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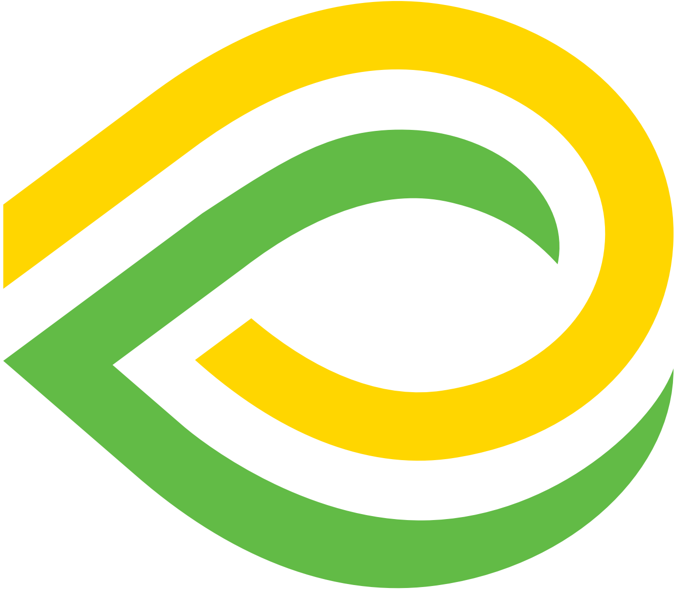
ENERGY EFFICIENCY &
RENEWABLE ENERGY

FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Life-Cycle Greenhouse Gas Emission Impacts of Forest Residue Preprocessing with Wet Milling



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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.

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List of Acronyms

CMA	Critical Material Attributes
CQA	Critical Quality Attributes
DOE	U.S. Department of Energy
GHG	Greenhouse Gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies model
LCA	Life-Cycle Analysis
QA	Quality Assessment

Executive Summary

The goal of this analysis was to evaluate the environmental impact of a Case Study that uses wet milling to preprocess logging residues before feeding to a catalytic fast pyrolysis conversion step. The results of the Case Study were compared to those of the status quo Base Case system where dry milling is used.

The results reveal that wet milling achieved 65% lower GHG emissions per dry ton of conversion-ready feedstock than the conventional dry milling technology. This is mainly because wet milling greatly reduced the energy consumption for drying. In addition, wet milling also generates fewer fines, thus improving the throughput of conversion-ready feedstock.

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Introduction

Conventionally, woody biomass preprocessing is energy-intensive and can be a hotspot for the supply chain greenhouse gas (GHG) emissions of wood-based biofuels. Delivery of high-quality feedstock at low energy consumption is important for reducing the carbon footprint of biofuels.

This study evaluates the GHG emissions of a wet milling process (referred to as Case Study hereinafter), in comparison to those of the conventional dry milling process (referred to as Base Case hereinafter), to understand the potential GHG emission impact of the wet milling process. The GHG emissions of the conversion-ready feedstock that meets all the Critical Quality Attributes (CQAs) for feeding to a catalytic fast pyrolysis process are evaluated for the Case Study where wet milling is used for size reduction and compared with those of a Base Case status quo system where dry milling is used. Results of this case study provide insights into the GHG emission impacts of wet milling as a preprocessing strategy.

Methods

The process mass and energy balance data for this study were obtained from the discrete event simulation done in subtask 8.2. Preprocessing Critical Quality Attributes, which are also the conversion Critical Material Attributes (CMAs), include an ash content ≤ 1.75 wt% and a carbon content ≥ 50.51 wt%, both on a dry basis, a moisture content ≤ 10 wt% on a wet basis, and a particle size between 1.18 mm and 6 mm (Thompson 2021). Figure 1 illustrates the schematic of the dry and wet milling preprocessing technologies.

