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On-farm Utilization of Bioenergy For Superheated Steam Drying

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Abstract

The following is a study on the design parameters for using superheated steam drying in order to dry 10,000 tons/year of corn kernels from 25% to 18% (wet basis). The purpose of this project is to achieve a higher drying efficiency, coupled with the use of a sustainable fuel source. The heat source for the project has been chosen to be a 2931 kW gasifier (10 MMBTU/hr), burning .64 tonnes of willow chips per hours. It was found that superheated steam drying affected corn quality negatively and that the drying costs broke even with market costs over a 20-year period if more than 16,000 tons of corn were dried per season.

Résumé

L'étude qui suit a porté une attention sur les paramètres de conception nécessaires pour utiliser la vapeur surchauffée afin de sécher 10,000 tons/an de grains de maïs, d'une humidité de 25% à 18% (sur une base de masse fraîche). L'objectif de ce projet était d'atteindre une meilleure efficacité lors du séchage, en plus d'utiliser une source d'énergie alternative. La source de chaleur pour le projet suivant est un gazificateur de 2931 kW, qui utilisera 0.64 tonnes/heure de paillis de saule comme combustible. Il a été découvert que l'utilisation de vapeur surchauffée lors du séchage affectait négativement la qualité du maïs et que les coûts étaient équivalents à ceux du marché sur une période de 20 ans si plus de 16,000 tonnes étaient séchés à chaque saison de séchage du maïs.

Summary of the previous proposal

As a reminder, the objectives of this project were the following:

- To use alternative fuels
- To test the efficiency of superheated steam drying
- To assess grain quality
- To design a superheated steam dryer system
- To assess the economic feasibility of a superheated steam drying corn drier

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Alternative Fuel Sources

As mentioned earlier, an alternative fuel source will be discussed the fuel source to be chosen are willow trees. Willow trees were chosen due to their higher energy yields per year and the lower time requirements. In the assumptions made, it was assumed that the SSD will be drying 10 000 tonnes of corn from 25% down to 18%. The thermal energy needed to supply the SSD will be obtained from gasifying the willow trees and then the gas will be burned inside a boiler to produce the steam. The willows can be grown as a dedicated crop that would need to be fertilized, and need to have pests managed, or can be grown as a buffer strip around the edges of the field to protect any neighbouring vegetation and/or water ways.

Another advantage of using willow trees is that when applying fertilizer, it is the current practice only to apply nitrogen fertilizers to the willow stand as the other fertilizers, phosphorus and potassium, do not need to be applied. This is because willow trees have a low requirement for these fertilizers.[1] This fertilizer requirement can be further reduced if the producer waits until the leaves have fallen to harvest. This returns more nitrogen to the soil before taking the willows and therefore helps keep more nutrients on the soil. We will apply 75 kg of nitrogen per hectare as our fertilizer

To determine the area needed to dry the corn, many factors must be taken into account such as the energy required to dry the corn, the efficiencies of both the SSD and the gasifier, and energy content of the willow trees among others. As mentioned earlier we will be drying 10 000 tonnes of dry corn at a rate of 25 tonnes per hour. To dry this amount of corn, 32 hectares of willows will be planted. This also works out to an increase in area of only 3.2%, or loss of area, depending on whether the crops will be a buffer crop, or a dedicated energy crop.

One more issue than must be raised if the willow stand will be a dedicated crop, and this is the control of pests. This issue specifically deals with the weeds that may smother out the crop once they are planted, or the spring after they are harvested. A detailed time line for establishing and maintaining the stand will be done, but for now, the types of herbicides and when to apply them will be discussed. Before the stand is applied, a contact herbicide is applied to the land that will be used to kill any weeds before the area is prepared to make the “seed” bed. Once the shoots are planted, the area will once again be sprayed with a pre-emergent herbicide which will prevent other weeds from taking either nutrients, or limiting the area exposed to sunlight. For the contact herbicide applied before planting, 2.5 kg of active ingredient (AI) /ha of glyphosate must be applied. For the pre-emergent pesticide, 2 different pesticides are applied, 2.24 kg of AI/ha of simazine and 1.12 kg of AI/ha. All of these pesticides are applied before the willows are planted. Once the willows are planted, the simazine will be applied again to ensure no weeds grow during the initial stages of the willows life.

The next issue that must be addressed is the extra amount of time that it will take the farmer to prepare, plant and harvest the willow stand. The way willow stands work is that they are harvested every 3 years. Therefore, in our 26 hectare plantation, there will only ever be one third of this stand harvested at any given time; meaning that there will only ever be 8.7ha that will need to be worked. The following table will give an outline if the time investments per year along with the task, season and occurrence of the task.

Operation	Season	Occurrence	1st year	2nd year	3rd year	4th to 20th year
Mow existing vegetation	Spring	One time	18.01	18.01	18.01	0
Apply contact herbicide	Spring	One time	14.83	14.83	14.83	0
Plough	Spring	One time	7.52	7.52	7.52	0
Disk	Spring	One time	1.06	1.06	1.06	0
Cultipack	Spring	One time	26.48	26.48	26.48	0
Seed cover crop	Spring	One time	4.87	4.87	4.87	0
Planting	Spring	One time	15.89	15.89	15.89	0
Apply pre-emergent herbicide	Spring	Re-occurring	6.46	6.46	6.46	6.46
1st year coppice	Spring	Re-occurring	16.95	16.95	16.95	16.95
Mechanical weed control	Spring	Re-occurring	4.87	4.87	4.87	4.87
Mechanical weed control	Spring	Re-occurring	2.22	2.22	2.22	2.22
Chemical weed control	Spring	Re-occurring	31.77	31.77	31.77	31.77
Fertilize	Spring	Re-occurring	0.00	0.00	0.00	0.00
Harvest	Fall	Re-occurring	0.00	0.00	0.00	0.00
Total time investment (hours)			150.92	150.92	150.92	62.28

As is seen, the most intensive times for working occur in the spring during the first 3 years during the spring with a total of ~112 hours spent preparing the bed and planting. However after these first 3 years, the labour requirements drop off dramatically and the farmer would then only spend 31 extra hours in the field during the spring and now the harvesting will start. This will take approximately an extra 25 hours.[2] All of these times are approximate depending on the size of the machinery used and power of the tractor. The list of the previous table also gives an idea of the order of the tasks that will be performed.

When the SSD is running, a person will be loading the gasifier at a rate of 0.64 tonnes of willows per hour. The willow trees will be burned within a few days of harvest to minimize the storage area needed will be minimized. This will also mean the willow chips will be burned “green” with a moisture content of ~50%.[3]

Experimental Method

The experiments performed were done in the Agricultural Machinery Shop located on Macdonald campus. Our experiments were performed under the supervision of shop technician Scott Manktelow and with input from Yvan Gariepy. Our experiment was designed to determine a drying curve for super heated steam drying of corn, and also to determine the time needed to dry corn from ~25% moisture down to ~18%, while measuring the temperature of the steam and the kernel temperature at various stages. The experiment was also designed to mimic as close as possible the steps of drying which are the drying of the corn with super heated steam and then followed by the dryaeration step.

Materials

- Water supply (preferably hot)
- Garden hose
- Needle valve
- 50ft of 1/4” copper piping
- 1 T connection of 1/4” copper piping
- 2 ¼” copper plugs
- 15ft^2 of galvanized sheet metal
- ~1ft^2 1/8” of wire mesh
- 10ft of angle steel
- Thermal insulation
- Scale (accurate to tenth decimal place)
- Caulking
- Heat supply
    - Acetylene torch
    - Acetylene fuel
    - Oxygen supply
- Grain corn
- Moisture tester

- Stop watch
- Thermocouple (2)

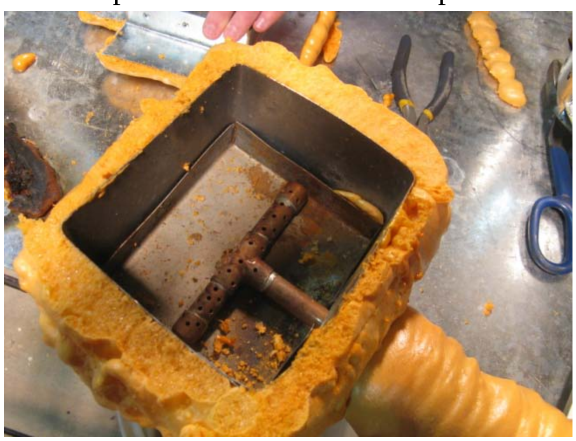
Procedure

1. Construct the super heated steam dryer and scale according the following pictures:
   Copper piping is coiled upon itself using a lathe
   
   Then braze the copper piping together as can be seen by the discoloured sides.

2. Next weld a steel plate on top of the copper piping. This is to prevent the heat from filling in the empty space above the piping in the sheet metal housing.
   

3. Create the sheet metal housing around the copper piping.

4. Connect one end of the copper to the needle valve (shown above on the left) and connect other the ‘T’ to the end of the copper piping. The ‘T’ must be perforated and have the open ends blocked with the cooper plugs.

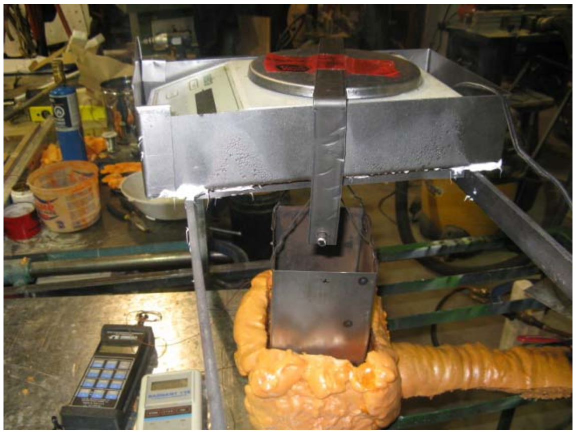


5. Create a sheet metal housing for the ‘T’ connection area (shown above).

6. Insulate any piping open to air that would have super heated steam in it.

7. Drill a drainage hole in the 'T' connection casing.
8. Install torch inside the sheet metal housing. Do not light!

9. Construct framework and a protective sheet metal casing for the scale. Insulate the sheet metal housing with the caulking to prevent any steam from getting onto the scale.



10. Construct the sheet metal housing for the corn. The mesh at the bottom of the case is attached by rivets.

it is important to note that the corn housing should fit inside the housing of the ‘T’ connection. This will force the super heated steam through the corn.

11. Set up the experiment without any water flowing through it. Adjust the position of the corn housing until it does not the edges of the ‘T’ connection housing. Tare the scale.

12. Turn on the water flow and adjust the flow using the needle valve, adjust the flow so that there is 60g/min of water flowing through it. Use the drainage hole to collect the water and measure it.

13. Turn on fuel supply and adjust the supply until the temperature directly below the corn housing is ~150°C (or your desired temperature). This may take several minutes. Once the steam reaches the super heated state, it will appear that there will be no steam coming out of the piping because super heat steam is “invisible”. DO NOT place your hand to see whether or not there is steam coming out. Take a piece of sheet metal and place over the steam chamber and remove it after a few seconds. If water condenses on the surface then you know that there is steam.

    IMPORTANT: when adjusting the temperature, it may be necessary to sacrifice a sample of corn to mimic the drying conditions. It was found that throughout the testing process, the temperature would fluctuate when the corn was removed from the steam. The temperature of the steam would increase when a sample of corn was placed in the steam chamber. This was likely due to the corn restricting the movements of the steam.

