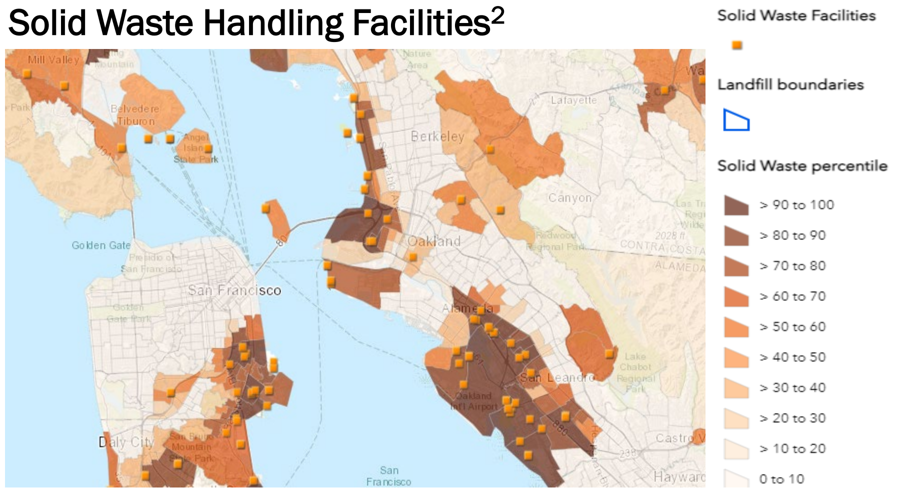
[1] https://legislature.vermont.gov/assets/Legislative-Reports/2016-DEC-Sludge-and-Septage-Report-1-16-2016.pdf
[2] https://www.dcwater.com/sites/default/files/documents/operating_budget_book_final.pdf
[3] https://www.waterrf.org/system/files/resource/2019-10/LIFT6T14%20web.pdf

Organic Waste is a Sustainability Liability

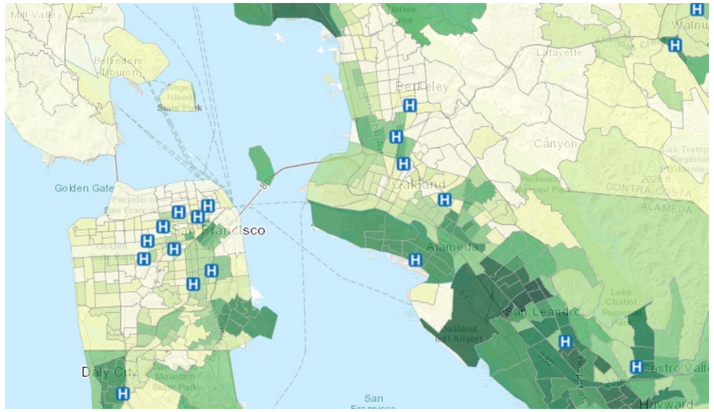
1937 Redlining Map[1]



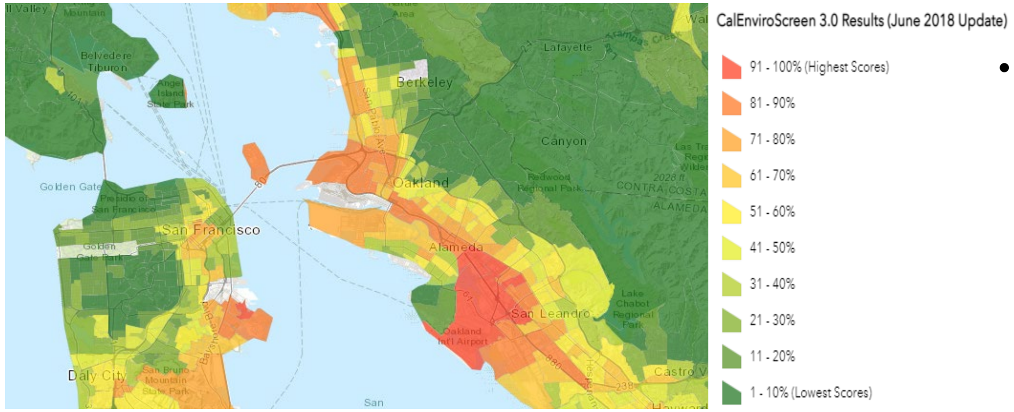
Solid Waste Handling Facilities[2]



