Bioenergy Production from MSW by Solid-State Anaerobic Digestion

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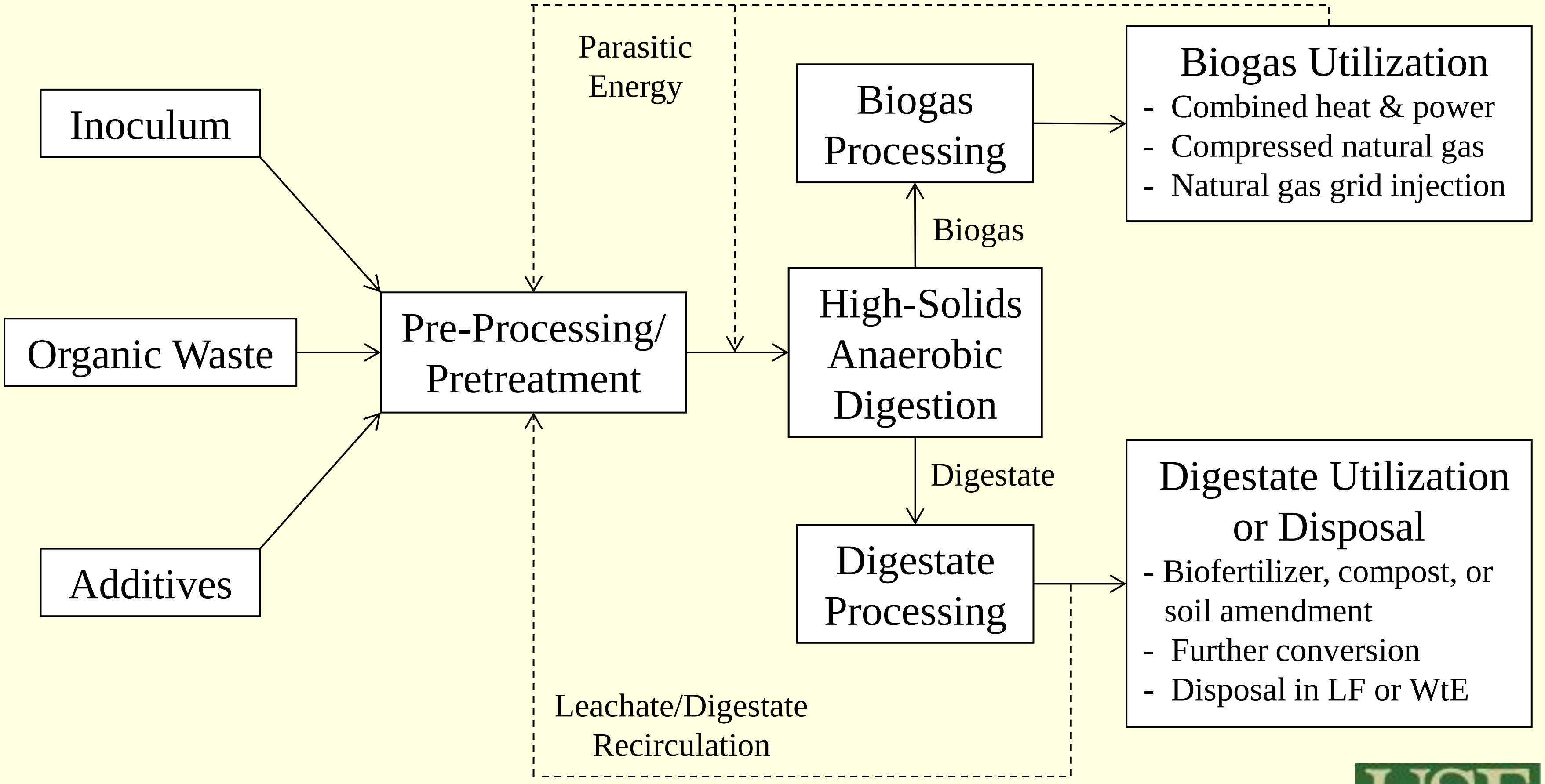
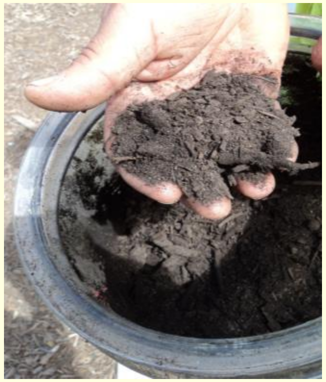
Presentation to TAG
February 16, 2016

Intro to HS-AD (a.k.a. SS-AD)

- *Designed to process feedstocks with > 15% total solids content.*



Zero Waste Energy, Monterey



Research Motivation

- Anaerobic Digestion (AD) of OFMSW results in:
  - Energy recovery/renewable energy generation
    - Reduces fugitive GHG emissions from landfills
    - Offsets GHG emissions from fossil-fuel derived energy
  - Nutrient recovery/organic fertilizer production
    - Reduces landfill leachate volume and strength
    - Offsets impacts of inorganic fertilizer production
- High-Solids AD (HS-AD) advantages over Liquid AD:
  - Reduced parasitic energy demand
  - Reduced reactor volume requirements
  - Reduced water usage and leachate generation

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Research Objectives

- Overall Goals
  - Contribute to the fundamental science of HS-AD and evaluate potential for implementation in FL
- Specific Objectives
  - 1. State-of-the-Art of HS-AD
    - Trends and drivers in the industry and appropriate technologies for FL
  - 2. Enhancing Bioenergy Production
    - Improve biodegradability of yard waste and explore co-digestion strategies
  - 3. Potential for HS-AD Implementation in FL
    - Identify promising locations for HS-AD based on existing MSW infrastructure and potential bioenergy production, GHG emissions reductions and nutrient recovery.
    - Evaluate economics and develop policy recommendations.

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Objective 1: State-of-the-Art

- Goals
  - Understand trends and identify primary drivers in the industry
  - Identify appropriate technologies for implementation in FL
- Methodology
  - Review published and “grey” literature
  - Developed chronological database of US HS-AD projects
  - Visits to facilities in California and the Netherlands

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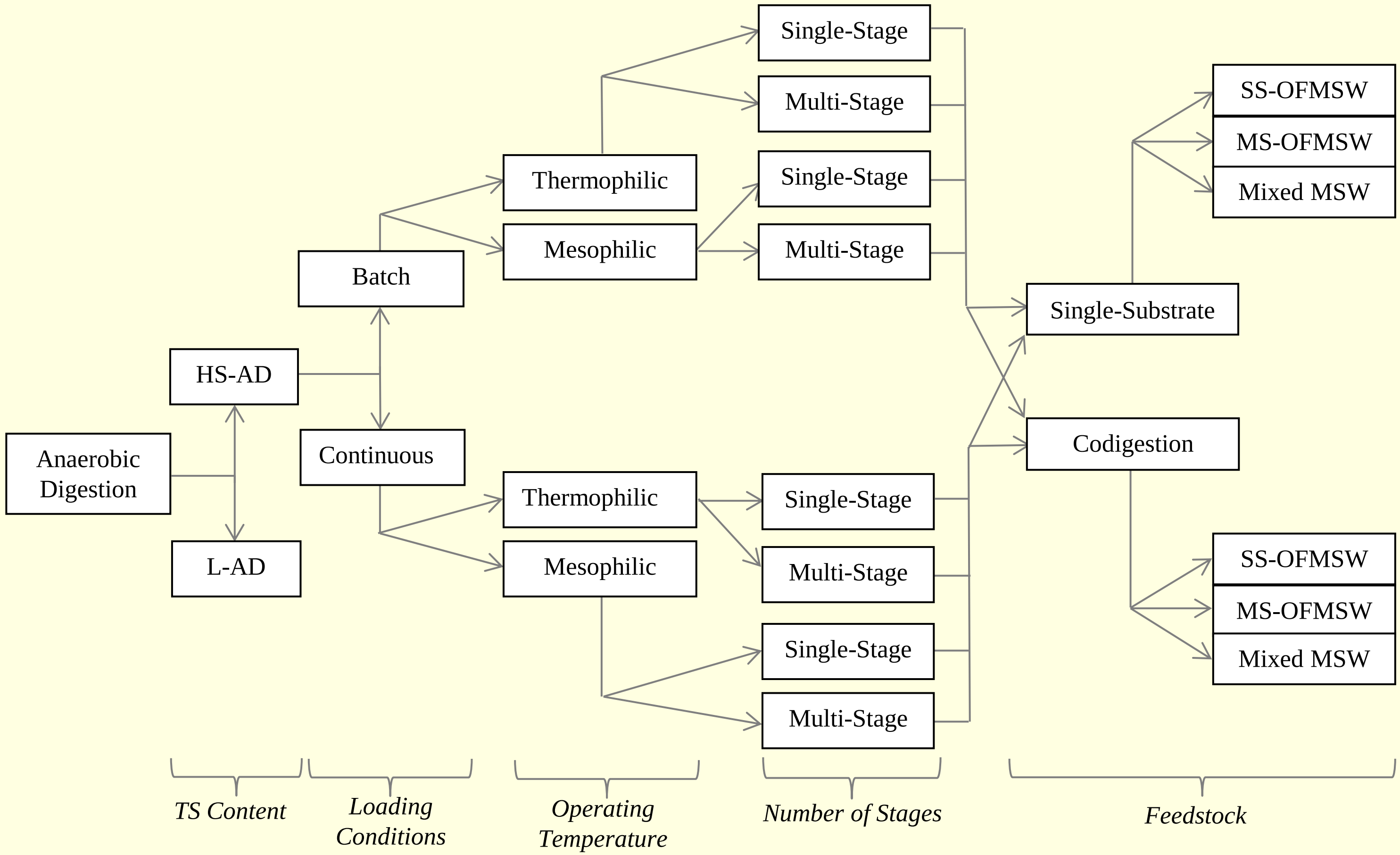
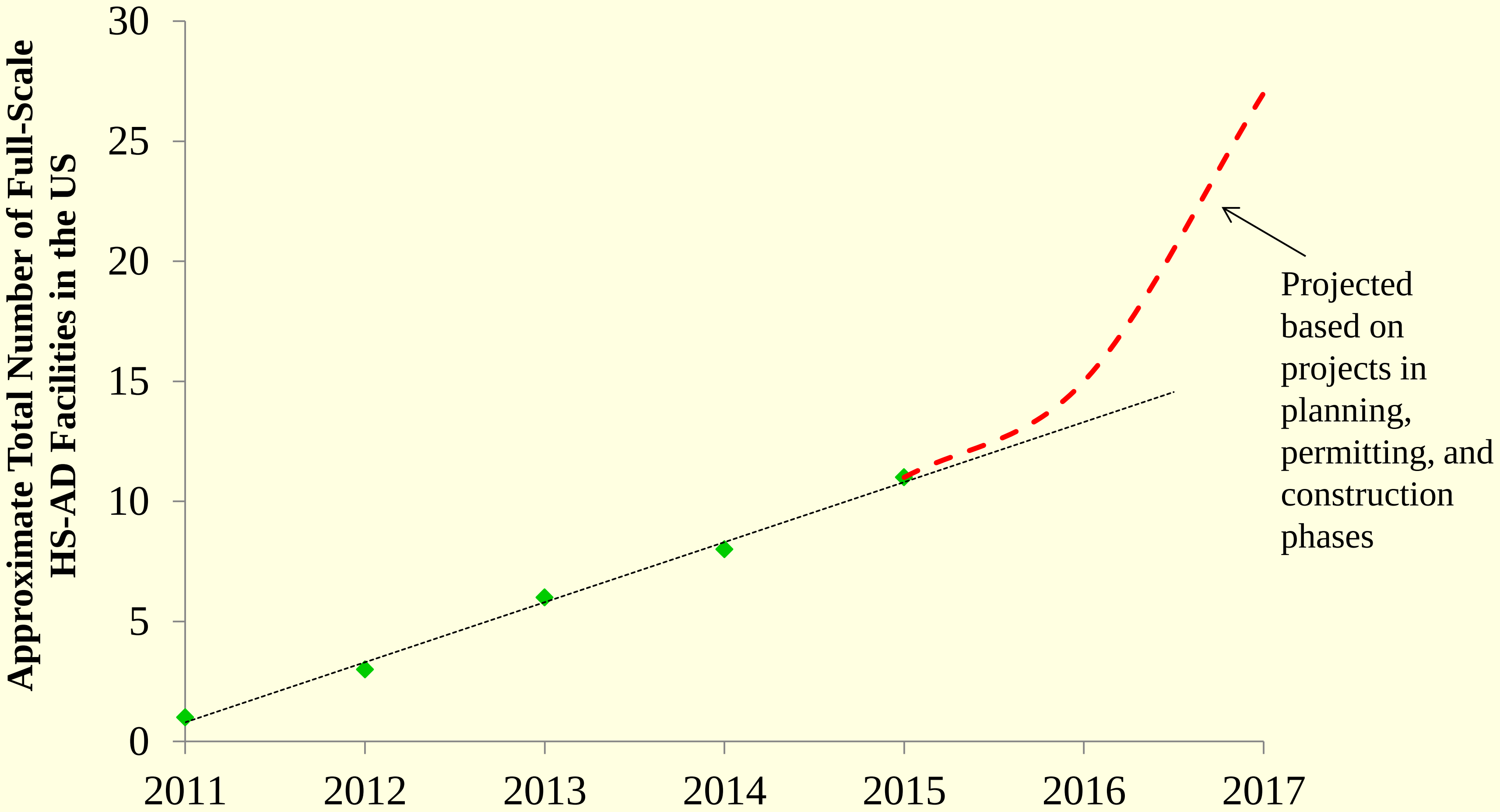
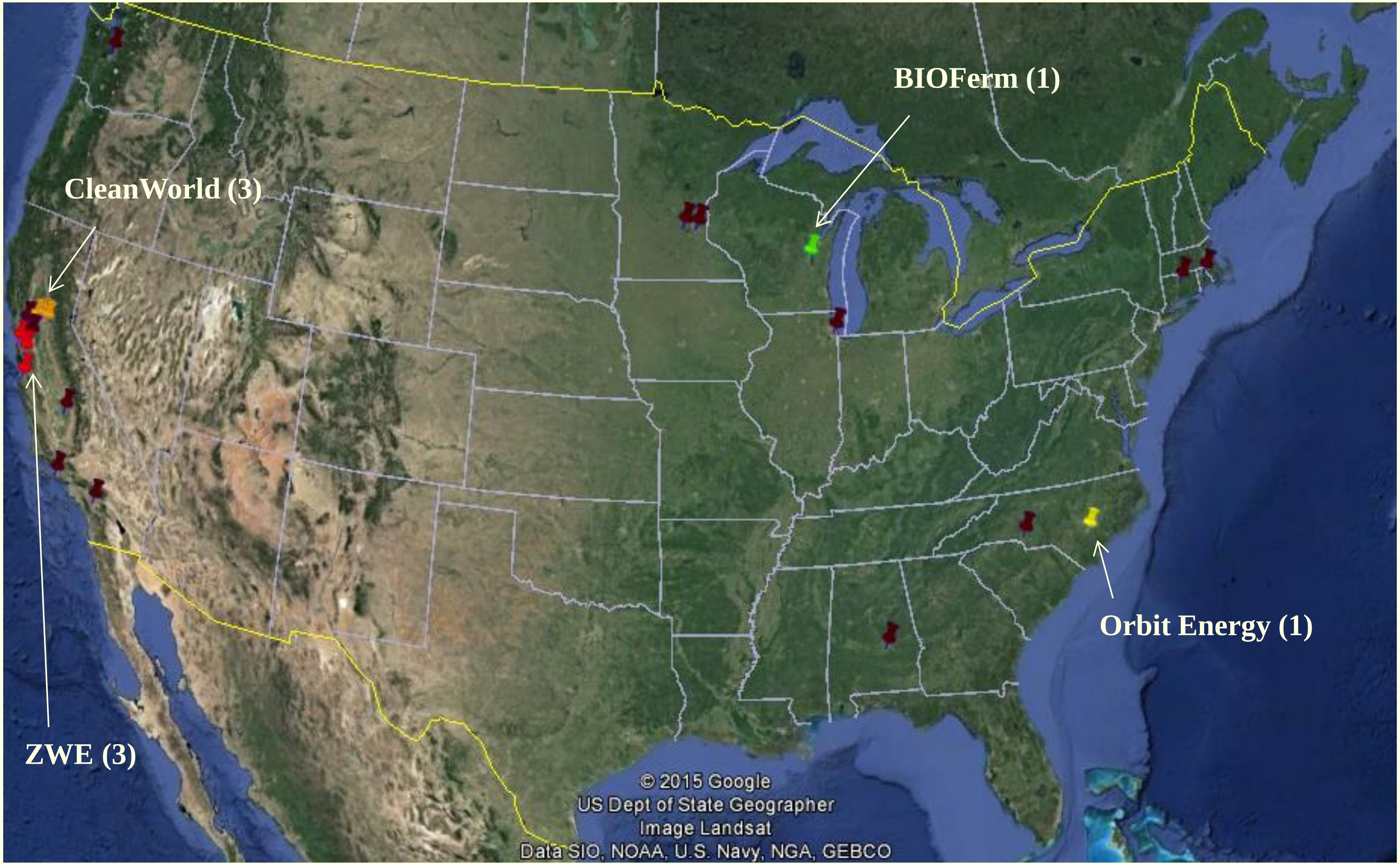
HS-AD Technology Classifications



