U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Organic Waste Conversion – Day 1

Beau Hoffman, Bri Farber, Katie Davis

Organic Waste Conversion Peer Review Panel

Name	Affiliation	Previous Peer Review Experience
Samantha MacBride (Lead Reviewer)	Baruch College (CUNY), Marxe School of Public and International Affairs	
Aaron Fisher	Ernst Maier	‘21
Tim LaPara	University of Minnesota – Twin Cities, Department of Civil, Environmental, and Geo-Engineering	
Musa Manga	University of North Carolina – Chapel Hill, School of Global Public Health	
Vanessa McKinney	US Environmental Protection Agency, Non-CO_2 Climate Change Program	

Housekeeping

Format:

- Each presentation is 20 minutes
  + 5 minutes of panel Q&A
  + 5 minutes of audience Q&A

- Ryan Lawrence will be giving time checks
  (10 min, 5 min, 1 min remaining)

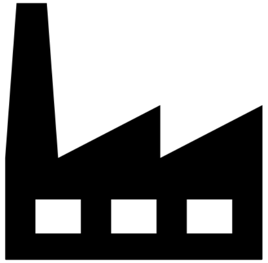
- Please do not take photos
  (ALL presentations will be posted publicly)

What we talk about when we talk about Organic Waste

Food Waste

Discarded food from residential, commercial, institutional, and industrial sources

91 lb/pp/yr



Sewage Sludge

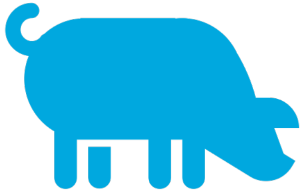
Solids remaining after wastewater processing

90 lb/pp/yr

Animal Manure

Organic material from concentrated animal feeding operations (e.g., dairy, swine)

240 lb/pp/yr



Fats, Oils & Greases

Animal byproducts and grease from food-handling operations (e.g., used cooking oil, animal fats, trap grease)

37 lb/pp/yr

(all numbers in dry lbs)

BETO's Strategy on Organic Waste

- **Significant congressional interest in solving these problems over the years:**
  - Renewable Natural Gas
  - Community Digesters/Solutions
  - International Collaborations
  - Innovative use of Biosolids

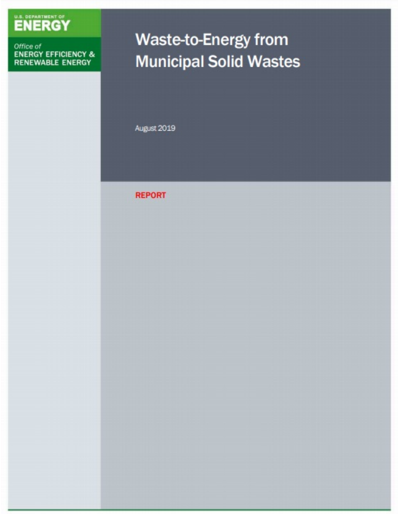
- **BETO has developed a multi-pronged strategy to:**
  1) Manage these economic, environmental and social liabilities
  2) Convert these liabilities into revenue streams
  3) Support community development and ownership of these projects

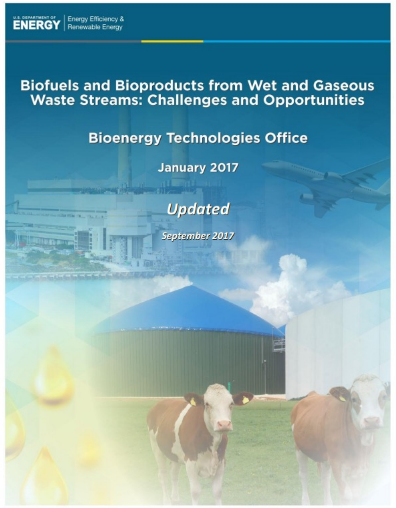
BETO's Activities on Organic Waste in 2019 - 2022:
5 Funding Opportunity Announcement Topics
~$50M in funding:

- >$22M on liquid fuels from waste
- >$12M on products/chemicals from waste
- >$16M on renewable natural gas or small scale digester systems

In addition:

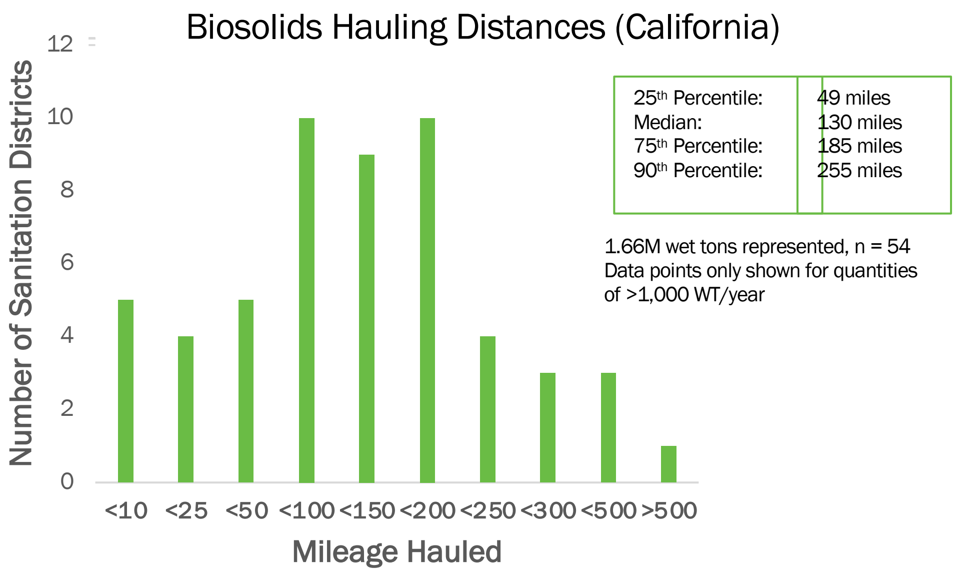
- ~$1M/yr on techno-economic and life-cycle analysis
- ~$1.5M/yr on experimental R&D



