Summary of Fluidized Bed Combustion (FBC) Project in Dorchester County

Prepared by

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Introduction

Biomass Heating Solutions Limited (BHSL) is an Irish corporation that has developed and deployed commercially successful manure to energy (M2E) technology in the European market place. The BHSL manure to energy technology is a distributed farm based approach to utilize manure to produce local heat, electricity, and fertilizer on the farm where the manure is created. In 2014, they established an American subsidiary, Biomass Heating Solutions (BHS), Inc. USA, and working with the Murphy family, who raise poultry for Mountaire, applied and received grant assistance from the Maryland Department of Agriculture to pilot this technology in Dorchester County.

Description of the Technology

The project's Energy Center is co-located on the poultry production site. This building houses the fluidized bed combustion (FBC) unit, the generator, an organic rankine cycle (ORC) unit (ElectraTherm), and fuel handling system. Poultry litter fuels the system and is stored in an adjoining manure storage building, with a top loader incorporated and linked by fuel transfer screws to the energy center. The ORC package also includes an air cooled condenser skid designed to remove excess heat energy from the ORC thermal fluid, with this skid section positioned at the side of the main building.

The FBC unit or 'Bubbling Fluidized Bed' type technology used by BHS operates through combustible particles suspended and held in gaseous suspension by upward moving hot air within a 'boiling chamber'. This produces a simulation of a fluidized bed due to the pseudo-fluid behavior of the particles in suspension. Although the particulate matter behaves similar to that of a fluid, it is composed of very small-scale solid particles. Therefore, the fluidization of the particulate bed causes an increase in surface area due to the constant agitation and separation of particles from one another. This increase in particle surface area increases the area available for contact between the combustible products and the oxygen within the boiler, and therefore, increases the reaction efficiency, similar to the use of adsorption catalysts.

The BHS system uses a series of air-to-water tube banks in a heat exchange mechanism to quickly reduce the gas temperatures from 900°C to 140°C, while generating hot water temperatures of up to 90°C inside the tubes. This hot water is pumped to a thermal storage vessel that acts as the distribution point for hot water used to the supply the necessary heat to the fan powered radiator systems in the poultry sheds.

The optimum ventilation philosophy used by BHS is to maximize use of this heat in the poultry houses and increase the ventilation rates. The objective is to foster conditions that result in drier litter, improve air quality, and ultimately improve bird performance and welfare.

The heat exchanger section comprises a refractory wall enclosure providing a gas-tight atmosphere surrounding the module banks. Heat exchanger surfaces are prone, where high alkali biomass fuels are the primary fuel, to severe fouling from ash deposits. To counter this, a series of custom designed rappers are placed adjacent to the heat exchange modules. The rappers work to maintain the high thermal efficiency of the design and also ensure that the flue gas flows remain constant, thus negating the risk of fugitive dust emissions. All ash is removed from this heat exchange mechanism as a valuable fly ash and is automatically transferred to sealed bags, which are stored on-site to be collected for sale. Ash from poultry litter combustion contains significant phosphorus (12-14% P) and potassium (10-18% K) levels, allowing its use as a fertilizer or soil amendment.

The water is circulated through the FBC heat exchangers and then to the ORC package. Energy transfer takes place in the ORC package via a purpose designed evaporator. The return water is circulated either directly back to the FBC or through a mixing header, which is designed to remove further energy for the purpose of heating the poultry houses.

The power generating technology is provided by ElectraTherm's Green Machine, which generates fuel-free, emission-free electricity from medium temperature hot water, utilizing an organic rankine cycle (ORC). The ORC package incorporates frequency, power, and voltage control modules.

Project Objectives

The key objectives of the BHS project were to demonstrate the safe combustion of poultry litter, reduce or eliminate the need for its land application, and repurpose the primary use of litter to generate thermal energy to heat the poultry houses. As conceived, the project would reduce nitrogen and phosphorus impacts to water quality, although some of the nutrients would be marketed as the ash byproduct for use as a fertilizer or soil amendment. Anticipated benefits to the poultry grower included:

- Reduction in heating costs,
- Bird welfare and performance improvements,
- Generation of electricity (for on-farm use or net metering),
- Potential to realize incentives, such as the proposed Thermal Renewable
- Energy Credits (RECS),
- Potential to reduce ammonia emissions from poultry production and ancillary
- environmental benefits, and
- Improvement of the sustainability of poultry farming in the state of Maryland by providing an alternative manure management strategy that is at least cost neutral.

