Project Title: Torrefaction and Densification of Biomass Fuels for Generating Electricity

Contract Number: RD3-4 Milestone Number: 01 Report Date: December 8, 2008

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Congressional District: 5th Congressional District

Project funding provided by customers of Xcel Energy
through a grant from the Renewable Development Fund

MILESTONE 1 REPORT

Executive Summary:

This project will research torrefaction and densification of biomass feedstocks to develop a biomass supply chain that will be both efficient and economical. The approach is to develop and optimize a torrefaction regime that will improve storage capabilities, handling methods, and biomass feedstock uniformity. The project is designed to support the following goals:

- Goal 1: Generate electricity, heat or syngas from renewable biomass energy sources that are readily available in Minnesota and approaching economic feasibility
- Goal 2: Strengthen the economy of rural Minnesota through value-added processes that capture renewable biomass energy production capability
- Goal 3: Increase accessibility to information that facilitates the adoption of biomass technologies to generate electricity and reduce fossil fuel use

During the past four months, Bepex International, along with the assembled team, have successfully developed a biomass supply chain, negotiated all required permits and subcontracts, and developed a fundamental and operational understanding of biomass torrefaction and densification for the production of a renewable carbon-neutral biomass-based solid fuel for the production of heat, syngas or electricity. The team's work has focused on a range of activities including: securing all required subcontracts and permits, conducting process research & development, completing the first harvest, storing and transporting biomass, designing and fabricating custom equipment, and conducting preliminary economic analyses.

Technical Progress: Process Research & Development (PRD)

Bepex has developed a robust process research & development (PRD) program to fundamentally understand biomass torrefaction and densification. Within this PRD effort are two main areas of focus: *bench scale testing* and *pilot scale testing*. The first bench scale tests were used to determine initial torrefying processing condition targets; further bench scale testing explored densification. Pilot scale testing consists of two distinct areas of work: *Single unit operations*, and *custom continuous process set-ups*. Single unit operation testing (size reduction,

drying, reacting, compaction, cooling, etc.) is performed to gain an understanding of the feasibility, capacity and operational performance parameters for each of the individual pieces of process equipment. The data from the single unit operation testing is then used to aide in the design of custom continuous process set-ups. Through this gradual increase in complexity and integration, we are able to develop a continuous biomass torrefaction and densification process.

Bench Scale Testing:

The bench scale research commenced in August 2007. This work consisted of two 13-run torrefaction process-window design of experiments (DOE), a post-torrefaction densification DOE, thermo gravimetric analysis (TGA) of the biomass mass loss kinetics, differential scanning calorimetry (DSC) measurements of the torrefaction reaction, and an investigation of the effect of using other inert gases as replacements for nitrogen.

Of significant interest is the completion of two full designs of experiments which explored the process window of the torrefaction regime itself. Research revealed that raw corn stover has a HHV (Higher Heating Value – Proximate Analysis (DAF – Dry Ash Free)) on an average of 8,000 btu/lb. Research further showed that by controlling the process reaction temperature and duration between 200 – 300 Celsius and 5 – 30 minutes in an inert environment (nitrogen) one can control the final HHV to approximately 10,000 btu/lb which represents approximately a 25% increase in the materials baseline calorific value (See Appendix A for Experimental Results).

During September & October 2008, a third DOE was completed which explored the effect of torrefaction temperature and time on the final briquette strength after densification. The torrefaction reactions took place in an inert nitrogen atmosphere; the reaction temperature was varied between 250 – 300 °C; the reaction time was varied between 5 – 30 minutes. After torrefaction, each biomass sample was densified in a heated die at uniform pressure. The research revealed that densifing the torrified biomass at elevated temperatures resulted in more durable briquettes. Additionally, it was observed that the final briquette water absorption rate decreased with higher torrefaction temperatures and longer torrefaction residence times.

Pilot Scale Testing: Single Unit Operations

The goal of the pilot scale testing was to gain an understanding of the feasibility, capacity, and operational performance parameters for each of the individual pieces of process equipment. The unit operations tested were: size reduction, drying, torrefying, and densifying. During testing, the mass flow rates and process settings were varied to match the optimal process outcomes determined during bench scale testing. The following list describes pilot scale single unit operation tests that were completed.

- Size reduction tests were performed (Disintegrator, Pulvocron, and tub grinders)
- Drying tests were performed in the Solidaire and fluid bed
- Air velocity tests were performed in the fluid bed
- Torrefying tests were performed in the solidaire and fluid bed
- Densification tests were performed in the CS25

The results of these tests have allowed us to empirically determine the mass flow rates and process settings for the 25 ton demonstration run in early 2009.