14. Once the construction is complete and the process is started, it should resemble the following photo:

15. Load 100g of a grain corn sample of known moisture content (using the moisture tester) to be dried. Make sure there are no broken samples.

16. Dry the corn until there is 18% moisture content remaining in the sample and then remove from the steam.

17. Put sample into a styrofoam cup and measure the kernel temperature.

18. Leave sample out to dry for the dryaeration process for 45 minutes. If possible, set up some type of forced ventilation with cold air. Hair dryers with some with a cold air setting would work.

19. Take the temperature once again and record the mass to determine the moisture content of the sample.

Stress Crack Analysis

The stress crack analysis is done as a measure of how damaging the process of super heated steam drying is to the grain corn samples.

Materials

- Previously drier grain corn samples
- Light source
- Piece of cardboard with holes smaller than the corn kernels

Procedure

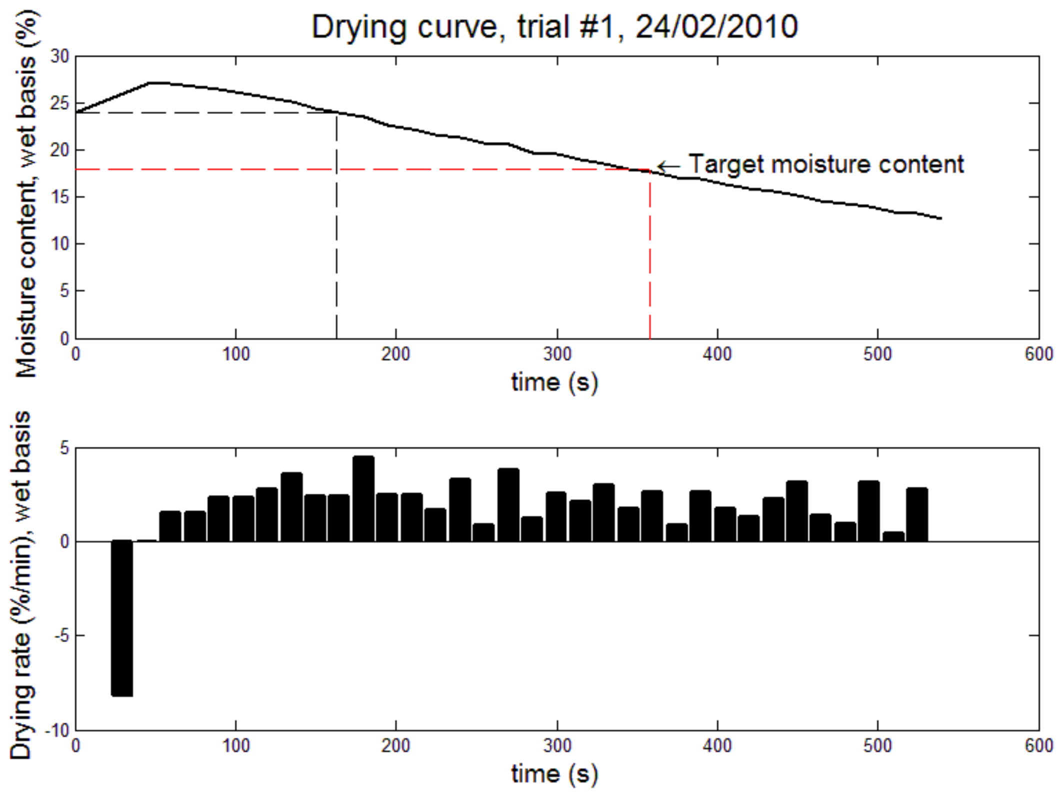
1. In a dark room, set up the card board piece on the light source with the holes directly over the light.

2. Place kernels over the hole and check signs for stress cracks. The cracks will appear brighter than their surroundings.

3. Take note of corn grains that are broken, have no cracks, or have 1, 2 or more than 2 cracks.

Drying curves

During the drying experiments, the total sample masses were sampled every 15 seconds in order to better understand the drying kinetics using superheated steam.



The previous drying curve shows evaporation rate changes over time, and the change in moisture content. As described during the first report, a condensation phase occurs at the beginning, due to a contact between steam and a material with a temperature lower than its condensation point. However, the condensation phase only lasted for 45 seconds. Past this point, the drying rate was relatively constant, without any falling rate phase. The absence of a falling rate is due to the fact that steam is already saturated in water vapour. Unlike air, the humidity of the drying medium is not a limiting factor for drying rates.

Results and discussion

Results were obtained by using samples of 100 kernels. Some of the kernels were broken and excluded from the experiment. 5 replicates were used from different superheated steam drying experiments and were compared to 3 samples obtained from a corn storage bin from Ferme Isabelle Inc., Côteaux-du-Lac.

	Superheated steam dryer						
Number of cracks	**1**	**2**	**3**	**4**	**5**	**Mean**	**Std. Dev.**
0	84.38%	84.78%	84.21%	85.71%	85.71%	84.96%	0.72%
1	12.50%	13.04%	10.53%	12.24%	13.27%	12.32%	1.08%
2	1.04%	2.17%	3.16%	2.04%	1.02%	1.89%	0.89%
2+	2.08%	0.00%	2.11%	0.00%	0.00%	0.84%	1.15%

	From storage bin				
Number of cracks	**1**	**2**	**3**	**Mean**	**Std. Dev.**
0	92.47%	97.67%	92.13%	94.09%	2.54%
1	5.38%	2.33%	6.74%	4.81%	1.85%
2	2.15%	0.00%	1.12%	1.09%	0.88%
2+	0.00%	0.00%	0.00%	0.00%	0.00%

Based on the results, it can be seen that there is a significant difference between corn kernels dried using superheated steam. The grain quality is affected because in order to achieve drying, the corn kernels need to reach a temperature of 100˚C for approximately 5 minutes, by using low-temperature superheated steam. A change in colour was also noticed visually. This change in colour can be due to thermal stresses that could cook the shell of the kernel. Very few opaque corn kernels (which could hint the cooking of the inner starch) were noticed, both in corn kernels from the storage bin and steam-dried samples.

sThis leads to one of the main conclusions of the current project: superheated steam drying will affect the quality of corn kernels. However, it is important to note that it could be a good alternative to less heat-sensitive materials, such as fine particles or for soy roasting, which needs to be heated up to 130˚C to inhibit tripsin.

Gasification

The issue of gasification was more-or-less limited to the heat transfer parameters required for the design of a superheated steam dryer system, as well as its economic cost. The scope of the work was mostly focused on superheated steam drying. However, here are some brief explanations on the 3 stages of gasification.

Gasifier

The gasifier will burn the organic carbon contained in the primary biomass feedstock. Overall, this combustion produces high quantities of a low-energy gas, composed of a mixture of methane (CH_4), carbone monoxide (CO), and dihydrogen (H_2). The heat value of the generated gas greatly depends on the concentration of chemicals in the given synthetic gas (syngas has a heat value of 4-13 MJ/m^3).

Boiler

The boiler is the chamber in which the synthetic gas' heat is released to the air, and is transferred to the superheater. Under an atmospheric-pressure reaction due to the heat input, the gas heats the air up to a temperature of 1500 ˚C.

Efficiency

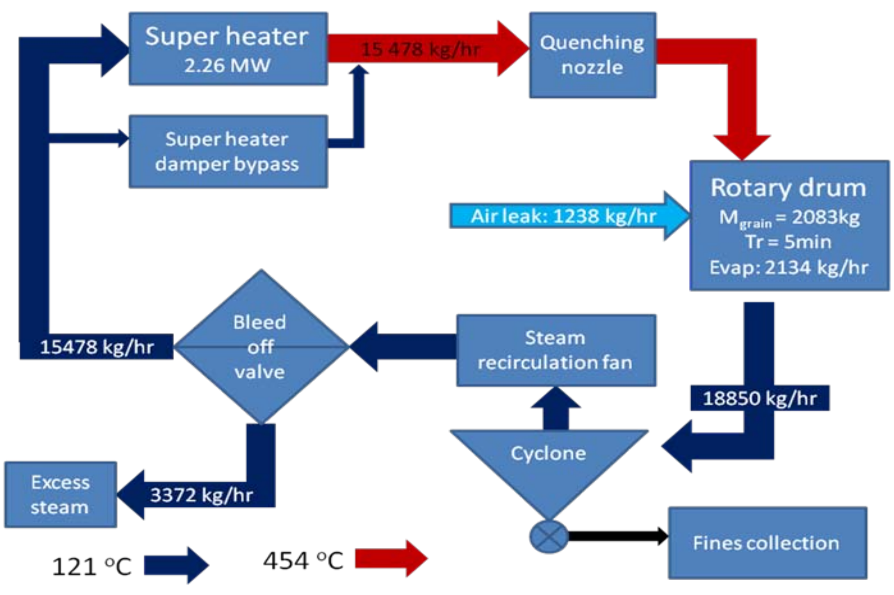
In order to attain the required gross heat input (2.243 MW_{th}), the gasifier needs to have a higher capacity, in order to account for its energy loss. It was determined that a 2.9 MWth gasifier would be able to obtain the required thermal energy, assuming a thermal efficiency of 80%. Its outlet gas temperature approximates 1500˚C, and its cost would be around 700,000 $CAN, based on discussions we had with Louis-Martin Dion, B. Eng. Bioresource Engineering.

Superheated Steam Dryer

The principle of superheated drying consists of utilizing available energy offered by superheated steam, which can be transferred to a wet product in order to remove excess moisture. Through heat transfer, energy from the steam is transferred to the corn kernels, therefore lowering steam temperature during the contact period. The allowable contact time between the superheated steam and product is limited to the condensation temperature of steam. During drying process condensation of steam due to low temperature is undesirable because it will increase product moisture and defeat the purpose of the dryer. Although there is a condition at the beginning of drying where steam will condensate on the product surface until it reaches a temperature of 100°C then the drying phase will begin.

System Components

For this application we are using a closed loop system where partial steam recirculation is achieved after a contact period with the product to dry. In order to control steam flows, 6 majors system component are required: superheating, temperature regulation, drying, recovery, recirculation and excess bleed off. To visualize the arrangement of each component, the following process flow chart represents the steam flow rates and temperature. In order to elaborate the drying system we had the collaboration of Michel Themens, process engineer at GEA Barr-Rosin. With our required drying specification, they quoted an equipment and supplied us with a heat and mass balance for the dryer, allowing to us to design most of the components where specifications were not supplied.



Superheater

This shell and tube counter current heat exchanger allow the hot flue gas from the gasifier to circulate on the shell of steel tubes in which flows the heating steam. From the heat and mass balance, we obtain the main constrain for the heat exchange with a required power of 7.71 MMBTU/hr our 2261 kW and gas temperature as follows.

