Phase II Bioenergy Production from MSW by High Solids Anaerobic Digestion

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2017 Quarterly Report # 3

July 3, 2017- Oct 6, 2017

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LIST OF ACRONYMS AND ABBREVIATIONS

B	Biosolids
$CaCO_3$	Calcium Carbonate
CH_4	Methane
CHP	Combined Heat and Power
FW	Food Waste
HS-AD	High Solids Anaerobic Digestion
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCI	Life Cycle Inventory
MSW	Municipal Solid Waste
NH_4^+	Ammonium
OFMSW	Organic Fraction of Municipal Solid Waste
OS	Oyster Shells
PV	Present Value
TS	Total Solids
VFA	Volatile Fatty Acids
VS	Volatile Solids
WtE	Waste to Energy
YW	Yard Waste (also known as green waste)

QUARTERLY REPORT #3

PROJECT TITLE: Phase II Bioenergy Production from MSW by High Solids Anaerobic Digestion

PERFORMANCE PERIOD: July 3, 2017-October 6, 2017

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The overall goal of this project is to improve the environmental and economic sustainability of HS-AD of OFMSW in Florida. Specific objectives for Phase II are to:

1. Investigate the performance of HS-AD of OFMSW with varying substrate ratios (yard waste [YW], food waste [FW], biosolids) and temperatures (35, 55 °C).
2. Apply life cycle analysis (LCA) to guide the selection of waste sources and operating conditions for HS-AD.
3. Compare HS-AD with other waste management options (e.g., landfilling, waste to energy (WtE), composting) to ensure economic and environmental sustainability.

WORK ACCOMPLISHED DURING THIS REPORTING PERIOD

Objective 1: Investigate HS-AD performance with varying substrates and temperatures

Bench experiment with addition of biosolids in HS-AD of FW+YW: The reactor set-up conditions for the second bench-scale experiment were described in the second quarterly report. Briefly, the goal for the second bench-scale experiment was to quantify the effects of biosolids addition in HS-AD of FW+YW. Figure 1 (a) and (b) shows the results of the cumulative biogas production and CH_4 yields for HS-AD with FW+YW and FW+YW+B, respectively. Both FW+YW and FW+YW+B digester sets had low pH on day 14, which caused low CH_4 production (Table 1, Figure 1). To increase pH, crushed oyster shells (1.5 g) as additional alkalinity sources were added to the digesters on day 15. As shown in Figure 1, after adding additional alkalinity, CH_4 production from digesters for FW+YW+B was significantly higher than that of the digesters for FW+YW. Table 1 shows that FW+YW+B had a higher alkalinity concentration when compared to FW+YW. Thus, addition of biosolids can improve the CH_4 yield as well as increased the alkalinity concentration in the digesters.

(a) (b)

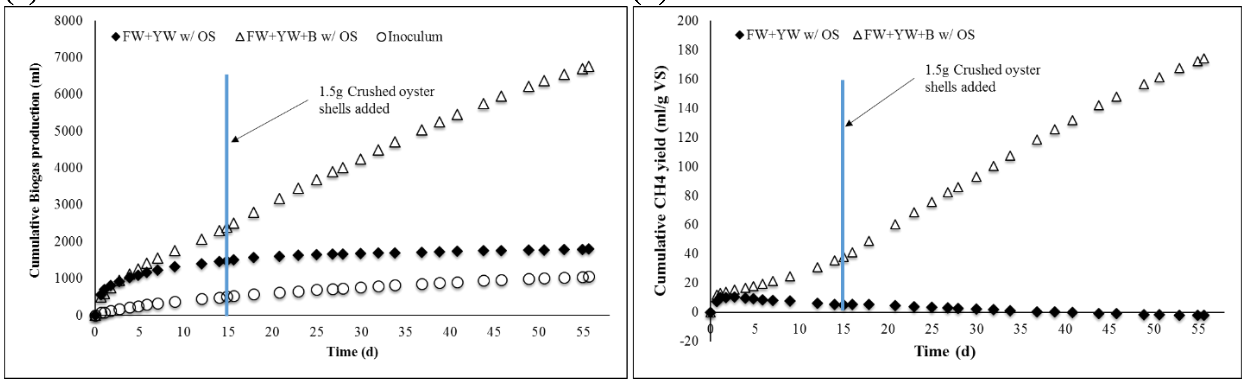

Figure 1. Biogas production of the HS-AD: (a) cumulative biogas production and (b) CH_4 yields.