Project Monitoring

The BHS monitoring contract supported installation of appropriate equipment for a monitoring system to measure function in the energy center and poultry houses, documentation of data, sampling of input and output litter and byproducts and their analysis by an approved lab for analysis, emissions testing to determine whether the technology meets MD air quality standards and tracking, and reporting of quarterly project progress.

A. University of Maryland – Bird Performance

A contract with Dr. Jon Moyle, University of Maryland Poultry Specialist, supported third party monitoring to analyze bird performance outcomes of the project. The monitoring configuration compared outcomes in two houses heated from the FBC unit with two houses used as a "control" and heated with the traditional propane system. Data was collected using the existing farm ROTEM controller system, as well as additional data points including bird scales, feed scales and a weather station. The data collection plan included:

- Poultry house temperature
- Poultry house humidity
- Poultry house CO_2
- Average bird weights
- Outside temperature
- Outside humidity
- Wind speed
- Feed intake
- Water intake

Findings

Use of the BHS system did not improve any production parameters measured during this evaluation. Bird weight, feed conversion, and mortality were statistically the same. There was a slight improvement in the chicken house environment during the early growth phase, as the humidity and CO_2 were lower during that time due to more heat and ventilation being provided to the houses. These improved conditions may have been more pronounced during the winter months and may have improved bird performance during that time if the system had been functioning continuously then.

Additionally, the full monitoring report identified several problems that were not properly addressed and influenced gaps in data and potential outcomes. The most significant related to the operation and runtime of the BHS-FBC unit. The BHS unit was not operational continuously and propane backups had to be used to maintain temperatures when the unit was down. This was a problem during the first week of both winter flocks, which is the time when heat is needed to support bird health the most. The lack of continuous operation may have been a contributing factor to the monitoring outcomes indicating no differences in production performance between control and FBC heated houses.

B. University of Maryland-Technology Performance

Dr. Stephanie Lansing and Dr. Gary Felton, and PhD candidate Abhinav Choudhury, University of Maryland, Department of Environmental Science and Technology, monitored the function of the technology, including efficiencies, life cycle and nutrient budget.

The monitoring requirements for the project during its year of operation included:

1. Energy center output
    a. BHS Monitoring:
        (1) temperature of the furnace chamber;
        (2) flue gas temperature at the cross-over between heat-exchanger banks and inlet to the bag filter;
        (3) hot water flow;
    b. Calculating energy use by circulation pumps, energy center, Organic Rankine Cycle electrical generation, compressors, and other components, as needed;
    c. Emission testing for SO_2, NOx and particulate matter - at least one test by an independent Environmental Monitoring company post commissioning; and
    d. Byproducts
        - Quantity poultry litter inputs related to quantity converted to ash
        - Nutrient value litter inputs and nutrient value ash output

2. Energy delivered to the houses
    a. Collect data using electricity and heat meters to calculate energy delivered to houses.
    b. Draft a Measurement & Verification Plan to set out the baseline of the current operating condition.

3. Nutrient budget before the Fluidized Bed Combustion ("FBC") is installed and after the FBC is installed will be compared and take account of nutrient value of poultry litter inputs, previous fate within the farm operation and life cycle in BHS system including fate of by-products containing nutrients.

4. To complete a life cycle assessment ("LCA") that will address nutrients, energy, and carbon flows and will evaluate and track:
    a.) On-farm mass nutrient balance;
    b.) The effectiveness of the technology in reducing the cradle to grave environmental impacts;
    c.) Changes in greenhouse gas emissions;
    d.) Eutrophication potential;

e.) Energy consumed/produced with each aspect of the fluidized bed combustion system (FBC) will be quantified; and,

f.) Adverse affects to human health and ecosystem biota.