Pilot Scale Testing: Custom Continuous Process Set-Up

Based on the results of the single unit operation testing, continuous drying, pre-heating and torrefying pilot scale systems were installed. Three continuous pilot-scale tests were performed during the month of September. The first was a continuous drying test; the second was a continuous torrefaction test; the third was a continuous drying and torrefying test. One additional continuous test was performed during October. This test was a continuous torrefying and densifying test. These tests allowed us to more accurately complete our energy and mass balance analysis, collect product samples and begin to collect baseline proximate analyses of the final products from a continuous pilot scale operation.

During the continuous drying test, biomass was dried to less than 1% moisture at feed rates between 50 – 100 lb/hr. During the continuous torrefying test, dry biomass was torrefied at rates between 50 – 100 lb/hr; the resulting HHV of the torrefied product was approximately 9,100 btu/lb based on an average of seven samples. During the continuous drying and torrefying test, biomass was dried and torrefied simultaneously at rates between 35 – 100 lb/hr. Many material and inert gas handing obstacles were overcome during the tests; the solutions were continuously integrated into the pilot-scale process as they arose.

We obtained and ground approximately 3,900 lbs. of corn stover to conduct additional pilot scale testing in October 2008. This testing incorporated the densification step into the continuous drying and torrefying operation. Four separate runs made up this particular battery of tests. The biomass was fed at rates that varied between 50 and 90 lb/hr. Process parameters were systematically varied throughout the tests to determine each input's effect on the final product.

As a result of the four tests, a successful pilot scale continuous biomass torrefaction and densification process was developed and feasibility proven out. The resulting product that was produced from these four tests had an approximate bulk density of 45 lb/ft^3 and specific gravity of approximately 1.2. The average higher heating value (HHV) of the product was 8,753 btu/lb with a Standard Deviation of 235 btu/lb. (n=10). The final briquetted product withstood crush strengths up to 150 pounds, which is the limit of our test.

The results of these tests have allowed us to determine the scale-up factors required to affect the Demonstration run in early 2009. Based on these scale-up factors, and lessons learned, custom equipment is currently being designed and fabricated to accommodate the 25 ton run.

Custom Equipment Design & Fabrication:

Starting in late October / early November 2008, our engineering team began to work on the engineering drawings for the custom-designed equipment to be fabricated for the 25 ton demonstration run. With equipment lead times averaging approximately 12 – 16 weeks, it is plausible that the start of our demonstration run will commence in the late March to early April 2009 timeframe with shakedown testing of the installed equipment just prior to that time. Currently, approximately 50% of the custom equipment has

been designed and fabrication commenced. The other 50% is nearly designed but fabrication has not yet commenced.

Preliminary Economic Analysis:

As a part of Milestone 2 we are in the process of generating a preliminary estimate on the installed cost and operating expenses of a commercial scale biomass torrefaction process plant designed to consume 30 tons/hour of raw feed. Additional scales will be investigated later in the program. The goal of the work will be to provide an estimate of the installed cost and operating expenses required for the process, based on the major equipment included in the preliminary design of the process.

The estimate will contain the following items:

- Preliminary process flow sheet with mass and energy balance
- List of the major equipment with budgetary quotations
- List estimated utility usage and associated costs
- Estimate of the total installed cost of the process
- Estimate of the total operating expenses

The preliminary process design, mass balance and energy balance is complete. We are in the process of generating (or obtaining) quotes for the major equipment and estimating the utility requirements for each. Once those estimations are complete, we will begin to work on estimating the total installed cost of the process and the total operating expenses of the process. Additional macroeconomic and co-location feasibility / details will be added during the 2009 economic analysis activities.

Biomass Harvest:

The harvest of biomass feedstock is essential for produce the 25 ton demonstration run in 2009 as well as to fundamentally understand the logistics and costs associated with its collection, storage and transportation to the processing facility. To this end, Bepex has successfully secured all required contracts and services to harvest, dry, pre-process (tub grind), store and transport the raw material to Bepex for the 25 ton run.

Primary and secondary harvest sites (260 acres of planted corn all inclusive) were selected in August 2008, from farms located in the Olivia, MN area. During the week of November 3, 2008, 55 dry tons of corn stover were successfully collected, transported from the field and stored from approximately 26 acres of the harvest site. The biomass is currently in storage and will be tub ground during the month of December to allow for the torrefaction pilot regime testing to commence with the same 'lot' of biomass as will be used for the 25 ton demonstration run.

A more detailed description of the harvest will be included in the Milestone 2 report. However, images from the biomass harvest can be seen in Appendix B.

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Milestones:
We have completed Milestone 1 and are simultaneously working on Milestone 2. Milestone 3, while not being explicitly worked on, is impacted by our Milestone 2 activities.