Cardiovascular Disease[2]



Overall CalEnviroScore[2]



Organic waste is generated by all members of society. However:

- Siting of waste handling infrastructure is disproportionately in disadvantaged communities[3]
- Environmental impacts are numerous from waste processing facilities: odor, noise, infectious disease vectors, litter, particulate emissions[4] …
- Leading to negative consequences, particularly health
- Social licenses are critical as approval rates are low for living near a waste-to-energy or waste resource recovery facility
  - -14% of survey respondents say they “approve” or “accept” living near a WTE plant (n=623)[5]
  - -11% say they “approve or “accept” living near a WRR facility (n=621)[5]

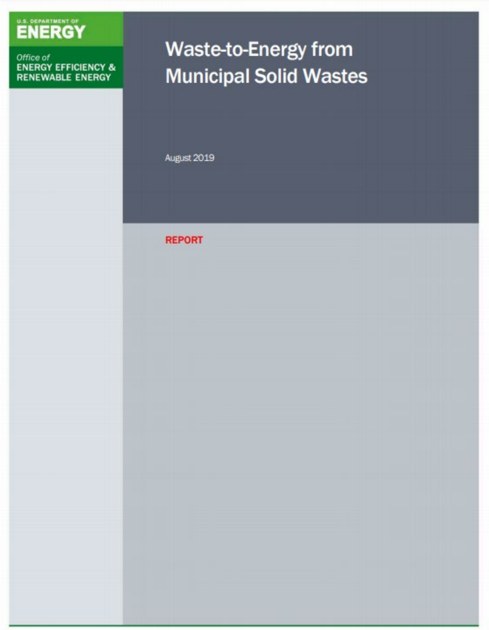
[1] https://dsl.richmond.edu/panorama/redlining/#loc=5/39.1/-94.58
[2] https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30
[3] Paul Mohai and Robin Saha 2015 *Environ. Res. Lett.* 10 115008
[4] Krystosik A, Njoroge G, Odhiambo L, Forsyth JE, Mutuku F and LaBeaud AD (2020) Solid Wastes Provide Breeding Sites, Burrows, and Food for Biological Disease Vectors, and Urban Zoonotic Reservoirs: A Call to Action for Solutions-Based Research. *Front. Public Health* 7:405. doi: 10.3389/fpubh.2019.00405
[5] Walton, A., McCrea, R., and Jeanneret, T. (2019). *Changes in Victorian attitudes and social acceptance in the waste and resource recovery sector: 2016 to 2019* CSIRO, Australia.

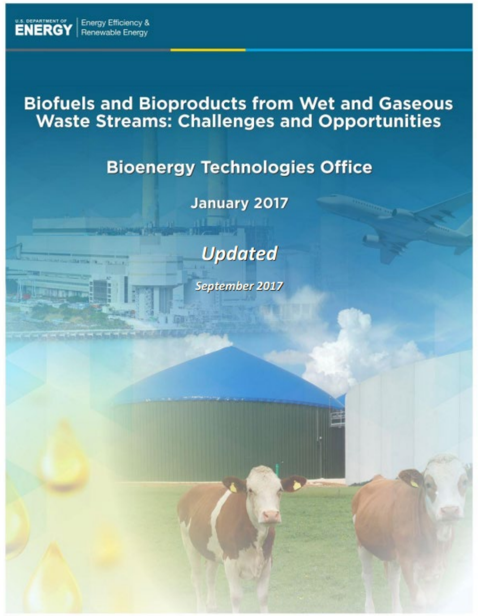
BETO’s Strategy on Organic Waste

- **Significant congressional interest in solving these problems:**
  - *“Within available funds, $5,000,000 is to continue the biopower program… $5,000,000 is to improve the efficiency of community and smaller digesters that accept both farm and food wastes…” – FY19 Senate Energy and Water Development Appropriations Subcommittee (SEWD)*
  - *“Within available funds, the agreement includes not less than $10,000,000 to establish a multi-university partnership to conduct research and enhance educational programs that improve alternative energy production derived from urban and suburban wastes. The Department is directed to collaborate with institutions in Canada and Mexico to leverage capacity and capitalize on North American resources.” – FY20 Explanatory Report for Energy and Water Development and Related Agencies*
- **Multi-pronged strategy to convert these economic and environmental liabilities into revenue streams**

