Contract No. R-020-029

"Commercial Application of Soybean Stalk as a New Alternative Fiber in Particle Boards"

Submitted by North Dakota State University

Principal Investigator: Dilpreet Bajwa

PARTICIPANTS

Sponsor	**Cost Share**
Masonite PrimeBoard Inc	$109,400 (cash)
Masonite PrimeBoard Inc	$ 91,000 (in-kind)
Subtotal Cost Share	$200,400
North Dakota Industrial Commission	$200,400
Total Project Cost	$400,800

Project Schedule – 36 months
Contract Date – March 15, 2014
Start Date – March 15, 2014
Completion Date – December 31, 2018

Project Deliverables:
Status Report: September 30, 2014 ✓ (dated 11/6/2014)
Status Report: March 31, 2015 ✓ (dated 5/21/2015)
Status Report: September 30, 2015 ✓ (dated 11/12/2015)
Status Report: March 31, 2016 ✓ (dated 8/17/2016)
Status Report: September 30, 2016 ✓ (dated 1/17/2017)
Status Report:* June 30, 2017* ✓ (dated 9/28/2017)
Status Report: ◆ March 31, 2018*
Final Report: January 31, 2019◆^ ✓

OBJECTIVE/STATEMENT OF WORK:

This project will study the feasibility of using soy stalk-wheat straw blends for low density fiber boards at commercial scale, and optimization of the manufacturing process to reduce the amount of fiber wasted during processing. The 50% match comes from Masonite, which has a manufacturing facility in Wahpeton. Masonite utilizes wheat straw, which due to increased demand and fluctuating acreage has doubled in price over the last six years, posing a threat to the industry.

Specifically, the project objectives include the following:

- To understand the logistics of collection, baling, & transferring biomass (soybean stalk) from the field to commercial processing plant.
- To understand the factors affecting the efficiency of processing biomass.
- Identifying changes in the equipment/machinery required to minimize the amount of fines generated during processing
- To optimize the composition of the low density particleboards that use a blend of soybean stalk and wheat straw to have similar or better physical & mechanical properties than the current boards

The bench scale research has already been conducted; this project will be testing it at a commercial scale.

If successful, this project could help retain and grow a manufacturing facility in North Dakota. It is anticipated that the project could have an economic impact of over $6 million. Additionally, the project partners at state university with ND industry, and has the potential to commercialize technology developed at NDSU.

STATUS:

The contract has been signed and work is underway. Subsequent to the signing of the contract an amendment was requested and approved to allow for the purchase of a hammer mill in the amount of $9,000 with funds that were not utilized for the purchase of the universal testing machine.

Semi-Annual Project Report - 1 dated 11/6/2014 received. It states in part:

This report summarizes the project activities for the period of April 2014 to September 2014. The investigators from NDSU (Dilpreet Bajwa &Sreekala Bajwa) met with their collaborators from Masonite PrimeBoard (JohnRobinson and Andrew Sutherland) in person or by phone on a biomonthly basis to discuss and develop a comprehensive plan that can lead to successful completion of this project. Major highlights in the first six months of the project are as follows:

NDSU (D. Bajwa and S. Bajwa) – The PIs ordered primary equipment required for sizing and processing of raw materials, and testing of finished product. The PIs were able to leverage some equipment funds from the Agricultural Experiment Station for the equipment purchase. For material sizing and processing, a new hammer mill with multiple screens was purchased from Schutte Buffalo. The hammer mill will enable us to optimize the processing conditions required to size soy stalks with minimal material loss as fines. The information generated from these tests will help the team to identify the equipment modifications or changes that will be required at the Masonite PrimeBoard facility. The second piece of equipment purchased is a Universal Testing Machine from Test Resources. It will be used to test the physical and mechanical properties of soybean straw based particle boards and compare against wheat straw based boards. The graduate and undergraduate students and other supporting staff were trained by the manufacturer on the proper usage of this equipment. The raw materials, wheat straw and soybean stalks needed for this research were procured by Masonite PrimeBoard at their plant site. The next step will be to process these materials at NDSU using the hammer mill by varying processing conditions and to identify critical factors that influence the particle size and the amount of fines. Also, a graduate student and an undergraduate student were hired to work on the project.

