Applied Energy 216 (2018) 662–677

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Development of a decision support tool for optimizing the short-term logistics of forest-based biomass

Krishna Teja Malladi[a], Olivier Quirion-Blais[a], Taraneh Sowlati[b,*]

[a] Industrial Engineering Research Group, Department of Wood Science, University of British Columbia, 2943-2424 Main Mall, Vancouver, British Columbia V6T-1Z4, Canada

[b] Industrial Engineering Research Group, Department of Wood Science, University of British Columbia, 2961-2424 Main Mall, Vancouver, British Columbia V6T-1Z4, Canada

HIGHLIGHTS

- Transshipment and routing models are developed for short-term biomass logistics.
- The models include biomass storage, pre-processing, and truck routing decisions.
- Models are applied to a large forest-based biomass logistics company.
- Average reduction of 12% in cost and fuel consumption is observed using the models.
- An Excel-based decision support tool is developed for the company.

ARTICLE INFO

Keywords:
Forest biomass
Logistics optimization
Sustainability
Transshipment problem
Vehicle routing

ABSTRACT

High cost of logistics is one of the barriers of using forest-based biomass for energy and fuel production. Biomass logistics is complex and includes interdependent decisions related to storage, pre-processing and transportation. While these decisions have been considered in numerous medium-term planning models, those for short-term planning are limited. The existing models focused only on optimal truck routing without considering intermediate storage facilities which are essential to match biomass supply and demand. In this study, a decomposition-based approach is used and optimization models are developed for the short-term planning of a large biomass logistics company located in the Lower Mainland region of British Columbia, Canada. The company deals with collection, storage, pre-processing and transportation of biomass. Several operational constraints related to truck-location compatibilities and truck-biomass compatibilities arising from heterogeneity of trucks and biomass types which further complicate the logistics planning are incorporated in the models. First, a transshipment model is developed and solved using a mixed integer formulation to determine comminution schedules and the number of truckloads of each biomass type to be transported each day using each type of truck. Then, a routing model, which uses the results of the transshipment model, is developed to determine the optimal routing for the available trucks. A decision support tool to optimize the company's weekly transportation and comminution operations is also developed for the company. Experiments were conducted on real data from the company over a span of four weeks. The results indicate 12% reduction in the total average cost and a similar reduction in fuel consumption compared to the actual routes implemented by the company. It is suggested that savings could be obtained by using larger trucks for longer distance transportation and smaller trucks for shorter distances. Direct delivery of biomass from suppliers to customers, bypassing the yard, could result in cost savings.

1. Introduction

There has been a growing interest in using alternative energy and fuel sources for sustainable development. Among alternative energy sources, forest-based biomass has received attention due to its advantages. It is a versatile source of energy that can be used to generate heat, electricity, biofuels or a combination of them [1]. It can be stored and used as per demand [2]. Its local availability in many regions could

* Corresponding author.
E-mail addresses: kmalladi@alumni.ubc.ca (K.T. Malladi), olivier.quirion-blais@ubc.ca (O. Quirion-Blais), taraneh.sowlati@ubc.ca (T. Sowlati).

https://doi.org/10.1016/j.apenergy.2018.02.027
Received 21 December 2017; Received in revised form 5 February 2018; Accepted 7 February 2018
0306-2619/

facilitate fuel security and could reduce carbon dioxide emissions as the carbon dioxide that releases during combustion is captured by trees during the photosynthesis process [3]. These advantages have encouraged the development of efficient technologies for converting it to energy and fuels.

Despite the potential advantages of using biomass for energy and fuel generation, the economic performance of a bioenergy project depends on the logistics cost [4,5]. Logistics, which involves collection, storage, pre-processing and transportation of biomass, could contribute to as much as 90% of the total feedstock cost in some cases [6]. Collection of biomass deals with picking up biomass from supplier locations, and can be demand-driven or supply-driven. In demand-driven collection, biomass is picked up from suppliers to meet the demand at conversion facilities. Supply-driven collection, similar to industrial waste collection, deals with the pickup of the entire quantity of biomass available at the supply points, irrespective of the demand. Storage of biomass deals with decisions related to the location and quantity of biomass to be stored. Biomass can be stored at supply points, conversion facilities, and/or at intermediate storage facilities. Pre-processing includes activities such as comminution and drying of biomass to meet the size and quality requirements for the conversion process. Transportation relates to the movement of biomass between different locations of the network. Similar to other forest products, biomass is transported by trucks, trains and ships, while trucking is the main mode of transportation in many regions [7].