BETO’s Activities on Organic Waste in FY19/FY20:
5 Funding Opportunity Announcement Topics
>$26M in funding:

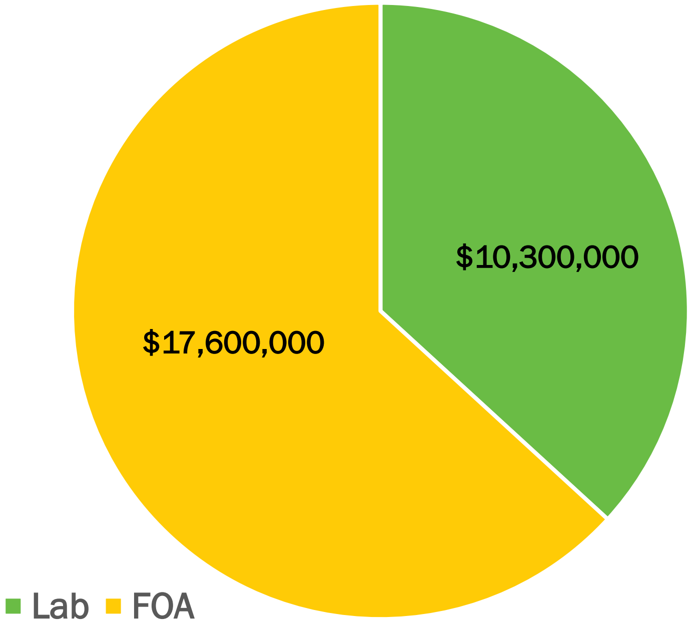
- >$4.5M on fuels from waste
- >$9.5M on products/chemicals from waste
- >$12.5M on Renewable Natural Gas or small scale digester systems





Project Management of the Organic Waste Portfolio

Projects Being Reviewed*:



	FOA	Lab AOP
Selection Method	Competitive	Lab Call
Open to the Public	✓	☒
National Lab Participant	Only as Subrecipient	Yes
Go/No-Go Decision Points	✓	✓
Verifications	✓	☒
Award Modifications Method	Contracting Officer (CO)	AOP Tool Change Control
Project Length	~3 years	3 years

- **In this session, we are reviewing 16 projects (9 Lab AOP, 7 FOA)**
- **BETO uses verifications, quarterly reporting, and regular project update meetings to monitor progress.**

Since Peer Review 2019:

  – 5 verifications conducted
  – 11 go/no-go decision points

**BETO funds additional work in this space through other funding mechanisms including the Technology Commercialization Fund and SBIR/STTRs. Those projects are not presenting.*

**Projects funded from FY20 FOAs, are not presenting as most have not completed negotiations/verifications as of 3/9/2021.*

Organic Waste Conversion, Day 1

- Today's session will be covering several aspects of the organic waste conversion portfolio:
  - Organic Waste Analysis
  - Liquid Fuels from Waste
  - Products/Chemicals from Waste

