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► **To cite this version:**

Evelyn Thomchick, Kusumal Ruamsook. Potential Woody Biomass Supply Chain Scenarios: A Conceptual Study. Vittal Prabhu; Marco Taisch; Dimitris Kiritsis. 20th Advances in Production Management Systems (APMS), Sep 2013, State College, PA, United States. Springer, IFIP Advances in Information and Communication Technology, AICT-414 (Part I), pp.416-424, 2013, Advances in Production Management Systems. Sustainable Production and Service Supply Chains. <10.1007/978-3-642-41266-0\_50>. <hal-01452142>

**HAL Id: hal-01452142**

**<https://hal.inria.fr/hal-01452142>**

Submitted on 1 Feb 2017

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# Potential Woody Biomass Supply Chain Scenarios: A Conceptual Study

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**Abstract.** The interconnectivity among various business entities and physical functions of woody biomass supply chains requires a system-wide perspective. Extant studies largely focus on individual business units or sets of activities. This paper takes a supply chain perspective to gain an understanding of potential woody biomass supply chains. The study draws insights from an extensive review of literature to conceptualize potential woody biomass supply chain scenarios. Three woody biomass supply chain scenarios and associated logistics activities were defined from the analysis of literature content. They are woody biomass sourcing from forest product manufacturers, forest landowners, and biomass pre-processers. Findings suggest that woody biomass as a marketable commodity creates business opportunities for loggers and forest product manufacturers. In moving forward, infrastructure and technological development is vital, encompassing logging capability and transportation and industrial infrastructure.

**Keywords:** Woody biomass, logistics strategies, supply chain scenarios

## 1 Introduction

Diminishing fossil fuel resources, increased competition for those fuels, and a growing realization of the economic and environmental impacts of the dependence on fossil fuels have led to a need to develop renewable energy resources. Bio-energy is one potential component of a renewable energy scenario for the future, accounting for approximately half (49%) of total renewable energy produced and consumed in the United States in 2012. A wide variety of biomass feedstock is currently used to produce bio-energy, ranging from woody biomass, agricultural wastes, to urban wastes. Of these feedstock varieties, woody biomass accounted for nearly half (45%) of the total biomass-based renewable energy consumed in 2012 (US Energy Information Administration, 2013). These figures demonstrate the considerable contribution of bio-energy, notably woody biomass-based energy, for national renewable energy effort.

However, managing biomass feedstock supply and its associated logistics activities are persistent issues. Inherently low in bulk densities, biomass feedstock creates

logistics challenges in terms of its volume that has to be handled, stored, and transported (Benjamin et al., 2009; Damery and Benjamin, 2007; Sokhansanj and Fenton, 2006; Weiner, 2010). Given the low value of biomass materials and logistics challenges involved, the costs of moving biomass feedstock from supply sources to a bio-refinery plant can be prohibitive and often exceed market values for the biomass itself (Kram, 2008; Nicholls et al., 2008).

Managerial predicaments also arise due to the many business entities that make up a woody biomass supply chain. These entities perform two important physical functions of a supply chain. The first function involves *production*, encompassing forest landowners who produce forest materials; loggers who harvest and convert trees into logs or wood chips; forest product manufacturers whose process residues produce woody biomass; pre-processors who turn forest materials into processed woody biomass such as wood chips and pellets; and bio-refineries who convert woody biomass into heat, electricity, chemicals, and transportation fuels to serve different customers (Allen et al., 1998; D'Amours et al., 2008; Frisk et al., 2010; Sokhansanj and Fenton, 2006). The second function involves *logistics* of moving the various stages of products from one point in the supply chain to the next, encompassing key activities such as transportation, materials handling, warehousing and storage, and inventory control (Coyle et al., 2008; Fisher, 1997).

The interconnectivity among various entities, the associated physical functions, and supply sourcing challenges require a total supply chain perspective. Yet, extant studies on woody biomass largely focus on individual entities or sets of activities. The gap in research, coupled with the still evolving nature of the industry, lead to woody biomass supply chains that are currently not well perceived. The primary objective of this paper is to conceptualize potential supply chain scenarios associated with woody biomass. Insights gained are imperative as a basis for further research to promote economically feasible bio-energy as a component of renewable energy scenario for the future.

## **2 Methodology**

To conceptualize and evaluate potential woody biomass supply chain scenarios, the study draws insights from extensive review of literature. Journal articles in the areas of supply chain and logistics, forest products, biomass feedstock, and bio-energy were selected from archival material available electronically at ProQuest and Academic Search Complete. Other principal data sources are the government and organization websites such as the US Energy Information Administration, the US Forest Service, and the International Energy Agency. Along with these data sources, informal interviews with five researchers in the fields of forest resources, agricultural sciences, and biomass energy were conducted to clarify and verify insights drawn from the literature.

