Analysis in Support of Biofuels and Bioproducts from Organic Wet Waste Feedstocks

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Waste-to-Energy
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2019 U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
Project Peer Review

Goal Statement

Goal: Develop conversion process design concepts and perform cost analyses to evaluate waste-to-energy opportunities to identify R&D needs and prioritization by BETO

Outcomes:

At the end of the project, we will have:

- Identified key performance targets and understand potential economic viability to assist R&D prioritization/decisions
- Investigated a broad range of wet waste conversion technologies for their economic and environmental sustainability potentials
- Utilized techno-economic analysis (TEA) and other cost assessment tools to study existing and novel process concepts on waste to fuels and chemicals conversion pathways

Relevance: WTE offers opportunities to reduce production costs of biofuels and bioproducts by converting cheap, readily available waste streams. In addition, WTE reduces landfills.

Quad Chart Overview

Timeline

- 10/1/2017
- 9/30/2020
- 40%

	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$200K	$400K

Partners: NREL (conversion platform analysis, strategic analysis), **ANL** and **PNNL** (data/info exchange, analysis tools)

Collaborators:

- ANL: 2.2.4.100 Arrested Methanogenesis for Volatile Fatty Acid Production
- NREL: 2.3.2.107 Separations in Support of Arresting Anaerobic Digestion
- NREL: 2.3.2.108 Reversing Engineering Anaerobic Digestion

Barriers addressed

At-A: Comparable, transparent, and reproducible analyses

At-B: Level analysis

At-C: Data availability across the supply chain

Objective

Explore and analyze three novel high economic potential WTE pathways to understand tradeoffs between utilization of wet organic feedstocks for biofuels and bioproducts versus existing practices for waste disposals

End of project goal

- Report economic potentials and specific process metrics to enable feasibility of WTE pathways
- Report key cost drivers to prioritize R&D directions
- Project a path forward to achieve BETO’s cost target for fuels and chemicals

1 - Project Overview

History:

- *Started in FY18 in response to 2017 BETO waste resource report on abundance of "underutilized waste resources"*
- *Started with the AD pathway in response to the peer review comments*

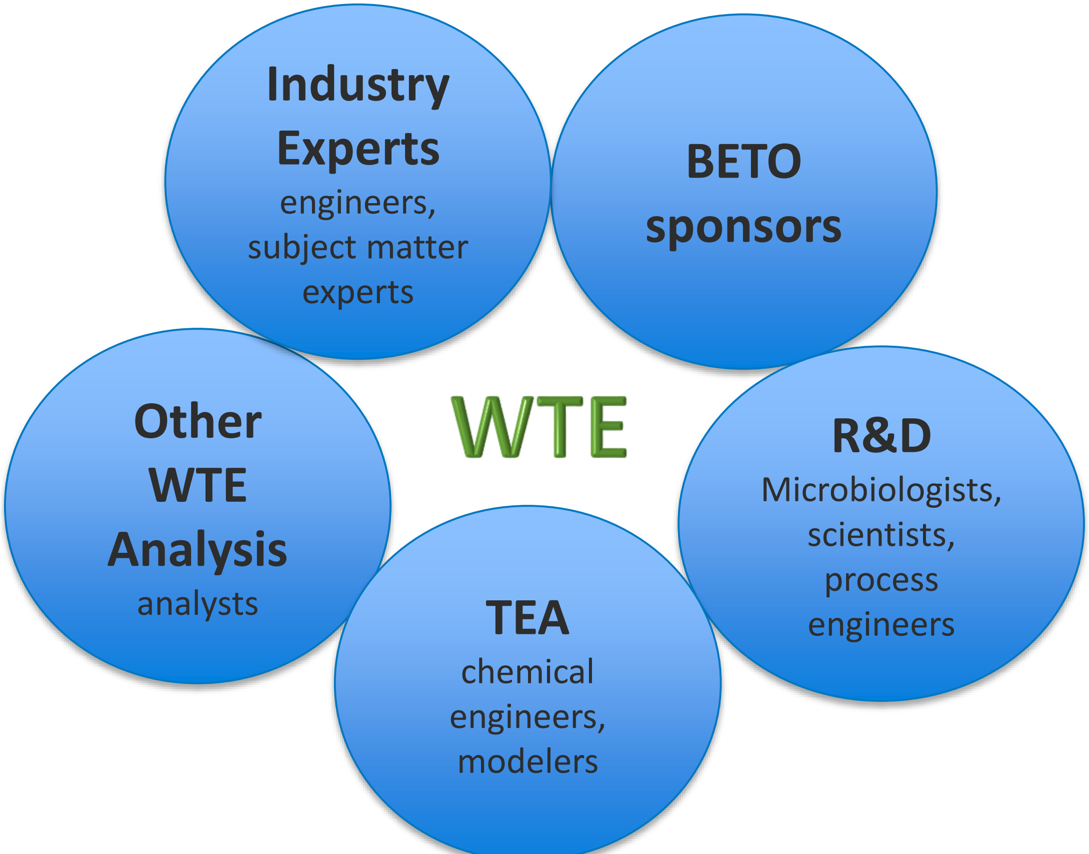
Working closely with R&D teams, industrial stakeholders and BETO