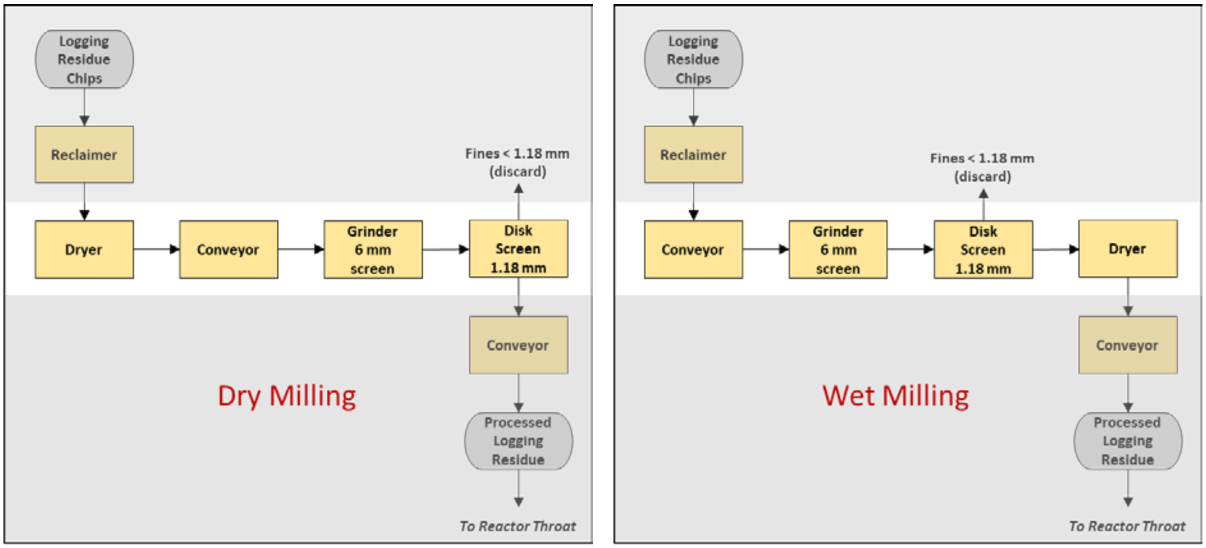

Figure 1. Preprocessing operations for dry and wet milling

The fuel type, energy consumption, and dry matter loss in each piece of equipment served as inputs to the life-cycle analysis (LCA) of preprocessing. Life-cycle GHG emissions of the conversion-ready feedstock exiting the preprocessing operations, including the upstream GHG emissions caused by logging residue production and harvest, were estimated with the

Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model (Wang et al. 2021) developed at Argonne National Laboratory. The carbon intensities of the harvested logging residues, natural gas, and the U.S. average electricity mix obtained from GREET are listed in Table 1. At each unit operation, the total emissions were normalized to the final materials that meet all the CQAs (i.e., the product). To illustrate the impact of discarded streams on the emission intensity of the product, normalized emissions at each unit operation were allocated to each output stream by mass, including the product, fines, and materials rejected by quality assessment (QA), as shown in Figure 2.

Table 1. Carbon intensities of biomass and fuels

Feedstock/Fuel	Value	Unit
Logging residues delivered to biorefinery	65.1	kg CO_2e/dry ton
Natural gas	77.1*	g CO_2e/MJ
Electricity	449.0	g CO_2e/kWh

* Includes GHG emissions from natural gas production and combustion.

Results and Discussion

Figure 2 illustrates the life-cycle GHG emissions per dry ton of the conversion-ready feedstocks in the Base Case and Case Study. The GHG emissions of the conversion-ready feedstock were 1,546 kg CO_2e/dry ton in the Base Case. The dryer was the largest contributor to the carbon intensity, contributing 1,365 kg CO_2e/dry ton due to its high energy consumption (2,328 kWh/dry ton, 98% of which being natural gas and the remaining being electricity). This presents the biggest opportunity for decarbonization that could be explored via the switch of fossil natural gas to waste or renewable gases. GHG emissions embedded in the delivered logging residues and grinder were the second and third largest contributors to the GHG emissions, accounting for 136 and 24 kg CO_2e/dry ton, respectively.

