



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

Contract Number: RD3-4 Milestone Number: 04

Report Date: Thursday, November 05, 2009

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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 4 REPORT

Executive Summary:

This project will research torrefaction and densification of biomass feedstocks to develop an efficient and economical biomass supply chain. 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

The main work activity that was conducted for Milestone 4, final product bulk analysis, relates to, addresses and brings value to the project goals in the following two ways:

- Confirmation of the final products physical attributes
- Validation of the final products ability to be used alongside existing coal infrastructure

The project continued its progress with work on Milestones 4, 5 and 6 during the months of July - October 2009. In June 2009, the demonstration run to produce 5 tons of torrefied products was successfully completed. The process of collecting, processing, analyzing and documenting the post-torrefied material continued in July 2009. In addition, the team spent time working on the final logistical and scientific details required for the early August 2009 co-firing test burn.



Technical Progress: Final Product Testing – Protocol & Benchmarking

The demonstration run to produce 5 tons of biocoal occurred in early June 2009. With the demonstration run completed the team turned its attention towards analyzing the final product that was produced during the demonstration run. While a majority of the final products chemical characteristics were discussed in the Milestone 3 Report this is not the only facet of the final product that needs to be characterized. Specifically, while the chemical characteristic of the biocoal product largely determine its suitability for use in existing pulverized coal electrical power plants the product must also have superior physical properties to allow it to be used in existing coal transportation infrastructure without modification to the fuel or infrastructure. These physical properties, such as bulk density, durability, equilibrium moisture, and crush strength are important as they largely determine the solid fuels suitability for use in existing bulk commodity and coal handling infrastructure worldwide. The final product must also have superior physical characteristics to that of raw biomass to justify processing the material into biocoal.

To analyze the final biocoal product that was produced during the demonstration run conducted in June 2009, the team started by developing a formal sampling protocol that was attached as an Appendix in the Milestone 3 Report. Specifically, we took samples from drums that represented every twelve hours of operation consisting of drums 11, 21, 29, 36 and 46. From these samples bulk density, durability, equilibrium moisture, and crush strength analysis of final product were then determined. While Hardgrove Grindability Index (HGI) analysis is also an important physical characteristics for the final products suitability for existing pulverized coal boilers this characteristic along with the elemental ash analysis of the final product will be presented in the Milestone 5 Report.

Bulk Density: Minimization of Solid Fuel Transportation and Storage Costs

The bulk density of a product dictates the total mass of that product of which can be shipped for a given volume of space. When transporting bulk commodities such as coal over long distances it is important that the product be as dense, or have as high a bulk density, as possible such that for each cubic foot of shipping space in a rail car, truck bed, barge or ocean going vessel the cost per ton of transporting that product is minimized. Typically, the higher the bulk density of the product, the lower the per/ton shipping costs of that product are.

The team collected three bulk density measurements from the final product every six hours of operation during the demonstration run conducted in June 2009. The average bulk density of the final torrefied product without fines was 39.9 lbs/ft³ with a standard deviation of 1.9 lbs/ft³ (n=33). However, in a commercial application it will be typical to have some level of fines in the final product when shipped to a potential customer thereby driving up the final bulk density to approximately 45 – 50 lbs/ft³. To be conservative, we decided to remove the fines entirely and measure the bulk density of only the torrefied and densified briquettes. The analyses were conducted by Bepex employees and shown in the table below.



Drum	Bulk Density (lbs/ft ³)			Average
	1	2	3	
7	37.6	38.7	39.6	38.6
11	38.3	39.5	40.6	39.5
17	36.7	39.2	39.7	38.5
21	45.1	42.2	40.5	42.6
25	41.2	42.5	43.2	42.3
29	38.2	39.6	40.4	39.4
32	37.4	40.0	40.3	39.2
36	38.3	38.8	40.6	39.2
40	40.5	40.6	41.9	41.0
46	37.6	38.7	39.4	38.5
51	37.7	39.9	43.4	40.3