Flue gas inlet	871^{o}C
Flue gas outlet	204^{o}C
Steam inlet	121^{o}C
Steam outlet	454^{o}C

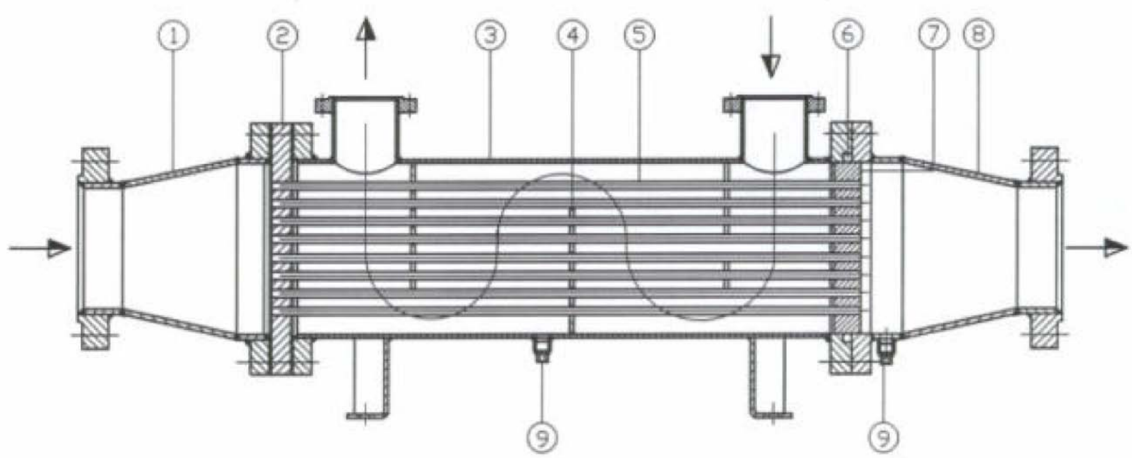
In order to obtain a required contact surface area we had to assume a heat exchanger coefficient. Engineering toolbox, specified values of 5to 35 W/m^{o}C for a gas/ gas shell and tube heat exchanger, therefore for our design we decided to use a value of 15 W/m^{o}C. By using the heat exchanger equation, the area can be obtained:

$$Q = UA\Delta Tm$$

With this procedure we find a required internal tube surface area of 728.5 m^2. With this number in mind we can find the required tube diameter and length that will form the heat exchanger. For sizing tubes, we have two constraints: the surface area and steam mass flow rates, which is 4.30 kg/s for a volumetric flow rate of 6.67 m^3/s at the entrance and 10.91m^3/s at the outlet. With such a volumetric flow rate we wanted to maintain a reasonable steam velocity in the tube to prevent unnecessary friction loss and also have a turbulent flow to increase heat transfer coefficient from the pipe wall to the steam. A third parameter required is the number of tubes to handle the flow rates. We proceeded by iteration by calculating flow characteristic for tube diameter of 0.0127m, 0.191m, 0.0254m and 0.0381m. With the last iteration required 406 tubes of 15m, with entrance flow velocity of 14.41m/s and exit flow velocity of 23.56m/s with respective Reynolds number of 271 630 and 132 559, yielding turbulent flows.

For sizing the shell, a layout for the 408 tube had to be designed, which we selected an equilateral triangular unit cell for each tube, that would form a hexagon when placed together. The tubes have a diameter of 0.0381m and they would be placed in the center of a triangular unit cell conscribed about a circle of 0.0508m. This configuration will allow a minimum spacing between the tubes of 0.0127m to allow flue gas circulation in the shell. Once all the unit cell are placed, together it would form an hexagon with a width of 1.45m and a height of 1.26m.. The hexagon pattern allows to be placed inside a cylindrical shell with an inside diameter of 1.45m. The following picture is a good representation of a longitudinal shell/ tube heat exchange as we are using in for this dryer.

We found that the shell required a diameter of 1.45m and the tube have a length of 15m. The Flue gas will enter the shell on its side as demonstrated on the picture and the steam will be transferred to all the tube from an increasing end section diameter from the inlet duct of 0.76m to the superheater's diameter of 1.45m. This section connector will be 1m length and the outlet section will also be the same length, as it reduces down to duct size of 0.76m. Therefore the total length of the super heater, along with its pipe connectors is 17m.



http://www.frigotherm.co.za/images/shell_tube_heat_exchangers.jpg

Temperature Regulation

In a steam system, temperature regulation is critical and accurate temperature control is very difficult to achieve, especially when bioenergy is used. In order to obtain a certain degree of temperature regulation for this dryer, two systems are installed, which are a super heater damper bypass and a two phase quenching nozzles.

The bypass will allow a partial or total bypass of the super heater as required during operation for rapid cool steam cool down or other events that could require shut off of the super heater. Also the bypass can be used when a high degree of temperature regulation is required and the quenching nozzles are not sufficient.

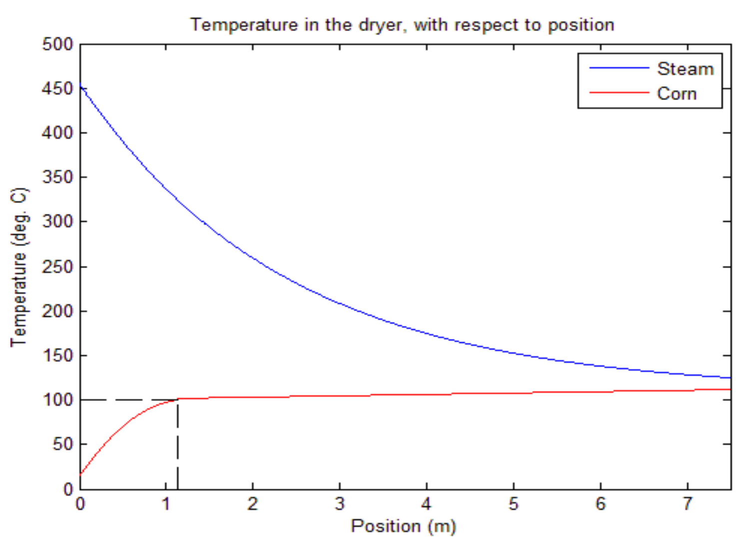
On the other hand the two phase quenching nozzle will allow a temperature reduction up to 50^oC when the steam is coming out of the superheater above recommended temperature. To reduce the steam temperature the quench nozzle will inject in a 50%, by volume, mixture of air and water at ambient temperature at a maximal flow rate of 0.24 kg/s, with a approximate density of 499.7 kg/m^3, in the hot steam duct. The quenching nozzles mist the air/ water mixture into a fog inside the duct to allow a rapid evaporation so that there is any trace of water moisture in the steam when it will enter the rotary drum. The selected nozzle are the BETE Micro Whirl nozzle, MW695, which allow a flow rate of 1.413 l/min, therefore 23 nozzles will be required to produce the desired 32.02 l/min to achieve 50^oC steam temperature reduction. *Nozzles details are in the annex.*

Rotary Drum

The rotary drum is the central piece of equipment of this dryer, where steam and corn kernels are in contact to achieve the primary drying stage. It is designed for a drying capacity of 25 000 kg/hr of wet grain with a moisture reduction from 25% to 18%. The grain’s residence time inside the dryer was determined to be approximately 5 min, by Michel Themens at GEA Barr-Rosin. Therefore, the total mass of grain inside the dryer is 1990kg of grain at an average moisture content of 21.5% WB. With the design grain flow rate the evaporation rate of the dryer is 2134 kg/ hr of water.

Grain flow rate is variable according the corn's moisture content; the grain flow rate can be adjusted by changing the drum's inclination. Then to control the grain entrance flow rate, a variable feed auger will slowly discharge grain inside the drum. On the outlet side a discharge hood will prevent excessive material to enter the steam loop. Then to discharge the grain from the drum, precautions are taken to prevent steam leaks. Therefore, a rotary valve will continuously remove grain from the bottom section of the discharge hood. The drum size is established with a diameter of 1.37m and a length of 7.62m. In order to produce a uniform curtain of falling grain to maximize heat steam to grain contact the drum shell is fitted with a lifting flight cruciform baffle. More details on the drum construction are supplied in section 4.1 of quotation in annex.

The dryer is designed with a steam and grain concurrent flow, where hot steam will enter with cold wet grain and cold steam will leave with hot dry grain. This design will allow to shorten the condensation phase where steam temperature will drop rapidly and the drying portion will be achieve with a smaller grain to steam temperature difference especially in the final stage where kernel damaging is critical. The grain and steam temperature profile inside the dryer are as following.



In order to achieve such a drying capacity, very high steam flow rates are required to supply sufficient energy to the corn kernels. A summary of the flow characteristic is presented in the following table:

	Entrance	Exit
Temperature	454^{o}C	121^{o}C
Mass flow	4.3 kg/s	5.22 kg/s
Density	0.394 kg/m^3	0.646 kg/m^3
Volumetric flow	10.91 m^3/s	8.08 m^3/s

The evaporated moisture from grain as well air leaks entering the dryer will contribute to build-up of the steam flow rate. Air leaks are mostly present in the drum from joints between movable and fixed parts. A second source of leaks to the drum is air pushed in with the wet material and air entering the drum trough the discharge rotary valve. The flow build-up corresponds to 0.59 kg/s of steam from evaporation and 0.34 kg/s from air leaks.

Further comparison of the actual dryer characteristics with the experimental dryer will be found in the Grain Quality section to determined possible impact on corn kernel due to scale up.

Steam Recovery

The main purpose of proposing a superheated steam dryer was to increase the drying efficiency due to the drying medium recirculation. From the drying chamber, the steam cannot be returned directly to the super heater because it may pick up fine particles within the drums. These particles have to be removed, because the system could accumulate particle in the steam after a certain period of time. Also, if suspended particles return to the super heater they can accumulate on the interior of the tube and increase fouling factor and reduce its efficiency.

From the drum outlet, steam is circulated through a high efficiency cyclone that will separate fines from the steam. Fines will deposit at the bottom of the cone after deceleration and will be removed with a rotary valve for proper isolation of the steam atmosphere and outside air. Steam will be blown from the top end of the cyclone with the recirculation fan that will redirect steam to the super heater.

The required recirculation fan for such a dryer is of considerable size. In fact, a centrifugal fan is fitted with a 75hp (56.4 kW) electric motor. The fan is of centrifugal type with backward curve blades for a combined efficiency of 67.5% (90% from the motor and 75% from the fan). This will lead to a total power input to the steam flow of 38.07 kW or a pressure differential of 4710.9 Pa.

Excess Steam Removal

As explained in the rotary drum section, steam build-up inside the rotary drum and if excess steam is not removed, the system's pressure will increase over time. The current system is designed to function at atmospheric pressures to maintain a low saturation point of steam, without creating vacuum. Therefore, a bleed-off valve is required to maintain proper pressure. Overall, 0.92 kg/s of steam have to be removed from the steam loop. This bleed-off valve is located after the recirculation fan on the steam duct where the highest pressure inside the system is found. Since the system operates at or slightly above atmospheric pressure, the bleed-off valve needs to be placed where the pressure will be the highest. This pressure differential between the closed system and the atmosphere will help proper functioning of the bleed-off valve.

Component Placement and Duct Work

The two largest components of the system are the superheater, with a length of 17m and the rotary drum with a length of 7.62m. To reduce duct length, the super heater and the rotary drum will be place parallel with the outlet of the super heater and the inlet of the drum been equal. The selected ducts for transporting steam between the components will have a diameter of 0.762m. Overall, the steam loop's system will be composed of approximately the rotary dryer, a fan, the cyclone separator that will reduce the number of fine particles during steam circulation, a superheater, and 4 ducts connecting the system together. It is estimated that the duct length will be approximately 15.24 m long (50') and will contain 4 long-radius, 90˚ bends.

The major pipe friction losses have been calculated and deemed as negligible. The superheater, on the other hand, will cause friction losses through major friction losses, contraction, and expansion losses that will account for 12% of the effective power of the fan (approximately 38 kW). The 4 duct fittings will also use 5.5% of the fan's power. Overall, more than 82% of the fan's power will be made available for the cyclone, assuming kinetic energy losses in the dryer are not significant.