- *Provide analysis data for selected conversion pathways*
  - *Key metrics and performance targets*
  - *Barriers and R&D needs for conversion strategies*
  - *Critical inputs and approaches for achieving cost targets*
- *Answer critical questions to address technology/process economics*
- *Build knowledge on key/novel waste conversion pathways*
- *Assess cost potentials*
- *Frame future research directions*

2 – Approach (Management)

Project management

- Multi-disciplinary team
- Regular communication with R&D project teams
- Regular communication with industrial stakeholders to ensure credibility
- Quarterly progress reports and routine check-ins to BETO sponsors



2 – Approach (Management, cont.)

Supports the highlighted projects

Analysis & Sustainability

- 4.1.1.30 Strategic Analysis Support
- 5.1.1.102 Biopower Analysis

Biochemical Conversion

- 2.1.0.100 Biochemical Platform Analysis
    - AD design

CO_2

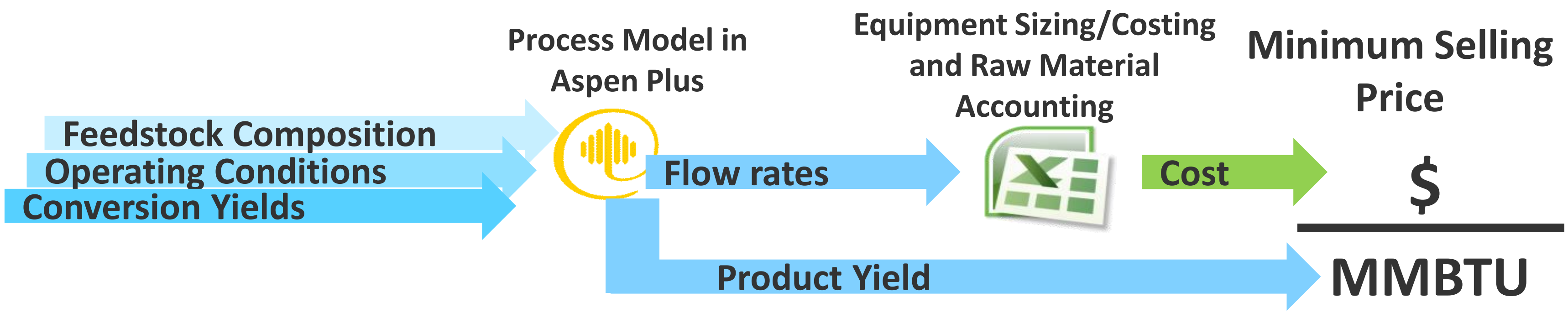
2.1.0.111 Analysis in Support of Biofuels and Bioproducts from Organic Wet Waste Feedstocks

Waste-to-Energy

- 2.1.0.104 Waste to Energy System Simulation Model
- 2.1.0.112 Waste-to-Energy: Feedstock Evaluation and Biofuels Production Potential
- **2.2.4.100 Arrested Methanogenesis for Volatile Fatty Acid Production (ANL)**
- 2.3.2.102 Biogas to Liquid Fuels and Chemicals Using a Methanotrophic Microorganism
- 2.3.2.106 CO2 Valorization via Rewiring Metabolic Network
- **2.3.2.107 Separations in Support of Arresting Anaerobic Digestion**
- **2.3.2.108 Reversing Engineering Anaerobic Digestion of Wet Waste for Biofuels Intermediates and Bioproducts**
- 2.3.2.201 Biogas Valorization: Development of a Biogas-to-Muconic Acid Bioprocess