Table 1. Results of chemical analysis for addition of biosolids in HS-AD using FW and YW.

Item	FW+YW w/OS				FW+YW+B w/ OS			
	Day 0	Day 14	Day 28	Day 56	Day 0	Day 14	Day 28	Day 56
TS (g/g)	0.20±0.01	0.18±0.01	0.18±0.02	0.18±0.01	0.20±0.00	0.18±0.00	0.18±0.00	0.16±0.00
VS (g/g)	0.17±0.01	0.15±0.01	0.15±0.02	0.14±0.00	0.17±0.00	0.13±0.01	0.13±0.01	0.12±0.01
pH	6.99±0	5.13±0.02	5.37±0.01	5.36±0.01	6.95±0.01	5.69±0.03	7.88±0.07	8.59±0.19
VFA (mg/L)	1,722±359	17,914±1,583	21,611±231	22,067±109	3,449±112	15,612±787	11,238±1,447	4,427±2,428
Alkalinity (mg $CaCO_3$/L)	550±6	933±59	5,396±96	6,230±240	563±19	485±109	6,318±702	9,302±2,000
sCOD (mg/L)	23,834±832	59,562±3,123	67,430±1,180	62,814±2,596	46,017±1,298	46,137±2,015	46,137±2,015	46,137±2,015
TN (mg/L)	904±15	2,216±76	2,672±43	3,158±98	1,097±31	2,705±156	2,952±225	3,249±400
NH_4^+-N(mg/L)	407±4	1,323±40	1,736±36	1,875±56	423±7	1,978±21	2,945±79	2,624±59
VFA/Alkalinity	3.13	19.2	4.01	3.54	6.13	32.2	1.78	0.48

Bench experiment with varying substrate ratios (FW+YW+B): In this study, the substrate ratio was varied: FW+YW+B_1 (1:1:1 by TS) and FW+YW+B_2 (1.4:3.1:1 by TS) (Figure 2). As shown in Figure 3, after 2 days, CH_4 production from both digesters was significantly reduced due to low pH (Table 2). Although the digesters contained crushed oyster shells as an additional alkalinity source (2g crushed oyster shells), the digester was not able to maintain the neutral pH because the rate of dissolution of oyster shells was relatively slow (Sengupta et al., 2007). The challenge related to low pH was encountered during this study and the results were inconclusive. Thus, additional experiments are being carried out to investigate optimal substrate ratio for the HS-AD using FW+YW+B during the 4th quarterly period. In addition, the inoculum is being slowly acclimated to the substrate using a larger fed batch flow reactor.

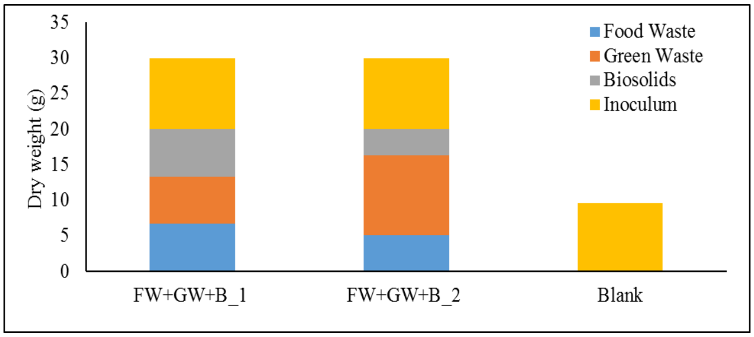

Figure 2. Digester compositions.

