INL/RPT-23-73943-Revision-0

Lignetics CRADA closeout report

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Changing the World's Energy Future

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Idaho National Laboratory

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Final CRADA Report

Lignetics CRADA

PROJECT INFORMATION

CRADA No.: 20-TCF-4 Completion Date: 01/31/2023

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Scope and Objective

Lignetics is one of the leading domestic producers of wood pellet fuels used for domestic heating. The company also produces pellets for other applications including animal bedding. The primary feedstock used for the production of Lignetics products is woody biomass. To improve the economics of pellet production, Lignetics is evaluating advanced preprocessing technologies developed by researchers at INL. In the proposed project, INL and Lignetics will work collaboratively to assess the feasibility of integrating INL's advanced preprocessing technologies (fractional milling, high moisture pelleting and low temperature drying) in Lignetics production facilities. The successful completion of the project relies on the integration of the fractional milling and high moisture pelleting (HMP) process and low temperature drying to improve the economics of woody biomass pellet production for use in biofuel and bioproduct applications. In the HMP process, the biomass loses some moisture during compression and extrusion through the pellet die due frictional heat developed. Also, as pellets have a definite size and shape, they can be further dried in low temperature grain or belt dryers. Belt dryers are better suited to take advantage of low-grade and waste heat because they operate at lower temperatures than rotary dryers (Tumuluru et al.) Rotary dryers, for example, typically require inlet temperatures of 260°C, but more optimally operate around 400°C. In contrast, the inlet temperature of a belt dryer, such as a commercially available vacuum dryer, can be as low as 10°C above the ambient temperature, although more typically they operate at higher temperatures, between 90°C and 200°C. Because of their lower temperature operation, fire hazards and emissions to the air are lower for belt dryers in addition to reducing drying and overall pelleting costs, INL's technology also has potential to reduce emissions at Lignetics facilities.

The objective of this project is to understand the woody biomass physical properties (moisture content, bulk density, geometric mean particle length, particle size and size distribution, and particle density) and design a pelleting process that will produce a consistent pellet with desired physical properties at reduced energy consumption. Specifically, the technical goals of the project are to consistently produce a woody biomass pellet product with a moisture content below 5 % (w.b.), a bulk density in the range of 35-45 lb/ft3, and a durability of >97.5%, at a 30% reduced pelleting cost (compared to conventional method followed by the industry) for fuel and byproducts application. INL will develop a material engineering solution, translatable to Lignetics, which integrates Advanced Preprocessing techniques including fractional milling, HMP, and low temperature drying to produce pellets meeting the required moisture, bulk density and durability specifications. If successful, INL's solution will be tested at-scale at a select Lignetics production facility.

Project Accomplishments

Initial Techno-Economic Analysis

In this quarter the focus of the work was to understand the cost of pelleting woody biomass using conventional pelleting process. Two pelleting scenarios were tested. The first scenario was the pelleting of sawdust into pellets. The data for processing sawdust into pellets was provided by Lignetics. One of Lignetics plants which is at Cascade was considered for this analysis. In the case of wood chips, we considered the conventional pelleting process of forest residues. INL data collected using pilot scale hammer mill, dryer, pellet mill and cooler was used for calculating the cost of pelleting forest residue chips using the conventional pelleting process. The Biomass logistics model was used to do techno-economic analysis. The analysis indicated that to process Sawdust into pellets with a starting moisture of 40 % (w.b.) at the Lignetics Cascade plant was about $ 50.41 /dry ton (Figure 1) whereas if we use forest residue the cost is about $60/dry ton. The drying costs were similar for saw dust and forest residue but the grinding of forest residue in stage-1 and stage-2 grinders cost roughly $13/dry ton.