<u>Isolation</u>

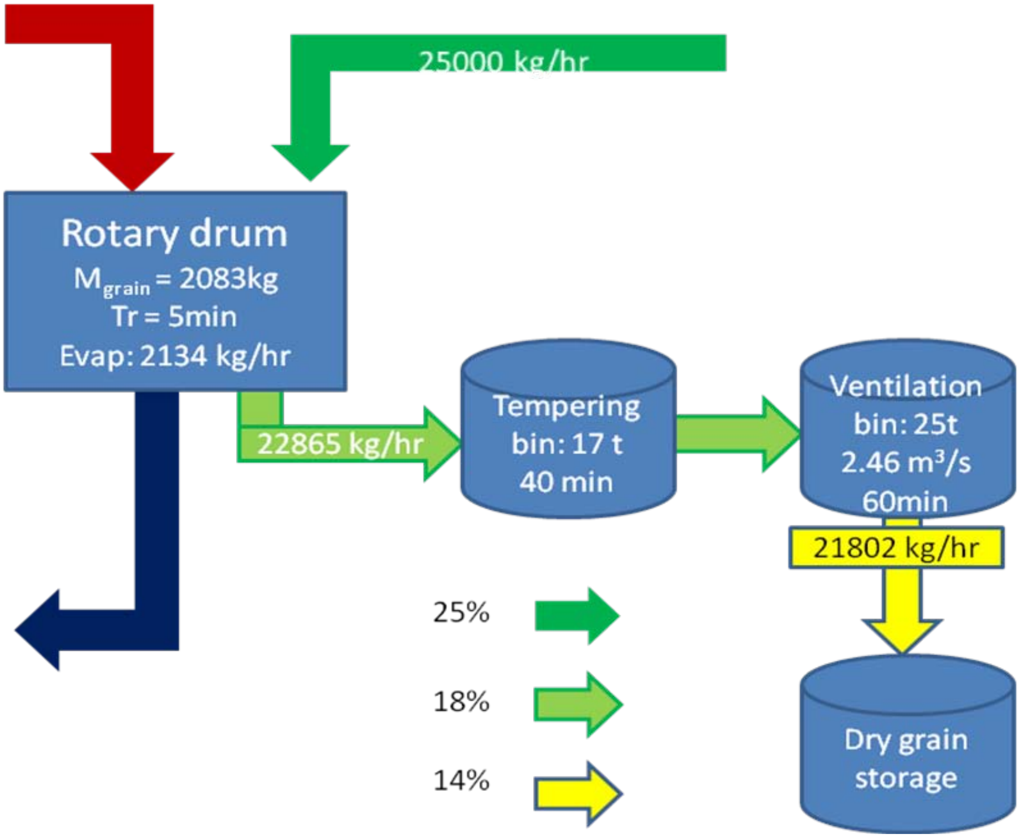
Due to the use of high temperatures across the whole system, a thorough isolation is required in order to limit heat losses, which would reduce the overall efficiency of the system and could endanger the safety of the workers, due to a high external temperature in the dryer's components. The dryer's temperature reaches 454˚C, whereas the gasifier outlet will reach 1500˚C.

After discussing with engineers at GEA Barr-Rosin, it was determined that superheated steam dryers should leak less than 5% of their energy. For the case of the proposed superheated steam dryer, the threshold energy loss was calculated as 113 kW. Annex E. shows the results obtained for the isolation requirements for the pipes of the steam system, the superheated steam dryer, and the gas burner's outlet pipe.

Mineral wool was chosen as the isolating material due to past experience with the material in calculations and because it was suggested by GEA Barr-Rosin. Mineral wool is a material with a low thermal conductivity that resists to heat stress and which is easy to install. It was found that with the following calculations, a total volume of 4.36 m^3 would be required in order to provide proper insulation to the dryer system.

Grain Handling

Grain corn is a product to be handled with care to prevent any damage to the kernel. With this two-phase drying system, significant grain handling is required to obtain a final moisture content of 14% down from the 18% at the outlet of the super heated steam dryer. The second drying phase is passive, because it uses the energy of the warm grain in order to achieve this final moisture reduction. This section will describe the system components required for handling corn from the wet bin storage all the way to final storage.



Wet grain reserve

As corn is harvested from the field following the wheatear patterns in a non continuous fashion, a certain amount of wet storage is necessary to maintain dryer operation. Non-continuous operations are not recommended because the biomass is the base energy source and because the start up process to fill up the system with steam will require a certain amount of energy. Therefore, we recommend having a minimum of 600t of wet storage in order to maintain a minimum of 24hr operation. Wet grain from this reserve would be transferred directly inside the rotary drum with the variable feed auger. This wet bin reserve would be placed directly next to the rotary drum, on the entrance side.

Dryaeration phase

From the outlet of the rotary valve discharging the rotary drum, a belt conveyer will transport hot corn to an 11m vertical bucket elevator, which will bring corn to a specially fitted bin for continuous dryaeration. This bin consists of a high narrow core of 4.57m, a eave height of 6.16m and a total height of 7.38m. This bin will have two flat bottom floors, creating two isolated distinct cells for two operation within the bin: the tempering and the ventilation.

The tempering phase consists of letting the grain in an isolated, unventilated space for a retention time of 40 minutes. This retention condition in combination with the high grain temperature will allow moisture migration to the surface of the kernels without any additional energy. This retention time represents a temporary storage of 15.25t. The hot grain discharge from the elevator will fall in the upper cell of the bin separated by a solid sealed floor. On this floor, a variable unloading sweep auger will collect grain to the center of the floor to let it fall to the second cell trough a rotary air lock valve to cut a much as possible air stream moving in the second cell.

The falling grain from the rotary valve and a dispersion system will evenly spread out the grain on top of the current grain mass. In the second phase the tempered grain will be submitted to high ventilation rates in order to remove the excess moisture that diffused to the kernel's surface. In this section, an air velocity through the grain of 0.15 m/s is required, resulting in a 2.46 m^3/s air flow rate. To supply such ventilation rates, a 5hp (3.75kW) centrifugal fan is required. To evacuate air from the bottom cell, there should be a 16.4m^2 of opening under the second floor in order to prevent unnecessary pressure build-up in the bin, which would reduce fan performance. The minimum residence time in this cell of 30 minutes, representing a minimum temporary storage of 11.43t. The evaporation rate to achieve the proper moisture reduction is 1063 kg/hr.

To remove the grain from this cell, a variable unloading sweep auger will collect grain to the center of the floor from under the mass and transport it out of the bin with an auger. From the dryaeration bin's outlet, a final auger can be connected on to transport grain to an elevator to discharge the dry grain to final storage bin. The final outcome of the drying process is a flow rate of 21.8t/hr of corn at a 14% moisture content.

Energy Analysis

It is well known that grain drying is a very energy-intensive process. The purpose of this project was to reduce energy required for grain drying. The proposition of superheated steam drying directly targets this objective, with the significant advantage of recirculating the drying medium. This section will analyse the energy aspect of our propose drying process from the fuel energy and electric energy required.

Installed Power

For this project the dryer is designed to dry 10 000t of wet corn with at a rate of 25t/hr for a total operation time of 400 hours not including start ups and shut downs. For calculation of dryer efficiency will be base on a 1 hr operation not including start up or shut downs, on the other hand for economic analysis a safety factor of 1.25 on electricity and 1.5 on fuel will be accounted.

For operation this dryer requires a significant number of electric motors. For a detailed motor’s energy consumption, please refer to the annex.

-	Drum drive:	20 hp
-	Feed metering screw	5 hp
-	2 product rotary valve	2 x 3 hp
-	Cyclone rotary valve	1 hp
-	Belt conveyer	2 hp
-	Bucket elevator	5 hp
-	Sweep unloading augers	2 x 5 hp
-	Bin unloading auger	3 hp
-	Bin ventilation fan	5 hp
-	Steam recirculation fan	75 hp
-	Flue gas recirculation fan	40 hp
-	Gasifier syngas fan	5 hp
Total installed power	**176 hp**	

Fuel Consumption

The main source of energy required for this drying system is energy absorbed by the superheater, with a required power of 2,260 kW. The superheater obtains its energy from hot flue gas produced by the gasification system that uses wood chips as its main energy source. A gasifier of the required size has an efficiency of 80%. With these two sources of energy, the evaporation efficiency of the dryer can be obtained.

Exhaust steam from the bleed-off valve at a rate of 0.92 kg/s and a temperature of 121^{o}C has a significant energetic value that could be used for other application, which is not in the scope of this project. The following table summarizes the evaporation efficiency and detail can be seen in *annex A.*

Electricity	93 748	kJ/ hr
Fuel source	10 168 097	kJ/ hr

Dryer evaporation	2 134	kg H_2O/ hr
Dryaeration evaporation	1 063	kg H_2O/ hr

Evaporation efficiency	**3 286**	**kJ/ kg H_2O**

Exhaust steam	6 328 271	kJ/ hr
Potential evap. efficiency	**1 307**	**kJ/ kg H_2O**

This high efficiency system has an evaporation energy rate of 3286 kJ/ kg of water. The proposed system is an improvement compared to any multi-stage dehydration presented in the proposal. By comparing the same drying methodology as we are using with the best efficiency obtained (3452 kJ/ kg of water), the improvement is not significant. On the other hand if we compare it with the potential evaporation efficiency of 1307 kJ/ kg of water evaporated, it then becomes a significant improvement.

Economic Analysis

For every project, a thorough economic analysis is required to determine its feasibility and profitability. A project could be an engineering marvel, but if in the end it doesn’t bring in a profit, the project is most likely not going to be accepted. For this project the economic analysis will be based on expected operation cost.

First, such a drying system is a very specialize equipment and has a very high capital cost, despite the limited utilization time over the year. The capital repayment will be amortized on a 20 years period with an estimated interest rate of 5%. The costs of each major component of the dryer are listed below:

- Superheated Steam Dryer 1 750 000$
- Gasifier 700 000$
- Grain Handling & Dryaeration 50 000$

Total **2 500 000$**

Operation cost calculation are divided in 2 sections: variable costs will include electricity, fuel (wood chips), labour and maintenance. The fixed cost will include anything that has to be paid independently of utilization time, like capital repayments and insurance. For calculating the total cost of each component, the calculations were based on an expected operation time of 400 hours required to dry 10 000t of wet corn. A safety factor will apply for certain items’ uncertainty during start up and unexpected operation times.

In the variable cost section electricity cost was accounted for at 0.08 $/kWh, which is higher than current farm rate at 0.746 $/kWh. Also a safety factor of 1.25 is accounted for on total electricity use. Fuel costs will be on an energy yield of 200 GJ/ ha with a production cost of 593.40$/ha and a safety factor of 1.5. Regarding labour, an estimated wage of 20$/hr with a safety factor on working hours of 1.5 and 1 employee is sufficient to maintain dryer operation, but usually grain elevators have 2-3 employee during harvest period to maintain proper operation of the plant. Finally, insurance rates of mechanical equipment are 0.41$ / 100$ of value, and maintenance rates are estimated to be 3% of original value. The following table summarize the annual cost for each item. Finally, operation are obtained on a unit ton basis and compared to current drying rates charges to farmers in grain elevator. Each item is also broken down on unit ton to have a quick evaluation of the price and the importance of each items. In the annex, a detailed chart is provided.

