U.S. Department of ENERGY | Office of Energy Efficiency & Renewable Energy

Waste to SAF: Challenges and Opportunities

Beau Hoffman

US DOE - Bioenergy Technologies Office

OUTLINE

Organic and non-recyclable municipal solid waste – an overview

DOE – BETO's Strategy on organic and non-recyclable MSW

- Quantifying the variability
- Building partnerships

Recent Technology Development Highlights

- MSW Sorting
- MSW Feeding
- Hydrothermal Liquefaction

WHAT I TALK ABOUT WHEN I TALK ABOUT ORGANIC WASTE

Food Waste

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

Sewage Sludge

Solids remaining after wastewater processing

Animal Manure

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

Fats, Oils & Greases

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

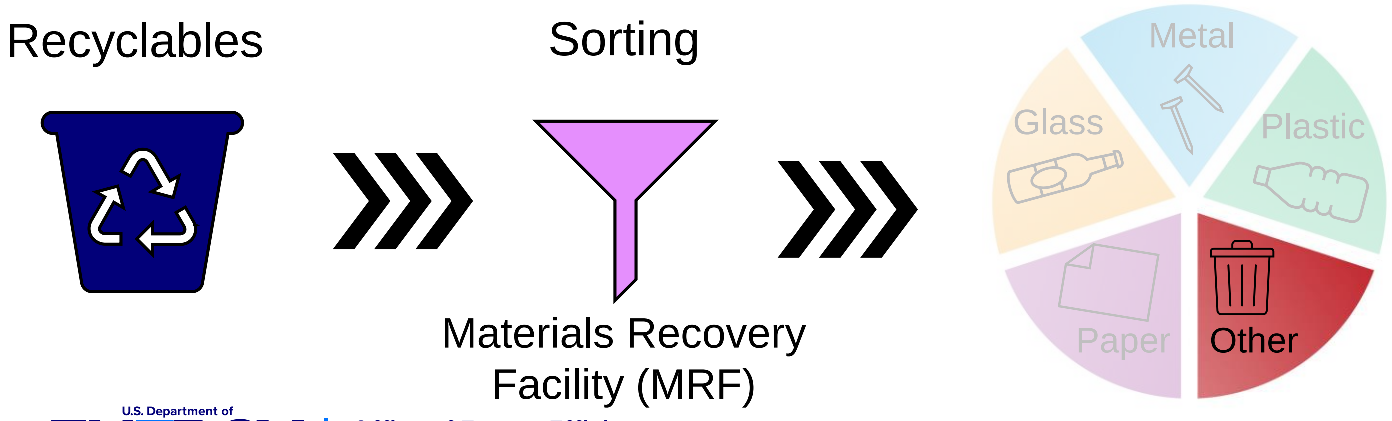
(all numbers in dry lbs)

MATERIAL RECOVERY FACILITY (MRF) WASTE STREAM

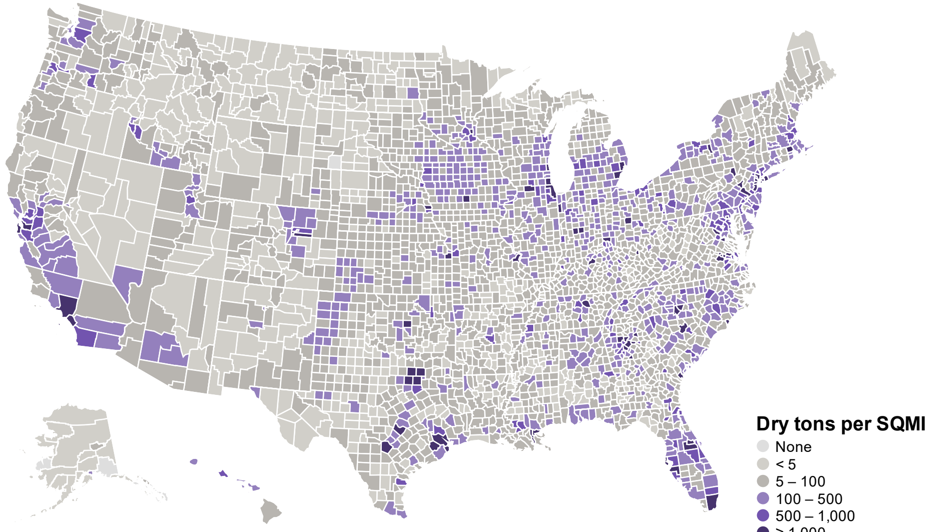
Recyclables are sent to a material recovery facility (MRF) for sorting

A landfill-bound waste stream exists for non-recoverable material (aka MRF residues)

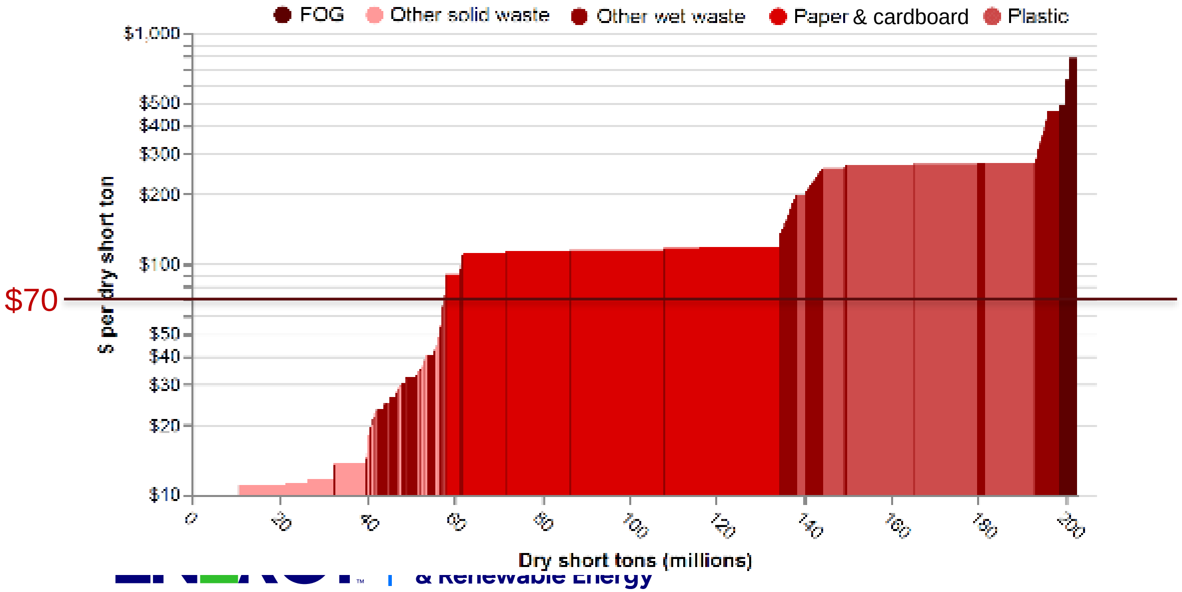
Gasification is a promising route to convert low-cost, low-value feedstocks

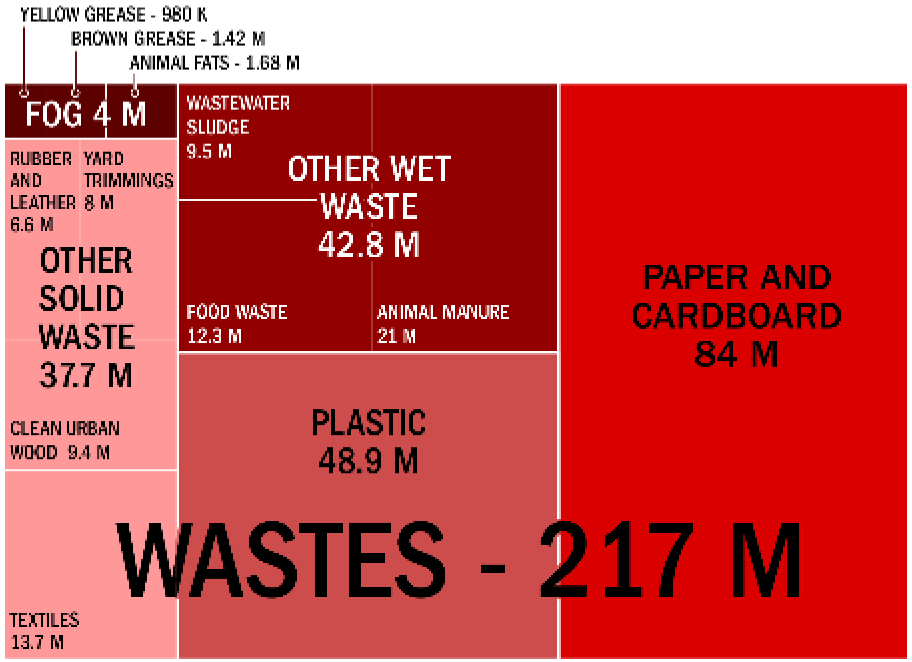


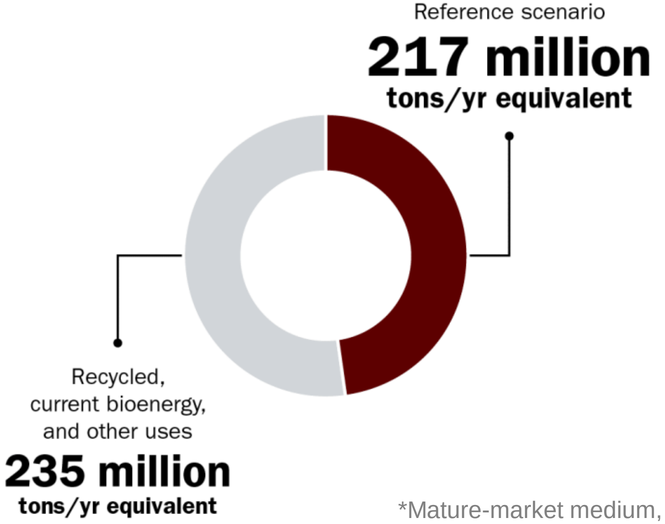
WASTE & BYPRODUCT RESOURCES CAN PROVIDE 180-220 MILLION TONS



Map depicts total w aste production, including currently used w astes, recycled w astes, and the potentially available fraction of w astes. Purple colors indicate sufficient supply density to support >750,000 tons per year w ithin a 50-mile radius.