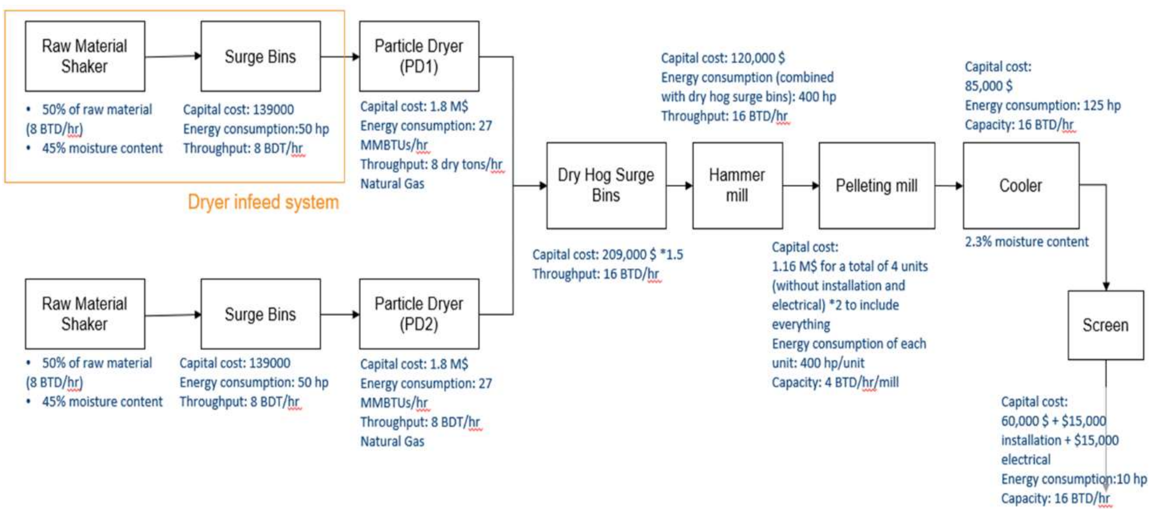

Figure 1: Processing flowchart for Lignetics Cascade plant (scenario 1)

Experimental plan development for High Moisture Pelleting (HMP) and Low-Temperature Drying

In this quarter, the focus of the work was to design experimental plans for both high moisture pelleting (Table 1) and low temperature drying processes (Table 2). After discussion with the Lignetics project team, a ratio of sawdust to shavings of 70% to 30% was selected. The process flow diagram was designed to process this mixed feedstock using INL's high moisture pelleting process. The process variables for the pelleting experiments will be the length to diameter (L/D) ratio of the pellet mill die as well as the feedstock moisture content. The L/D ratios to be tested in these experiments are between 8-12, and the moisture contents to be tested will be between 20-30% (w.b.). During the pellet drying experiment, a laboratory scale grain dryer will be used to understand the drying kinetics of the high moisture pellets under varying conditions such as various airflow rates and drying temperatures. Mathematical models will be developed using the drying experimental data to better understand the drying kinetics and establish the drying rate constants. The rate constant and moisture loss data can then be further used to design low temperature pellet dryers.

Process variables			
Expt. no	Wood chips moisture (%, w.b.)	L/D ratio	Pellet properties
1	20	9	Pellet moisture content (%, w.b.) Pellet unit density(kg/m3)
2	20	10	

3	20	11	Pellet bulk density (before and after drying) (kg/m3) Pellet tapped density (kg/m3) Green durability (%) Cured durability (%) Pelleting energy consumption (kWh/ton)
4	20	12	
1	25	9	
2	25	10	
3	25	11	
4	25	12	
1	25	9	
2	30	10	
3	30	11	
4	30	12	
Screen size in the hammer mill (1/4-inch) Pellet die diameter: 6 mm			

Table 1: Experimental Plan for initial high moisture pelleting tests

Expt. No	Air Temperature	Drying Air Flowrate
Experiment 1	No heat	35 cfm (5% air inlet opening)
Experiment 2	No heat	50 cfm (10% air inlet opening)
Experiment 3	40 °C	35 cfm (5% air inlet opening)
Experiment 4	40 °C	50 cfm (10% air inlet opening)
Experiment 5	70 °C	35 cfm (5% air inlet opening)
Experiment 6	70 °C	50 cfm (10% air inlet opening)

Table 2: Low-Temperature drying test plan for high moisture pellets.

Initial High Moisture Pelleting Tests on Pilot Scale Pellet Mill varying initial moisture content and Low-Temperature Drying tests with model development for thin layer drying process.

In this quarter we have conducted tests on high moisture pelleting of woody (30% shaving+70% sawdust) Douglas fir biomass. The raw material is conditioned to different levels of moisture (20, 25 and 30%, w.b.) and is further hammer milled. The raw material was passed through the hammer mill fitted with 1/4 -inch screen and is then pelleted. The raw material properties before and after grinding were measured. We have selected an L/D ratio of 9 and three different moisture contents of 20, 25 and 30% for testing. The pellets produced were measured for physical properties such as moisture content, unit, bulk and tapped density and durability. The physical properties of pellets produced indicated that the bulk density and durability values were between 600-700 kg/m3 and durability of about 97%. The pellets produced were further dried in a low temperature dryer (Figure 3) to understand how the drying temperature and drying time influence the moisture loss. The data indicated that drying of the pellets at 80°C helps to meet the desired moisture content of <5 %(w.b.). Drying data is further used to develop models for thin layer drying process. The models developed accurately predicted the moisture loss phenomena with a coefficient of determination values of 0.99.