Day 2 – TUESDAY, MARCH 9, 2021

Start Time EST	End Time EST	ORGANIC WASTE		
		Presentation	Organization	Presenter
9:15 AM	9:45 AM	GATHER, TECH CHECK, NETWORKING QUESTIONS - 30 MIN AHEAD OF EACH SESSION		
9:45 AM	4:20 PM	**Organic Waste**	***Conversion Program***	***Beau Hoffman***
9:45 AM	10:00 AM	Organic Waste Conversion - Session Overview	*BETO*	*Beau Hoffman*
10:00 AM	10:35 AM	Waste-to-Energy: Feedstock Evaluation and Biofuels Production Potential - NREL	*NREL*	*Anelia Milbrandt*
10:35 AM	11:10 AM	Waste-to-Energy: Feedstock Evaluation and Biofuels Production Potential - PNNL	*PNNL*	*Tim Seiple*
11:10 AM	11:45 AM	Bench Scale HTL of Wet Wastes	*PNNL*	*Michael Thorson*
11:45 AM	12:00 PM	BREAK		
12:00 PM	12:35 PM	Analysis and Sustainability Interface - PNNL	*PNNL*	*Lesley Snowden-Swan*
12:35 PM	1:10 PM	A Catalytic Process to Convert Municipal Solid Waste Components to Energy	*Worcester Polytechnic Institute*	*Michael Timko*
1:10 PM	1:45 PM	BREAK		
1:45 PM	2:20 PM	Separations in Support of Arresting Anaerobic Digestion	*NREL*	*Eric Karp*
2:20 PM	2:55 PM	Integrated Biorefinery for Chemicals and Fuels Production from Waste Biomass	*Visolis*	*Deepak Dugar*
2:55 PM	3:10 PM	BREAK		
3:10 PM	3:45 PM	Novel and Viable Technologies for Converting Wet Organic Waste Streams to Higher Value Products	*State University of New York, Albany*	*Yanna Liang*
3:45 PM	4:20 PM	Electro-Enhanced Conversion of Wet Waste to Products Beyond Methane	*Colorado State University*	*Kenneth Reardon*
4:20 PM	4:40 PM	**Reviewer Wrap Up and Debrief**	***Reviewers***	

Liquid Fuels and Products from Organic Waste Strategy

- **Organic Waste provides an alternative feedstock for meeting office-wide goals:**
  - (one of) BETO's FY21 Government and Performance Accountability Act (GPRA) Goals:

    By end of FY21, decrease MFSP for a new pathway to less than $3.03/gge (modeled, nth plant economics)
  - Conversion R&D FY29 goal:

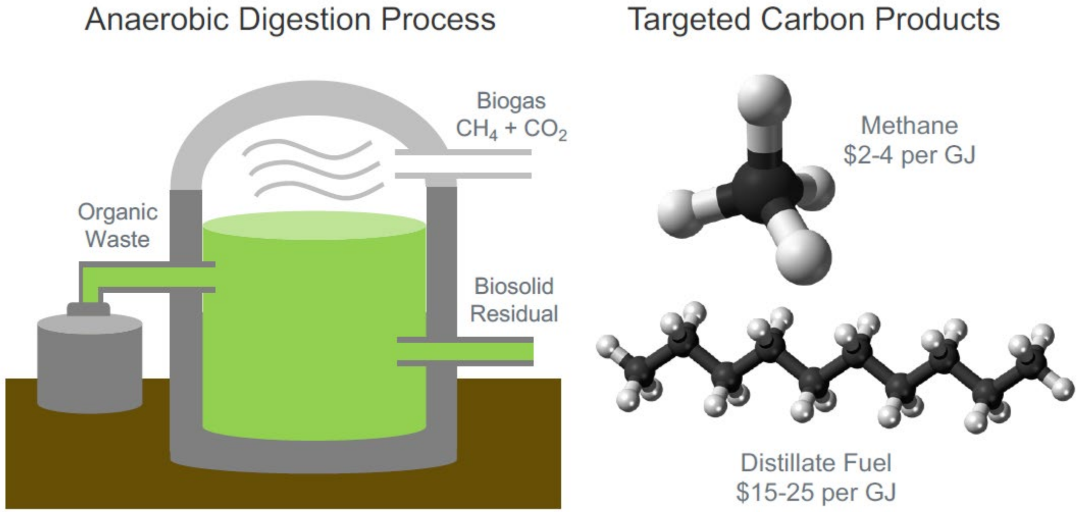
    By end of FY29, MFSP <$2.5/gge using economically advantaged feedstocks and >70% GHG reductions
  - Feedstock Technologies FY24 goal:

    *By 2024, develop feedstock supply systems (using mechanical, chemical, and thermal processing) for feedstock streams (e.g., energy crops, **industrial wastes, plastics, and MSW**) that produce the CMAs necessary for conversion at a modeled price of $84/dry ton.*
  - Feedstock Technologies FY30 goal:

    By 2030, develop science-based strategies and technologies to cost-effectively transform ***carbon sources*** into sustainable, energy-dense, and ***conversion-ready*** feedstocks at 90% ***operating effectiveness*** that meet a delivered cost **of *$71/dry ton*.**

Liquid Fuels and Products from Organic Waste Motivation

- **Liquid Fuels can have increased value relative to biogas:**
- **Some processes (e.g. Hydrothermal liquefaction) have waste conversion rates far higher than anaerobic digestion**
  - Reduced disposal liability, fewer methane emissions
- **FOAs/lab calls have called for reduction in disposal costs/production of intermediates**



Vardon (2020), ACS Green Chemistry and Engineering

Hydrothermal Liquefaction

GLWA; Pacific Northwest National Laboratory; The Water Research Foundation (www.werf.org); Illinois; Princeton University; WPI; Mainstream Engineering; metrovancouver; UC Riverside; MIT (Massachusetts Institute of Technology); Central San (Central Contra Costa Sanitary District)

Fuels via Arrested Anaerobic Digestion

NREL; world energy; Co-Optimization of Fuels & Engines; ChemCatBio (Chemical Catalysis for Bioenergy); Los Alamos National Laboratory; Earth Energy Renewables; Nexus Bioenergy

Chemicals/Products via Arrested Anaerobic Digestion

University of Maryland; Princeton University; University at Albany (State University of New York); Colorado State University; Leprino Foods; Visolis; UC Davis; Argonne National Laboratory; South Dakota Mines; Bioprocessing Separations Consortium; NREL; Unilever; UCI (University of California, Irvine)

Liquid Fuels and Products from Organic Waste Motivation

Key Remaining R&D challenges:

Hydrothermal Liquefaction

- Feedstock formatting/preprocessing/homogenization and rheology (stable pumpability at high solids, >20%)
- Demonstrating stability of catalysts used in hydroprocessing (100s or 1,000s of hrs)
- Cost-effective management of process waste streams (esp. aqueous and solid streams)
- Demonstrating feasibility of blended wastes (e.g. waste water residuals with food waste)
- Quantifying environmental services provided (N, P, K recovery, PFAS management, microplastics)
- Co-processing/refinery integration or use of biocrude in other applications (e.g. heating)

Fuels/Chemicals/Products from Arrested AD

- Process separations and integration (esp. recovery of VFAs)
- VFA/intermediate titers at pre-commercial levels (10s of g/L)
- Testing of products to ensure performance relative to incumbent
- Continuous demonstration of processes (100s of hrs)
- Qualifying jet fuel species for ASTM qualification

Organic Waste Conversion, Day 2

- Today's session will be covering several aspects of the organic waste conversion portfolio:
  - Advanced/Small scale anaerobic digestion
  - Biogas upgrading to RNG and other products