*Mature-market medium, reference scenario, all prices

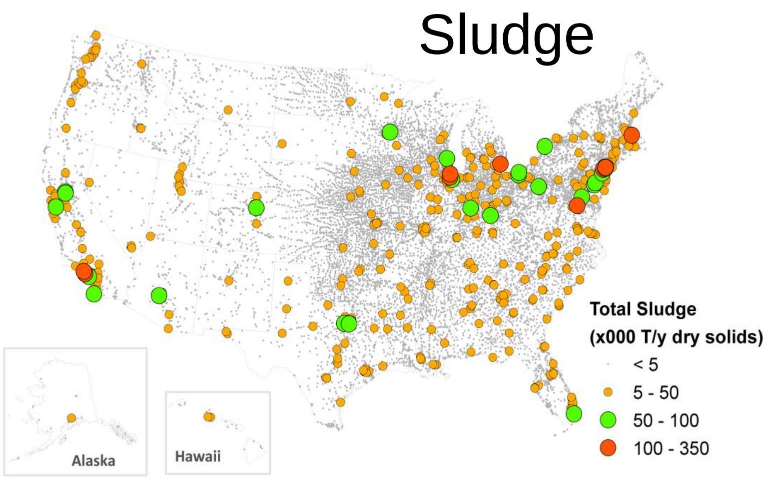
Source: https://www.energy.gov/sites/default/files/2024-03/beto-2023-billion-ton-report_2.pdf

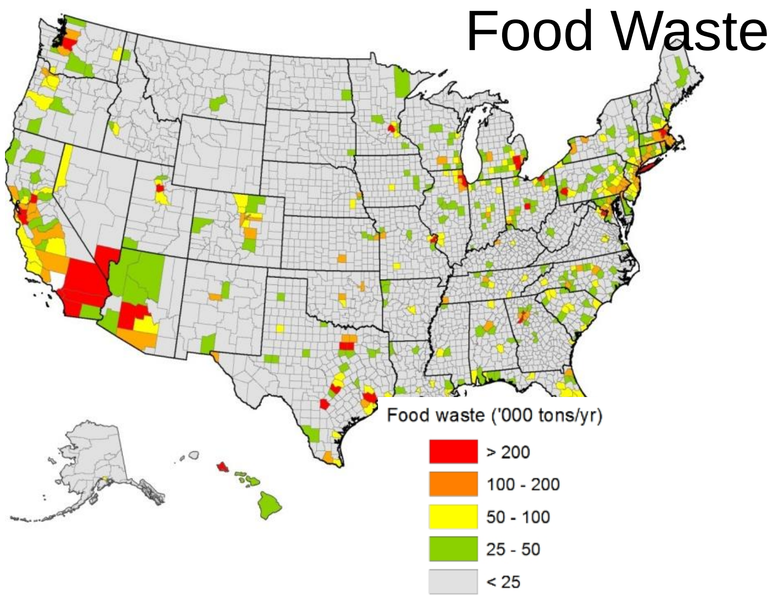
GEOGRAPHIC DISTRIBUTION OF ORGANIC WASTE

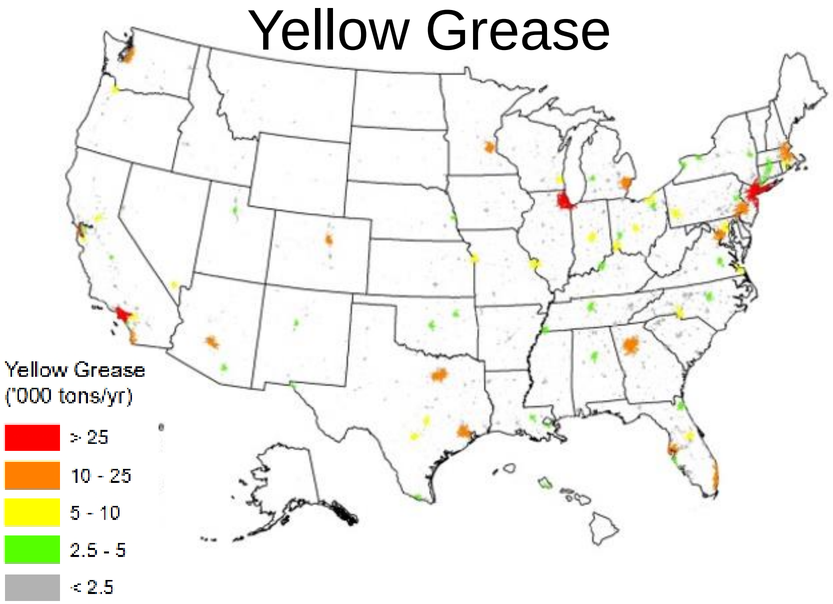
Wet Resources	Annual Beneficial Utilization (Current): Estimated Resource Availability (MM Dry Tons)	Annual Beneficial Utilization (Current): Inherent Energy Content (Trillion Btu)	Annual Beneficial Utilization (Current): Fuel Equivalent (MM GGE)[2]	Annual Potential Excess[1]: Estimated Resource Availability (MM Dry Tons)	Annual Potential Excess[1]: Inherent Energy Content (Trillion Btu)	Annual Potential Excess[1]: 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

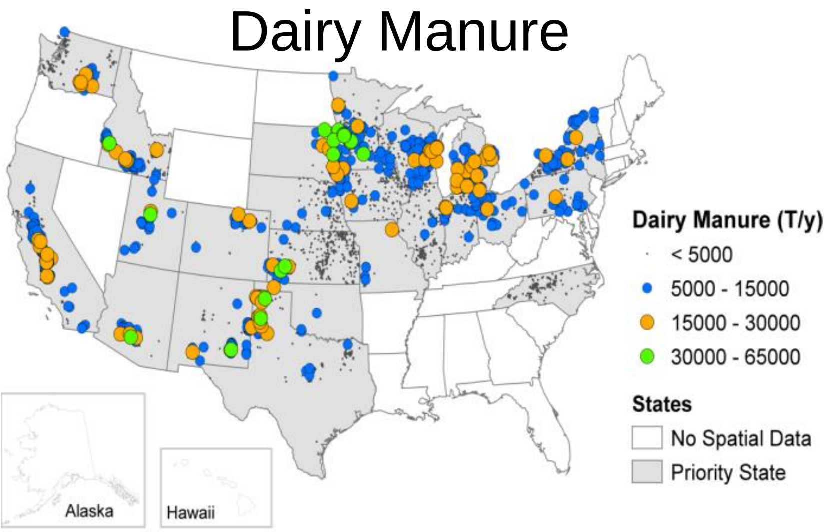
[1] Unused excess in this definition includes landfilled biosolids and other wet resources.

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



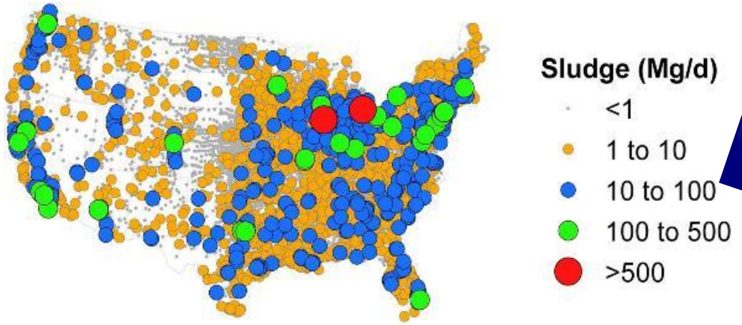


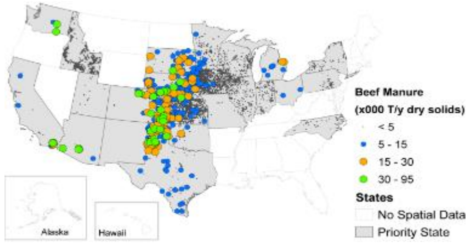




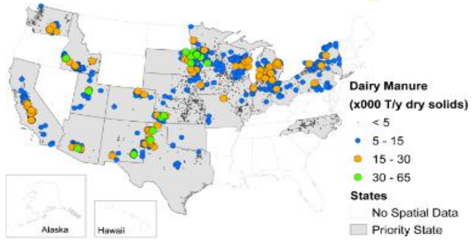
Milbrandt, A., Seiple, T., Heimiller, D., Skaggs, R., Coleman, A. "Wet waste-to-energy resources in the United States". *Resources, Conservation and Recycling.* Volume 137, October 2018, Pages 32-47.
Seiple, T. et al. "Municipal wastewater sludge as a sustainable bioresource in the United States". *Journal of Environmental Management.* Volume 197, July 2017, Pages 673-680.