Masonite PrimeBoard (J. Robinson and A. Sutherland) – The Masonite PrimeBoard plant has already initiated the purchase of soybean stalks for the production year 2014-15. To date they have purchased ~ 2000 tons of soy straw for the preliminary trials. They are currently evaluating and refining the procedures involved with collection, bailing, transportation and storage of the soybean stalks for extended period.

Semi-Annual Project Report 2 dated May 21, 2015 received. It states in part:

This is a second report which summarizes the project activities for the eriod from October 2014 to April 2015. Evan Sitz, a graduate student in Mechanical Engineering Department was hired in September 2014 to work on this project.

NDSU (D. Bajwa and S. Bajwa) – The PIs received the primary equipment required for sizing and processing of raw materials, and testing of finished product. A new hammer mill with multiple screens was purchased from Schutte Buffalo and installed in the Pilot Plant of Agricultural and Biosystems Engineering building at NDSU.

Two main tasks conducted by researchers at NDSU include 1) Processing of soybean and wheat stalks 2) Manufacturing of particle boards and testing

Task 1 - Hammer milling of straw (Soy and Wheat) is an integral step involved in the processing and has been incorporated into the fiberboard and resin testing in order to identify optimal processing conditions for producing viable fibers from baled straw. Several material processing experiments were run using hammer mill to size soy stalks to evaluate the impact of operating and material conditions on material loss as fines. The effect of straw moisture content, milling speed, and screen size used in the fiber milling process on the amount of fines produced from the process were quantified; larger fines content has been shown to deteriorate particleboard performance and generally reduce processing efficiency. Wheat and soybean straw fibers were milled, under the processing conditions of the straw as follows: fiber moisture content was set at 5 wt.%, hammer tip speed set at 88.2 ft./s, 117.8 ft./s, and 147.3 ft./s; and screen sizes of 3/8” and 1” round holes. Initial testing has shown that

milling speed did not affect the amount of fines in soybean straw while wheat fibers produced more fines content as milling speed increases. Initial testing has shown that more fines were produced at lower fiber moisture content.

Task 2 - A second set of experiments focused on the manufacturing and testing of the fiber boards. Several tests were performed to characterize the properties of medium density particleboards composed of wheat and soybean fibers as well as soybean-based resins. These tests include initial resin characterization for potential resin mixtures, testing of the mechanical properties of particleboards for preliminary formulations. Preliminary resin characterization was carried out to determine viable resin mixtures to be used in the preliminary and final fiberboard formulation. Four resins that are commonly used in the fiberboard processing industry were identified for use, including methylene diphenyl diisocyanate (MDI), phenol formaldehyde (PF), urea formaldehyde (UF), and melamine urea formaldehyde (MUF). Lap shear testing was used to evaluate the adhesive shear strength of the resins, with the four resins mixed at various ratios by weight. Five formulations of particleboards were created using various mixtures of wheat and soybean fibers. Mechanical testing was performed on the particleboard formulations in accordance with ASTM D1037, with flexure testing, water absorption, internal bond strength, and screw withdrawal resistance tests being performed.

Masonite PrimeBoard (J. Robinson and A. Sutherland) – In the last six months, Masonite PrimeBoard purchased additional soybean straw for use in their particleboards as well as conducted several commercial trials to understand the processing, drying and refining of the material. To date they have purchased over 2,500 tons of soybean straw valued over $200,000. Currently the material is being stored in the open area outside their manufacturing facility, similar to how they store wheat straw.

Material Collection and Transportation - Most of the soybean straw was procured from within 50-75 mile radius of the manufacturing facility. The optimal collection and bailing method was found to be using private contractors (bailers). The standard bale sizes that can fit the current processing equipment include 4’x4’ or 3’x4’ bales. The weight of the bale has to be around 1000 lbs. The freight and transportation cost of these bales ranges from 10-15 $/ton.

Some of the initial processing trials conducted on the production lines using soybean straw and wheat straw blends have shown promising results. The soybean straw had lower moisture content than wheat straw therefore it required less drying. However, the soybean straw was less bulky (higher bulk density) and much stronger than wheat straw, requiring additional processing. The processed soybean straw material exhibited stringy strands. Additional processing has also caused production of more fines which is a negative attribute. The material processing data generated by NDSU will be incorporated into future trials that may help to reduce the fines. The particleboards made from soybean and wheat straw blends exhibited mechanical properties comparable to 100% wheat straw boards. A series of trials are planned in coming months that will focus on modifications of processing equipment and raw material properties as well as composition of the particleboards.

