QUARTERLY PROGRESS REPORT

05/30/18 to 08/31/18

PROJECT TITLE: Environmental and Economic Impacts of Energy Production from Municipal Solid Waste

PIs: John N. Kuhn (jnkuhn@usf.edu; 813 974 6498) & Babu Joseph (bjoseph@usf.edu; 813 974 0692)

University of South Florida
Department of Chemical & Biomedical Engineering

COMPLETION DATE: 08/31/2018

WEB ADDRESS: http://www.eng.usf.edu/~jnkuhn/Hinkley2017.html

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

Research Description

Municipalities today are faced with a variety of options on dealing with solid waste. Tools and guidance are needed to make sound decisions, regards to both environmental and economic factors, that takes into account various site specific constraints such as land and water availability, energy costs and needs, and government policies and tax incentives. The goal of this project is to quantify the benefits of various traditional and proposed Waste-to-Energy (WTE) technologies versus landfilling. The results will aid in identification of an optimal process for maximizing profitability while minimizing environmental impact given various scenarios and constraints. The proposed effort leverages previous and current efforts on the demonstration of syngas production from landfill gas and design and application of selective FTS catalysts (production of diesel and jet fuel) funded by the Hinkley Center, the Florida Energy Systems Consortium (FESC), and the Department of Energy (DOE).

The five WTE technologies selected for this comparison are gasification or anaerobic digestion to produce electricity, incineration to produce heat and power, or gasification to produce compressed natural gas or liquid hydrocarbon fuels (i.e., diesel). These five technologies will be compared to landfilling and single-stream recycling to reach a total of 7 scenarios. These processes will be evaluated at the system level, such as done by the PIs for various WTE and biomass conversion schemes already, to quantify the key parameters needed for making a sound decision taking into consideration economics and environmental impact. These parameters include CAP-EX, OP-EX, energy input requirements, GHG emissions, water input requirements, co-product generation and use/market (if any), solid waste production (if any), and profitability. The process simulations will include a sensitivity analysis, which will include a variable production scale, process lifetime, degrees of tax credits, etc. on the eight parameters identified to compare the conversion technologies.

Work Completed To-Date

In this reporting period, we improved the calculations within the decision-making tool by adding more sources and data for the anaerobic digestion. We accounted for inflation by changing the value of the USD in the source year to the 2017 USD value using the CEPCI index. The listing of different costs under capital expenses by the various sources prompted the creation of a baseline for comparison. The baseline of comparison included capital expenses as a function of equipment cost, engineering/installation costs and cost of purchasing land. Once the capital expenses from the various sources reflected the same baseline, a plot of capital expenses (in 2017 USD) as function of plant capacity (tons) was generated (Fig. 1). This graph was plotted to verify that the trend line of capital cost per ton decreasing with plant capacity increases was followed. The trend line was followed, except for the first points in the data. We believe the deviation was due to several capital cost per ton of smaller magnitude being divided by several large-scale plant capacity.