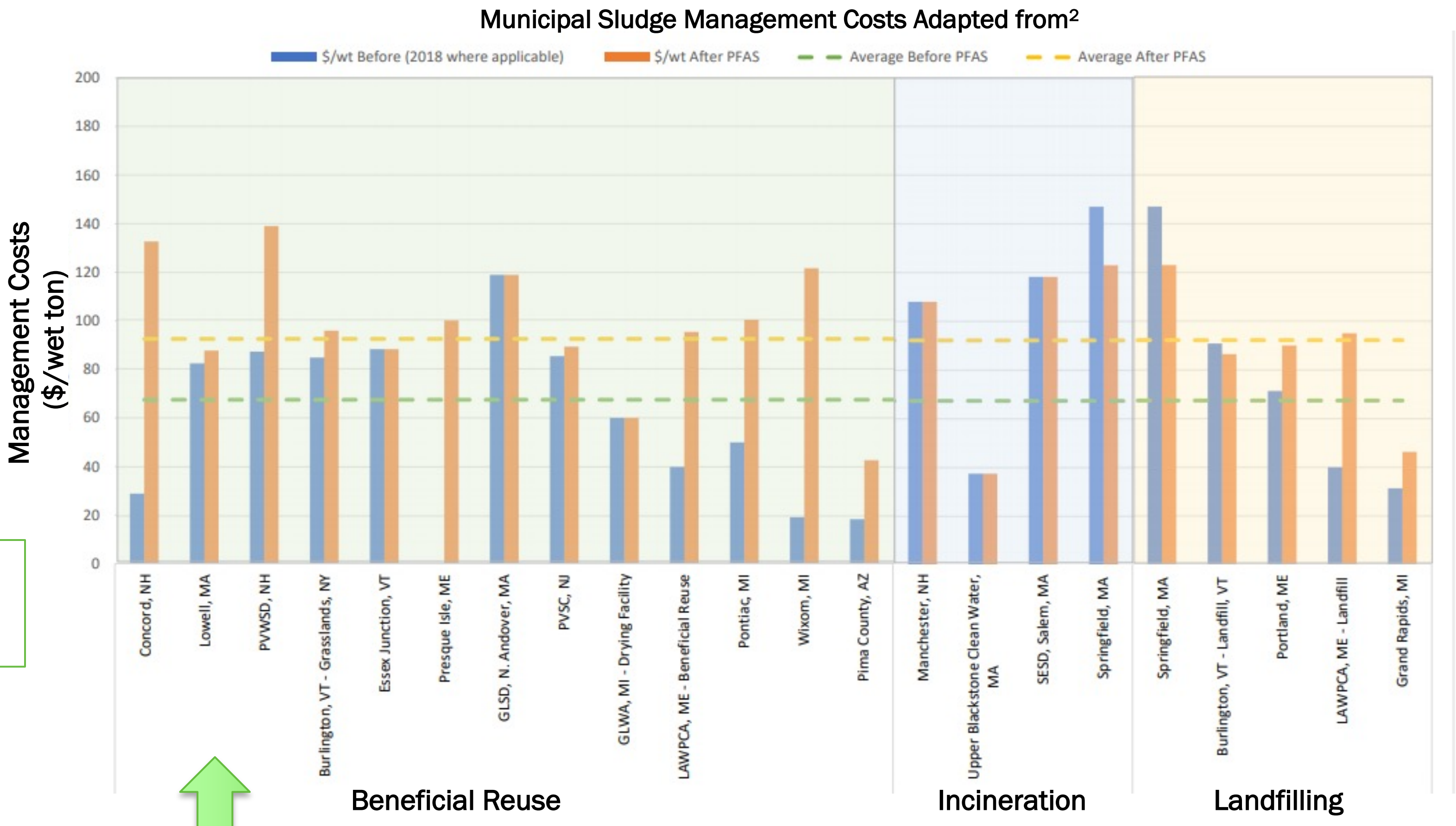


Economic Impacts of Organic Waste Processing

- Municipal waste processing costs are increasing nationwide
  - *"it is estimated that 40% of a wastewater treatment facility's total annual operating cost is spent on solids management[1]"*
- Average tipping fees at landfills increased by 5.2% from 2018 to 2019[3]
  - Nationwide average of $55/ton



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



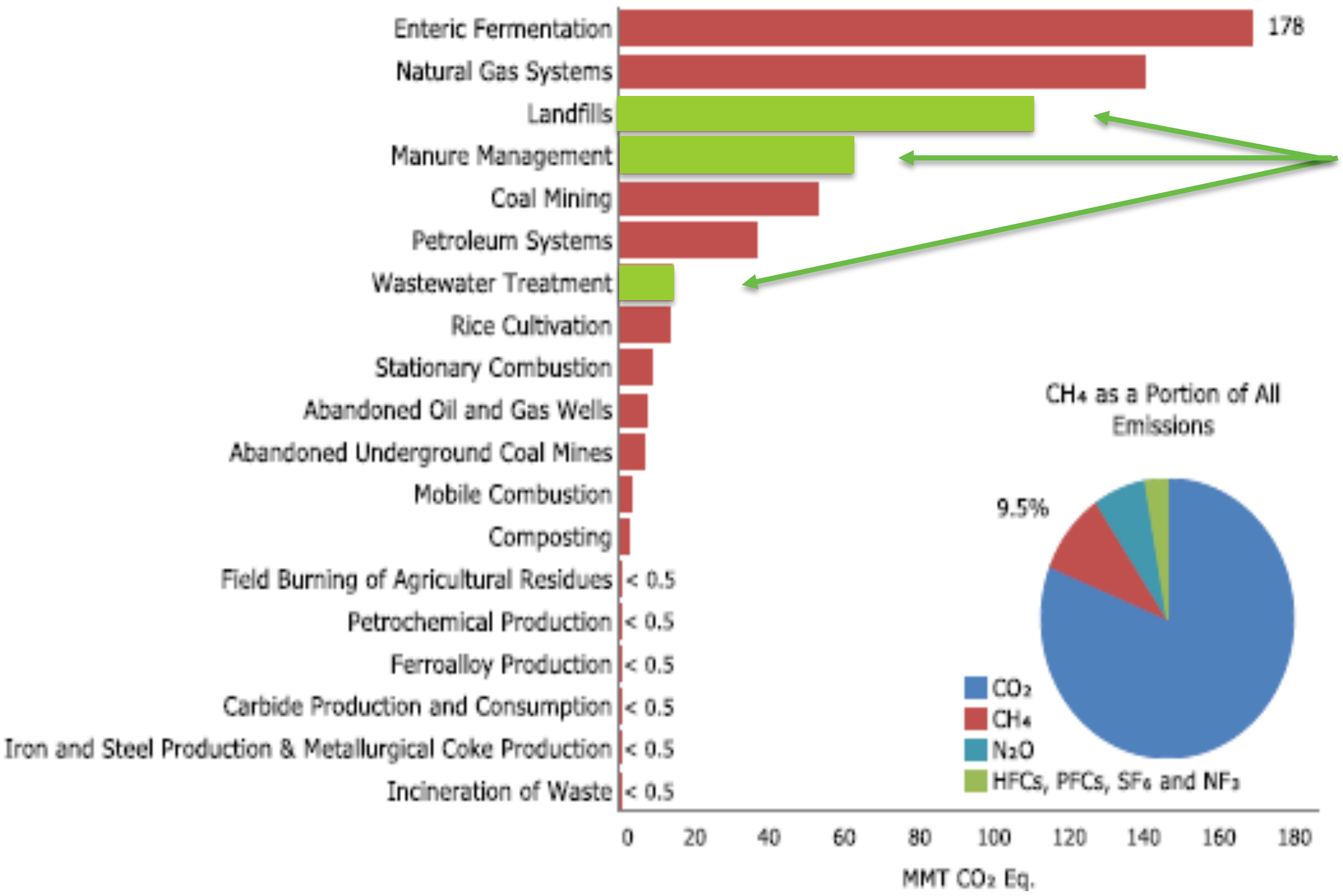
Average sludge management costs have increased by 37% since 2018 due to PFAS

[1] https://legislature.vermont.gov/assets/Legislative-Reports/2016-DEC-Sludge-and-Septage-Report-1-16-2016.pd

[2] https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/cost-analysis-of-pfas-on-biosolids---final.p

