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Cost minimization of supplying biomass for ethanol biorefineries

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ABSTRACT

A major hurdle facing commercial biofuel production is the cost of producing the feedstock. Since biofuel feedstock is bulky in nature, a large proportion of cost needed to be allocated for harvesting and transportation of feedstock. Economic viability of ethanol production from cellulosic feedstock depends in part of the cost to produce, harvest and deliver feedstock to the ethanol production facilities. A well-developed harvesting and transportation system does not exist for most feedstock. Hence to determine accurate estimation of the harvest, transportation and storage costs is important in ethanol production. The objectives of the study are to determine the optimal harvesting unit for ethanol biorefinery and estimate harvesting, storage and transportation costs of switchgrass under various harvesting schedules. A biorefinery with the annual capacity of processing 4.16 million gallons of ethanol was considered. Based on average dry matter yield, total production area needed for annual harvesting was estimated. The harvesting units needed for the continuous harvest and supply of biomass were estimated based on information on the capacity of machineries etc. Accordingly various costs associated with operating and maintaining harvesting unit were estimated. Transportation units needed were estimated for continuous supply of feedstock to the refinery and the associated costs were calculated.

The number of machinery needed for a harvesting unit for the 90 day harvesting schedule are the most while year round harvesting schedules needs lesser number of machinery for a harvesting unit. Harvesting switchgrass in 90 day schedule is the most expensive scenario with all harvesting, hauling and storage costs added together. Year round harvesting schedule occurs as the least costly scenario. Sensitivity analysis shows the positive trend for harvesting and hauling costs to biomass yield, ethanol conversion technology, distance and decreasing trend for the range of truck speed considered. The results generated in this study will be useful in designing optimal harvest schedule of biomass for ethanol biorefinery.

1. Introduction

Energy is the most important factor of production in economy around the globe, and 90% of energy being produced commercially, comes from the non-renewable sources [1]. The growing concern with rising oil prices and global warming and its consequences are the immediate justification for reducing dependence on fossil fuels [2]. Also, predicted shortage of fossil fuel in future has encouraged researchers to look in to alternatives of petroleum derivatives [3]. Currently the USA consumes 19 million barrels of petroleum per day [4], and 70% of these are used for transportation. Thus, research on an alternative for transportation fuel has become significant. Over 60% of the 19 million barrels of crude oil consumed in USA per day is imported [5]. Due to instability in oil market, it is crucial to discover alternate energy sources for future energy security. On the other hand, burning fossil fuels leads to concentrations of pollutants in water and air. It is the largest contributor of greenhouse gas emissions. This also is a justification for the need for alternate energy sources.

In recent past, many candidates for fossil fuel alternatives have been found and carefully evaluated [6]. Ethanol based biofuels produced from bioenergy feedstock is one notable alternative. Large amount of feedstock can be used to produce ethanol which are classified as first and second generation feedstock. In the first generation, ethanol is produced mainly from sugar and starch biomass. Lignocellulosic biomass represents the second generation feedstock [7].

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To reduce the dependency on petroleum, the U.S. government has imposed a series of regulations and policies to support biofuel production. For example, the United States Congress passed the Energy Independence and Security Act of 2007. This act mandates a minimum of 36 billion gallons of renewable fuel production annually by 2022 [8]. Following this act, a RIN (Renewable Identification Number) system was developed and executed by the U.S. EPA (Environmental Protection Agency) in 2010 to ensure compliance with this act [9]. The Billion Ton Report proposed that 30% of liquid transportation fuel be produced from renewable resources by 2030 [10]. To meet these goals, ethanol produced from corn kernels will not be sufficient hence need to explore wide range of suitable ethanol feedstock for various geographic regions.

2. Problem statement

Meanwhile, several concerns have been raised regarding the production of first generation biofuels. One major concern centers on the issue of higher food prices due to competition with food crops. As the commodity prices have increased significantly since 2006, the increasing demand by the biofuel sector for feedstock has been considered as one of the main contributors [11]. Some of the problems associated with first generation biofuels can be addressed by shifting to second generation biofuels, where the lignocellulosic feedstock is to be produced from perennial energy crops grown on arable land [7].