The carbon intensity of the preprocessed feedstocks in the Case Study (544 kg CO_2e/dry ton) was 65% lower than in the Base Case. The main reason for the reduction in carbon intensity was the reduced energy consumption by the dryer. The dryer contributed 396 kg CO_2e/dry ton in the Case Study, which was 71% lower than the Base Case because smaller particles dry more efficiently due to improved heat and mass transfer. As a result, the energy consumption by the dryer in the Case Study is 1,238 kWh/dry ton, 47% lower than in the Base Case. The great GHG emissions reduction for the dryer outweighed the slight increase of 18 kg CO_2e/dry ton in the grinder GHG.

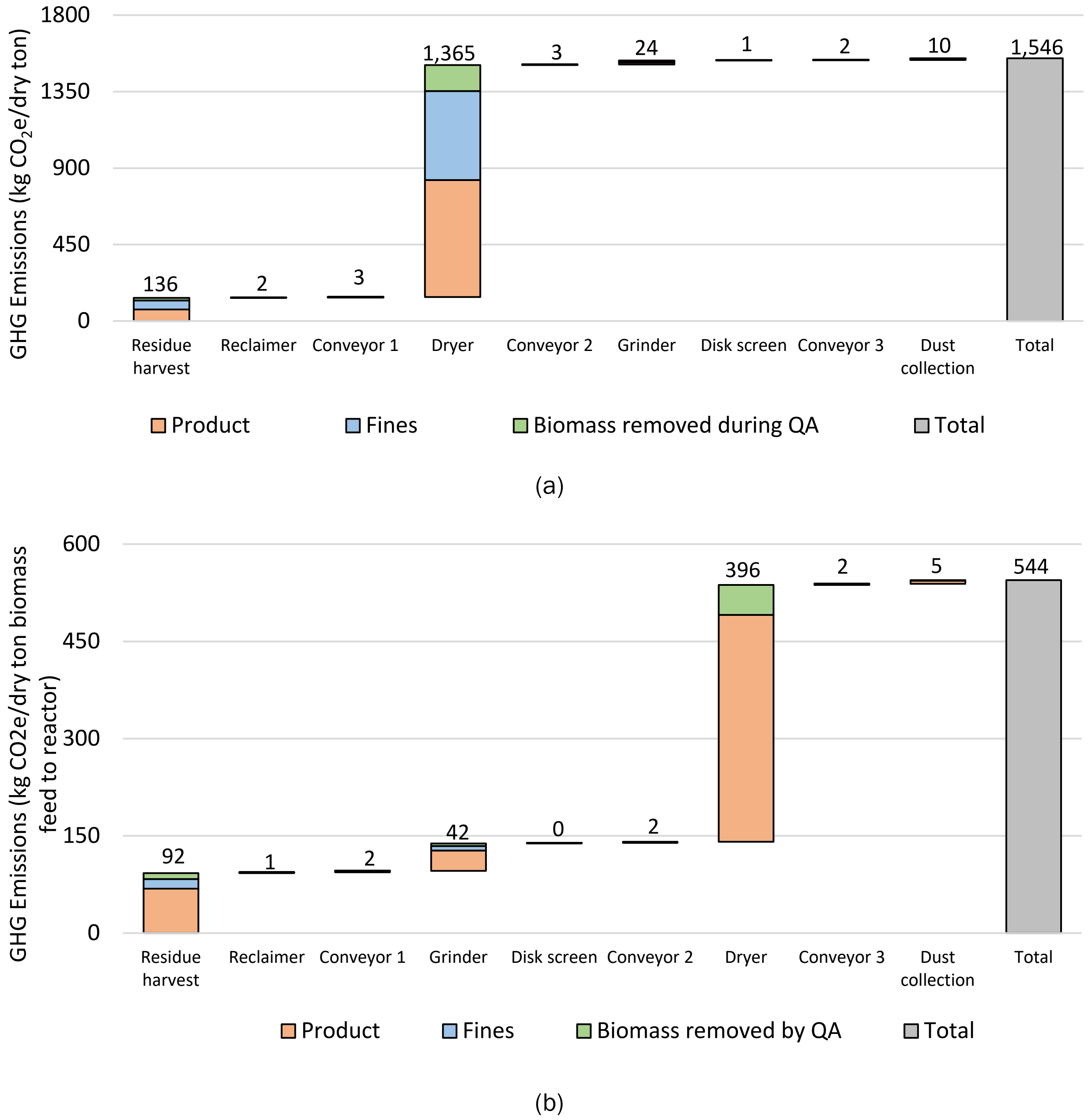

Figure 2. GHG emissions of preprocessed feedstocks in the (a) dry milling and (b) wet milling

Another reason for the reduction in the life-cycle GHG emissions in the Case Study compared to the Base Case was the improved overall biomass throughput (Figure 3). In the Base Case, 0.41 ton of fines were generated during dry milling and discarded per ton of biomass fed to preprocessing. In comparison, biomass loss as fines was reduced to 0.17 ton per ton of biomass fed to preprocessing in the Case Study. As a result, the overall biomass throughput was improved greatly from 48% in the Base Case to 69% in the Case Study.

