Project Title:
**Research to Apply Kinetic Disintegration System to Process Various Biomass Feedstocks for Pelletization**

Contract Number: RD3-69

**Milestone Report Number 8**

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# (Public)
# MILESTONE REPORT


**EXECUTIVE SUMMARY**: Minnesota Valley Alfalfa Producers (MNVAP) researched the application of a Kinetic Disintegration System ("KDS") to process biomass for pellet production. As compared to raw biomass, biomass pellets are more efficiently transported, stored and utilized for the generation of power in electric power facilities that cannot accommodate raw biomass as a feedstock. Characteristics of KDS technology make it capable of handling a wide variety of feedstocks that have varying levels of moisture. During the project MNVAP compared and analyzed biomass pellets manufactured from biomass processed from the KDS to biomass pellets manufactured from MNVAP's conventional method for processing biomass. The resulting biomass pellet products could be used for energy production by cofiring with coal and in combined heat and power applications.


MNVAP is a Minnesota farmer-owned cooperative founded in 1994 to process and market alfalfa products and identified the biomass pellet market as a value-added opportunity. The processing of biomass pellets offers economic and environmental benefits to agricultural-based municipalities and regions in Minnesota. KDS technology was invented for use in pulverizing ores and minerals. Research from this project applied the technology to processing biomass, gathering information on performance and a demonstration to determine if the KDS process is a more energy efficient option for processing biomass when compared to the current biomass processing methods. The KDS process dries and grinds the biomass feedstock in one process, eliminating the need for energy-intensive drying process prior to grinding. Engineers designed, fabricated, and integrated new instrumentation for feedstock analysis and other equipment to

support the KDS processing line with the goal to achieve through-put capabilities comparable to MNVAP's current processing method.

Testing was done on a various biomass feedstocks to identify KDS processing performance and analyze pellet characteristics. The Agricultural Utilization Research Institute (AURI) conducted laboratory tests of final product pellets manufactured with biomass processed from the KDS and conducted performance assessment of the remodeled KDS equipment. AURI assisted MNVAP collecting data to determine the baseline KDS performance and conduct preliminary pelleting trials to analyze material processed from the existing biomass processing method and the KDS method.

It was discovered that the KDS could not support the through-put capacity required for MNVAP's biomass processing of 5-7 ton biomass per hour. To optimize the KDS performance for an increased through-put rate of biomass that has an acceptable particle size for pelleting would require a specific moisture and fiber length. These optimization processes would increase production costs from the current processing system.

The MNVAP biomass pelletization processing project had a number of goals:

- Undertake a value-added project to strengthen the MNVAP organization and increase revenue flows for farmer-owners,
- Improve rural economies economically and environmentally,
- Further the biomass industry by utilizing Kinetic Disintegration technology to process numerous and various feedstocks, with varying moisture content levels, into biomass pellets
- Further the biomass industry by exploring economic benefits of KDS use in processing biomass for pelletization (increased through-put potential, lower energy use, improved transportability resulting in cost reductions or increased market reach, etc.)
- Gain knowledge regarding operating specifics of the KDS

MNVAP was uniquely positioned to undertake this project. As an established, successful cooperative organization already involved in the processing of light density fibrous materials, a characteristic of most of the biomass feedstock materials to be studied. MNVAP was set-up and operating the equipment necessary to process the fibrous material. Equipment needed to handle fibrous materials is different than equipment needed to handle grain processing. Fixed costs of a pelleting manufacturing operation are already well-understood and the existing alfalfa processing business helps carry those costs. Additionally, MNVAP had already purchased the new equipment to be utilized in this project and had roughly a year's worth of experience with this equipment before the biomass research project began.