Future work will focus on the fiber hammermilling operation and identify the changes required in the current processing equipment for minimizing the fines, and improving the fiber aspect ratio. Particleboard manufacturing trials will be conducted at Masonite’s manufacturing site. The particleboards will be evaluated for their quality and performance characteristics.

Semi-Annual Project Report - 3 dated November 12, 2015 received. It states in part:

This is the third report which summarizes the project activities between June 2015 and October 2015. The investigator from NDSU met with their collaborators from Masonite PrimeBoard on July 15, 2015 along with graduate student Evan Sitz to discuss project progress and share the results of the work that has been going on

at NDSU. The project team revisited the comprehensive research plan to ensure project tasks are progressing satisfactorily.

Described below are some of the major highlights of the last six months work on the project. Tables 1-4 that go with this information are posted on the website with Semi-Annual Project Report - 3.

NDSU (D. Bajwa, S. Bajwa, E. Sitz)

In the last six months material processing and characterization was the main focus. The hammer mill purchased through the funding from NDIC was extensively used to process wheat and soy stover. The primary objective of this work was to identify the impact of processing variables on the particle size and production of fines. This task will help the research team in optimizing the processing variables for the production of good quality uniform size particles with minimal fines. The processed material was used for wheat and soybean fiberboard production. In this testing we varied the straw moisture content, milling speed, and screen size used in the fiber milling process to reduce the fines produced from the process; larger fines content have been shown to reduce fiberboard performance and generally reduce processing efficiency. Wheat and soybean straw fibers were milled, with the processing conditions of the straw as follows: fiber moisture content of the total straw weight set at 5 wt.%, 15 wt.%, and 25 wt.%; hammer tip speed set at 88.2 ft./s, 117.8 ft./s, and 147.3 ft./s; and screen sizes of 3/8" and 1" round holes. Currently all 36 unique runs of the wheat and soybean straw fibers have been milled using the Shcutte-Buffalo hammer mill. Approximately 60% of these runs have been sieved to date using a Humboldt vertically oscillating sieve shaker. Three samples of ~50 grams each were taken from each run using ASTM C702 as the standard sampling method to create homogeneous sample distributions. Each sample was run in the sieve shaker for 10 minutes using 20 mesh, 40 mesh, 60 mesh, and 80 mesh screens, with the fibers passing through the 80 mesh screens accounting for the fines content. The measured fines content produced from hammer milling for each condition can be seen in Tables 1-4. The results thus far show that soybean fines content has a low dependence on the hammer tip speed in comparison to wheat. The results also indicate that screen size has a significant effect on reducing fines in wheat straw but does not affect soybean fines content as significantly. The common factor that does affect fines generation is the moisture content of the fibers, which has the general effect of reducing produced fines. Interestingly, the soybean fibers appear to be more responsive to the hammer tip speed at higher moisture content levels, as evidenced by the results in Table 3.

Masonite PrimeBoard (J. Robinson, A. Sutherland and E. Sitz)

There were numerous material processing related experiments conducted at the industrial partners facility. Several processing parameters for reducing fines were identified from experimental trial runs at the PrimeBoard location in Wahpeton, ND. The most significant factor in reducing fines content in milled fibers is close control of blinding in the screening process. Blinding is a process that occurs when fibers that are passing through a screen are the same size as the holes in that screen. This process was shown to significantly affect screens of 60 mesh or finer, which is the level at which fibers begin to reduce fiberboard properties. Trials specifically showed that regular clearing of the screening in the fiber conveying process reduced the average fines content used in the press from 14% to 3-4%, resulting in a significant reduction of board failures, reducing resin consumption, and improving the overall consistency of the board properties. Investigation of the fiber refining process for wheat also showed that using a variable drive to vary hammer tip speed with changing moisture content allowed for an optimization of the fines content that was being sent to be screened, allowing for optimization of fines production depending on the incoming fiber moisture content.

Semi-Annual Project Report - 4 dated August 17, 2016 was received. It states in part:

This is the fourth report which summarizes the project activities between November 2015 and July 2016. The investigator from NDSU met with their collaborators from Masonite PrimeBoard on December 17, 2016, March 16 and April 8, 2016 along with graduate student Evan Sitz to discuss project progress and share the results of

the work that has been going on at NDSU. Described below are some of the major highlights of the work accomplished during this time period.

