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Value proposition of coatings or new alloys on hammer wear

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Changing the World's Energy Future

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Value proposition of coatings or new alloys on hammer wear

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Disclaimer

About the Feedstock-Conversion Interface Consortium

The Feedstock-Conversion Interface Consortium (FCIC) develops first-principles-based knowledge and tools to understand, quantify, and mitigate the effects of feedstock and process variability across the bioenergy value chain, from the field and forest through downstream conversion. The FCIC is a collaborative and coordinated effort involving researchers in many different disciplines. It is led by the U.S. Department of Energy's Bioenergy Technologies Office (BETO) and includes researchers from nine national laboratories: Argonne National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, National Energy Technology Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories.

Research within the FCIC focuses on two complementary conversion pathways: (1) the low-temperature conversion of corn stover to fuels and chemicals using deacetylation and mechanical refining, enzymatic hydrolysis, and biological upgrading of the sugar- and lignin-rich streams; and (2) the high-temperature conversion of pine residues to fuels using catalytic fast pyrolysis and hydrotreating. Each pathway covers three sequential process areas—biomass harvest and storage, preprocessing, and conversion.

The FCIC is organized into eight collaborative tasks working in each of these process areas. The Feedstock Variability task investigates biomass attribute variations that originate in the harvest and storage process area; the Preprocessing, Materials Handling, and Materials of Construction tasks investigate the effects of biomass variability in the preprocessing area; and the High-Temperature Conversion and Low-Temperature Conversion tasks investigate the effects of biomass variability in the conversion process area. Two supporting tasks (Crosscutting Analyses and Scientific Data Management) support all FCIC research.

The Feedstock-Conversion Interface Consortium uses first-principles-based science to de-risk biorefinery scale-up and deployment by understanding and mitigating the impacts of feedstock variability on bioenergy conversion processes

energy.gov/fcic

Availability

This report is available electronically at no cost from http://www.osti.gov.

Report Authors

Damon S. Hartley, Idaho National Laboratory

David N. Thompson, Idaho National Laboratory

L. Michael Griffel, Idaho National Laboratory

List of Acronyms

BETO	Bioenergy Technologies Office
DOE	U.S. Department of Energy
FCIC	Feedstock-Conversion Interface Consortium

Executive Summary

The goal of this Case Study was to compare the cost savings from improving the life span of parts that wear within a system to the additional material cost required to reach varying levels of improved life span. We recognize that the failure limits and system performance are representative of a single system that may or may not exist in the real world, however, our goal for this analysis was not to provide an answer for a specific system or to provide a full understanding the economics of all potential systems. The analysis was performed using relative changes from the base alloy cost and considered relative improvements in part life in order to generalize the comparison without referencing specific alloys or coatings that might be employed. Ultimately, this work provides a first check of the potential for improving wear characteristics of grinder hammers to provide a meaningful and impactful benefit to biomass preprocessing and conversion systems.

Based on this work, increasing the life of the hammers by 3× in a corn stover processing system will yield a benefit of reducing the delivered feedstock cost by approximately $2.25/dry ton, assuming no increase in hammer cost. However, it is unlikely that it would be possible to maintain the hammer cost (ca. $3,000 per set or around 2% of the capital cost of the grinder) while also increasing the life of the hammers. In the case that the hammer cost is increased, the amount of the that cost increase will be limited by the benefit that is provided. From this work we found that the relative hammer cost increase could outpace the relative hammer life improvement and still be economic, with the ratio of relative hammer cost increase to relative wear performance increase being proportional to the relative wear performance increase. From the data, the relative premium that can be paid for an improved hammer across all the price points ranged from 1.1-1.22× the expected life increase.

Including moisture variability in the simulation raised the delivered feedstock cost and there were substantial changes in both down events and down times. When moisture variability was added there were nearly 43× the failures and more than 10× the amount of down time caused by moisture than resulted from the wear alone. In addition, as the life of the hammers was increased, there was a corresponding increase in the number of failures due to moisture. When the number of failures due to wear decrease, more material can be put through the system. With more units of biomass material, more units that are outside the operational limits of the system are introduced resulting in failures. However, even with the increase in failures due to moisture, the impact to the system that is realized by increasing the life of the hammers was roughly the same as was seen in the wear only scenario.