A complete analysis of data will require several months. This will include analysis of data from 6 flocks –from December 2016 to March, 2018. Their analysis will examine data during FBC run times. Outcomes will also be heavily influenced by the inconsistent operation and breakdowns of the FBC system. Data will be partitioned to examine outputs from the FBC when poultry litter feedstock was in use and outputs when the backup diesel operated the FBC to develop an analysis of the operation and efficiencies of the FBC. Preliminary outcomes include:

- On average, 45.1% of the wet poultry litter sample was combustible, with an average moisture content of 39.2%.
- The average carbon to nitrogen ratio was 7.8 to 1.
- The average heating value of the poultry litter was 2386 cal/g (4292 BTU/lb).
- Thermal energy production was more continuous during the initial project period.
- Electrical energy was intermittent, as most of the energy from the poultry litter was used for heating the houses.
- Electricity production ranged from 0.7 to 4.0% of the total energy produced.
- Biomass conversion to energy efficiency was consistent throughout the study, with an average 55.3% of the heating value of the poultry litter being converted into thermal energy after losses.
- When tested, the system met Maryland air quality requirements.

C. University of Maryland, Environmental Finance Center

The Environmental Finance Center conducted a financial assessment of the technology. This included:

a.) Assembling data to characterize and track capital, operation, and maintenance expenses and decommissioning costs associated with the life cycle of each technology,

b.) A cash flow analysis (Return on Investment (ROI) and other factors) and an analysis of other expenses to determine the feasibility of implementing the technology and whether/how public financing mechanisms factor into their transferability.

c.) Aggregation of farm data to develop a static hypothetical model to evaluate the policy drivers in combination with on-farm data. This resulted in an assessment of the costs and marketability of the technology on the project farm, including co-product market assessments.

Key Findings

Based on available information, the fluidized bed combustion system at Double Trouble Farm (when continuously operating) appears to result in approximately $2,503 in annual losses for the farmer and/or vendor. The project, when fully operational would benefit from a $29,024 net decrease in the energy line, due to avoided energy expenses and assuming the sale of renewable energy credits. Also beneficial to the project's bottom line is the sale of the ash byproduct at a value of $65/ton. However, these benefits are offset by a $22,343 increase in operations and maintenance, materials, and services costs, as well as by substantial lost income from the sale of unprocessed litter (estimated to be worth a total of $18,000 at the price of $18/ton).

This result does not account for any environmental impacts from operating the system, such as reduced water quality degradation from land application of untreated poultry litter. Further, it does not include any revenue from net metering or accelerated poultry growth rates, as initial performance has not borne out these anticipated benefits as discussed above. For the project to be considered cost effective, defined here as having a simple payback less than the useful life of the technology, or 25 years, the system would need to yield cost savings and/or revenue totaling approximately $110,000 per year through enhanced bird production, net metering, nutrient trading credit sales, and/or monetized environmental benefits.

Project Implementation

The Murphy family own and operate a total of 16 poultry houses. The farm site where BHS system was implemented, Double Trouble, consists for 4 poultry houses growing on average a total of five flocks each year. The Murphy's sell the majority of the poultry litter they produce and it is transported off farm. A number of factors impacted the implementation of the project and may have influenced the outcomes. They include:

1. Project engineering and design

a. The change of the project location resulted in a change of the utility company and unplanned cost for a three-phase hook up. In an effort to reduce costs BHS initiated a re-design of the system, so that it would run on single phase power by running a CHP with a stand by generator. Subsequently the cost for installing three phase power was significantly reduced and the original design became more cost effective. BHS determined that their original business plan including selling excess electricity to the grid could be implemented and the original concept of a three-phase power configuration was re-designed for implementation. MDA did not impose requirements nor have the expertise to critique and compare the redesigns to the system originally proposed. Changes to the design or the equipment source/quality may have contributed to issues with system operation and its capacity for generating energy.

b. The FBC systems successfully operating in the United Kingdom were fabricated in Ireland. The equipment for the system installed in Maryland was fabricated in South Korea in an effort to reduce the price point of the system. Although after completion it was shipped to Ireland for testing and then repackaged and shipped to the Double Trouble farm. There may have been changes to the materials used or quality controls in place that impacted the operation and maintenance costs of the system and contributed to lengthy down times.

c. Poultry litter originating from Maryland was processed by one of the FBC systems operating in UK and no variations in feedstock which required system modification were noted. The feedstock run through the US system contained rocks and other foreign material, initially causing severe damage to the unit. As a result, a screening device was added to the system to prevent rocks from entering the FBC and a large magnet was installed to remove foreign metal matter from the poultry litter to prevent damage to the machinery.