39.9 Global Average

1.9 StDev

Durability: Suitability of Bulk Handling for Global Intermodal Transportation

The durability of a bulk commodity such as coal or biocoal is important as each time the product is moved from one point to another along the transportation supply chain the product impacts itself and has an opportunity to fall apart and/or break down into dust. Additionally, once the biocoal reaches the coal yard of the electrical utility it is moved once again by the solid fuel handing system to consist of conveyers, bucket elevators, surge bins, and misc. conveyance systems. The more 'durable' coal or biocoal is, the more the product will stay together in its original sizing. Additionally, it is important that the product does not turn into dust during transport otherwise there are increased explosion hazards, air quality concerns, and the dust has decreased utility by the power plant as it is harder to move and transport to the coal pulverizer for subsequent combustion. Finally, if the coal/biocoal turns into dust it has a higher specific surface area which increases the reactivity with the environmental oxygen present thereby accelerating ambient temperature thermal oxidization resulting in increased chances of coal pile fires and/or decreased calorific values.

To simulate these transportation supply chain bulk handling impacts and solid fuel handing aspects at the electrical utility on the biocoal, the team collected 5 samples from the June 2009 5 ton production run and conducted durability analysis on the samples and then compared its performance to that of typical grades of coal. The team sent the samples to Mineral Labs Incorporated (MLI). MLI performed a Tumbler Test (ASTM 0441-07) on each of the 5 samples submitted. Under the specified ASTM test, the samples are to be sized 1- 1/2" x 1". The briquettes only qualified by size designation for this procedure when two briquettes were joined together. Therefore MLI abbreviated the ASTM procedure by reducing the starting size to 1" x 3/4" which reflected the natural size of the biocoal samples. The results for this test and the official analysis letter are attached to this Milestone Report as an appendix. The table below shows durability test results (ASTM 0441-07) of different types of coals as compared to the average biocoal from our production run:



	Biocoal	Bituminous Steam Coal	Sub-Bituminous Coal	Anthracite
Dust Index	9-12	7-14	8-15	5-9
Friability Index	34-40	32-50	34-55	30-43

Some of the observations during the testing of the biocoal included:

- The biocoal briquettes maintained their original shape after testing
- Over 86% of the material remained larger than 1/2" after testing
- Dust and fine particles created from briquette edges and not from chipping or splitting of briquettes
- Fine dust particles (minus 48 mesh) created from abrasion of the test instead of typical material handling applications

Based on the results from the durability testing it is clear that biocoal produced by our team performs very similarly to Anthracite, Bituminous, and Sub-Bituminous coals typically seen in the United States. In some cases, the biocoal product performed better than its coal counterpart – in particular bituminous and Sub-Bituminous coals with biocoal having a lower maximum friability index as compared to these two classes of coals traditionally used for the production of electricity. The team is encouraged by these results as it indicates that the biocoal can be shipped via traditional intermodal bulk commodity methods such as rail, barge, truck or ocean going vessel without any modification to this existing infrastructure or the solid fuel. Additionally, and just as importantly it appears the biocoal can be moved and conveyed by traditional coal yard and electrical utility solid fuel handling systems on its way to the pulverizers without any modification of the infrastructure of the solid fuel.

Equilibrium Moisture: Resistance to Moisture Uptake during Transportation and Storage

Equilibrium moisture analysis was used to help better understand the biocoals hydrophobic nature as compared to its raw form and to that of coal. The equilibrium moisture of a product has an impact on its ability to be moved, transported and stored with the same ease as coal. The lower the equilibrium moisture of the product the less water, or more hydrophobic, the final product is thereby lowering its propensity to take on water and break apart and/or become lodged within the shipping container it is located in. Additionally, the final biocoal is no longer biologically active, or said another way it no longer has the ability to rot as does raw biomass making it easier to store and ship without fear of molding or rotting of the product.