WASTE BLENDING: POSSIBILITY OR FEEL-GOOD STORY? A: BOTH

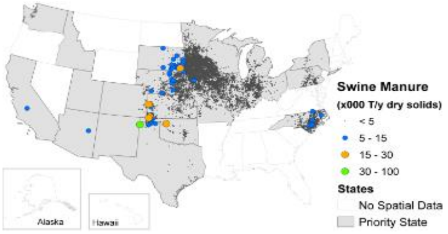




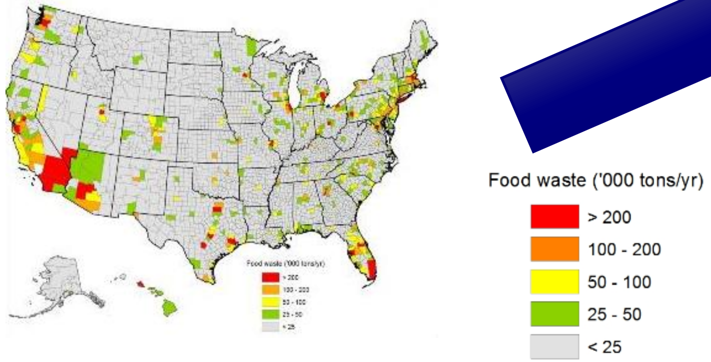
Feedlot Beef

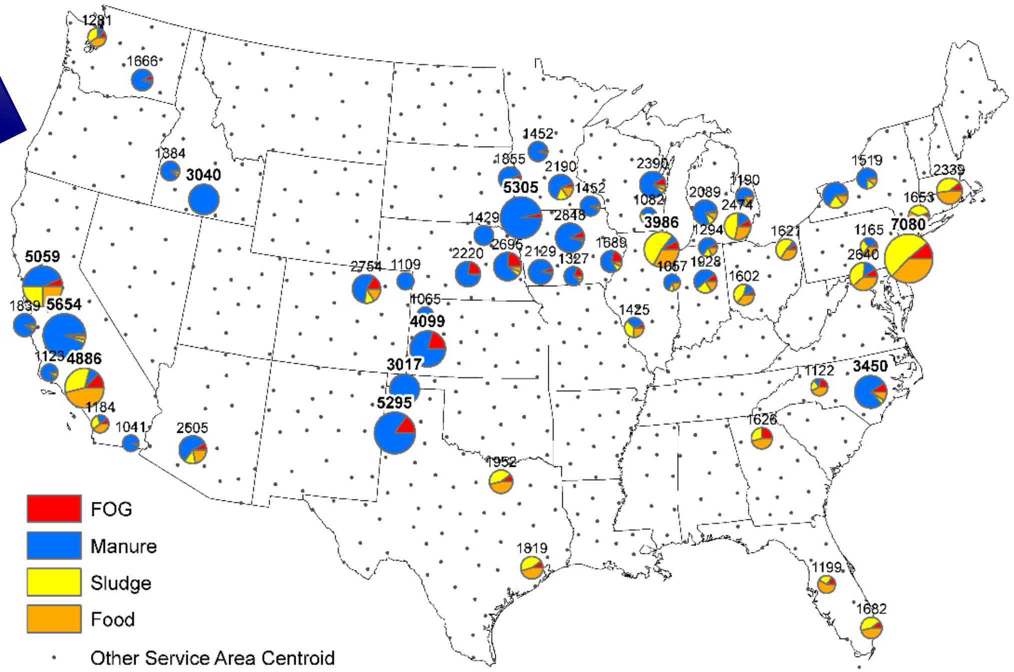


Dairy



Market Swine





NREL
NATIONAL RENEWABLE ENERGY LABORATORY

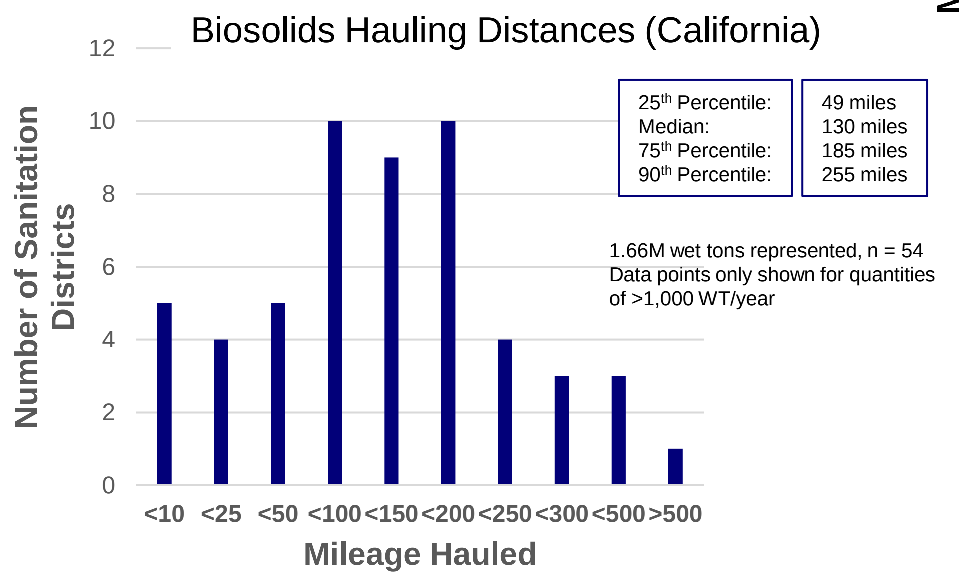
Pacific Northwest
NATIONAL LABORATORY

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

Blending of organic wastes is economically feasible

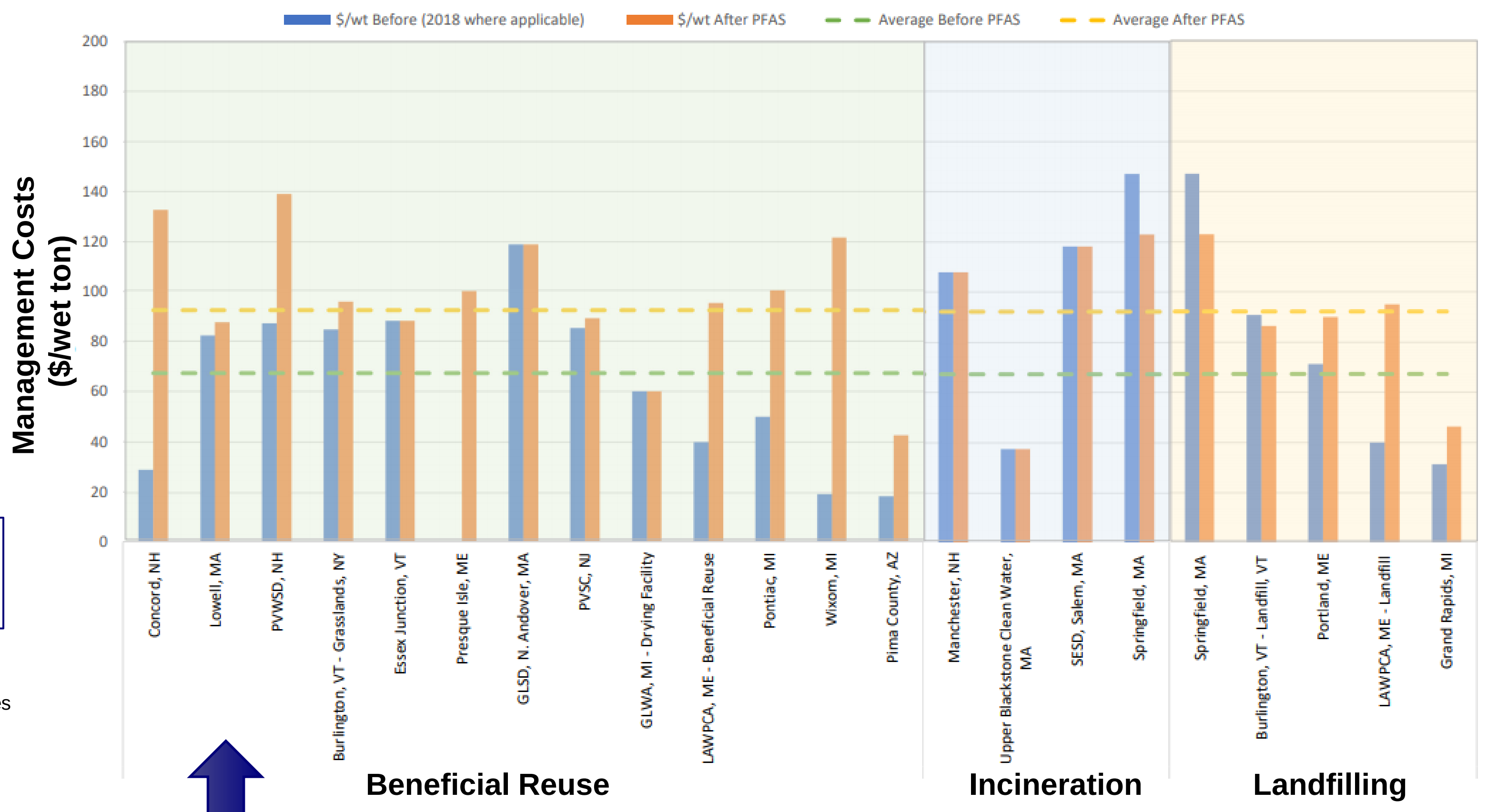
ECONOMIC IMPACTS OF ORGANIC WASTE PROCESSING

- 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

Municipal Sludge Management Costs Adapted from[2]



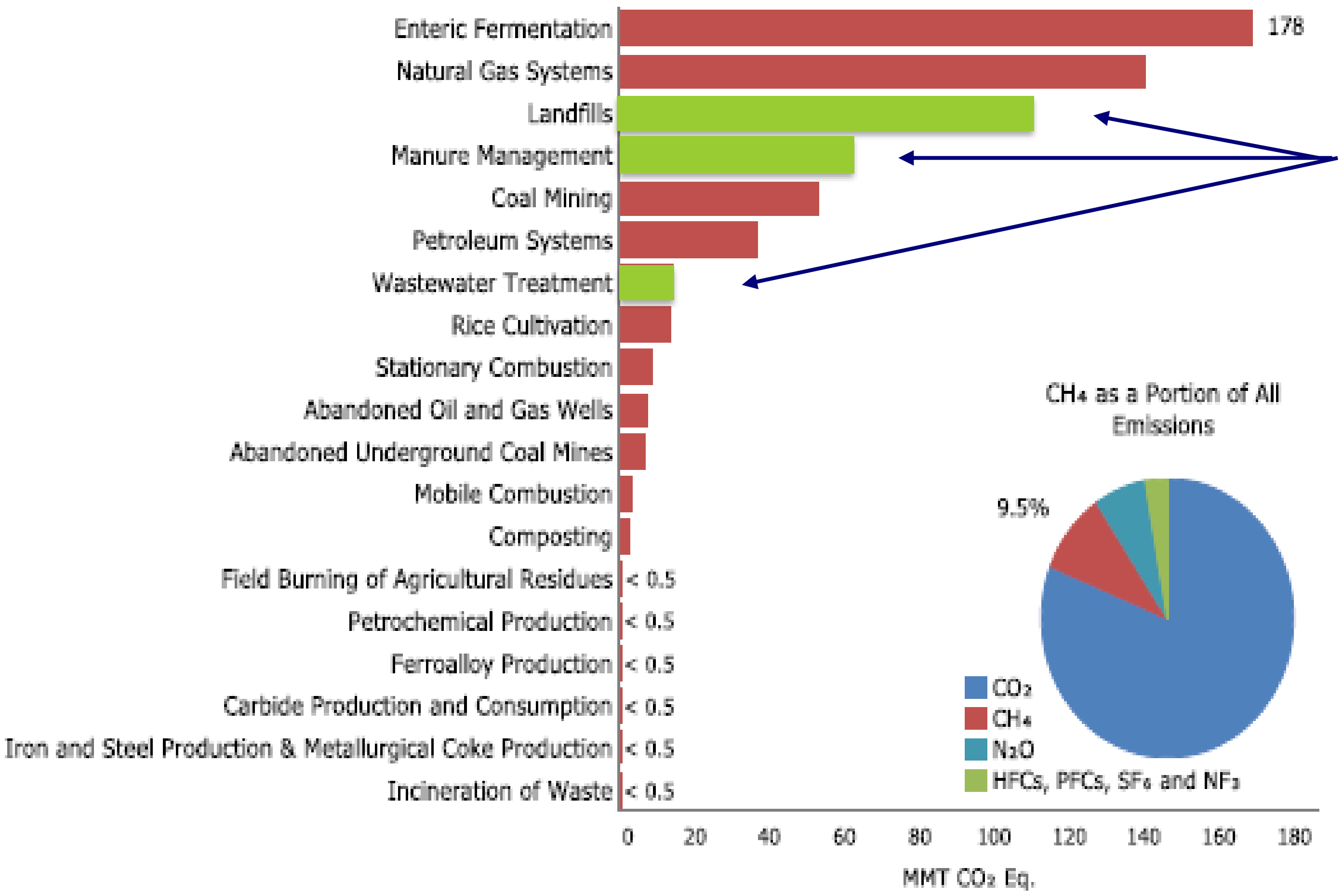
Average sludge management costs have increased by 37% since 2018 due to PFAS

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

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

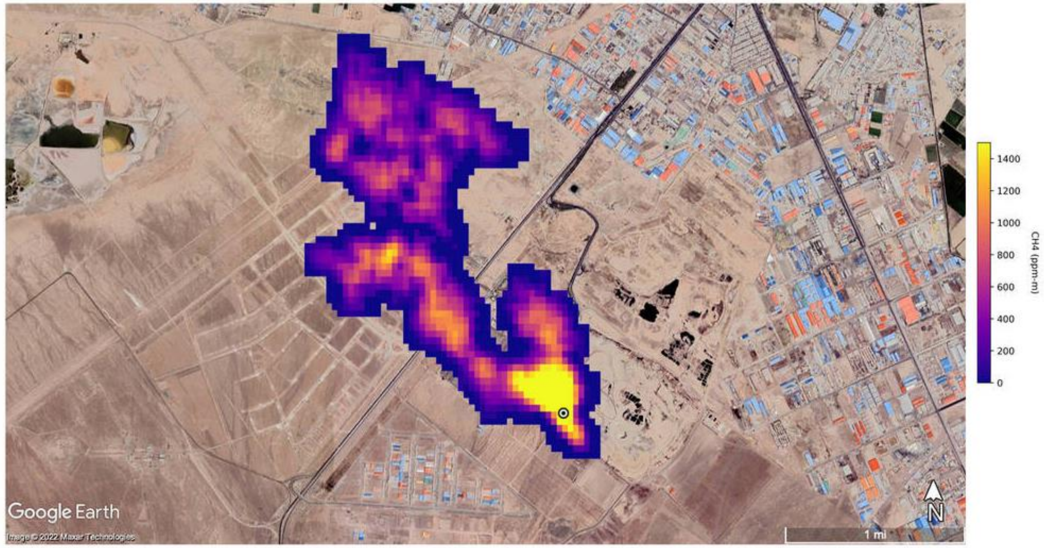
[3] https://www.wastetodaymagazine.com/article/eref-releases-analysis-national-msw-landfill-tipping-fees/#:~:text=The%20average%20MSW%20landfill%20tip,states%20without%20active%20WTE%20facilities.

