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Challenges and Opportunities for Wet-Waste Feedstocks – Resource Assessment

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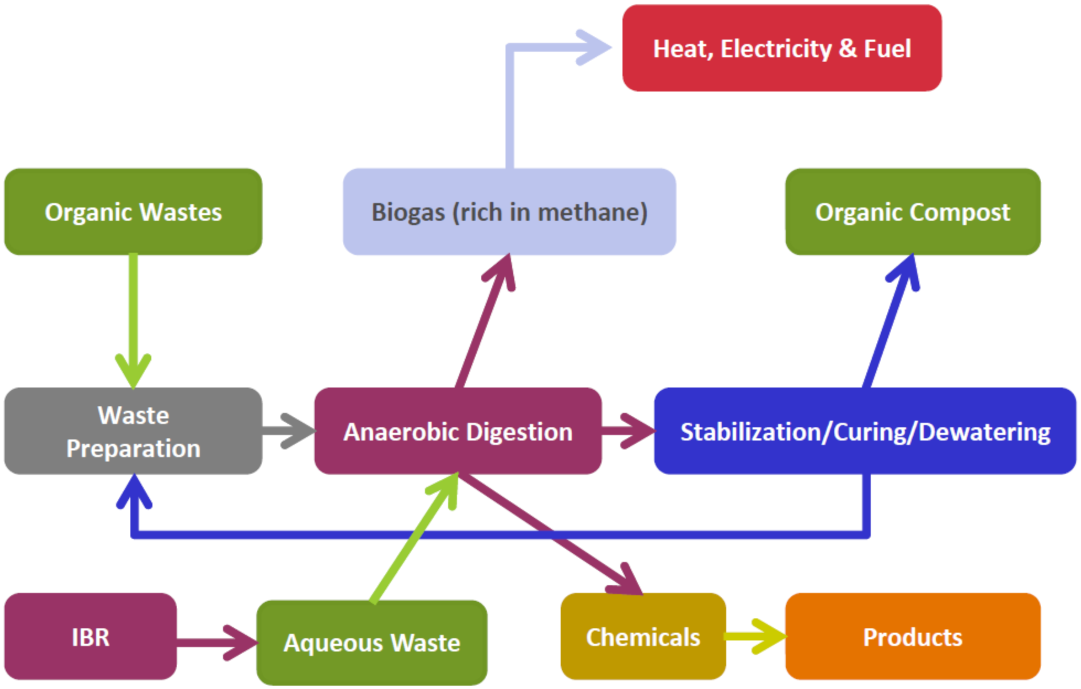
BETO Waste-to-Energy Efforts

There is a significant near-term market entry opportunity to develop WTE technologies in the U.S., specifically with regard to anaerobic digestion at landfills to recycle organic waste biomass into renewable energy, thereby enabling a national network of distributed power and biofuel production sites.

Waste-to-Energy Cycle



Waste streams that could be considered for use include:

- Municipal solid waste
- Landfill gas
- Waste streams from waste water treatment plants (WWTPs)
- Bio-solids (from thermochemical or biochemical biofuel pathways)

*From presentation by Jonathan Male at Waste-to-Energy Workshop on 11/05/2014

Resource Assessment Approaches – MSW

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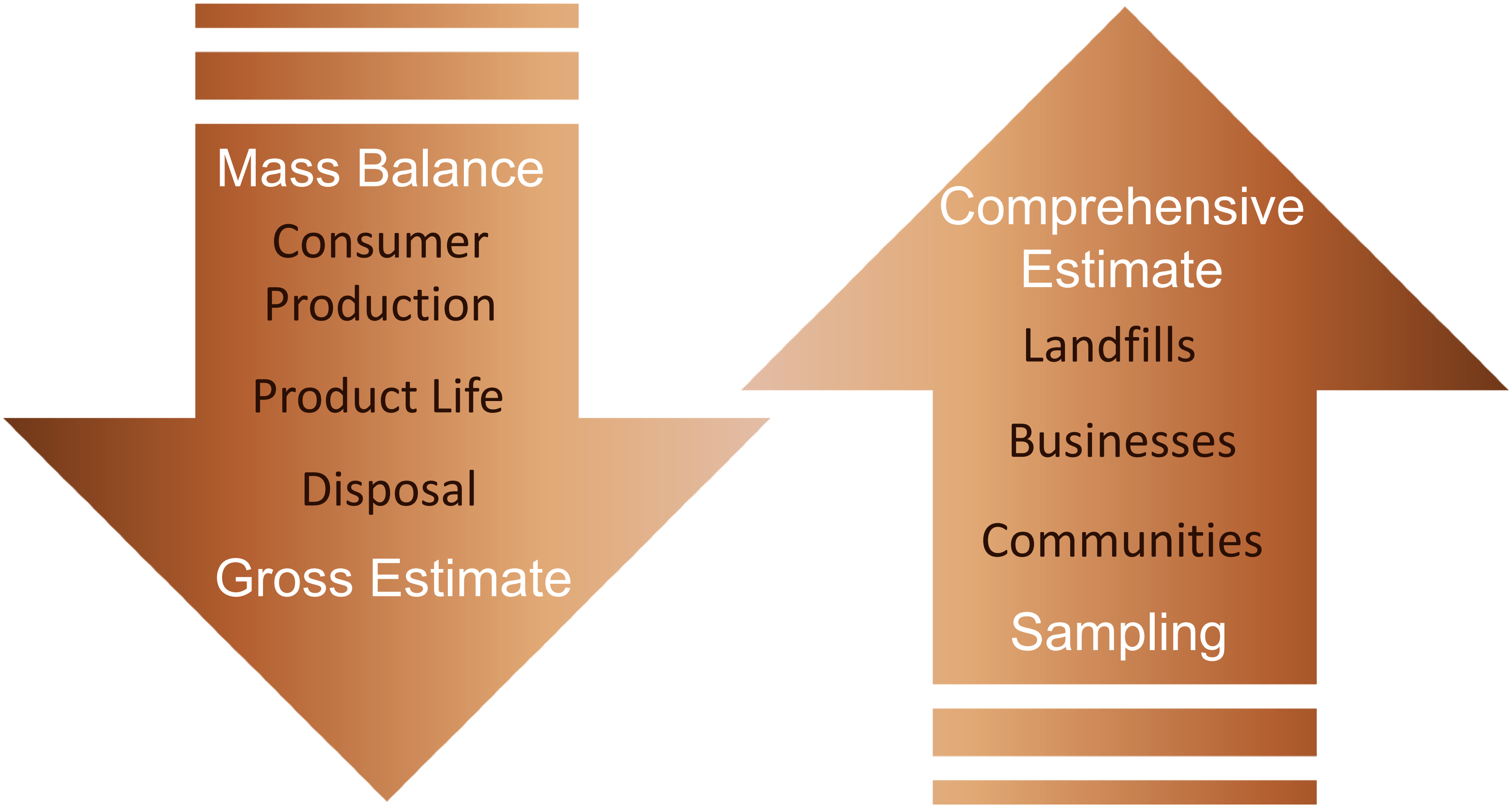