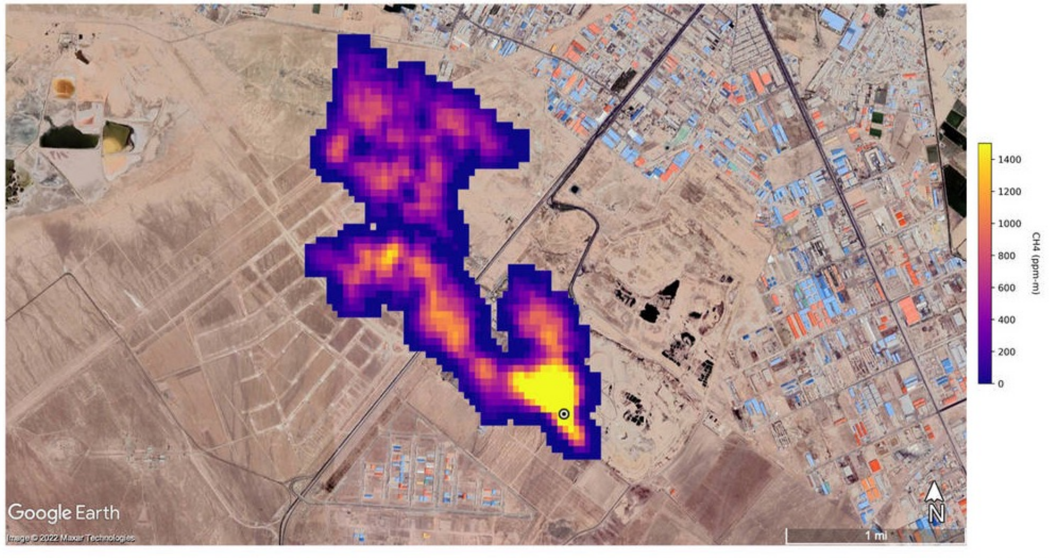
[3] https://www.wastetodaymagazine.com/article/eref-releases-analysis-national-msw-landfill-tipping-fees/#:~:text=The%20average%20MSW%20landfill%20tip,states%20without%20active%20WTE%20facilities.

Environmental Impacts of Organic Waste Processing



>230 MMT CO_2e/yr GHG emissions (CH_4, NO_x, CO_2)

- Landfills are the 3rd largest source of CH_4 emissions nationwide, (114 MMT CO_2e/yr)
- Between 2020 and 2060, the number of available landfills will have decreased by 69%
- Organic waste landfill bans have been implemented in >7 states, many communities have also implemented targets or zero waste

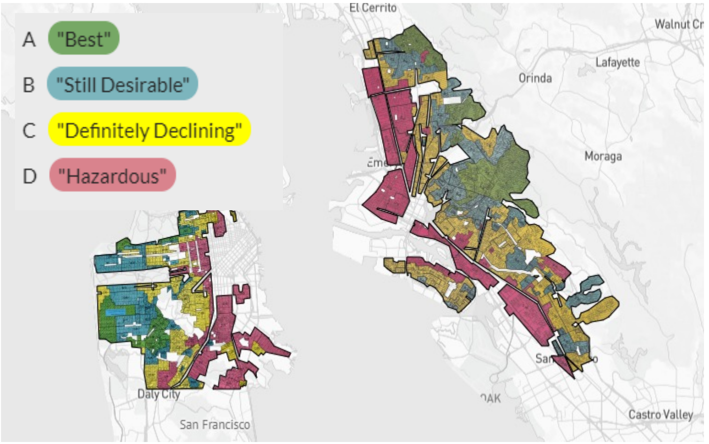


A methane plume at least 3 miles (4.8 kilometers) long billows into the atmosphere south of Tehran, Iran. The plume, detected by NASA's Earth Surface Mineral Dust Source Investigation mission, comes from a major landfill, where methane is a byproduct of decomposition.
Credits: NASA/JPL-Caltech

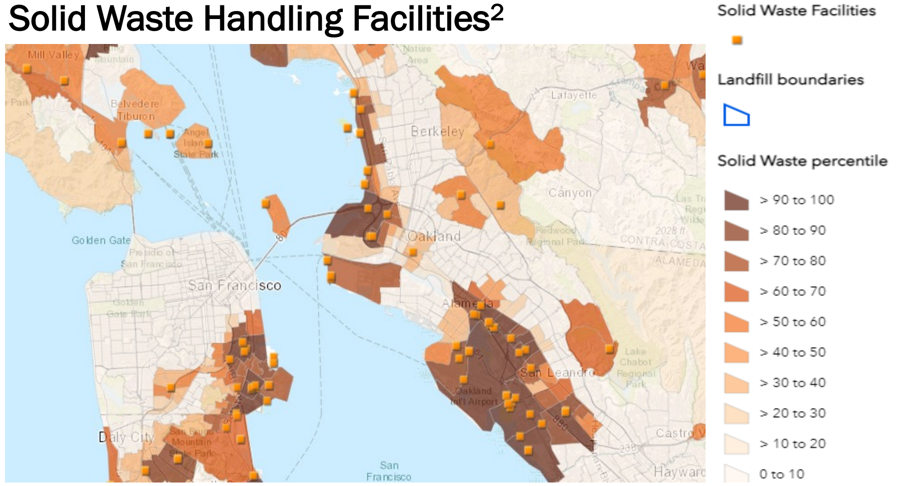
Source: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Social Impacts of Organic Waste Processing

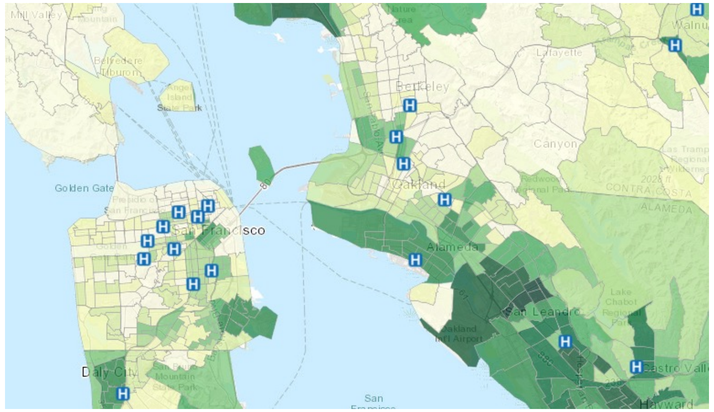
1937 Redlining Map[1]



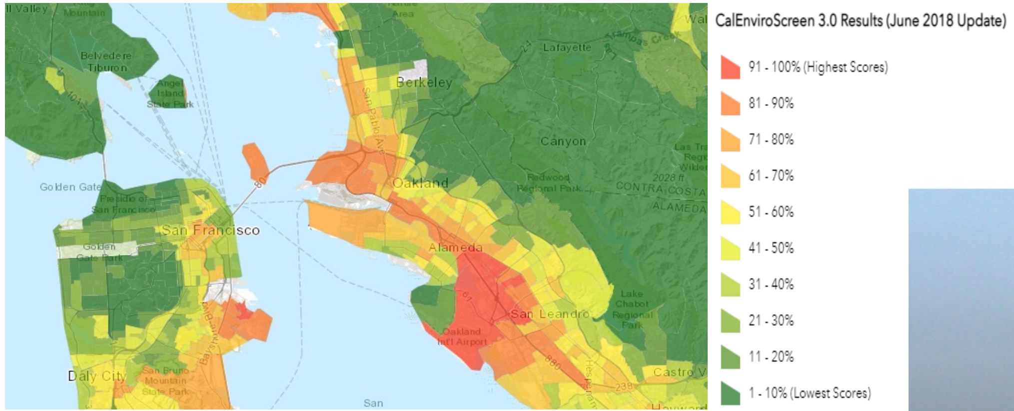
Solid Waste Handling Facilities[2]



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 license to operate is critical:
  - -14% of survey respondents say they "approve" or "accept" living near a WTE plant (n=623)[5]

UNEARTHED

[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.