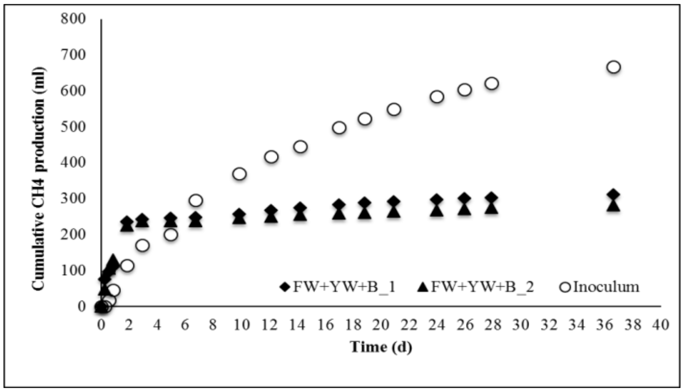

Figure 3. Cumulative CH_4 production for different substrate ratios.

Table 2. Results of chemical analysis for varying substrate ratios.

Item	FW+YW+B_1		FW+YW+B_2		Blank (Inoculum only)	
	Day 0	**Day 14**	**Day 0**	**Day 14**	**Day 0**	**Day 14**
TS (g/g)	0.20±0.01	0.19±0.006	0.20±0.01	0.19±0.01	0.20±0.001	0.19±0.001
VS (g/g)	0.17±0.01	0.15±0.01	0.17±0.01	0.15±0.01	0.14±0.002	0.14±0.001
pH	6.72±0	5.66±0.03	6.97±0.01	5.38±0.06	8.23±0.01	8.39±0.03
VFA (mg/L_	3,092±333	10,894±459	2,940±66	13,946±764	271±1	310±17
Alkalinity (mg $CaCO_3$/L)	1,015±12	2,889±50	1,079±6	1,694±113	1,694±6	3,455±49
sCOD (mg/L)	13,682±2,083	22,501±810	12,215±347	21,123±897	4,913±375	2,741±21
TN (mg/L)	1,008±31	2,168±32	963±60	2,026±98	1,082±17	1,207±82
NH_4^+-N(mg/L)	444±37	1,510±90	459±15	1,466±38	731±12	1,160±25

Bench experiment using mixture of fast and slow release alkalinity sources: To maintain a neutral pH in the digester, different ratios of fast and slow release alkalinity sources were used for the HS-AD of FW+YW+B (Figure 4). In this study, sodium bicarbonate and crushed oyster shells were used as fast and slow release alkalinity sources, respectively. As shown Figure 5, low CH_4 content in the biogas has been observed for all digesters, even though these digester sets had the addition of the fast release alkalinity source. Chemical analysis of the digestates are currently being carried out and the results will be updated in the 4th quarterly report. Based on the data for chemical analysis, additional experiments will be carried out to investigate an optimal ratio of alkalinity sources for the HS-AD using FW+YW+B during the 4th quarterly period.

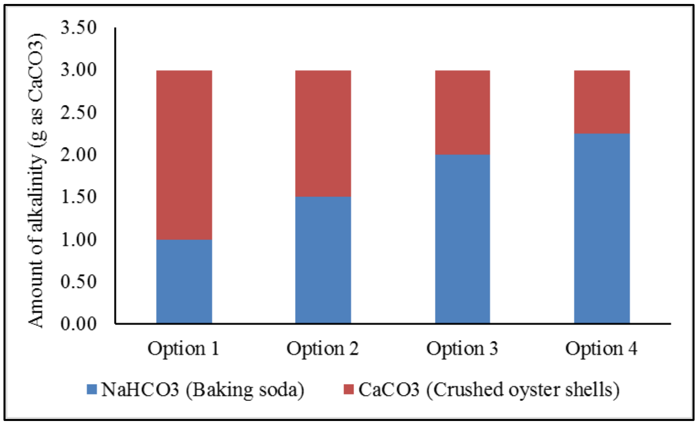

Figure 4. Different ratios of alkalinity sources added in the HS-AD.