Over 800 pages of documents were examined and coded on three levels according to Glaser and Strauss (1967) and Strauss and Corbin (1998). In the first level, key activities pertinent to the production and logistics functions of supplying woody bio-

mass to a bio-refinery are identified, and the properties that characterize each activity are examined. Then, in the second level, we made connections between categories (in this case, the key activities identified above) by exploring the conditions and interactions that influence the processes of supplying woody biomass. This coding allowed us to integrate data into core categories or potential woody biomass supply chain scenarios. Then, using the core supply chain scenarios as a guide, we selectively coded the existing data obtained from literature survey and additional data gathered from the informal interviews to describe each scenario. At the end of this third-level coding, we have established the descriptions of potential supply chain scenarios.

### 3 Conceptualizing Woody Biomass Supply Chain Scenarios

Three potential woody biomass supply chain scenarios are identified and depicted in Figures 1–3. They are: (1) woody biomass sourcing from forest product manufacturers, (2) woody biomass sourcing from forest landowners, and (3) woody biomass sourcing from biomass pre-processers. We briefly describe each scenario in turn as follows.

#### 3.1 Woody Biomass Sourcing from Forest Product Manufacturers

The first scenario, depicted in Figure 1, is currently preferred by most bio-refineries (Morgan, 2009).

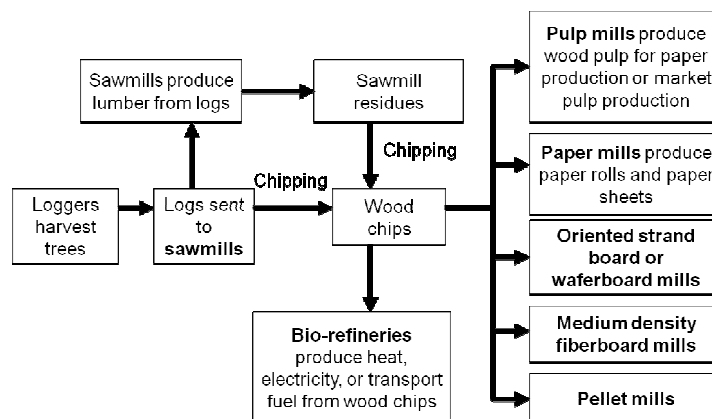


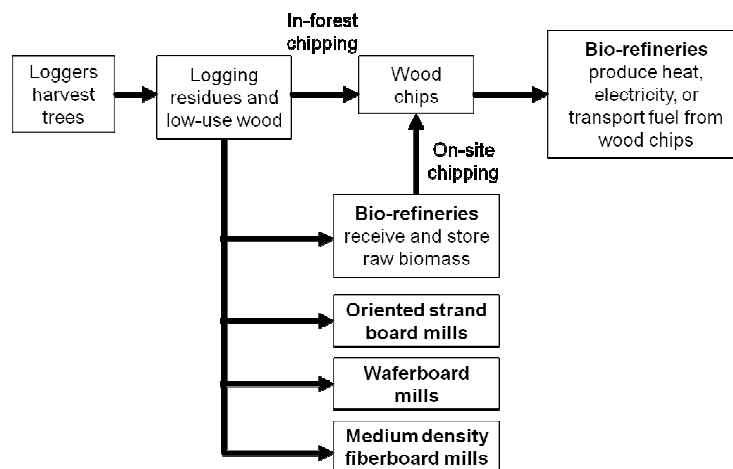
Fig. 1. Woody Biomass Sourcing from Forest Product Manufacturers

In this scenario, residues produced by primary wood processors, such as sawmills and their lumber customers, are the primary feedstock for both the bio-refineries and secondary forest product manufacturers such as pulp mills, paper mills, and pellet mills (Ray 2010). Classified as industrial private landowners, these forest product manufacturers possess large forest assets for uses in their manufacturing requirements (Benjamin et al., 2009; Frisk et al., 2010; IBISWorld, 2009; McDill, 2011). They

contract independent loggers for harvesting timber and delivering logs from their forestland to their production facilities (Myers and Richards, 2003). In general, approximately 80 percent of the output loggers generated—typically the lower part of the tree that has a larger diameter, and thus a higher value—is transported directly to a nearby sawmill for processing. The upper, thinner parts of the tree that have lower value are commonly delivered to pulp mills and paper mills (Crooks, 2005; D’Amours et al., 2008; Frisk et al., 2010; IBISWorld, 2009, 2010). These loggers typically use trucks and equipment they owned or leased to make the deliveries to the mills (IBISWorld, 2010), although in some cases transport service providers or contract haulers (e.g. trucking companies and rail carriers) may also be involved (Bolding et al., 2009). In turn, the mills delivery mill chips to the bio-refineries according to the arrangement between the parties, which vary in terms of transportation mode used, and size and frequency of deliveries (Liu, 2010; McDill, 2011; Roth, 2010).