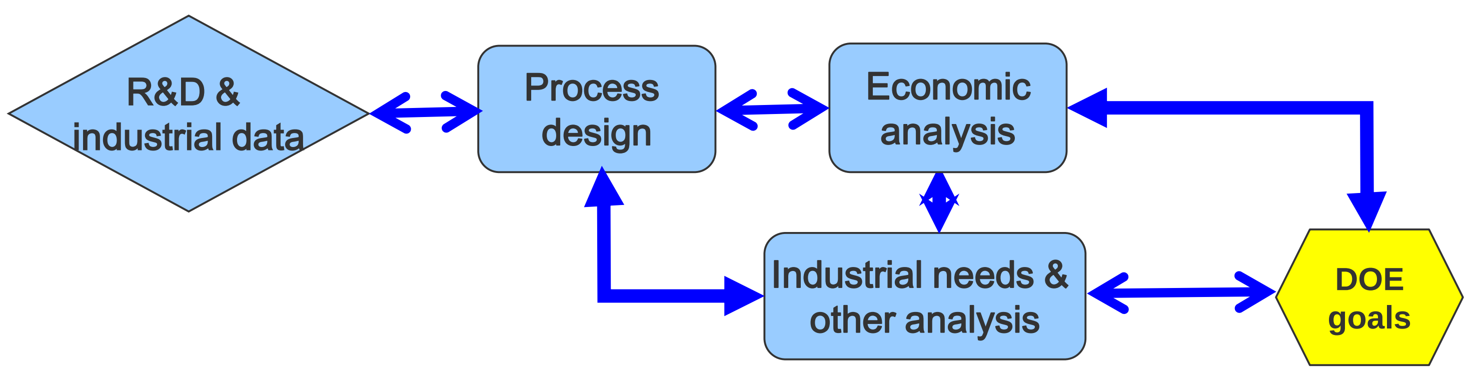
2 – Approach (Technical)

Analysis consistent with conversion, strategic analysis TEA platforms



Approach:

- Modeling is rigorous and detailed with transparent assumptions
- Discounted cash-flow rate of return on investment, equity payback, and taxes
- Provide strategic, comparative cost analysis for various conversion technologies
- Iterative analysis process among R&D, DOE goals, LCA on key technology targets



2 – Approach (Technical)

Challenges

- Data from literature have high degree of variability
- Uncertainties in early stage R&D

Critical success factors

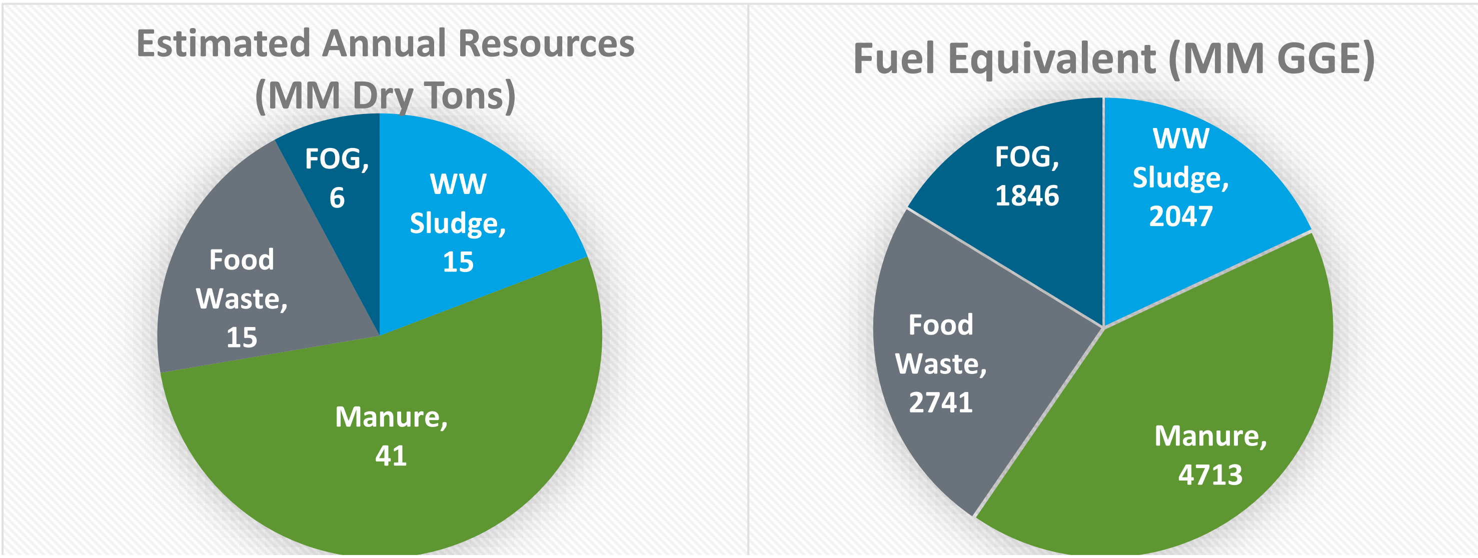
- Models accurately and realistically represent important attributes of processes
- Provide data to inform research priorities and key process metrics
- Provide data to identify research gaps and most impactful process improvement opportunities in BETO WTE R&D programs