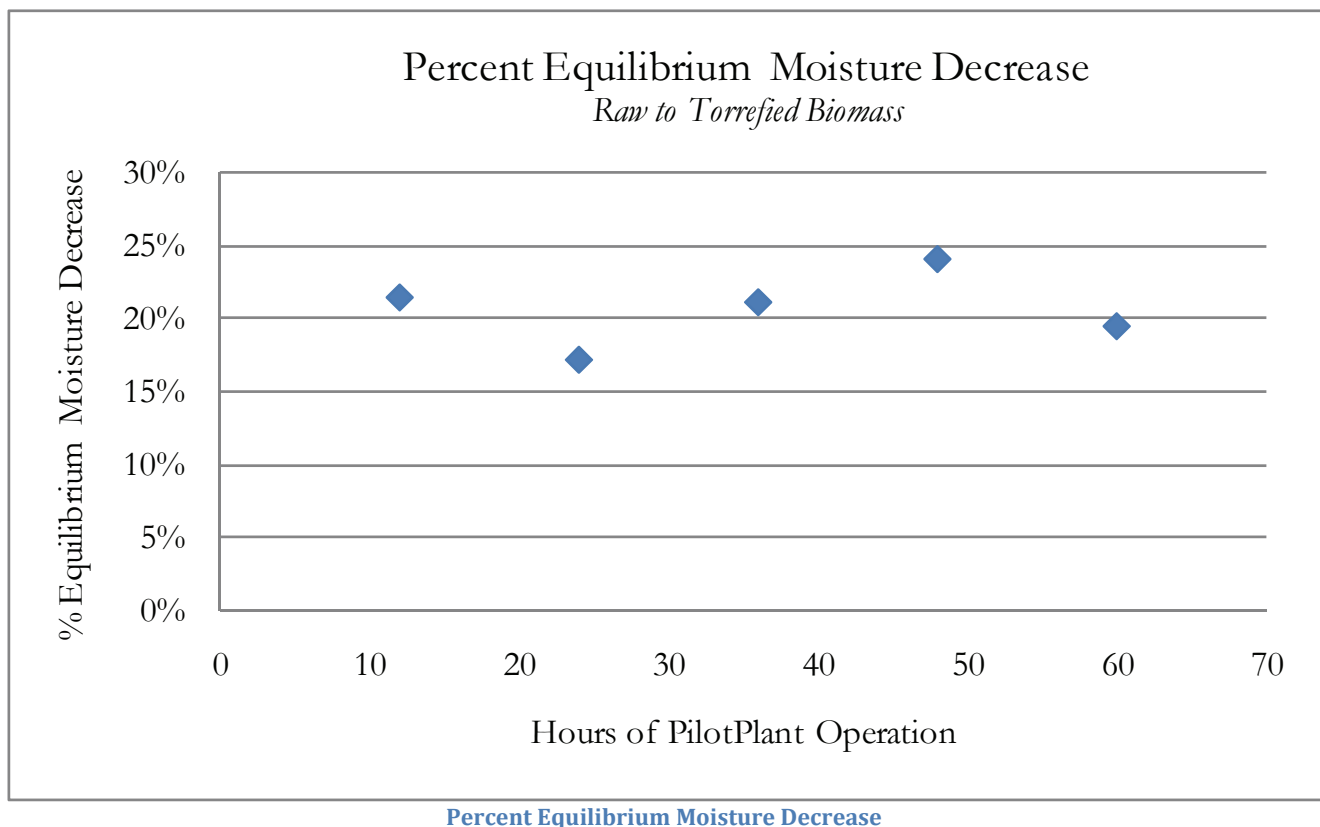
	Equilibrium Moisture	
	Torrefied	Coal
Avg.	23.9%	22.7%
StDev.	0.8%	0.49%



Five samples of biocoal from the 5 ton production run, coal used in our co-firing trial (Milestone 6), and raw corn stover were submitted to SGS North America for equilibrium moisture analysis. The results clearly show that post torrefied biomass is more hydrophobic than raw biomass and has similar equilibrium moisture as compared to Montana sub-bituminous coal. As per ASTM D1412 the raw corn stover biomass samples submitted had an average equilibrium moisture of 30.1% with a StDev of 0.4% whereas the post torrefied corn stover samples had an average equilibrium moisture of 23.9% with a StDev of 0.78% - representing an average 20.6% decline in equilibrium moisture from raw to torrefied final product. Additionally, the sub-bituminous coal samples had an average equilibrium moisture of 22.7% with a StDev of 0.49% leaving both sub-bituminous and torrefied corn stover with nearly the same propensity to take on water.

