Bioenergy Production from MSW by Solids State Anaerobic Digestion

Gregory R. Hinds, George Dick, Sarina Ergas and Daniel Yeh
Department of Civil & Environmental Engineering
University of South Florida

for

Hinkley Center for Solids and Hazardous Waste Management
University of Florida P.O. Box
116016
Gainesville, FL 32611
www.hinkleycenter.org

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Abbreviations, Acronyms, and Units of Measurement

OFMSW - Organic Fraction of Municipal Solid Waste

MSW - Municipal Solid Waste

P&P - Pulp and Paper Mill

AD - Anaerobic Digestion/Anaerobic Digester

SS-AD - Solids State Anaerobic Digestion

WWTP - Wastewater Treatment Plant

TS - Total Solids

VS – Volatile Solids

SGEF - Student Green Energy Fund

SWD - Southwest District

Quarterly Progress Report

August 18, 2014- November 17, 2014

PROJECT TITLE: Bioenergy Production from MSW by Solid State Anaerobic Digestion

PROJECT DIRECTOR(S): Dr. Sarina Ergas and Dr. Daniel Yeh

AFFILIATION: University of South Florida

COMPLETION DATE: August 17, 2015 **PHONE NUMBER:** 813-974-1119

PROJECT WEBSITE: http://mbr.eng.usf.edu/yardwaste/

Work Accomplished During this Reporting Period:

During the first quarter of this Hinkley Center project, progress was made on the following tasks: literature review, bench-scale reactor studies, industry survey and project dissemination.

Literature review: The following objectives are serving as a guide for the literature review: review the science of solid state anaerobic digestion (SS-AD), refine research questions/hypotheses and methodologies for bench- and pilot-scale experiments, identify and review full-scale SS-AD operations in the US and Europe, review the challenges and recent progress associated with SS-AD, identify SS-AD designs/operations that may be appropriate for Florida, and develop an understanding of what it takes to successfully implement, operate, and maintain a full-scale SS-AD operation. The following is a summary of our preliminary findings from the literature review:

- Anaerobic digestion is considered to be one of the most environmentally friendly processes for converting biomass into energy (EurObserv'er, 2010; Lubken et al., 2010).
- A number of different designs for SS-AD were identified and a wide variety of operating methods have been reviewed. Each of the designs and operating methods have their own unique set of advantages and disadvantages. Full-scale operations that specifically utilize OFMSW (food and yard waste) as substrate have been the focus of this review.
- Four full-scale SS-AD of OFMSW operations in the US have been identified and reviewed: Oshkosh, Wisconsin; Davis, California; Sacramento, California; and San Jose, California. By the time the second quarter report is complete, it is expected that a manuscript will be complete, covering the state of the art of SS-AD for bioenergy production from OFMSW and documenting existing SS-AD operations in detail (SS-AD design, system capacity, substrate(s), pretreatment/grinding method, inoculation method, post-treatment/digestate utilization, capital costs, operation and maintenance costs, advantages and disadvantages.
- Although food waste is easily degraded, the lignin in yard debris acts as a barrier to the microbial population that performs hydrolytic conversion of cellulose (Tong et al., 1990). The main factor that influences the slower anaerobic degradation of these wastes is the hydrolysis of cellulose, mainly due to its crystalline structure, the association of the cellulose and hemicellulose with the lignin and the low activity of the cellulose enzymes present in conventional digesters. Lignin; however, is considered the most important factor affecting the hydrolysis of the cellulose component in lignocellulosic material. The initial degradation

step is difficult because the ligno-carbohydrate complexes create a barrier for microbial conversion. Thus degradation of yard waste requires thermal or chemical pretreatment or long retention times (Ghosh and Bhattachatyya, 1999; Tong et al., 1990).