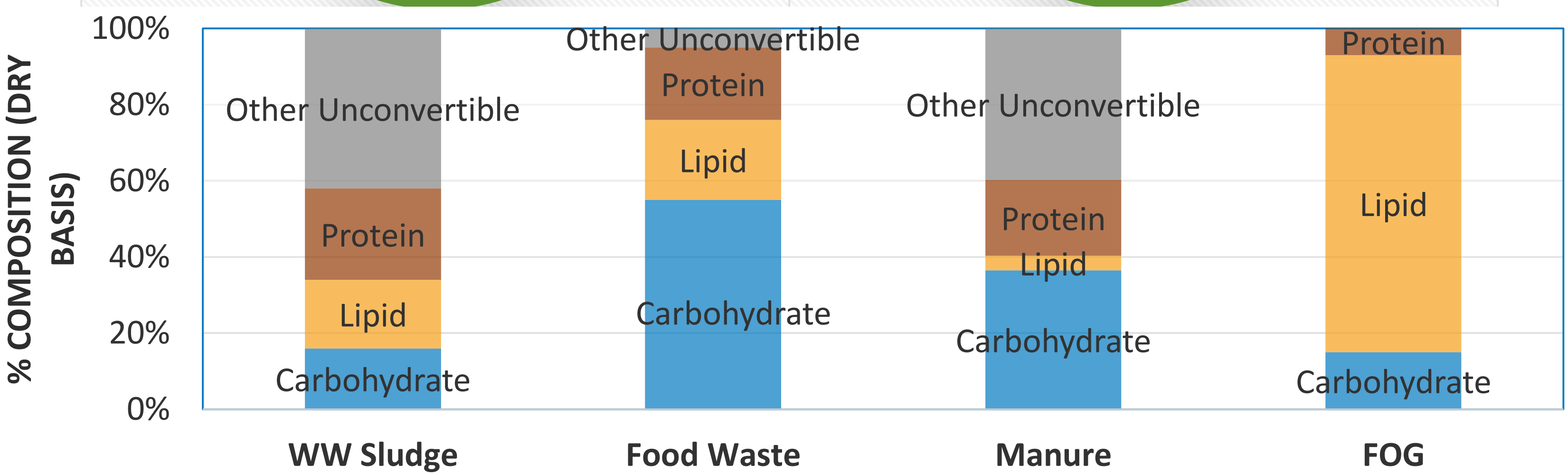
Interfaced successfully with project teams:

- **Phase I** : **established AD baseline, defined arrested AD** process concept and **baseline TEA frameworks** and models with each R&D team (completed)
- ***Phase II***: ***validate*** *and evolve* ***TEA*** *models by iterating with three R&D teams on preliminary TEA data (on-going)*
- ***Phase III***: *detailed cost assessment with studies on key cost drivers,* ***report major TEA findings and approaches to get to BETO cost targets*** *(on-going)*

3 – Technical Accomplishments/Progress Results

Selected four types of wet waste feedstocks based on BETO's guidance and in collaboration with the resource analysis team:





https://www.energy.gov/sites/prod/files/2017/02/f34/biofuels_and_bioproducts_from_wet_and_gaseous_waste_streams_full_report.pdf