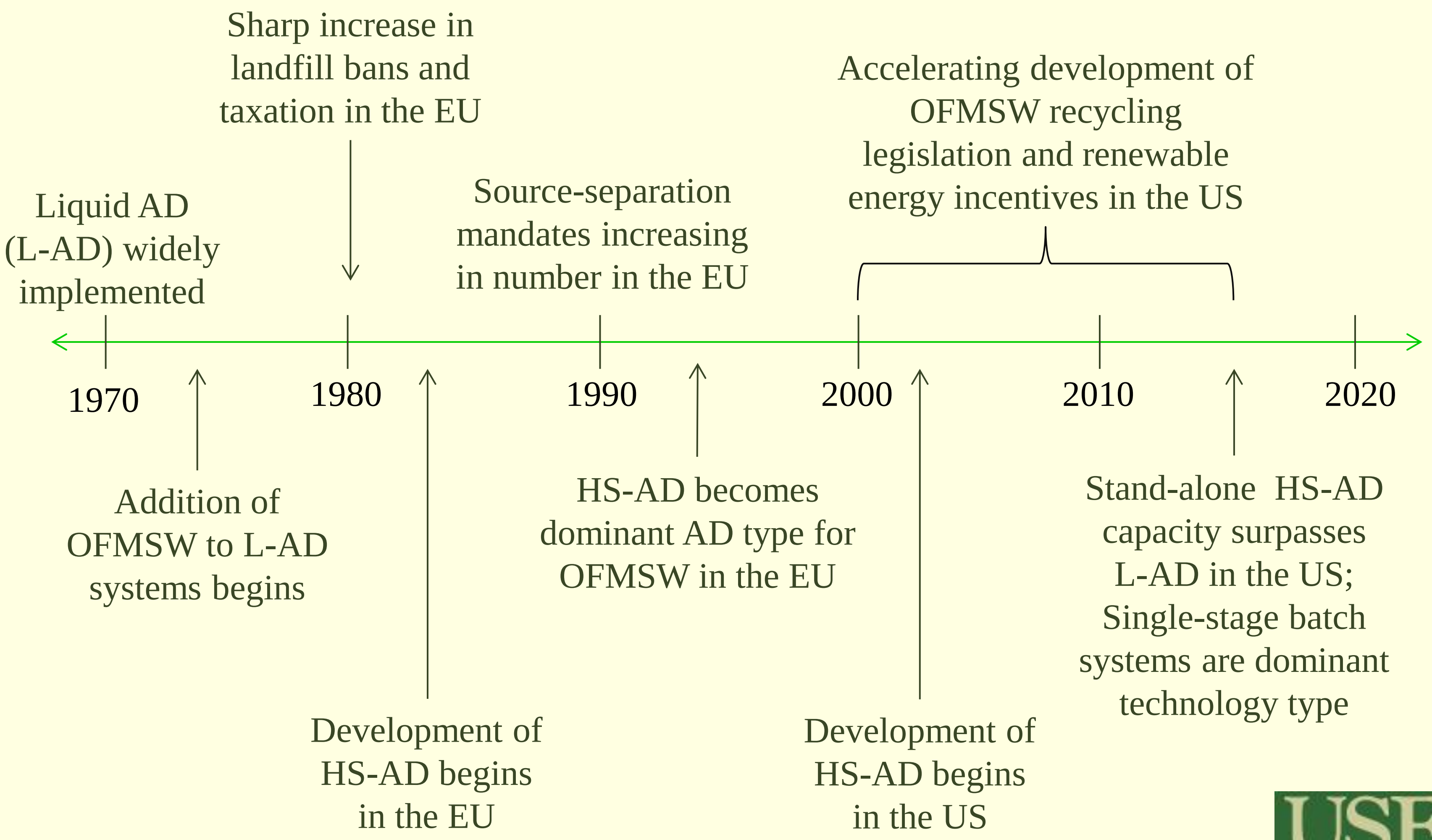
HS-AD Development in the US



HS-AD Locations in the US



HS-AD Development Timeline

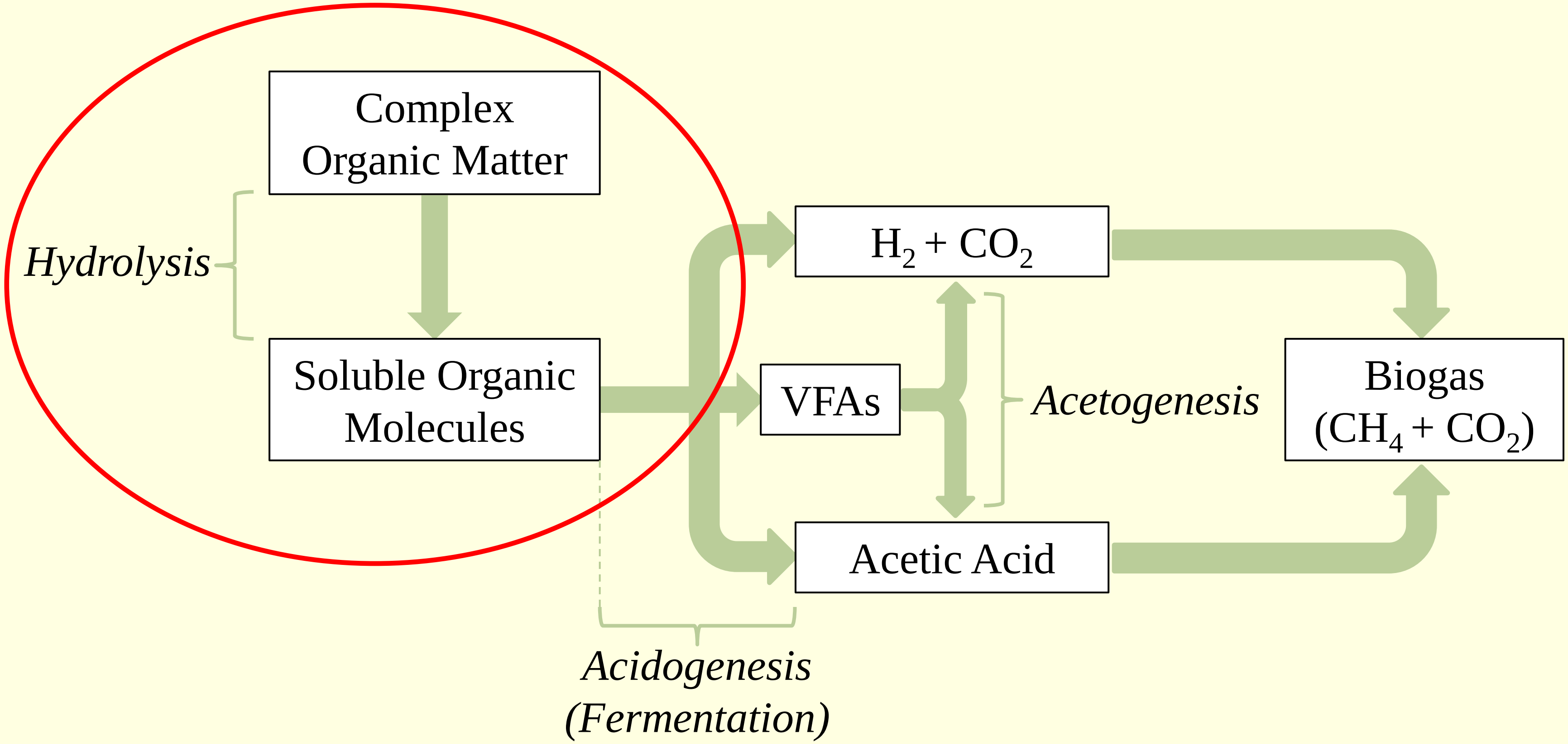


Summary of Major Findings

- Policy promoting OFMSW recycling in the US increasing:
  - 20 states now have yard waste landfill bans, 5 have food waste bans
  - 7 have landfill diversion targets
  - Over 200 communities offer separate collection of food waste
  - *Required* source-separation in San Francisco, Seattle, VT, and CT
  - 29 states now have renewable portfolio standards
- HS-AD implementation parallels policy development
  - HS-AD has surpassed L-AD for OSFMW processing capacity
  - CA is leading the way with policy and HS-AD development
- Single-stage, batch, thermophilic, “garage” type systems are the most suitable for Florida
  - Low cost, simple operation, reliable

Objective 2: Enhancing Bioenergy

- The Lignocellulosic Challenge



Objective 2: Enhancing Bioenergy

- Goals
  - Study the effects of bioaugmentation with pulp and paper mill anaerobic sludge on methane yields in batch HS-AD of yard waste
  - Determine whether enhancements can be sustained via digestate recirculation
- Hypothesis
  - Hydrolytic microorganisms in pulp and paper sludge are adapted to lignocellulosic waste and therefore have a greater capacity to degrade lignocellulosics than a conventional inoculum