2. Project maintenance

a. There were issues obtaining parts when system breakdowns occurred. The initial system and subsequently a majority of the parts required for its maintenance and repair were purchased from manufacturers outside the U.S. and took three to twelve weeks to secure and install.

b. The mixed source of parts resulted in miss-matches. Mixing metric and English hose and piping resulted in leaks that were never fixed. Having electronics that work on 50 hz and 60 hz resulted in incorrect data.

c. The out of country sourcing of parts stymied the involvement of U.S. subcontractors to assist with onsite trouble shooting and repairs.

3. Project management

BHS personnel responsible for system design, procuring equipment, overseeing implementation, managing its operation, and supporting IT changed throughout the project period. There was a lack of consistency among individuals when making decisions or trying to resolve problems.

Lessons Learned

- The importance of communication throughout the project is primary to a successful project. There should have been a single, consistent point person throughout both the implementation and monitoring periods who was readily available to the farmer, MDA and monitoring representatives and who kept all parties abreast of project changes or issues.

- Continuity of system management would have improved outcomes. BHS personnel responsible for system design, procuring equipment, overseeing project implementation, managing its operation, and supporting IT needs and monitoring changed throughout the project period. There should have been a system of communication or an open log narrative should have been kept and reviewed when staff changed. Rationale for all design changes needs to be carefully documented so that new staff has a clear history of why changes were made. This "log" should have been an open document to which BHS, the farm operator, MDA, and the monitoring team had access.

- The quality or characteristics of the feedstock needs to be determined and addressed before the final system design and installation.
  - Fuel contaminated with foreign objects caused damage to the FBC unit and resulted in downtime for repairs. Communication with US poultry handling specialists should take place to avoid this problem in the future. Data on US poultry litter characteristics is readily available and US poultry production differs from the European model. Retrofits to the US project equipment including magnets and pre-screening of the feedstock occurred only after equipment was damaged. (Also there may have been more cost-effective modifications to address pre-screening if prior planning had occurred.)
  - The US feedstock quality had a lower calorific value, coupled with moisture content being out of the specified range and would be a factor in reduced output from the FBC. The FBC can combust fuels with heating values (LHV) under ideal conditions of 8 MJ/kg and with a tolerable range of 7.5 MJ/kg plus (LHV). The ideal moisture content is 40% with a tolerable range of moisture content at 35 to 45%. The poultry litter feedstock from Murphy's farms had an LHV varying from 6.88 to 9.07 MJ/kg and moisture content ranged from 31.3% to 46.5%. If continuously operational, the unit would have consumed more fuel, but the output would have been lower.

- The equipment quality may have been adversely impacted by changing its fabrication from Ireland to South Korea. The "proven" technology approved for the project was the FBC system fabricated in Ireland. Changing the manufacturing process resulted in too many unknown factors being added to the pilot.

- The existing propane heating system should have been connected and served as a default backup system if the technology primary (or secondary) heat source failed. In this case, the propane heating system should have turned on automatically if the primary and secondary BHS heat systems failed to perform as required to maintain house temperature.

- A signed contract should be in place between the technology vendor and the farm partner before the equipment is installed on the farm that addresses expectations of roles and obligations for the vendor and the farm partner and the fate of the equipment after the project is complete.

Summary

Although the project did not meet expectations, BHS met contract obligations to implement the project and operated it over the required one year despite the challenges highlighted. They continued to utilize company resources to replace parts and bring in technical staff from their Ireland division of the company to assist with operation and troubleshooting throughout the project period.

Although preliminary testing of feedstock in the FBC prior to this project occurred, outcomes of the tested "batch" did not demonstrate the full range of differences in the material as compared to the UK. Differences included lower calorific value in the feedstock, varying moisture and the occurrence of foreign matter. No data is available on methodologies related to the preliminary testing of poultry litter.

As a result of this project BHS either has or plans to:

- Redesign the combustion and gas pass transition sections to prevent ash build up,
- Improve combustion air flow and distribution in the fluidized bed to reduce ash fouling,
- Improve water flow distribution through heat exchangers to prevent overheating and increase lifecycle,
- Strengthen the mechanical rapping points of the heat exchangers to prevent ash fouling,
- Revise its O&M model as a result of many of the lessons learned from the US project, (Anticipated changes include involvement of local mechanical and electrical contractors for installation, creation of consignment stock of spare parts on site, involvement of the farmer with daily onsite inspections and unscheduled maintenance) and
- Address the need to procure more parts in the U.S.