The graph below shows the percentage equilibrium moisture decrease of the final product as compared to the raw feedstock as a function of the June 2009 five ton demonstration run. Samples taken representing every 12 hours of operation showed that the pilot plant operation maintained a steady final product over the duration of the demonstration run.

More studies with the final product will need to be conducted to allow more conclusive results to be drawn, but the early indications are that the final biocoal material can be utilized alongside coal in an outdoor setting for bulk transport and coal pile storage with minimal concern of its uptake of moisture from the environment at rates exceeding that of its counterpart - coal.



Crush Strength: Resistance to Briquette Fracture during Transportation and Storage

While the durability of the product measures its resistance to product physical degradation during relative motion between briquettes during bulk handling loading, unloading and intermittent shocks during shipping, crush strength measures the final products resistance to static and dynamic loading conditions seen during transportation and storage of the product. For example, when the product is stored in a pile the static loading on the bottom of the pile can reach elevated levels of pressure. Crush strength measures the force (lbf) required to cause catastrophic briquette failure. The team used a Rimac (Mark-10) brand plunge force testing device that was calibrated with a maximum 150 lbf reading.

Instead of only testing individual briquettes from product representing only every 12 hours of operation, the team decided to test individual briquettes produced representing product every 6 hours of operation. Specifically, biocoal briquettes from drums 7, 11, 17, 21, 25, 29, 32, 36, 40, 46, and 51 were sampled and subjected to a crush strength test. Fifteen individual biocoal briquettes were randomly selected using the sampling protocol attached as an appendix of the Milestone 3 report. From these 15 samples the analytical chemist randomly choose twelve from each drum to subject to the crush strength test.

After testing all twelve biocoal briquettes from drums 7 and 11 it became apparent that the biocoal briquettes could withstand greater forces than what our Rimac device could subject them to. Therefore, for drums 17 and 21 we subjected five biocoal briquettes to the crush strength test and for drums 25, 29, 32, 36, 40, 46, and 51 we subjected only three biocoal briquettes to the crush strength test. Only one out of the 55 samples catastrophically failed at a force below 150 lbs. Based on these results, the team is optimistic about the final biocoal briquettes ability to be used in existing bulk commodity intermodal transportation infrastructure and its ability to be stored in larger static piles with minimal risk of the product failing under its own weight.

Technical Progress: Co-Firing Test Combustion

The team, during the months of May – August 2009 worked to finish the contract negotiation, work to obtain the appropriate testing parameters, acquire coal, produce the torrefied and densified biomass, and coordinate the logistics of conducting the co-firing test combustion. The team successfully completed the contract negotiations to conduct the post-production test combustion services at a pilot scale pulverized coal boiler (550,000 btu/hour). Additionally, in July 2009 the team worked with Xcel Energy power plants to obtain specific boiler operating parameters that could be “dialed in” by the pilot scale pulverized coal boiler.

The team, upon receipt of this coal, took multiple samples to conduct various analyses to include proximate, ultimate, equilibrium moisture, elemental ash analysis, and hardgrove grindability index testing. The proximate and ultimate analyses of the coal and the torrefied biomass were used to develop the blending ratios for the co-firing tests. The results of the external analyses and the co-firing results will be presented in the Milestone 5 report.

The team successfully conducted co-firing trials at three different co-firing ratios on August 10, 2009 to include: 1) 100% coal to create a benchmark, 2) 10% torrefied biomass, and 3) 30% torrefied biomass





blends with the same coal. The team used a Montana sub-bituminous coal sourced from the Xcel Energy Sherco power plant.

Technical Progress: Process Research & Development (PR & D)

As a part of our ongoing development efforts in the core biomass torrefaction and densification process the team began to brainstorm the lessons learned from our previous five ton demonstration run as well as to reflect on the prior pilot testing conducted thus far. This brainstorming session provided the team with a list of possible evolutionary improvements in the existing biomass torrefaction and densification pilot plant that could be implemented prior to our final 25 ton demonstration run. Ideas such as improvements in material selection and/or specific surface coatings on \ wear surfaces to improve the process equipments resistance to wear, and options to streamline the operation itself were addressed and early implementation plans set in motion. The team, over the next several months will continue to revisit our existing process and look for ways to continue to refine the process, the equipment layout, and how the system itself is operated.