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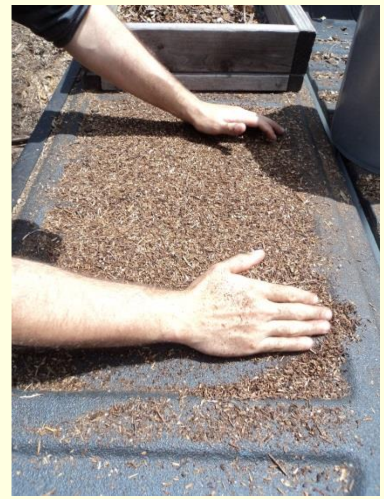
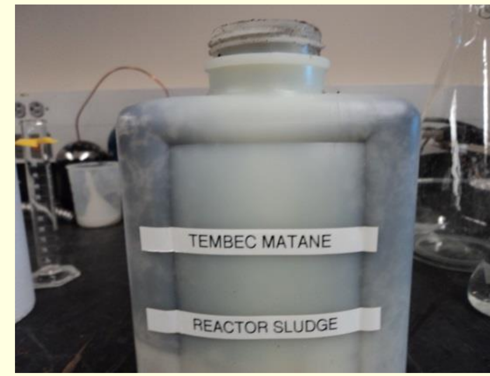
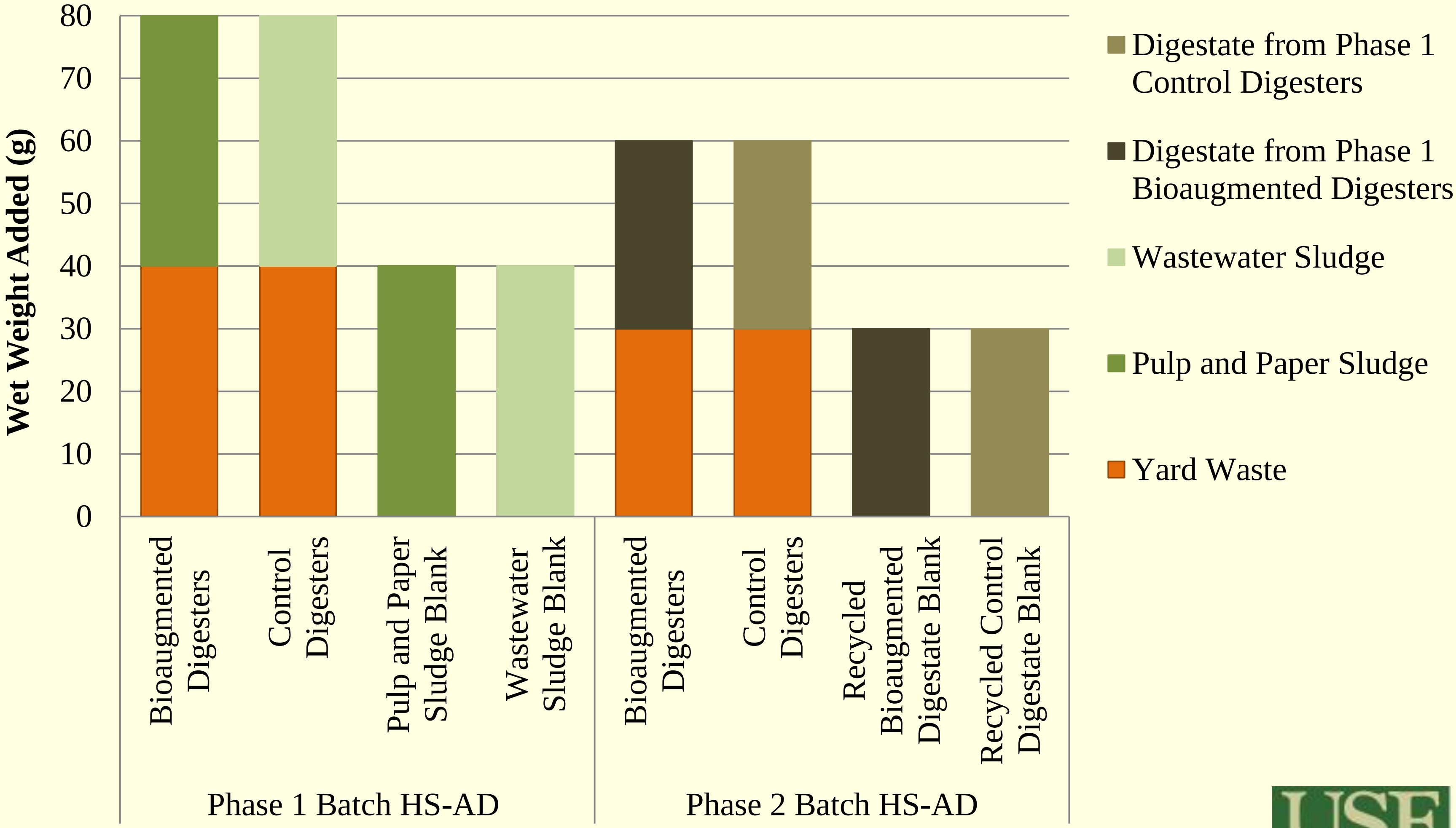
Materials and Methods

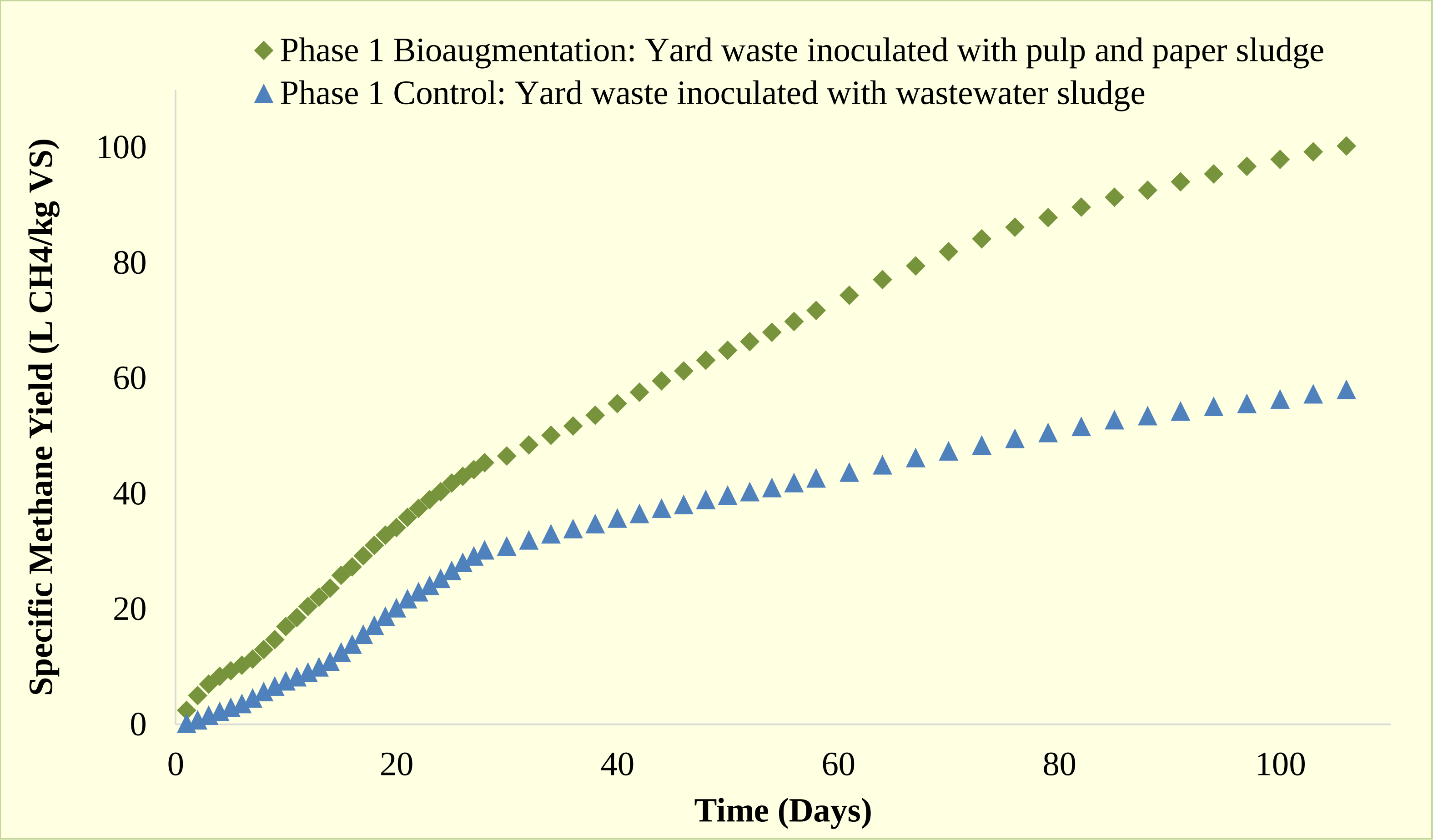




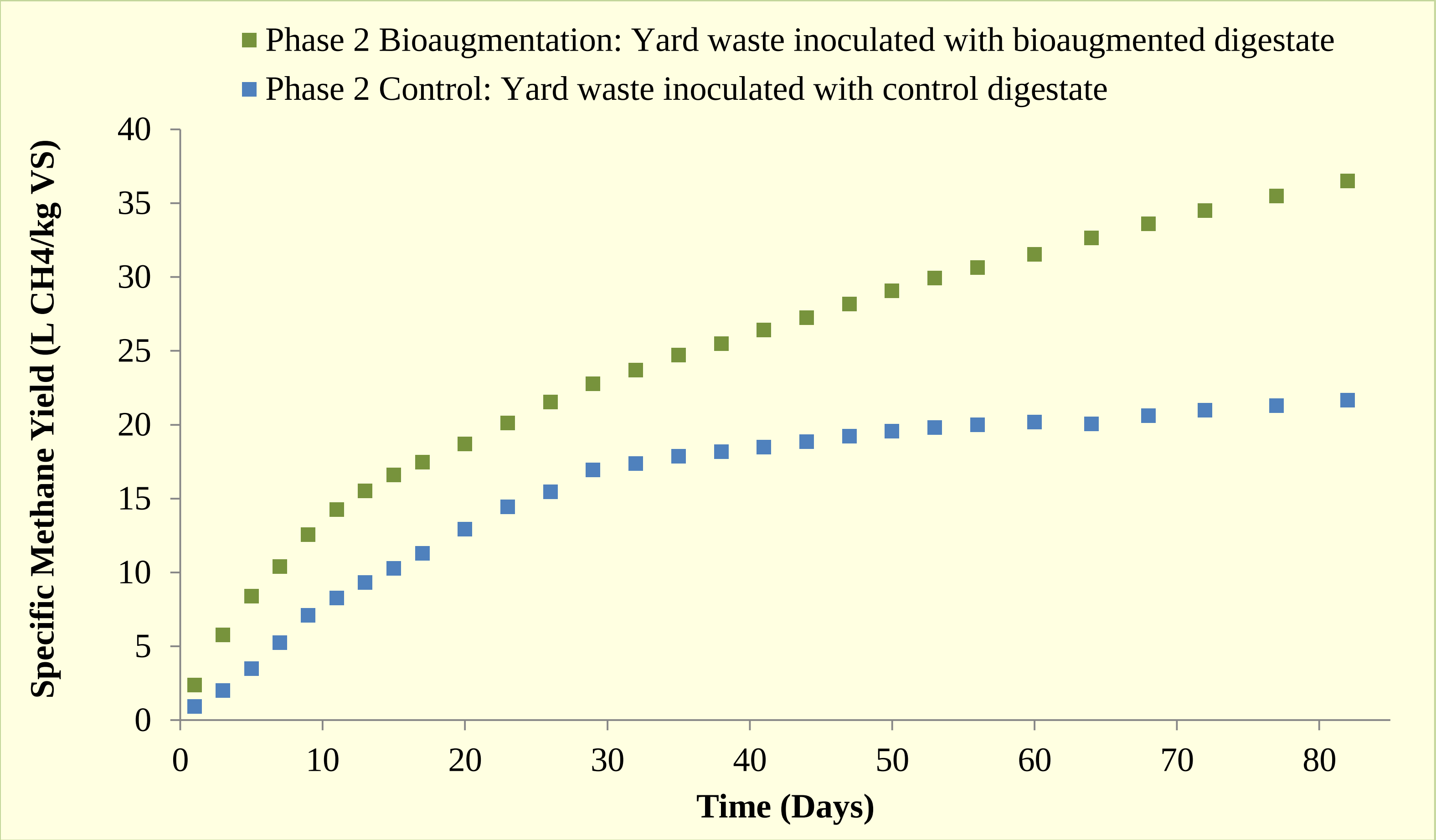
Digester Compositions



Phase 1 Specific Methane Yields



Phase 2 Specific Methane Yields



Summary of Major Findings

- Results suggest that this strategy could serve as a low impact alternative to pretreatment
  - Significant enhancements in methane yields achieved and sustained through bioaugmentation with pulp & paper sludge
- Chemical and lignocellulosic data support hypothesis
  - VFA concentrations indicate methanogenesis was rate-limiting in bioaugmented digesters while hydrolysis was limiting in control digesters
  - 16%, 16%, and 2% less lignin, cellulose, and hemicellulose in bioaugmented digestate relative to control digestate
- Need for future research:
  - Effects of varying substrate to inocula ratios
  - Mechanisms of methane yield enhancement
  - Bioaugmentation of OFMSW co-digestion mixtures – food, yard, biosolids.
  - Pilot and full-scale testing

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Objective 3: Implementation in FL

- Goals
  - Identify best FL counties for HS-AD implementation based on:
    - Existing MSW infrastructure
    - Potential bioenergy production & GHG emissions reductions
    - Potential for nutrient recovery.
  - Evaluate economics and develop policy recommendations.
- Methodology
  - Review published and “grey” literature and FDEP data
  - Consider findings from State-of-the-Art assessment
  - Estimate potential bioenergy production, GHG reductions and nutrient recovery

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Incentive for HS-AD Implementation

- 75% recycling goal by 2020
  - Current statewide recycling rate = 50%
    - Yard and food waste recycling rates = 51% and 7%, respectively
  - 12% of waste stream is yard waste and 7% is food waste
    - *Up to 13% increase in recycling rate achievable via OFMSW recycling*
- Renewable energy generation
  - Up to 500MW of renewable energy could be produced
    - 175 MW electricity (~1% of FL total demand, > $120M) + 200 MW heat
    - OR: 80 million DGEs of CNG per year (~11.5% of FL total demand)
    - 660,000 MTCO_2E per year offset (~$3.2M - $400M)
- Nutrient recovery
  - Up to 7,000 TPY and 3,500 TPY of N and P, respectively (~$ 2.1M)