NDSU (D. Bajwa, S. Bajwa, E. Sitz)

In the last seven months the research work focused on primarily material processing, identifying the factors that influence the production of fines when particleboards are made using soy straw and wheat straw. The hammer mill and sieve shaker purchased through the NDIC funding was extensively helpful to understand how material properties can influence the production of fines.

Hammer Milling of Straw Fibers

The primary objective of this task was to identify the impact of processing variables on the particle size and production of fines. Both wheat and soybean straw fibers were milled using a W-6-H Model Hammer Mill (Schutte Buffalo, Buffalo, NY). Two different screen sizes (round holes; 3/8" and 1" holes), three different milling speeds as controlled by the variable frequency drive (equivalent hammer tip speed; 26.9 m/s, 35.9 m/s, 44.9 m/s), and three different fiber moisture contents (5 wt%, 15 wt%, 25 wt%) were tested in accordance with the design of experiment.

Characterization of Fiber Distribution

Once the hammer milling of all wheat and soybean fibers at each condition were completed, the fines content, and viable fraction for each sample set needed to be obtained. The fiber distribution was found by using a Humboldt H-4325 Series Sieve Shaker to separate the different fiber sizes from the milled samples. Four different sizes of sieves were used as an adaptation of ASTM E1757: a 20 mesh sieve, a 40 mesh sieve, a 60 mesh sieve, an 80 mesh sieve, and a final catch pan to catch particles finer than 80 mesh. Statistical analysis was conducted on the data obtained in this research to gain objective results on the effect that each variable had on the response values considered.

Results

The results of hammer milling of soy stover and wheat straw at various conditions were evaluated by analyzing the fines content and viable fraction produced after processing of the fibers. The results of several processing conditions with multiple replications show that the lowest fines content fraction observed occurred for several conditions, with the lowest finest content being 0.30% ± 0.04% for soybean at 15% moisture using a 44.9 m/s hammer tip speed and 1" round holes screen. The highest fines content was found to be 2.63% ± 0.61% for wheat at 25% moisture using a 35.9 m/s hammer tip speed and 3/8" round holes screen. The highest viable fraction content was 32.62% ± 2.51% for soybean at 5% moisture using a 44.9 m/s hammer tip speed and 3/8" round holes. The lowest viable fraction was 4.77% ± 1.16% for wheat at 15% moisture using a 26.9 m/s hammer tip speed and 1" round holes. From the ANOVA it was seen that all four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the fines content, and the fines content was also significantly influenced by several higher order interactions between factors. Specifically the wheat straw's fines content and viable fraction were both significantly affected by the fiber's moisture content, the screen's hole sizes, and hammer tip speeds. The soy stover's viable fraction was significantly affected by the fiber's moisture content, the screen's hole sizes, and hammer tip speeds. However, it was found that for the fines content, the hammer tip speed has negligible effect on the fines content, while the screen size and moisture content proved to be significant effects.

Overall for both wheat straw and soy stover, the optimal levels to be used in an industrial application are wholly dependent on the cost of production. Reduction of fines helps to keep retention of fibers high, as the fines are unrecoverable for usage in board production. However, it is also possible that the increase in the viable fraction and subsequently smaller amount of material that needs to be further processed could outweigh the financial loss of the fines. Further economic analysis of the production with material costs and processing costs could

potentially be performed to find what conditions induce the least cost solution, but no claims can be made in that regards based solely on this research.

Future Tasks
The next two tasks will focus on manufacturing particleboards both in laboratory and at the Masonite PrimeBoard production facility in Wahpeton, ND using wheat and soy stover and evaluating their physical and mechanical properties followed by economic analysis of harvesting, bailing and transporting soy stalk to the production site. The results from that work will help to identify the optimal ratio of two different fibers that can be used in production so that particleboards quality and performance is not compromised. The economic analysis will be help to compare the cost of using soybean straw versus wheat straw.

Semi-Annual Project Report - 5 dated January 17, 2017 was received. It states in part:

This is a fifth report that summarizes the project activities between August 2015 and January 2017. In the last six months research focused on the evaluating the material processing variables and analyzing the data obtained from processing and testing particleboards.