The project also included a biomass assessment of the Midwest to determine the quantity and location of biomass availability. (See 2012 Midwest Biomass Inventory in the appendix for detailed breakdown). According to AURI's Midwest Biomass Inventory Assessment, 2012; Billion-Ton Study Update 2011. Corn stover is the largest source of biomass among crop residues making up nearly 7 million of the 13.6 million tons of material available in 2012. No perennial grasses or woody energy crops are expected to be produced in the seven-state region in

2012. Forest biomass and mill residue make up less than 25% of the total biomass available and about 10% of non-grain and oilseed biomass.

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

**Project Benefits**: MNVAP uses natural gas for drying. The KDS doesn't use any other natural fuel besides electricity. The KDS would be beneficial if natural gas wasn't available for drying. Project research found that the current MNVAP process for preparing biomass to be pelletized is more efficient than using the KDS. Drying large quantities of biomass through a rotary drum dryer was more efficient than using the KDS. Energy efficiency for the KDS process was 3,198 Btu per pound of moisture removed compared to the current system at 2,937 Btu per pound of moisture removed. Secondly, the KDS operated at 1.6 tons per hour with 15.4% moisture shredded alfalfa compared to MNVAP's current process at 7.2 tons per hour of pre-pellet material. Information obtained from the research resulted in MNVAP's decision to save time, labor and capital by not moving forward with full installation and incorporation of the KDS into their current processing system.

**Project Lessons Learned:** The primary question for this project was "Does the KDS operate with less total horsepower (energy efficiency)?" Project research provided answers for several of the original objectives.

- Can an increase in through-put from 3-4 tons/hour to 5-7 tons/hour be achieved?
  No. Maximum through-put observed with the KDS process was 1.6 tons per hour at 37% working load. Adjusted through-put assuming a linear increase would equal a 2.2 ton per hour through-put at 80% load compared to the current MNVAP system at 7.2 ton per hour at 80% working load.
- Can the KDS accept a wider selection of input feed stocks?
  Yes. Alfalfa hay and grass hay blends were successfully processed through the KDS for testing purposes.
- Can higher moisture biomass be dried efficiently?
  Yes but with a reduction in the rate of processing. KDS moisture removal performance was tested with three different moisture levels in alfalfa hay. The KDS was capable of producing a dryer material at 11.2% moisture compared to the rotary drum dried and hammer mill product from their current process, producing moisture levels at 12.7%; both processes started with alfalfa moisture of 15.4%. However there was a significant reduction in product through-put due to the limited capacity of the KDS process as compared to the current process. The KDS operated at 1.6 tons per hour with 15.4% moisture alfalfa compared to MNVAP's current process at 7.2 tons per hour of pre-pellet material. Energy efficiency for the KDS process was 3,198 Btu per pound of moisture removed compared to the current system at 2,937 Btu per pound of moisture removed.

- Can high and low moisture materials be blended and dried efficiently?

Yes. Blended grass hay and alfalfa hay were utilized during the 'high' moisture KDS test. Blended material appeared to improve KDS drying performance efficiency. Blended high moisture material required 2,674 Btu per pound of moisture removed compared to 4,103 Btu per pound of moisture removed in the non-blended hays. However through-put was very limited compared to their current process that operates on an average of 3,414 Btu per pound of moisture removed.

- Can the energy use (fossil fuels) required in (the former) drying process be eliminated completely, due to KDS single dry/grind operation?

Not observed during initial testing. Data obtained indicates the KDS process cannot maintain adequate through-put required (base on tons per hour) to efficiently dry alfalfa hay. This can be observed in Table E. Retention time required of the material within the KDS process to meet moisture requirements for pelleting reduced through-put to one ton per hour.

- Does KDS single dry/grind process use less energy than previous grinding process?

No. Total energy cost during the control trial was $1.86 per ton for the KDS process compared to $5.10 per ton on MNVAP's current process. However to compare equivalent through-put values the comparison would be $8.37 per ton for the KDS compared to the $5.10 per ton with the current process.

- How does addition of additional equipment effect the net-energy-required equation?