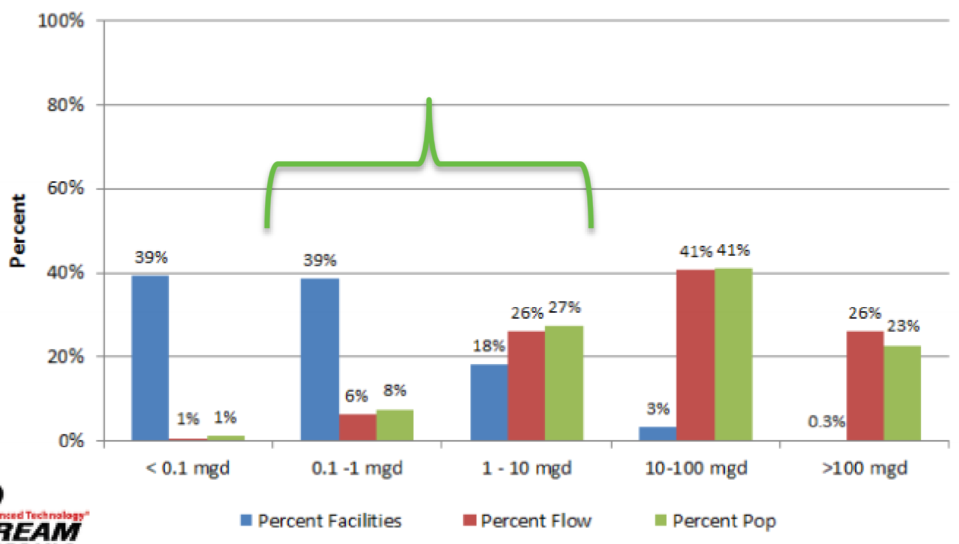
Day 3 – WEDNESDAY, MARCH 10, 2021

Start Time EST	End Time EST	ORGANIC WASTE		
		Presentation	Organization	Presenter
9:15 AM	9:45 AM	GATHER, TECH CHECK, NETWORKING QUESTIONS - 30 MIN AHEAD OF EACH SESSION		
9:45 AM	2:55 PM	**Organic Waste**	***Conversion Program***	***Beau Hoffman***
9:50 AM	10:00 AM	Organic Waste Conversion - Session Overview	*BETO*	*Beau Hoffman*
10:00 AM	10:35 AM	Production of Methane From Organic Waste Streams with Novel Biofilm-Enhanced Anaerobic Membrane Bioreactors	*ANL*	*Meltem Urgun-Demirtas*
10:35 AM	11:10 AM	Maximizing Bio-Renewable Energy from Wet Wastes (M-BREWW)	*University of Illinois, Urbana-Champaign*	*Lance Schideman*
11:10 AM	11:45 AM	Develop an efficient and cost-effective novel anaerobic digestion system producing high purity of methane from diverse waste biomass	*Washington State University*	*Shulin Chen*
11:45 AM	12:00 PM	BREAK		
12:00 PM	12:35 PM	Advanced Pretreatment/Anaerobic Digestion	*Washington State University*	*Birgitte Ahring*
12:35 PM	1:10 PM	Biomethanation to Upgrade Biogas to Pipeline Grade Methane	*NREL*	*Kevin Harrison*
1:10 PM	1:45 PM	BREAK		
1:45 PM	2:20 PM	Modular Microbial Electromethanogenesis Flow Reactor for Biogas Upgrading	*LLNL*	*Sarah Baker*
2:20 PM	2:55 PM	Biogas to Liquid Fuels and Chemicals Using a Methanotrophic Microorganism	*NREL*	*Michael Guarnieri*
2:55 PM	3:25 PM	**Reviewer Wrap Up and Debrief**	***Reviewers***	

Small Scale AD Motivation

- **BETO has defined 'community scale' as less than or equal to five dry tons/day**
  - Economics become challenging at this point
  - >75% of the US' ~15,000 POTWs are less than 5 dry tons/day
- **FOAs have investigated strategies to reduce disposal costs by >25%, improve carbon conversion**

Comparison of POTW by # of facilities, percent of waste, and population served (15,014 plants total)



Innovative Reactor Designs

Aqua-Aerobic Systems, Inc.; Mainstream Engineering; Illinois; Texas Tech University; Colorado State University; Urbana & Champaign Sanitary District; University of Michigan; Argonne National Laboratory; Roeslein Alternative Energy; Metropolitan Water Reclamation District of Greater Chicago; Los Alamos National Laboratory

Biogas yield improvements / increased waste conversion

Washington State University; Regenis; DVO; City of Walla Walla; CleanVantage; Pacific Northwest National Laboratory; Jacobs

Acceptance of Additional Waste/ Co-digestion

Northwestern University; Argonne National Laboratory; University of Michigan; GLWA