The investigator from NDSU (Dilpreet Bajwa) met with their collaborators from Masonite PrimeBoard (Andrew Sutherland, New Plant Manager, and Evan Sitz, New Engineer) on January 13th to discuss project progress and share the results of the work that has been going on at NDSU. It is worthy to mention that Evan Sitz (a graduate student) who worked on this project for two years was hired by Masonite PrimeBoard as an engineer. The project team again revisited the research plan and related tasks to ensure project tasks are being executed satisfactorily. All the goals were reviewed to check if any critical task was missed in the last two years. Importance of communication was again stressed between all collaborators, students and funding agency. It was decided we meet more frequently in Wahpeton, ND in the next few months and share information via emails, with Masonite PrimeBoard plant personnel. The company also gave an update on the current material use, processing and discussed various items related to incorporating soy stover in the wheat straw.

The major highlights of the last six months (August 2016 – January 2017) work are described below followed by additional detail specifically discussing the contributions made by each party.

Project Update NDSU (D. Bajwa, S. Bajwa, A. Norris) In the last six months the research work focused on primarily on evaluating material processing, variables, analyzing the data statistically to derive meaningful conclusions. The aim was to identify critical material processing variables that Masonite PrimeBoard can follow while processing new feedstock on their equipment and reduce generation of fines. The particleboards using wheat and soy fibers were manufactured in in the lab and their physical and mechanical properties were again evaluated to confirm the earlier reported findings. The hammer mill, sieve shaker and universal testing machine purchased through the NDIC funding was extensively helpful to evaluate material processing variables and the mechanical properties of the particleboards.

Identification of key variables impacting production of fines
In this task the primary goal was to identify the impact of processing variables on the particle size and production of fines. Both wheat and soybean straw fibers were milled using a W-6-H Model Hammer Mill (Schutte Buffalo, Buffalo, NY). As reported earlier two different screen sizes, three milling speeds and three different fiber moisture levels were considered in this experiment.

Results
The data analysis showed that the key variables that are related to production of unwanted fines. The four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the fines content, and the fines content was also significantly influenced by several higher order interactions between

factors. The wheat straw's fines content and viable fraction were both significantly affected by the moisture content, the screen's hole sizes, and hammer tip speeds. However for the soy stover's viable fraction was significantly affected by the fiber's moisture content, the screen's hole sizes, and hammer tip speeds. Overall it was found that for the fines content, the hammer tip speed has negligible effect on the fines content, while the screen size and moisture content proved to be significant effects.

Physical and Mechanical Properties of the Particleboards

Once the soybean straw fibers, wheat straw fibers, and resins had been obtained the materials were ready to be pressed into a testable board. The fibers were analyzed for moisture content using an Arizona Instrument LLC Computrac® Max® 4000XLMoisture Analyzer (Chandler, AZ). The water and resin was sprayed using an atomizing spray gun, with the fibers themselves being continually agitated in a cement mixer. After sufficient spraying of the resin, the mixture of resin and fibers were laid into a custom produced aluminum mold that would press 305 mm x 305 mm panels. Once the fibers had been laid out, a second, the top half of the mold with a Teflon sheet between it and the fibers was laid onto the top half using guide pins. The two halves of the mold were then placed into a preheated Carver Hot Press Model 4122. Once the final press load had been achieved, the mold was held together for 5 minutes, with the load applied to the boards being equivalent to 2117 kPa of pressure on the surface of the pressed board. After cooling and conditioning the boards were tested for physical and mechanical properties using MTS Universal testing machine. The different jigs used to test the particleboards are shown in in the 5th Semi Annual report posted on the website.