(a) (b)

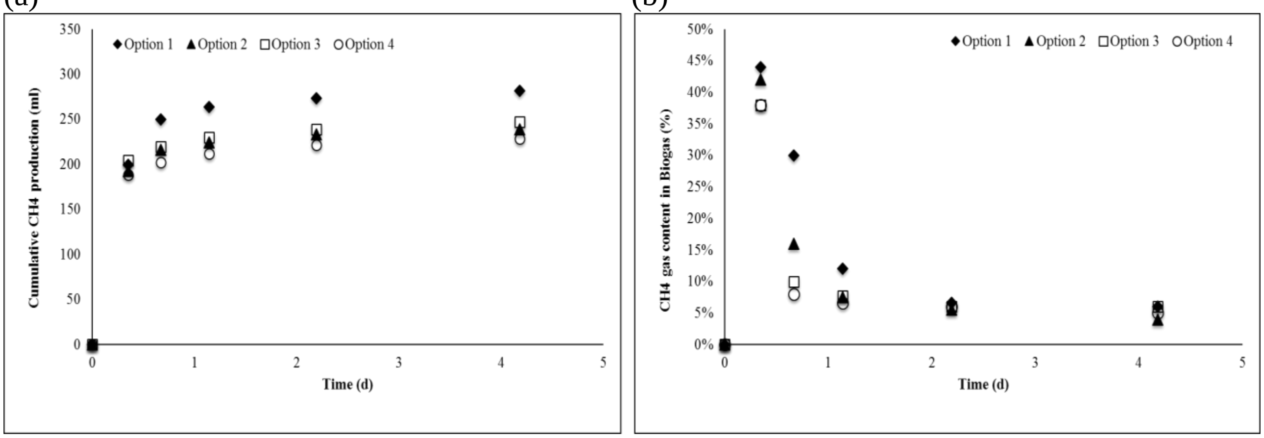

Figure 5. Biogas production of the HS-AD with different ratios of alkalinity mixture: (a) cumulative CH_4 production and (b) CH_4 content in biogas.

Objective 2: Apply life cycle assessment (LCA) to guide the selection of waste sources and operating conditions for HS-AD

An Excel based program has been developed to conduct the life cycle inventory (LCI) for HS-AD. Input data for the Excel program includes system's specifications (e.g., digesters' dimensions, annual capacity, percent occupation, retention time, percolate tank dimensions, pipe dimensions) and operational information related to waste composition and CH_4 yield (e.g., dry composition, moisture content, Total Solids (TS), Volatile Solids (VS), and average heat capacity). The Excel program can be modified to calculate the inventory for HS-AD with other operating conditions, such as different operating temperatures, annual capacity, and dimensions. The inventory for HS-AD (mesophilic condition, annual capacity: 60,263 tons waste) is shown on Table 3. LCA results for HS-AD with mesophilic and thermophilic conditions will be presented in the 4th quarterly report.

Table 3. Summary table for HS-AD LCI from Excel Program.

