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BIOMASS FEEDSTOCK SUPPLY CHAINS

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Abstract

The use of ethanol has gained popularity as a result of the growing desire to reduce dependency on foreign oil and concerns about potential climate change. Cellulosic ethanol from woody biomass may be less costly than other forms of ethanol. The feedstock supply chain for processing timber used in biomass-based ethanol has traditionally followed a forward supply chain structure. Unlike feedstock supply chains with the traditional supply chain activities of suppliers, distribution networks, transportation modes, capacity and inventory, this paper proposes an alternative view of the feedstock supply chain using concepts found in reverse supply chains. These activities include uncertainty in supply, collection points, inspection, and quality issues of the timber are applied. This unique application of both forward and reverse supply chain formats takes into account the life and carbon cycles, while at the same time providing a better understanding of the feedstock supply chain.

Keywords: biomass, ethanol, reverse supply chains, closed-loop supply chains, forward supply chains, carbon dioxide sequestration

Introduction

Interest in ethanol has been on the rise because of the ever-increasing need for the United States to take action to decrease its dependency on foreign oil, as well as its overall generation of greenhouse gas emissions from transportation fuels. Biomass-based ethanol has gained special attention because of its positive environmental impacts since it is a renewable source of energy, and its potential to be more inexpensive than other types since the cost of cellulosic ethanol produced from grain exceeds the value of the fuel itself (Wyman, 1994). Traditionally, the research that has been performed on developing supply chains for the delivery of woody biomass from its source in the forest to the ethanol plant has followed forward supply chain activities. The purpose of this research is to propose an alternate view of the woody biomass supply chain in which a new forward supply chain is introduced in conjunction with a proposed reverse supply chain. This integrative approach is used to develop a closed-loop supply chain framework that identifies carbon as the main component moving throughout the woody biomass supply chain. The goal for considering this alternate approach is to gain a better understanding of the dynamics involved in the overall supply chain.

As previously stated, the transportation of woody biomass to a cellulosic ethanol plant has traditionally been viewed as a forward supply chain. The major activities in forward supply chains are facilities configuration, transportation modes, inventory control, and information management (Simchi-Levi, Kaminsky, & Simchi-Levi, 2003). Research based around woody biomass supply chains has been focused on the investigation and sometimes optimization of each of these activities since the woody biomass network structure has normally been viewed as a forward supply chain. However, not all of the details of the supply chain are identified using strictly a forward view. These will be discussed later when the new supply chain frameworks are introduced.

The balance of the paper is organized as follows. The traditional forward view of woody biomass supply chains will be introduced, followed by the proposed alternate approach where the forward supply chain has a different starting point than what has normally been done. Next, the reverse supply chain activities involved in woody biomass supply chains will be described. Finally, the notion of carbon being the common product throughout the woody biomass supply chain will be used to introduce the closed-loop supply chain framework.

The Traditional Forward Supply Chain View

The facilities configuration activity in forward supply chains has been at the center of research when designing an optimal woody biomass supply chain. The locations of harvesting areas, storage yards, and holding facilities have been analyzed in order to potentially identify an ideal facility configuration given a specified demand of biomass (De Mol, Jogems, Van Beek, & Gigler, 1997). The ideal configurations for the facilities were then used to develop the forward supply chain for the woody biomass.

Consistent with forward supply chain activities, much research has been performed in the area of collection and transportation modes. The Biomass Research and Development Board (2008) identified the importance of collection and transportation in a woody biomass supply chain by focusing on collection and transportation of the woody biomass in a target area, feedstock logistics, and the board's plan to develop a viable forward supply chain. More specific research on transportation modes for woody biomass has investigated the economics of single shipments of woody biomass in the form of wood chips using rail or truck, as well as transshipment of the woody biomass involving a combination of both rail and truck (Mahmudi & Flynn, 2006).

The inventory requirements for a biomass supply system were analyzed with a mathematical model to simulate how much woody biomass is needed at different times throughout the year to meet varying weather related demands seen at a heating plant (Gunnarsson, Ronnqvist, & Lundgren, 2004). Some of the analysis for the inventory component involves the optimization of the inventory by taking into account the losses that occur during storage due to drying. (De Mol, Jogems, Van Beek, & Gigler, 1997). The inventory issues raised through the existing research are all directly applicable to the forward supply chain and its dynamics.

Research on the role of information management has been conducted to analyze its effects on the supply chain that are directly applicable to the woody biomass supply system. The effects of traditional information sharing, where the supplier only sees the order information, is compared with a full information sharing system where there is immediate access of inventory information between all parties involved (Cachon & Fisher, 2000). This research can be applied to the previously discussed woody biomass supply chains in which proper information management must take place so that the optimal level of inventory can occur based on the changing demand of the cellulosic ethanol plant (Gunnarsson, Ronnqvist, & Lundgren, 2004).