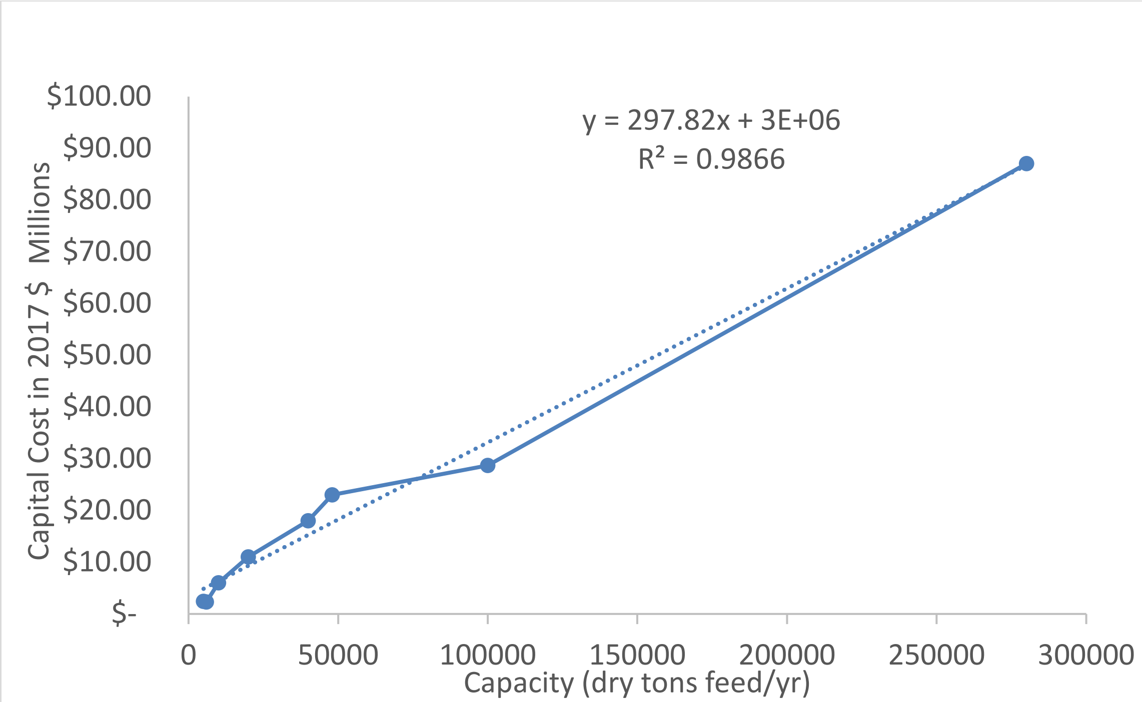

Fig. 1. Total Capital Cost of an Anaerobic Digestion Plant

The operational expense data for anaerobic digestion was also updated. The update will enable more accurate calculation of the operational expenses as a function of fixed capital investment, cost of operating labor, cost of utilities, and cost of raw materials. The cost of operating labor will be determined by the number of processing steps in the designed WTE plant. A research on the cost of utilities was also carried out and it was discovered that for farm/agricultural manure waste of low solids content, the utilities cost was covered by 10% of total electricity production of the WTE plant. For MSW or high solids waste, the cost was 30% of the total electricity production since a pre-processing step and a higher retention time is needed for this type of waste.

In addition, we added default ultimate and proximate analysis for all the types of feed (MSW, WWTP sludge, animal manure, farm waste, yard waste) and determined biogas production rate in SCFM (standard cubic feet per min). Thorough analysis and calculations were also performed in other to improve the accuracy and determine the individual components (CH_4, CO_2, H_2S, H_2O, and NH_3) in the biogas. This was determined using the Buswell Mueller equation shown below:

$$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right)H_2O$$
$$\rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3d}{8} - \frac{e}{4}\right)CH_4$$
$$+ \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4} + \frac{3d}{8} + \frac{e}{4}\right)CO_2 + dNH_3 + eH_2S$$

The Buswell Mueller equation helps determine the chemical composition of the feed while and the stoichiometric amounts of H_2O, CH_4, CO_2, NH_3, and H_2S can be determined using an ultimate analysis performed on the feed. The downside of this equation is that it assumes complete conversion of the feed, and this assumption is not accurate, as only the volatile matter in the feed has the potential to become biogas. To make a more accurate prediction when using the Buswell Mueller equation, the proximate analysis of the feed was also utilized. The ultimate analysis gives the carbon percentage in the feed while the proximate analysis gives the fixed carbon percentage in the feed. The difference between those two percentages is the percentage of volatile carbon in the feed. The percentages of hydrogen (H), sulphur (S), and nitrogen (N) were assumed to completely converted to biogas. The coefficients a, b, c, d, e for the Buswell Mueller equation were found using the percentage of volatile matter carbon, and the percentage of H, S, and N from the ultimate analysis. Once these coefficients were found the stoichiometric ratios of CH_4, CO_2, H_2O, H_2S, and NH_3 were found. Based on the amount of feed in the system, the moles of CH_4, CO_2, H_2O, H_2S, and NH_3 can be found using these coefficient ratios. The water content in the Buswell Mueller is on the reactants side, and therefore represents the amount of water needed to react with the feed to create CH_4, CO_2, H_2O, H_2S, and NH_3. However, the amount of water vapor in the biogas was found by assuming the biogas is saturated with water. The anaerobic digestion process is running at a thermophilic temperature of 55 ºC, so the saturation pressure of water at this temperature was found. Water vapor, CH_4, CO_2, H_2S, and NH_3 make up the biogas. The addition of all these components' moles make up the total biogas. Then, the ideal gas law was used to find the volume of biogas obtained from the feed undergoing an anaerobic digestion process. However, studies show that practically, about 40-65% of the organic material is broken down, scaling the biogas yield down. (Curry and Pillay 2012). So, the total volume of biogas calculated was multiplied by the average value, 52%.

The amount of solid digestate was found by assuming that solid digestate is composed of the amount of the feed that is made up by fixed carbon and ash. The liquid digestate is then found by performing an overall mass balance on the system. The user will need to input the moisture content (%) in the feed and their desired solids content in the digestor which will in turn determine if the process is high-solids anaerobic digestion or low-solids anaerobic digestion. The mass balance determines the amount of water that is liquid digestate and the amount of water that is recycled back into the digester to maintain the percent solids content desired by the user.

The energy content in the feed was determined using the Dulong equation along with the ultimate analysis for the feed. The energy content in the biogas was determined by multiplying the percent of CH_4 in the biogas times the heating value of biogas. The amount of energy contained in the solid digestate was determined by using the Dulong equation, and assuming all the energy comes from the fixed carbon. The energy usage of the anaerobic digestion process was found by subtracting the energy in the feed minus the energy in the biogas and the feed.

Curry, N.; Pillay, P., Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy* **2012,** *41*, 200-209.

Future Tasks

Our future direction involves us completing the biogas purification tab. We will also be determining the operational expenses for activated carbon beds, iron sponge beds, water scrubbers, and chillers on a per kilogram of contaminant removed basis. The capital expenses for activated carbon beds, Iron sponge beds, water scrubbers, and chillers on a per volume of biogas basis will also be determined

TAG Meetings Scheduled

Our next TAG meeting has been tentatively scheduled for Friday, October 5, 2018.