Top-down
(EPA Estimates)

Bottom-up
(Source-Specific)

MSW Top-Down Approach – Results

Materials	Mass Generated (MM sTon)	Percent of Total Generation
Paper and Paperboard	85.3	33.9
Glass	13.2	5.3
Metals		
Ferrous	14.2	5.7
Aluminum	3.26	1.3
Other Nonferrous	1.65	0.7
Total Metals:	**19.1**	**7.6**
Plastics	29.5	11.7
Rubber and Leather	6.54	2.6
Textiles	11.8	4.7
Wood	13.9	5.5
Other Materials	4.55	1.8
Total Materials in Products:	**164.79**	**73.2**
Other Wastes		
Food Scraps	31.3	12.4
Yard Trimmings	32.4	12.9
Miscellaneous Inorganic Wastes	3.72	1.5
Total Other Wastes:	**67.42**	**26.8**
Total MSW:	**251.31**	**100**

Franklin Associates, EPA 2007

Bottom Line

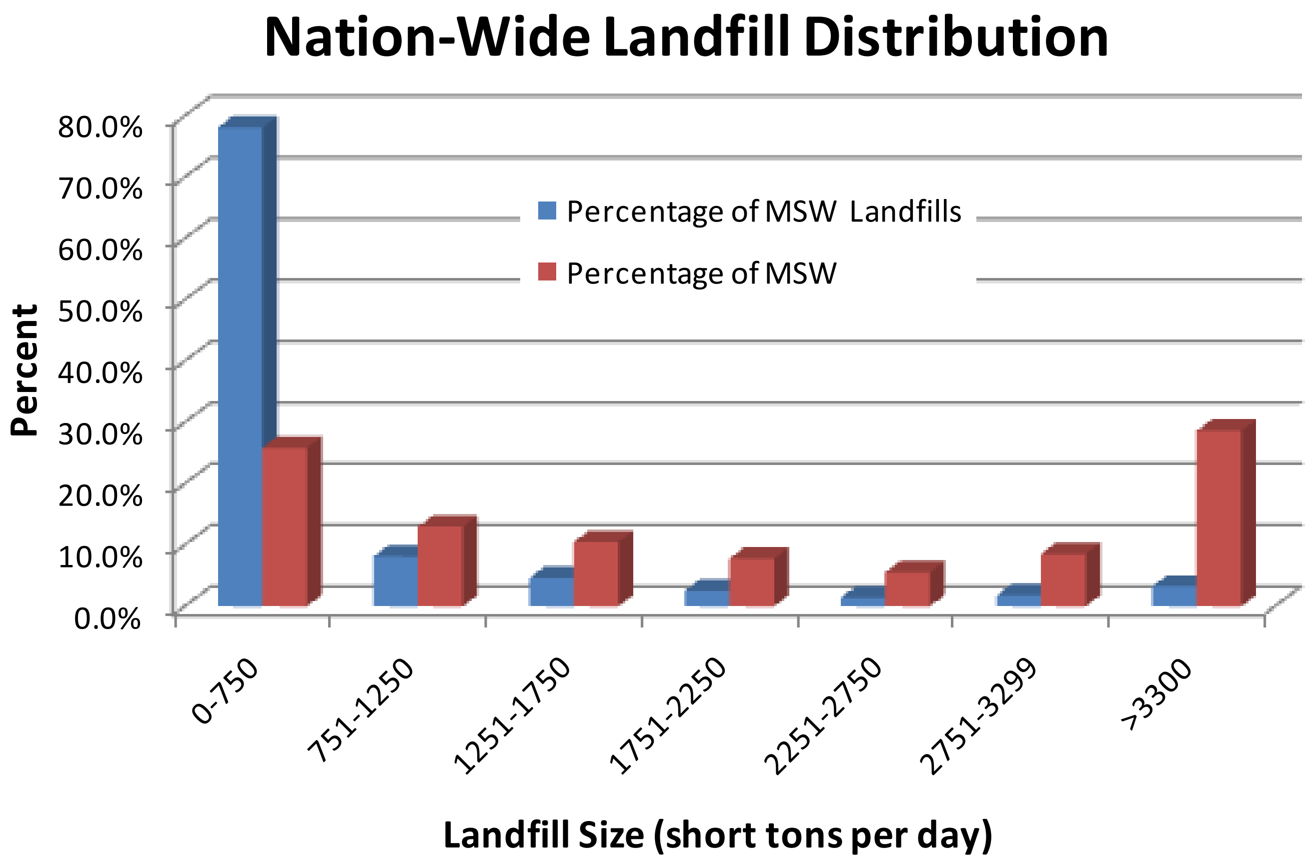
31 M stons →WTE

82 M stons →Recycled

138 M stons→ Landfill

MSW Bottom-Up Approach – Results

- Landfill site-specific data available in 44 states
  - Missing: Alaska, Kansas, Montana, Rhode Island, Wyoming, Florida
  - Result: 341 M stons (2006)



Why The Discrepancies?