Physical and Mechanical Property Test Results

The moisture absorption tests showed that the resin choice and fiber choices were the only significant factors affecting the water absorption. The model accuracy was given by R2 = 86.04%, with adjusted R2 = 83.42%, indicating the model has good adequacy in determining the variability in water absorption properties. The statistical test results for modulus of rupture show that the resin and fiber type and the interaction between the fiber choice and the edge or center sample position were the most influential factors. The model accuracy was given by R2 = 75.06%, with adjusted R2 = 70.57%, indicating the model has moderate accuracy in determining the variability in MOR properties. The modulus of elasticity test results shows that the resin was the most influential factor, while fiber choice does not have a significant effect. The model accuracy was given by R2 = 52.76%, with adjusted R2 = 48.38%, indicating the model has poor accuracy in determining the variability in MOE properties. For internal bond the resin choice and fiber choices as well as their interaction were significant factors in affecting the internal bond strength. For screw withdrawal test resin, fiber type, the sample's position within the board and the interaction between the fiber choice and the resin choice were the most influential factors. It can be concluded that for both wheat and soy straw, the optimal levels to be used in an industrial application are wholly dependent on the cost of production. Soy straw is effective alternative to wheat straw. Although medium density wheat and soy straw board don't meet ANSI 208.1 or 208.2 requirements, it is feasible that boards could still be used in low load applications that do not require the standards of ANSI boards.

Masonite PrimeBoard Tasks

Our industrial partner Masonite PrimeBoard mainly focused on the following tasks in the last six months:

1. As planned in the research PrimeBoard plant continued using soy straw in their production run. In the last six months they used approximately 500 thousand pounds of soy straw. The inclusion of soy straw required some minor adjustments on the initial processing side.

2. Several material processing and handling trials to reduce production of fines were conducted based on the preliminary information obtained from NDSU work is helping them to run trials.

3. The company reported that the storage life of soy stalk is better than wheat straw. Although color was visible on soy stalk bales but the product quality is better than wheat straw. This information will help them to procure and store soy straw for longer period.

4. One challenge with soy straw is the contamination in the straw. Due to heavy rains last year the bales had soil, corn beet etc. They are exploring a better time for collecting, bailing and transporting the material to their plant.

5. They are also studying the impact of moisture on processing the raw material in winter.

Future Tasks

The main objective left in the project is the economic analysis of harvesting, bailing and transporting soy stalk to the production site. The economic analysis of the material collection and transportation cost as well as processing costs will be performed to find what conditions induce the least cost solution. The work related to these tasks will be carried out in next 8-10 months. The results from this work will help to identify the optimal ratio of two different fibers that can be used in production of particleboards of high quality.

1/27/2017

NDSU has requested a no-cost extension asking for submission of the final report on March 31, 2018. The amendment granting their request has been forward to NDSU for their consideration.

1/30/2017

Amendment has been signed by NDSU.

9/28/2017

Semi-Annual Project Report - 5 dated January 17, 2017 was received. It states in part:

This is a sixth report that summarizes the project activities between January 2017 and August 2017.

The investigators from NDSU (Dilpreet Bajwa and Andrew Norris) met with their collaborators from Masonite PrimeBoard (Andrew Sutherland, Plant Manager, and Evan Sitz, New Engineer) on May 18th and later on August 15, 2017 to discuss project progress and share the results of the work that has been going on at NDSU. The company also gave an update on the current material use, processing and discussed various items related to incorporating soy stover in the wheat straw. The project team again revisited the research plan and related tasks to ensure all the project tasks are completed before the revised end of the project. All the goals were again reviewed to check if any critical task was missed in the last three years. It was decided that we should revisit the processing of raw materials though hammer mill. There are some material processing inefficiencies in the plant that can be fixed to improve the output and lower energy consumption. Incorporation of some recent advancement in the hammer mill design can be extremely beneficial for the company, so it was decided to run some trials with modified hammers and screens. Although this task was accomplished in the beginning of the project but both research team and collaborator thought it will worthwhile evaluating new technology. The new trials are planned to be executed in the November or December 2017 when the production slows down.

The major highlights of the last six months (January 2017 to August 2017) work are described below followed by additional detail specifically discussing the material harvesting and transportation.

Project Update

NDSU (D. Bajwa, S. Bajwa, A. Norris, and C. Rehovsky)

In the last six months the research work primarily focused on assessing economics of material collection, baling, transportation and related costs, some work also focused material processing, and evaluating a new biobased resin for use in the particleboards. The aim was to identify the important factors that influence the cost of different raw materials. Before initiating this objective the research team had a detailed meeting with Masonite personal to understand how they calculate the material cost and what variables are important for

them to know that can impact their pricing structure. Some of the factors that can impact the final material cost to collaborator are material type, distance, type of bales, collection method, transportation mode, fuel cost, time of the year and competition or demand for other applications. After understanding how these variables have historically influenced the material cost the research team decided a matrix that will collect all this information so it can be rationally analyzed to make meaningful conclusions.

