OPTIMIZING TRANSPORTATION COST FOR BIOMASS SUPPLY CHAIN

by

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Biomass conversion is largely impacted by the cost of transporting biomass materials. As a result, businesses need optimization solutions to optimize their transport operations, allocate resources effectively, and reduce their environmental impact. As part of the process of biomass conversion, this paper discusses the transport and biomass optimization problem in detail. The paper presents optimization of transportation cost of two biomass products, natural gas, and bio fuel during the process of biomass conversion final products depending on the transport routes and other factors.

Key words: *biomass, biomass supply chain, optimization, transportation*

Introduction

Biomass is organic material that is renewable and derived from animals and plants. Biomass stores chemical energy derived from the Sun. Photosynthesis produces biomass in plants. Various processes can convert biomass into renewable liquid and gaseous fuels, or biomass can be set on fire directly for heat. There are three major types of biomass production: the first includes edible crops such as corn and sugarcane, the second includes non-edible crops such as stems, leaves, husk*, etc.,* and the third generation is primarily based on algae. Biomass remains a significant source of energy in several nations, particularly for lighting and cooking in developing nations. As a method of avoiding CO_2 emissions from the use of fossil fuels, the use of biomass fuels for mobility and electricity generation is growing in many developed nations. Biomass can be utilized in residential applications for space heating and cooking. Wood is the most common source of fuel, but many other substances are also utilized. New designs for woodstoves can increase the cooking or heating system's efficiency, thereby reducing the amount of fuel required. Businesses and industries utilize biomass for a variety of purposes, including space heating and hot water heating. Many industrial facilities, such as sawmills, produce organic waste naturally.

Biomass has recently gained attention as a viable alternative to fossil fuels, among the various RES. It is renewable, environmentally friendly, and abundant. Due to its ability to

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photosynthesize, biomass has been touted as the best origin for biofuel production over the past several decades. The movement of biomass from the land to its final use for bioenergy production is known as the biomass supply chain, fig. 1. The effectiveness of this chain is crucial to the economic variability of biorefineries: since biomass is relatively inexpensive, the supply chain costs represent a large proportion of the cost per ton of biomass delivered to biorefineries.

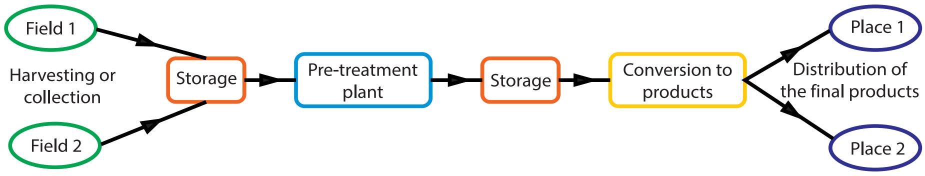

Figure 1. Biomass supply chain network

A biomass supply chain typically includes the following operational elements biomass harvesting and collection, biomass storage, biomass pre-treatment, transportation, transformation of biomass to final product and Distribution of final products to users. Transportation is the interlinked factor of biomass for the processing process within this paper, the transportation cost during this process is optimized.

Literature review

Ultimately, supply chain management is about facilitating the networked flow of materials cost-effectively and sustainably. A variety of biomass supply chain design and operational components may benefit from modelling and methods studied by the optimization field. There is a high occurrence of the following technical problems: Transportation and conversion problems, scheduling problems (based on harvesting, collection, storage, and transport), facility location problems, routing of vehicles problems (related to harvesting, collection, storage, and transportation), and technology selection problems (associated with pretreatment).

The optimality of biomass supply chains and optimization methods have been reviewed in several comprehensive reviews [1]. A key challenge in handling biomass supply chains is the selection problem (which occurs in the process of pretreatment and conversion).

There need to be long-term planning horizons with annual decisions for forest residue supply chain models of 10 years [2, 3]. Using aggregated annual biomass demand and supply data, supply chain design models were developed. Since data is aggregated over yearly time steps, these models do not take into account the storage decisions usually based on weekly or monthly time steps. Logistics decisions have generally been made independently of supply chain design decisions for forest residue supply chains. In most forest-based biomass supply chain models, long planning horizons were accounted for. However, few models considered decisions regarding temporary storage yards at a distance beyond one year [4, 5]. For the location of intermediate storage and pre-processing yards within these models, a one-year planning horizon is incorporated due to the transient nature of harvest sites. With crop rotation cycles being short and farm locations fixed, models of agriculture-based biomass can incorporate supply chain design and logistics decisions over a one-year horizon. Therefore, many biofuel logistics models have taken facility location and transportation into account [6, 7].