Examination of the system under the full variability that would be experienced by a biorefinery allowed for quantification of uncertainty associated with the proposed changes. Using Monte Carlo analysis it was determined that there was a delivered feedstock cost range of approximately $2.20/dry ton that could be experienced based on the distributions values of ash and moisture modeled. However, the relative cost reductions that were found in the wear only scenario hold across all the scenarios.

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Introduction

The conventional methods of delivery of biomass feedstocks for conversion utilize systems that were originally developed for traditional agriculture and forestry applications for the handling and processing of biomass. A characteristic of these systems is passive management of material properties and quality, contributing to wide variability in delivered biomass properties including moisture, ash and convertible organic content. When the cellulosic materials arrive at the biorefinery, there are still preprocessing steps that are required to prepare them for the conversion process, with the most common operation being size reduction. Size reduction is often necessary to produce a material that can be moved through the system and converted efficiently. During size reduction, the comminution equipment experiences wear, especially on the knives or hammers (Oyedeji et al. 2020). Worn hammers and cutting edges lead to reduced throughput and higher energy consumption in the comminution operations, resulting in higher cost and a lower efficiency in producing materials meeting desired specifications of both particle size and shape.

Biomass is prone to becoming contaminated with inorganic material during harvest and collection. High levels of inorganic contamination result in high rates of erosive wear of equipment, requiring increased maintenance on the equipment and additional unplanned downtime. In these types of situations, being able to extend the life of wear parts would reduce the costs associated with repair and replacement, as well as increasing the overall uptime of the system. While extending the life of critical equipment parts has potentially important ramifications for the economics of an operation depending on the cost/part life relationship; it is important to examine the trade-offs of incorporating these new technologies into a system to identify the required benefits necessary to justify the additional expenditure. Often this is not straightforward. For example, while if the cost of an upgraded part was double the standard, then to a first approximation the life expectancy of that part must also be doubled to break even. However, there are confounding factors, such as how much the throughput changes as result of the change to the equipment.

Methods

The preprocessing system that was modeled is shown in Figure 1. The trade-offs associated with increasing the life of hammers in a biomass preprocessing system by changing the materials of construction and the associated cost were evaluated using a discrete event simulation model of this system, which is described in Hartley et al. (2020). The model developed for the published study utilized numerical models generated from data collected in the DOE Biomass Feedstock National User Facility at Idaho National Laboratory to predict the throughput and energy consumption impacts to equipment based on the dynamically changing properties of the corn stover moving though the system. Included in the simulation were equipment failures and associated process downtime that were informed by the operational experience of the pioneer biorefineries.

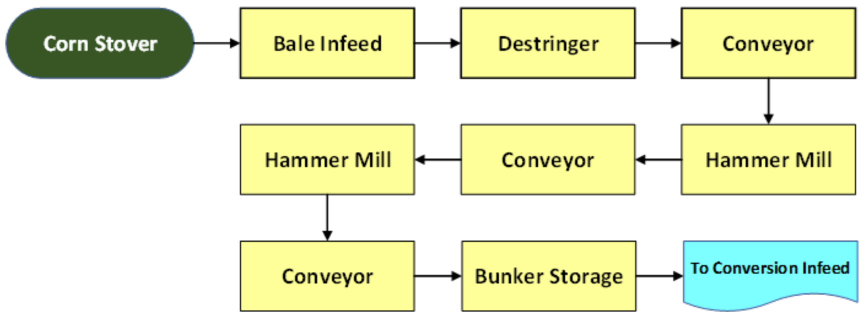

Figure 1. Flowsheet of the preprocessing system operations

To examine the economic impact of using reduced wear alloys in place of the standard construction materials for hammers in a hammermill processing corn stover, we used the model to perform a sensitivity analysis on the system performance and cost at different levels of hammer cost and increased hammer life. The replacement cost associated with the wear of hammers was assumed to be $3,000 per set of hammers (Naimi et al. 2006; Ortiz-Landazuri and Colay 2019), which is roughly 2% of the capital cost of the grinder (2016$); additional delivered feedstock cost increases would also include the cost associated with the lost production. For the analysis, the relative life of the hammers was increased by increments of 25% to a maximum of 3× the baseline life; while the relative cost of the hammers was increased by increments of 50% to a maximum of 5× the baseline hammer cost. The model utilized a fixed set of biomass units, drawn randomly from a population, to maintain comparability between the model runs. The compositional distributions used to define the population, were based on the work of Templeton et al. (2010).