Figure 2: High Moisture pellets made at about 27% (w.b.) initial moisture content.

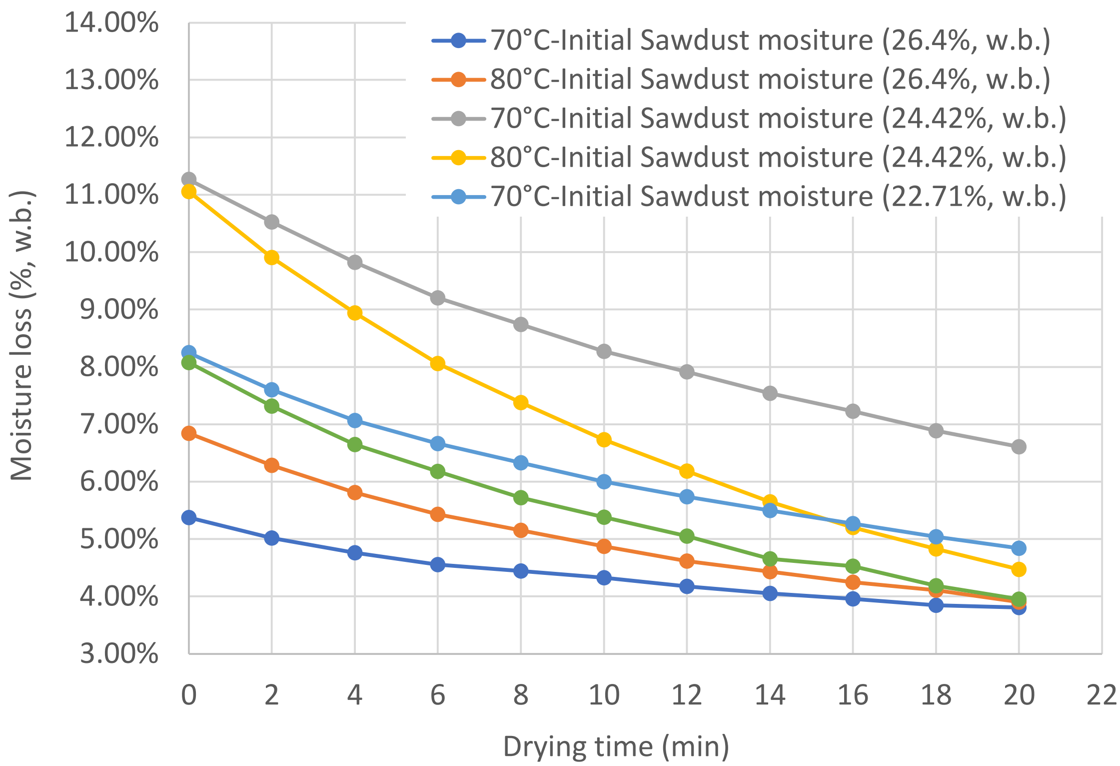

Figure 3: Low-Temperature drying tests using grain dryer.

HMP tests varying pellet die compression ratios and initial moisture.

Tests were performed using Length over Diameter (L/D) ratio dies of 8 and 9 on various moisture contents ranging from 20-30% as well as a "baseline" test with the as-received moisture of roughly 12%. Pellet property data was taken of pellet samples collected directly after pelleting as well as after a cooling period of 2-3 hours and are denoted as Wet and Dry in Table 4 below.