Logistics operations can be expensive and challenging due to the complexities involved at the operational level. Collecting residues from industrial sites is particularly challenging due to limited storage space, which necessitates timely pickup of residues irrespective of the demand for biomass. When biomass supply and demand do not match, storage of biomass becomes imperative at some intermediate facilities. Moreover, these residues can be of different types, and some of them may require additional pre-processing such as comminution before they can be used in the conversion facilities. Depending on equipment availability, comminution can take place at supply points, conversion facilities and/or intermediate facilities which necessitates an integration of transportation, storage planning and pre-processing scheduling. In addition, restrictions related to requirement of specific truck types to carry each type of biomass often exist due to differences in size and properties of biomass types. Moreover, not all truck types can visit all locations of the supply chain due to limitations on truck size and space available at each location. This results in a transportation network with multiple products, multiple supply and demand points, and heterogeneous fleet of trucks with restrictions related to truck type-product type compatibilities and truck type-location compatibilities leading to a complex planning problem. In the presence of an intermediate storage yard, additional decisions regarding whether biomass picked up from each supplier should be delivered to the storage yard or directly to a customer, and whether to meet the demand of a customer by delivering biomass from the yard or from a supplier complicate the decision making process. Storage and pre-processing decisions must be taken along with the transportation decisions. Furthermore, daily truck routes must be determined to minimize the total transportation costs.

Previous research on biomass supply chain logistics optimization mostly focused on long-term and medium-term planning [4]. Optimization models dealing with short-term planning are limited in number. Previous short-term logistics optimization models focused on daily tuck routing decisions in networks with multiple suppliers and customers [8], or multiple suppliers and a single customer [9], without considering storage at intermediate sites. These studies considered either a single type of truck [9] or multiple types of trucks [8]. The study by Han and Murphy [8] which considered multiple types of trucks assumed that the transportation quantities of biomass were pre-determined and dealt only with routing trucks to satisfy the transportation orders. Zamar et al. [9] included decisions related to the quantity of biomass to be picked up from suppliers using identical trucks making the transportation decisions relatively simple. Short-term biomass logistics optimization models which consider the entire network including biomass suppliers, storage facilities and customers, along with decisions related to storage and comminution of biomass, and daily transportation using multiple truck types were not developed in the literature.

This study addresses the above-mentioned gaps by developing optimization models for the short-term planning of biomass logistics using the case of a large biomass logistics company located in the Lower Mainland, British Columbia, Canada. The company deals with collecting biomass from several industrial sites and delivering feedstock to customers. Biomass types collected from suppliers include sawdust, shavings, clean wood and unclean wood. While sawdust and shavings are delivered to customers without pre-processing, clean and unclean wood are comminuted into chips and hog fuel, respectively, before they are delivered to customers. The company owns a central yard where biomass collected from suppliers can be stored, and clean and unclean wood can be comminuted using chippers and grinders. Each supplier can supply multiple types of biomass and each customer can demand multiple types of feedstock. Transportation of biomass is carried out using a heterogeneous fleet of trucks, and restrictions related to truck-location compatibilities and truck-product compatibilities further complicate the problem. Each supplier and customer could be visited by more than one truck type depending on the truck-location compatibilities, and each truck type can carry more than one biomass type. Each week, the company receives information about supply and demand quantities from each supplier and each customer for the following week. Depending on the information received, the company makes decisions related to comminution and transportation of biomass. Comminution decisions prescribe the quantity of each type of biomass to be comminuted at the yard each day. Transportation decisions include the quantities of biomass to be transported to the yard, to be sent directly from suppliers to customers, and quantities of feedstock to be sent from the yard to customers. Transportation decisions also include the truck type to be sent to each location and the resultant routes to be taken by each truck. Currently, transportation and comminution decisions are made by the logistics managers of the company. The overall goal of this paper is to develop optimization models to optimize the company's weekly logistics planning and provide a decision support tool to the company. Fig. 1 shows a schematic of the logistics operations of the company.

2. Literature review

Numerous optimization models were developed in the literature to minimize biomass logistics cost. They can be divided into two groups based on the decision planning level: tactical and operational. Most of the models encountered in the literature focused on tactical level planning with medium-term planning horizons. A group of these models focused on agriculture-based biomass (e.g., [10,11]) and few of them considered forest-based biomass (e.g., [12,13]). Studies on agriculture-based biomass logistics, such as those by Ekşioğlu et al. [10] and Memişoğlu and Uster [11], included decisions related to the locations of the conversion facilities along with other logistics decisions in their models. On the contrary, facility location decisions were not included in forest-based biomass logistics optimization models as these decisions are generally incorporated in long-term strategic planning models (e.g., [14]).

Biomass logistics models for medium-term planning considered one-year planning horizon with either weekly (e.g., [15]) or monthly decisions (e.g., [16,17]). In these studies, transportation decisions were included in the mathematical models as product flow values between different locations of the network during each period of the planning horizon. A few of these studies, such as those by Akhtari et al. [13] and De Meyer et al. [18], included decisions related to the storage of biomass at intermediate facilities to account for biomass seasonality. Other