3 – Technical Accomplishments : Phase I AD Baseline

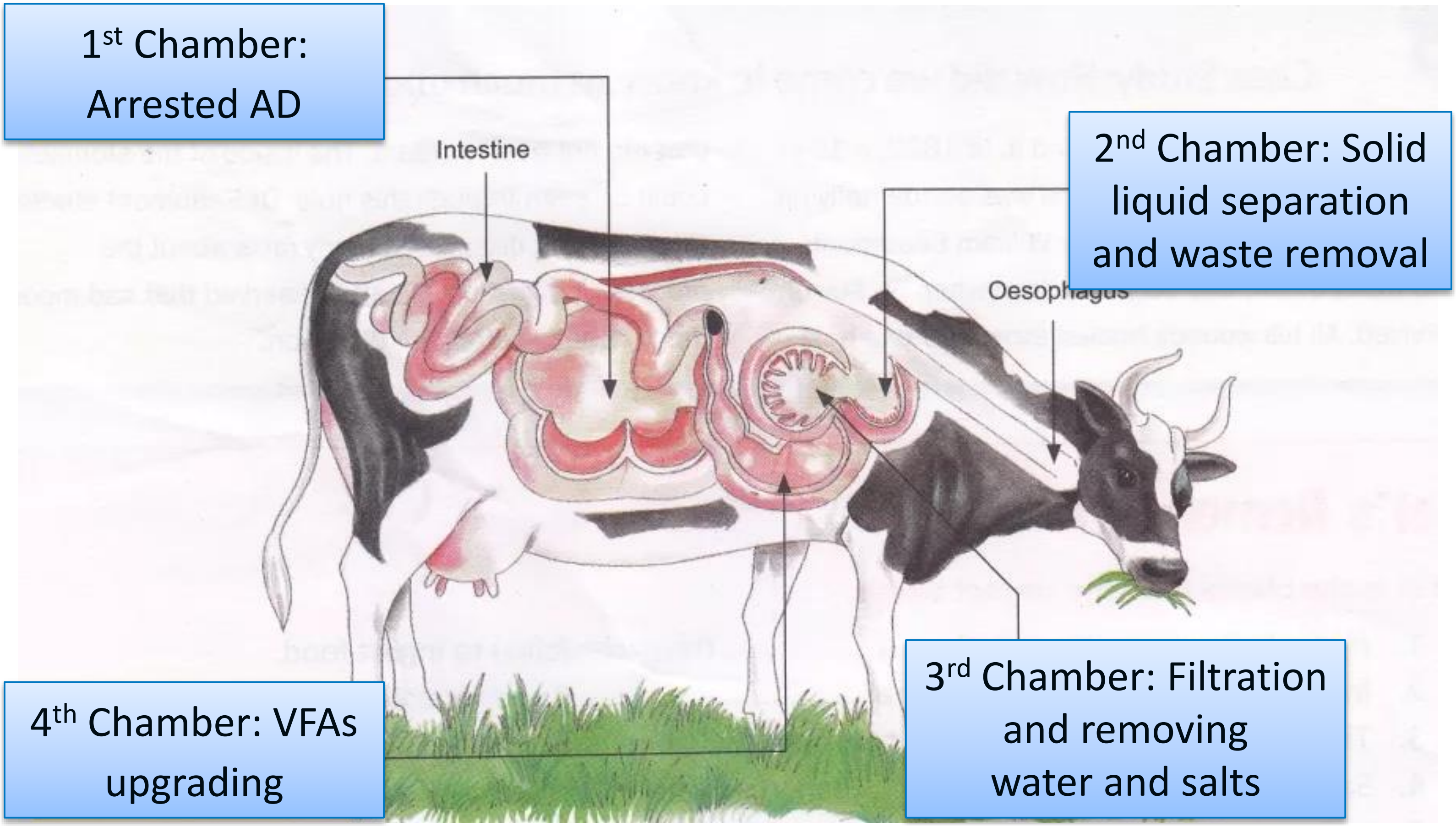
Key takeaways:

- Established AD baseline with four wet waste feedstocks
- Reported energy & mass yields, cost data

		WW Sludge	Food Waste	Manure	FOG
Scales		1 – 300 MGD	1 – 250 wet tons/day	1 – 250 wet tons/day	1 – 200 wet tons/day
Energy Density (MMBTU/dry ton)		17.7	20.8	15.5	35.4
Wet Waste Resources	**Dry tons (MM)**	14.8	15.3	41	6.1
	Trillion Btu	237.6	318.2	547.1	214.3
TS (%)		primary sludge: 2-6% secondary sludge: 2-10%	25%	7%	5 - 94%
Biogas Yield	**m^3/dry ton**	454 – 544	586	513	1,060 – 1,290
	kcf/dry ton	16—19	21	18	37—46
	MMBtu/dry ton	10—12	13	11	23—18
Biogas Energy Yield (%)		57%	60%	50%	64%—78%
Biogas Cost ($/MMBTU)	**Literature**	$1.0 – $189.1	$11.1 – $88.0	$2.2 – $49.7	$4.7 – $25.9
	This Work	$2.5 – $14.4	$5.7 – $26.3	$22.0 – $108.3	$6.5 – $34.5
	CapdetWorks	$9.0 - $38.3	$12.3 – $26.3	$9.9 – $34.8	-