Materials		
Concrete		
Concrete for Digesters	0.0799	kg/kg Wet Waste
Concrete Percolate Tank	5.75E-04	kg/kg Wet Waste
Total Concrete	0.0805	kg/kg Wet Waste
Steel		
Rebar Concrete Digester	3.66E-03	kg/kg Wet Waste
Digesters' Gas-tight Doors	7.55E-06	kg/kg Wet Waste
Percolate Tank (BioFerm)	4.64E-04	kg/kg Wet Waste
Piping Aeration Phase	3.68E-05	kg/kg Wet Waste
Piping Biogas Stream	1.39E-05	kg/kg Wet Waste
Piping Exhaust Gas Stream	2.13E-06	kg/kg Wet Waste
Total Steel	0.0042	kg/kg Wet Waste
Polyurethane		
Solid Polyurethane Foam Gas-tight Door Insulation	7.72E-06	kg/kg Wet Waste
Solid Polyurethane Foam Digester Insulation	5.85E-04	kg/kg Wet Waste
Solid Polyurethane Percolate Tank Insulation (BioFerm)	3.31E-05	kg/kg Wet Waste
Total Polyurethane	6.26E-04	kg/kg Wet Waste
Polystyrene		
Solid Polystyrene Foam Digester Insulation	8.79E-05	kg/kg Wet Waste
Total Polystyrene	8.79E-05	kg/kg Wet Waste
Fiberglass Reinforced Plastic		
Fiberglass Reinforced Plastic Digester Insulation	1.28E-03	kg/kg Wet Waste
Polyvinyl Chloride (PVC)		
PVC Piping Percolate Circulation (BioFerm)	2.20E-06	kg/kg Wet Waste
PVC Biofilter Water System Piping	2.96E-08	kg/kg Wet Waste

Total PVC	2.23E-06	kg/kg Wet Waste
High-Density Polyethylene (HDPE)		
HDPE Biofilter Peat Tank	1.28E-05	kg/kg Wet Waste
HDPE Biogas Storage Bag (BioFerm)	1.63E-04	kg/kg Wet Waste
Total HDPE	1.76E-04	kg/kg Wet Waste
Peat (with a bulk density of 250 kg/m^3)		
Peat Biofilter	1.11E-04	kg/kg Wet Waste
Energy		
Digesters' Heat Requirement	61.51	kJ/kg Wet Waste
Digesters' Heat Losses	27.01	kJ/kg Wet Waste
Percolate Tank's Heat Losses (BioFerm)	2.59	kJ/kg Wet Waste
Percolate Circulation Pumping Electricity Requirement (BioFerm)	0.011	kJ/kg Wet Waste
Air Blower Electricity Requirement	1.066	kJ/kg Wet Waste
Biogas Collection Electricity Requirement	2.605	kJ/kg Wet Waste
Exhaust Gas Electricity Requirement	0.156	kJ/kg Wet Waste
Biofilter Water System Pump Electricity Requirement	0.002	kJ/kg Wet Waste
Biogas Water Removal Cooling Unit Electricity Requirement	1.135	kJ/kg Wet Waste
CHP Electricity production (37.3% efficiency)	270	kJ/kg Wet Waste
CHP Heat production (37.3% efficiency)	358	kJ/kg Wet Waste
Water		
Water requirement	0.0326	kg/kg Wet Waste

Objective 3: Compare HS-AD with other waste management options (e.g., landfilling, waste to energy (WtE), composting) to ensure economic and environmental sustainability

To calculate fuel consumptions for food and yard waste collection and transportation, our team has requested data for the amount of FW and YW treated in transfer stations in City of Tampa. Also, postdoctoral (Eunyoung Lee) and undergraduate (Eduardo Jimenez) researchers will visit the Mckay Bay Scale House (Tampa) on Oct 11th to obtain collection and transportation data. Thus, refined collection and transportation costs, the land acquisition cost, and life cycle cost (LCC) will be updated in the 4th quarterly report.

DISSEMINATION ACTIVITIES

1. Poster presentation at 2017 SWANA summer conference and Hinkley Center Colloquium in Fort Myers, FL, July 24-25, 2017

2. Poster presentation at Renewable Energy Systems and Sustainability Conference in Lakeland, FL, July 31-Auguest 1, 2017.