For this analysis, three model scenarios were considered: (1) a fixed moisture content of 20% for all biomass units, with stochastic ash properties; (2) both moisture and ash generated stochastically, utilizing the same order of draw from the moisture and ash distributions at each life and cost point; and (3) both moisture and ash generated stochastically for each life and cost point. The first case was used to isolate the impact of the wear and hammer replacement on the system. The second case was utilized to provide a comparison of the relative impact of reducing wear on the baseline system under normal operational conditions (i.e., including variable moisture). Finally, the third case was used to provide some insight into the variability of results given the potential ranges of properties that affect the system.

Results and Discussion

Scenario 1 – Impact of Wear Only on Preprocessing System

The addition of coatings and/or changes in the alloys that are used to produce the wear parts of equipment will only directly affect the service life of the parts. Increasing the wear resistance, there are fewer occurrences of needing to take a piece of equipment offline to perform repairs and maintenance, resulting in an overall increase in throughput and a reduction in the average cost of the delivered feedstock at the reactor throat. Figure 2 illustrates the reduction in down events for the relative hammer life multipliers from 0.5× to 3×; while Figure 3 shows the modeled decrease in downtime. Through increasing the relative hammer life from base scenario to a life expectancy of 3× the base case the number of failures and amount of time the system was down due to wear dropped by more than 67%. Across all levels of relative hammer cost, the shapes of the resulting cost curves were similar, with the price decreasing as the life of the hammers increased. Figure 4 shows the delivered feedstock cost (at the conversion reactor throat) for each level of increase of relative hammer cost from 1× to 5×. While every improvement in life expectancy of the material improved the economics when the hammer cost was assumed to stay the same, as the price of the improved hammers increased the expected life had to improve by a greater amount to improve the economics. However, the relationship between life and costs was not one to one, instead as the life increased it was economically feasible to pay more. In the case of a 3× improvement in life the material could cost 3.66× as much as the original hammer material and still produce feedstock costs below the base case. From the data the relative premium that can be paid for an improved hammer material across all the relative hammer price points ranged from 1.1-1.22× the expected relative hammer life increase.