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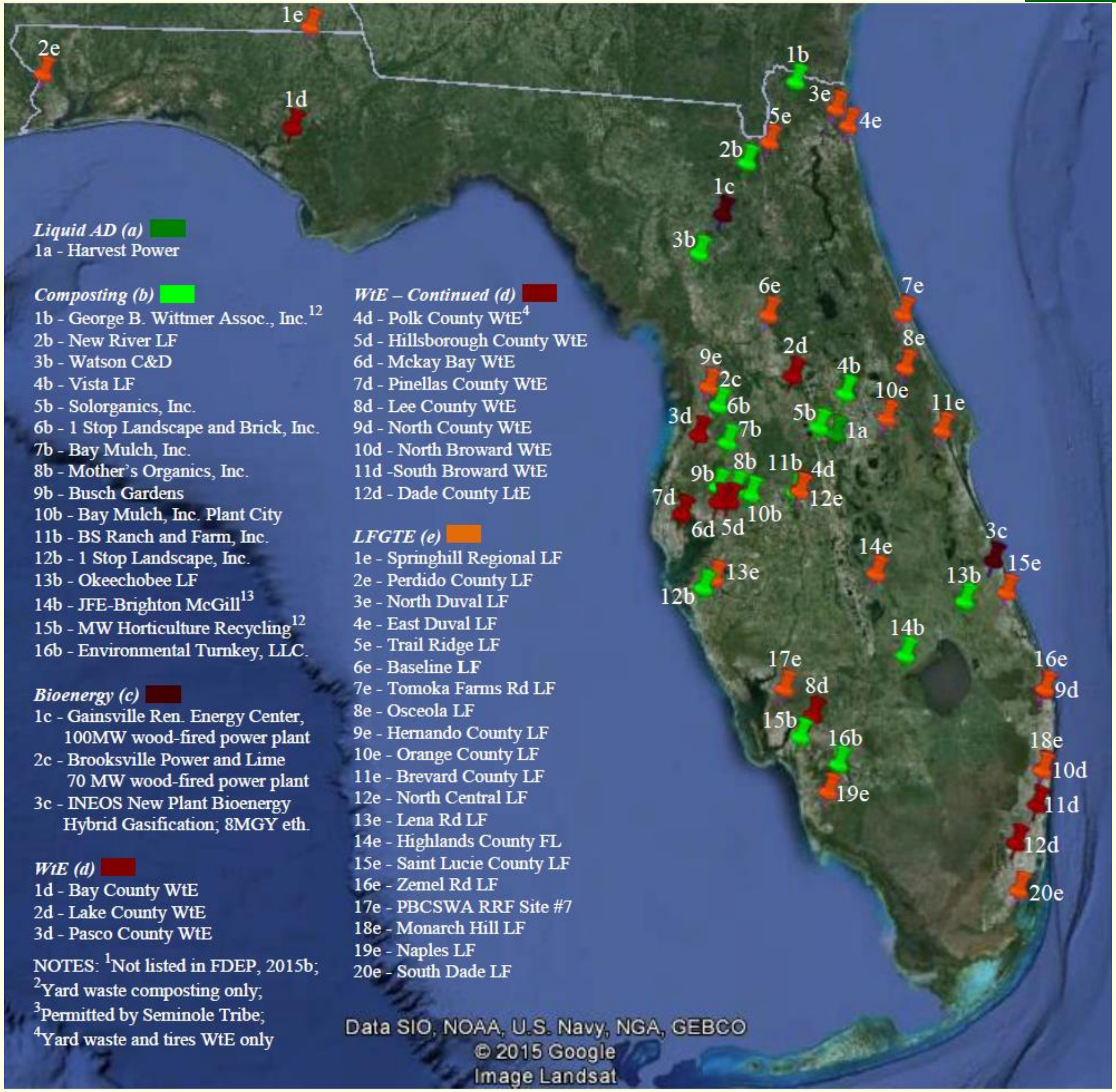
OFMSW "Recycling" Infrastructure



OFMSW Recycling Infrastructure

Outlook in Florida

- Counties where implementation is most feasible:
  - Miami-Dade, Broward, Palm Beach, Hillsborough, Orange, Pinellas, Duval, Lee, and Alachua
- Ideal locations for demonstration:
  - Universities, existing composting plants, or landfills with LFGTE
- Primary barrier: Economics
  - Average landfill tipping fee in FL = $43.65
  - Break-even HS-AD tipping fee without energy sales = $41 – $53
  - With energy sales = $4 – $32
  - Lack of markets for compost and lack of regulatory drivers

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Summary of Major Findings

- Outlook is promising, especially in highly populated counties
- Potential environmental and economic benefits are significant
- Economic sustainability is reliant upon numerous factors
  - Local tipping fees
  - Quantity, quality, and proximity of available feedstock
  - Energy and compost markets and renewable energy incentives
  - *Public-private partnerships*
- Legislative incentive has potential to greatly improve the feasibility of HS-AD implementation; recommendations:
  - Bans on landfilling food waste and yard waste
  - Mandated source-separation of food waste and yard waste
  - Policies promoting compost use and renewable energy generation

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Additional Research

- Pilot System
  - Preliminary studies developing operation standards
- Co-digestion
  - Yard waste, food waste, biosolids
- Oyster Shells
  - Waste product, alkalinity source
- Micro-aeration
  - Improving biogas quality

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Students & Postdoc

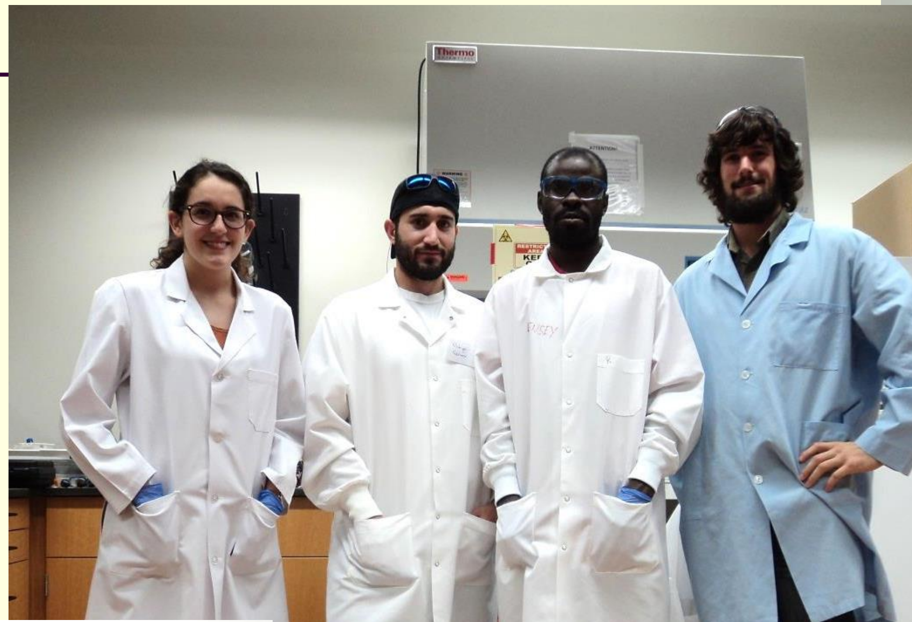
- Graduate and Postdoc

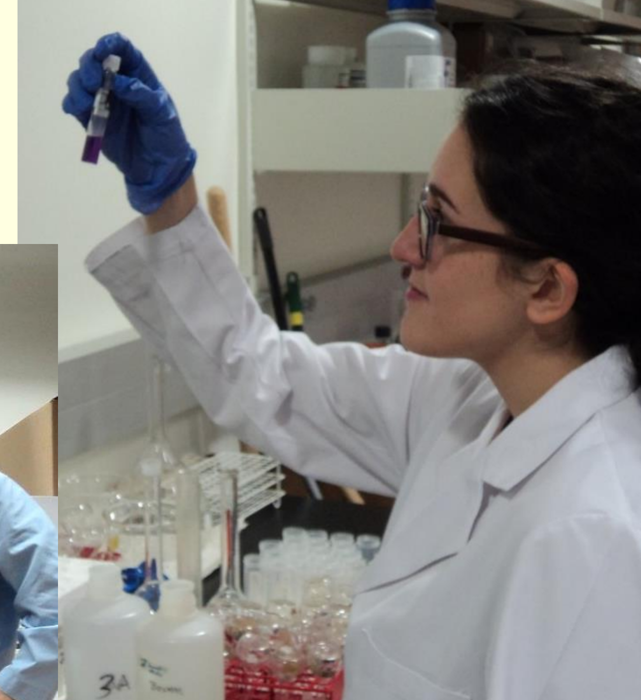
Name	Rank	Department	Institution
Hinds, Gregory	MS	Civil & Environmental Engineering	USF
Dick, George	MS	Civil & Environmental Engineering	USF
Wang, Meng	Postdoctoral Researcher	Civil & Environmental Engineering	USF
Anferova, Natalia	Visiting PhD student	Water Technology & Environmental Eng.	Prague Univ. Chemistry & Technology
Dixon, Phillip	PhD	Civil & Environmental Engineering	USF

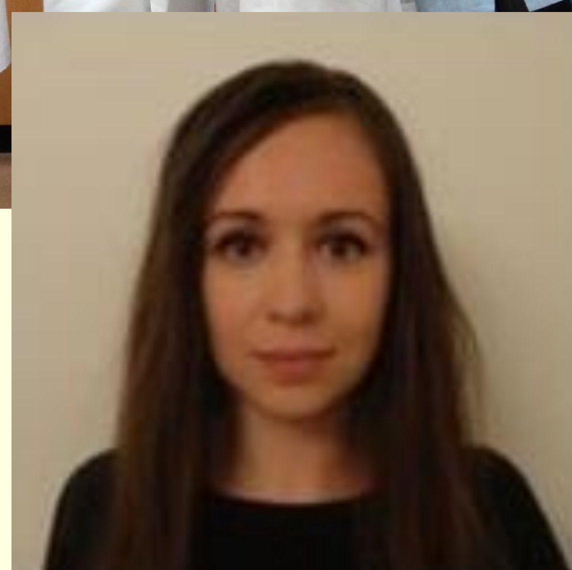
- Undergraduate

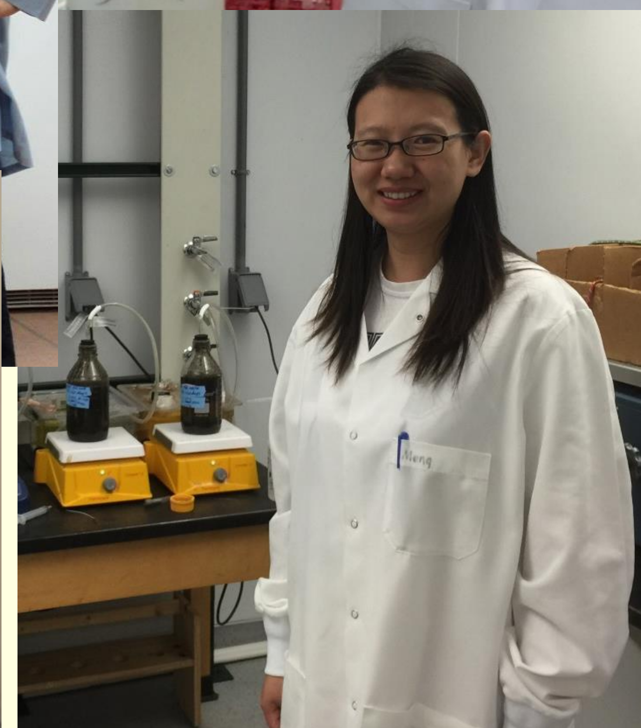
Name	Rank	Department	Institution
Ariane Rosario	Third Year	Civil & Environmental Engineering	USF
Lensey Casimir	Fourth Year	Civil & Environmental Engineering	USF

Students & Postdoc









Feedback on Final Report

Suggestions for Future Research

Acknowledgements

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HS-AD Vendors in the US

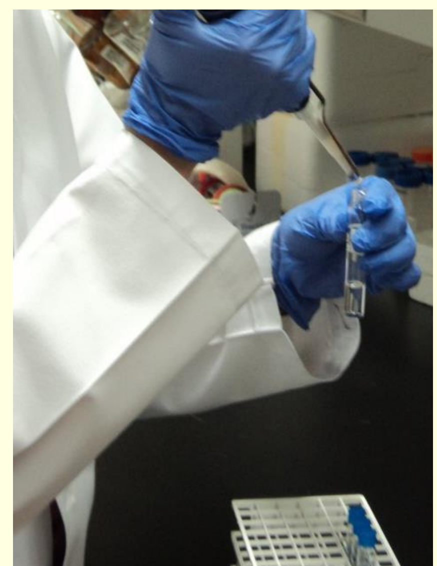
Vendor Name	Main Office Location	Founding Year	Primary Partnerships	# of Facilities in Operation in the US	# of Facilities in Development in the US
Zero Waste Energy, LLC	California	2009	Eggersmann Group, Bulk Handling Systems, Environmental Solutions Group	≥ 3	≥ 7
CleanWorld Corporation	California	2009	UC Davis, Synergex	≥ 3	≥ 1
Orbit Energy, Inc.	North Carolina	2002	McGill Environmental	≥ 1	≥ 5
BIOFerm Energy Systems	Wisconsin	2007	Viessmann Group, Schmack Biogas	≥ 1	≥ 1
Organic Waste Systems, Inc.	Belgium (subsidiary in Ohio)	1988	NR	≥ 0	≥ 1
Harvest Power, Inc.	Massachusetts	2008	GICON Bioenergie GmbH	≥ 0	≥ 1
Eisenmann Corporation	Germany (subsidiary in Illinois)	1977	NR	≥ 0	≥ 2
Turning Earth, LLC.	Denmark (subsidiary in Georgia)	2009	Solum Group, Aikan A/S	≥ 0	≥ 1
EcoCorp, Inc.	Maryland	2000	NR	≥ 0	≥ 0