METRICS

1. List of graduate student and postdoctoral researchers funded by this Hinkley Center project:

Last name, first name	Rank	Department	Professor	Institution
Dixon, Phillip	PhD Student	Civil/ Environmental Engineering	Ergas	USF
Lee, Eunyoung	Postdoctoral Researcher	Civil/ Environmental Engineering	Zhang	USF
Wang, Meng	Postdoctoral Researcher	Civil/ Environmental Engineering	Ergas	USF

2. List of undergraduate researchers working on this Hinkley Center project:

Last name, first name	Rank	Department	Professor	Institution
Bittencourt, Paula	BS student	Mechanical Engineering	Ergas	USF
Jimenez, Eduardo	BS Student	Civil & Environmental Engineering	Ergas/Zhang	USF
Casimir, Lensey	BS Student	Civil & Environmental Engineering	Ergas	USF
Stolte Bezerra Lisboa Oliveira, Deborah	BS Student	Chemical & Biomedical Engineering	Zhang	USF
Stolte Bezerra Lisboa Oliveira, Luiza	BS Student	Chemical & Biomedical Engineering	Zhang	USF

3. List of research publications resulting from this Hinkley Center project.

   No peer reviewed publications have resulted from this project thus far.

4. List of research presentations resulting from this Hinkley Center project during this quarter.

	Title/Authors	Conference/Date
1	Effects of Biosolids Addition and Alkalinity Sources on High-Solids Anaerobic Co-digestion of Food Waste and Green Waste. Phillip Dixon, Eunyoung Lee, Paula Bittencourt, Eduardo Jimenez, Meng Wang, Qiong Zhang, and Sarina Ergas	2017 SWANA summer conference and Hinkley Center Colloquium, Fort Myers, FL, July 24-25, 2017
2	Effects of Biosolids Addition and Alkalinity Sources on High-Solids Anaerobic Co-digestion of Food Waste and Green Waste. Phillip Dixon, Eunyoung Lee, Paula Bittencourt, Eduardo Jimenez, Meng Wang, Qiong Zhang, and Sarina Ergas	Renewable Energy Systems and Sustainability Conference in Lakeland, FL, July 31-Auguest 1, 2017

5. List of who has referenced or cited your publications from this project?

   At this time, the results from this research study have not been referenced by others.

6. How have the research results from this Hinkley Center project been leveraged to secure additional research funding?

   - Phillip Dixon was partially supported by an NSF funded Partnership in International Research and Education (PIRE) grant during the 2017 academic year.
   - Paula Bittencourt and Eduardo Jimenez were partially supported (40%) by funds from the USF College of Engineering Research Experience for Undergraduates (REU) program.
   - A proposal was submitted to the Environmental Research and Education Foundation (EREF) on the topic of "Enhanced Bioenergy Production from Lignocellulosic Wastes."
   - A proposal was submitted to the USDA on the topic of, "Production of High Value Added Products from Sugarcane Bagasse via High Solids Anaerobic Digestion and Thermo-Catalytic Conversion."
   - A proposal was submitted to the US-Israel Binational Agricultural Research and Development (BARD) fund on the topic of, "Production of High Value Products from Agricultural Residues via High Solids Anaerobic Digestion, Pyrolysis and Thermo-Catalytic Conversion."

7. What new collaborations were initiated based on this Hinkley Center project?

   We have initiated collaborations with the following researchers:
   - John Kuhn, Department of Chemical & Biomedical Engineering, USF
   - Babu Joseph, Department of Chemical & Biomedical Engineering, USF
   - Oz M. Gazit, Faculty of Chemical Engineering, Technion Israel Institute of Technology
   - Ellen R. Graber, Faculty of Soil, Water & Environmental Sciences, ARO-Volcani Center, Israel

8. How have the results from this Hinkley Center funded project been used (not will be used) by FDEP or other stakeholders? (1 paragraph maximum).

At this time, the research has not been used by FDEP and other stakeholders.

TAG MEMBERS

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REFERENCES

Sengupta, S., Ergas, S. J., & Lopez-Luna, E. (2007). Investigation of solid-phase buffers for sulfur-oxidizing autotrophic denitrification. Proceedings of the Water Environment Federation, 2007(2), 1139-1159.