Research conducted indicates additional milling of the hay fiber prior to entering the kinetic disintegration equipment significantly improves through-put; however it did not improve drying efficiency (Table E-KDS Processing out of Roskamp 500 Hammer Mill). The additional milling would increase the energy consumed in the process and therefore reduce the net-energy in the final product.

- Can blending occur within the KDS?

Yes. Alfalfa hay and grass hay were successful processed through the KDS for testing purposes. The level of blending was not fully evaluated but the it would appear that blending at some level is possible.

- Does the KDS operation remain well-within MPCA limits?

Not evaluated. Although the project was delayed due to MPCA air emission concerns so that the system would operate within MNVAP's air quality permit. Temporary permits were obtained to test the KDS. An additional baghouse was needed to permanently operate the KDS.

- Can the heat produced in the KDS be recycled?

Doubtful due to the high moisture content contained within the flashed moisture.
Flash moisture is moisture lost due to rapid evaporation. Its wet air saturated in water with no presents of heat.

**Usefulness of Project Findings:** The KDS is not currently being used by MNVAP. The KDS has been dismantled for proof that the KDS is not operational with the MPCA temporary permit and temporary electrical hook up from the electrician. In order to evaluate the KDS to MNVAP's current biomass pelletization process, data was collected during the processing and drying of alfalfa prior to pelleting. Energy data was collected along with product through-put. During AURI's evaluation, data collected indicated a total processing cost of $6.26 per ton for the current system; this included only the processing segment along with natural gas utilization for the drying process. The KDS would only have the potential to replace a segment of the current process which would occur after alfalfa is ground through the shredder and Williams hammer mill. Energy utilization post Williams hammer mill is $5.10 per ton prior to pelleting. AURI used the data collected to determine an energy value per moisture removed from the process following the Williams hammer mill, electrical energy was converted to British Thermal Unit energy, this value was 2,937 Btu per pound of moisture removed using the current process.

The KDS was first evaluated utilizing pre-ground product from the shredder and Williams Hammer Mill: this would be the logical processing flow. During the KDS testing, the classifier within the KDS unit remained stationary to eliminate variability between tests. The classifier has a direct effect on particle size; although the classifier remained stationary, the motor capacity of the classifier was at peak operating load indicating it was producing a 'fine' ground material at the levels tested.

KDS moisture removal performance was tested with three different moisture levels in alfalfa hay. The KDS was capable of producing a dryer material at 11.2% moisture compared to the rotary drum dried and hammer milled produced from MNVAP's current process, producing moisture levels at 12.7%. Both processes started with alfalfa moisture of 15.4%. However there was a significant reduction in product through-put due to the limited capacity of the KDS as compared to the current processing method. The KDS operated at 1.6 tons per hour compared to MNVAP's current processing rate of 7.2 tons per hour of pre-pellet material, both tested with 15.4% moisture alfalfa. Total energy cost during the control trial was $1.86 per ton for the KDS process compared to $5.10 per ton on MNVAP's current process. However to compare equivalent through-put values the comparison would be $8.37 per ton for the KDS compared to the $5.10 per ton with MNVAP's current process. Energy efficiency for the KDS process was 3,198 Btu per pound of moisture removed compared to the current process at 2,937 Btu per pound of moisture removed. A wide range in moisture removal was seen with the mid-moisture alfalfa and the high-moisture alfalfa that can be observed in Table B. The KDS performed very well on moisture removal; a discrepancy in data was observed with the high-moisture alfalfa having a greater moisture removal along with improved through-put over the mid-moisture alfalfa; this could be due to a blend of grass hay with the high-moisture alfalfa and variation in drying characteristics between the plant materials.

Test results can be viewed in Table A and B below.

**TECHNICAL PROGRESS**: Initial research focused on preparation of a preliminary flow diagram for the modified KDS process and the establishment of testing parameters for processed biomass and pellets manufactured from the processed biomass. Testing protocols were formed to establish a baseline performance of the KDS that was used to compare the performance of the KDS after modifications were made to the KDS. Equipment to process raw biomass fibers in the KDS was designed, fabricated and installed. A hoop style shed was constructed to house the KDS machine and auxiliary conveyors required to transfer test biomass material to the KDS for evaluation.