	8-Low	**8-20%**	**8-25%**	**8-30%**	**9-Low**	**9-20%**	**9-25%**	**9-30%**
Die L/D	8	8	8	8	9	9	9	9
Initial MC Goal (%)	12	20	25	30	12	20	25	30
Pre-Milling (%)	**12.3**	**20.2**	**25.1**	**30.1**	**12.3**	**23.6**	**25.4**	**30.7**
Std Dev	1.6	0.2	0.2	0.1	1.6	1.0	1.0	0.2
Post-Milling (%)	**10.8**	**18.6**	**23.6**	**25.5**	**10.8**	**21.8**	**25.1**	**29.4**
Std Dev	1.3	1.0	0.7	1.1	1.3	0.3	1.4	0.7
Wet Pellet (%)		**6.6**	**6.3**	**10.3**		**9.4**	**10.6**	**13.8**
Std Dev		0.16	0.15	0.09			0.59	0.45
Dry Pellet (%)	**5.9**	**5.3**	**4.3**	**5.1**	**2.5**	**5.1**	**4.5**	**5.0**
Std Dev	0.14	0.10	0.37	0.16	0.14	0.82	0.10	0.07
Wet BD (kg/m3)		**709**	**720**	**598**		**672**	**666**	**555**
Std Dev		6.0	5.2	17.7		3.9	4.7	11.1
Wet TD (kg/m3)		**757**	**771**	**639**		**720**	**709**	**610**
Std Dev		6.8	4.4	19.4		4.0	3.0	7.3
Wet UD (kg/m3)		**1293**	**1308**	**1268**		**1219**	**1222**	**1224**
Std Dev		29.01	15.18	38.83		41.33	50.04	51.57
Wet Dia. (mm)		**6.32**	**6.31**	**6.31**		**6.37**	**6.28**	**6.35**
Std Dev		0.021	0.016	0.062		0.053	0.039	0.054
Dry BD (kg/m3)	**740**	**688**	**726**	**623**	**704**	**659**	**666**	**540**

Std Dev	7.6	3.4	8.2	2.0	1.5	1.9	4.7	2.3
Dry TD (kg/m3)	**793**	**740**	**772**	**673**	**763**	**711**	**709**	**599**
Std Dev	3.5	5.6	0.8	3.8	0.5	3.5	3.0	0.7
Dry UD (kg/m3)	**1322**	**1287**	**1294**	**1259**	**1287**	**1215**	**1222**	**1197**
Std Dev	17.8	20.3	34.3	24.9	47.25	54.1	50.0	22.6
Dry Dia. (mm)	**6.33**	**6.35**	**6.28**	**6.26**	**6.26**	**6.24**	**6.28**	**6.22**
Std Dev	0.019	0.018	0.031	0.027	0.021	0.043	0.039	0.032
Wet Durability (%)		**96.5%**	**96.6%**	**95.8%**		**96.4%**	**97.5%**	**96.4%**
Std Dev		0.13%	0.31%	0.07%		0.15%	0.03%	0.40%
Dry Durability (%)	**92.5%**	**96.5%**	**97.0%**	**96.2%**	**95.8%**	**96.9%**	**97.5%**	**96.7%**
Std Dev	0.33%	0.24%	0.04%	0.13%	0.28%	0.06%	0.03%	0.52%

Table 3: Pellet properties for high moisture pellets made using L/D dies of 8 and 9.

Completion of pellet die testing with varying initial moistures and pellet die ratios, updates to TEA.

This quarter, we completed high moisture pelleting tests that were planned for the Douglas Fir feedstock blend (30% shavings: 70% sawdust) provided by Lignetics (Table 4). The pelleting tests conducted this quarter were using pellet mill dies with varying length over diameter ratios (6,7,10,11) at different initial moisture levels. Previously, tests were conducted on L/D ratios of 8 and 9, and the data collected this quarter was then compared to determine the optimal moisture content and pellet mill die with respect to the pellet quality and processing costs. It was determined after analyzing the data that the optimum conditions selected would be an initial moisture content of 30% and utilizing the 8 L/D die. To come to this conclusion, a techno-economic analysis needed to be performed to understand the cost implications of this selection. This analysis estimated a cost for processing the material of $37.09/dry ton, which was an improvement of 25.4% over the initial baseline analysis.