- A number of studies have demonstrated the effectiveness of thermal, chemical and biological pre-treatment of the straw material (Ghosh and Bhattachatyya, 1999; He et al., 2008; Hendriks and Zeeman, 2009; Menardo et al., 2012; Zhang and Zhang, 1999; Zhao et al., 2010), however, these approaches have not been shown to be energy efficient.
- Co-digestion with other wastes has been shown to enhance methane production from lignocellulosic wastes (Lehtomaki et al., 2007).
- Sludge generated in the pulp and paper mill industry likely contains microbial populations that are already acclimated to lignin-containing waste material. *Clostridium cellulovorans,* for example, originate in wood chips and produce enzymes (e.g. cellulosome) needed to overcome the lignin challenge (Tamaru et al., 2010).
- It is unknown whether bioaugmentation with P&P AD sludge improves the biochemical methane potential (BMP) of yard waste (lignocellulosic material) in SS-AD. Dr. Wendy Mussoline's studies suggest that the microbial community and nutrients in the paper mill sludge are capable of overcoming the lignocellulosic challenge and accelerating the hydrolysis stage of the SS-AD process for both rice straw and sugar cane bagasse, thus maximizing the methane potential from these feedstocks.
- The significance of the substrate to inoculum (P&P AD sludge) ratio is unknown. Dr. Mussoline's studies showed a correlation between substrate to inoculum ratio and increase in BMP of lignocellulosic material (the more inoculum, the higher the BMP). However, the increase in BMP when a small volume of inocula was used was not significantly different from the BMP increase when a larger volume was used. Ideally, only a small volume of inoculum would be needed to obtain the majority of the BMP increase associated with the bioaugmentation method).
- It is unknown whether P&P AD sludge originating microbes (e.g. *Clostridium cellulovorans)* maintain their population in the SS-AD environment. Ideally, only one P&P AD sludge inoculation would be required and the resulting increase in biogas yield would be accomplished in subsequent digesters via inoculation with digestate/leachate from the first digester (as opposed to inoculating each subsequent digester with P&P AD sludge).
- It is unknown what yard waste to food waste ratio will optimize the SS-AD conditions (e.g. C:N, %TS, alkalinity, et.c.) thereby maximizing biogas yield and quality. According to Brown and Li, 2013 "Co-digestion of food waste with yard waste increased both methane yield and volumetric productivity considerably over SSAD of only yard waste. Increased methane yields and volumetric productivities were observed with increases in the percentage of food waste to 10% and 20% of the substrate at F/E ratios of 2 and 1, respectively. The highest volumetric productivity of 8.6 Lmethane/Lwork obtained at a loading of 10% food waste at an F/E ratio of 2."
- The appropriate method for the bench-scale studies was identified to be the Biochemical Methane Potential (BMP) assay method as described by Angelidaki et al., 2009 and Owens and Chynoweth, 1993. This method was officially established in 2009 as the recommended

method for conducting bench-scale anaerobic digestion research to improve the comparability of published results.

Bench-scale reactor study: Two reactors and two blanks were successfully setup in our laboratory, as shown in Figure 1. The reactors are being monitored for gas production but will soon be sacrificed and reconstructed with improved methodology and increased understanding of research objectives. In the next phase, eight reactors will be set up - four will contain only yard waste and "seed sludge" and the other four reactors will have yard waste, seed sludge, and P&P AD sludge. This will provide triplicate treatments for statistical purposes (Angelidaki et al., 2009) and an additional reactor for intermediate sacrifice and chemical analysis. The reactors will be monitored for 60 days and the digestate/leachate will be used to inoculate a subsequent (round two) set of reactors. The procedure for the reactor set up was developed based on the BMP assay method described by Angelidaki et al., (2009) and Owens and Chynoweth, (1993).