Variable cost

Fuel	5 028,12 $	0,56 $
Electricity	3 749,92 $	0,42 $
Labor	12 000,00 $	1,35 $
Maintenace	75 000,00 $	8,43 $

Fix cost

Repayment	197 986,68 $	22,25 $
Insurance	10 250,00 $	1,15 $

Total cost	**304 014,72 $**
Drying cost ($/ t)	34,16 $
Market cost ($/ t)	22,50 $

From this economic analysis, the total cost scenario for drying 10 000 tonnes of wet corn cost an equivalent of 34.16$ per dry tonne of corn. This cost is 51.8% higher than the current price on the market that grain elevator charge for drying corn. The price makeup for commercial grain drying services is based on 0.90$ per percentage point of moisture (for propane cost between 0.35 to 0.45 $/l), therefore for corn at 25% moisture it will cost 22.50$ per tonne. In drying, costs are capital investments for the equipment and energy cost for operation. It was explained to us that the price is divided between the two major drying expenses; first, the equipment associated cost should represent the section of the price from 0% to 14% (moisture of dry corn) and the energy cost represents the section from 14% to 25% in our cost or to the moisture of wet corn to dry. The following table compares the price for current commercial grain dryer and our superheated steam dryer.

	Equipment cost	Energy cost
	0-14%	14%-25%
Current market	12,60$/t	9,90$/t
Steam dryer	33,15$/t	0,98$/t

The proposed drying system has a very low energy cost due to on-farm use of biomass energy. On the other hand, the operating cost associated to equipment investment and maintenance makes up more than 97% of the cost. From this situation, it can be easily concluded that the proposed drying system is underused at 400 hrs/year. In fact such equipment should be in operation at least 6000 to 7000 hours per year.

From such a price difference, a scenario for break-even cost has been made. With a 20-year capital repayment, it would require drying of 16 000 tonnes of wet corn, yielding a cost of 22.22 $/t of dry corn. This solution is still feasible with a required operation time of 640 hours or 26 days, although it might require increased storage for wet corn to allow operation during rainy days when harvesting is not possible. If the repayment schedule were changed to 10 year, 22,500 tons of wet corn would be required. Although with this amount of corn and the current dryer size, it would take 900 hours or 38 days of operation, which is nearly impossible for corn harvest with the climatic condition that south western Québec has. The harvesting period generally stretches from October 20th to November 15th.

Comparison between the experimental and the rotary drum dryers

Since superheated steam drying is a complex process that requires the use of expensive materials, an experiment was conducted in order to assess the grain quality during drying. Here is how the experimental superheated steam dryer compares to the proposed rotary dryer suggested in the project.

As the two dryers are of different sizes and answered different functions, it is important to compare the heat transfer characteristics of both dryers. Both dryers have been treated as heat exchangers between the steam and the corn, with the contact surface being the corn’s surface itself. Overall, the heat exchanger coefficients are quite different (140 W/m^2 ˚C for the experimental dryer and 19 W/m^2 ˚C for the rotary dryer), due to the very different contact surface and power requirements. It has also been shown that the rotary dryer will absorb a larger quantity of its initial steam flow rate, due to a higher temperature difference.

Overall, the superheated steam dryer used has a very limited capacity. Experiments were carried on with 100-gram samples and were not continuous-flow dryers. However, the temperature ranges were important and the proposed experimental dryer can yield results of somewhat a pertinent interest for grain quality after superheated steam drying. However, this dryer could not be used as a scale-up model in order to prepare an industrial-scale dryer.

Conclusion

This project served multiple purposes, but its final objective was to improve the sustainability of farms by using local bioenergy sources as feedstocks and by improving the efficiency of drying. Overall, it has been concluded that superheated steam drying would affect the quality of corn, but that its use would fit better for other types of crops that would be less sensitive to heat stress. It has also been shown that the initial capital investments of superheated steam drying were higher than in conventional drying, but that it accounted for an improved efficiency. Finally, biomass gasification also had high initial capital costs, but its fixed costs in fuel energy were very small and very limited.

In conclusion, the project proved that large productions were necessairy in order to make superheated steam drying cost-effective (more than 16,000 t/year, in the case of corn), that gasification applied well as an alternative feedstock for such productions compared to propane burning, and that steam drying was a more efficient drying method than heated air drying.

Annex A. Energy Analysis

Energy from motors:

Electric motor	#	Current	Voltage	Power (W)
75 hp	1	68.7	575	39503
40 hp	1	37	575	21275
20 hp	1	19	575	10925
5 hp	6	5.28	575	18216
3 hp	3	3.36	575	1932
2 hp	1	2.2	575	1265
1 hp	1	1.1	575	633
Total				93748
Electric energy (kJ/hr)				337493

Gasifier requirements:

Superheater (W)	2259577
Burner efficiency	80%
Gross power (W)	2824471.25
Required fuel energy (kJ/hr)	10,168,097

Total energy and evaporation efficiency:

Total energy input (kJ/hr)	10,505,589
Dryer evap. rate (kg/hr)	2134.11
Aeration evap. Rate (kg/hr)	1063
Evaporation efficiency (kJ/kg)	3286

With steam recovery:

Exhaust energy	(kg/hr)	Temp (C)	h (kJ/kg)	Energy (kJ)
Dry air	1230	121	394.92	485,752
Steam	2142	121	2727.6	5,842,519
Total				6,328,271
Evaporation efficiency (kJ/kg)	1306.592047			

Annex B. Economic scenarios

Scenario 1: 10,000 t/year, 20 year payback period

Total grain to dry (t)	10,000.00
Moisture content	25%
Total dry grain	8,900
Drying capacity (t/hr)	25.00
Drying time (hr)	400.00
days	16.67

Equipment cost

SSD	1,750,000.00$
Gassifier	700,000.00$
Dryaeration	50,000.00$
Total investment	2,500,000.00$

20 yr payback 5% interest

Monthly payment	16,498.89$
Yearly reinbursment	197,986.68$
Repairs & maintenance 3%	75,000.00$
Insurance (0,41$/ 100$)	10,250.00$

Fuel cost

energy yield (GJ/ha)	200.00
Prod. Cost (ha)	593.40$
Energy cost (kJ)	0.00000297$
Energy use (kJ/hr)	2,824,471.25
Total energy cost ($/hr)	8.38$
S.F on energy use	1.50
Total energy cost ($/yr)	5,028.12

Electricity cost

Usage rate kWh/hr	93.75
Electricity rate $/kWh	0.08 $
Safety factor	1.25
Electricity cost	3,749.92$

Labor

S.F. On labor	1.50
Total labor	600.00
Labor rate (hr)	20.00$
Labor cost ($)	12,000.00$

Overall:

Variable cost

Fuel	11,313.28$	0.56$
Electricity	8,437.32$	0.42$
Labor	27,000.00$	1.35$
Maintenace	75,000.00$	3.75$

Fix cost

Repayment	318,196.56$	15.89$
Insurance	10,250.00$	0.51$

Total cost	**450,197.16 $**
Drying cost ($/ t)	22.48 $
Market cost ($/ t)	22.50 $

	Equipment cost	Energy cost
	0-14%	14%-25%
Current market	12,60$/t	9,90$/t
Steam dryer	33,15$/t	0,98$/t

Scenario 2: 16,000 t/yr, 20 year payback period

Total grain to dry (t)	16,000.00
Moisture content	25%
Total dry grain	14,240
Drying capacity (t/hr)	25.00
Drying time (hr)	640.00
days	26.67

Equipment cost

SSD	1,750,000.00$
Gassifier	700,000.00$
Dryaeration	50,000.00$
Total investment	2,500,000.00$

20 yr payback 5% interest

Monthly payment	16,498.89$
Yearly reinbursment	197,986.68$
Repairs & maintenance 3%	75,000.00$
Insurance (0,41$/ 100$)	10,250.00$

Fuel cost

energy yield (GJ/ha)	200.00
Prod. Cost (ha)	593.40$
Energy cost (kJ)	0.00000297$
Energy use (kJ/hr)	2,824,471.25
Total energy cost ($/hr)	8.38$
S.F on energy use	1.50
Total energy cost ($/yr)	8,045.00

Electricity cost

Usage rate kWh/hr	93.75
Electricity rate $/kWh	0.08$
Safety factor	1.25
Electricity cost	5,999.87$

Labor

S.F. On labor	1.50
Total labor	960.00
Labor rate (hr)	20.00$
Labor cost ($)	19,200.00$

Overall:

Variable cost

Fuel	8,045.00 $	0.56 $
Electricity	5,999.87 $	0.42 $
Labor	19,200.00 $	1.35 $
Maintenace	75,000.00 $	5.27 $

Fix cost

Repayment	197,986.68 $	13.90 $
Insurance	10,250.00 $	0.72 $

Total cost	**316,481.55 $**
Drying cost ($/ t)	22.22 $
Market cost ($/ t)	22.50 $

	Equipment cost	Energy cost
	0-14%	14%-25%
Current market	12,60$/t	9,90$/t
Steam dryer	33,15$/t	0,98$/t

Scenario 3: 22,000 t/year, 10 year payback period

Total grain to dry (t)	22,500.00
Moisture content	25%
Total dry grain	20,025
Drying capacity (t/hr)	25.00
Drying time (hr)	900.00
days	37.50

Equipment cost

SSD	1,750,000.00$
Gassifier	700,000.00$
Dryaeration	50,000.00$
Total investment	2,500,000.00$

10 yr payback 5% interest

Monthly payment	26,516.38$
Yearly reinbursment	318,196.56$
Repairs & maintenance 3%	75,000.00$
Insurance (0,41$/ 100$)	10,250.00$

Fuel cost

energy yield (GJ/ha)	200.00
Prod. Cost (ha)	593.40$
Energy cost (kJ)	0.00000297$
Energy use (kJ/hr)	2,824,471.25
Total energy cost ($/hr)	8.38$
S.F on energy use	1.50
Total energy cost ($/yr)	11,313.28

Electricity cost

Usage rate kWh/hr	93.75
Electricity rate $/kWh	0.08$
Safety factor	1.25
Electricity cost	8,437.32$

Labor

S.F. On labor	1.50
Total labor	1,350.00
Labor rate (hr)	20.00$
Labor cost ($)	27,000.00$

Overall:

Variable cost

Fuel	11,313.28 $	0.56 $
Electricity	8,437.32 $	0.42 $
Labor	27,000.00 $	1.35 $
Maintenace	75,000.00 $	3.75 $

Fix cost

Repayment	318,196.56 $	15.89 $
Insurance	10,250.00 $	0.51 $

Total cost	**450,197.16 $**
Drying cost ($/ t)	22.48 $
Market cost ($/ t)	22.50 $

	Equipment cost	Energy cost
	0-14%	14%-25%
Current market	12,60$/t	9,90$/t
Steam dryer	33,15$/t	0,98$/t

Annex C. Comparison between experimental dryer and rotary drum dryer

	Experimental dryer		Rotary drum dryer	
Initial mass (or mass flow)	0.1	kg	6.94	kg/s
Initial moisture content	25	%	25	%
Final moisture content	18	%	18	%
Residence time	360	sec.	300	sec.
Inlet steam temperature	160	˚C	454	˚C
Outlet steam temperature	140	˚C	121	˚C
log-mean temp. difference	79.8	˚C	137.5	˚C
Power transferred	694	W	3,344,000	W
Contact surface with corn	0.0619	m^3	1,289	m^3
Heat exchanger coefficient	140	W/m^2 ˚C	18.87	W/m^2 ˚C
Initial steam flow rate	0.001	kg/s	4.29	kg/s
Evaporation rate	0.085	kg/hr	2.13	t/hr
Final steam flow rate	0.001	kg/s	5.23	kg/s

Annex D. Willow harvesting

SSD will dry 25 tonnes per hour and will need 2.26MW of power.