Pellet Die L/D	**6**	**6**	**6**	**7**	**7**	**7**	**10**	**10**	**10**	**11**	**11**
Initial MC Goal	**20**	**25**	**30**	**12**	**20**	**25**	**20**	**25**	**30**	**20**	**25**
Date	**3/1**	**3/1**	**3/2**	**11/23**	**1/18**	**1/18**	**3/8**	**3/8**	**3/9**	**3/22**	**3/17**
Pre-Milling MC	**19.7%**	**24.7%**	**28.5%**	**12.3%**	**21.2%**	**26.7%**	**20.5%**	**24.6%**	**29.8%**	**26.0%**	**26.7%**
Std Deviation	0.1%	0.1%	0.1%	1.6%	0.10%	0.01%	0.07%	0.04%	0.12%	0.13%	0.07%
Post-Milling MC	**17.8%**	**20.5%**	**27.1%**	**10.1%**	**18.7%**	**24.3%**	**18.6%**	**20.1%**	**23.6%**	**23.09%**	**24.9%**
Std Deviation	0.4%	2.1%	0.2%	0.5%	0.7%	1.2%	0.3%	1.7%	3.2%	0.4%	0.1%
Wet Pellet MC	**13.1%**	**13.7%**	**19.5%**	**3.9%**	**12.6%**	**13.5%**	**9.2%**	**7.1%**	**5.6%**	**4.7%**	**9.7%**
Std Deviation	0.68%	1.80%	0.36%	0.28%	0.81%	0.52%	0.37%	0.33%	0.13%	0.23%	0.98%
Wet Bulk Density (kg/m3)	**563.4**	**438.2**	**429.6**	**640.5**	**568.3**	**586.3**	**676.6**	**660.9**	**704.5**	**745.6**	**644.8**
Std Deviation	6.96	4.41	2.02	6.12	1.99	2.14	2.19	4.23	5.42	11.31	10.16
Wet Tapped Density (kg/m3)	**608.5**	**485.9**	**473.4**	**698.1**	**614.7**	**635.3**	**728.1**	**707.2**	**747.9**	**798.7**	**695.9**
Std Deviation	14.18	5.21	0.79	1.18	2.10	4.29	5.76	1.62	9.40	11.67	10.93
Wet Unit Density (kg/m3)	**1305.7**	**1198.2**	**1233.1**	**1346.9**	**1113.5**	**1089.2**	**1291.1**	**1226.9**	**1293.9**	**1293.0**	**1259.2**
Std Deviation	23.12	34.23	43.34	38.73	53.47	69.64	8.86	38.86	47.04	25.73	23.10
Wet Diameter	**6.34**	**6.41**	**6.38**	**6.30**	**6.47**	**6.54**	**6.27**	**6.26**	**6.26**	**6.27**	**6.33**
Std Deviation	0.021	0.044	0.052	0.012	0.084	0.065	0.010	0.039	0.021	0.058	0.021
Wet Durability	**96.5%**	**89.0%**	**89.3%**	**97.7%**	**97.7%**	**95.9%**	**94.9%**	**96.5%**	**96.0%**	**94.0%**	**95.1%**
Std Deviation	0.30%	0.15%	0.45%	0.17%	0.02%	0.78%	0.27%	0.37%	0.25%	0.50%	0.43%

Table 4: Pellet properties for high moisture pellets made with L/D dies of 6,7,10,11.

Fractional Milling testing showing the effects on pellet quality

Conducted fractional milling tests to understand the effects of varying particle size distributions on pellet quality and energy consumption during the pelleting process. By utilizing different size screens in the orbital screener, varying particle size distributions were obtained. Average mean particle sizes ranged from 1.24mm with the 5/32" fractional milled test to 1.36mm with the 3/16" fractional milling performed. Grinding energy consumption was significantly reduced by up to 70% over testing done without fractional milling. Pellet testing was performed using the raw material without any size reduction, which eliminated the grinding costs, but increased the pelleting energy consumption by up to 42% and reduced pellet mill throughput by 43% over the fractional milled material. Further testing at full scale is needed to confirm these trends. Pellet quality was not significantly reduced during these tests with a minimum of 95.5% durability for all the runs, while maintaining a bulk density of at least 570 kg/m^3.

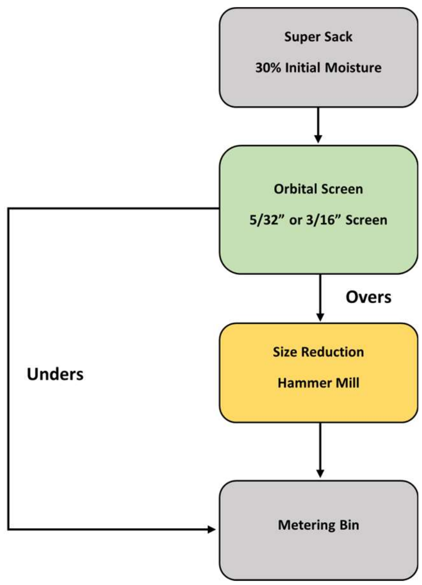

Figure 4: Fractional Milling flow diagram for fractional milling used for Douglas fir experiments.