- Bottom-up estimate (341 M stons) is more than 35% greater than top-down estimate total (251 M stons) and 147% greater than top-down estimated to be actually available (138 M stons)
  - Non-MSW
    - C&D debris
    - Agricultural residues
    - Biosolids: 20% of 8 M dry stons handled by landfills (EPA-530-R-99-009 1999, EPA-832-R-06-005 2006)
  - Estimation methods at landfill sites (scales, volumetric reporting)
  - Uncertainty of post-landfill diversions
  - Similar discrepancy in other studies (Simmons, 2006)
- Wet resources impacted by of spatial and seasonal variability

Site-specific resource analysis necessary for understanding potential

Site-Specific Resourcing & Conversion

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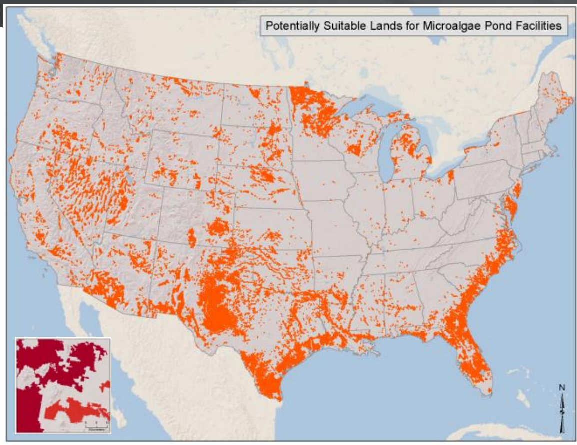
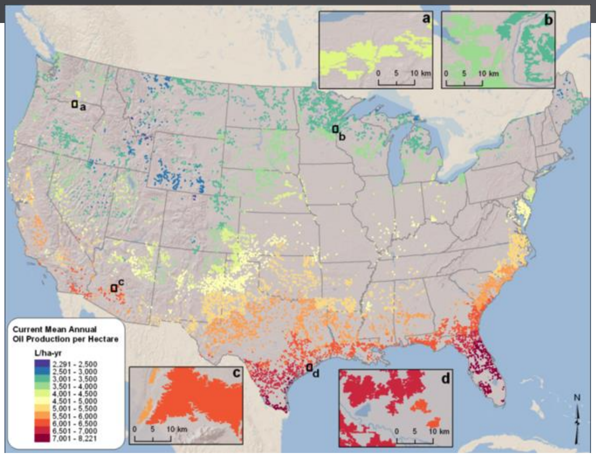
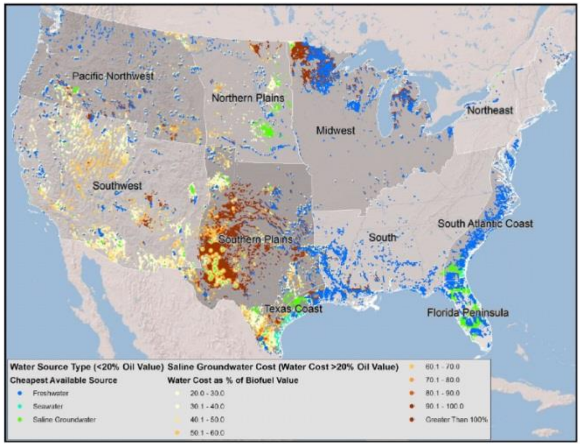