The gasifier has an efficiency of 80% therefore the total power that will need will be:

$$\frac{2.26MW}{80\%} = 2.83MW = 10.17\frac{MJ}{hour}$$

Knowing that our willow stand has and a yield of 10 tonnes/ha and an energy yield of 16 GJ/tonnes of willow @ 50% moisture content[3] we can conclude that we will need to burn:

$$10\frac{tonnes\ of\ willows}{ha} * 16\frac{GJ}{tonnes\ of\ willows} = 160\frac{GJ}{ha}$$

$$\frac{10.17MJ}{hour} \div \frac{160GJ}{ha} = 0.064\frac{ha}{hour} * 10\frac{tonnes}{ha} = 0.64\ \frac{tonnes\ of\ willows\ burned}{hour}$$

To find the area needed to dry 10 000 tonnes of corn

$$0.064\frac{ha}{hour} * \frac{10\ 000\ tonnes}{25\ tonnes\ of\frac{corn}{hour}} = 25.6\ ha * 1.25\ safety\ factor = 32\ ha$$

The table describing the time taken for the tasks was based on the following table assuming a total area of ~32 hectares:

Operation	Operating Rate (hours/ha)	Total hours	Season	Occurrence	1st year	2nd year	3rd year	4th to 20th year
Mow existing vegetation	1.5	47.66	Spring	One time	15.89	15.89	15.89	0
Apply contact herbicide	0.5	15.89	Spring	One time	5.30	5.30	5.30	0
Plough	1.7	54.02	Spring	One time	18.01	18.01	18.01	0
Disk	1.4	44.48	Spring	One time	14.83	14.83	14.83	0
Cultipack	0.71	22.56	Spring	One time	7.52	7.52	7.52	0
Seed cover crop	0.1	3.18	Spring	One time	1.06	1.06	1.06	0
Planting	2.5	79.43	Spring	One time	26.48	26.48	26.48	0
Apply pre-emergent herbicide	0.46	14.62	Spring	Re-occurring	4.87	4.87	4.87	4.87
1st year coppice	1.5	47.66	Spring	Re-occurring	15.89	15.89	15.89	15.89
Mechanical weed control	0.61	19.38	Spring	Re-occurring	6.46	6.46	6.46	6.46
Mechanical weed control	1.6	50.84	Spring	Re-occurring	16.95	16.95	16.95	16.95
Chemical weed control	0.46	14.62	Spring	Re-occurring	4.87	4.87	4.87	4.87
Fertilize	0.21	6.67	Spring	Re-occurring	2.22	2.22	2.22	2.22
Harvest	3	95.32	Fall	Re-occurring	0.00	0.00	0.00	31.77
Total time investment (hours)					140.33	140.33	140.33	83.04

The values for time, fertilizer and herbicide application were taken from the following table.

Table 2
Field operations data for base case

Operation	Implement used	Implement weight (kg)	Tractor power[a] and weight	Operating rate (h ha^{-1})	Input rates and comments
Mow existing vegetation	1.8 m brushhog	470	54 kW 3240 kg	1.5	(55% of acreage)
Apply contact herbicide	7.6 m boom sprayer	670	37 kW 2572 kg	0.5	Glyphosate: 2.5 kg AI ha^{-1}
Plow	1.45 m Moldboard plow[b]	1226	60 kW 3683 kg	1.7	
Disk	3.4 m tandem harrow disk	1053	54 kW 3240 kg	1.4	(2 × coverage)
Cultipack	3.0 m cultipacker	635	54 kW 3240 kg	0.71	(2 × coverage)
Seed covercrop	12.2 m broadcaster	100	37 kW 2572 kg	0.10	2.5 bu. winter rye ha^{-1} (50% of acreage)
Planting	4 row Salix Maskiner Step	1400	78 kW 5670 kg	2.5	15,300 cutting units ha^{-1}
Apply pre-emergent herbicide	7.6 m boom sprayer	670	37 kW 2572 kg	0.46	Simazine: 2.24 kg AI ha^{-1} Oxyfluorfen: 1.12 kg AI ha^{-1}
1st year coppice	2.1 m sicklebar mower	270	54 kW 3240 kg	1.5	
Mechanical weed control	Modified row cultivator	500	37 kW 2572 kg	0.61	(54% of acreage)
Mechanical weed control	Badalini rototiller	400	54 kW 3240 kg	1.6	(29% of acreage)
Chemical weed control	7.6 m boom sprayer	670	37 kW 2572 kg	0.46	Simazine: 2.24 kg AI ha^{-1} (5% of acreage)
Fertilize	7.6 m spreader	180	75 kW 4192 kg	0.21	100 kg N ha^{-1} ammonium sulfate
Harvest	Salix Maskiner Bender	1250	78 kW 5670 kg	3.0[c]	

[a]Maximum power take off (PTO) power.
[b]Plow width is average of two used: 4 × 36 cm (137 cm width) and 4 × 41 cm (152 cm width).
[c]Extensive harvesting with the Maskiner Bender has not yet occurred in New York. Harvesting rates are based on data from European studies using earlier models of this machine.

Table from Heller, Keoleian et al., 2003

Annex E. Isolation

Mineral wool (k = 0.09 W/m˚C) is used for the system, due to its resistance to high heat stress.

Parameters and sections :

Section	L (m)	q (W)	r0 (m)	Ti (˚C)	Tf (˚C)	k (W/m˚C)
Pipes						
Dryer-cyclone	3.33	-11,170	0.381	121	30	0.09
Cyclone-superheater	9.14	-30,660	0.381	121	30	0.09
Superheater-dryer	3.33	-11,170	0.381	121	30	0.09
Rotary drum dryer	7.62	-60,000	0.6858	400	30	0.09
Gasifier pipes	15	-60,000	0.381	1500	30	0.09

Results : outer radius, required volume of mineral wool

Section	r1 (m)	Vtotal (m^3)	Vpipe (m^3)	Visolation (m^3)
Pipes				
Dryer-cyclone	0.39	1.57	1.52	0.05
Cyclone-superheater	0.39	4.30	4.17	0.13
Superheater-dryer	0.39	1.57	1.52	0.05
Rotary drum dryer	0.70	11.87	11.26	0.61
Gasifier pipes	0.47	10.37	6.84	3.53

Total volume of mineral wool: 4.36 m^3

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March 19, 2010

McGill University
Montreal, Quebec

BUDGET PROPOSAL

ONE ROTARY SUPERHEATED STEAM DRYER

For

Corn kernel

For

McGill University.

Barr-Rosin Enquiry No. E10033

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1. CLARIFICATIONS TO PROPOSAL

1. In reference to the RFQ received on March 15, 2010 for the McGill University project, GBRI is proposing one (1) Superheated Steam Rotary Dryer to dry corn kernel from 25% M.C. down to 18% M.C. as specified in Section 2.1. Performance Data.
2. Due to the type of feed stock going to the dryer, we have selected as material of construction stainless steel 304L for the first section of the drum and carbon steel for the last portion of it.
3. For the dryer design purposes, we assumed that the dryer heat sources would be hot temperature flue gas from a propane air heating system.
4. We also estimate an amount of approx. 500 ACFM of incondensable in the dryer bleed-off (generated steam) that the customer will have to treat. Normally this small stream is routed to the propane air heating system to be combusted.
5. The generated condensate would contain approx. 1,500 PPM of BOD which is mostly fine particles not collected by the SSD cyclone.
6. Instrumentation, controls and variable frequency drives are excluded from our scope of supply. Local controls and gas train for the gas fired heater are included.
7. Advantages of the Superheated Steam Dryer include:
   - No particle emissions to atmosphere
   - No RTO needed
   - Low primary energy requirement
   - Very accurate control of product moisture
   - Absence of oxygen - No risk of explosion
   - Ease of operation – few control loops required

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2. DESIGN BASIS

2.1 Performance Data – Rotary Superheated Steam Dryer

The Barr-Rosin system would be designed to ***continuously*** dry at the following capacities:

System Design Basis	Nominal	
Product	Corn Kernel	
Feed Rate	55,115	lb/hr
Feed Moisture	25	%
Product Rate	50,410	lb/hr
Product Moisture	18	%
Evaporation	4,705	lb/hr
Operating Steam Temperature	250 – 850	ºF
Operating Steam Pressure	0	psig
Product Temperature In	59	ºF
Product Temperature Out	200	ºF
Flue Gas (Heat Exchanger Input)	1,600	ºF
Flue Gas (Heat Exchanger Output)	~ 400	ºF
Energy		
Heat Exchanger - Energy Absorbed)	7.71	MMBTU/hr
SSD Total Bleed-off Stream, 0 psig	7,435	lb/hr
SSD Exhaust Humidity (expected)	1.75	lb H_2O/lb DA
SSD Wet Bulb Temperature (expected)	197	ºF

Notes:
1. The above values are preliminary until process design is agreed and finalized.
2. Moistures are on a wet basis and free moisture content.

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2.2 Material Properties

Material Specific Heat (on dry solids)	0.43	Btu/lbºF
Bulk Density – wet	82	lb/ft^3
Bulk Density – dry	82	lb/ft^3

2.3 Utilities

The following utilities will be required for the SSD:

Description	Conditions
Heat Sources	Propane
Electrical Power – Motors	480V, 3 ph, 60 Hz (up to 200 HP) 4000V, 3 ph, 60 Hz (above 200 HP)
Compressed Air 1. Clean, Dry and Oil-Free 2. Fail Safe Damper Operation	90 psig

2.4 Motors and Geared Motors

The following motors are included in our supply. They would be supplied as follows:
- Motors 200 HP and smaller: 460V, 3-phase, 60 Hz
- Motors larger than 200 HP: 4160V, 3-phase, 60 Hz
- All motors would be protected for operation in a safe area

In general, absorbed power is approximately 80% of installed power

Rotary Drum	Installed Power
Drum Drive	20 HP
Materials Handling	**Installed Power**
Feed Metering Screw	5 HP*
Product Rotary Valve	3 HP
Rotary Valves Cyclone	1 HP
Fans	**Installed Power**
Steam Recirculation Fan	75 HP
Flue Gas Recirculation Fan	40 HP
Combustor Air Fan	5 HP

* VFD (Note: VFD supplied by others)

Description	Installed Power	Normal Absorbed Power (Expected)
SSD System	152 HP	110 BHP

2.5 Site Conditions

The system would be designed for the following conditions:

Description	Conditions
Site Location	TBD
Dryer Location (rotating equipment indoors)	Indoors/Outdoors
Winter Ambient Temperature (minimum)	TBD
Summer Ambient Dry Bulb Temperature (maximum)	TBD
Summer Ambient Wet Bulb Temperature (maximum)	TBD
Elevation Above Sea Level	TBD

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3. SYSTEM DESCRIPTIONS

3.1 Direct-Fired Rotary Drying Systems

One (1) **Superheated Steam Drying (SSD)** system is proposed to meet the specified design duty listed in *Section 2.1 Performance Data*.

A feed metering screw will transfer the wet feed material from the buffer/feed system to the inlet of the rotary dryer.

The rotary dryer, who is fitted with radial lifting flights a cruciform baffles, will produce a uniform curtain of falling material during its rotation to ensure high heat transfer rate, and prevent overheating and burning of particulate. The cruciform baffles enable operation at higher face velocities reducing the diameter of the dryer.

The bulk of the dry product would be collected in a specially designed outlet hood. Entrained fines would be conveyed by the exhaust gas and collected in high-efficiency cyclones and discharged via rotary valves.

The system would be operated using superheated steam as the drying medium in a closed recirculation cycle with indirect heating of the recycle gas using a heavy duty shell-and-tube heat exchanger. A continuous purge of evaporated water and any infiltration of incondensable gas would be bled-off downstream of the main recirculation fan. This superheated steam would be available for heat recovery (by others).