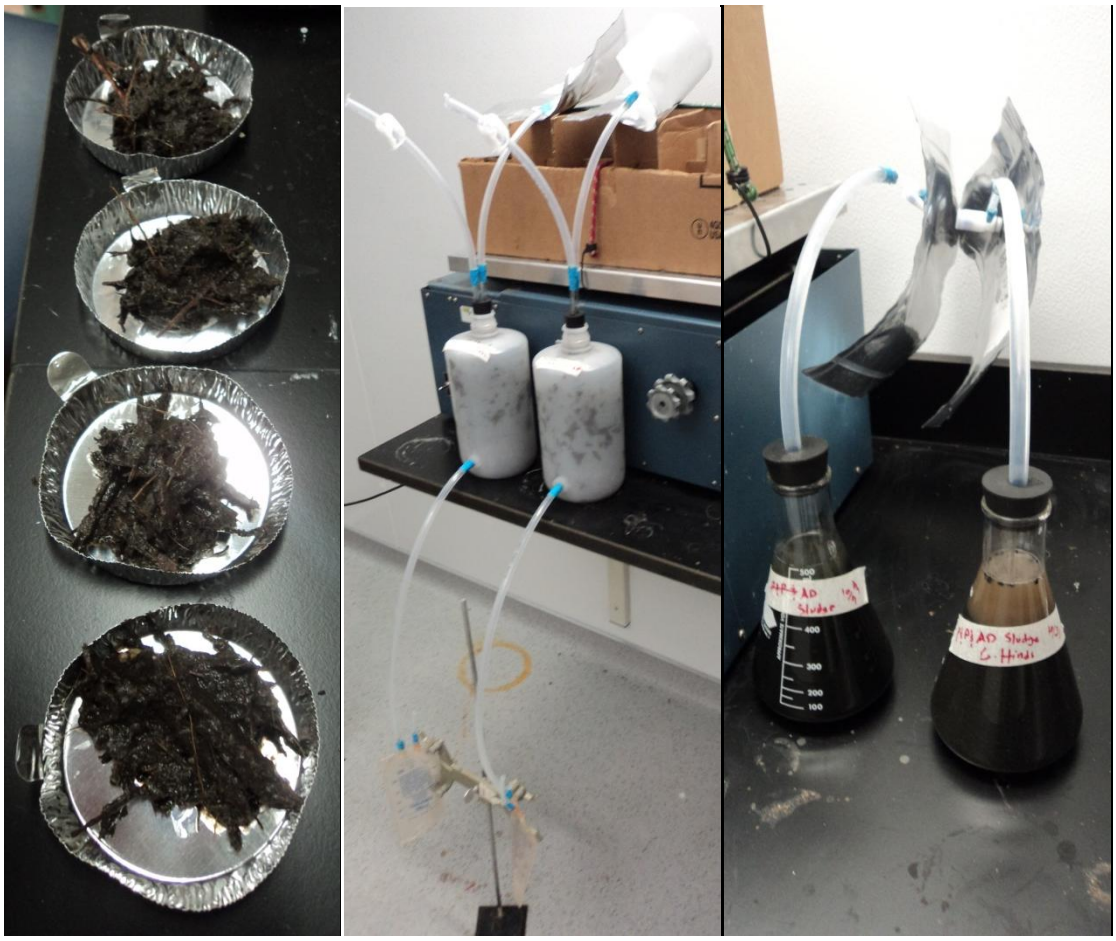

Figure 1: Samples taken from the mixtures for the first bench-scale reactors (left); bench-scale reactors, one with P&P AD sludge and one without, gas bags on the top and IV bags on the bottom for the purpose of manual leachate recirculation (center); blanks which have the same quantity of inocula as what was mixed into the reactors.

Industry survey: The goals of the industry survey are to assess resource availability in Florida, identify the most suitable substrates for SS-AD in Florida, identify possible collaborators for full-scale demonstration of SS-AD in Florida and educate stakeholders about the potential for SS-AD. Local solid waste facilities are being contacted and personnel interviewed to identify and document current practices of disposal/reuse of OFMSW (mulching, incinerating, landfilling, composting, etc.). In addition, we are quantifying the amount of OFMSW according to subcategories yard waste (mulch and other debris), biosolids and industrial, institutional and residential food waste.

The state of Florida has a total of 42 active Class I landfills (> 20 tons of MSW per day) and 30 Class III landfills (construction and demolition materials). Additionally, the state has 12 active waste-to-energy facilities which send MSW to an incinerator to generate electricity and the byproduct, ash, is sent to the landfill, conserving space within the landfill. If the incinerator is inactive or the facility receives more MSW than the incinerator can manage, MSW is deposited directly in the landfill. Yard waste is either transported to landfills for disposal or to facilities that only handle yard waste and no MSW. Most facilities mulch the yard waste, while one facility offers composting as an alternative. A comparison of statewide facilities with those in the southwest district (SWD) is shown in Figure 2.

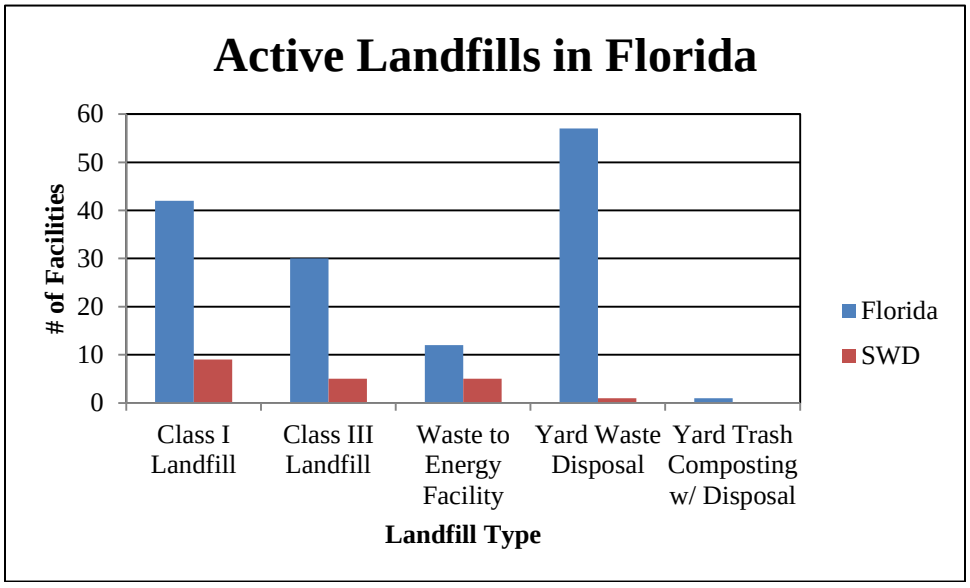

Figure 2: Active landfills in Florida and the Southwest District.