### 3.2 Woody Biomass Sourcing from Forest Landowners

The second scenario, depicted in Figure 2, makes use of forest materials that contribute the potentially most abundant sources of woody biomass in the United States (Nicholls et al., 2008).



**Fig. 2.** Woody Biomass Sourcing from Forest Landowners

In this scenario, forest biomass is sourced from landowners that can be public entities (e.g. federal, state, and local and municipal land and forests), private industrial entities (e.g. saw mills, and pulp and paper mills), or non-industrial private entities (e.g. individuals or corporations other than forest product industry) (Biomass Research and Development Board, 2008b; D’Amours et al., 2008). As in the first scenario, forest landowners contract loggers for felling standing timber, delivering the outputs, and disposing logging residues. Decisions on the methods of residue disposal (e.g. piling and burning, scattering throughout a site to decompose, and processing as

biomass) may be left to the loggers, or set forth by landowners and third-party environmental certification standards for sustainable forest management practices (Benjamin et al., 2009; Elmore, 2009; Yepsen, 2008).

In turn, bio-refineries transact with the loggers for the forest biomass. Biomass can be delivered in either chipped or non-chipped forms. The former involves in-forest chipping, which is well integrated into existing timber harvesting systems (D'Amours et al., 2008; Gunnarsson et al., 2004). In this case, loggers with portable wood-chipping equipment produce wood chips from logging residues and from whole trees of non-merchantable quality for direct sale to bio-refineries and other buyers such as pulp and paper mills (D'Amours et al., 2008). Unlike clean chip by-products from forest product manufacturers, these logging chips (also called dirty chips and hog fuel) are characterized by high moisture and varied physical quality in terms of size, shape, and chemical makeup (Benjamin et al., 2009; Kimbell et al., 2009; Kram, 2008; Weiner, 2010; Yepsen, 2008). These characteristics render biomass that has low net energy density by mass, is unsuitable for long-term storage, and is uneconomical for long distance transportation (Crooks, 2005; Goldstein, 2006; Jackson et al., 2010; Liu, 2010; McDill, 2011; Wallace, 2011; Richard 2011). Coupled with the often geographically dispersed forest lands, transportation cost could easily exceed the costs of biomass itself (Bolding et al., 2009).

Alternatively, non-chipped forest biomass can be transported to bio-refinery facilities where it will be chipped using a larger-scale, more powerful stationary chipper (D'Amours et al., 2008). In comparison to the in-forest chipping, this alternative gives the bio-refineries greater control over the chipping process and offers a cost advantage gained from economies of scale and the powerful equipment used. These advantages, however, are offset by the more expensive cost of transporting non-chipped, as opposed to chipped, forest biomass to the refinery facilities (D'Amours et al., 2008; Jackson et al., 2010).

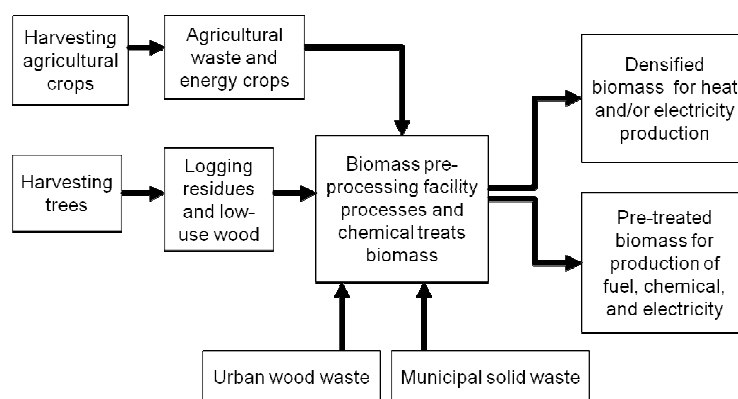
### **3.3 Woody Biomass Sourcing from Biomass Pre-Processors**

The third scenario, illustrated in Figure 3, depicts business opportunities that emerged from the need to pre-process and pre-treat biomass to alleviate production and logistics issues pertinent to biomass.

In this scenario, woody biomass suppliers are relatively large facilities with storage capacity and flexible system capable to pre-process and pre-treat a wide range of biomass materials. The biomass supply chain in this scenario resembles that of a hub-and-spoke system of biomass processing and distribution (Carolan et al., 2007; Roth, 2010; Yepsen, 2008, 2009). A typical biomass pre-processor assumes a role of an *intermediary* who engages in securing and establishing contracts for various types of biomass from various sources. It also manages the collection, storage, pre-process, and delivery of biomass to the bio-refinery and other biomass users (Carolan et al., 2007; Sokhansanj and Fenton, 2006).