3 – Technical Accomplishments : Phase I Arrested AD Process Design

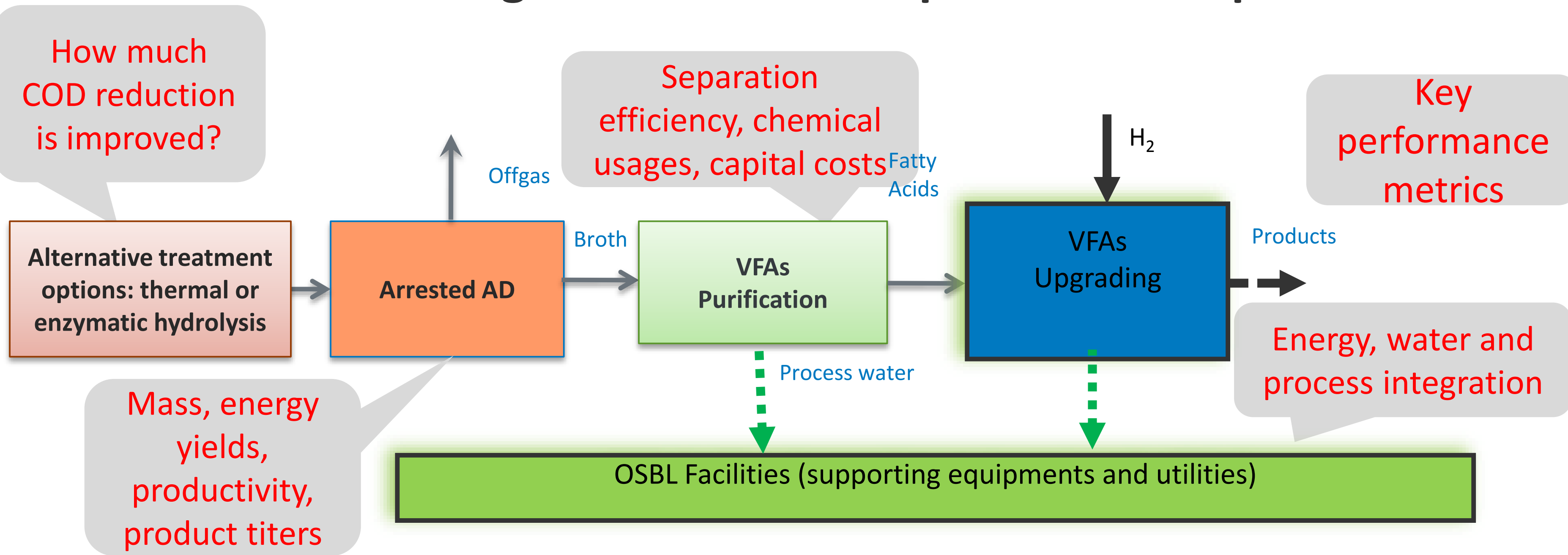
What we can learn from nature: VFAs are produced from microbial carbohydrate digestion in ruminants, as a natural occurring concept



- Rumen (1st chamber): produce VFAs, as main energy source
- Reticulum and omasum (2nd and 3rd chambers): separate VFAs
- Abomasum (4th chamber): digest acids to energy