MNVAP's current biomass processing system requires biomass fibers to through a shredder process and two hammer mills. A hammer mill first reduces the length of the long stem alfalfa fibers before the biomass goes onto a rotary drum after which it goes through a second hammer mill for the final milling process. The KDS process uses the initial hammer mill but then performs both a drying and milling process. Two process lines were put in place for product and efficiency evaluation. One process line used MNVAP's existing biomass material processing method and the second process line incorporated the KDS for processing material. Conveying, drying and dryer equipment was designed, fabricated and integrated to test and identify functionality and feasibility for the KDS to replace a portion of the rotary drum dryer and final hammer milling process.

Test runs of the KDS process allowed for performance optimization and the collection of data to gain knowledge regarding operating amperages, classifier space requirement that affects fiber length, drying efficiency, and through-put. Tests findings resulted in the re-design of the product flow through the KDS fiber milling process and into the pelleting operation. Modifications to the KDS were designed, fabricated and installed. The redesigned KDS was operated and compared to MNVAP's current processing method. The KDS process could not support the through-put capacity required for MNVAP's biomass processing of 5-7 tons biomass per hour. Optimization processes that many improve the through-put rate would also increase production costs from the current processing system. Findings from the research resulted in MNVAP's decision to not install and incorporate the KDS into their current biomass processing system.

Pelleting trials were also conducted on ground alfalfa from MNVAP's current biomass processing stream and biomass from the KDS processing. Pellets were produced and evaluated for through-put and energy utilization. During the pelleting trials with material produced on the KDS, the process had to be stopped several times due to plugging of ground material in the pellet mill conditioner outlet and the chute to the feeder cone. Although the pre-pellet bulk densities were similar between the two processes, with their current processing having a 13.5 pound per cubic foot bulk density compared to the 13.0 pound per cubic foot bulk density of the KDS produced material, the material from the KDS has a small percentage of stringy texture which causes plugging and difficulty in handling. Pellet durability and densification testing was also conducted. Densities between the two processes were very comparable with KDS pellets having a 41.5 lb. per cubic foot density and pellets from MNVAP's current biomass processing having a 41.0 lb. per cubic foot density. Pellet production from KDS processed biomass operated at 1.6 tons per hour with 15.4% moisture alfalfa compared to MNVAP's current process of 7.2 tons per

hour. Total energy cost during the control trial was $6.58 per ton for the KDS process was 3,526 Btu per pound of moisture removed.

The Agricultural Utilization Research Institute (AURI) assisted MNVAP with the initial collection of data to determine baseline KDS performance parameters and conducted preliminary pelleting trials to analyze material processed through MNVAP's existing biomass processing procedure. (AURI) then performed laboratory tests of final product pellets and conducted a performance assessment of the remodeled KDS equipment.

In order to evaluate the KDS system to MnVAP's current system, data was collected during the processing and drying of alfalfa prior to pelleting. Energy data was collected along with product through-put. During AURI's evaluation, data collected indicated a total processing cost of $6.26 per to for their current system; this included only the processing segment along with natural gas utilization for the drying process. The KDS system would only have the potential to replace a segment of their current process which would occur after alfalfa is ground through the shredder and Williams hammer mill. Energy utilization post Williams hammer mill is $5.10 per ton prior to pelleting. AURI used the data collected to also determine an energy value per moisture removed from their process following the Williams hammer mill, electrical energy was converted to British Thermal Unit energy, this value was 2,937 Btu per pound of moisture removed using their current process.

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A wide range in moisture removal was seen with the mid-moisture alfalfa and the high-moisture alfalfa that can be observed in Table B. The KDS performed very well on moisture removal; a

discrepancy in data was observed with the high-moisture alfalfa having a greater moisture removal along with improved through-put over the mid-moisture alfalfa; this could be due to a blend of grass hay with the high-moisture alfalfa and variation in drying characteristics between the plant materials.