The research discussed to this point focuses on how the woody biomass supply system fits into the four main forward supply chains activities that were identified previously. Since the research views the cellulosic ethanol plant as the final destination for the woody biomass, the supply chain is intuitively viewed as forward because it is primarily demand driven. Because the woody biomass system is viewed as a demand driven network, all of the characteristics of forward supply chains are then investigated and applied to the biomass system. Research efforts then are limited to each of the forward supply chain activities in an attempt to potentially identify

ways to improve cost effectiveness and overall efficiency of the supply chain. The Biomass Research and Development Board (2008) focuses on the main forward supply chain activities in an attempt to create a woody biomass supply chain that can be implemented at a national level. However, if the starting point of the forward supply chain is shifted, an alternate view of the woody biomass supply chain can be developed to reveal and describe supply chain dynamics that are not identified in the traditional approach just described.

An Alternate View of the Forward Supply Chain

This paper proposes the notion of viewing the beginning of the forward supply chain at the point at which trees in a forest start sequestering carbon, i.e., the point at which the trees start growing leaves. To view carbon sequestration as the beginning of the forward supply chain for woody biomass, one must look at carbon as being the main component being moved through the supply chain rather than the woody biomass itself. When applying the main activities involved in forward supply chains to the carbon sequestration process in a tree rather than to how the activities are traditionally applied as previously described, many significant observations can be made.

The facility of the forward supply chain now becomes the trees that are sequestering carbon in a forest. Each facility (tree) is essentially a process facility that transports carbon dioxide from the atmosphere into its leaves through the stomata, and through photosynthesis, converts the carbon from the carbon dioxide into glucose. The glucose then is converted into cellulose in the tree, which can be used later to produce cellulosic ethanol. Once the tree eventually converts the carbon dioxide into cellulose, the tree then becomes a storage facility for the carbon now in the form of cellulose. The number and type of facilities (trees) will affect the overall efficiency and effectiveness of the carbon sequestration process of the forest. A large

forest will sequester more carbon than a smaller forest and specific species can sequester carbon more rapidly than others (EPA, 2006). Benefits that can be realized by taking this alternate approach include the ability to cultivate a forest with a specific quantity and type of species so that it will sequester the highest amount of carbon dioxide from the atmosphere. The faster the forest grows, the sooner it can be sold for a profit and be converted into cellulosic ethanol. This observation is not apparent in the traditional view of the woody biomass supply chain.

Availability[1] in the forward supply chains is directly related to the amount of carbon dioxide converted to cellulose by a forest. The forest stand will continue to sequester carbon throughout its life until it reaches a saturation point where it can no longer sequester any additional carbon. Once a tree reaches this saturation point, it will begin to decay and release the accumulated carbon back into the atmosphere if not properly maintained (EPA, 2006). This issue makes the knowledge of how much cellulose is available within a forest at a given time very important. The benefit that can arise from taking this alternate view is observed with the potential knowledge of when a forest has its highest availability of cellulose, or at its maximum carbon sequestration level. If this availability knowledge is gained, then the inventory of usable cellulose can be maximized, and then by using forest management practices, the forest can be harvested before the trees start to decay. This aspect is not observed when taking the traditional forward supply chain approach described earlier.

The information management activities of forward supply chain can be applied to the alternate view of carbon sequestration by a forest. If the owner of a forest manages all of the information involved in carbon sequestration correctly, they can maximize their forest

[1] Availability in forest management practices refers to the amount of wood harvested from a forest for use in production.
Inventory in forest management practices refers to the amount of trees in a forest that can be harvested for future use.

productivity and growth, and also create value after the forest's useful life is over through a reverse supply chain, which will be discussed in detail later. Using information management correctly, proper harvesting can occur at the desired time, which would not be realized with the traditional supply chain view.

The Reverse Supply Chain Component

In order to recover the value of the carbon stored as cellulose in the tree, a decision is made to harvest the tree, thus completing the forward supply chain. The harvesting of the tree then starts the beginning of the reverse supply chain for the woody biomass to recover the value of the carbon as cellulose through the eventual conversion to cellulosic ethanol. The purpose of this section is to show how the process of value recovery for the carbon can be described with the main activities of reverse supply chains, which include product acquisition, reverse logistics, inspection and disposition, reconditioning, and distribution and sales (Guide Jr. & Van Wassenhove, 2002).

Viewed through the product acquisition activity, the carbon in the form of cellulose is retrieved, just as products in reverse supply chains are retrieved, through harvesting procedures. The quality, quantity, and timing of the harvest, or retrieval, have to be carefully managed, using proper forest management practices, in order to effectively start the reverse supply chain (Guide Jr. & Van Wassenhove, 2002). Taking this alternate view of the supply chain can identify uncertainty in supply issues, such as permission to harvest specific forests or not, that would not otherwise be identified when viewing it as a forward supply chain.