RNG Motivation

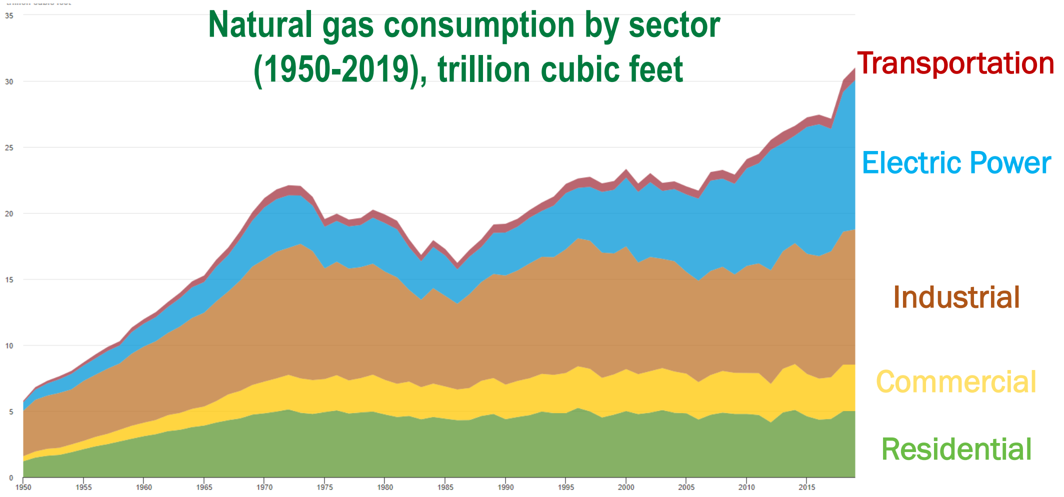
- **Natural gas usage is growing or flat in all sectors**
- **Decarbonization of heating is very difficult**
  - Avoided methane emissions are significant (e.g. Dairy digesters in CA)
  - Strong desire in the Northeast to find RNG supply
- **Immediate compatibility with existing infrastructure, opportunities for grid-scale storage**
- **FOAs/lab calls have targeted LCOE, pipeline compatible RNG**

Advanced Biogas Upgrading

mosaic AECOM NapaSan Lawrence Livermore National Laboratory NREL MANGO MATERIALS San Diego State University 1897 NC State

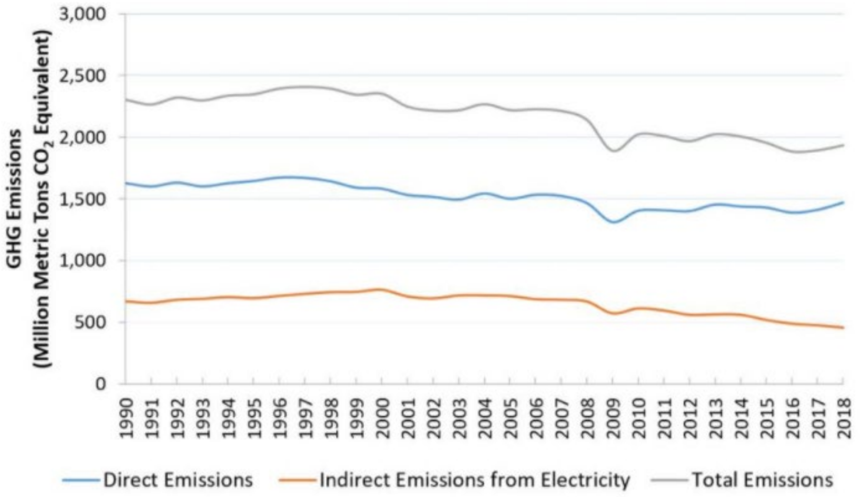
Power-to-Gas

Lawrence Livermore National Laboratory NREL Electrochaea Stanford University Summit Natural Gas MAINE SoCalGas A Sempra Energy utility



https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

Greenhouse Gas Emissions from Industry, 1990-2018



https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Small Scale AD and RNG Motivation

Key Remaining R&D challenges:

Small Scale AD

- Demonstrating feasibility of blended wastes (e.g. waste water residuals with food waste)
- Achieving meaningful continuous operations (100s or 1,000s of hrs)
- Demonstrating economic competitivity with existing AD (e.g. improvements in HRT/SRT, yield)
- For membrane systems: managing fouling

RNG & Power to Gas

- Achieving pipeline quality NG specs (>97% methane, <3% CO_2, etc.)
- Achieving meaningful integrated and continuous operations (100s or 1,000s of hrs) on real biogas streams
- Demonstrating robustness of novel sorbents for CO_2 capture (for biogas upgrading) (100s of regen cycles)
- Demonstrating robustness of organisms for biomethanation/Power to Gas (1,000s of hrs)