Test results can be viewed in Tables A and B below.

AURI also conducted a biomass assessment of the Midwest to determine the quantity and location of biomass availability.

Results obtained from Milestone 8 indicate the current MNVAP process for preparing biomass for pelletization is more efficient drying large quantities of biomass through a rotary drum dryer. Energy efficiency for the KDS process was 3,198 Btu per pound of moisture removed compared to the current process at 2,937 Btu per pound of moisture removed. Secondly, the KDS process operated at 1.6 tons per hour with 15.4% moisture shredded alfalfa compared to MnVAP's current process at 7.2 tons per hour of pre-pellet material. Information obtained from this research resulted in MNVAP's decision to save time, labor and capital by not moving forward with full installation into their current processing system.

The KDS project created a platform to focus on the efficiency of MNVAP'S current operation of processing. It gives MNVAP a better knowledge of current technology that could be incorporated into current operations. It was discovered that the KDS technology could not support the current through-put capacity required for current biomass processing operations. It was also discovered that to improve through-put and performance, optimization of the KDS technology produced a moisture and material fiber length which deviated from MNVAP's current system. Biomass particles from the KDS were not the optimal size acceptable for pelleting which required more visual and hands on to monitor for best efficiency so automation would seem to be non-negotiable.

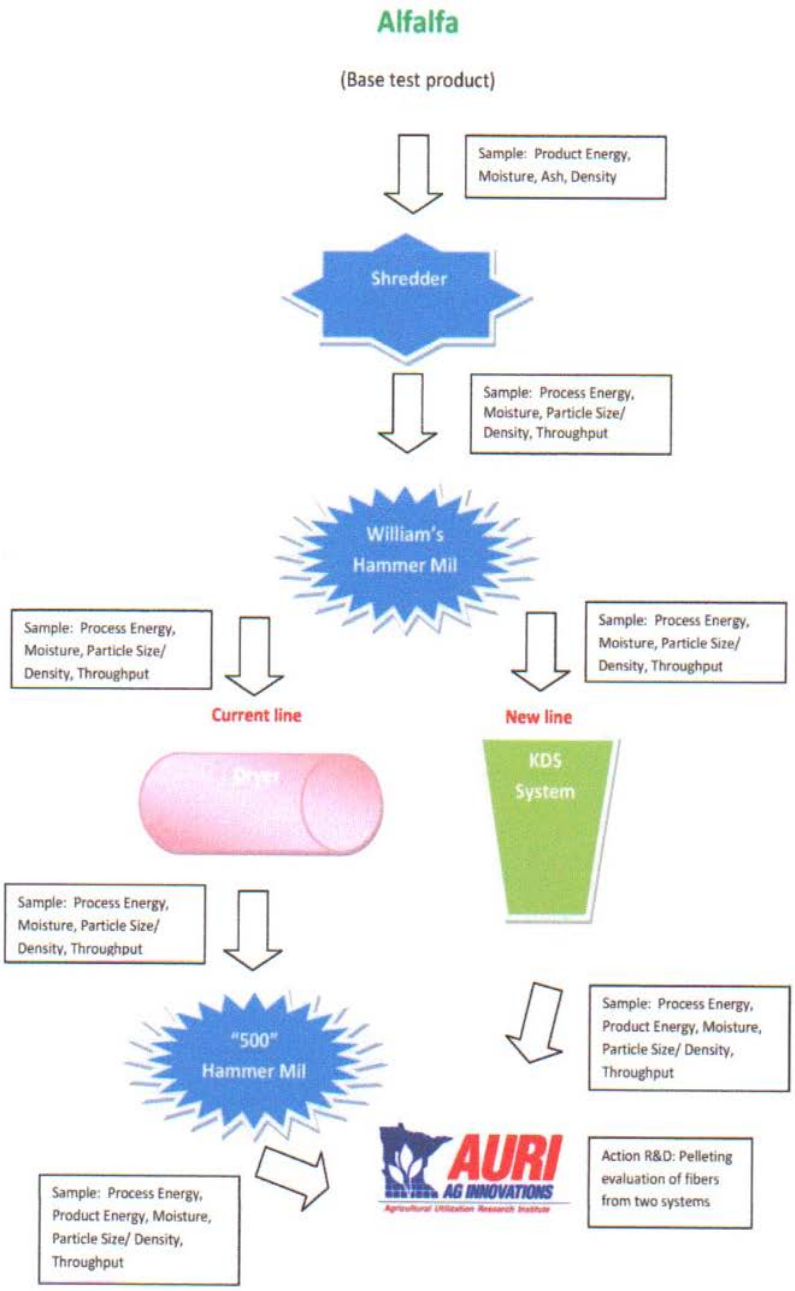
MNVAP realized the KDS technology wouldn't work as efficiently as their current operation. Research funding provided from this grant prevented MNVAP from making a poor decision installing the KDS technology at this time. The KDS technology would not have improved the efficiency of MNVAP'S current method for processing raw biomass that can be pelletized and used as a renewable fuel product.