Information Dissemination Activities:

The project website is up and includes basic information about the project. A poster will be presented at the USF College of Engineering Research Day on November 19, 2014. Information was also disseminated to TAG members at the TAG meeting on November 6, 2014.

Project Metrics:

1. Graduate students funded by this Hinkley Center project:

Last name, first name	Rank	Department	Professor	Institution
Hinds, Gregory	Masters Student	Civil/ Environmental Engineering	Dr. Sarina Ergas	University of South Florida
Dick, George	Masters Student	Civil/ Environmental Engineering	Dr. Daniel Yeh	University of South Florida

2. Undergraduate researchers working on this Hinkley Center Project:

Ariane Rosario, Civil & Environmental Engineering, Advised by Dr. Sarina Ergas, University of South Florida

3. Research publication resulting from this Hinkley Center project:

No research publications have been submitted at this time.

4. Research presentations resulting from this Hinkley Center project:

This research project will be presented at the University of South Florida, College of Engineering Research Day on Wednesday, November 19, 2014.

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

The University of South Florida charges every student a green energy fee of one dollar per credit hour. This green energy fee is used to support sustainable and environmental technologies that could be used at the University to aid in accomplishing the University sustainability goals. Greg Hinds and a team of students (one undergraduate Civil Engineering student, two graduate Environmental Engineering students, and one graduate Business student) prepared and submitted a Student Green Energy Fund (SGEF) proposal in October. The objectives listed in the proposal were to conduct a feasibility study for the implementation of SS-AD on the USF, Tampa campus, to implement a "source separation campaign", which would involve the installation of separate waste bins for biodegradable wastes, and to update an educational kiosk on the project in the Marshall Student Center. A link to the proposal will be posted on the project website. Unfortunately, the proposal was not selected for funding in the cycle; however, the review committee provided good feedback and encouraged future proposal submittal. In addition, a grant proposal was submitted to the Bill & Melinda Gates Foundation by PI Ergas and two USF graduate students, Maureen Kinyua and Greg Hinds. The proposal seeks to gain funding to study the applicability of SS-AD in the developing world for the purpose of safe waste disposal and biogas generation for use as a cooking fuel, for heating, and for lighting.

6. What new collaborations were initiated based on this Hinkley Center Project?

The collaboration between students for the SGEF proposal was initiated. The student team didn't receive funding from the SGEF but worked together to prepare the proposal and plan to continue to work together to strengthen and resubmit the proposal in the spring. The collaboration

between Maureen Kinyua and the student research team was also initiated. Other collaborations between industry professional (yard waste processing facility managers, landfill managers, etc.) and the student research team are ongoing.

7. How have the results from this Hinkley Center funded project been used by FDEP or other stakeholders?

The results have not yet been used by the FDEP or other stakeholders.

Tag Members:

TAG Member	Affiliation	Title
Steven G. Morgan	Florida Department of Environmental Protection	Waste Permitting, Environmental Services Section, SW District
Wendy Mussoline	UF, Dept. of Soil & Water Science	Postdoc, Environmental Biotechnology Lab
Juan R. Oquendo	Gresham, Smith, & Partners	Sr. Environmental Engineer & Waste to Energy Leader
Debra R. Reinhart	UCF, Dept. Civil, Environmental & Construction Eng.	Professor & Assistant Vice President
Larry Ruiz	Hillsborough County	Landfill Operations Section Manager
Adrie Veeken	Attero, the Netherlands	Bio-based Products Business Developer
Shawn Veltman	CHA Consultants	Director of Technical Services, Water & Wastewater

Tag Meeting:

The first TAG meeting was held on November 6, 2014. Shawn Veltman, Larry Ruiz and Mr. Tim Vinson, Research Coordinator for the Hinkley Center, attended in person. Wendy Mussoline, Stephanie Bolyard (representing Debra Reinhart), Juan Oquendo and Mr. John Schert, Director of the Hinkley Center, participated remotely via Go to Meeting. The discussion was very productive and yielded several valuable insights. After the discussion, TAG members who attended in person were given a tour of the lab facilities in which the initial startup of the SS-AD experiments were being performed.

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