The next step in the reverse supply chain for the carbon in the form of cellulose is the reverse logistics involved in transporting it from the forest to the ethanol plant. This transportation has to be coordinated carefully so that it can be cost effective and efficient, and

similar to the forward supply chain, can be done with different transportation modes such as truck or rail. Reverse logistics can also take intermediate storage areas into account when transporting the cellulose from the forest to the cellulosic ethanol plant. Depending on the quantity and location of the cellulose, the transportation route and mode involved in the reverse logistics can vary with each case. This variation with each case is a common trait for this activity of reverse supply chains (Guide Jr. & Van Wassenhove, 2002).

After the logs are transported to the cellulosic ethanol plant, the inspection and disposition stage of the reverse supply chain begins. The logs delivered must be fresh enough so that they have the proper moisture content so that the cellulose can be converted into ethanol properly. Logs that exhibit extensive decay are rejected from the supply chain.

Once inspected and disposition made, the logs can be moved to the reconditioning, or conversion, stage. During the conversion process, the cellulose is converted to simple sugars by enzymes and from there is fermented into cellulosic ethanol (Wyman, 1994). The value of the carbon in the cellulose has been successfully recovered by the conversion, reconditioning, of it into cellulosic ethanol to be used for heat or transportation needs.

Closing the Loop

Once the cellulose is converted successfully into cellulosic ethanol, the final activity of the reverse supply chain occurs. Distribution and sales of the cellulosic ethanol can be made to businesses that that will eventually sell it as transportation fuel. Education of the customer on the economic and environmental benefits of ethanol may assist in succeeding with this last aspect of the reverse supply chain (Guide Jr. & Van Wassenhove, 2002). The consumers that buy the cellulosic ethanol will eventually burn it thereby combining the forward and reverse supply system into a closed-loop supply chain.

After the ethanol is burned for transportation fuel, the carbon in the ethanol is transformed into carbon dioxide in the atmosphere. Carbon dioxide gas emissions are shown to be 85% lower than those from gasoline. This carbon dioxide forms a closed-loop supply chain because it then reenters the forward supply chain described earlier as carbon sequestration of a forest. This closed-loop supply chain can occur indefinitely, and is more beneficial for the environment through this alternate view because the carbon dioxide emitted into the atmosphere can now be reutilized by new trees growing in the same forest that was harvested and converted into cellulosic ethanol.

Summary

This research provides a closed-loop supply chain view of the woody biomass supply chain by using reverse and redefined forward supply chain activities. This novel approach emphasizes that coordinating the forward supply chain of the forest sequestering carbon complements the reverse supply chain of transporting the cellulose and converting it to ethanol allowing for the most success in the entire supply chain. This coordination is a common trait of reverse supply chain success (Guide Jr. & Van Wassenhove, 2002). This implies that planting specific quantities and species of trees that can sequester carbon rapidly and using proper forest management practices so that harvesting occurs at the forest's optimal sequestration level will allow for the maximum amount of cellulosic ethanol to be produced in the reverse supply chain. If a large quantity of ethanol is being sold and burned, then a larger amount of carbon dioxide is being emitted for reuse by growing trees to start the process all over again and form the closed-loop supply chain.

In essence, managing the flow of carbon in a closed-loop supply chain view provides the framework for further work in forest inventory management, optimal forest harvesting models,

and planned supply. A goal for further work can include the minimization of carbon dioxide in the atmosphere through optimization of the proposed closed-loop supply chain framework.

References

Biomass Research and Development Board. (2008). *National Biofuels Action Plan.* Biomass R&D Board.

Cachon, G. P., & Fisher, M. (2000). Supply Chain Inventory Managment and the Value of Shared Information. *Management Science* , 1032-1048.

De Mol, R., Jogems, M., Van Beek, P., & Gigler, J. (1997). Simulation and optimization of the logistics of biomass fuel collection. *Netherlands Journal of Agricultural Science* , 219-228.

Guide Jr., V. D., & Van Wassenhove, L. N. (2002). The Reverse Supply Chain: Smart manufacturers are designing efficient processes for reusing their products. *Harvard Business Review* , 25-26.

Gunnarsson, H., Ronnqvist, M., & Lundgren, J. T. (2004). Supply chain modelling of forest fuel. *European Journal of Operational Research* , 103-123.

Mahmudi, H., & Flynn, P. C. (2006). Rail vs Truck Transport of Biomass. *Applied Biochemistry and Biotechnology* , 88-103.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2003). *Designing & Managing the Supply Chain: Concepts, Strategies & Case Studies.* New York: McGraw-Hill/Irwin.

U.S. Environmental Protection Agency (EPA). (2006, October 19). *Carbon Sequestration in Agriculture and Forestry*. Retrieved March 2010, from US EPA Web site: http://www.epa.gov/sequestration/faq.html

Wyman, C. E. (1994). Ethanol From Lignocellulosic Biomass: Technology, Economics, and Opportunites. *Bioresource Technology* , 3-15.