ENVIRONMENTAL IMPACTS OF ORGANIC WASTE PROCESSING



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

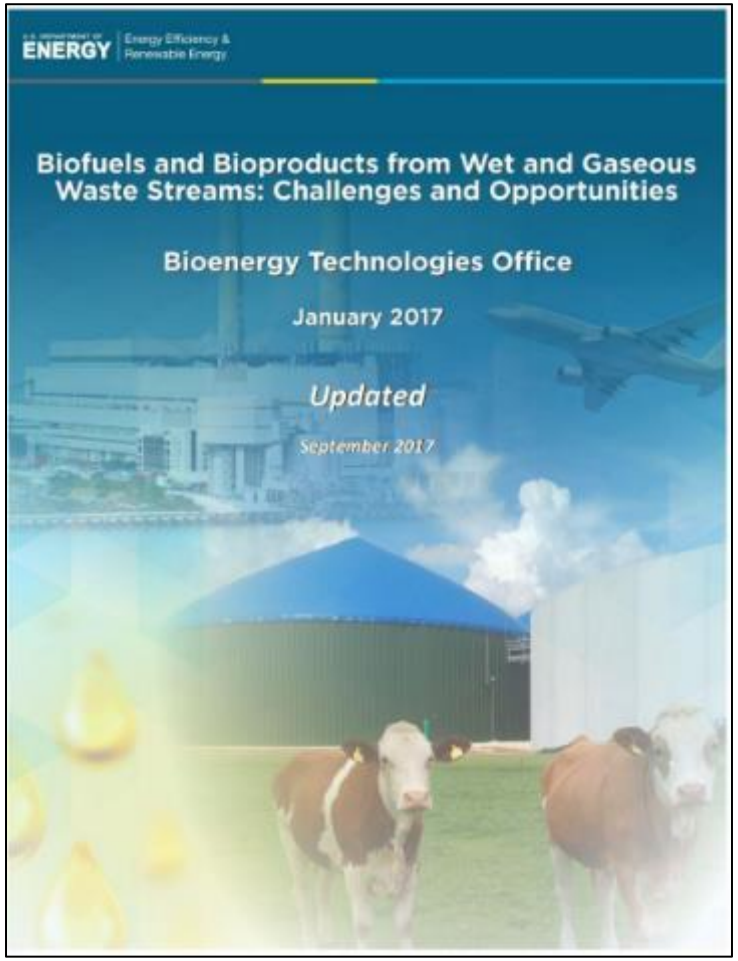
- Landfills are the 3rd largest source of CH_4 emissions nationwide, (114 MMT CO_2e/yr)
- Between 2020 and 2060, the number of available landfills will have decreased by 69%
- Organic waste landfill bans have been implemented in >7 states, many communities have also implemented targets or zero waste

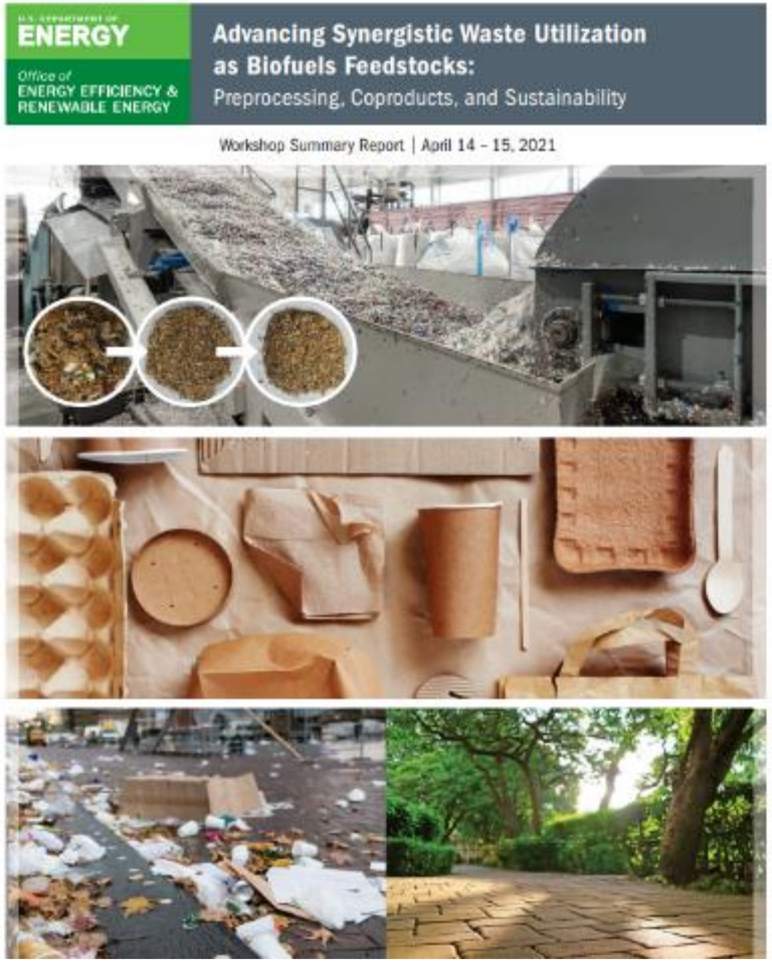


A methane plume at least 3 miles (4.8 kilometers) long billows into the atmosphere south of Tehran, Iran. The plume, detected by NASA's Earth Surface Mineral Dust Source Investigation mission, comes from a major landfill, where methane is a byproduct of decomposition.
Credits: NASA/JPL-Caltech

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

BETO'S RECENT WORKSHOPS AND REPORTS ON WASTE TO ENERGY





US DOE'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:

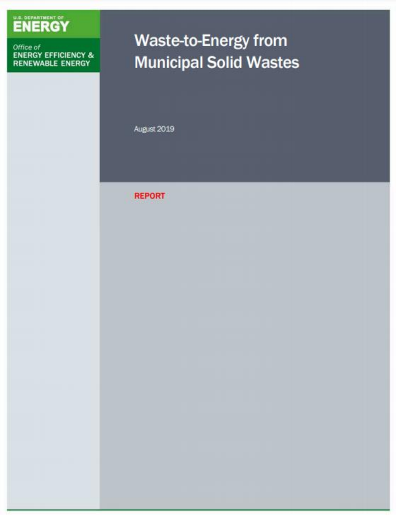
1) Manage these economic, environmental and social liabilities
2) Convert these liabilities into revenue streams
3) Support community development and ownership of these projects

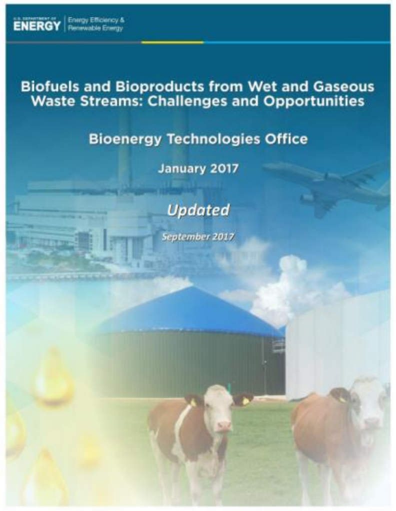
BETO's Activities on Organic Waste in 2019 - 2022:
5 Funding Opportunity Announcement Topics
~$50M in funding:

- >$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 analysi
- ~$1.5M/yr on experimental R&D





3-YEAR MSW FOA CAMPAIGN

Current BETO MSW Feedstock R&D includes:

- MSW stream fractionation and sorting
- Characterization of variability
- Decontamination and preprocessing
- Development of value-added co-products to increase the feedstock value and support the production of sustainable fuels
- Environmental, Economic, Social sustainability analysis
- Joint R&D activities on Plastics Chemical Upcycling and Design within BOTTLE

2020
- MSW Fractionation

2021
- MSW Characteriz-ation and Tool Development

2022
- MSW Preprocessing and Sustainability

3-YEAR MSW FOA CAMPAIGN: AWARD RECIPIENTS

FY20: Subtopic 2A – Advanced Fractionation and Decontamination of MSW

FY21: Subtopic 1A – Measurement of variability of key MSW characteristics within and across unique MSW streams

Subtopic 1B – Development of novel methods for rapid/real-time measurements

FY22: Subtopic 1A – Advanced MSW Preprocessing for Conversion-ready Feedstocks

Subtopic 1B – High Value Co-product Development from MSW

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NATIONWIDE DATABASE OF WASTE CHARACTERISTICS

An online, publicly available database

Two waste characterization concepts merged into a single source:

- Composition
- Characteristics

Harmonized data

Interactive, geospatial

Downloadable data, charts, maps

Users able to contribute and share data and products

Created with user in mind

Leverages existing data

	Remainder/Composite Plastic	Durable Plastic Products	Film/Wrap/Bags	S/EPS Product
Pacific	1%	2%	5%	1%
Rocky Mountain	2%	2%	5%	1%
Midwest	3%	2%	6%	1%
Southwest	3%	2%	6%	1%
Southeast	3%	2%	7%	1%
Northeast	3%	1%	6%	1%

CASCADIA CONSULTING GROUP: CREATING RESOURCE-SHED MSW MAPS – STARTING WITH EXISTING DATASETS

Methodology

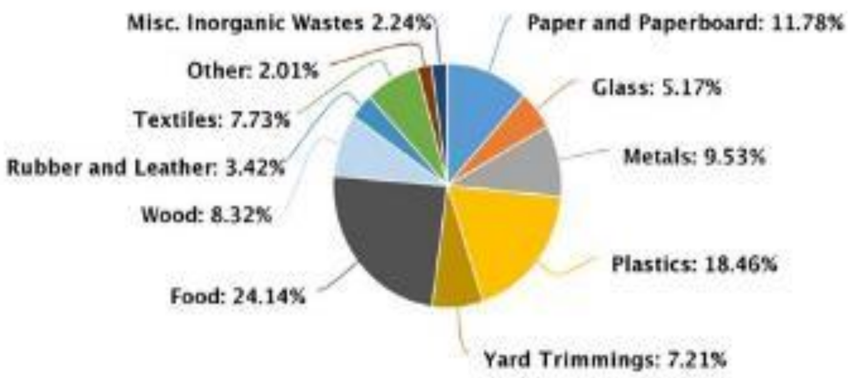
- Some studies would include this load since it's going to landfill
- Others would exclude since it was generated at a construction site

Data relevance

- Not enough/wrong categories
- Materials not size graded
- No measurement of heating values, variations in availability/freshness

Category compatibility

- Every study sorts samples into different categories.
- As we combine data sets, we lose granularity until the resulting data has so little detail that it no longer serves a useful purpose



# of Wood Material Types	Statewide	Largest City	Largest County	2nd Largest County	3rd Largest City	All Data Combined
1						
2						
3						
4						
5						
6						
7						

