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Research paper

Economic analysis of woody biomass supply chain in Maine

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ABSTRACT

An economic biomass supply chain model for Maine was developed to estimate the delivered cost of biomass chips using the stumpage price paid to the landowner, the cost of harvesting and chipping the logging residues, and the cost of transporting the biomass chips to a biorefinery for biofuel production. Harvesting costs were estimated using Maine-specific productivity equations, harvesting assumptions, and hourly costs, but the resulting model is applicable to any region with woody biomass. Transportation costs were estimated using round trip distance to the potential biorefinery. The delivered cost of biomass was estimated for multiple scenarios, including different machine cost rates, variables impacting machine productivity, transport distance, and stand characteristics. When biomass was treated as a waste product (only chipping costs included), the estimated delivered biomass cost was $11/green tonne (GT) (with a sensitivity analysis range of $4 to $24/GT), less than half the current biomass chip price in Maine ($28/GT). When a portion of the harvesting cost was included in the delivered biomass cost, the estimated delivered biomass cost increased three-fold to $30/GT (with a range of $8-$82/GT). The results of this analysis will serve as a portion of an integrated sustainability assessment for a new biofuel pathway. This model can be easily adapted to other geographical regions with different site-specific inputs.

1. Introduction

As the US seeks to decrease reliance on fossil fuels by increasing the use of renewable energy, woody biomass (tree tops and branches - also called energy wood and harvest or logging residues) has received increased attention as a possible renewable feedstock for electricity generation, heating, and transportation fuels. The expanded US Renewable Fuel Standard (RFS2) sets annual volume requirements for biofuel production, which increase annually and gradually include larger percentage standards for advanced biofuels (anything other than corn starch ethanol) [1]. As over 80% of Maine is forested, the highest proportion of any state in the US, Maine is a strong candidate for producing biofuel from logging residues [2]. Additionally, Maine has an active biomass chip market, in which the tree tops and limbs are chipped and sold to generate heat or electricity, providing approximately 15% of total energy for the state [3]. However, in many cases all of the biomass is still left on site. Woody biomass from Maine is of particular interest for producing environmentally sustainable biofuels because nearly all of the harvested forests are naturally regenerated; clear-cutting is rare; and biomass is typically underutilized. Unlike some biofuel feedstocks, woody biomass does not conflict with food production or require inputs such as fertilizer, insecticides, or pesticides [4] (which could harm wildlife and water quality). Forests are also able to maintain species diversity better than monocrops [5].

The University of Maine Forest Bioproducts Research Institute (FBRI) has developed a new production pathway that converts wood derived cellulose into a drop-in biofuel using thermal deoxygenation (TDO), which can be used to produce biofuel from logging residues [6]. The overall goal of this study is to estimate the cost of purchasing the biomass chips within the area surrounding a potential TDO biorefinery in Old Town, Maine. An economic biomass supply chain model was created to accomplish this goal. This model can be adapted for a variety of geographic regions, by replacing Maine-specific parameters and equations with site-specific information from other regions.

1.1. Maine biomass supply chain

The biomass supply chain in Maine is integrated with conventional roundwood harvesting and involves many different landowners (98% of forestland is owned privately [2]), logging and

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trucking contractors, and end users. In some cases, the landowner sells trees and timber products to a logging contractor for a stumpage price prior to harvest. It is also common for landowners to pay loggers contract prices for harvest and transport. Then the landowner markets the wood products separately. Either way all parties must be compensated out of the mill delivered price. We chose to model the process using publicly available stumpage prices [7], which approximate the contracted harvesting price, as similar costs would need to be covered. The logging contractor then harvests the trees and removes the tree tops and branches (biomass) from the bole [8]. Biomass is usually transported to a roadside landing during or after harvest and chipped to increase load density for transport. Trucks transport the biomass chips to a purchasing facility. The final cost of the delivered biomass chips to the purchasing facility includes stumpage, harvesting, chipping, logging contractor profit margin, and trucking costs (Fig. 1).

Biomass is chipped in conjunction with timber harvesting as part of an integrated harvesting operation. Three different harvesting methods are commonly used in Maine: whole tree (WT), cut-to-length (CTL), and tree length (TL). Each method varies in cost, amount of biomass harvested, environmental impact, and the type of machines used. Our biomass supply chain model assumes a WT harvest method because 82% of Maine forest products by volume are harvested using the WT method [9] and because a greater proportion of biomass is recovered with WT than with other harvesting methods as the entire tree is transported to the roadside landing. The typical WT method in the Northeast uses a feller-buncher to cut down the tree, a grapple skidder to drag a bunch of trees to the roadside landing, and a stroke delimber to remove the biomass at the landing. At least a portion of the biomass is placed on trails to reduce erosion and soil compaction in accordance with Maine Forest Service (MFS) water quality best management practices [10].