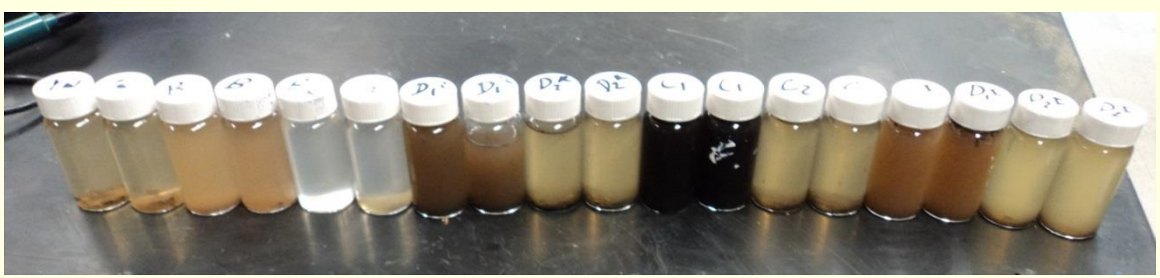
US Technology Characteristics

Vendor Name	Operating Temperature	TS Content	Loading Conditions	Number of Stages	Retention Time	Parasitic Energy Demand
Zero Waste Energy, LLC	Thermophilic	< 50%	Batch	1	21 days	20%
CleanWorld Corporation (formerly CleanWorld Partners, LLC)	Thermophilic	~10%	Continuous	3	20-30 days	
Orbit Energy, Inc.	Thermophilic	< 45%	Continuous	1	"short"	8%
BIOFerm Energy Systems	Mesophilic	25-35%	Batch	1	28 days	5-10%
Organic Waste Systems, Inc.	Thermophilic or Mesophilic	< 50%	Continuous	1	20 days	NR
Harvest Power, Inc.	Thermophilic	NR	Batch	2	≥ 14 days	NR
Eisenmann Corporation	Thermophilic	NR	Continuous	1	NR	NR
Aikan North America, Inc.	Thermophilic	NR	Batch	2	NR	NR
EcoCorp, Inc.	Thermophilic	35-40%	Continuous	1	20 days	20%

NR = Not Reported; Information reported here was derived from technology vendor websites and personal communications

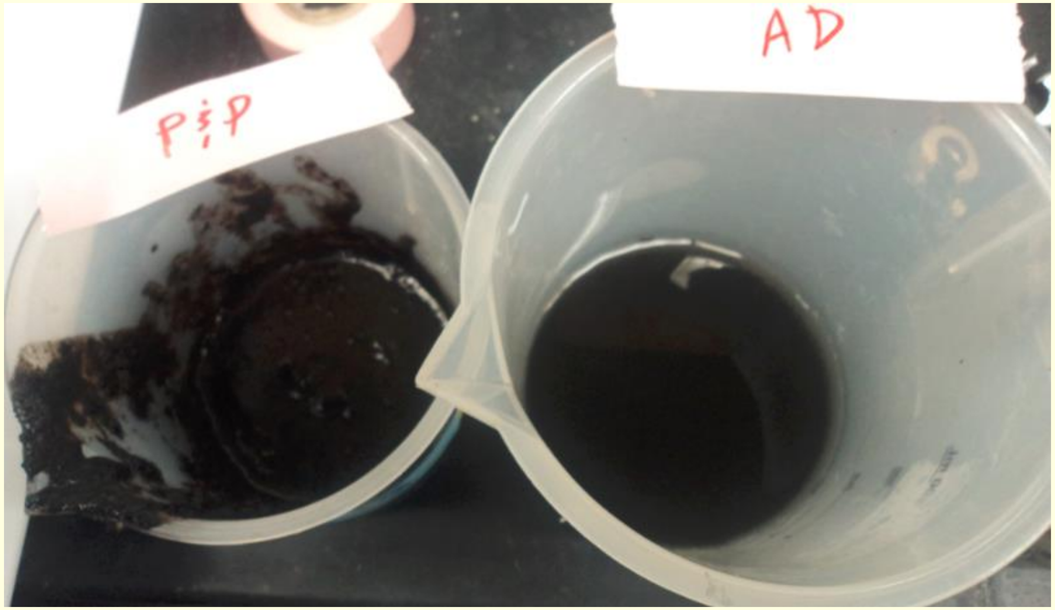
Materials and Methods Cont'd



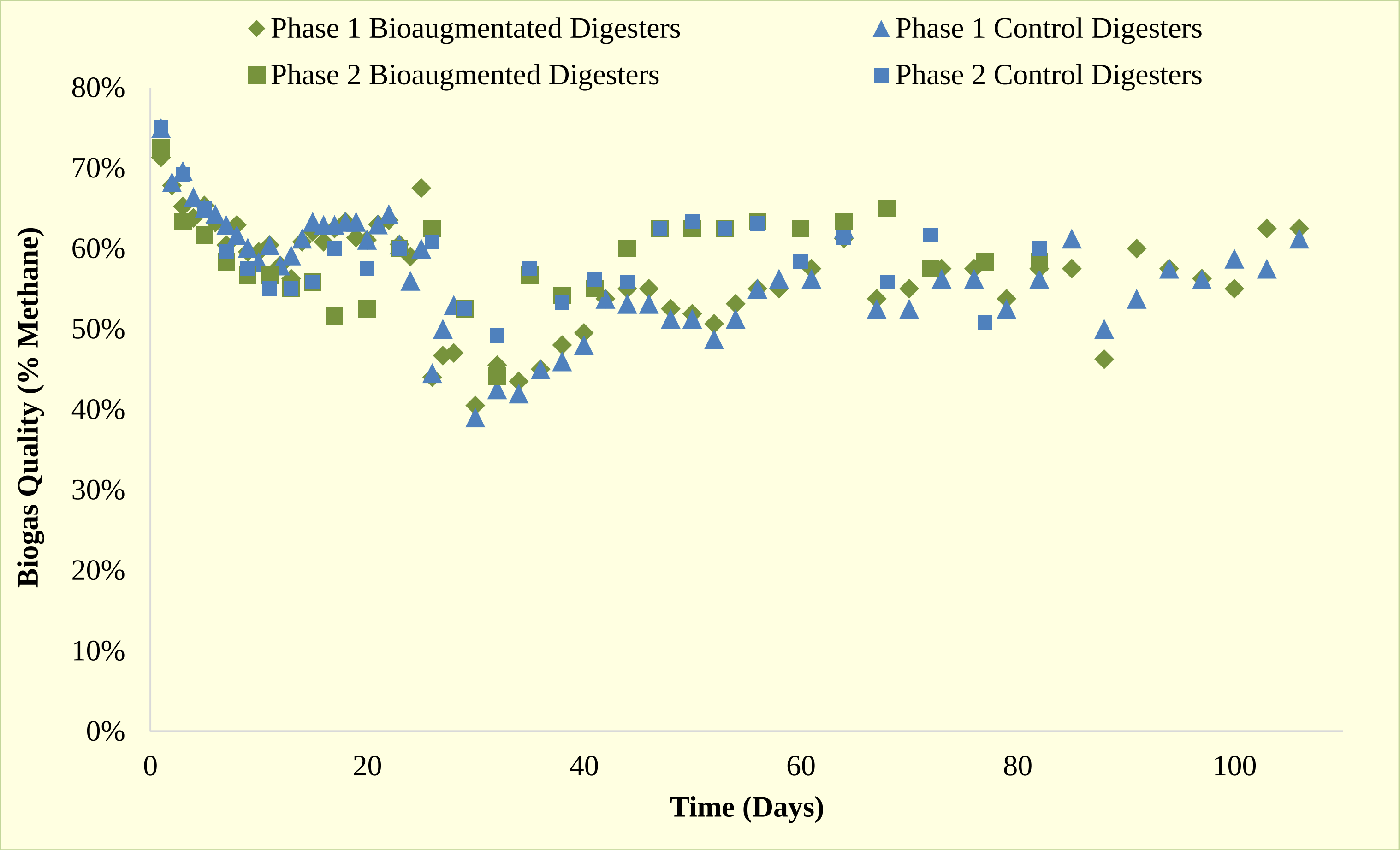


Inocula and Substrate Characterization

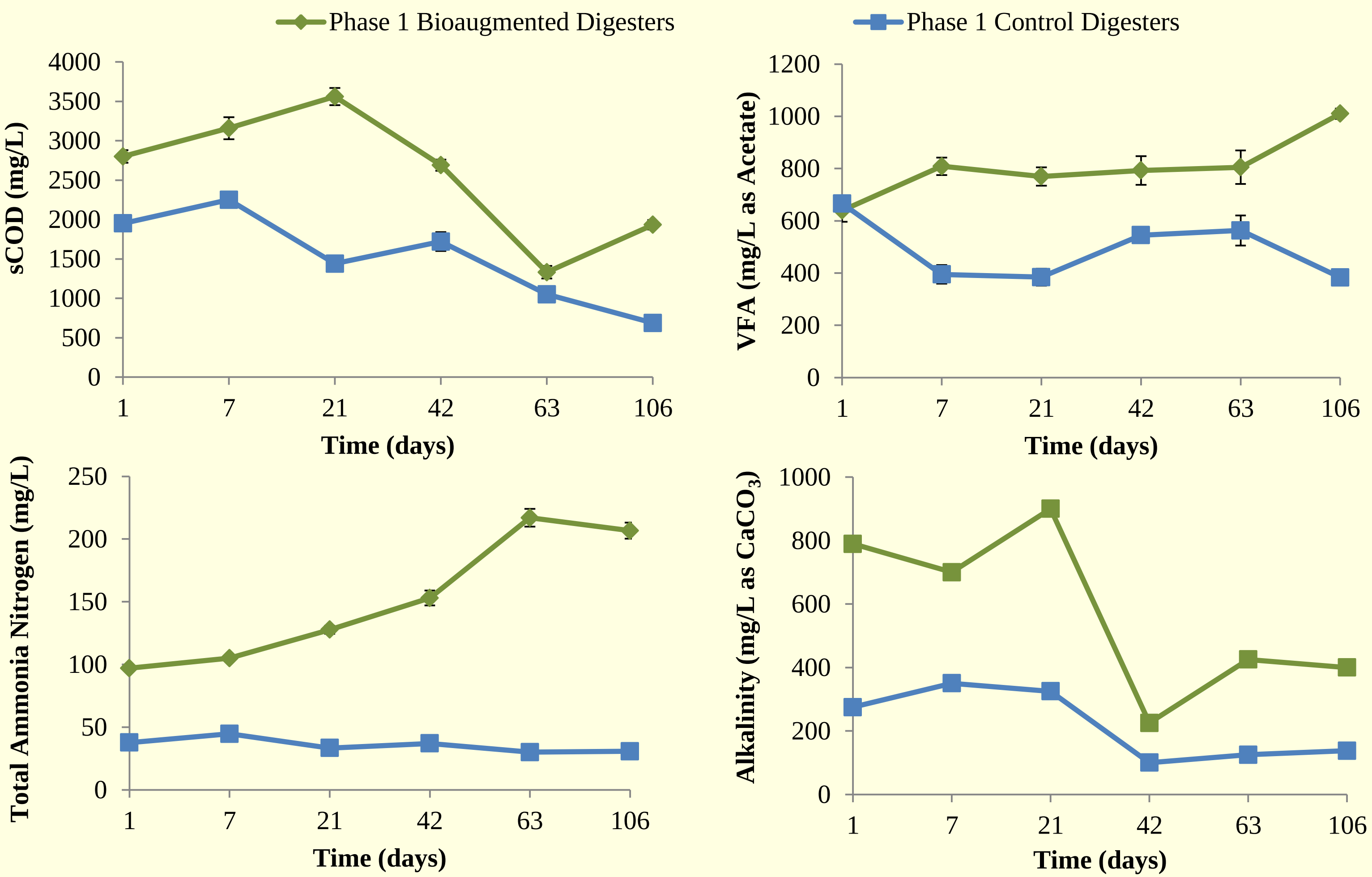
	Pulp and Paper Sludge	Wastewater Sludge	Yard Waste for Phase 1 Batch HS-AD	Digestate from Phase 1 Bioaugmented Digesters	Digestate from Phase 1 Control Digesters	Yard Waste for Phase 2 Batch HS-AD
Alkalinity (mg/L as $CaCo_3$)	2,100	580	50	400	140	25
TS (% of wet weight)	10.0 ± 0.2	0.6 ± 0.0	50.8 ± 3.4	18.5 ± 0.1	23.7 ± 0.3	64.2 ± 0.5
VS (% of wet weight)	8.4 ± 0.1	0.4 ± 0.0	46.4 ± 2.9	16.6 ± 0.1	21.7 ± 0.2	60.1 ± 0.4