A cost-effective biomass supply chain is dependent on transportation due to biomass's low bulk density and the geographical dispersion of biomass suppliers [8]. Depending on the type of facility, biorefineries or pretreatment facilities would process the biomass after collection. Pretreatment must be carried out before intermediate biomass can be transported to the biorefinery. According to an optimization perspective, transportation problems can be divided into two types. Firstly, there is a design problem, while secondly, there is an issue with vehicle routing. Construction of the road network and determining the material flow on the network, or planning the most efficient routes for vehicles are both concerned with the road network and trying to reduce the overall cost of the transportation system. We consider both the biomass feedstock distribution network and the biomass product distribution network. The optimal location of a biorefinery in the transportation network can be determined by using a MILP model developed by Kang *et al.* [9]. In addition determining the location of the biorefinery and the network material flow, the model also calculates the system costs. A study by Bai *et al.* [10] incorporates the impact of traffic congestion into the problem. The location of biorefineries and flow patterns of transportation networks are addressed using a MIP model with a non-linear objective function. The goal of this study is to achieve the optimum solution as quickly as possible using a heuristic algorithm based on Lagrangian relaxation and to further enhance the solution, using two branch-and-bound algorithms.

Considering biomass' physical characteristics and its typically dispersed, small- to medium-sized suppliers, it's a popular option transport biomass by truck over short distances. Research suggests that to produce second-generation biofuels at a competitive price, large capacity plants are necessary to gain economies of scale. In order to operate high capacity plants, many farms must be located in distant locations. It is therefore, possible to reduce transportation costs by using rail, barge, and multimodal infrastructure [11, 12]. Multimodal facilities are introduced into the biomass supply chain by Hess *et al.* [13]. The model is then solved using Bender's biodegradation algorithm. According to Roni *et al.* [14], a multi-objective MILP incorporates social as well as environmental objectives. Transportation-related

Emissions are measured for the environmental impact, while the number of jobs created for the social impact [14].

Utama *et al.* [15] developed an optimization algorithm based on ant colonies (ACO) that finds routes for transporting raw biomass and finished goods. Based on the needs of the local community, Ayoub and Yuji [16] examine a biomass network driven by demand. By using Gas, the issue can be resolved. This algorithm starts by decomposing the network flows into multiple production paths, starting from the sum of flows along paths from supply nodes to demand nodes and the sum of flows around directed cycles. As the algorithms are being refined, the second phase involves minimizing the total cost and emission of the network by calculating material flows throughout it.

The ACO an algorithm is used to schedule multiple operations involving biomass along a road network for the enhancement of the ant colony, Beck and Sessions [17]. Total transportation expenses should be minimized in which on-road expenses and modification costs are included. Before using ACO to solve a MIP, a MIP must be formulated. Finding the optimal combination of vehicles and road modifications. In terms of total transportation costs, it can reduce them by 27%. Obtain the lowest possible annual cost for a biomass-to-hydrogen network. Using the MILP method, Woo *et al.* [18] determine the optimal location, flow, quantity, and import of hydrogen to establish the network design.

Mathematical modelling

In this paper, an optimization function is developed for the transportation cost during the complete process of the biomass supply chain or process from the collection or harvesting of biomass to the distribution of the final product to the market or users.

Objective function

Transportation is key to a supply chain that is cost-effective. The proposed single objective function is to minimize the total transportation cost which is incurred at one point only when the quantity supplied from one unit to another.

$$\text{Minimize } TC = \breve{f}_p \times \breve{f}_c \times Q_{fs1} \times \frac{\breve{d}_{fs1}}{\breve{C}_{vm}} + \breve{f}_p \times \breve{f}_c \times Q_{s1pt} \times \frac{\breve{d}_{s1pt}}{\breve{C}_{vm}} + \breve{f}_p \times \breve{f}_c \times Q_{pts2} \times \frac{\breve{d}_{pts2}}{\breve{C}_{vm}} + \breve{f}_p \times \breve{f}_c \times$$

$$\times Q_{s2pp} \times \frac{\breve{d}_{s2pp}}{\breve{C}_{vm}} + \breve{f}_p \times \breve{f}_c \times Q_{ppeu1} \times \frac{d_{ppeu1}}{\breve{C}_{vm}} + \breve{f}_p \times \breve{f}_c \times Q_{ppeu2} \times \frac{\breve{d}_{ppeu2}}{\breve{C}_{vm}}$$

Constraints

The constraints of given model is defined as:

– Capacity constraint

Quantity of raw material that shipped from Storage 1 to pretreatment should be less than or equal to the highest capacity of respective Storage 1:

$$\sum\sum Q_{s1pt} \le C_{s1}$$

Quantity that transferred from pretreatment to Storage 2 should be less than or equal to the highest capacity of respective pretreatment:

$$\sum\sum Q_{pts2} \le C_{pt}$$

Quantity that moved from Storage 2 to production plant should be less than or equal to the highest capacity of respective Storage 2:

$$\sum\sum Q_{s2pp} \le C_{s2}$$

– Balance constraints

Quantity supplied from production plant to end-users should be less than or equal to quantity which enter respective production plant from Storage 2 using any mode of transport:

$$\sum_{pp}\sum_{eu1} Q_{ppeu1} + \sum_{pp}\sum_{eu2} Q_{ppeu2} \le \sum_{s2}\sum_{pp} Q_{s2pp}$$