Milestone 2 consists of furthering the development of the torrefaction process itself to include torrefaction regime pilot testing (shake down testing), mass & energy balances, preliminary economic analysis, custom equipment fabrication, biomass harvesting and generally getting ready for the 25 ton demonstration run to take place in 2009. We do not currently foresee any issues or delays coming up that would slow the program down for an on time completion of Milestone 2 deliverables.

Project Status:
It took longer to negotiate and execute all of the required subcontracts and obtain all required permits than originally anticipated. As such, Milestone 1 deliverables took approximately one month longer than originally planned. However, as the physical deliverables for Milestone 1 have no linkage to Milestone 2 deliverables, we currently anticipate that Milestone 2 will be completed on time as originally planned. However, due to the lead times associated with several of the key demonstration scale custom equipment fabrications, it is likely that the 25 ton demonstration run will start in late March / early April 2009 instead of late February / early March 2009.

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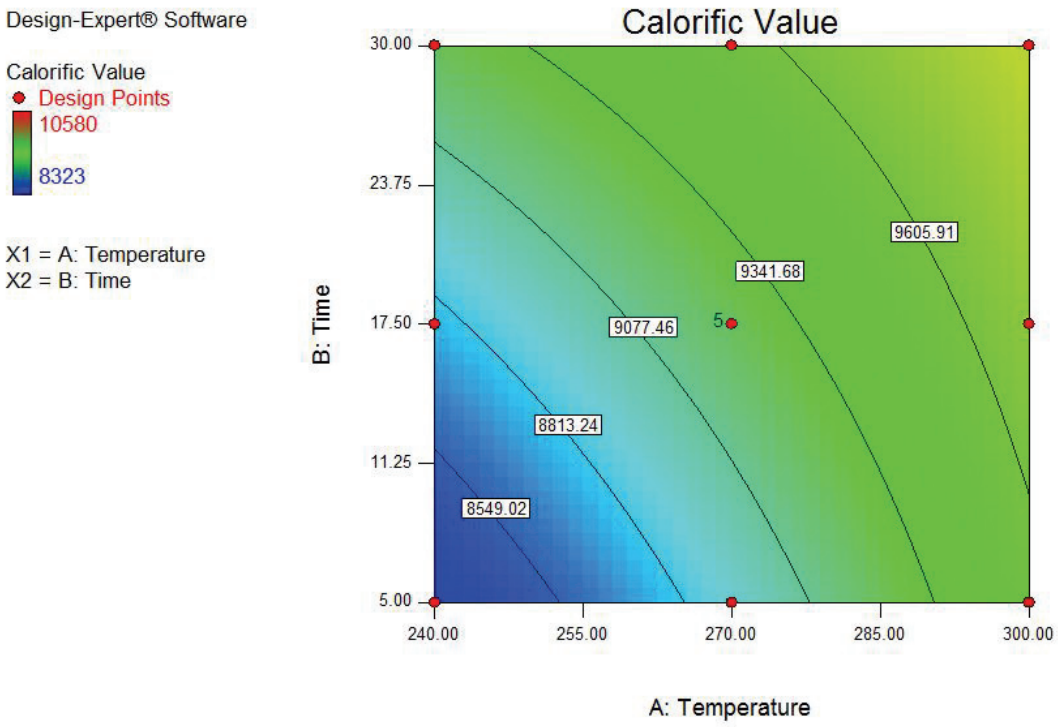
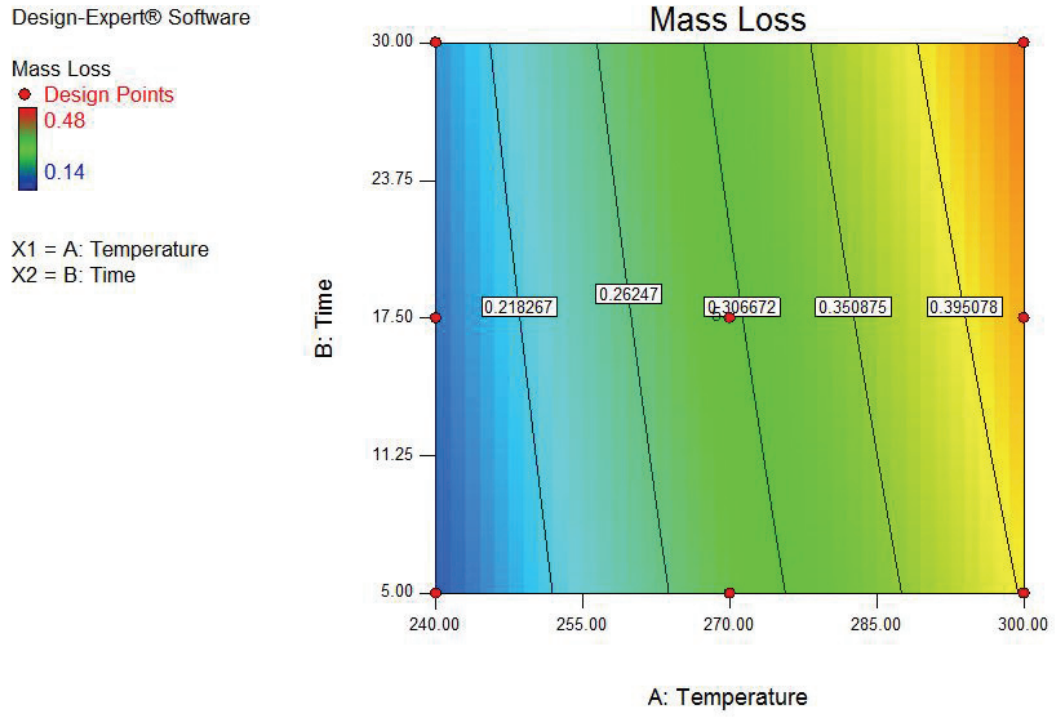
Appendix A:





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Appendix B:

Biomass Harvest Field: O'Halloran Brothers Farms, Olivia, MN

Single Pass Harvester: Iowa State University

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Beaver Creek Transport: Walking Floor Trailers with Open Tops

Corn Stover & Grain Collection via Side winding: Iowa State University, O'Halloran Brothers Farms & Beaver Creek Transport

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Indoor Biomass Storage: Beaver Creek Warehouse & Beaver Creek Transport
Unloading Collected Corn Stover (Approximately: 3 Dry Tons / Load)

Collected Corn Stover: Representative Close Up Image

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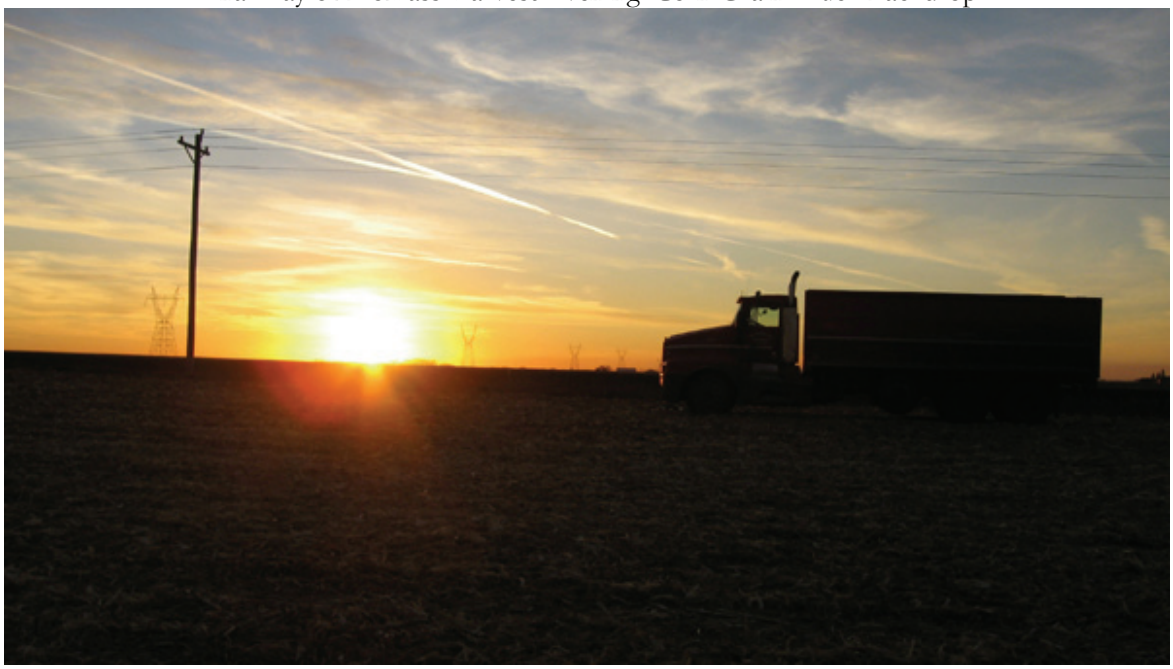
RIETZ®

Post Harvest Field Image: O'Halloran Brothers Farms, Olivia, MN

Final Day of Biomass Harvest Evening: Corn Grain Truck Backdrop



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