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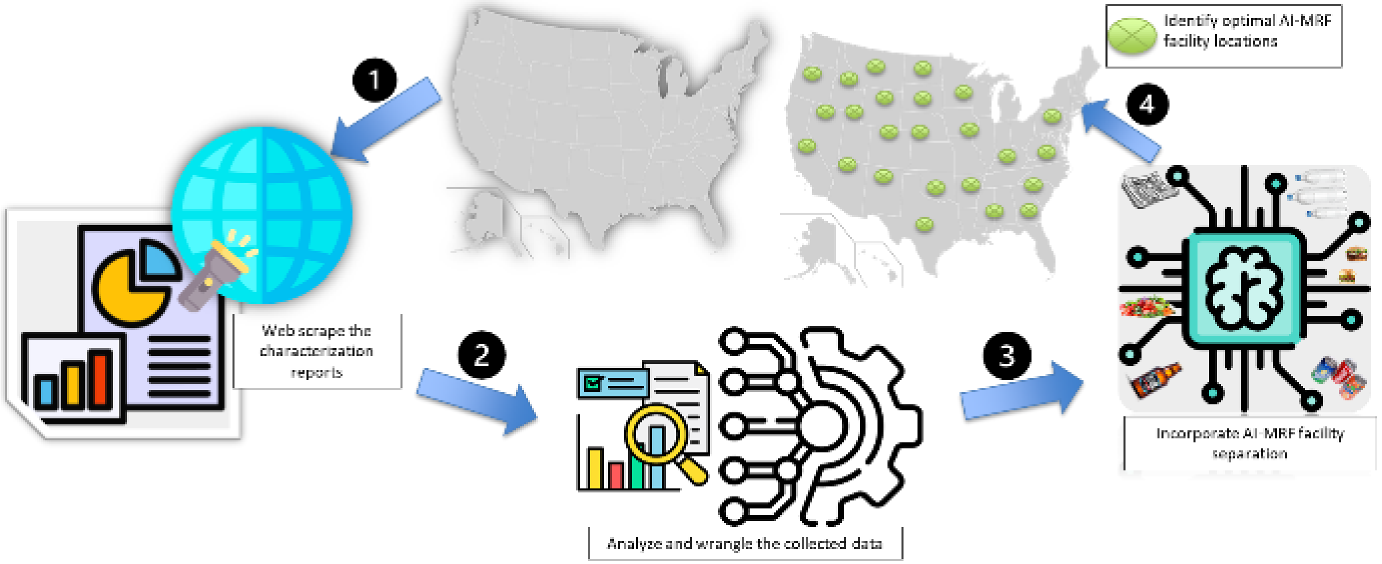
FOA: 0002423
AWARD: DE-EE0009666

CASCADIA CONSULTING GROUP

DEVELOPING ROBUST NMSW CHARACTERIZATION DATABASE FOR INTEGRATED ANALYSIS OF ECONOMIC, ENERGY, AND ENVIRONMENTAL IMPACTS TO FACILITATE PRODUCT VALORIZATION.

AI-Enabled Hyperspectral Imaging Augmented with Multi-Sensory Information for Rapid/Real-time Analysis of Non-Recyclable Heterogeneous MSW for Conversion to Energy

Control Number 2423-1501; Award Number: DE-EE0009669



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BIOENERGY TECHNOLOGIES OFFICE

NC STATE UNIVERSITY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

IBM

CARY LIVE INSPIRED

DATA COLLECTION SUMMARY

A total of 153 reports were collected via web scraping from 36 states, of which 67 reports contain NMSW waste composition data.

NC STATE UNIVERSITY

Total Reports Scraped - 153

Total States Reported- 46

States With NMSW Reports- 36

Reports with Category-Wise NMSW Composition Data- 67

Data Categories: Paper, Plastic, Metal, Textile, Glass, & Food.

Challenge 1: Lack of standardization in data formats.

- Solution: A standard format was created, and all data were transformed to conform to this format.

Challenge 2: Missing data in certain states.

- Solution: Performed data imputation using statistical and ML methods.

SYSTEMATIC CHARACTERIZATION OF VARIABILITY IN MSW STREAMS TO IDENTIFY CRITICAL MATERIAL ATTRIBUTES FOR FUEL PRODUCTION

Mapping and valorizing trash from:

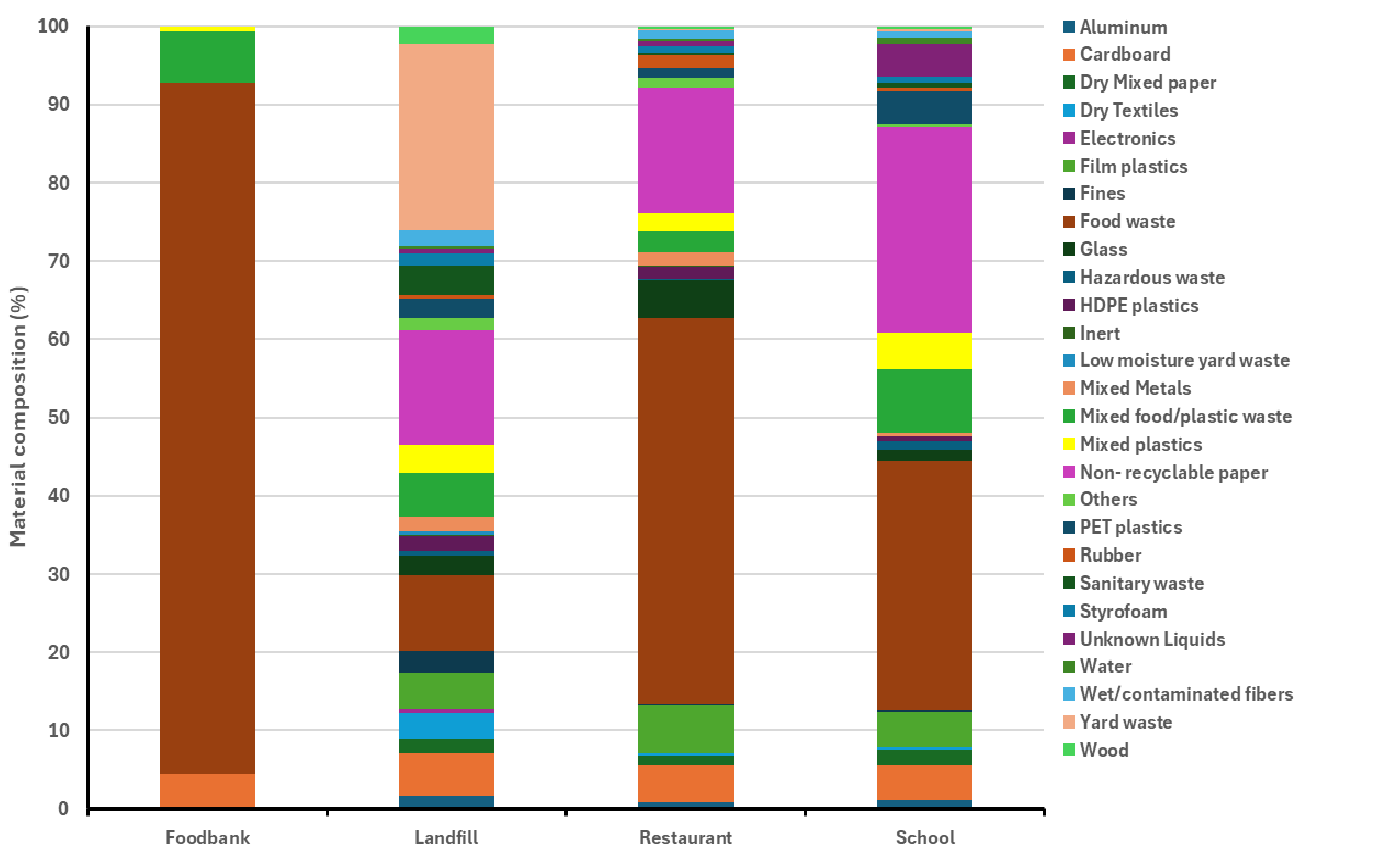
- Restaurants
- Schools
- Universities/Institutions
- Grocery Stores
- Landfills

Show the incentives for creating a circular bioeconomy

UNIVERSITY OF MARYLAND

PI: Stephanie Lansing, University of Maryland

MSW MATERIAL COMPOSITION DIFFERS ACROSS SOURCES



Foodbank had the highest % of food waste.

Restaurants had more food waste than schools.

Landfill had lowest % of food waste.

Landfill samples had the highest % of yard waste.

UNIVERSITY OF MARYLAND

CONCLUDING THOUGHTS ON VARIABILITY

A lot of work been/being done already

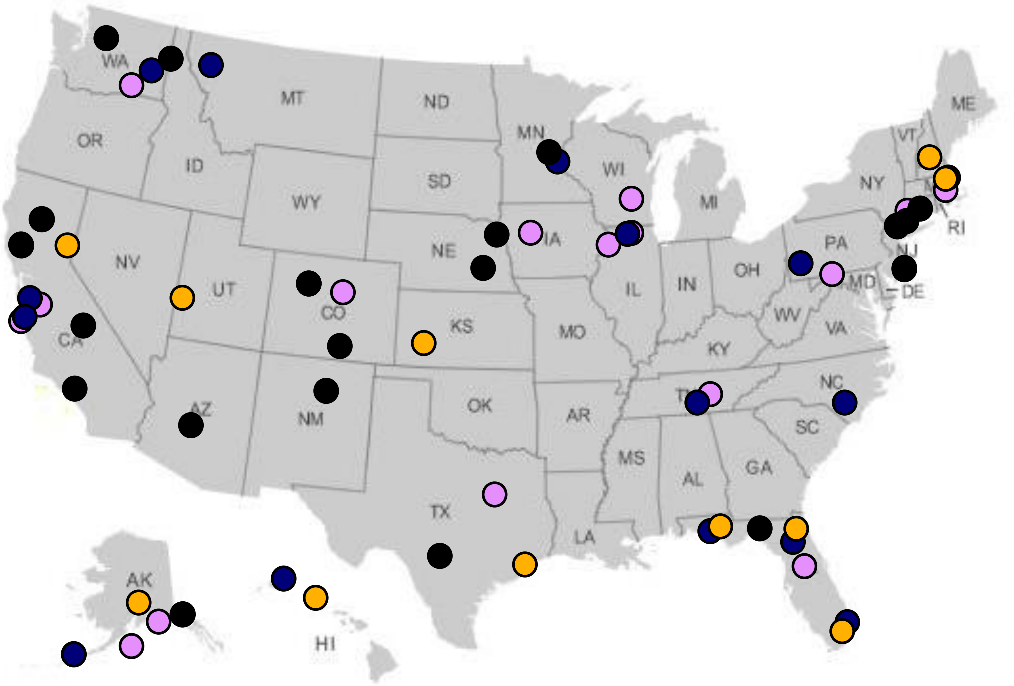
- Need to coordinate among entities to avoid repetition
- Need to coordinate methods and metadata to ensure interoperability
- Need to coordinate among government agencies to create the most logical combination of databases, ensuring crosstalk and longevity

Database(s) should always keep the user in mind

This is a work in progress and we're leveraging existing efforts as well as existing expertise in database development, design, and maintenance

TECHNICAL ASSISTANCE – LOCAL CONTEXT MATTERS

- **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**

COMMUNITY WASTE FOA SELECTEES AT A GLANCE

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

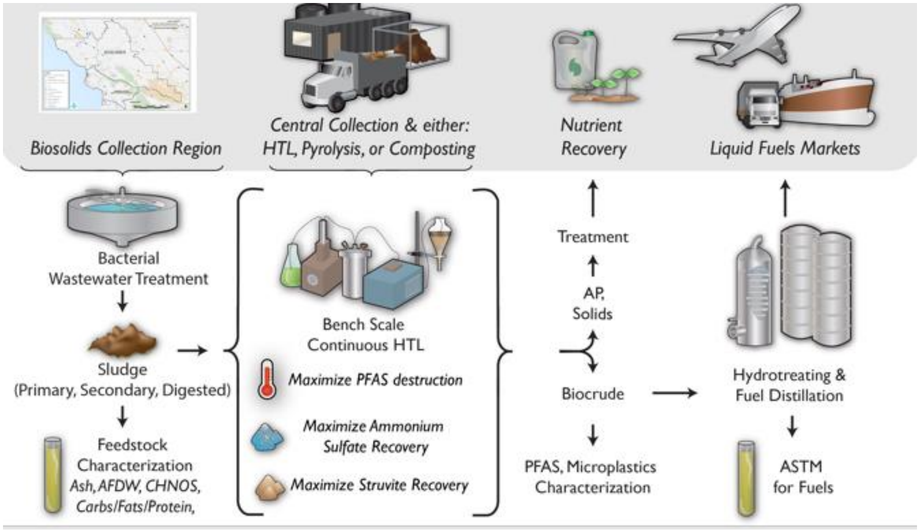
Project's Key Outcomes:

- Quantification and vetting of many environmental and social indicators
- Triple bottom-line siting analysis
- Long duration on-site demonstration of HTL system with other utilities and community members
- Evaluation of other regional wastes for utilization

COMMUNITY WASTE FOA SELECTEES AT A GLANCE

Upper Salinas Resource Conservation District

- California has ambitious organics diversion goals (>50% by 2025)
- Many wastes are currently being trucked out of state which has serious cost and environmental impacts



Project's Key Outcomes:

- Quantify the degree to which fluorinated species, microplastics, and other contaminants of concern are mitigated (>80% destruction)
- Establish plans for a centralized biosolids treatment nexus (involving many of the WWTs from the region)
- Complete a comparative siting and technology analysis of pyrolysis vs HTL vs anaerobic digestion vs composting

COMMUNITY WASTE FOA SELECTEES AT A GLANCE

Great Lakes Water Authority
Detroit, MI

Green Era

Town of Yarmouth, MA

National Rural Elec.
Coop Assn.

Upper Salinas – Las
Tablas Cons. District

City of Gainesville, FL

Peaks Renewables, P2G

Utilizes renewable hydrogen to convert carbon dioxide into renewable methane, water, and heat

Step 1, Renewable electricity generation:

Wind
Solar
Hydro
Ocean
Geothermal
→ e^-

Step 2, Electrolysis:

$$2\,H_2O + e^- \rightarrow 2H_2 + O_2 + Heat$$

Step 3, Biomethanation:

$$4\,H_2 + CO_2 \xrightarrow{Biocatalyst} CH_4 + 2H_2O$$

Project's Key Outcomes:

- Installation of a 700L bioreactor system, co-located at a dairy waste digester
- >1,000 hours of operation to produce pipeline quality biomethane
- Address pipeline congestion and wind energy curtailment challenges facing Maine

CONCLUDING THOUGHTS
COMMUNITY PARTNERING

Local context matters

- What are the problem waste stream(s)?
- What infrastructure is available?
- What problem are we trying to solve?
- Who defined the problem statement?

Communities have varying degrees of risk and risk aversion

And skepticism is growing

But transparency can go a long ways!

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Recent Technology Development Highlights

MSW Sorting
MSW Feeding
Hydrothermal Liquefaction

MSW SORTING – AMP ROBOTICS

- AMP Robotics has developed AI-powered technology and equipment for global waste and recycling companies
- The recycling industry's largest fleet of 345 AI units deployed in 80+ facilities in 8 countries across 3 continents
- AMP owns and operates 3 secondary processing facilities in the US (Denver, Cleveland, Atlanta)

AMP's AI computer vision systems and robots operating in a single- stream recycling facility

74B+

Objects Identified in 2022

50+

Material Categories

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AMP ROBOTICS™

MSW SORTING – AMP ROBOTICS

AMP Cortex ™
- 2-3x picking rate (80-120 picks/min) increase compared to manual sorting (40 picks/min)
- 99% sorting accuracy
- Can recognize up to 8 separate waste commodities

AMP Vortex ™
- Film and light density materials separation
- 120 picks/minute

Implementing a test at their Virginia sorting facility:
- Delivering multiple samples for gasification and pyrolysis testing
- Developing multi-modal sensor for waste-to-fuel material attributes

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AMP ROBOTICS™

MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

Feedstock properties vary and affect feedability

- Density
- Particle size and distribution
- Particle aspect ratios
- Moisture/contaminants
- Age and storage conditions
- Triboelectricity (static)

Gasifiers require robust solids handling capabilities to manage feedstock variability

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Idaho National Laboratory

Oak Ridge National Laboratory

NREL National Renewable Energy Laboratory

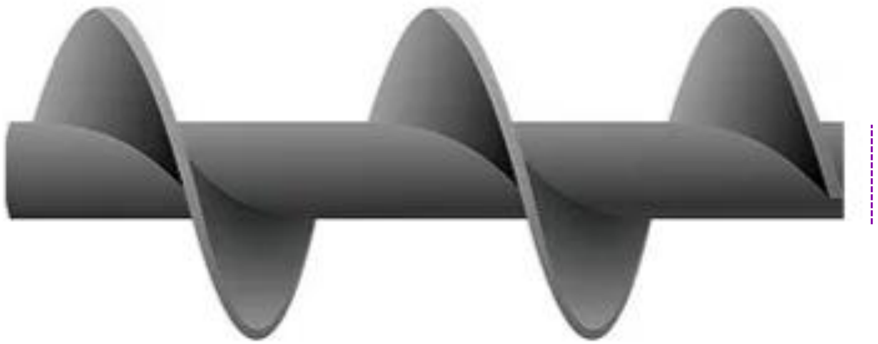
fcic Feedstock-Conversion Interface Consortium U.S. Department of Energy

MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

Screw Convery Design Parameters

Goals:
1. Increase **fill volume**
2. **Spread** material to facilitate feeding
3. Maintain adequate **strength**

Standard Flight; Shaft Diameter



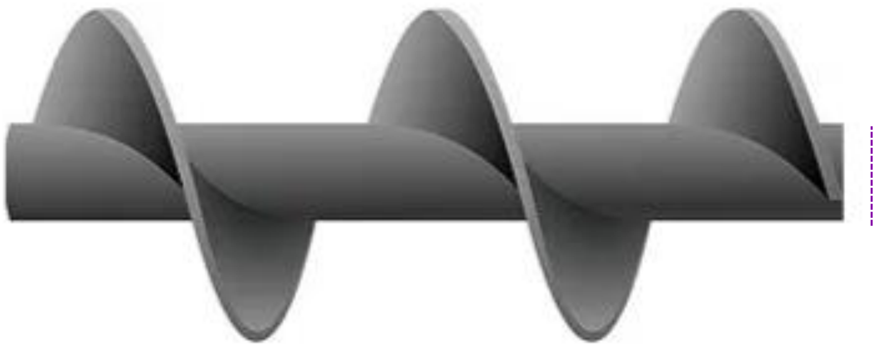
MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

Screw Convery Design Parameters

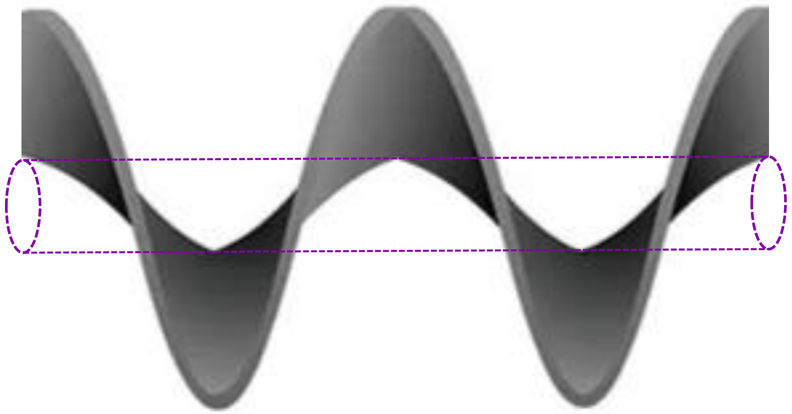
Goals:
1. <u>Increase **fill volume**</u>
2. **Spread** material to facilitate feeding
3. Maintain adequate **strength**

- Shafted or shaftless design
  - Shaft/void diameter
- Constant or variable pitch; how variable?
- Pitch spacing and pitch width

Standard Flight; Shaft Diameter

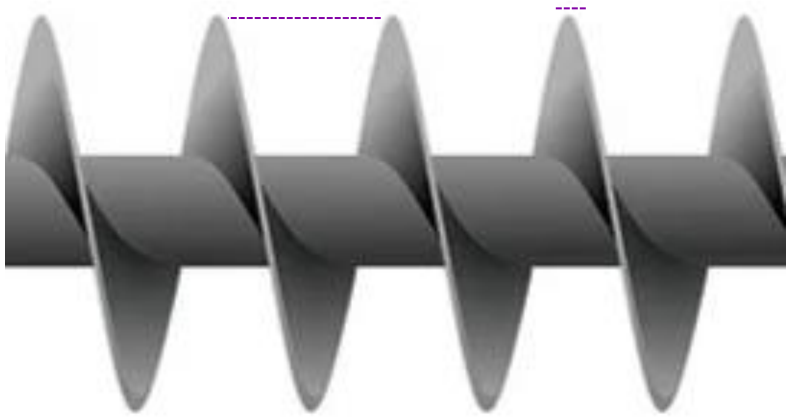


Shaftless; Void Diameter



Variable Pitch

Pitch Spacing and Width



MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

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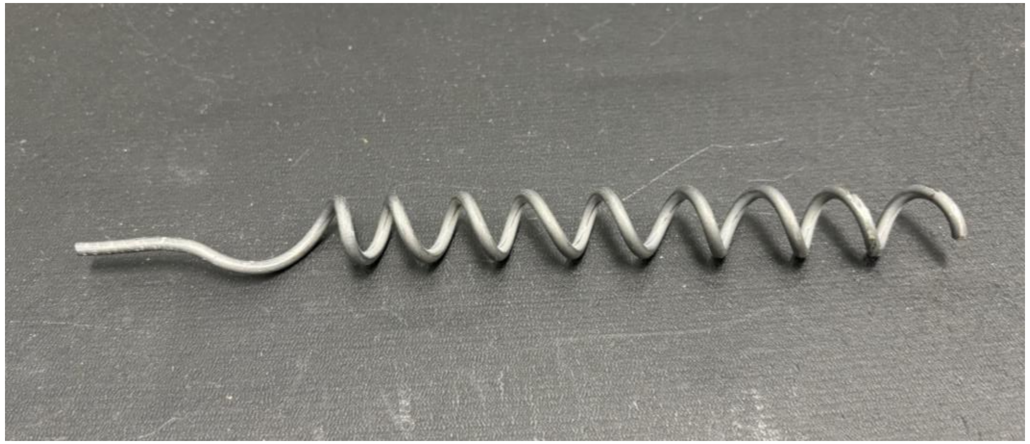
Variable Pitch: Shafted and Shaftless