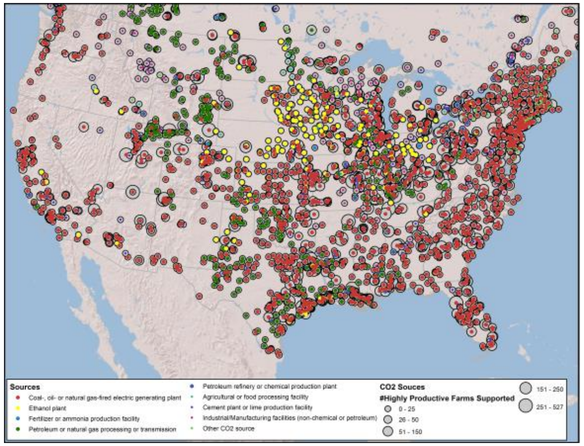
30 Years of Local Hourly Meteorology

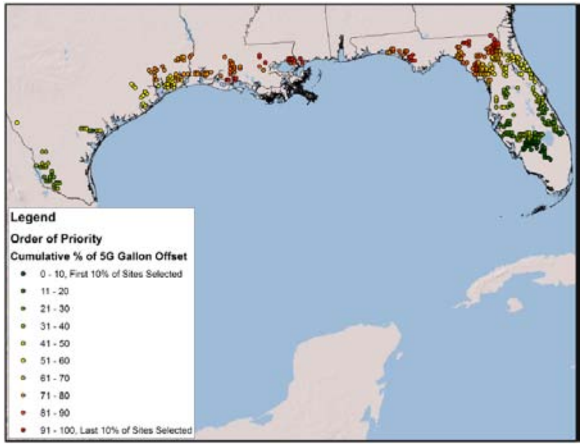
Land, Water, Infrastructure

Operational Costs –vs- Production



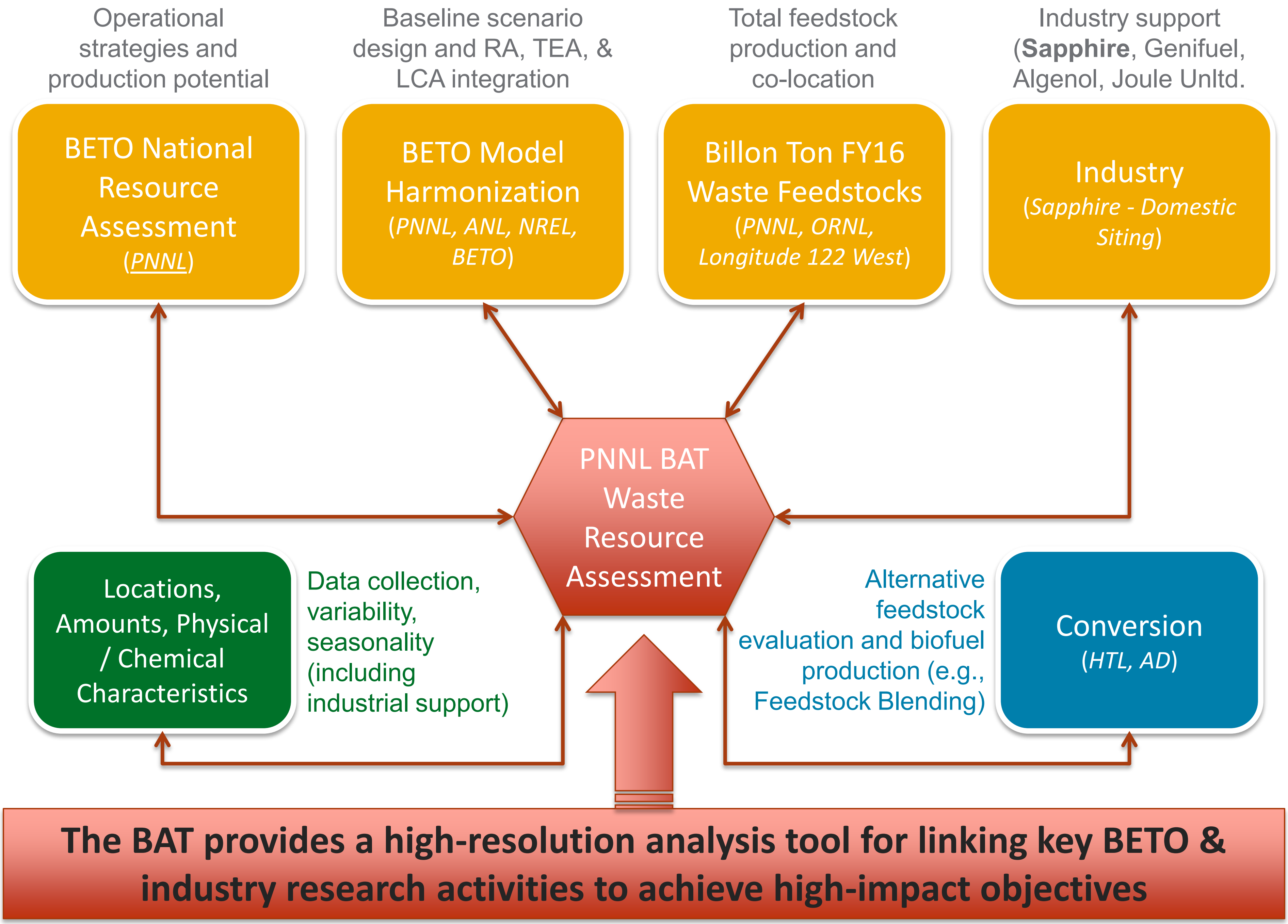






Biomass Assessment Tool (BAT)

Fine temporal and spatial scale for site potential, risks, and ranking



Operational strategies and production potential
Baseline scenario design and RA, TEA, & LCA integration
Total feedstock production and co-location
Industry support (**Sapphire**, Genifuel, Algenol, Joule Unltd.
BETO National Resource Assessment (PNNL)
BETO Model Harmonization (*PNNL, ANL, NREL, BETO*)
Billon Ton FY16 Waste Feedstocks (*PNNL, ORNL, Longitude 122 West*)
Industry (*Sapphire - Domestic Siting*)
PNNL BAT Waste Resource Assessment
Locations, Amounts, Physical / Chemical Characteristics
Data collection, variability, seasonality (including industrial support)
Alternative feedstock evaluation and biofuel production (e.g., Feedstock Blending)
Conversion (*HTL, AD*)
The BAT provides a high-resolution analysis tool for linking key BETO & industry research activities to achieve high-impact objectives

Alternative Feedstock Evaluation and Biofuel Production (e.g., Waste to Energy)