	5/32"	3/16"	As-Is
Geometric Mean Particle Size (mm)	1.24	1.36	2.04
Moisture Content (%)	12.2%	6.3%	5.5%
Std Dev	0.29%	0.15%	0.10%
Bulk Density (kg/m^3)	569.0	699.1	718.0
Std Dev	4.03	2.61	1.13
Tapped Density (kg/m^3)	624.0	743.9	772.1
Std Dev	2.53	2.56	0.55
Unit Density (kg/m^3)	1252.3	1303.6	1323.0
Std Dev	35.36	32.42	16.61
Diameter (mm)	6.36	6.31	6.29
Std Dev	0.024	0.032	0.028
Durability (%)	96.9%	96.2%	95.5%
Std Dev	0.18%	0.18%	0.10%
Energy Consumption (kWh/dry ton)	218.8	293.2	310.0
Throughput (dry ton/hr)	0.167	0.125	0.117

Figure 5: Pellet properties for pellets made from various particle size distributions.

Integrated demonstration of HMP and fractional milling processes using commercial scale equipment with updated TEA

Wood heating pellet production is an energy intensive and complex process that requires management of various process conditions such as: initial moisture content, initial particle size, pellet mill die selection, and feed rates. There are certain pellet quality metrics that are required to produce a quality marketable heating pellet such as durability, final moisture content, and density. To produce pellets meeting these quality standards, the processing requires many different pieces of equipment, and each have their own operating parameters. The use of hammer mills, conveyors, rotary kiln driers, oscillating screens, and pellet mills are all required. The purpose of this study is to investigate potential process improvements by utilizing a high moisture feedstock and reducing the load on the natural gas rotary kiln drier and shifting some of that drying load to the various pieces of equipment. This process has been demonstrated with different feedstocks but is being investigated here for a Douglas fir softwood feedstock consisting of a mixture of 70% sawdust and 30% shavings in the form of lumber mill residuals. Previous tests focused on a smaller scale pellet mill have shown initial results that may indicate that this process improvement that we are focused on may return process improvements. During the large-scale testing completed this quarter, we found that this feedstock was highly sensitive to moisture content for the energy consumption and throughput of the hammer milling and pelleting processes at the commercial scales studied. As the feedstock moisture increased, the energy consumption of the pellet mill increased by roughly 4 times as compared to a feedstock with about half the initial moisture. Pellet quality also was significantly impacted by the increased moisture content. These results were unexpected since we had data with similar process conditions using a smaller scale pellet mill with good pellet quality, but throughput and energy consumption wasn't explored as part of the previous testing. Our results indicate that although there may be process improvements possible, processing high moisture feedstock has a significant negative impact on energy consumption, throughput, and pellet quality. Further work is needed to understand the point at which the moisture content is optimal for producing marketable pellets while at the same time reducing the processing costs at this commercial scale, as well as the furthering the understanding of the material differences between woody and herbaceous feedstocks with regards to pellet quality.

	Baseline	**High Moisture**
Moisture Content (%)	**7.7%**	**12.9%**
Std Dev	0.73%	1.29%
Bulk Density (kg/m^3)	**46.4**	**54.7**
Std Dev	13.50	3.95
Tapped Density (kg/m^3)	**48.5**	**56.6**
Std Dev	14.74	3.64
Diameter (mm)	**6.349**	**6.169**
Std Dev	0.073	0.073
Unit Density (kg/m^3)	**72.8**	**68.3**
Std Dev	75.42	5.36
Durability (%)	**98.4%**	**87.7%**
Std Dev	0.57%	2.39%

Table 5: Pellet Properties for baseline and HMP tests on commercial scale equipment.

Benefit to DOE

Greater understanding of the operational bounds of high moisture pelleting and additional insights into pelleting woody material both from a material pre-processing and from an economic perspective.

Economic Viability

The proposed technologies of high moisture processing and fractional milling did not respond well to the woody feedstock from an economic viability standpoint. Energy consumption was significantly increased by processing wet Douglas fir feedstock through a hammer mill and pellet mill while the throughput of this equipment was significantly reduced. When performing the techno-economic analysis of the process for a proposed plant capable of producing 134,000 dry tons of pellets per year with a 30-year lifespan, the estimated cost was $42.33/dry ton. The analysis also showed that for a process that utilizes large rotary kiln dryers and processes the feedstock after it has been dried, shows an estimated cost of $39.19/dry ton.

Data and Reports

No outside publications or reports related to this project.

Project Status and Summary

Current project status is complete. Milestones were all met, but target objectives were not reached with respect to economics.