Switchgrass, a perennial warm-season grass native to the USA, is widely recognized as a primary lignocellulose feedstock based on its high biomass content, strong adaptability to various soil conditions, and its beneficial nature to the environment [12]. In the whole process of producing switchgrass for ethanol, harvesting and hauling cost counts for a large portion among all the expense categories. In general, biorefinery can be classified into three classes based on capacity namely, large, medium and small scales. According to the economy of scale, the production costs associated with these different levels of biorefinery are different. Researchers have evaluated various aspects of harvesting, hauling and storage cost, but have mostly focused on large and medium scales. Harvesting and hauling costs for supplying feedstock for small-scale ethanol biorefineries is rarely mentioned. The main objective of this study is to analyze the effect of timing on switchgrass harvesting and hauling cost for ethanol biorefineries. The paper present various scenarios and factors to be considered in designing harvest and hauling cost model for ethanol biorefinery; identify harvesting units needed and analyze the harvesting costs under different time schedules and also determine the hauling unit needed for efficient transportation of feedstock to ethanol biorefinery.

3. Methodology and data sources

Biomass production from switchgrass is considered for the harvesting and hauling cost model. Fig. 1 shows the flow of feedstock from fields to biorefinery [13]. The annual feedstock requirement depends on the capacity of ethanol plant. The focus for this study is on a biorefinery with the capacity around 5 million gallons/year.

Biomass harvesting unit consists of mowers, rakes, balers, field transporters, 150 hp tractors that can pull balers and 95 hp tractors that can pull mowers and rakes. Harvesting unit needed also depends on harvesting schedule. Accordingly, year round, 3 months and 6 months harvesting schedules were considered in the model. According to literature, a mower can harvest around 1.3 ha/hr (10.4 ha/day), assuming 8 working hours/day [13]. The average capacity of baler is 1.0 ha/day, and of rake is 1.7 ha/day. Considering various timing intervals, different harvest units were determined.

3.1. Hauling cost

There are different options for transporting harvested biomass to biorefinery. Biomass can be directly transported to the processing site using direct wagon pulled by tractors. If sufficient hauling units are not available, on farm storage facility is needed to store harvested biomass. For the year round harvesting schedule, three satellite storage locations are considered in the model. For a 40 km radius, the satellite storages are located at 13, 32 and 40 km radius. Storage at the site of biorefinery plants are considered for 3 months and 6 months harvesting schedule since storage on-site is considered more convenient and less costly due to large quantity of biomass. The storage site is assumed to have lifetime of 30 years.

The next option is to transport the biomass to storage facility using transfer wagons/ semi-trailers. The average capacity of a

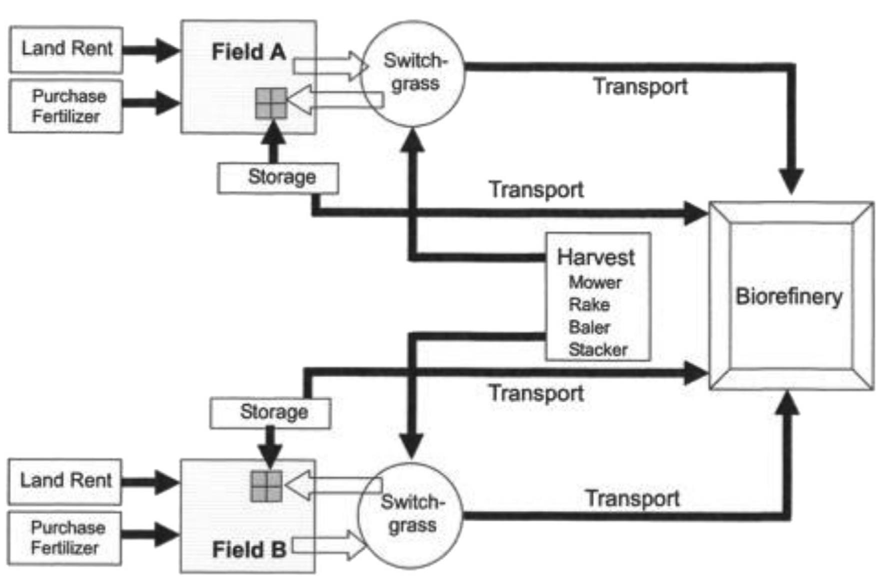

Fig. 1. Flow of switchgrass feedstock from fields to a biorefinery (adopted from Hwang, 2007).