APPENDIX:

Data Collection Flowchart
2012 Midwest Biomass Inventory
Table A----Current process results
Table B----KDS process results

**LEGAL NOTICE**

***Data collection flowchart***



## 2012 Midwest Biomass Inventory

The table below shows the biomass available in Minnesota by feedstock for 2012. Corn stover is the largest source of biomass among crop residues making up nearly 7 million of the 13.6 million tons of material available in 2012. No perennial grasses or woody energy crops are expected to be produced in the seven-state region in 2012. Forest biomass and mill residue make up less than 25% of the total biomass available and about 10% of non-grain and oilseed biomass. Sources: AURI Midwest Biomass Inventory Assessment, 2012; Billion-Ton Study Update 2011.

| **Minnesota Biomass Inventory (1,000 tons)** | |
|---|---|
| Agricultural Biomass | |
| Crop Residue | |
| Barley Straw…… | 43 |
| Corn Stover…….. | 6,998 |
| Oat Straw…….. | 0 |
| Wheat Straw…… | 420 |
| Total | 7,460 |
| Hay | 4,602 |
| Total | 12,062 |
| Dedicated Energy Crops | |
| Perennial grass…… | 0 |
| Woody Energy Crops……. | 0 |
| Forest Biomass | |
| Logging Residue & Thinning.. | 873 |
| Other Removal Residue……. | 656 |
| Total | 1,528 |
| Secondary Biomass | |
| Mill Residue…… | 12 |
| **Total** | **13,602** |