Here are the links to the first TAG meeting.

http://www.eng.usf.edu/~jnkuhn/TAG%20Meeting%20Kuhn%20USF.mp4

https://youtu.be/dFUBl0jvNF8

TAG Members

John Schert	Director	Hinkley Center
Wester W. Henderson	Research Coordinator III	Hinkley Center
Devin Walker	Process Engineer	T2C-Energy
Matt Yung	Researcher	Nat. Renewable Energy Lab
Tim Roberge		T2C-Energy
Richard K Meyers	SWRS Program Manager	Broward County Solid Waste and Recycling Services
Lee Casey	Chief of Environ. Compliance (Retired)	Miami Dade County Dept of Solid Waste

Canan “Janan” Balaban	Asst. Director	Florida Energy Systems Consortium
Ron Beladi	Vice-president	Neel-Schaffer, Inc.
Rebecca Rodriguez	Engineer Manager II	Lee County Solid Waste Division
Linda Monroy	Project Manager Associate	Lee County Solid Waste Division
Sam Levin	President	S2LI
Charles “Peb” Hendrix	Chief Operating Officer	LocatorX
Tony Elwell	Staff Engineer I	HSW Engineering, Inc
Nada Elsayed	Scientist, PD	Catalent Pharma Solutions Inc
Yolanda Daza	Process TD Engineer	Intel Corporation
James Flynt	Chief Engineer	Orange County Utilities Department
Gita Iranipour	Engineer Associate	Hillsborough County Public Utilities Department
Luke Mulford	Water Quality Manager	Hillsborough County Public Utilities Department
Ray Oates	Solid Waste Compliance Manager	Citrus County Division of Solid Waste Management

Metrics:

1. List graduate or postdoctoral researchers funded by THIS Hinkley Center project.

Name	Rank	Dept.	Professor	Institution
Sokefun, Yetunde	3rd year PhD student	Chemical Engineering	Kuhn/Joseph	USF

*2. List undergraduate researchers working on **THIS** Hinkley Center project.*

First Name	Dept.	Institution	Professor
Daniela Chinchilla	Chemical Engineering	USF	Kuhn/Joseph
Anna Wright	Chemical Engineering	USF	Kuhn/Joseph

*3. List research publications resulting from **THIS** Hinkley Center projects.*

Naqi, Ahmad "Conversion of Biomass to Liquid Hydrocarbon Fuels via Anaerobic Digestion: A Feasibility Study" (2018). M.S. Thesis, Chemical and Biomedical Engineering, USF, Tampa.

Zhao, X., Naqi, A., Walker, D.M., Roberge, T., Kastelic, M., Joseph, B., and Kuhn, J.N., "Conversion of landfill gas to liquid fuels through TriFTS (Tri-reforming and Fischer-Tropsch Synthesis) process: A feasibility study" submitted.

*4. List research presentations resulting from **THIS** Hinkley Center project.*

Stachurski, P., Joseph, B., and Kuhn, J.N., "Waste-to-Energy Technologies: Developing a Decision Making Tool for Municipalities and Private Companies", USF UG Research Colloquium, Tampa, FL, April 2018.

Naqi, A., Joseph, B., and Kuhn, J.N. "Techno-economic Analysis of producing Liquid Fuels from Waste through a combined Biochemical and Thermochemical Route", 2018 AIChE North Central conference, West Lafayette IN, April 2018

Naqi, A., Joseph, B., and Kuhn, J.N., "A Feasibility Study on Biofuel Production Using Anaerobic Digestion and Thermochemical Catalysis", AICHE Annual Meeting, Pittsburgh PA, October 2018.

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

None at this time.

6. Provide an explanation of how the research results from this Hinkley Center project and previous projects have been leveraged to secure additional research funding.

We have submitted the following proposals:

Sustainable Energy, Nutrient and Water Recovery from Organic Wastes for Space Applications (in collaboration with Dr. Ergas, Professor of Civil and Environmental Engineering, USF, T2C-Energy, LLC). Submitted to Florida-Israel Innovation Partnership. This will be resubmitted in 2018.

Intensified biogas conversion to value-added fuels and chemicals (in collaboration with National Renewable Energy Laboratory, and an industrial partner). Submitted to DOE BETO. This proposal is pending.

7. List new collaborations that were initiated based on this Hinkley Center project.

A collaboration was initiated with Dr. Ergas of USF, National Renewable Energy Laboratory, and an industrial partner, which resulted in the above named proposals.

8. Provide an explanation of how have the results from this Hinkley Center funded project have been used (not will be used) by the FDEP or other stakeholders?

None at this time.

Student Researchers

The current student researchers on this project are Yetunde "Tosin" Sokefun, Anna Wright, and Daniella Cerna Chinchilla. These students are 5th, 4th, and 3rd from the left in the subsequent picture. Paul Stachurski (B.S.) and Ahmad Naqi (M.S.) also worked on this project prior to graduation.