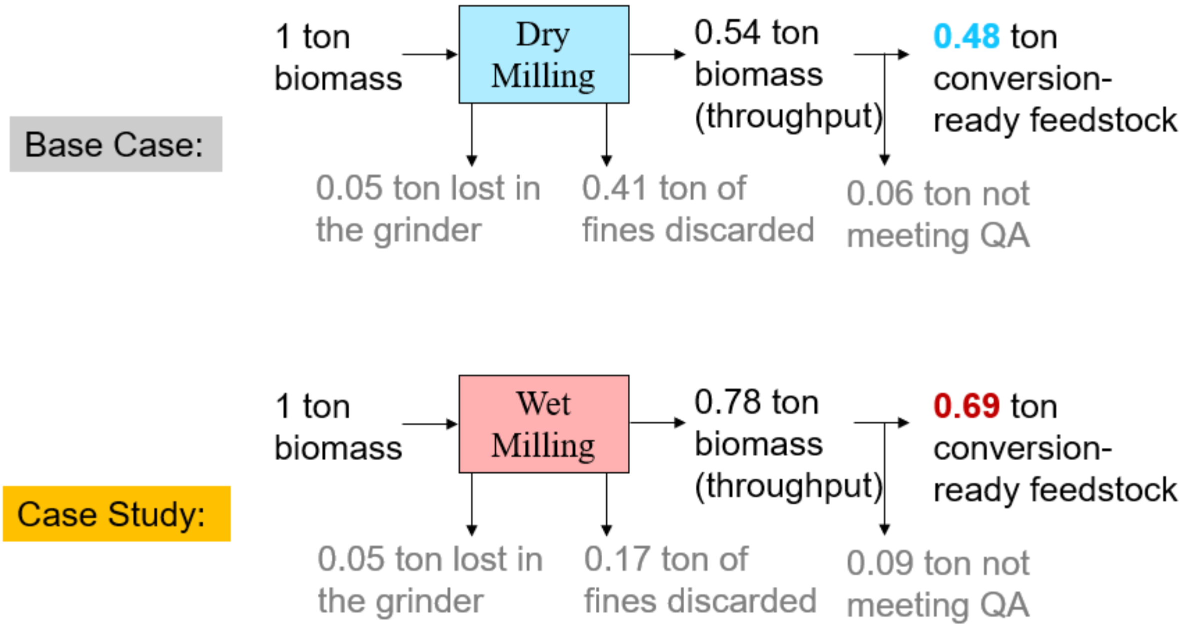

Figure 3. Mass balance results for dry and wet milling

Figure 4 shows the breakdown of the carbon intensity of the conversion-ready feedstock in the Base Case and Case Study. Wet milling not only greatly lowered the carbon intensity of the conversion-ready feedstock but also reduced the GHG emissions caused by biomass loss during grinding and QA. 49% of the GHG emissions were caused by the biomass loss in the Base Case. This is because the biomass loss went through the energy-intensive drying milling process and consumed energy, which eventually drove up the carbon intensity of the conversion-ready feedstock. In comparison, biomass loss was only responsible for 15% of the total GHG emissions due to avoidance of drying energy requirement of the biomass that ends up being fines and an improved biomass throughput.

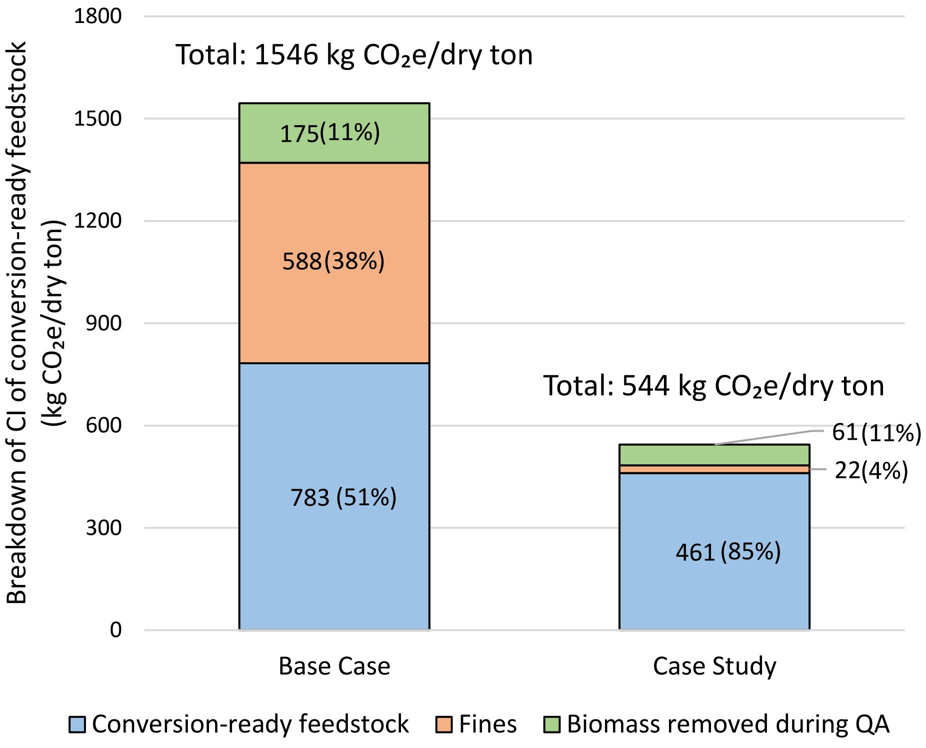

Figure 4. Breakdown of the carbon intensity of the conversion-ready feedstock preprocessed with dry and wet milling

Conclusion and Next Steps

This study evaluates the environmental impact of wet milling of logging residues, as compared to the status quo Base Case dry milling system. Wet milling reduced system energy consumption and biomass loss during preprocessing, thus achieving 65% lower carbon intensity of the conversion-ready feedstock than the Base Case. The results reveal the significant emission reduction benefit of using wet milling for biomass preprocessing. A future cross-boundary LCA case study, which accounts for the impact of wet milling on the downstream conversion process, is needed to evaluate the impact of wet milling on the life-cycle GHG emissions of the hydrocarbon fuel product.

Citations and References

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Acknowledgments

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