Economic Analysis:

Additionally, the team has begun to refine its preliminary economic analysis to include co-location aspects with traditional corn based ethanol production facilities. As the 2007 Energy Independence and Security Act lays out only those advanced biofuels that reduce greenhouse gas emissions by 50% or greater will be eligible for future blender tax credits of 45 cents a gallon of ethanol. When the ethanol plant is powered by coal, this is not the case. To understanding this dynamic better, the team is investigating the possibility of an industrial biocoal production facility to be co-located with an existing corn ethanol plant.

Analysis is being conducted on the co-located biocoal facility to produce excess heat (52 mmbtu/hour) and biocoal from corn stover sourced from the same regional farmers who provide the corn grain to the ethanol plant. Additional work is also looking at the biocoal facilities ability to both power the facility to reduce its net greenhouse gas footprint via excess heat and combustion of biocoal to allow the facility to reduce greenhouse gas emissions by 50% or greater and to sell the biocoal off as an additional commodity product to regional electrical utilities using existing rail links.

Milestones:

We have just completed Milestone 4 are currently working on Milestones 5, 6 and 7.

Milestone 4 primarily consists of developing benchmarks and testing our product and that of substitute products (namely that of coal) to compare and contrast their storage and bulk handling characteristics.

Milestone 5 consists of conducting the co-firing test combustions utilizing the product produced during Milestone 3. We have completed the contract negotiations and successfully completed the co-firing trial on August 10, 2009. The team is now working on analyzing the preparing the final report from these tests.

Milestone 6 consists of completing the economic analysis and PR&D, completing the biomass harvesting for second harvest season and completing the optimization of the torrefaction regime for the second demonstration run.





Milestone 7: consists of generally getting ready for the final demonstration run and producing 25 tons of biocoal from corn stover.

Project Status:

The project has completed the Milestone 4 deliverables of developing benchmarks and testing our product and that of substitute products (namely that of coal) to compare and contrast their storage and bulk handling characteristics. The project has nearly completed the analytical work required for the submission of our Milestone 5 deliverables and has commenced on working on our Milestone 6 objectives while starting to schedule the final production run required for Milestone 7.

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From: Rodney Campbell
Office: Salyersville, KY
Date: September 14, 2009
Copy: Brad Lyon - MLI

To: Kevin Grotheim
Business Development Manager
Bepex International, LLC
333 N.E. Taft Street
Minneapolis, MN 55413

Re: Torrefied and Densified Corn Stover Briquette "Biocoal" Evaluation

Mineral Labs, Inc., appreciates the opportunity to provide these test results for samples submitted by your company on torrefied and densified corn stover briquettes "biocoal". The comments below explain the procedures used in this analytical process and comparison of results to coals found in the United States.

MLI performed a Tumbler Test (ASTM D441-07) on each of the 5 samples submitted. Under the specified ASTM test material needed to be sized at 1-1/2" x 1". The briquettes only qualified by size designation for this procedure when two briquettes were joined together. MLI also abbreviated the ASTM procedure by reducing the starting size to 1" x 3/4" which reflected the natural size of the biocoal. The results for both test are attached to this letter.

The following table shows test results of different types of coals compared to biocoal:

	Biocoal	Bituminous Steam Coal	Sub-Bituminous Coal	Anthracite
Dust Index	9-12	7-14	8-15	5-9
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- Fine dust particles (minus 48 mesh) created from abrasion of test instead of typical material handling applications

Should there be any questions about these test results or comments please feel free to call.

Respectfully,



Mineral Labs, Inc.

Box 549
Salyersville, Kentucky 41465
Phone (606) 349-6145

CERTIFICATE OF ANALYSIS

Company

Bepex International LLC
333 N.E. Taft Srreet
Minneapolis, MN 55413, USA

Date Analyzed

9/9/2009

Tumbler Test ASTM D 441-07 - Abbreviated Method

Sampled By: Customer Sample Type: Mail_in

Lab #	ID	% Friability	Dust Index
99002345	ML-001	39.5	12
99002346	ML-002	35.0	11
99002347	ML-003	37.5	11
99002348	ML-004	36.5	9
99002349	ML-005	34.5	9

Submitted By

R. Housh