Key Risk for Algal Biomass Production: Spatial/Temporal Variability

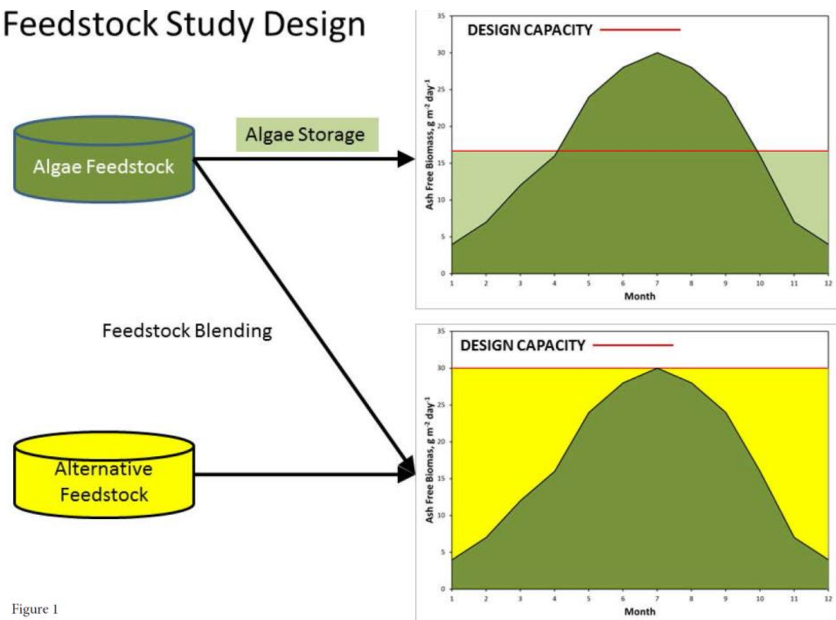


Figure 1

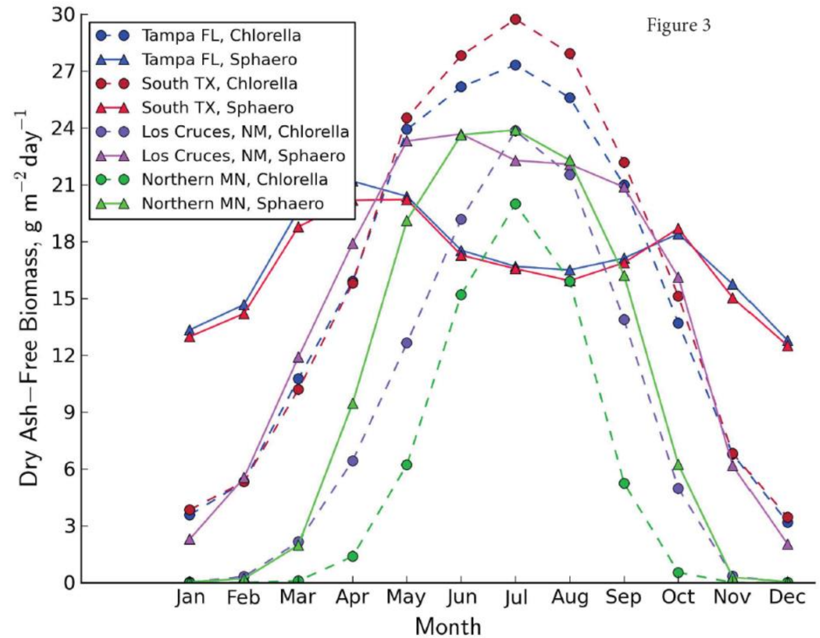


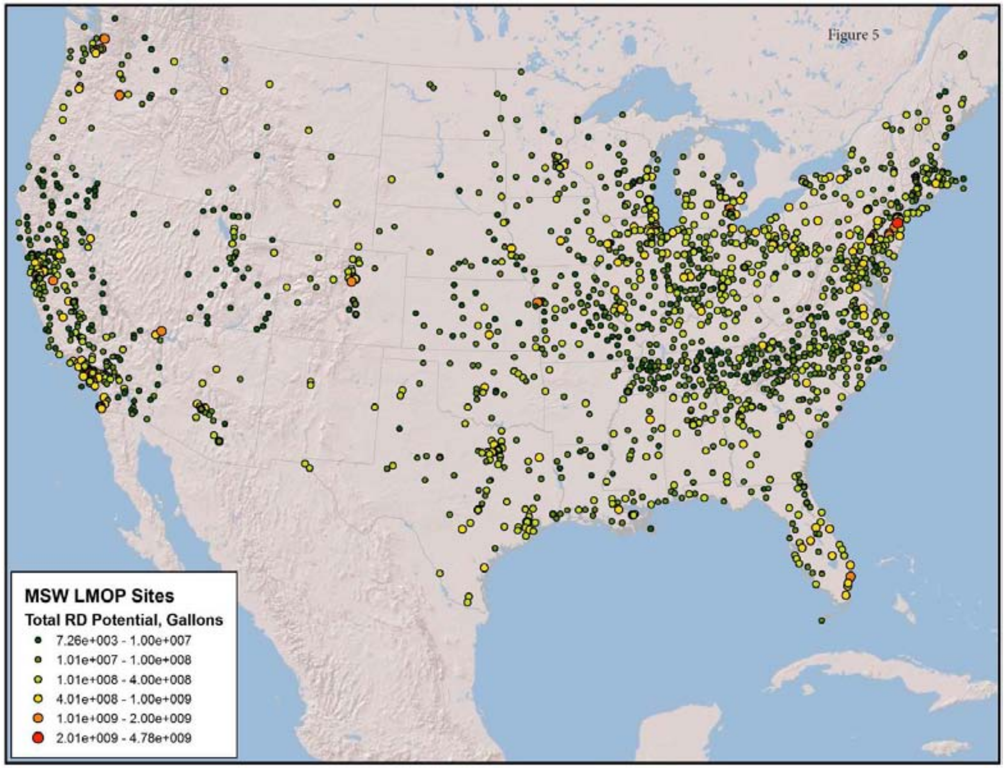
Figure 3

- Regional, seasonal, and short term algal production variability introduce considerable inefficiency and uncertainty to algal biofuel enterprise design and operations.
- Blending w/alternative feedstocks having superior storage and transportation properties (MSW, Biosolids, animal manure, etc.) offers potential for stabilizing feedstock throughput.