2021 Peer Review Feedback

Recommendations:

1) **Include an eye towards commercialization**
   a) Consider side streams being generated
   b) Increased focus on integrated operations
2) **Use caution with FOA metrics**
   a) Don’t let certain metrics override the more important focus of technology development
   b) Specific numbers can obscure progress towards TRL improvement
3) **Increased emphasis on tech transfer and partnerships with municipalities, waste management orgs, and other potential early adopters**

Peer Review Agenda

DAY 4 – Thursday, April 6, 2023				
8:00 AM	*10:00 AM*	*Registration, Breakfast, Plenary*	*All*	
10:00 AM	10:15 AM	Technology Area Daily Intro	BETO	
10:15 AM	10:45 AM	Advanced Pretreatment/Anaerobic Digestion	Washington State University	Birgitte Ahring
10:45 AM	11:15 AM	Develop an efficient and cost-effective novel anaerobic digestion system	Washington State University	Shulin Chen
11:15 AM	11:45 AM	Maximizing Bio-Renewable Energy from Wet Wastes (M-BREWW)	University of Illinois at Urbana-Champaign	Lance Schideman
11:45 AM	*1:00 PM*	*Lunch*	*All*	
1:00 PM	1:30 PM	Integrated biochemical and electrochemical technologies (IBET) to	University of Michigan	Lutgarde Raskin
1:30 PM	2:00 PM	Biomethanation to Upgrade Biogas to Pipeline Grade Methane	NREL	Kevin Harrison
2:00 PM	*2:50 PM*	*Break*		
2:50 PM	3:20 PM	Upgrading Biogas through in situ Conversion of Carbon Dioxide to	Washington University at St. Louis	Zhen (Jason) He
3:20 PM	3:50 PM	Renewable Natural Gas from Carboneaceous Wastes via Phase	North Carolina State University	Fanxing Li
3:50 PM	4:20 PM	Catalytic Upgrading of Carbohydrates in Waste Streams to Hydrocarbons	North Carolina State University	Sunkyu Park
4:20 PM	*5:00 PM*	*Closed Door Comment Review Session*	*Reviewers*	

Improvements to anaerobic digestion

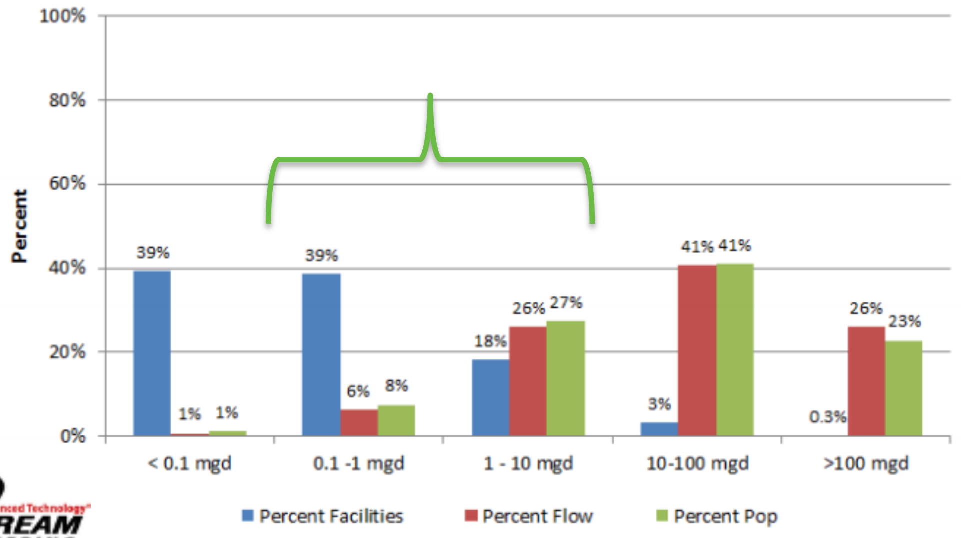
Renewable natural gas / biogas upgrading

Paper waste valorization

Small or “Community” Scale AD R&D

- **BETO defines ‘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)
- **Funding Opportunity Announcements (FOA) 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

50th Anniversary AQUA-AEROBIC SYSTEMS, INC. A Metawater Company 1969 – 2019

MAINSTREAM ENGINEERING

ILLINOIS

TEXAS TECH UNIVERSITY

Colorado State University

UCSD URBANA & CHAMPAIGN SANITARY DISTRICT

University of Michigan

Argonne NATIONAL LABORATORY

ROESLEIN ALTERNATIVE ENERGY, LLC

Metropolitan Water Reclamation District of Greater Chicago

Los Alamos NATIONAL LABORATORY

Biogas yield improvements / increased waste conversion

WASHINGTON STATE UNIVERSITY

REGENIS AN ANDGAR COMPANY

DVO renewables at work

City of Walla Walla

CleanVantage

Pacific Northwest NATIONAL LABORATORY

Jacobs

Acceptance of Additional Waste/ Co-digestion

Northwestern University

GLWA

Argonne NATIONAL LABORATORY

University of Michigan

RNG (Biomethane) R&D

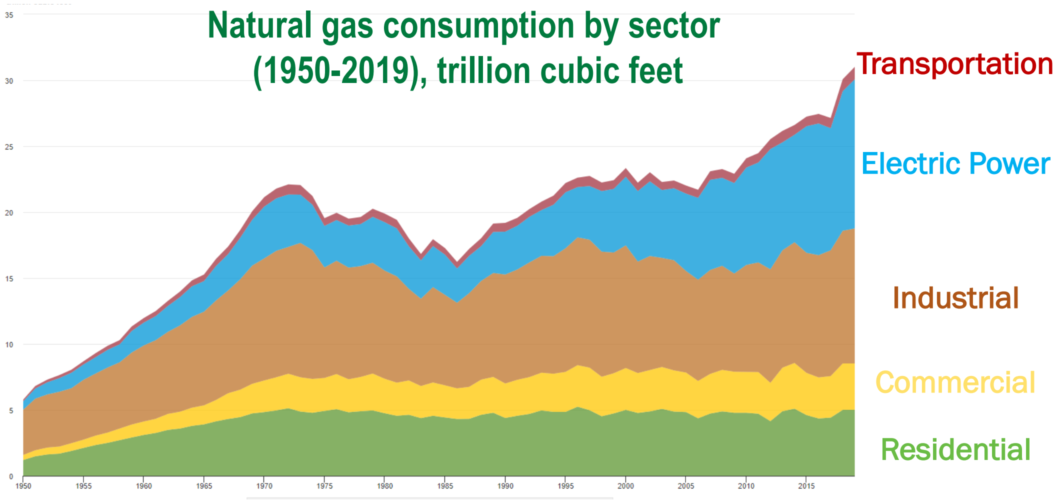
- Natural gas usage is growing or flat in all sectors
- Decarbonization of heating is very difficult
  - Avoided methane emissions are significant (e.g. Dairy digesters in CA)
  - Strong desire in the Northeast to find RNG supply
- Immediate compatibility with existing infrastructure, opportunities for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