Biogas Quality



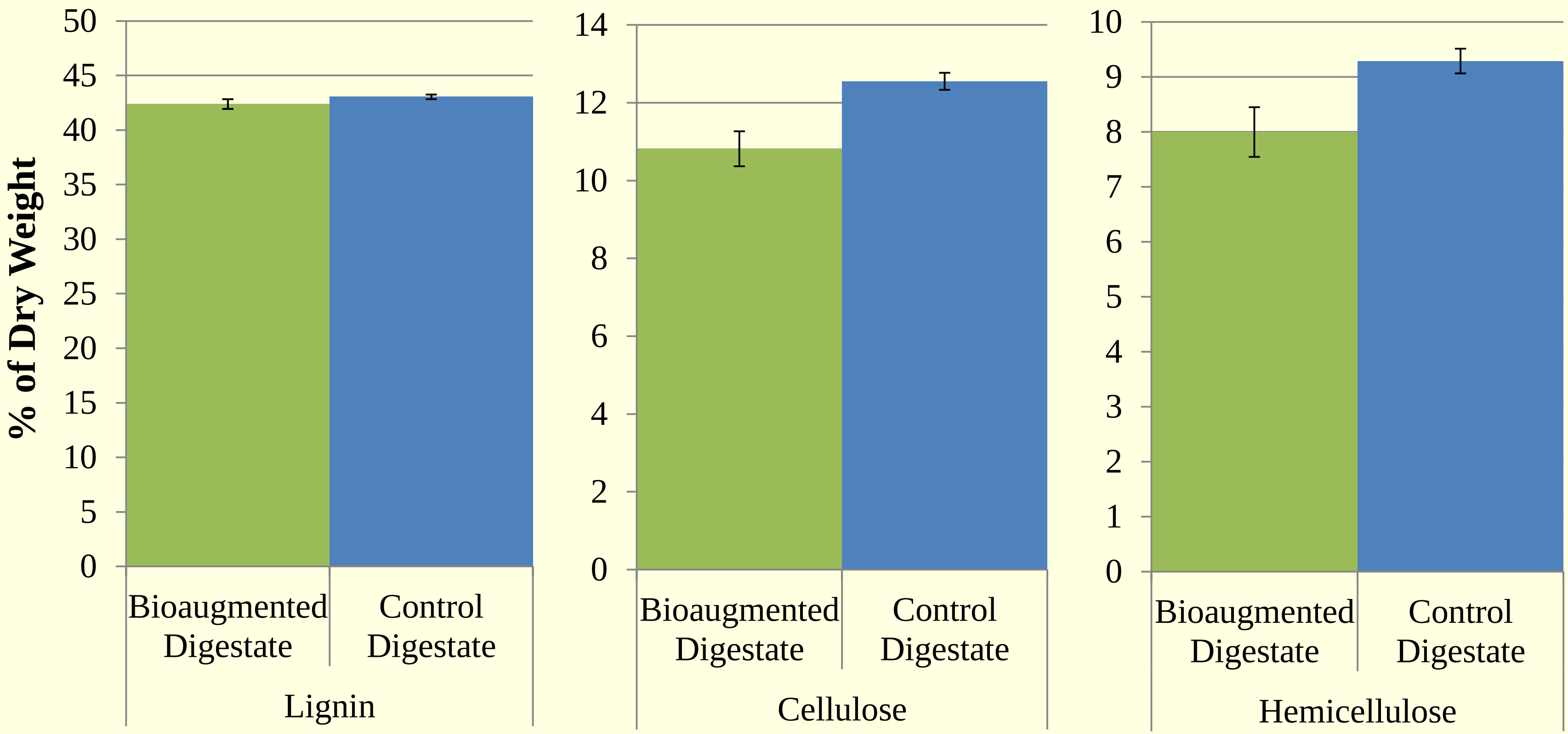
Chemical Analysis



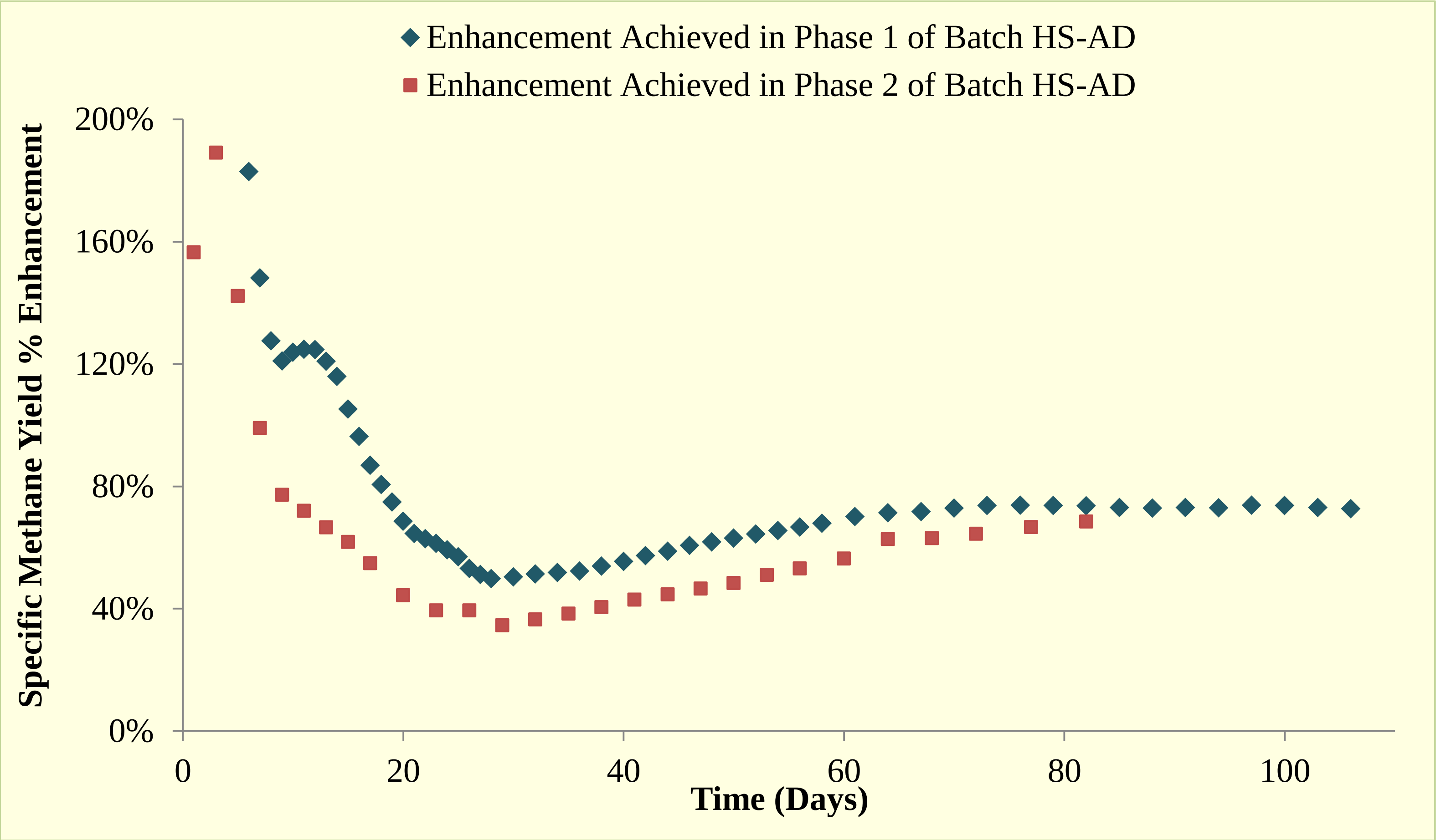
pH = 7.1-8.4 (in bioaugmented digesters); 6.3-8.0 (in control digesters)

Lignocellulosic Analysis

- Lignin, cellulose, and hemicellulose contents in the bioaugmented digestate were 2%, 16%, and 16% less, respectively, than in the control digestate



Methane Yield Enhancements



Benefits of HS-AD Implementation in FL

	Yard Waste	Food Waste	Total
Assumed Generation Rate (short tons/year) =	3,700,000	2,200,000	5,900,000
Assumed Volatile Solids Fraction (% by wet weight) =	0.60	0.15	
Assumed Biogas Generation (m^3/kg VS) =	0.30	0.50	
Total Energy Content (GWh/year) =	3,520	870	**4,390**
Total Electricity Generation Potential (GWh/year) =	1,230	300	**1,530**
Total Electricity Generation in Florida (GWh/year) =			246,200
Fraction of Florida Electricity Demand Fulfilled =	0.5%	0.1%	**0.6%**
OR:			
CNG Generation (DGE/year) =	63,400,000	15,700,000	**79,100,000**
Total CNG Consumption in Florida (DGE/year) =			688,000,000
Fraction of Florida CNG Demand Fulfilled =	9.2%	2.3%	**11.5%**

Note: Assumes 9.7 kWh-m^{-3} CH_4, 9.8 kWh-L^{-1}diesel, 35% electrical conversion efficiency, and 67% CNG conversion efficiency; mass conversion factor = 907 kg per short ton

	Nitrogen	Phosphorous
Assumed Digestate Generation Rate (short tons/year) =	3,540,000	3,540,000
Assumed Total Solids Content (%) =	20%	20%
Assumed Available Fraction (%) =	1.0%	0.5%
Nutrient Recovery Potential (short tons/year) =	**7,080**	**3,540**

Note: Assumes 40% mass reduction in HS-AD; mass conversion factor = 907 kg per short ton

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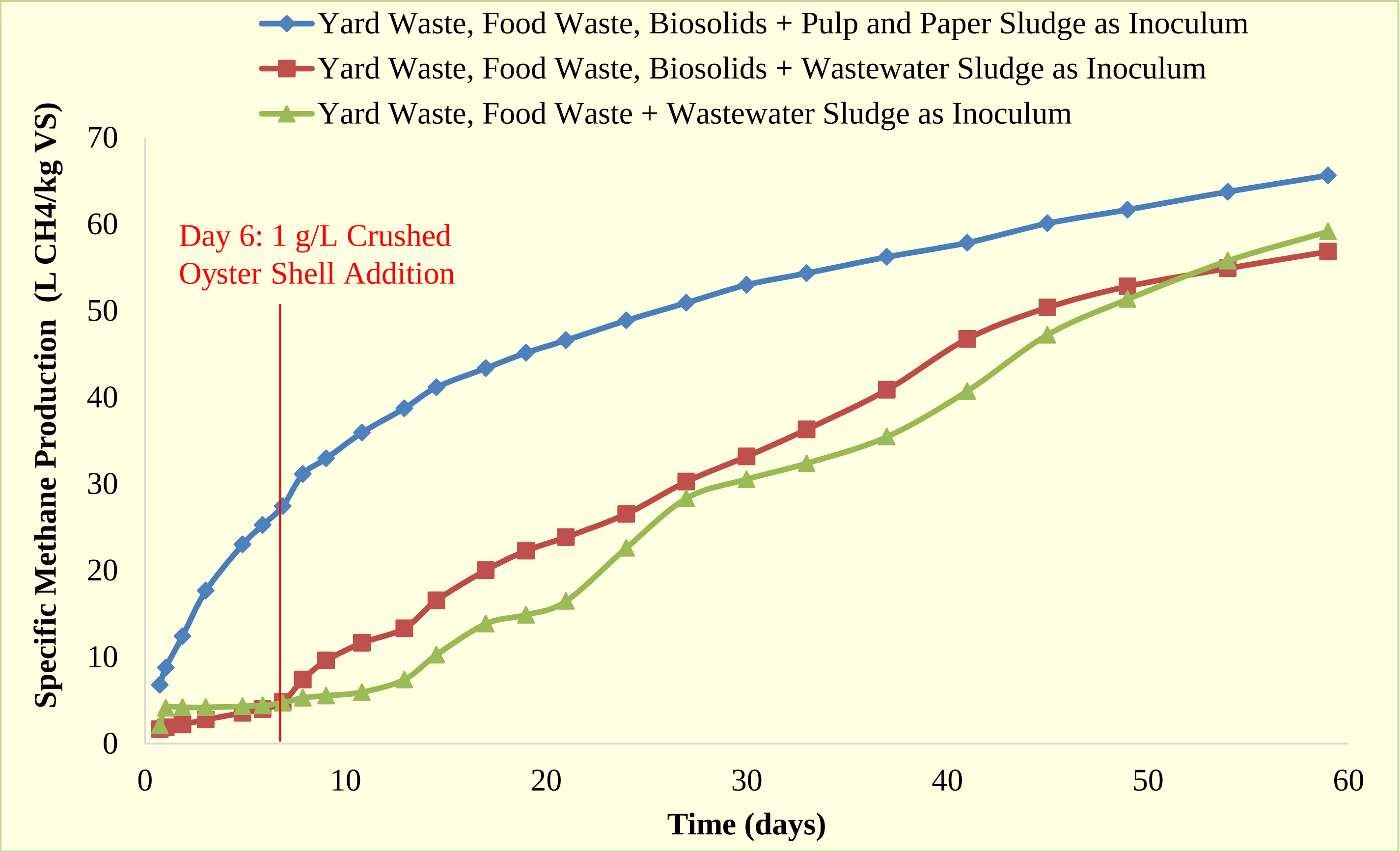
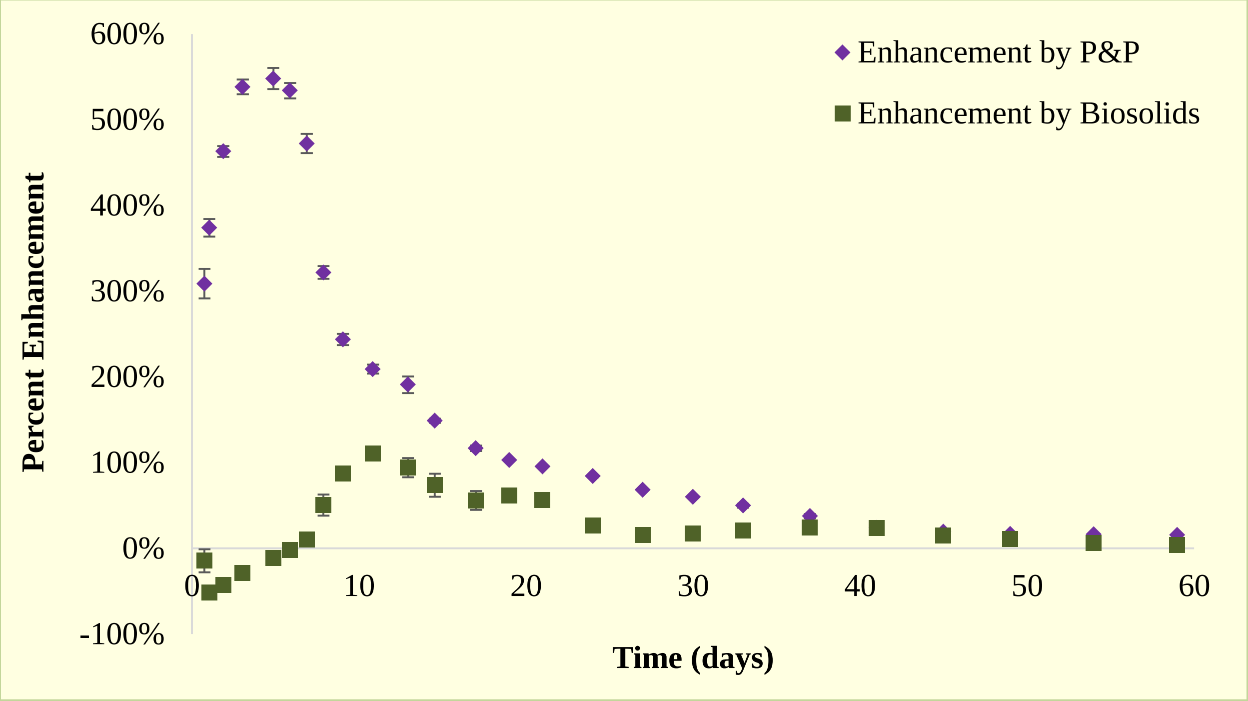
Preliminary Codigestion Study