Variable pitch **with shaft** – 1/8” flight

Never clears feed

Shaftless Variable Pitch – 1/8” flight



Feed clearing time = 60-70 s

The **shaftless design** is more effective at conveying post-MRF feedstock

Use a shaftless design

MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

Shaftless, Constant Pitch, 3D-Printed Screws

1/8” flight
0” shaft void dia.
5/8” flight spacing

Feed clearing time = 15-20 s

1/8” flight
1/4” shaft void dia.
5/8” flight spacing

Feed clearing time = 15-20 s

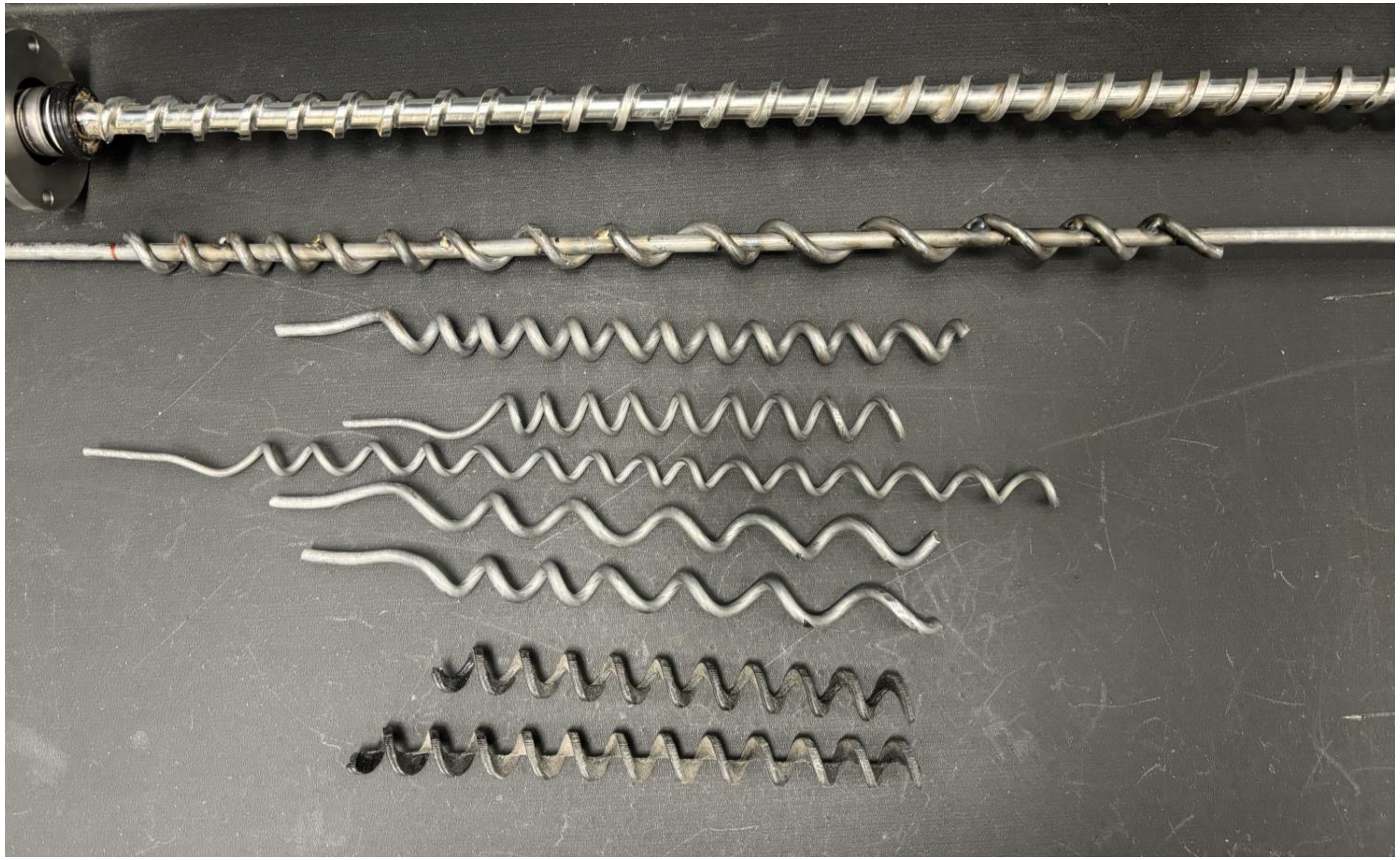
Target clearing time ~16 s

The square edges convey material more effectively than round edges
No significant difference between no void and ¼” void diameter

Balance void diameter with screw shear strength

MSW FEEDING – BETO FEEDSOCK CONVERSION INTERFACE CONSORTIUM

- Prototyped and tested relevant screw design parameters to determine most important factors for feeding post-MRF material:
  - Shaftless
  - Constant pitch
  - Narrow pitch distance
  - Minimum pitch width and void diameter dependent on strength
- Achieved targeted feed clearing time of 15-20 seconds



Daniel.Dupois@nrel.gov

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Oak Ridge National Laboratory

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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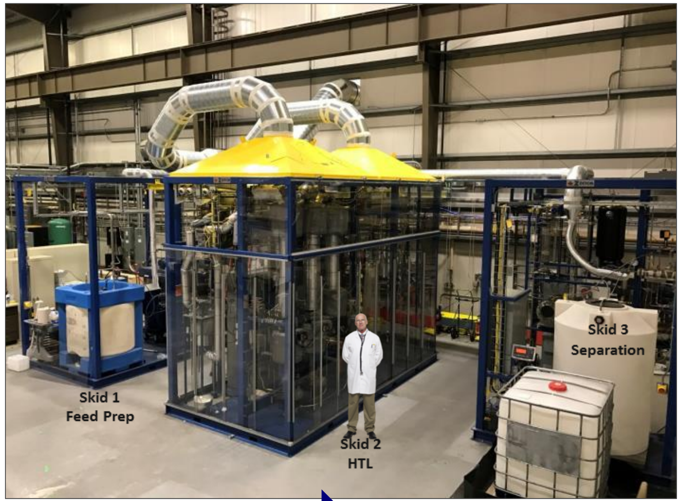
HYDROTHERMAL LIQUEFACTION – PACIFIC NORTHWEST NATIONAL LABORATORY

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

The Water Research Foundation www.werf.org

leidos

WPI

Princeton University

Washington State University

Pacific Northwest National Laboratory

metrovancouver

UC Riverside University of California

Massachusetts Institute of Technology

Illinois

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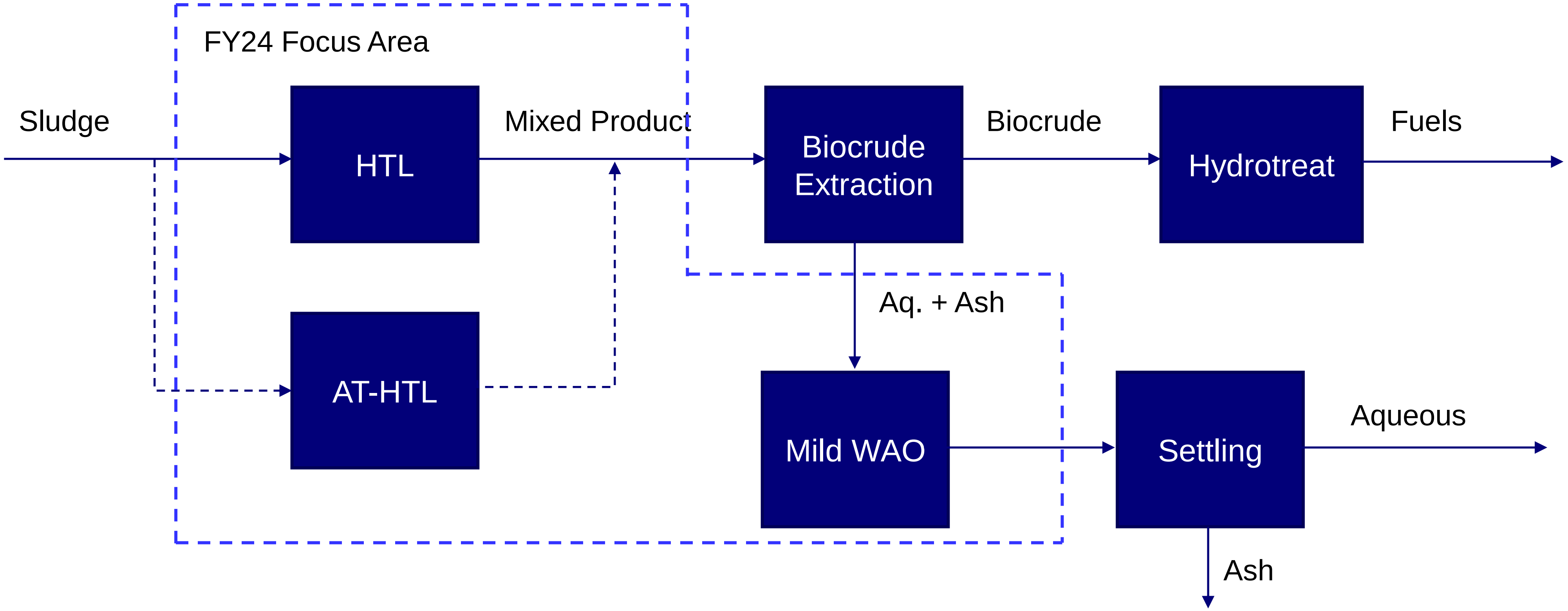

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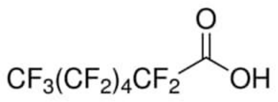
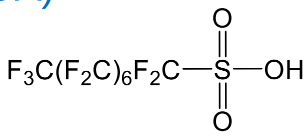
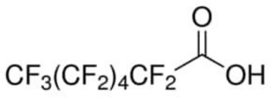


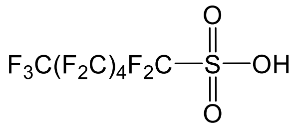
Perfluorooctanoic acid (PFOA)



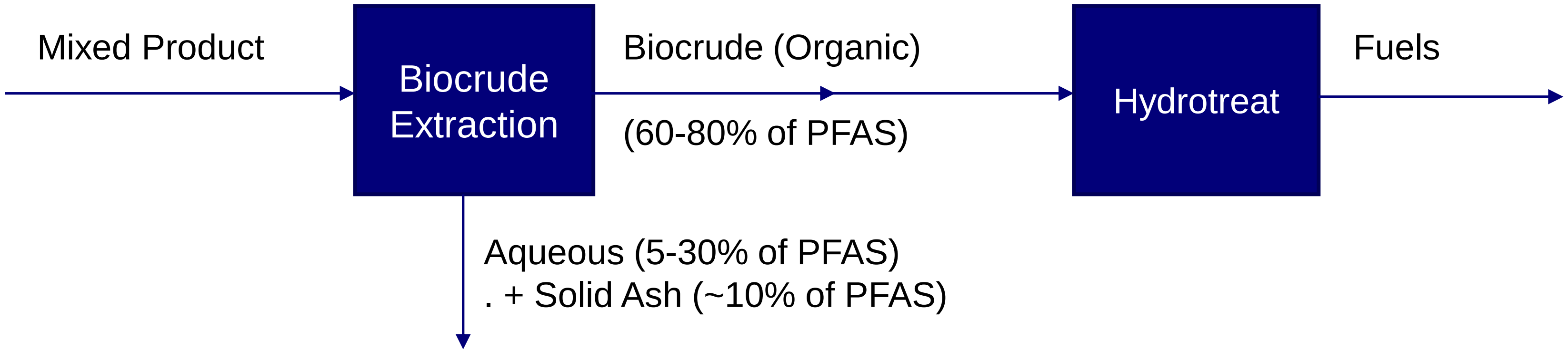
Perfluorooctanesulfonic acid (PFOS)



Perfluoroheptanoic acid (PFHpA)



Perfluorohexanesulfonic acid (PFHxS)*



>10,000x reduction in PFAS/PFOS chemicals through hydrotreating (3 spiked samples)