Trucks transport biomass chips directly from forest to end-user. While data are not available for Maine, the average forest product trucking distance in neighboring states (New York, Vermont, and New Hampshire) is 74 km, and approximately 75% of logging contractors in these states subcontract at least a portion of their trucking [9].

1.2. Review of existing biomass supply chain studies and models

While several studies have estimated biomass harvesting and transportation costs nationally [11,12], in the Northwest [13–15], Southeast [16–18], and in the upper Midwest [19,20], few studies have addressed the Northeast [21]. In Maine, some recent studies have addressed individual aspects of the biomass supply chain, such as logging contractor characteristics and harvesting methods [9], harvesting productivity [22,23], early commercial thinning costs [24], and challenges for expanding biomass harvesting in Maine [25]; however, no studies have thoroughly analyzed the costs for harvesting and transporting biomass to the end user in Maine. Since harvesting practices, harvest block characteristics, and species composition vary by state, harvesting productivity, cost, stumpage prices, and transportation costs need to be analyzed at the state level to accurately estimate the feedstock cost for a potential biorefinery.

As machine productivity and cost rates are used together to estimate unit cost of production, applicable productivity equations and accurate costs that represent current machines and practices are essential for accurately estimating in-state harvesting costs. The Fuel Reduction Cost Simulator (FRCS) [43] is a spreadsheet-based tool developed by the US Forest Service to estimate the cost of harvesting and delivering timber and woodchips to roadside for a specified area of forestland. FRCS includes three variants: West, North, and South. FRCS-North, updated in March 2010, incorporates machine specific costs, regional variations such as differences in the added cost of harvesting hardwood trees, and state specific labor costs [26]. However, it does not include productivity equations or costs specific to Maine or the Northeast [22]. FRCS-North machine cost rate (average hourly cost to own and operate a piece of equipment) calculation assumptions, including wages and benefits estimated using a wage index based on Missouri from 2000 to 2007, do not reflect current costs in Maine. There is a general lack of machine productivity estimates applicable to Maine in academic literature as well [27]. For example, most productivity studies focus on low-density stands (fewer than 100,000 trees/km^2), whereas Maine stands range from 100,000 to 480,000 trees/km^2 [27].

Additionally, many biomass cost estimates do not include all of the costs along the supply chain. Abbas et al. [28] use FRCS to estimate delivered biomass costs in Michigan at $8-$107/green tonne (GT) (WT harvest, 30% tree removal) and $8-$105/GT (WT harvest, 70% tree removal), with most of the total cost attributed to harvesting (nearly 50%) and transportation (nearly 30%). However, they do not include profit, overhead, or management expenses in the final calculations. The US Department of Energy (DOE) and Oak Ridge National Laboratory also use FRCS in the Billion-Ton Update (BTU), which estimates sustainable annual US biomass availability and cost (at the roadside, not including transport to the end user) for biofuel production: 30-129 million dry tonnes/y nationally (at $22-$110/dry tonne, respectively), and 0.17–1.00 million dry tonnes/y in Maine (at $22-$220/dry tonne, respectively) [12]. These results are based on WT harvesting (with a minimum of 30% biomass left on site to return nutrients to the soil and reduce runoff) and only include chipping and stumpage costs (no costs associated with other harvesting machines).

While biomass may currently be a waste product of the forestry industry, resulting in many studies allocating the entire harvesting cost to timber products, this does not take into account the opportunity cost of allocating resources to harvesting biomass. Some studies in the Southeast have shown that this opportunity cost may be important [16,17], and limiting biomass harvesting cost to only chipping may underestimate the total cost. Conrad et al. [16] compared the cost of WT harvesting (with different harvesting equipment than Maine) and transportation of roundwood in North Carolina under three scenarios: 1) roundwood harvesting only (no biomass chipping); 2) integrated roundwood harvesting and biomass chipping; 3) biomass chipping only (no roundwood harvesting - similar to BTU). The authors [16] found that a contractor could earn a profit of $1.52/tonne for harvesting roundwood under scenario 1 and lose $0.28/tonne under scenario 2. Conrad et al. [16] estimated that for the integrated harvesting system to reach its

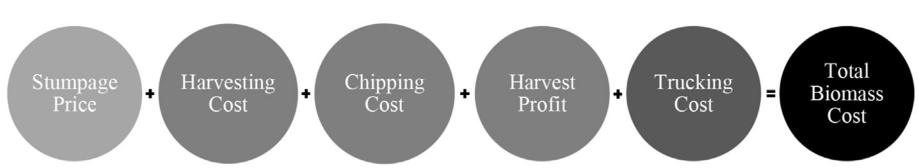

Fig. 1. Biomass Supply Chain Costs Cost of biomass delivered to purchasing facility (i.e., electricity generator, biorefinery).