Propane would be provided as primary heat source for the dryer. The final temperature of the flue gas going to the SSD superheater would be 1,600ºF. To maximize thermal efficiency of the drying system, the majority of the SSD superheater exhaust gases would be recycled back to the air heater and only a portion of the spent gases would be sent to atmosphere.

Superheated steam would circulate at a slightly over atmospheric steam pressure while 1,600°F hot flue gas would be used on the shell side of the superheater as a heating medium.

A material handling system consisting of discharge airlock rotary valves and conveyors would transport the dried product away from the collection devices.

The dryer would be controlled by maintaining a constant exhaust temperature and modulating the heat-exchanger inlet flue gas temperature with respect to the evaporative rate.

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4. EQUIPMENT SPECIFICATION

Outlined below is the equipment specification for a each rotary drying system that would be supplied as part of the project scope.

4.1 Rotary Superheated Steam Dryer (SSD)

4.1.1 GEA Barr-Rosin Co-Current Rotary Dryer – 4.5 ft. diameter by 25 ft. long

One unit – comprised of the following components:

a) Shell and Internals

The dryer shell and end plates would be fabricated throughout in 304L stainless steel and would carry two forged steel tyres mounted on machined pads and a bolt-on chain ring. The tyres would be of the floating type and constructed of machined C1040/45 forged steel. Each tyre would be mounted on thick machined support pads and would be located by welded steel segmented blocks on both sides. The shell thickness would be increased under the tyres to a single reinforcing plate. The edges would be tapered to match the main shell plates to minimize stress concentration.

Each shell ‘strake’ would be rolled from one circumferential ‘mill plate’ requiring only a single longitudinal welded joint. All “T” joints would be staggered by 180º.

The internals of the dryer would be fabricated in *heavy duty 304L* stainless steel and consist of peripheral shell flighting. All flights would be bolted to cleats welded to the shell to allow easy future removal and flight replacement, if required, except where they must be welded onto structural members. All internal bolts would be tack-welded.

The feed end of the dryer would be provided with a 304L stainless steel external stiffening flange and a labyrinth seal channel with woven fabric band.

A series of mild steel angle rings would be welded to the outside of the drum, over the full length, for attachment of insulation and cladding (as required by others).

The shell would be supported at two locations giving approximately equal load distribution.

b) Trunnion and Thrust Wheel Assemblies

Four – solid trunnion wheels would be manufactured from machined C1040/45 forged steel and would be mounted on high tensile 4140 steel shafts running in SKF self-aligning, spherical roller bearing plummer blocks. The bearings would be designed for a minimum L10 life of 80,000 hours and would be fitted with lip seals, grease nipples and end caps.

Two – thrust rollers would be manufactured from alloy forged steel, each mounted on a high tensile steel shaft running in two SKF spherical roller bearings. The face of the rollers would be bevelled to ensure effective contact with the tyre. Each thrust roller assembly would be mounted on an adjustable base, which would be bolted to the underframe on either side of the discharge end tire.

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c) Underframes (Roller Bedplates)

Each underframe would be fabricated from heavy rolled steel 'I' Sections and would be provided with machined faces for mounting the trunnion and thrust roller assemblies.

Jackscrew adjustment would be provided for each pillow block and thrust roller base. The base flange of the underframes would be fitted with levelling screws and arranged for mounting on concrete foundations (supplied by others).

d) Rotary Drum Drive

The drive would be designed to transmit 20 HP on a continuous basis with a drum speed of approx. 3 rpm, and would be comprised of the following:

(i) One – driven segmented-type carbon steel chain sprocket, complete with roller chain.
(ii) One- 20 HP variable speed duty, 1800 rpm TEFC High Efficiency electric motor with class 'F' insulation. Excluding frequency inverter.
(iii) One – 'Falk' gear type high speed coupling, to suit the input shaft of the gear reducer and electric motor.
(iv) One – Sumitomo quadruple reduction, single helical gear reducer with cooling coil, arranged for foot mounting and provided with parallel shaft extensions which would be keywayed for the mounting of the drive sprocket. Service factor 1.5 AGMA.
(v) Combination bedplate, fabricated from rolled steel sections, for mounting the gear reducer and electric motor.
(vi) Adjustable baseframe for mounting beneath the entire bedplate, fabricated from rolled steel sections, and provided with slotted pads and jackscrews for alignment of the sprocket, i.e. allowing adjustment of the drive as a complete unit.

The base flanges would be designed for mounting on concrete foundations.

All drive components would be pre-assembled onto the bedplate and adjustable baseframe prior to dispatch.

Note:The 20 HP drive provided would permit the restart of the drum in an upset condition.

e) Guards

Chain Guard

The guard would be fabricated in sections from mild steel of welded and bolted construction, and would be designed to fully enclose the chain drive.
The guard would be provided with rolled steel supports to trunnion wheel bases, clean-out door on the underside, inspection cover and attachment for oil drip feed lubrication.

Wheels

All wheels would be provided with steel guards, fully enclosing each rotating assembly (wheels and shafts only).

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f) Dryer Exhaust / Discharge Hood

The discharge hood would be fabricated from 304L stainless steel suitably stiffened to prevent vibration. The outlet hood design is complete with baffles to limit the material going to the cyclones. Flanged connections would be provided for the product and drying air outlet.

g) Drum Seals

The feed end of the dryer would be provided with a 304L stainless steel external stiffening flange and a labyrinth seal channel with woven fabric band. The discharge section would be fitted with a wear band and platelet-type seal.

h) Lubrication

Wheels

The support wheel guards would be fitted with automatic weighted graphite blocks for lubrication of the support rollers and tyres (or Rotary Dryer Specialties APGA system).

Superheater

4.1.2 Superheater (Flue Gas) - 8 MM BTU/hr

One – for elevating the steam pressure and temperature of the recirculated steam to what is required by the superheated dryer. The tubes would be constructed in 304L stainless steel. The frame is fabricated in 304 stainless steel and carbon steel.

Drying Loop

4.1.3 Drying Duct

One lot – to link the disc shredder to the cyclone to form the drying section. Fabricated of 304L stainless steel, the ductwork will be prepared and supplied for welding on site with manholes where necessary.

4.1.4 High Efficiency Cyclone

One – for separating the dried product from the superheated steam. Fabricated of 304L stainless steel and supplied complete with inlet, outlet, and product discharge connections and manholes.

4.1.5 Interconnecting Ducting

To connect cyclone, superheater and fan including bellows-type expansion joints where necessary. Fabricated in 304L stainless steel. Supplied in sections for welding on site and with manholes where necessary.

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4.1.6 Steam Recirculation Fan

One – for recirculating the process steam through the system. The heavy-duty mechanical seal fan would be a centrifugal type supplied complete with 304L stainless steel casing, impeller, OSHA approved shaft guard, direct drive including the 75 HP motor.

4.1.7 Two-Phase Quench Nozzles

Located in the hot air duct with grade 310 stainless nozzles and pipe, 316SS inlets and 304SS flange for connecting to the Client’s compressed air and water supply for effective control of dryer temperature and for use should an emergency situation arise.

4.1.8 Steam Snuffing Connections

Steam snuffing connections would be provided on the hot air box, heat exchanger inlet hood, cyclones and cyclone exhaust header.

Flue Gas Recirculation Loop

4.1.9 Propane Air Heating System – 10 MM BTU/hr

One - for elevating the temperature of the ambient air to that required by the SSD heat-exchanger. The air heater casing would be fabricated in 304L stainless steel. With Maxon (or equal) duct mounted burner, the unit would be supplied complete with pre-piped and pre-wired gas train to IRI/FM standards, burner management system and local panel giving fault annunciation. Nominal design heat rating shall be 8 MM Btu/hr.

4.1.10 Flue Gas Recirculation Fan

One – heavy duty centrifugal type, SWSI, Arrangement 1, 1800 RPM, V-belt drive, for recirculating the exhaust gases from the heat exchanger back to the combustion system. The fan would be supplied complete with carbon steel casing, impeller, OSHA approved guard, including 40 HP motor. A radial vane inlet damper complete with electric actuator would be supplied for start-up purposes and for adjustment of the airflow.

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4.1.11 Interconnecting Ductwork

One lot – to link all the above components. The ductwork would be supplied in flanged sections and stiffened where necessary. All ductwork would be of carbon steel construction, unless otherwise specified. The dryer duct is to be insulated (by others) with mineral wool for heat conservation.

- Hot Air Duct - approx. 15 ft long, connecting the outlet of the combustion system to the indirect heat exchanger (refractory lined).
- Exhaust Duct - approx. 30 ft long, connecting the outlet of the heat exchanger to the flue gas recirculation fan inlet.

- Recycle Air Duct - approx. 30 ft long, connecting the flue gas recirculation fan to the combustion system.

4.1.12 Heat Exchanger Bypass Damper

One – opposed blade type in 316L stainless steel construction, for bypassing of the heat exchanger as required. Complete with electric actuator, positioner, and limit switches.

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Materials Handling System

The rotary drying system would be equipped with the material handling system outlined below to feed and discharge the biomass product from the drying system.

4.2.1 Rotary Drum Feed Screw

One – cantilevered design, fabricated in 304L stainless steel, for transporting wet material from the Customer's upstream process and discharging it into the rotary drum. The screw would have a cylindrical casing with drop bottom section for easy cleaning access, inlet and outlet connections as required, continuous screw flight, bearings, gear reducer and 5 HP motor.

4.2.2 Hopper Outlet Rotary Valve

One – constructed with 304 stainless steel rotor and cast iron housing, discharging dried biomass from the hopper discharge screw conveyor into the Customer downstream process equipment while maintaining an air seal. Supplied completely with body, rotor, outboard bearings, and 3 HP motor.

4.2.3 Cyclone Rotary Valve

One – constructed with 304 stainless steel rotor and cast iron housing, each discharging dried biomass from cyclones while maintaining an air seal. Supplied completely with body, rotor, outboard bearings and 1 HP motor.

4.2.4 Discharge Belt Conveyor

One – 15 ft long, to convey dry particles from the cyclone rotary valve and hopper outlet rotary valve up to the customer's storage room. The belt conveyor would be complete with belt, idlers, pulleys, and 3 HP motor.

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5. SERVICES

5.1 Barr-Rosin Engineering Services

A typical plant start-up will require the following start-up services, consisting of a 4-week program with forty-two (42) shifts, each of 12-hour duration. The service program would be scheduled in three (3) periods as follows:

- Mechanical Check-out: one (1) engineer for 5-7 days, maximum 12-hour days, to review installation (supports, guides, expansion, insulation, alignment, drives etc.) and to prepare final punch-list;
- Mechanical Commissioning: one (1) engineer for 5-7 days, maximum 12-hour days, to assist in continuous operation of system with no solids and no load, to commission fans with technician, to commission air heater with technician, to check-out control systems;
- Process Commissioning:
  a) Part 1: two (2) engineers for 5-7 days, maximum 12-hour shifts, to monitor continuous operation of system with water only, then with wet feed from plant not necessarily at capacity, full functionality testing, final interlock testing, and control loops in AUTO;
  b) Part 2: two (2) engineers for 5-7 days, maximum 12-hour shifts, to monitor continuous operation on wet feed at design conditions with performance testing (72 to 120 hrs), to complete hands-on operator training, and to hand-over to end user.