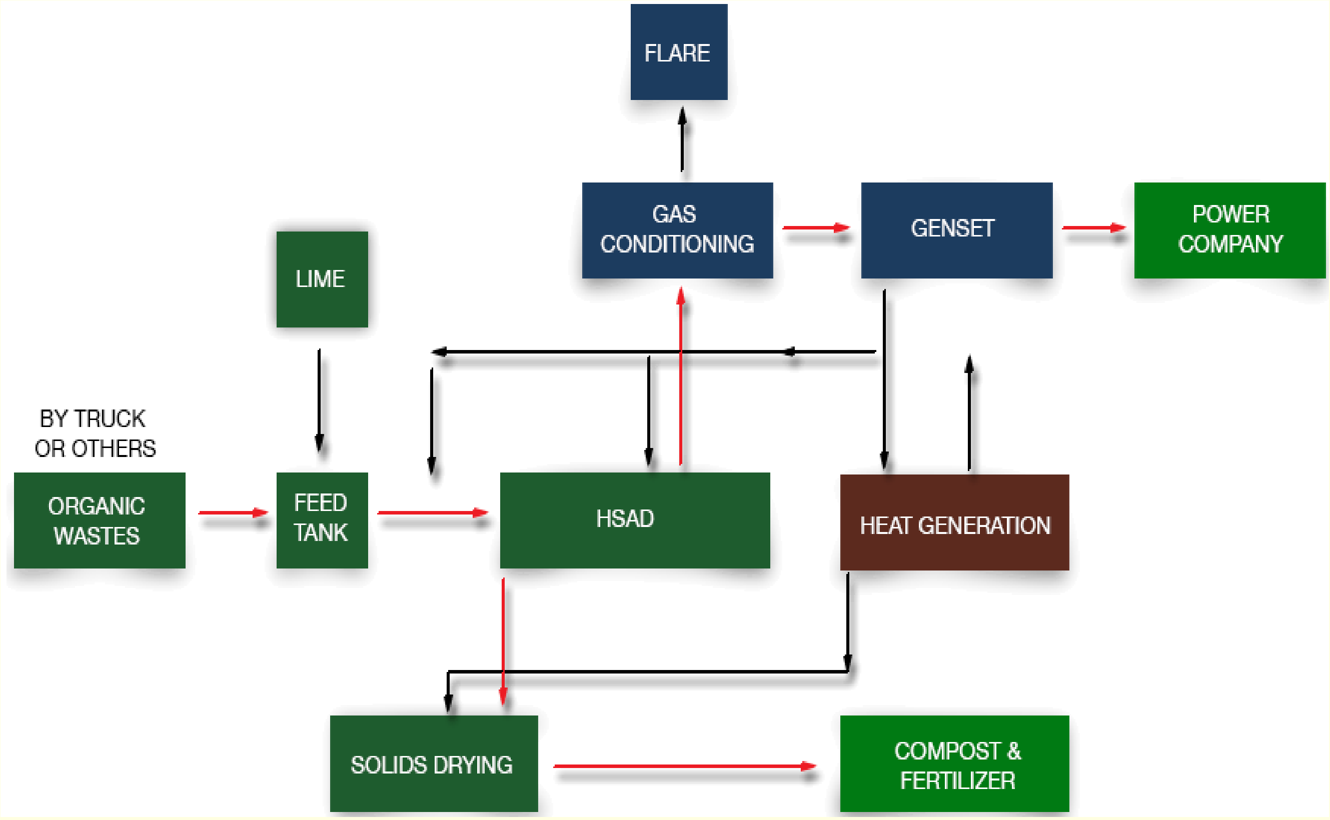
Preliminary Codigestion Study



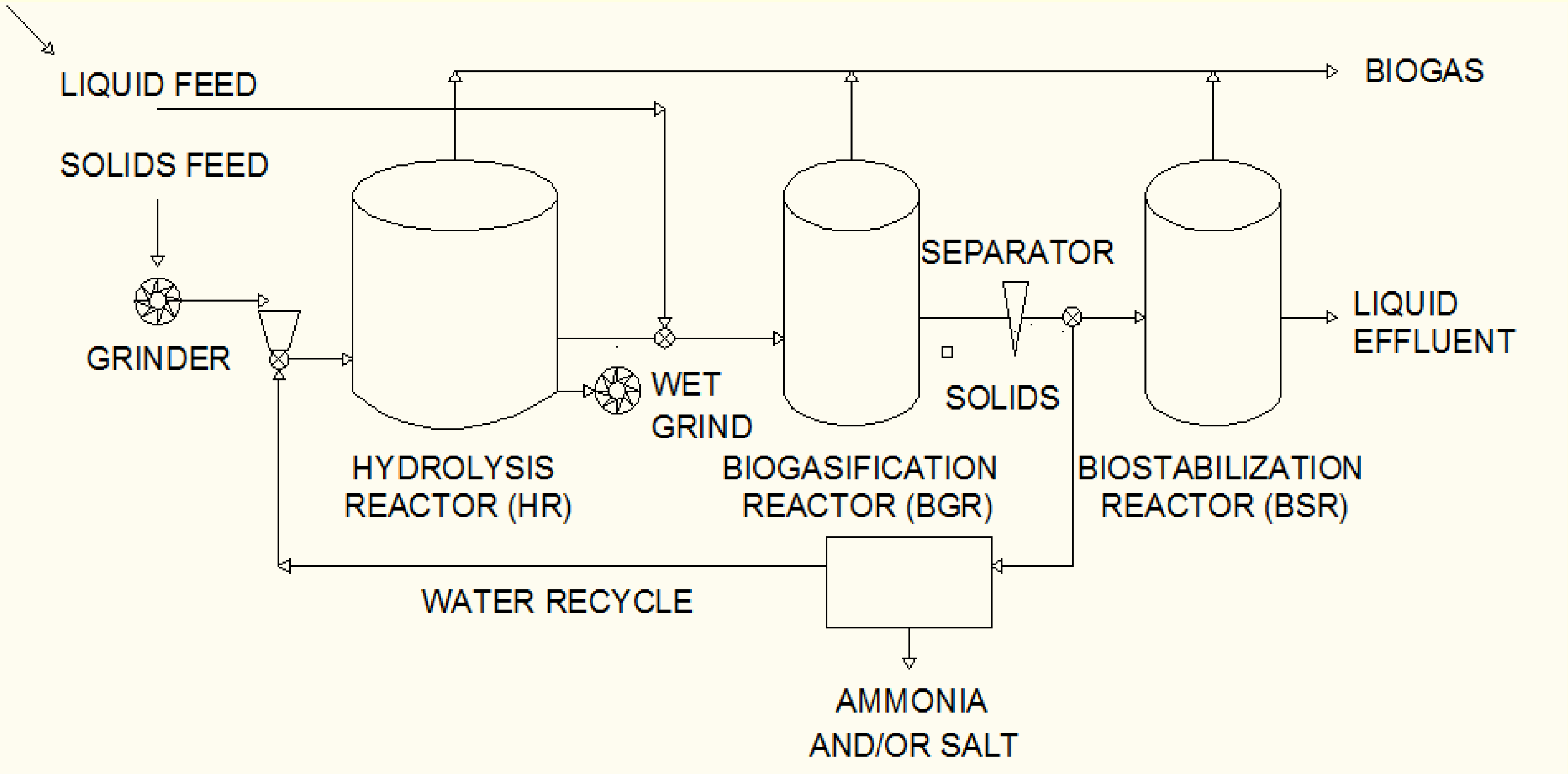
	D1	D2	D3	B1	B2
Yard Waste (g)	40	40	40	0	0
Food Waste (g)	5	5	5	0	0
Biosolids (g)	15	15	0	0	0
Wastewater Sludge (g)	0	90	67.5	0	90
Paper Mill Sludge (g)	90	0	0	90	0
Total mass	150	150	112.5	90	90