The research team first conducted an in-depth research on the biomass collection and transportation logistics. In the past few years there have been some studies related to corn stover, and wheat straw collection and transportation mostly for biomass for fuel or animal feed applications. Some of the constraints that were set in analyzing the cost structure included consistent supply of wheat straw and soy stover, profitability for farmer, bioprocessor and all the intermediaries. Removal rates that do not damage the soil over long term was also considered a factor for wheat straw. Removal rates of 2.0-2.5 tonne/acre of wheat straw and 1.0 to 1.5 ton of soy stover were taken into account. Material harvest and collection time ranged from late summer to early fall. The preferred bale type was high density square bales (11-12/ft^3) weighing 800 to 1200 lbs. The ideal material collection and transportation distance was 50-80 miles that would not significantly impact material cost.

Some of the results showed that fall harvest biomass yields are higher however cons are that higher moisture content, narrow harvest window and sometime lower harvest equipment availability. Trucking will be the dominant transportation mode for the processing plant. Transportation cost for every move less than 62.13 m is approximately $17/tonne. Majority of biomass bales should be directly transported from farm to the processing plant. On-farm storage is usually cost competitive but carries risk for processing plant. On-farm storage costs 8.33$/tonne whereas at plant site it varies with location from 9.00-22.00 $/tonne. Flatbed trucks are most effective for shipping. Open storage is more economical than covered and the bales can be stacked up to 6 rows in height. The increased margin for farm producers from wheat straw and soy stover harvest can vary from $80-120 per acre. The results discussed are from one set of the data, we are currently collecting more information for fall 2017 season. The team plans to collect a minimum of three sets of data related to material cost. It will help the industrial collaborator to understand the price variability due to collection time, year, crop yield and changing biomass pattern.

The research team is going to continue collecting and analyzing additional data on material type, collection methods and transportation logistics. It is expected that with a large data set we should be able to develop a strong raw material pricing model for the collaborator. The outcome of this task should help the collaborator in understanding the price structure of various feedstock and improving their profitability.

1/12/2018 - Dilpreet Bajwa requested a no-cost extension to December 31, 2018 to file the final report. He indicated that Masonite PrimeBoard, industrial collaborator on this project, received a new technology to process soybean and wheat straw so they requested Dr. Bajwa to help with the testing and evaluation of new technology. This new technology would significantly reduce the waste generated in the plant. The no-cost extension has been granted.

1/3/2019 – NDSU has requested and been granted a no-cost one month extension to finish the project.

2/15/2019 – Final report received. The report states in part:

The first objective of work was to understand the logistics and cost of soy stalk collection, transportation to processing plant. It was found standard square bale sizes measuring 4'x4', 4'x8' or 3'x4' bales weighing under 1000 lbs were ideal for processing. The freight and transportation cost of these bales ranges from 10-15 $/ton. The ideal material collection and transportation distance was 50-80 miles. The second objective was to

understand the factors affecting the efficiency of processing agricultural biomass. The study found that soybean stalk has lower moisture content than wheat straw therefore, it required less drying. However, the soybean straw was less bulky (higher bulk density) and much stronger than wheat straw, that requires additional processing time. Additional processing results in the production of more fines, which is a negative, attribute. Third objective investigated the processing equipment changes required to process soybean straw. The data analysis showed that the four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the fines content. The wheat straw's fines content and viable fraction were both significantly affected by the moisture content, the screen's hole sizes, and hammer tip speeds. A new hammermiller design with modified rods, hammers, and lock collars was tested that showed some reduction in the fines and energy consumption. The forth objective focused on the physico-mechanical properties of the particleboards. The results showed that particleboards made from soybean and wheat straw blends exhibited mechanical properties comparable to 100% wheat straw boards. Wheat straw can be replaced up to 75% without significant reduction in the properties of the boards. Overall, the study demonstrated that soybean stalk could be a viable alternative biomass material that can be tapped for manufacturing particleboards. Use of soybean stalk can help Masonite PrimeBoard to offset some raw material cost and can generate some additional income for soybean farmers. The outcomes of this project would significantly benefit both public and private sectors.

More details are available in the full report. This contract is now closed with a returned commitment of $7,034.74.

◆Amendments 1/12/2018
ˆAmendment 1/3/19
2/27/2019