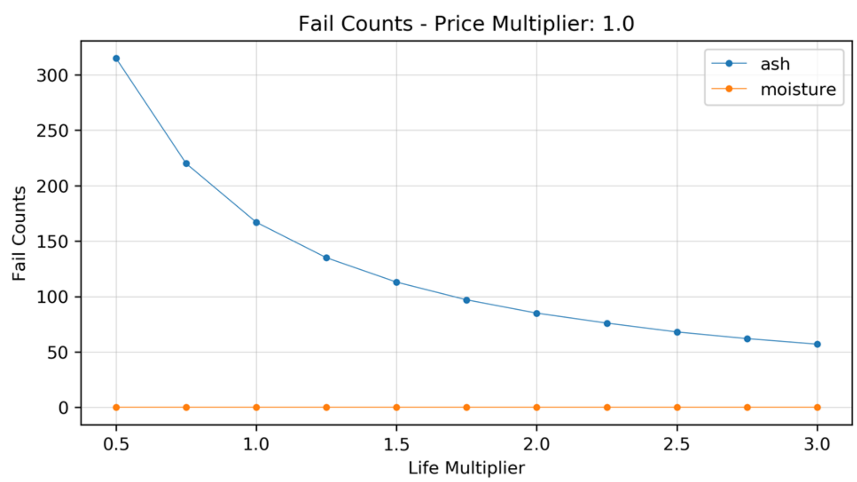

Figure 2. System failures due to wear of hammers during the simulation period

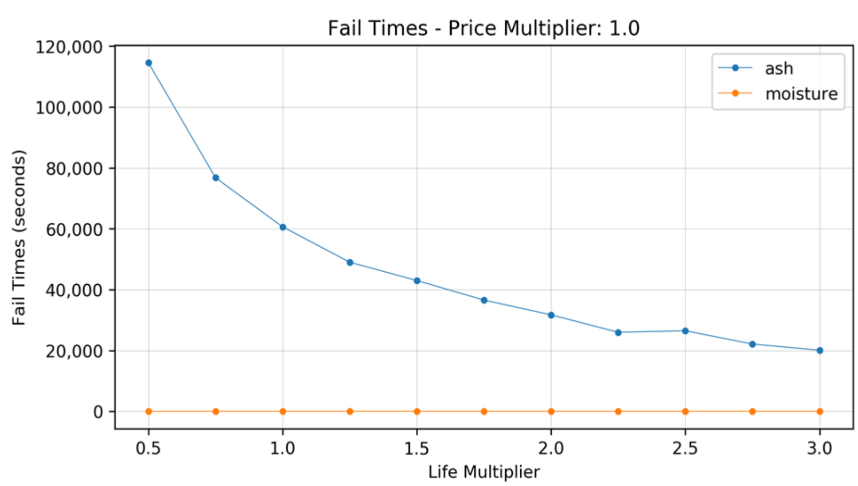

Figure 3. Downtime experienced from hammer wear during the simulation period

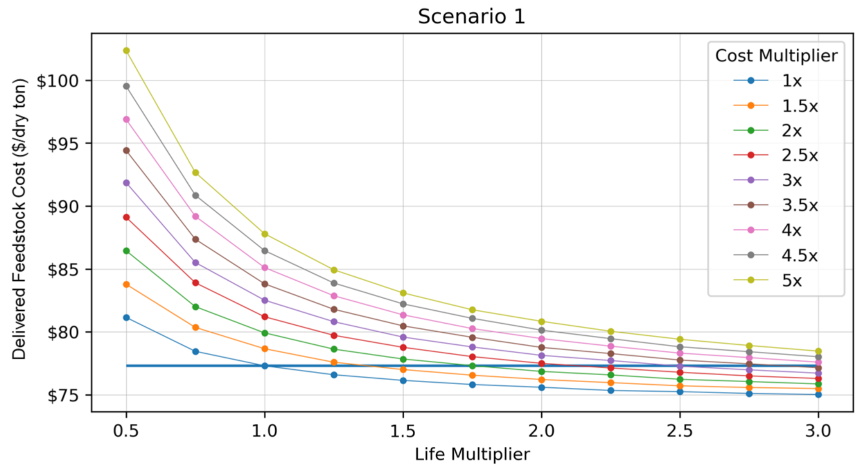

Figure 4. Delivered feedstock cost ($/dry ton) resulting from simulating the system for 350 operational days under hammer life and cost assumptions and fixed 20% moisture content; the horizontal blue line between $75 and $80/dry ton represents the base case delivered feedstock cost, hence, any values below this line are economical

Scenario 2 – Impact of Wear on Preprocessing System with Moisture Variability

In the first scenario, it was demonstrated that improving the life, even with some increase in material cost, improved the economic performance for the system. However, in the first scenario any failures not associated with the wear of the hammers were eliminated. In this second scenario, the moisture content was allowed to vary as would be seen in a processing system, but the same collection of values for ash and moisture were use across all combinations of life and cost multipliers. With moisture variability added to the simulation, there were substantial changes in both down events (Figure 5) and down times (Figure 6). In the base scenario, there were nearly 43× the failures and more than 10× the amount of down time caused by moisture than resulted from the wear. In addition, the slope of the moisture failure line in Figure 5 is positive, indicating that as the life of the hammers increases the number of failures due to moisture increase. The reason for this increase is that as the number of failures due to wear