– Demand constraints

The demand constraint shows that amount shipped from production plant to end user 1 and end user should be equal to the expected demand from end user 1 and end user 2:

$$\sum_{pp}\sum_{eu1} Q_{ppeu1} = D_{eu1}$$

$$\sum_{pp}\sum_{eu1} Q_{ppeu2} = D_{eu2}$$

– Non-negative constraint

Quantity flowed from fields to Storage 1, Storage 1 to pretreatment, pretreatment to Storage 2, Storage 2 to production plant and production plant to end users using mode m of transport should be greater or equal to zero:

$$Q_{fs1},\ Q_{s1pt},\ Q_{pts2},\ Q_{s2pp},\ Q_{ppeu1}, \text{ and } Q_{ppeu2} \ge 0$$

Case study

In terms of latitude, Pakistan lies between 23 °N and 27 °N and in terms of longitude, it lies between 60 °E and 76 °E. Located in a geographically diverse region, Pakistan experiences all types of climates. December to February is the coolest and driest month, March to May is the hottest month, and mid-May to November is the summer and monsoon season [19]. With the country's population and economy growing rapidly, the federal government has been under constant pressure to fund and revise its energy portfolio. There are 39.7% of employed Pakistanis employed in the agriculture sector, which contributes 24 percent to the GDP [20]. Agricultural production contributes 60% of Pakistan's export earnings, providing raw materials for industry and a market for industrial products [21]. Among all biodegradable materials, biomass will contribute significantly to the current energy crisis in the country due to its widespread availability and decentralized nature.

Pakistan has a road network, railway system, air traffic, and shipping system. About 96% of freight in the country is transported via the road network, while 92% of passengers are transported via the road network. There are approximately 374054 km of roads in the country. In total, there are 14480 km of national highways and 3280 kilometers of motorways, which account for approximately 3.5% of the total road network. Total strategic routes and expressways amount to approximately 263 km [22]. In addition automobiles, buses, trucks, minivans, rickshaws, and others, the road network is used by a variety of vehicles [23].

There are many types in which biomass is treated and converted to usable product, different types of transport is used depending upon the conditions of road network and field area therefore, cost for the transfer of raw material for treatment varies. Furthermore, transportation of raw material for the production of two usable products natural gas and fuel is discussed in the paper.

As a developing nation, Pakistan is experiencing severe energy and economic crises at the moment. 202 million Barrels fuel and 1436261 million cubic feet of natural gas is annually consumed by the country. The amount of crude-oil imported by Pakistan each year is approximately 60 million barrels and 248550 billion cubic feet of natural gas every year. The agricultural nation of Pakistan produces a large amount of biomass every year which may prove to be a valuable raw material for future renewable green energy sources. Therefore, it might be a potential source of biofuel and Biogas in Pakistan. A substantial amount of both can be produced locally in Pakistan because the country produces 121 millionns of agricultural biomass and 200 millionns of animal manure (buffalo, cattle, sheep, and goats) and dropped by 1210 million poultry per year [24]. Fuel price, $\check{f}_p$, in Pakistan is 138 Rs per Liter.

Table 1. Fuel consumption and capacity of different vehicle

Vehicle	Fuel consumption $\check{f}_c$ [km per L]	Capacity of vehicle
Tractor	2.8	20 tons
Tanker	3.2	30000 Liter

During case study all the distances such as from fields to Storage 1, Storage 1 to pretreatment plant, pretreatment plant to Storage 2 then for production plant and distribution are all assumed values.

Table 2. Values of parameters distances from field to storage

Parameter	Distance [km]	Parameter	Distance [km]
$\check{d}_{fs1}$	20.0	$\check{d}_{s2pp}$	0.5
$\check{d}_{s1pt}$	1.9	$\check{d}_{ppeu1}$	2.3
$\check{d}_{pts2}$	1.5	$\check{d}_{ppeu2}$	3.0

Table 3. Storage capacities

Storage	Capacity
1	500000 tons
2	500000 tons

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Nomenclature

$\check{C}_v$ – capacity of vehicles using mode m
C_{s1} – storage capacity of Storage 1
D_{eu1} – demand at end user 1
D_{eu2} – demand at end user 2
$\check{d}_{fs1}$ – distance from fields to Storage 1
$\check{d}_{fs1pt}$ – Distance from Storage 1 to pre-treatment, [km]
$\check{d}_{fpts2}$ – distance from pre-treatment to Storage 2, [km]
$\check{d}_{fs2pp}$ – distance from Storage 2 to production plant, [km]
$\check{d}_{fppeu1}$ – distance from production plant to end user 1, [km]
$\check{d}_{fppeu2}$ – distance from production plant to end user 2, [km]
$\check{f}_p$ – fuel price in rupees
f_c – fuel consumption rate
Q_{fs1} – raw material quantity supplied from fields to Storage 1
Q_{s1pt} – quantity shifted from Storage 1 to pre-treatment
Q_{pts2} – quantity transferred from pre-treatment to Storage 2
Q_{s2pp} – quantity supplied from Storage 2 to production plant
Q_{ppeu1} – quantity transferred from production plant to end user 1
Q_{ppeu2} – quantity transferred from production plant to end user 2

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