Advanced Biogas Upgrading

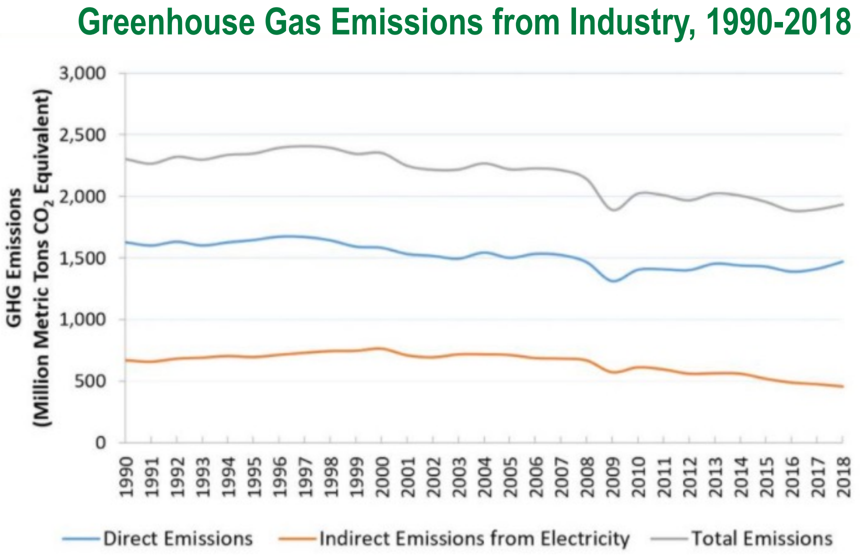
NREL, Washington University in St. Louis, NC State, mosaic, AECOM, NapaSan, Lawrence Livermore National Laboratory

Power-to-Gas

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



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



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

Relevant FOAS / Funding Opportunities

Biopower FOAs	• TRUCK FOA (FY19) • PDABB (FY18)	Projects must improve LCOE by 25%* Projects must exceed an EROI of 5	NCSU (Li) WSU (Chen) UIUC
Next Gen AD FOAs	• Rethinking AD (FY19)	Improve carbon conversion efficiency by at least 50%* Reduce net disposal costs of the waste feedstock by >25%	WSU (Ahring)
Other	• Urban/Suburban Waste (FY20)	Projects must improve LCOE by 25%*	Michigan
RNG FOAs	• Biopower Lab Call (FY18) • RNG FOA (FY21)	Meet Pipeline specs (>97% CH_4...) Time on stream	NREL (Harrison) Clinton P2G** WashU UVa**

*Relative to an appropriate benchmark technology
**Not presenting today

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Organic Waste Conversion – Day 2

Beau Hoffman, Bri Farber, Katie Davis

Housekeeping

Format:

- Each presentation is 20 minutes
  + 5 minutes of panel Q&A
  + 5 minutes of audience Q&A

- Ryan Lawrence will be giving time checks
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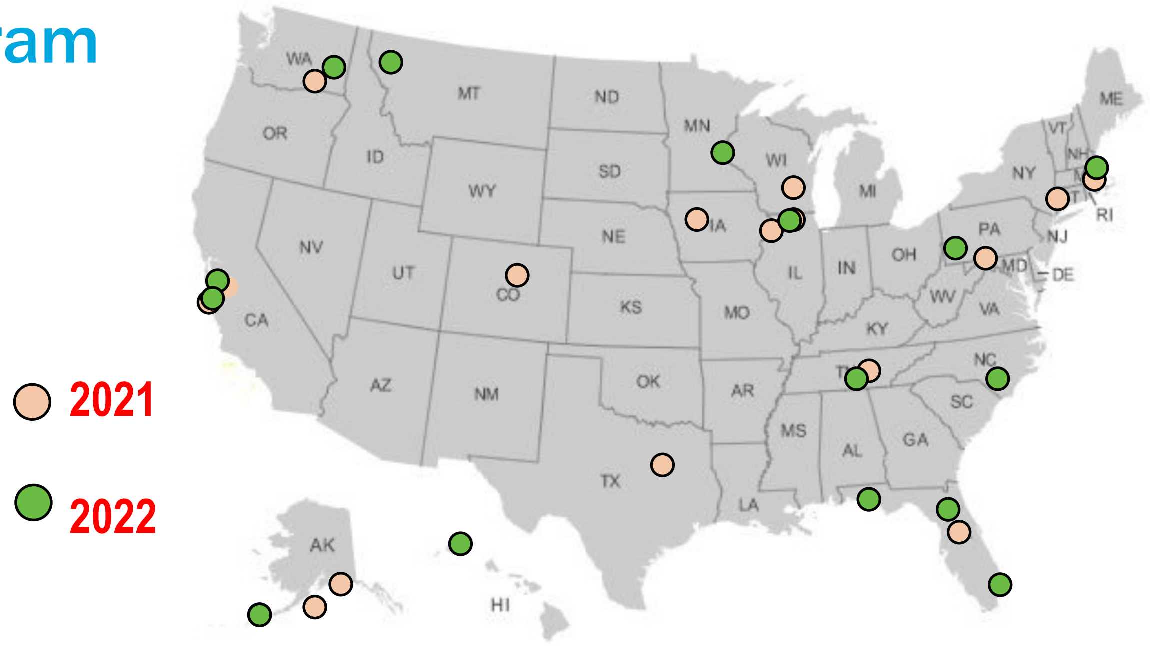
What have we done since 2021?

What have “we” (you) done since 2021?

1) Launched Technical Assistance Program

- **Goal: The goal of the WTE technical assistance is to mobilize data and information compiled about organic waste streams and:**
  - Provide this data to local decision makers
  - Deploy the analyses that have been developed for a variety of energy/resource recovery strategies
  - Foster local public-private partnerships.
- **Eligibility**: All U.S. municipalities in the lower 48 states, Alaska, Hawaii, and U.S. territories, as well as tribal governments
- **Cost: No cost to applicants-** municipalities are expected to provide in-kind support during planning and execution of the technical assistance agreement



Common Themes:

- Cost-benefit analysis is popular
- Municipalities want case studies
- Community champions are key
- Let communities define the problem statement

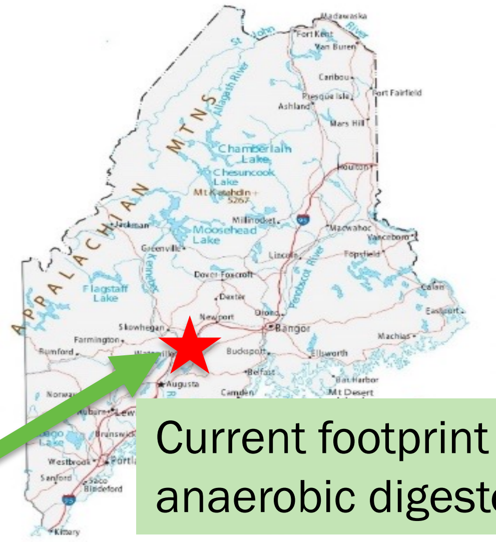
What have “we” (you) done since 2021?

2) Scaled up (and moved out) some technologies!