A pre-processor's large-scale, flexible system permits physical transformation (e.g. pre-processed briquettes, pellets, and torrefied biomass) and chemical transformation (e.g. pre-treated to alter chemical component) of a wide range of biomass feedstock to

satisfy the quality and quantity requirements of biomass users before making delivery (Roth, 2010; Yepsen, 2008). Hence, aside from improving the quality of biomass as feedstock, these processing technologies are also logistically advantageous, making it possible to economically transport biomass over greater distances and to store large quantities of biomass for longer periods of time. Production cost advantage is also achieved because of economies of scope gained from the variety of feedstock used and flexible product mix, and economies of production scale and powerful equipment used (Carolan et al., 2007; Jackson et al., 2010; Sokhansanj and Fenton, 2006; Taylor et al., 2010).



**Fig. 3.** Woody Biomass Sourcing from Biomass Pre-Processing Facilities

## 4 Conclusion

This conceptual study identifies three potential woody biomass supply chains and reveals the roles and interactions between different members in performing the production and logistic functions of the supply chains. Three important implications in moving woody biomass-based bio-energy forward arise from the findings summarized in Table 1.

First, loggers play an important production role in all three scenarios. To take advantage of the new biomass market opportunities, logging capacities must be developed and new managerial and operational practices must be devised to integrate the existing operations and emerging biomass business (Benjamin et al., 2009; Biomass Research and Development Board, 2008b; Damery and Benjamin, 2007; Elmore, 2009; Kram, 2008; Yepsen, 2008, 2009).

Second, forest product manufacturers possess technological and infrastructural advantages that render them competitive as biomass suppliers. They have access to their abundant industrial forestlands, well-established transportation systems, and the on-site infrastructure for pre-processing, storage, and handling of woody biomass. The new markets of biomass as feedstock for bio-energy present great opportunities for business expansion that leverage these existing capital investment and resources (Benjamin et al., 2009; Frisk et al., 2010; Jackson et al., 2010; Sklar, 2008). A more

vertically integrated avenue is to expand into the bio-refinery business and become an “integrated forest product bio-refinery” enterprise that produces bio-products (e.g. heat, transport fuel, and bio-chemical) in addition to conventional forest products (Damery and Benjamin, 2007; Feng et al., 2010; Kimbell et al., 2009).

**Table 1.** Woody Biomass Supply Chain Scenarios: Key Parties, Roles, and Advantages/Disadvantages

Scenarios	Forest material production	Harvesting	Physical pre-processing	Chemical pre-treating	Biomass delivery	Biomass storage	Advantage/Disadvantage to Biomass Buyers
Sourcing from Forest Product Mfr. (FPM)	FPM	Logger contracted by FPM	FPM	Bio-refinery	Between bio-refinery and FPM	Bio-refinery	<ul style="list-style-type: none"> <li>Established sector: Clean chips</li> <li>Supply depending on FPM production</li> </ul>
Sourcing from Forest Landowner (FLO)	FLO	Logger contracted by FLO	Logger or bio-refinery	Bio-refinery	Bio-refinery arranges own shipment with loggers	Bio-refinery	<ul style="list-style-type: none"> <li>Established sector, potentially most abundant sources</li> <li>Dirty chip; high transport cost</li> </ul>
Sourcing from Pre-processor (PP)	FLO	Logger contracted by PP	PP	PP	Between bio-refinery and PP	PP	<ul style="list-style-type: none"> <li>Economy of scale and scope: feedstock to specification</li> <li>Not yet established sector</li> </ul>

Finally, infrastructure development is vital to enhance reliability and efficiency of the production and logistics functions of woody biomass supply chains. Transportation infrastructure, in particular, is much needed to tap into the abundant, yet highly dispersed forest biomass resources. Additionally, an extensive industrial infrastructure is required to advance the current experimental operations to commercial stages. Industrial infrastructure encompasses not only the bio-refinery facility itself, but also pre-processing and treatment facilities, and communication technology needed to improve logging and biomass harvest efficiencies (Benjamin et al., 2009; Jackson et al., 2010; Kimbell et al., 2009).

**Acknowledgments.** This work was funded by a Pennsylvania State Sustainability Seed Grant awarded by the Pennsylvania State Institutes of Energy and the Environment (PSIEE). We thank Dr. Jude Liu, Dr. Marc E. McDill, Dr. Tom Richard, Dr. Gregory W. Roth, and Mr. Bob Wallace for their valuable insights on the woody biomass, forest management, and renewable energy industries.



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