Orbit Energy Process

- Developed by the DOE
- Uses proprietary microbial consortium

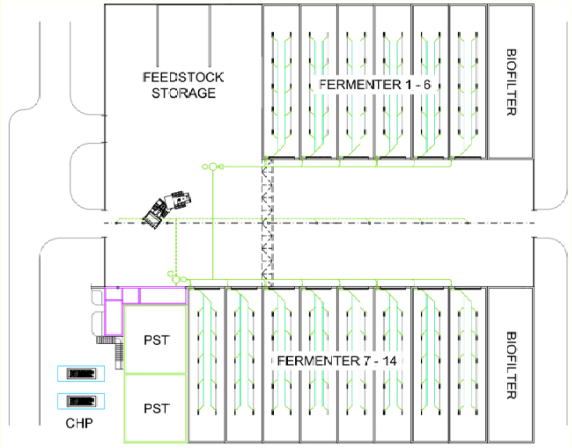


Clean World Technology

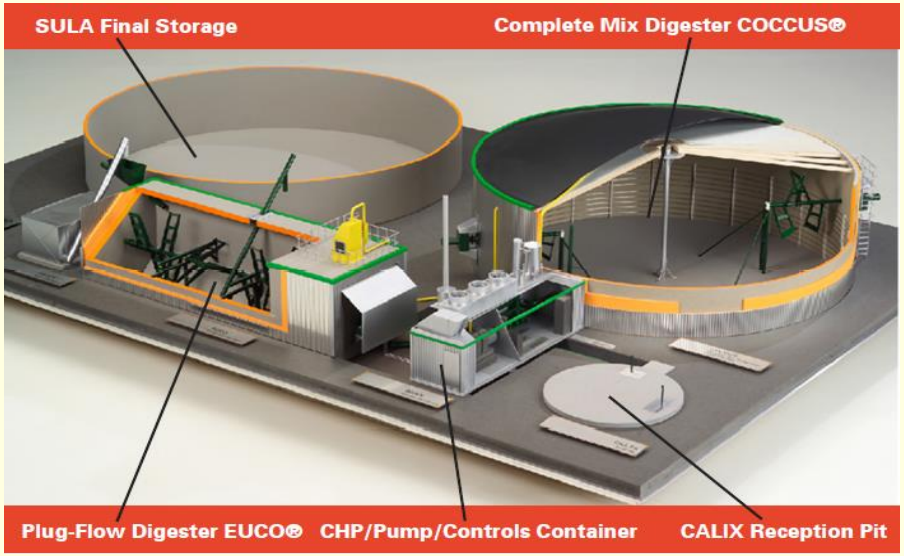


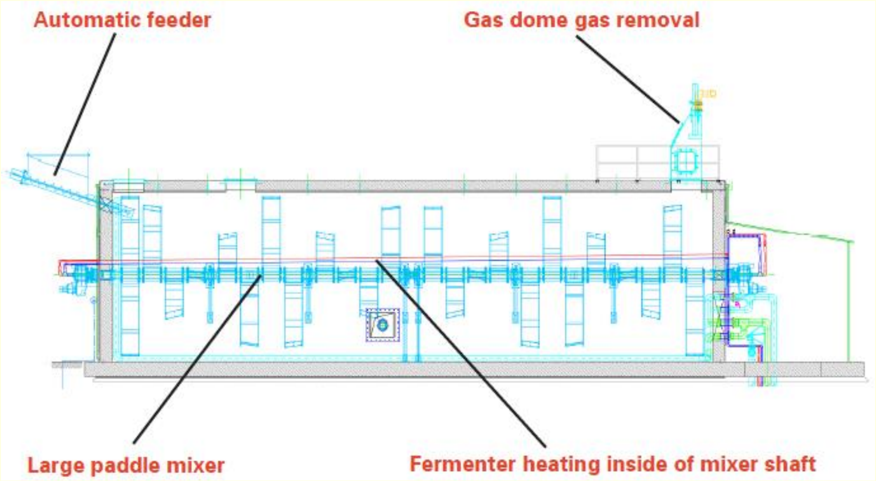
Clean World UC Davis

BIOFerm Dry Fermentation Technology and UW Oshkosh Facility

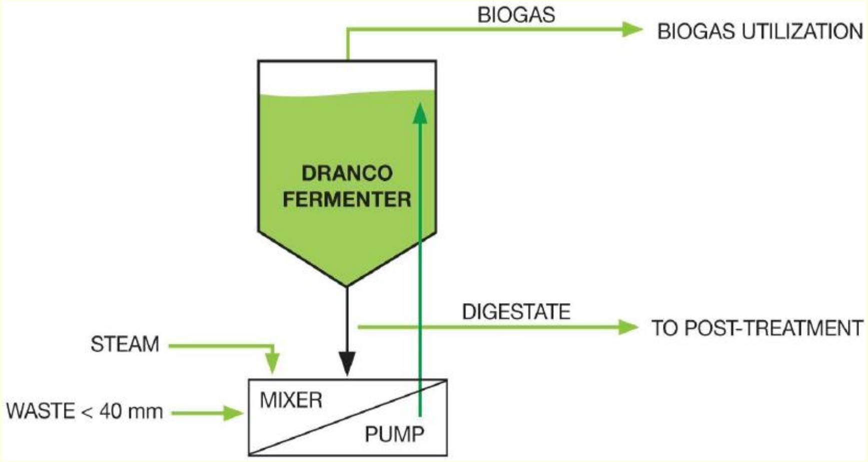


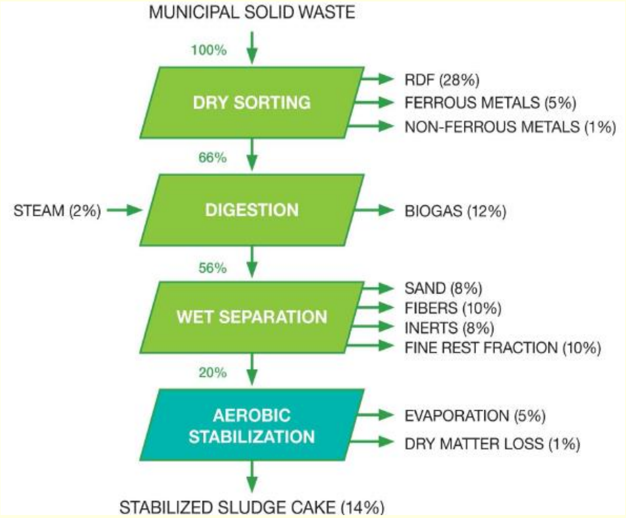
BIOFerm EUCO Technology



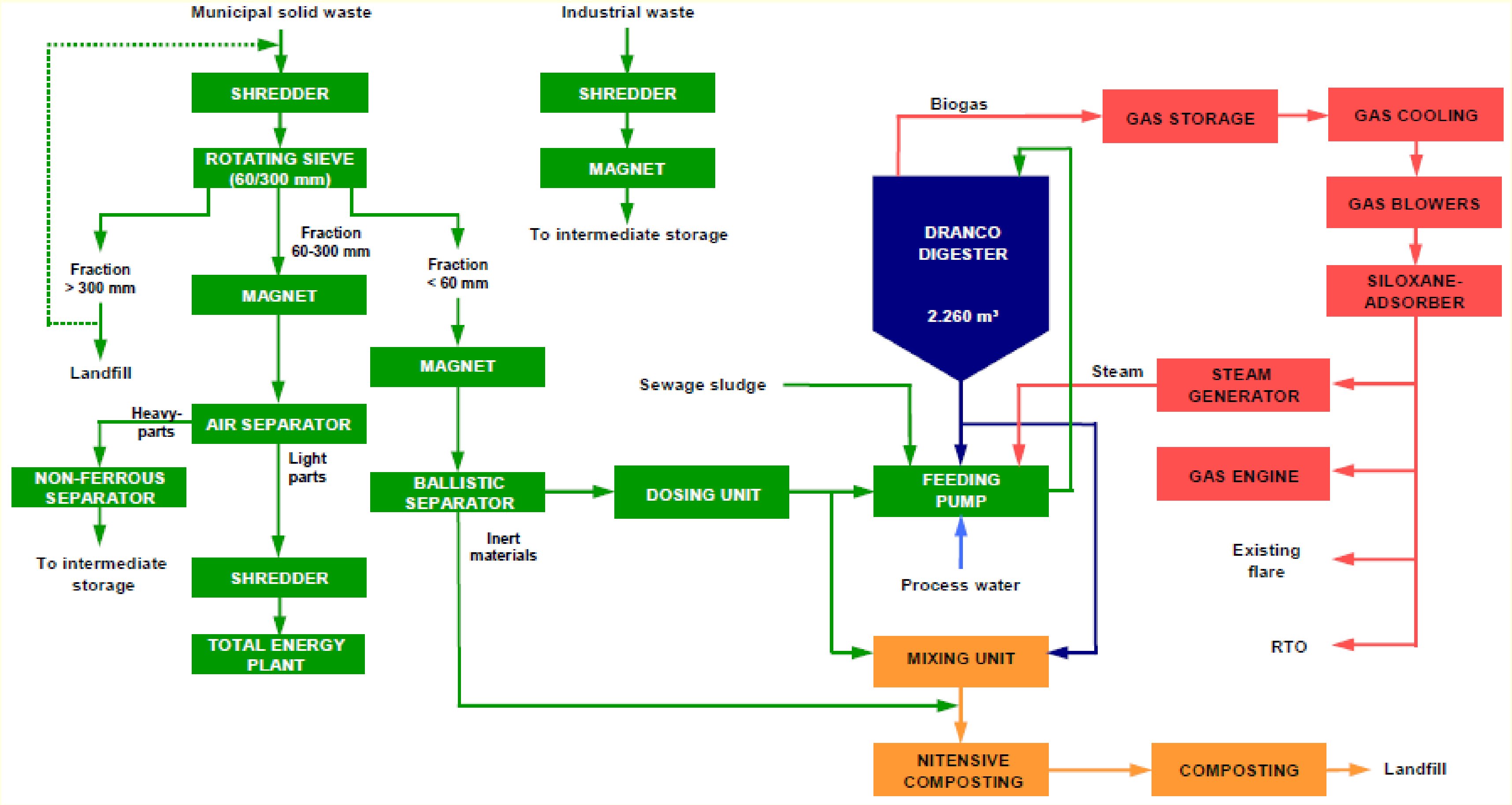


DRANCO Diagram, Sordisep Process, and Brecht I and II Facilities

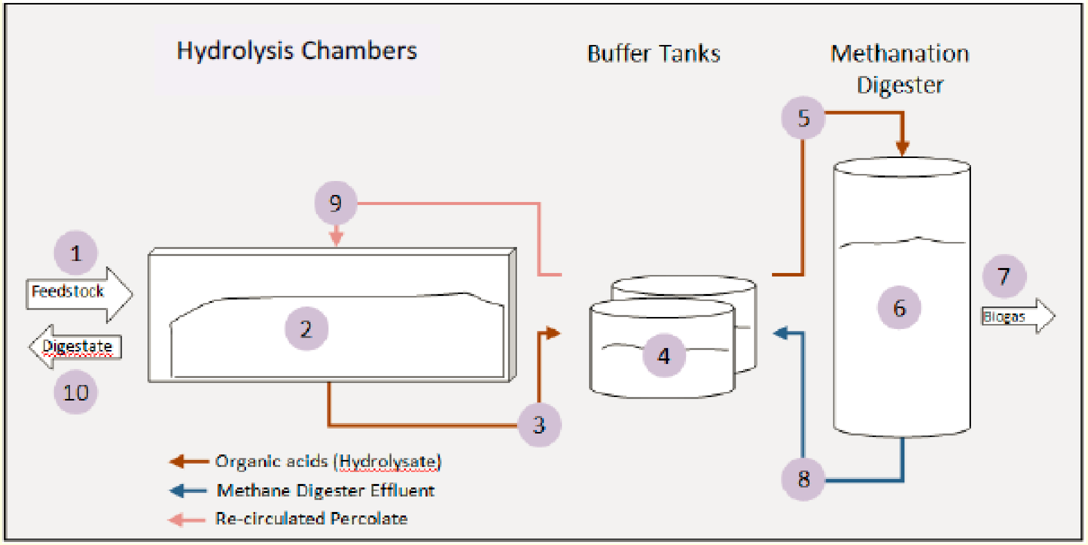




DRANCO Pohlsche Heide with Partial Steam Digestion



Harvest Power HS-AD in BC



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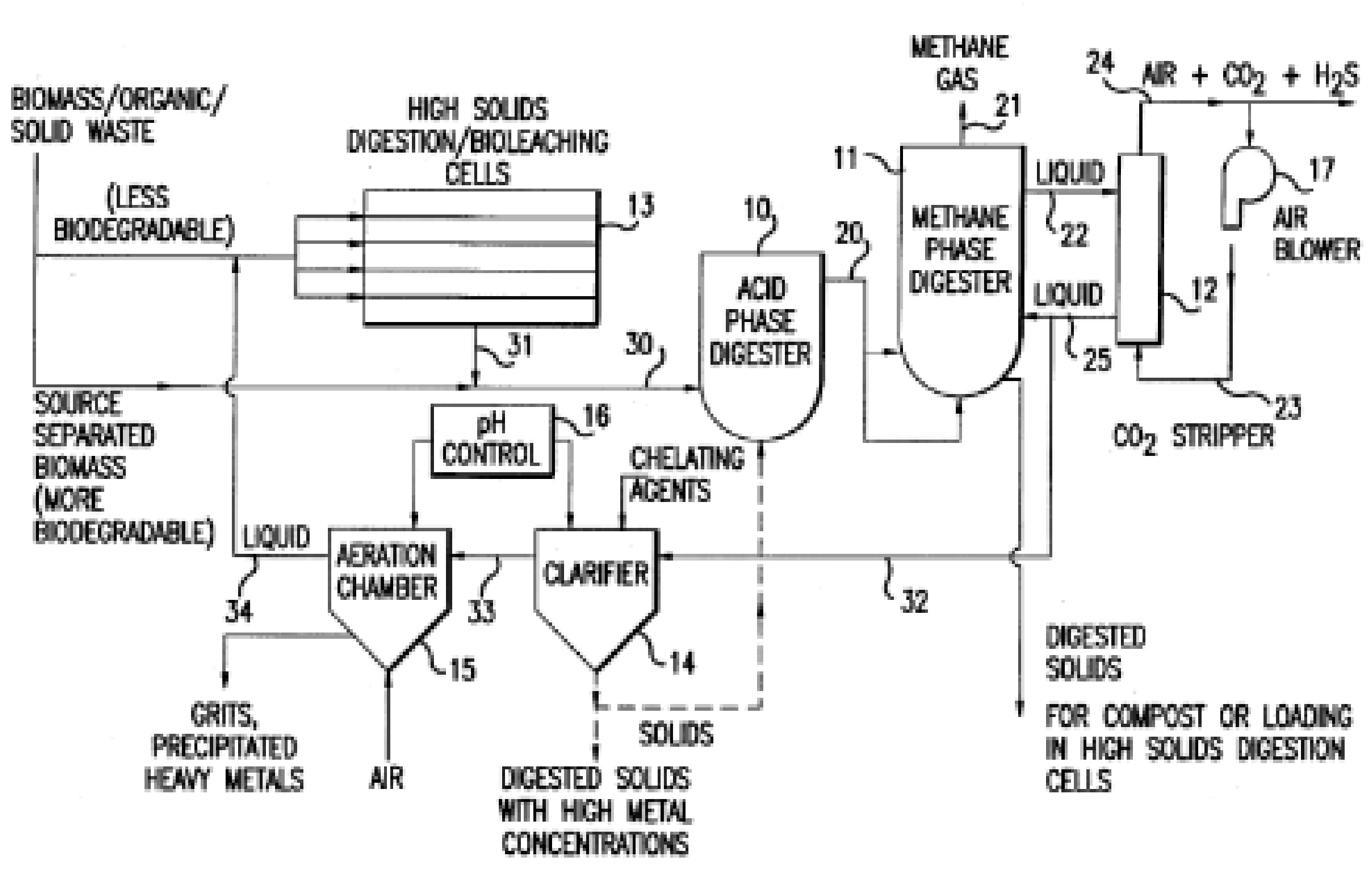
Aikan North America Technology



Aikan North America Hartford, CT

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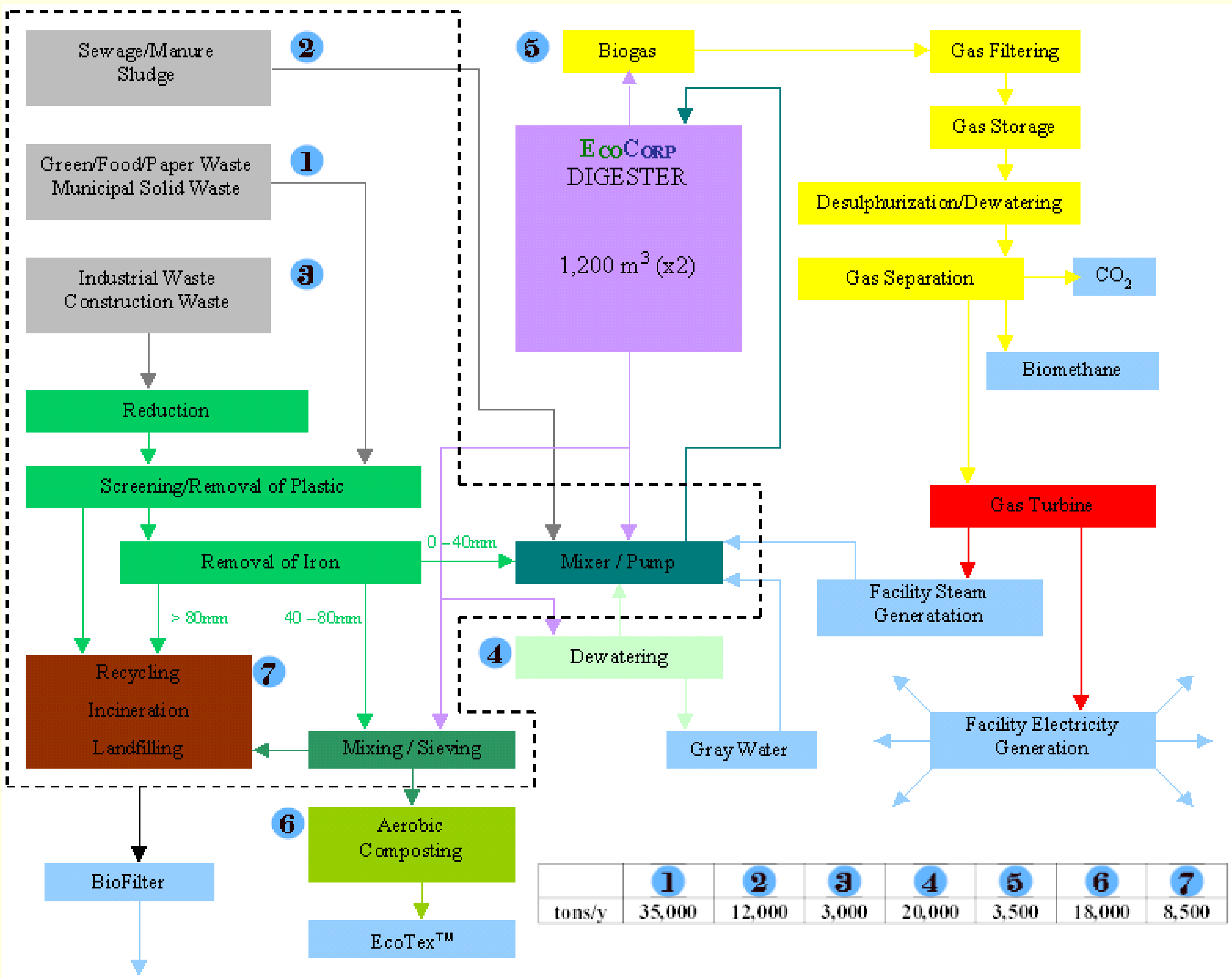
EcoCorp Process Diagram



	1	2	3	4	5	6	7
tons/y	35,000	12,000	3,000	20,000	3,500	18,000	8,500

ZWE San Jose Process Diagram