Summit Natural Gas MAINE

Electrochaea

NREL



Current footprint of solids storage/ anaerobic digesters

Relocate SoCalGas 700L 18-bar bioreactor system from NREL to Summit’s dairy digester in Maine

Future footprint of HTL System

metrovancouver

Pacific Northwest NATIONAL LABORATORY

Sludge feed
10 wet tonnes or
2 dry tonnes/day

→ Hydrochar 300 kg/day

→ Aqueous 8,000 L/day

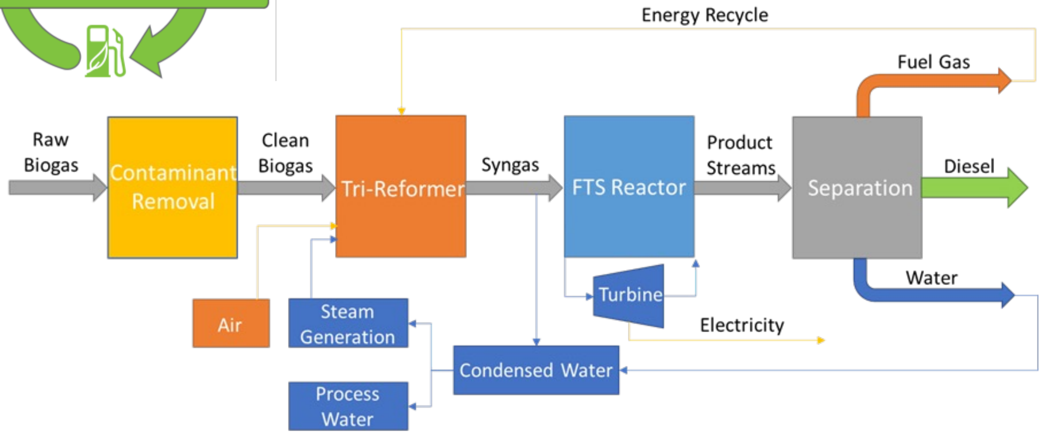
→ Biocrude 750 L/day

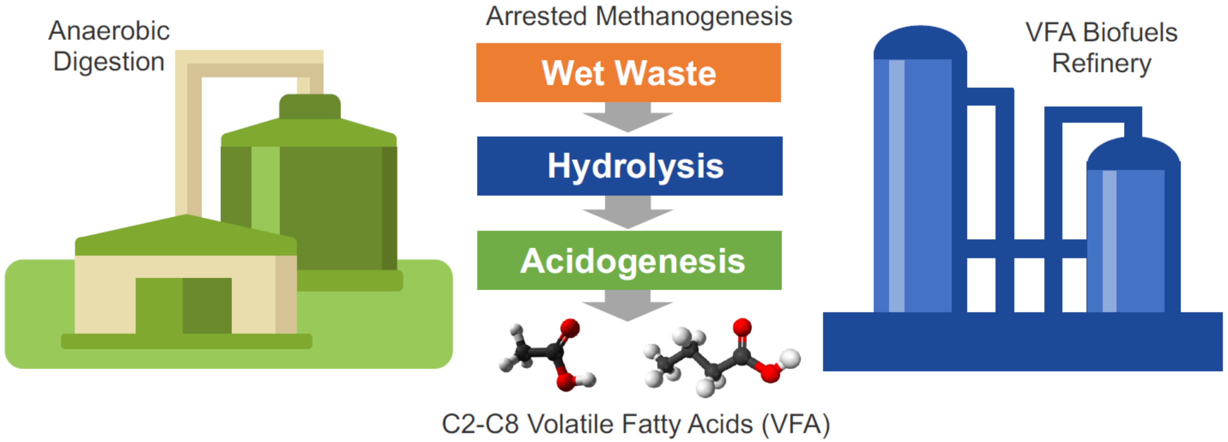
What have "we" (you) done since 2021?

2) Scaled up (and moved out) some technologies!

ALDER FUELS NREL

T2C-ENERGY





Property	Diesel	20 vol% blend
T90 (°C)	333	268
Cetane #	44	+11% 49
YSI	215*	-20% 173*
LHV (MJ/kg)	45	40
Cloud T (°C)	-9.7	-11.4
Flash T (°C)	61	62
Viscosity (cSt)	2.66	2.12

Cost and Sustainability Metrics

Fuel Selling Price $3.81/GGE

GHG Reduction 235%

Fuel Yield 47 GGE/dry tonne

Carbon Yield to Biofuel 29%

Fossil/Biofuel Energy 44%

What have “we” (you) done since 2021?

2) Scaled up (and moved out) some technologies!

HTL:

- Metro Vancouver (Vancouver, BC)
- Aloviam (Austin, TX)
- MicroBio Engineering & GLWA (Detroit, MI)

Power-to-Gas

- Clinton P2G (Clinton, ME)

Biogas Upgrading

- T2C Energy (Lecanto, FL)

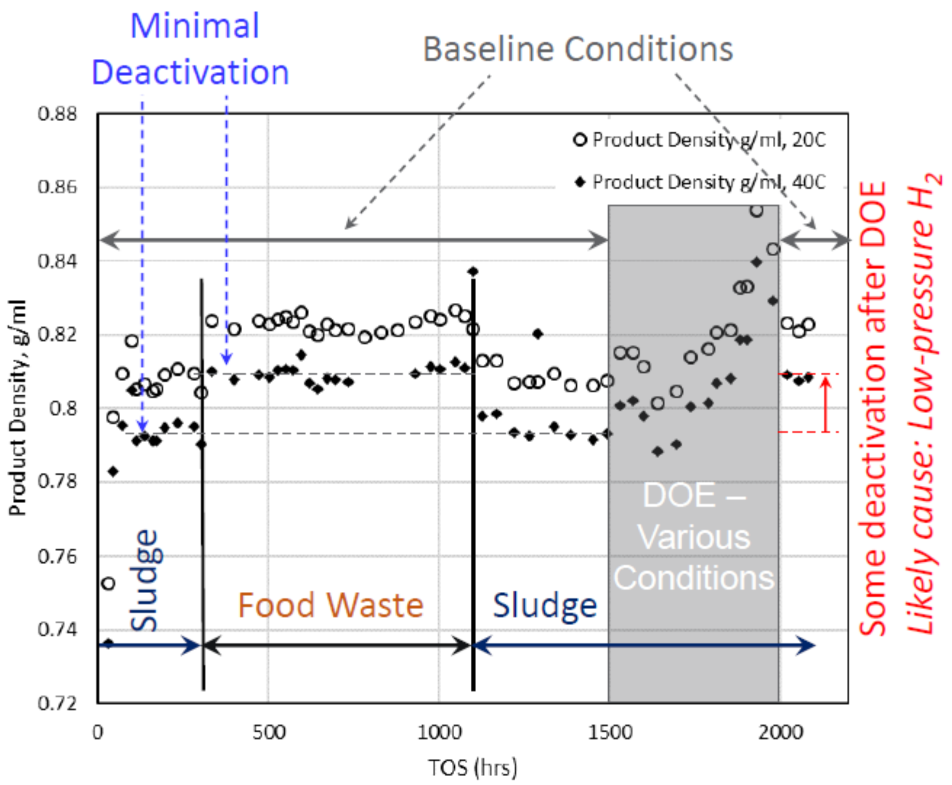
SAF from organic waste

- Alder Fuels

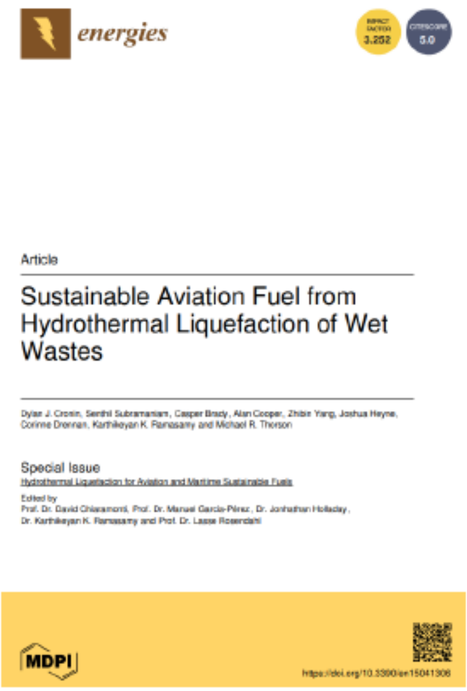
What have "we" (you) done since 2021?