First Step: Broadly Assess Potential for Blending of Individual Feedstocks

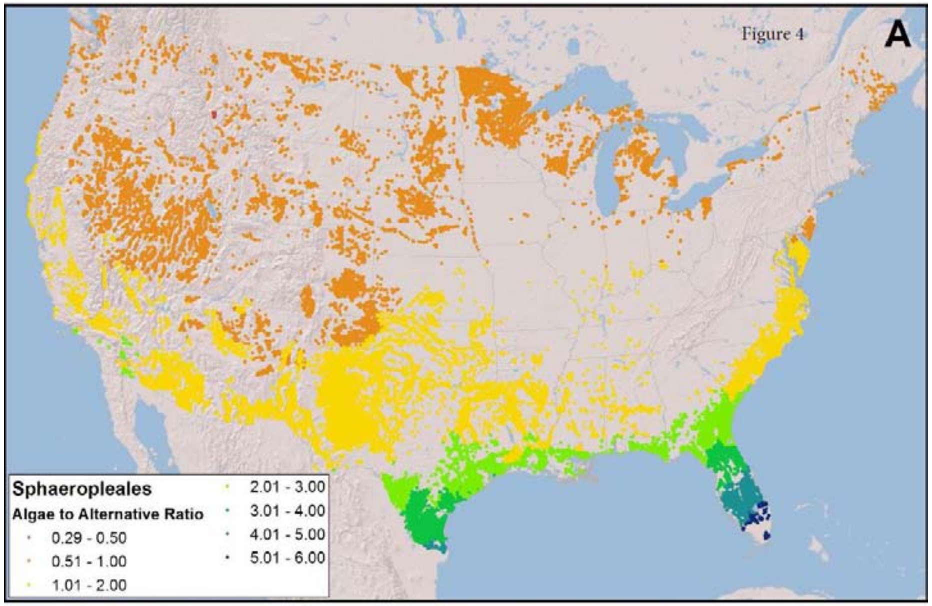
Municipal Solid Waste

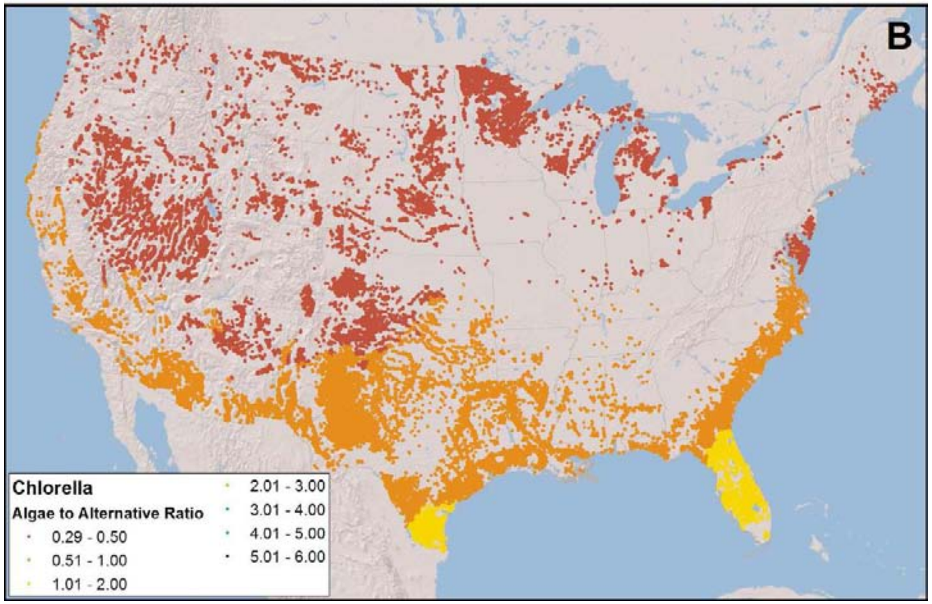
- Two Sources
  - Legacy (in-place waste)
  - Collections
- Multiple components w/high carbon content (e.g., paper, wood, yard and food waste)
- Challenge:
  - Sorting and pre-processing
- Analysis:
  - EPA Landfill Methane Outreach Program (LMOP)
  - 2,235 landfills were generally geo-located



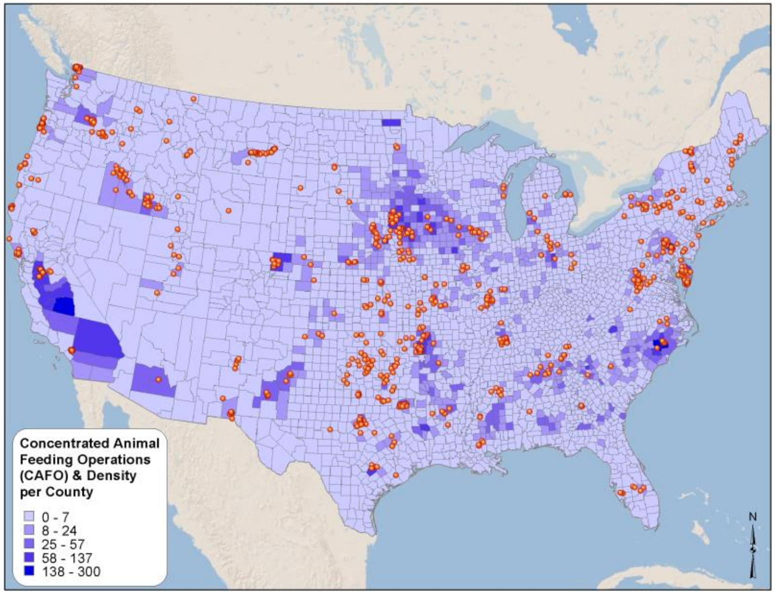
Algae – MSW Feedstock Blending Opportunity

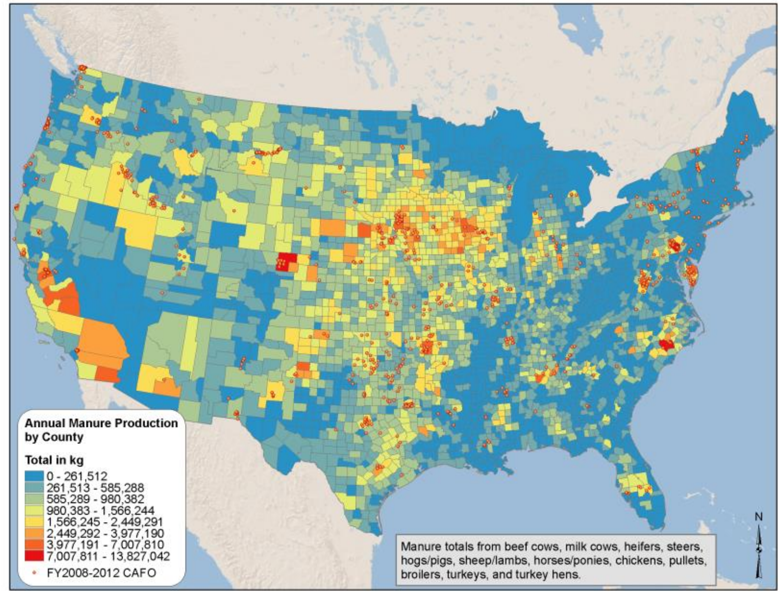
- Specify processing design capacity at maximum monthly mean algal production
  - Satisfy algal biomass shortfall via MSW
- *Sphaeropleales* with blending:
  - 15.2 BGY RD
  - Land requirement reduced by 34%
  - Slight decrease in water use
- *Chlorella* with blending
  - 16.9 BGY
  - Land requirements reduced by 50%
  - Water consumption reduced by 62%
- Reduction in nutrients