3 – Technical Accomplishments : Phase I Arrested AD Process Design

Translating into arrested AD process concept

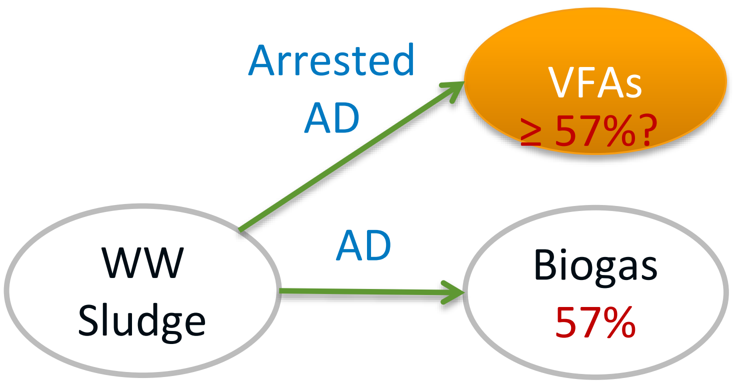


Identify key performance metrics for core unit operations

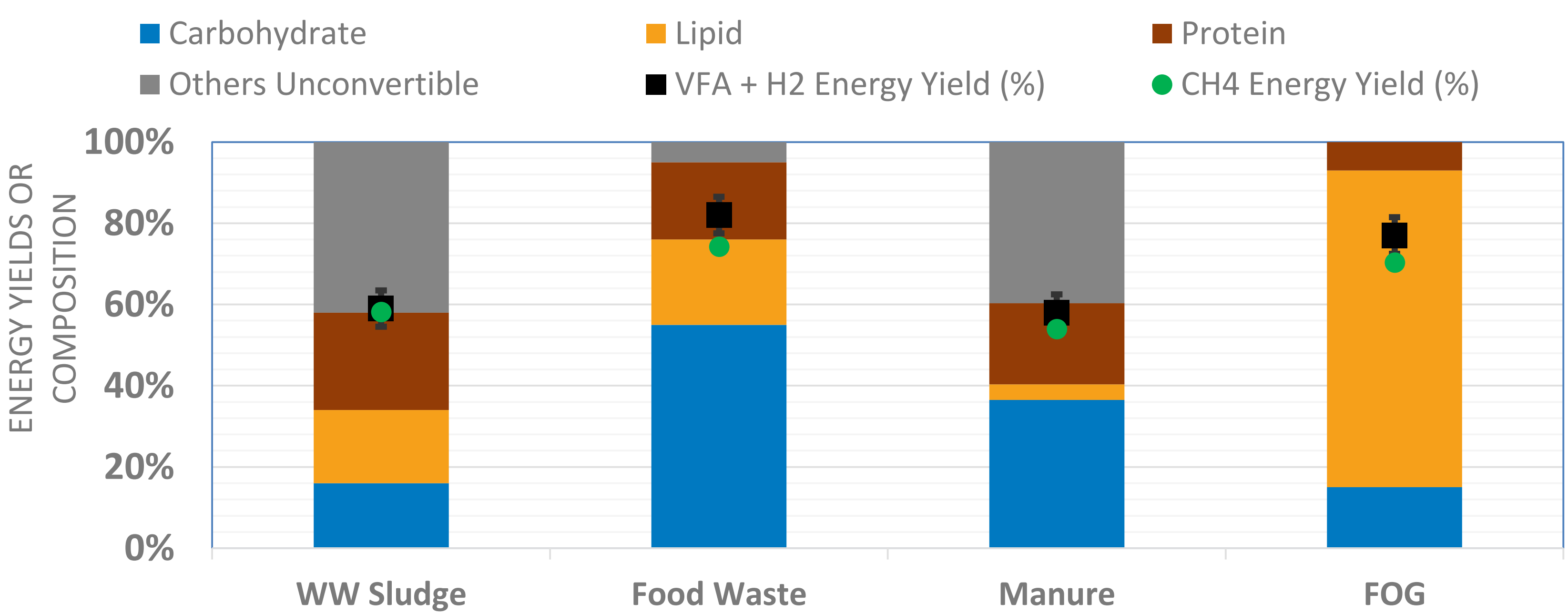
- Energy/mass yields, productivity, product titers are critical to arrested AD
  - Example: 63% COD reduction has been demonstrated with no CH_4 detected
  - Example: productivity must be ≥ 0.5-1.0 g/L/hr to be economically competitive
- Separation efficiency, low cost separation are critical to purification
  - VFA products are acetic, propionic, lactic, and butyric acid
  - Example: over 85% separation efficiency has been demonstrated

3 – Technical Results on Arrested AD

Demonstrated that energy yield into VFAs is similar to that into biogas for most waste feedstocks



- ≥ 60% of energy yield from sludge to VFAs has already been demonstrated
- Food waste: ~78% (varying with VFAs distribution)



4 – Relevance

This project has broad relevance to society, industry and BETO

Industry Benefits	Project Relevance and Contributions
Identify positive value in materials presently disposed of in landfills. Convert currently underutilized domestic biomass and waste resources to produce increasing volumes of biofuels, biopower, and bioproducts	• Analyze a broad variety of WTE pathways for production of fuels and chemicals; • Work with R&D teams directly, providing consistent reliable data and useful models cross platform; • Match technologies and products with appropriate scales
Provide analytical basis for strategic planning, decision-making, and assessment of progress to support BETO goals	• Verify cost competitiveness with commercialized WTE, waste disposal options; • Transparent and peer-reviewed TEA models support BETO's mission
Focus on technology development priorities and identify key drivers and hurdles for industry growth	• Look for cost reductions through R&D and process improvements; • Engage with industrial stakeholders and communicate WTE technology benefits; • Publish analysis results including state of technologies (SOTs) to support data/info needs

4 – Relevance

Industry already interested in our work and is helping us on modeling and on providing useful data/information

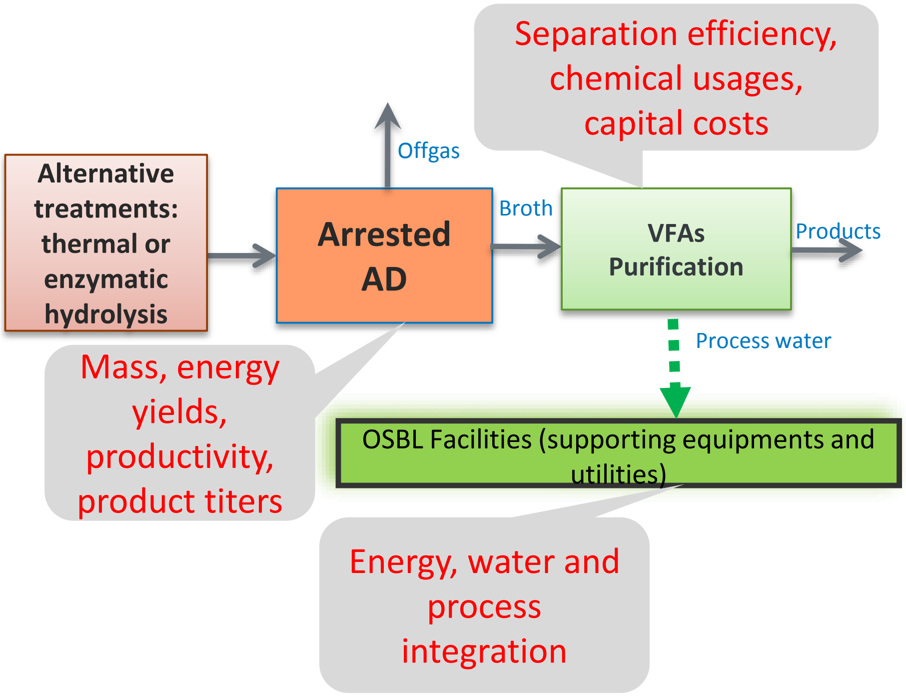
- Solicitate feedback from expert stakeholders (such as Denver Water, Denver Metro Wastewater Reclamation District, SoCal Gas, and others)
- Fine tune AD or arrested AD costs
- Look for retrofitting or bolt-on opportunities by working with industrial collaborators