**Table A –Current process results** Process Flow Schematic

***Current Process*** ***14,400*** *pounds per hours (7.2 ton/hr.) @ estimated 80% of working load*

Energy Consumption

| Equipment | Hp | Voltage | Amperage | P.F. | Energy Use (Kw) | Btu equivalent | Elec. Cost ($0.065/K wh) | Through-put (ton/hr) | Total process cost per ton | Post Wm's hammer mill cost per ton | Moisture removed (%) post Wm's hammer mill | Post Wm's hammer mill energy cost (Btu) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bale buster/shredder | 2 X 50 | 470 | 62 | 0.82 | 41.39 | 141,228.5 | $2.69 | 7.2 | $0.374 | | | |
| Short drag | 10 | 470 | 5.9 | 0.82 | 3.94 | 13,443.8 | $0.26 | 7.2 | $0.036 | | | |
| Long drag | 10 | 470 | 5.9 | 0.82 | 3.94 | 13,443.8 | $0.26 | 7.2 | $0.036 | | | |
| Leveling drum | 10 | 470 | 7.5 | 0.82 | 5.01 | 17,094.8 | $0.33 | 7.2 | $0.045 | | | |
| Williams Hammer mill | 250 | 470 | 111 | 0.82 | 74.10 | 252,839.7 | $4.82 | 7.2 | $0.669 | | | |
| Pit fan | 150 | 470 | 102 | 0.82 | 68.09 | 232,332.7 | $4.43 | 7.2 | $0.615 | $0.615 | | 232,332.7 |
| Dryer drum | 10 | 470 | 7.9 | 0.82 | 5.27 | 17,982.0 | $0.34 | 7.2 | $0.048 | $0.048 | 2.73% | 17,982.0 |
| Dryer fan | 150 | 470 | 151 | 0.82 | 100.80 | 343,943.9 | $6.55 | 7.2 | $0.910 | $0.910 | | 343,943.9 |
| Screener | 20 | 470 | 4.7 | 0.82 | 3.14 | 10,714.1 | $0.20 | 7.2 | $0.028 | $0.028 | | 10,714.1 |
| Screener auger | 10 | 470 | 1.9 | 0.82 | 1.27 | 4,333.4 | $0.08 | 7.2 | $0.011 | $0.011 | | 4,333.4 |
| Roskamp "500" mill | 2 X 250 | 470 | 332 | 0.82 | 221.62 | 756,198.8 | $14.41 | 7.2 | $2.001 | $2.001 | | 756,198.8 |
| | | | | **Totals:** | 528.55 | 1,803,555.5 | $34.36 | | $4.77 | $3.61 | 2.73% | 1,365,504.9 |
| Gas consumption | 1.6 therm per hour (or 1.6 Mbtu/hr) X $3.8/therm= $6.08/hr or **$0.84/ton** | | | | | | | | $1.49 | $1.49 | | |
| | | | | | | | | **Process Cost Totals:** | **$6.26** | **$5.10** | | |

**Btu energy consumption per ton:** **1,587,727** **Energy required per pound moisture removed (Btu/lb):** **3,414.00**

*14,865 lbs in - 14,400 lbs out= 465 lbs moisture removed / 1,587,727 total Btu =* ***3,414*** **Btu/lb moisture removed**

**Table B – KDS process results**

***KDS Process*** ***3,204*** *pounds per hours (1.60 ton/hr.) @ 37% of working load*

Energy Consumption - amperage constant for test comparison

| Equipment | KDS - 470 V X 220 Amp | Classifier - 180 V X 5.1 A Blower - 312 V X 31 A | P.F. | Energy Use (Kw) | Btu equivalent | Elec. Cost ($0.065/ Kwh | Through-put (ton/hr) | Cost per ton | Beginning moisture | Post KDS processing moisture | Moisture removed (%) | Energy required per pound moisture removed (converted to Btu/lb moisture) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KDS-Processing out of Williams hammer mill (*37% of working load* ) | 103,400 | 10,590 | 0.82 | 161.90 | 552,426 | $10.52 | 1.60 | **$6.58** | 15.38 | 11.24 | 4.14% | 3,526 |
| KDS-Processing out of Roskamp "500" hammer mill | 103,400 | 10,590 | 0.82 | 161.90 | 552,426 | $10.52 | 2.34 | **$4.50** | 12.65 | 10.19 | 2.46% | 4,064 |
| KDS-Processing out of Buster/Shredder mill | 103,400 | 10,590 | 0.82 | 161.90 | 552,426 | $10.52 | 1.08 | **$9.74** | 18.90 | 17.84 | 1.06% | 14,607 |
| KDS-Processing out of Williams "mid' moisture alfalfa | 103,400 | 10,590 | 0.82 | 161.90 | 552,426 | $10.52 | 1.08 | **$9.74** | 15.62 | 10.36 | 5.26% | 4,103 |
| KDS-Processing out of Williams "high" moisture alfalfa | 103,400 | 10,590 | 0.82 | 161.90 | 552,426 | $10.52 | 1.15 | **$9.15** | 16.29 | 8.74 | 7.55% | 2,674 |