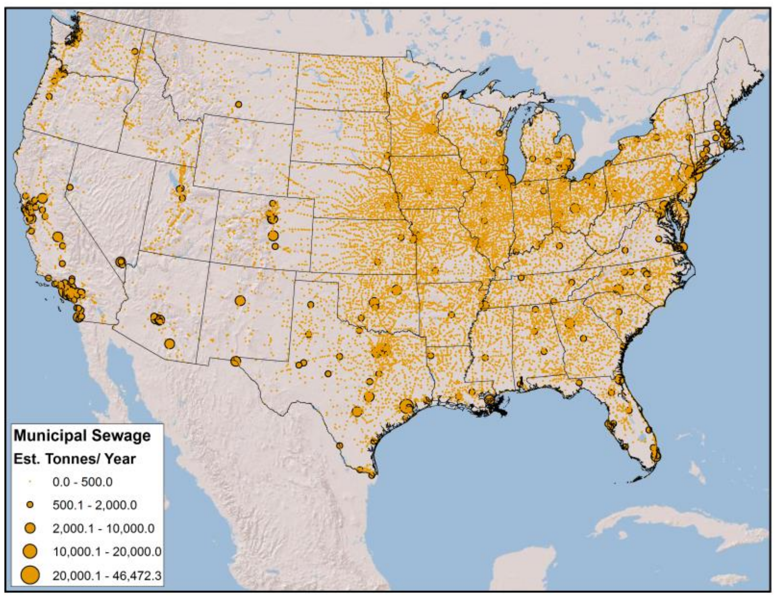




Other Candidate Feedstocks







Hydrothermal Liquefaction (HTL) Overview

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Hydrothermal Liquefaction (HTL)

- Conversion of a biomass slurry (e.g., wood, algae, other) to bio oil and aqueous product
  - ~ 350°C
  - ~ 3000 psig

Slurry Feedstock

HTL

Bio oil Product

+

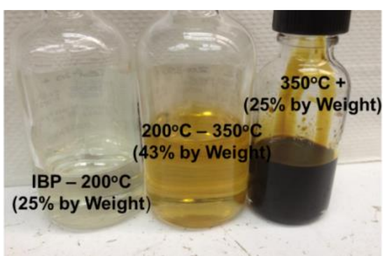
Aqueous Product (contains organics)

Current PNNL Efforts:

Bio oil product is refined via **Catalytic Hydrotreament** and fractionated by **Distillation** to gasoline, diesel, jet fuel, and bottoms

Catalytic Hydrotreatment

Catalytic Hydrothermal Gasification (CHG)



Fuel Fractions

Distillation

Hydrotreated Bio oil

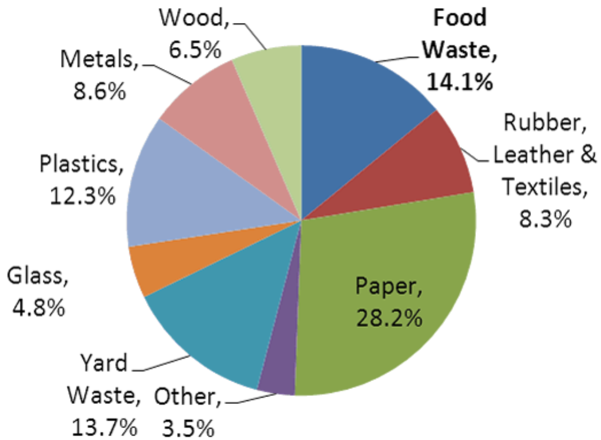
Clean Aqueous Product

Current PNNL Effort:

Catalytic Hydrothermal Gasification (CHG) may be used to convert aqueous product to medium BTU gas and clean water

Pairing Resources with Conversion – Hydrothermal Liquefaction (HTL)

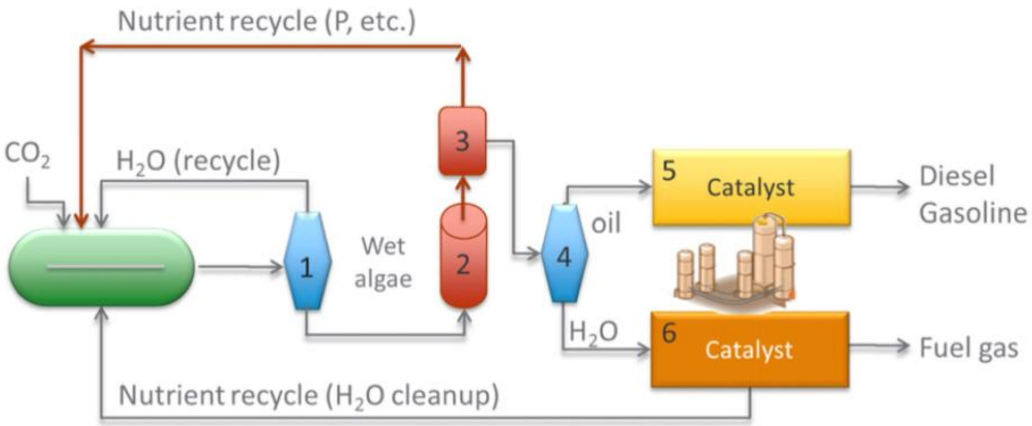
- Moisture Content
  - HTL requires feedstock to be 20% to 35% dry solids
  - Secondary sludge and algae can be as low as 2% dry solids
  - Typically need to dewater algae and biosolids in pre-treatment
  - Some MSW components can be relatively low in moisture content
    - Paper (6% ~34% of MSW), cardboard (5%), textile (10%), wood (20%)
  - Blending to achieve moisture content requirements can avoid the need for energy intensive dewatering (e.g., algae + paper + wood)
- Co-location can be designed to minimize transportation
  - HTL conversion + landfill + algae production + municipal biosolids



Source: Municipal Solid Waste in the United States: 2009 Facts and Figures, EPA

Additional Considerations

- Environmental sustainability potential
  - Reduced water and land impacts per unit biofuel
  - Nutrient recycling
  - Extended landfill life due to recycling
  - Reduced environmental N, P
- Considerable uncertainty
  - HTL conversion R&D is preliminary and has been limited to individual feedstocks
    - Conversion efficiency
    - Product quality
    - Residuals



Elliott et al., 2013 Process development for hydrothermal liquefaction of algae feedstocks in a continuous-flow reactor. Algal Research, 2(4):445-454.

What is the Opportunity?