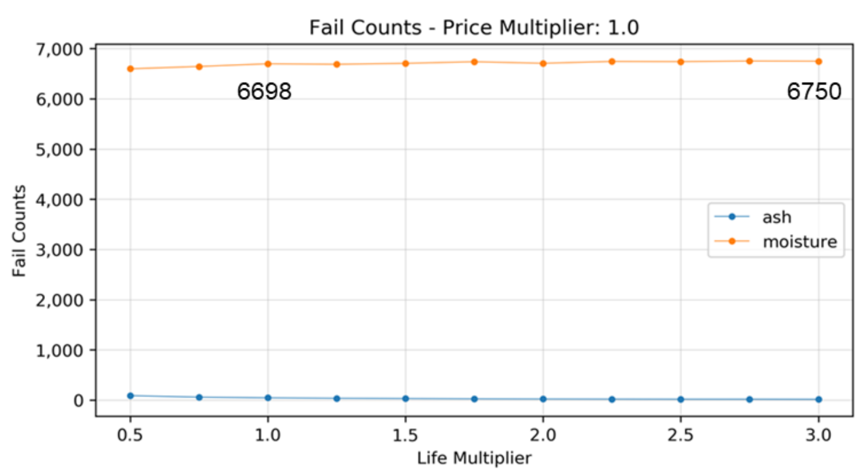

Figure 5. System failures due to wear of hammers and moisture impacts during the simulation period

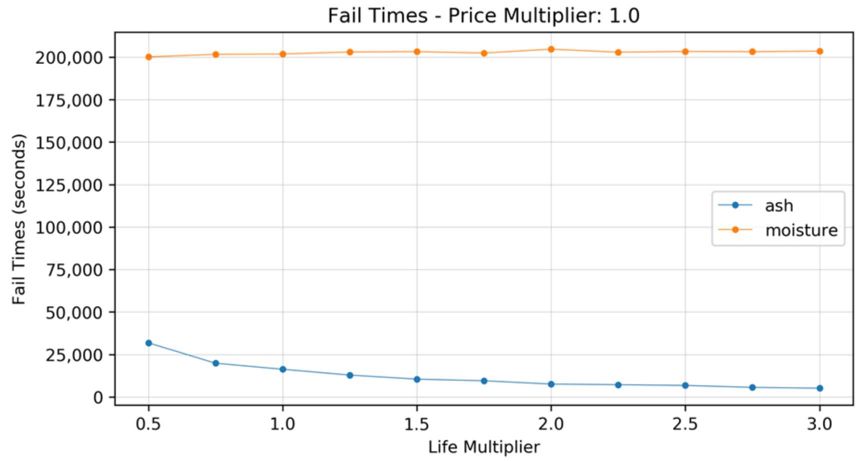

Figure 6. Downtime experienced from hammer wear and moisture during the simulation period

decrease, more material can be put through the system; with the variability in the moisture content, more units of material that are outside the operational limits of the system are introduced. However, even with the increase in failures due to moisture, the impact to the system that is realized by increasing the life of the hammers is roughly the same as was seen in the wear only scenario (Figure 7).

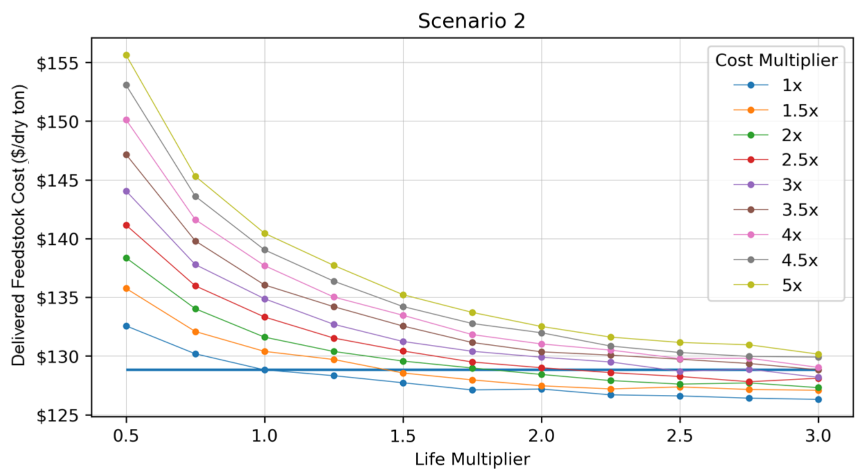

Figure 7. Delivered feedstock cost ($/dry ton) resulting from simulating the system for 350 operational days under hammer life and cost assumptions and variable moisture content; the horizontal blue line between $125 and $130/dry ton represents the base case delivered feedstock cost, hence, any values below this line are economical