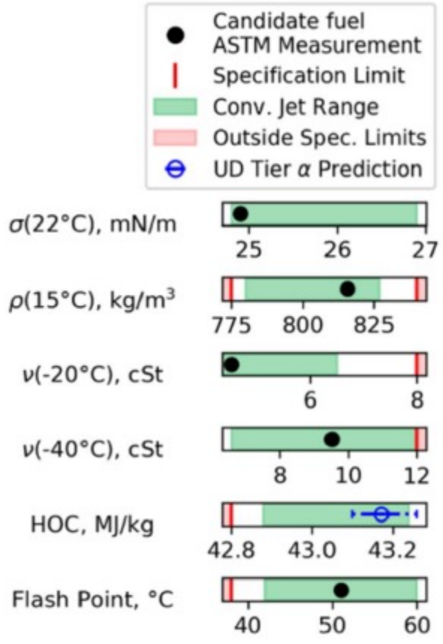
3) Done some impressive things in the lab!

>2,000 hours on stream from HTL biocrude



Demonstrated potential for SAF from HTL biocrude





What have “we” (you) done since 2021?

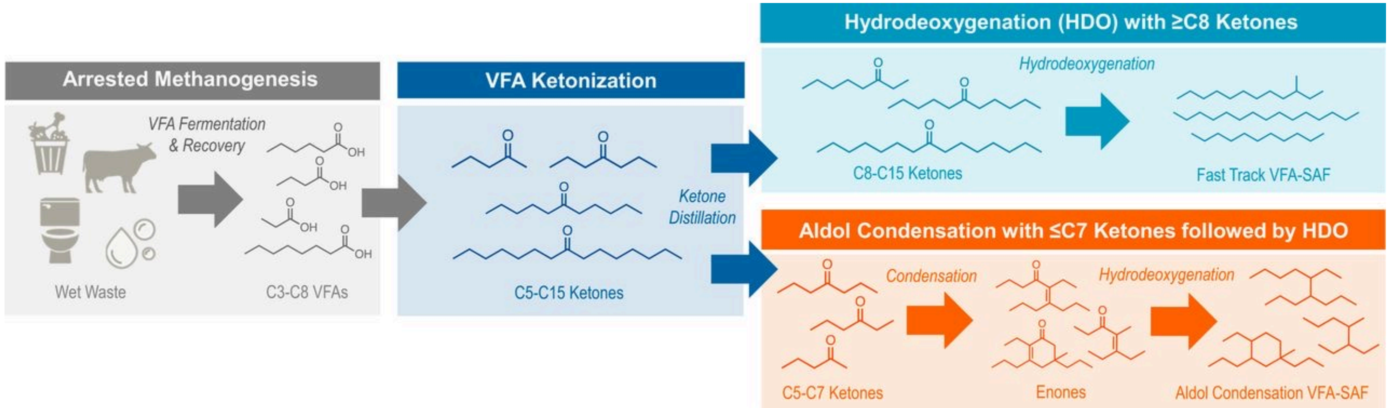
3) Done some impressive things in the lab!

BBC

Climate change: Jet fuel from waste 'dramatically lowers' emissions

By Matt McGrath
Environment correspondent

15 March 2021



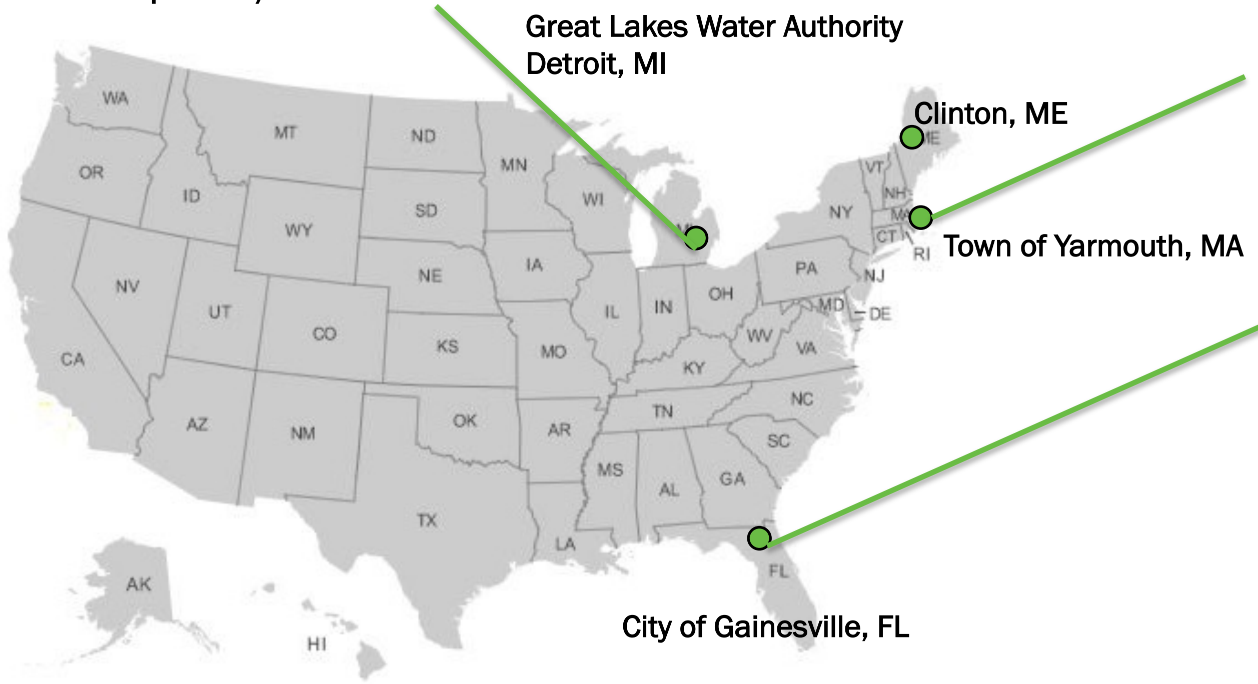

Toward net-zero sustainable aviation fuel with wet waste–derived volatile fatty acids

What have "we" (you) done since 2021?

4) Partnered Directly with Communities!