= 2.7 billion barrels of oil equivalent per year

40% of our crude oil usage each year

What Are the Localized Scales?

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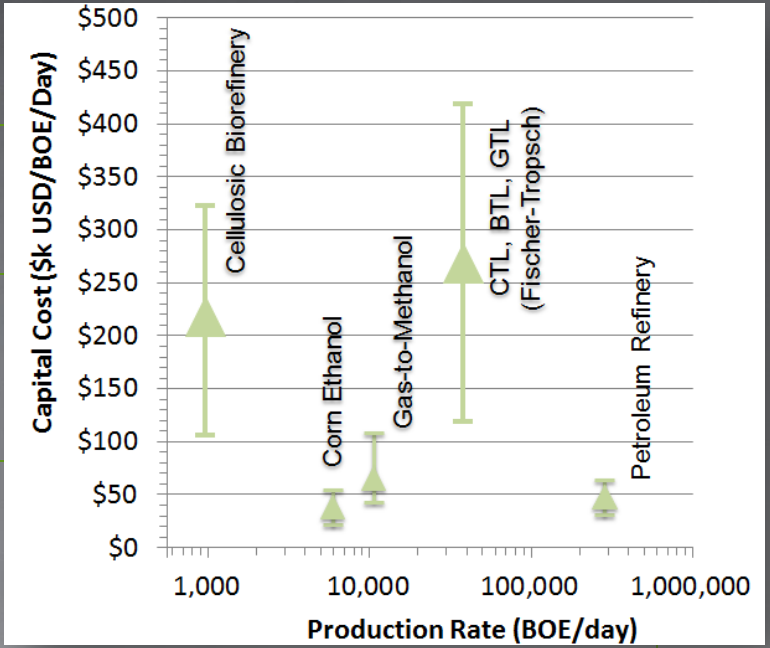
Envisioned local facility

Local sources of food, agricultural, and forest waste	2-20 BOE/D
Local sources of animal waste	4-150 BOE/D
CO_2 from dry mill	10-300 BOE/D
Local sources of municipal and industrial solid waste	70-1500 BOE/D

How Do We Get Cost-Competitive?

Goal

Goal is to achieve parity on capital cost on a per unit basis—$50k per (BOE/day)



Why can it be economical?

- Savings through mass production
- Risk reduction at small scale
- Low cost feeds
- New science and technologies that scale linearly with cost

Technologies that scale up often do not economically scale down

Acknowledgements

The BAT Team

- Rick Skaggs, André Coleman, Mark Wigmosta

The Wet Waste HTL Team

- Doug Elliott, Rich Hallen, Andy Schmidt, Justin Billing, Todd Hart, Gary Maupin, Karl Albrecht

And,

- John Holladay, Cynthia Jenks

Appendix

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History of HTL Technology

- Developed in 1930s for coal
- Developed in 1970s for biomass
- Albany, OR pilot-scale (1 ton/day) demonstration
  - Douglas fir chips
  - PERC – biocrude recycle with CO as reducing gas
  - LBL – aqueous process, acid pretreatment, no recycle, 18 wt% slurry
- Limited pilot-scale testing in US, Canada, and Europe
  - Shell HTU (1980s) – aqueous process, thermal softening, no alkali
- No commercial-scale HTL operations

PNNL has been at cutting-edge of HTL efforts for biomass conversion. It is now possible to develop efficient, scalable, affordable HTL systems.

NAABB-Reliance-PNNL-Genifuel

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Continuous 1 metric ton/day (40 L/hr) pilot HTL/CHG pilot system for algal feedstock; NAABB-Reliance-PNNL-Genifuel Hydrothermal System 2014

- 2012 - present
- NAABB leverages results from NABC
- One of several HTL piloting efforts with algae feedstocks

Approx Skid Dimensions:
16'(L) x 7'(W) x 8'(H)

RFS2 Language on Land Use

- From RFS2: 40 CFR 80.1401
  - Renewable biomass means each of the following (including any incidental, de minimis contaminants that are impractical to remove and are related to customary feedstock production and transport):
    (1) Planted crops and crop residue harvested from existing agricultural land cleared or cultivated prior to December 19, 2007 and that was nonforested and either actively managed or fallow on December 19, 2007.
    (2) Planted trees and tree residue from a tree plantation located on non-federal land (including land belonging to an Indian tribe or an Indian individual that is held in trust by the U.S. or subject to a restriction against alienation imposed by the U.S.) that was cleared at any time prior to December 19, 2007 and actively managed on December 19, 2007.
    (3) Animal waste material and animal byproducts.
    (4) Slash and pre-commercial thinnings from non-federal forestland (including forestland belonging to an Indian tribe or an Indian individual, that are held in trust by the United States or subject to a restriction against alienation imposed by the United States) that is not ecologically sensitive forestland.
    (5) Biomass (organic matter that is available on a renewable or recurring basis) obtained from the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, in an area at risk of wildfire.
    (6) Algae.
    (7) Separated yard waste or food waste, including recycled cooking and trap grease, and materials described in § 80.1426(f)(5)(i).

Feedstock Evaluation and Biofuels Production Potential (Waste-to-Energy)

Background
RA has demonstrated impacts of spatial and seasonal variability / uncertainty in feedstock production on biorefinery location, design, and operations.

Premise
Feedstock production risk (e.g., algae) can be mitigated by blending of multiple biomass sources coupled with a robust direct liquefaction biofuel conversion technology (e.g., HTL).

Guiding Questions

- What are critical conversion technology (e.g., HTL) feedstock requirements and limitations for prescribed products and co-products?
- What are critical physical/chemical characteristics for blending of algae, energy crops, and alternative feedstocks including MSW, biosolids, agricultural residues, forest resources pathways, and food processing waste?
- What regional/site-specific blends of alternative feedstocks are needed to meet sustainable throughput design specifications at a given biorefinery?
- Considering both spatial and temporal variability in feedstock production, where should biorefineries be located and at what scale to fully utilize feedstock resources to achieve biofuel production goals?
- What are the economic and environmental benefits and risk reductions derived from recycling waste materials for feedstock blending?