As reported:

Sample	PFOA	PFOS	PFHpA	PFHxS
Feed Slurry (GWT24) solid 2*	7.51 ppm	5.39 ppm	8.48 ppm	0.12 ppm
Solids	-	5.51 ppm	-	0.19 ppm
Biocrude product	0.041 ppm	48.5 ppm	0.018 ppm	1.25 ppm
Aqueous product	165 ppt	111 ppb	188 ppt	7.91 ppb

There was no detection in the product water sample and main catalyst bed sampl

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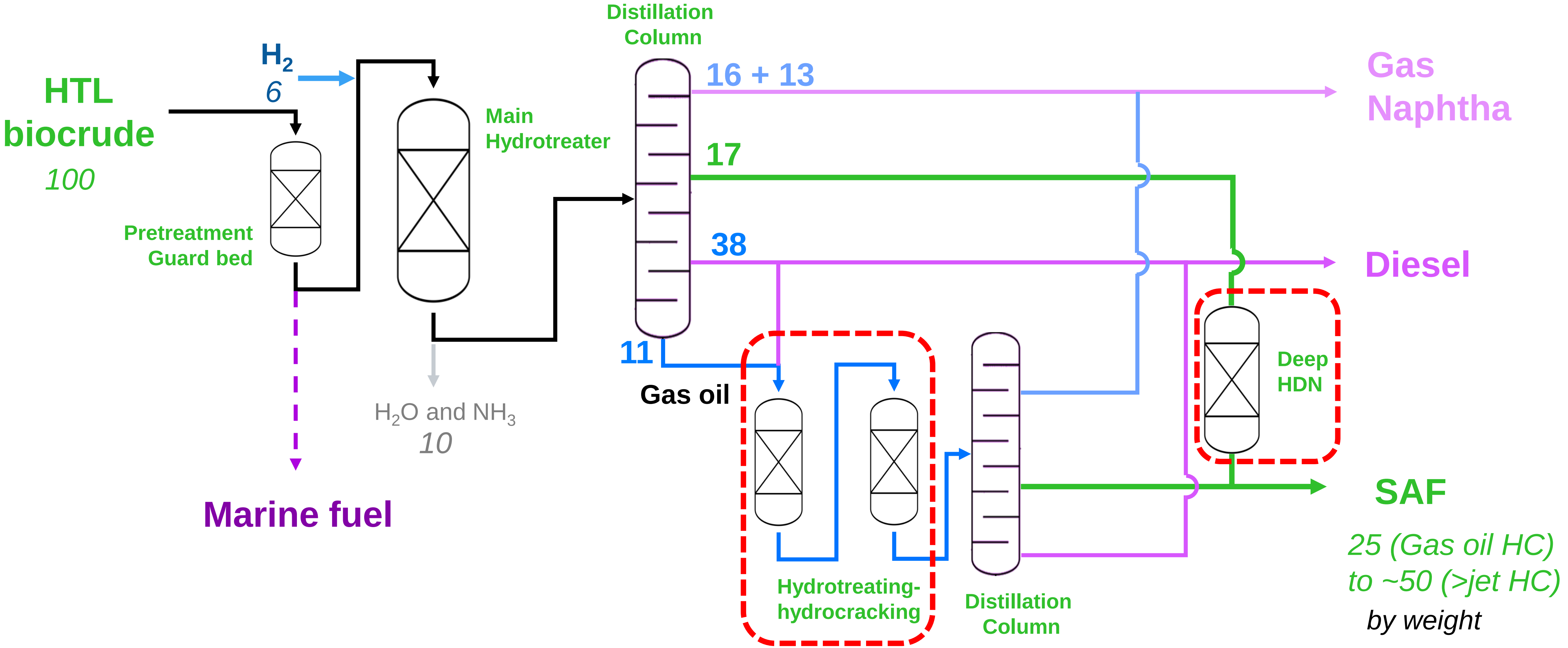

Additional hydroprocessing steps, including deep HDN and hydrocracking, are required for maximizing SAF yield and meeting SAF specification

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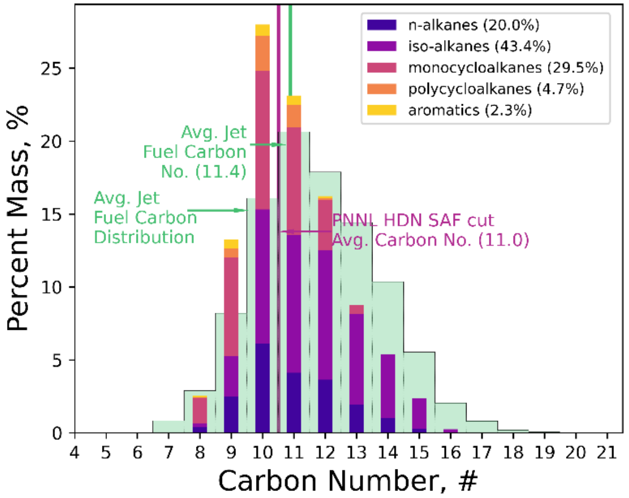

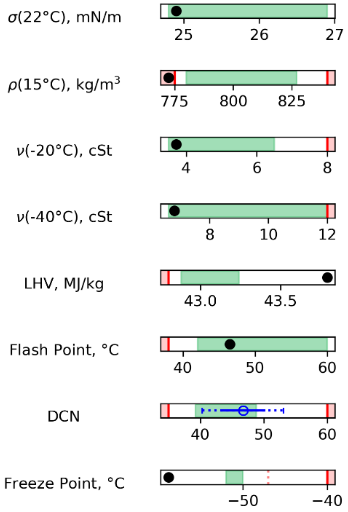

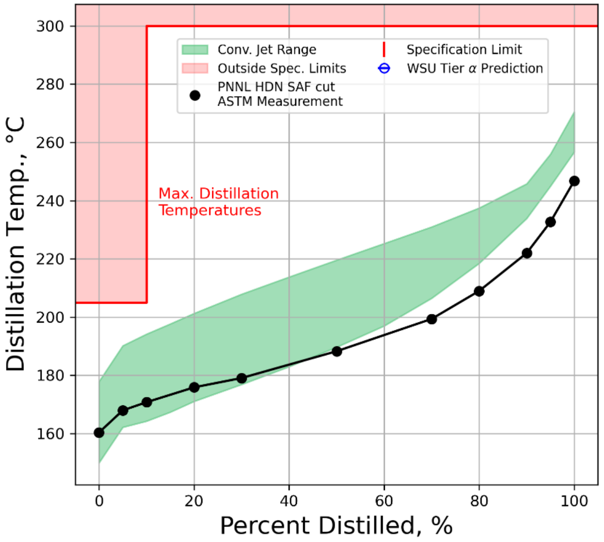

Jet Fuel Thermal Oxidation Test

- Deep HDN confirmed, <0.1 ppm N
- Properties either within or better than the conventional fuel range based on Tier Alpha/Beta analysis
- Preliminary TEA indicated an anticipated additional processing cost of <$0.05/gal for deep HDN
- ***Next:*** thermal stability analysis at higher N
  >1,000 HDN catalyst test

Huamin.Wang@pnnl.gov
Michael.Thorson@pnnl.gov

Pacific Northwest NATIONAL LABORATORY

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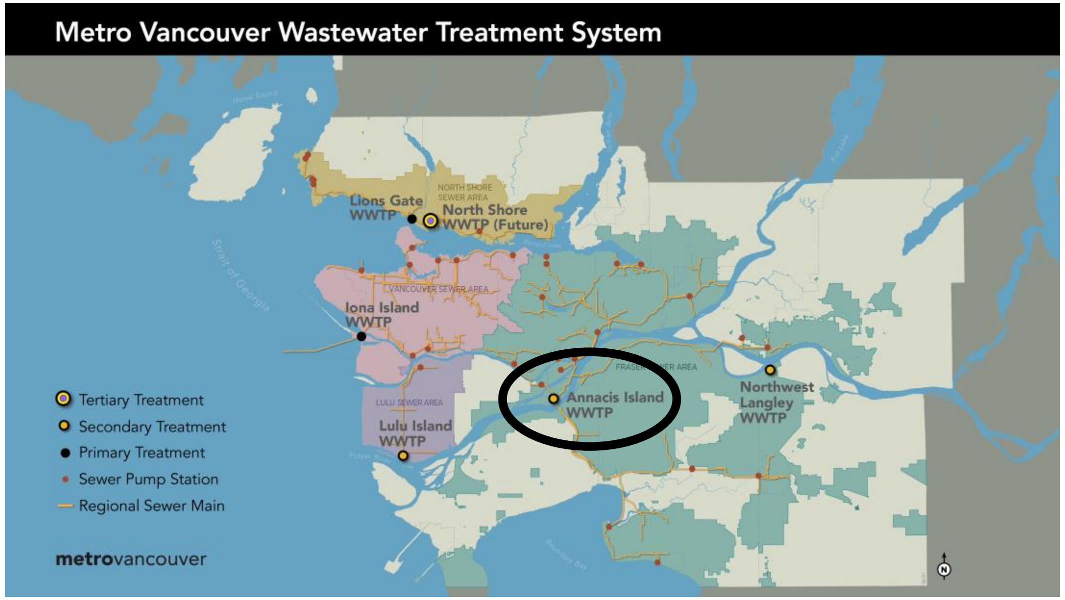

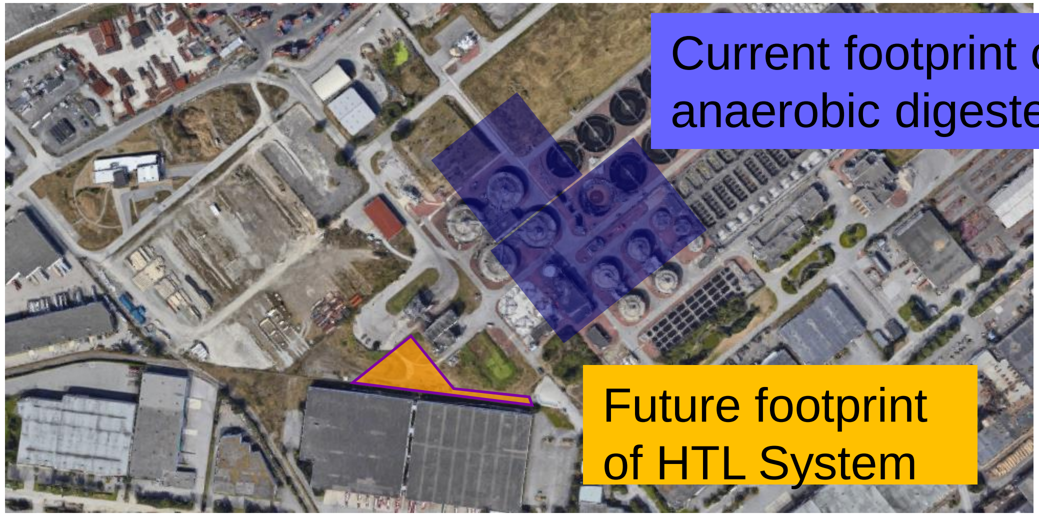

Current footprint of solids storage/ anaerobic digesters

Future footprint of HTL System

Sludge feed
10 wet tonnes or
2 dry tonnes/day

Hydrochar
300 kg/day

Biocrude
750 L/day

Aqueous
8,000 L/day

Estimated CI reductions of >85%

metrovancouver

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Questions?

Beau Hoffman

Beau.Hoffman@ee.doe.gov

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