Scenario 3 – Uncertainty assessment of result

The third scenario was undertaken as way to develop an understanding of the variability of delivered feedstock cost that may be seen in the results due to the stochastic nature of both ash and moisture in biomass feedstocks. For this scenario, a Monte Carlo analysis was completed by performing 50 modeling runs, allowing the moisture and ash values to be drawn randomly for each point during the simulation. The Monte Carlo runs were only completed at the cost multiplier of 1×, with the uncertainty bounds expected to be similar at each cost multiplier. Figure 8 shows the results of the Monte Carlo analysis, with the line representing the mean value

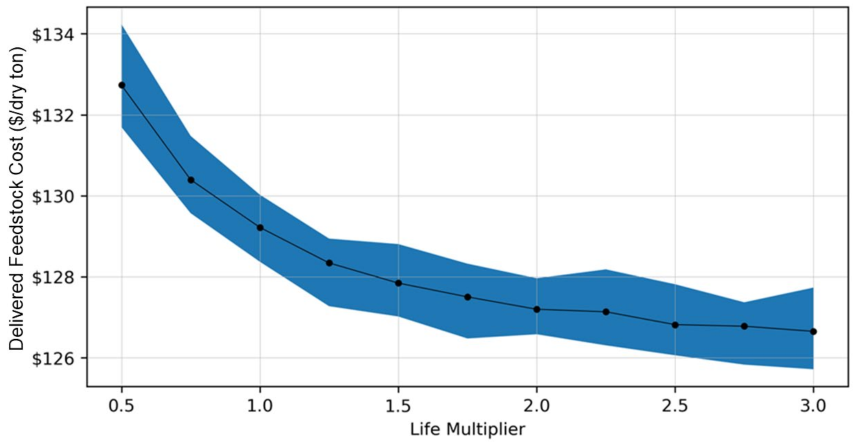

Figure 8. Graphical representation of 50 run Monte Carlo simulation with stochastically generated ash and moisture values; the line represents the means with the shaded area representing the range of values returned

for the runs and the blue area representing the range of values returned for the 50 individual runs. It can be noted that the blue area has a jagged appearance; this is the result of only having 50 data points at each location but provides an indication of the uncertainty that can be expected. From the figure at each point there is approximately a range of ±$1.10/dry ton, at each point. The significance of these results is that if the feedstocks are expected to be higher in ash or moisture over time, either due to harvesting practices or plant ecology, the relative improvement in cost due to increasing wear resistance will be consistent with the simulation results but the total cost will be higher than the mean.

Discussion

The goal of this Case Study was to compare the cost savings from improving the life span of parts that wear within a system to the additional material cost required to reach varying levels of improved life span. We recognize that the failure limits and system performance are representative of a single system that may or may not exist in the real world, however, our goal for this analysis was not to provide an answer for a specific system or to provide a full understanding the economics of all potential systems. The analysis was performed using relative changes from the base alloy cost and considered relative improvements in part life in order to generalize the comparison without referencing specific alloys or coatings that might be employed. Ultimately, this work provides a first check of the potential for improving wear characteristics of grinder hammers to provide a meaningful and impactful benefit to biomass preprocessing and conversion systems.

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Conclusion and Next Steps

- Increasing the life of hammers by 3× provides a delivered feedstock cost benefit of approximately $2.25/dry ton assuming that the relative cost of the hammer material of construction is not increased.
- The feasible area of relative hammer cost increase ranges from 110% to 122% of the relative life increase, i.e., a 3× life increase can cost 3.66× the cost of the original hammers
- Beyond a 3× increase in relative hammer life, little economic benefit is realized
- Even when moisture impacts are included, the relationship between relative hammer cost and relative hammer life was reduced only slightly to a range of 108% to 116%
- From the simulation we would expect delivered feedstock costs to be within ±$1.10/dry ton, based on the uncertainty analysis

Next Steps

- Broaden the extent of wear on equipment:
    - Pneumatic systems
    - Frictional wear in transport
    - Cutting edges for knife mills and rotary shear
- Incorporate the simulation methodology to examine differing system designs

- Utilize findings from FCIC R&D in Task 5: Preprocessing to improve modeling estimates and include impacts to material attributes (e.g., particle size distribution) as wear progresses
- Develop methods to incorporate ash speciation (e.g., mineral type) and the resulting wear rates associated with the ash species, in collaboration with FCIC Task 1: Materials of Construction

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