5 – Future Work (FY19 and On-Going Efforts)

- **Build process concepts and TEA models** for BETO funded R&D projects on arrested methanogenesis
  - On-going efforts: alternative treatment options if cost beneficial, sensitivity analysis on cost impact from production distribution, etc.
- **Perform Go/No-Go:**
  - **Milestone**: Determination of whether there is a research path for the 3 arrested AD technologies that can realize techno-economic advantages relative to biogas or to VFAs in the chemical markets
- Report key cost drivers, technical challenges, most critical performance targets for R&D needs as critical inputs to R&D teams, BETO WTE platform and to justify overall biorefinery economic viability for industry

5 – Future Work

Work with WTE industry, verify cost competitiveness, look for cost reductions to achieve BETO cost goals



- **Improve energy and mass yields** (e.g. higher than biogas yield of 57% from sludge)
- **Optimize acid separation technologies** (e.g. in-situ acid recovery)
- **Identify the right product slates** (e.g. max cost by optimize C2-C6 distribution)
- **Alternative process strategies** (e.g. trade-off with enzymatic hydrolysis, pretreatment technologies, etc.)

5 – Future Work (FY20 and Beyond)

Overall project planned outcomes:

- Detailed process design reports and **economic evaluations for WTE pathways** based on industrial and research scientific inputs
- Report key cost drivers, cost breakdowns, value proposition over the current approach of disposing wet wastes, and project path forward to **achieve BETO's cost target for fuels and chemicals**
- **Report SOTs** for all three projects with vetted research data

Key planned aactivities

- Expand, vet models and analyses through stakeholder and R&D engagements
- Leverage existing analysis tools, collaborate with biogas upgrading, CO_2 utilization and biopower projects
- Collaborate with conversion platform on hydrocarbon pathways to maximize out the process economics by converting biorefinery waste on-site
- Work with GREET team to quantify sustainability impacts from sustainability of either a standalone WTE or a biorefinery with WTE bolt-on strategies
- Publish key TEA findings

Summary

- **Goal:** Develop process design concepts and TEA models to address key questions in support of the WTE opportunities
- **Relevance:** broad relevance to society, industry and BETO by providing solutions on reducing wastes and converting wastes to valuable fuels and products
- **Approach:**
  - Develop **reliable, realistic and useful models** to support WTE R&D
  - **Provide credible results to assist decision making in bioenergy investment**
  - Work **highly integrated with R&D** project teams
  - **Work with industrial experts** and stakeholders to understand cost potentials
- **Key accomplishments:**
  - Established a TEA framework for both biogas and VFAs
  - Performed analysis to understand theoretical challenges of AD and arrested AD (energy and mass yield potentials)
  - Identified several priorities for near term R&D efforts(e.g. carbon yields, waste destruction efficiency, separations, etc.)
  - **Energy yields are similar and VFA has more value**
- **Future work:**
  - Work with industrial stakeholders and subject matter experts to understand WTE potential
  - Vet analysis approach and results, and quantify impact of uncertainties
  - Report and publish cost data

Acknowledgement

- DOE Bioenergy Technologies Office
  - Brandon Hoffman and Mark Philbrick

  http://www.eere.energy.gov/biomass

- Analysis Team
  - Arpit Bhatt, Jennifer Clippinger and Anelia Milbrandt

- R&D Teams
  - ANL: Meltem Urgun-Demirtas
  - NREL: Violetta Sanchez I Nogue, Eric Karp and Steve Decker

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Additional Slides

3 – Technical Accomplishments:

Worked with resource analysis team to determine realistic plant scales