Great Lakes Water Authority

- One of the largest WWTs in the country
- GLWA currently incinerates, land applies, or landfills their biosolids at significant expense
- Their incinerator is expected to cost >$250M to replace/retrofit



Yarmouth, MA

- Over 30,000 excess tons of organics 'on-Cape', 30% diversion goal by 2030
- Towns are seeing a 2x increase in disposal costs
- Cape Cod Commission has assembled 15 towns to commingle the waste and evaluate a novel digester

City of Gainesville

- All wastes currently managed 'out-of-county'
- 5 Mgal/yr fats/oils/greases, 600kT food waste
- Looking for strategy to meet City and County zero waste goals (90% by 2040)

Peer Review Agenda

Start Time MDT	End Time MDT	Title	Organization	Speaker
DAY 5 – Friday, April 7, 2023				
8:00 AM	*8:30 AM*	*Registration, Breakfast*	*All*	
8:30 AM	8:45 AM	Technology Area Daily Intro	BETO	
8:45 AM	9:15 AM	Waste-to-Energy Technical Assistance	NREL	Anelia Milbrandt
9:15 AM	9:45 AM	Waste-to-Energy: Optimized feedstock aggregation and blending at scale	PNNL	Tim Seiple
9:45 AM	10:15 AM	Analysis and Sustainability Interface - PNNL	PNNL	Lesley Snowden-Swan
10:15 AM	*10:30 AM*	*Break*	*All*	
10:30 AM	11:00 AM	Bench Scale HTL of Wet Wastes	PNNL	Michael Thorson
11:00 AM	11:30 AM	Denitrogenation of wet waste-derived biocrude to meet SAF specifications	PNNL	Michael Thorson
11:30 AM	12:00 PM	A Catalytic Process to Convert Municipal Solid Waste Components to Energy	Worcester Polytechnic Institute	Mike Timko
12:00 PM	*1:00 PM*	*Lunch*	*All*	
1:00 PM	1:30 PM	Synergistic Thermo-Microbial-Electrochemical (T-MEC) Approach for Drop-In Fuel Production from Wet Waste	Princeton University	Z. Jason Ren
1:30 PM	2:00 PM	Novel and Viable Technologies for Converting Wet Organic Waste Streams to Higher Value Products	The Research Foundation of SUNY, University of Albany	Yanna Liang
2:00 PM	2:30 PM	Innovative Polyhydroxyalkanoates (PHA) Production with Microbial Electrochemical Technology (MET)	University of Maryland	Stephanie Lansing
2:30 PM	3:00 PM	Electro-Enhanced Conversion of Wet Waste to Products Beyond Methane	Colorado State University	Ken Reardon

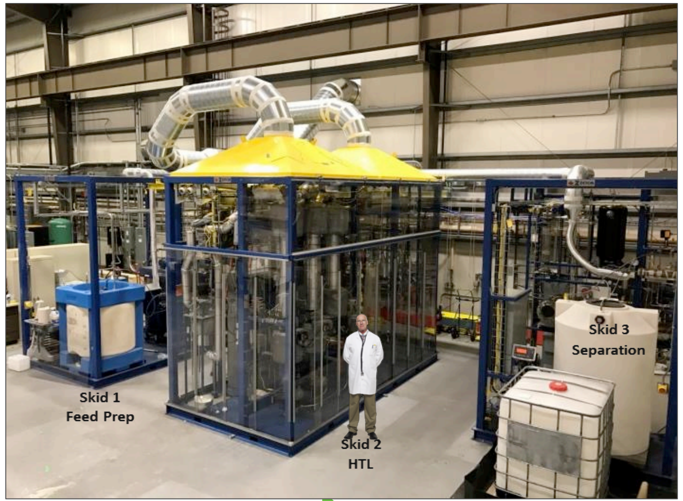
Analysis Efforts

Hydrothermal Liquefaction

Products from waste

Liquid Fuels from Waste – Hydrothermal Liquefaction

HTL is a process that uses heat and pressure to convert biological materials to biocrude oil in about 15 minutes, using the same principles that nature transforms biological materials to crude oil over centuries



The crude oil from waste water is rich in diesel-range hydrocarbons and has high cetane (~70)

- Fuel has been evaluated by Colorado State University in engine tests (5-15% blends)- no negative impact on performance nor emissions observed
- Very high organic conversion rates relative to traditional anaerobic digestion (94-99%). *This is very important to the business case*

Research priorities have focused on:

- Side stream management
- Time on stream
- Integration with existing WRRFs

Wet biological material (e.g. waste water residuals) → **HTL** → Stable biocrude oil (up to 60% yield) → **Hydroprocessing** → Hydrocarbon fuels (95%+ yield)

Drop-in fuels

GLWA Great Lakes Water Authority

Washington State University

Pacific Northwest National Laboratory

The Water Research Foundation www.werf.org

metrovancouver

leidos

UC Riverside University of California

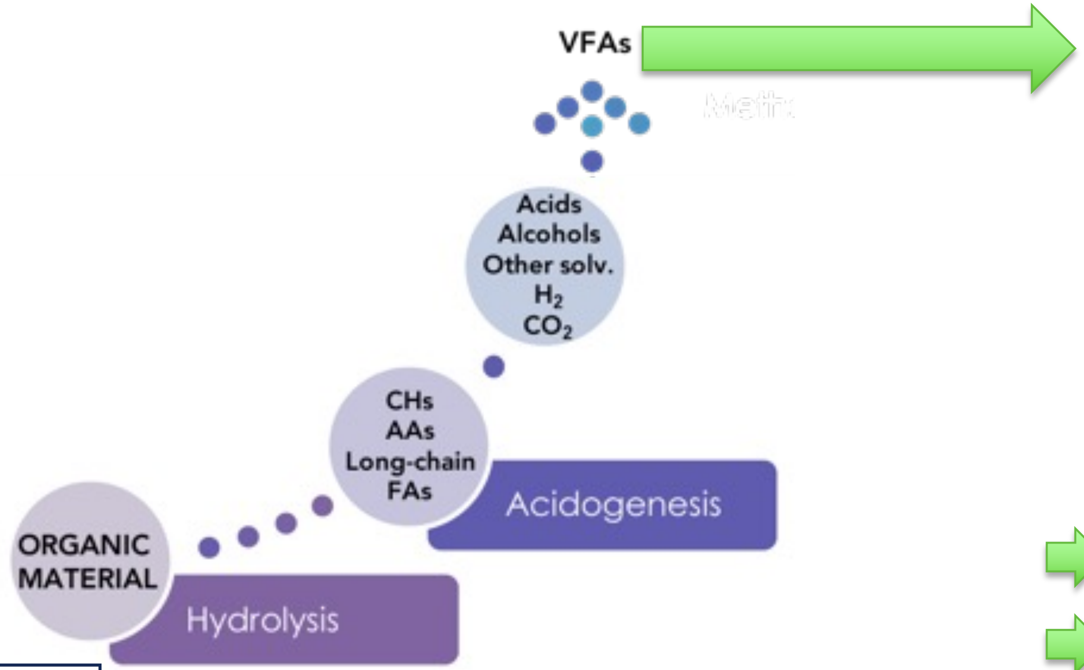
WPI

Princeton University

Massachusetts Institute of Technology

Illinois

Bioproducts / Biochemicals from Waste



Biochemicals and bioproducts

From organic acids, demonstrated a variety of products are possible via biological and chemical catalysis:

- **Polyurethane**
- **Polyester resins**
- **Polyacids/Polyols**
- **Terpenes**
- **Olefins**

- Enables closing of carbon cycles
- Decarbonization of materials/plastics
- Higher value products enable smaller scale/footprint operations
- More efficient or environmentally benign manufacturing processes (avoiding need for chemicals like nitric or sulfuric acid)

FOAS/lab calls targeted separations strategies, improved carbon conversion efficiency

Relevant FOAS / Funding Opportunities

FOA category	Funding opportunities	Requirements	Institutions
Biopower FOAs	• PDABB (FY18)	Projects must improve LCOE by 25%* Projects must exceed an EROI of 5	WPI
Next Gen AD FOAs	• Rethinking AD (FY19) • Community Scale Wastes (FY20)	Improve carbon conversion efficiency by at least 50%* Reduce net disposal costs of the waste feedstock by >25%	SUNY-Albany Princeton Maryland
Other	• Urban/Suburban Waste (FY19)	Projects must improve LCOE by 25%*	CSU

*Relative to an appropriate benchmark technology

**Not presenting today

Questions

Contact Info:

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