Barr-Rosin's on-site presence is to advise and assist in the proper commissioning of the dryer. Any buyer related delays resulting in additional start-up time and travel would be invoiced according to the following service schedule, plus travel and lodging expenses.

Standard rate (USD):	$1,000.00 per eight (8) hour shift or portion thereof, and $125.00 per hour beyond 8 hours in given day.
Week-end rate (USD):	$1,500.00 per eight (8) hour shift or portion thereof, and $187.50 per hour beyond 8 hours in a given day.
Holidays (USD):	$2,000.00 per eight (8) hour shift or portion thereof, and $250.00 per hour beyond 8 hours in a given day.

Holidays include the following dates:

New Year:	January 1st to January 3rd
Easter:	To be advised (4 days including a weekend)
Quebec Provincial Day:	June 24th
Canada Day:	July 1st
Labour Day:	1st Monday of September
Thanksgiving:	To be advised (3 days including a weekend)
Christmas:	December 23rd to December 31st

The services of a fan technician would be required for start-up. This technician commissioning costs would be invoiced directly from the 3rd party to eliminate any additional charges.

Four (4) sets of Operating and Maintenance Manuals would be provided in electronic and hard copies.

5.2 Barr-Rosin Site Supervisor

The presence of a Barr-Rosin site supervisor onsite during the installation of the dryer is recommended. We estimate that our site supervisor would be required onsite for approximately 10-12 weeks. The services of a Barr-Rosin site supervisor could be available during installation of the dryer for a charge of $700 USD per day plus travel and lodging expenses.

5.3 Drum Site Assembly and Installation

The field portion of the drum assembly includes the verification of trunnion alignment and arrangement once they have been set in place by the millwrights. This step is essential to the longevity of the rotary drum system. The unit will be shipped in one piece with the tyres and sprocket removed. This is to limit the overall diameter and weight of the unit to make shipping in one piece attainable. Upon the arrival of the drum to site, the on-site crew will supervise the unloading (crane(s) supplied by others), and provide equipment onto which to place the unfinished drum. The tyres will be installed along with their retention blocks (crane(s) provided by others). The insulation angles that will have been left off in the shop, to allow installation of the tyres, will be welded in place. Our crew will supervise the lifting of the drum onto the trunnions, (cranes supplied by others). The sprocket will be installed in place to insure proper alignment. We reserve the right to do this on the ground, should all necessary dimensions for its locations be easily gathered and figured. Also included is a single return trip during system commissioning to train the dryers to run appropriately while at operating temperature.

5.4 Technical Service

GEA Barr-Rosin will include a Service Contract for the first year of dryer operation. The Service Contract would ensure optimal operation and continued performance of the Barr-Rosin Drying and Cooling Systems for DDGS and related co-products, and would entail the following scope:

- Telephone Support: Barr-Rosin would provide unlimited telephone support to the plant. Also provided would be an Emergency Service phone number to access the Barr-Rosin Inc. Emergency Service Line 24 hours per day, seven days a week.

- Site Visit: One (1) comprehensive performance audit per year. The site visit would include a review of the drying and cooling system, both on-line and off-line.

  a) The on-line evaluation of the drying and cooling system would include collection of the following data:

     - *System Airflow Measurement* for the Dryer and Fluid Bed Cooler, compensated for temperature, pressure, and humidity.
     - *Temperature and Pressure Profile* for overall drying and cooling system.
     - *Complete Sample Moisture Content Profile* including wet cake, syrup, conditioned feed material, intermediate product, and final product.
     - *Operating Data* for selected performance campaign.

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b) The off-line evaluation of the equipment would include detailed internal inspection of the following key components:
   - Combustion / Thermal Oxidizer System
   - Paddle Mixers
   - Screws Conveyors
   - Rotary Drum
   - Cyclones
   - System Fans
   - Cooler
   - Accessible Ductwork
   - Instrumentation
   - Heat exchanger

- Training: An on-site awareness training seminar would be given to the operators and maintenance personnel to review general operation, updated procedures, and discuss current issues during the site visit.

- Report: A detailed written report outlining the visit, process evaluation, and recommendations for improvement would be submitted within 14 days of the visit. The process evaluation would include a detail model of the energy and material balance and hence an interpretation of the plant's drying and cooling performance.

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6. PRICING AND DELIVERY

6.1 Budgetary Pricing

Our price for design, manufacture and supply of the following items are provided below:

ROTARY DRYING SYSTEM		
4.1. – One (1) Rotary SSD Drum	Included	CAD
4.2. – Material Handling System	Included	CAD
Budgetary Pricing for One (1) System	**$1,750,000 +/- 25%**	**CAD**

Ex-works
All applicable taxes are extra.

6.2 Payment Terms

The above prices are based upon the following payment terms:

- 30% with receipt of order
- 30% with 50% fabrication
- 30% upon delivery, pro-rata
- 10% upon process commissioning; not to exceed 6 months after delivery

6.3 Delivery Schedule

The anticipated time to supply the complete drying system is approximately 40 -44 weeks from issuance of purchase order. This delivery time is dependant on fabrication availability and will be confirmed at the time of order. The schedule is based on a two (2) week turnaround time for approval of general arrangement and P& ID drawings.
The anticipated time to supply two complete drying systems is 42 weeks from confirmation of purchase order. The schedule is based on a two (2) week turnaround time for approval of general arrangement and P&ID drawings. A breakdown of the schedule is presented below:

6.4 Project Schedule*

Engineering Documentation:

- Process & Instrumentation Diagram 8 weeks
- Preliminary General Arrangement 12 weeks
- Instrument and control datasheets 12 weeks
- Anchor Bolt Drawings 14 weeks
- Operation & Maintenance manuals 30 weeks

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Delivery:

- Air Heater	34 weeks
- Rotary Drum	42 weeks **
- Fans and Dampers	34 weeks
- Material Handling Equipment	34 weeks
- Heat Exchanger	42 weeks **

* Equipment delivery is based on a two (2) week turnaround on approval drawings (P&ID and General Arrangement).

** The delivery of the rotary drum and heat exchanger will be confirmed upon placement of order.

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7. EXCLUSIONS

Our supply is limited to design and supply of listed equipment items only. We specifically exclude the following goods and services:

- All applicable taxes. All taxes shall be assumed and paid by the Customer.
- Authorities' approval for construction and operation of the plant (GEA Barr-Rosin would co-operate and supply information as required).
- Offloading of equipment at site
- Civil engineering and design (GEA Barr-Rosin would supply loading and bolting plans).
- Civil works of any kind
- Foundations or modifications to existing structures or buildings
- Foundation bolts (GEA Barr-Rosin would supply specification of minimum requirements)
- Building/cladding, building modifications
- Plant lighting
- Craneage (unless installation provided by GEA Barr-Rosin).
- Thermal or acoustic insulation and installation thereof (specification would be supplied by GEA Barr-Rosin if insulation supplied by Buyer).
- Acoustic enclosures
- Supply of utilities including natural gas, compressed air, steam and electricity.
- Design and supply of fire suppression and steam snuffing systems
- Water and steam utilities for fire suppression and snuffing
- Utility supply pipework, control valves and manual valves other than those clearly shown within our scope on the flow diagram (up to battery limits).
- Instrument panel & controls (except for burner management system sited local to burner).
  NB: Schedules, specifications and required data would be provided by Barr-Rosin if Buyer supplies MCC and control system.
- Electrical cabling and instrument wiring
- Wet feed supply
- Product conveying system, pellet mill, silos and packing facilities
- Extended runs of inlet or exhaust ductwork
- All utilities, raw materials and labour for testing, commissioning and operating the plant, which are to be provided by the Customer.
- Analysis and laboratory equipment
- Cost of witnessed equipment testing
- Energy integration added runs of ducting.
- Any and all environmental tests required, including measurement of noise and dust levels by outside bodies.
- Running spares and wear parts
- Instrumentation
- Frequency inverters and motor starters
- Commissioning and third party commissioning
- Site supervision
- Packing & shipping

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8. APPENDIX A

8.1 Motor List

Superheated Steam Dryer	Installed Power	Anticipated Absorbed Power
Rotary Drum	20	-
Feed Metering Screw	5	-
Steam Recirculation Fan	75	-
Flue Gas Recirculation Fan	40	-
Discharge Airlock Rotary Valve Hopper	3	-
Discharge Airlock Rotary Valve	1	-
Discharge Belt Conveyor	3	-
Combustion Air Fan	5	-
Total Superheated Steam Dryer Power	**152 HP**	**110 BHP**

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MicroWhirl™

NEW! FLOW RATES NOW TO 1.413 l/min!

Fine Atomization

Metal

DESIGN FEATURES

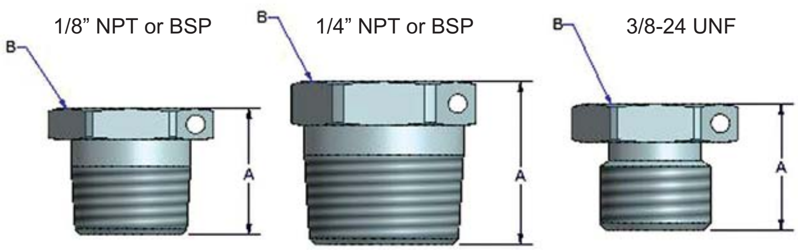
- Outstanding atomization
- Rugged pinless design
- Drip-free performance
- 70 micron polypropylene filter
- Safety wire hole available
- U.S. Patent #7198201
- Minimum operating pressure 7 bar

SPRAY CHARACTERISTICS

- Mist at low pressure; fog at high pressure

Spray pattern: Cone-shaped Fog
Flow rates: 0.032 to 1.413 l/min

Fog



Shown with optional 1.59mm (1/16") diameter safety wire hole

Dimensions (mm)

Pipe Size	A	B
1/8"	12.3	11.1
1/4"	17.5	14.3
3/8-24UNF	10.8	12.7

Dimensions are approximate. Check with BETE for critical dimension applications.

MicroWhirl Flow Rates and Dimensions

Fogging, 70° Spray Angle, 1/8", 1/4" BSP or NPT or 3/8" - 24 UNF Pipe Sizes

Male Pipe Size	Nozzle Number	K Factor	LITERS PER MINUTE @ BAR								Wt (g)
			7 bar	20 bar	40 bar	70 bar	100 bar	140 bar	170 bar	200 bar	
1/8" or 1/4" or 3/8"-24UNF	MW085	0.0122	0.032	0.055	0.077	0.102	0.122	0.145	0.160	0.173	7.09
	MW105	0.0151	0.040	0.068	0.096	0.127	0.151	0.179	0.197	0.214	
	MW125	0.0180	0.048	0.081	0.114	0.151	0.180	0.213	0.235	0.255	
	MW145	0.0209	0.055	0.093	0.132	0.175	0.209	0.247	0.272	0.296	
	MW195	0.0281	0.074	0.126	0.178	0.235	0.281	0.332	0.366	0.397	
	MW275	0.0396	0.105	0.177	0.251	0.332	0.396	0.469	0.517	0.560	
	MW695	0.09988	0.316	0.447	0.632	0.836	0.999	1.182	1.302	1.413	

Nominal Angle 20° 70°

Atomization Level mist light fog fine, heavy fog

increasing pressure

Flow Rate (l/min) = K $\sqrt{bar}$

Standard Materials: 303 and 316 Stainless Steel, Polypropylene filter (Viton O-ring seal supplied for 3/8"-24 UNF connection)

Spray angle performance varies with pressure. Contact BETE for specific data on critical applications.

MISTING

***TO ORDER:** specify pipe size, connection type, nozzle number, spray angle, and material.*