Minimizing the Cost of Agriculture Waste for Cellulosic Biofuels

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ABSTRACT

Several studies have evaluated ways to reduce biomass cost through optimization of biorefinery location thus reducing biomass transport cost. While other studies have provided models for farmer supply response and participation (market structure), there is a gap in understanding how biomass transportation costs are related to farmer incentives. This study bridges this gap. A biomass cost model is developed to evaluate the trade-offs between biomass transport cost, incentives to farmers, farmer participation, biorefinery size, and alternative feedstock availability. This article finds that a focus on optimizing biomass transport cost and biorefinery location, without considering the relationships between biomass transport cost and farmer incentives increases biomass cost by 15% to 20%.

Key words: corn stover, supply market structure, biomass cost model, cellulosic biofuels

INTRODUCTION

The large availability of agriculture waste and its potential for energy has shifted attention to second generation biofuels produced from cellulosic biomass such as agricultural residue and perennial grasses [1]. Studies have found that biomass used for energy production, has a potential to deliver 33 to 1,135 EJyr for about 50 years worldwide [2]. The U.S. has over 1 billion tonnes of biomass available per year for cellulosic biofuels [3].

The cellulosic biomass supply chain involves growing and harvesting biomass, and then transporting biomass to a conversion plant.

Unlike corn grain, long distance transportation of stover is not economically feasible [4]. Additionally, large scale biomass storage over extended periods of time is challenging [5].

Collecting, transporting, and storing biomass materials are the majority of cellulosic biomass costs [6]. Farmers or growers expect incentives that allow them to generate positive returns on their investments. Incentives vary with the changes in market structure and regional supply and demand dynamics. Relationships exist between farmer participation and the types of incentives offered [7,8].

Several studies have developed biomass cost optimization models, using an integrated biomass transportation model [9,10,11]. Recent advances include optimization of the entire biofuel supply chain [12,13,14].

However, in the development of optimization models the relationships between farmer incentives and biomass transportation costs are often ignored. This study addresses this gap, by providing a model that considers the intricate relationships between biomass transport cost and farmer supply response. This model can be used by managers for evaluating trade-offs by considering the relationships between biomass transport cost, incentives to farmers, farmer participation, variation in stover supply, biorefinery size, and alternative feedstock availability. These variables allow biorefineries to minimize biomass costs and develop optimal supply chain designs. While the model focuses on agricultural waste (corn stover), it can also be applied to other sources of agricultural waste-based biomass.

BIOMASS COST COMPONENTS

The amount of agriculture waste (biomass) generated is proportional to crop yield [16]. However, a portion of the biomass produced cannot be collected and is abandoned on the ground, preventing soil erosion and allowing retention of soil organic carbon [16]. For simplicity, it is assumed that the biorefinery is located at the centre of a circular region as shown in Figure 1. Similar assumptions have been made by several other studies in literature [6,17,18]. Biomass supply region *R* depends on the amount of biomass available per unit area, or biomass yield density (t $ha^{-1}yr^{-1}$), and the size of the biorefinery (t yr^{-1}).

Cost components of any agriculture waste-based biomass can be divided into fixed and variable costs [19]. For our purposes, fixed costs are considered to be independent of biomass yield, while variable costs change with variations in biomass yields. These cost components are:

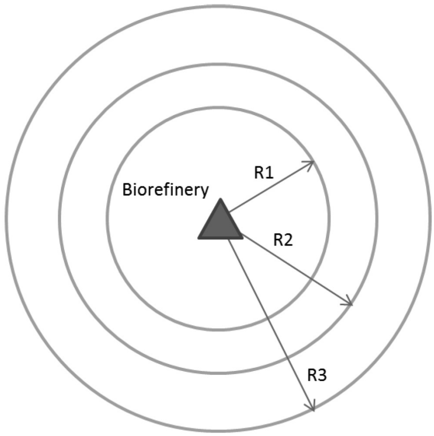

Figure 1. Biorefinery supply radius to meet capacity requirements.

Variable Costs

Biomass Transport Cost is dependent on the supply region (Figure 1), and therefore varies with changes in biomass yields that result in changes in supply radius. Incentives for farmers is their share of profit, which varies with changes in market structure and regional dynamics in supply and demand [7,11,20]. Studies have shown that removal of agricultural waste often results in increased use of fertilizers to compensate for the loss of soil nutrition, and to maintain soil organic carbon (SOC) [16]. Therefore, farmers would expect compensation for the biomass in proportion to the increased cost of fertilizer. Nutrition replacement costs is largely independent of biomass yield, but would vary with fertilizer prices [16,21,22,23].

Figure 2. Fixed and variable biomass costs.

Fixed Costs

The relatively fixed components of biomass cost consists of the costs of biomass harvesting, storage and handling [7,9,11,20]. The variable biomass cost can therefore be derived as:

$$Biomass\ Cost = Transport\ Cost + Incentives + Nutrition\ Cost + Fixed\ Cost \qquad (1)$$

Biomass Transport Cost

Several studies have provided a general framework for determining biomass transport cost when the biorefinery is located at the centre of a circular region as shown in Figure 1 [17]. Using results from these studies, we express biomass transport cost as:

$$\boldsymbol{Biomass\ Transport\ Cost} = 0.75\,\tau\,\beta\,(\phi\,\boldsymbol{M})^{-0.5}\,\boldsymbol{S}^{0.5} \qquad (2)$$

Where:

ϕ farmer participation rate

τ Tortuosity Factor or ratio of actual road distance to straight line distance

β unit transport cost of stover ($\$\ t^{-1}\ km^{-1}$)

S biorefinery capacity ($t\ yr^{-1}$)

M The density of corn stover distribution

Using equation 2, variation in transport cost with biomass yield (availability) is modelled for the U.S. county of Champaign, Illinois, using 1990-2013 data of corn grain yields (Figure3).

The results in Figure 3 show that the relative standard deviation (RSD) of transport cost is less than the corresponding variation in biomass yields.

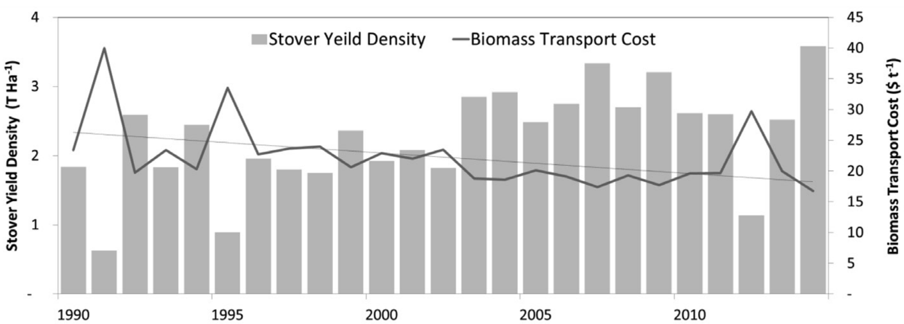

Figure 3. Variations in stover yield density M vs. biomass transport cost. The bars are collectable stover yield densities M for the county of Champaign, in Illinois U.S. (f = 25%, S = 500kt yr^{-1}). The solid line is the corresponding stover transport cost.

Farmer Incentives *N*

A relationship exists between farmer participation *f* and farmer incentives *N* [8]. Higher incentives enable more farmers to overcome the barriers to market entry. Using data from a survey result in a U.S. corn district of Iowa [7], the empirical relationship between incentives offered and farmer participation is assumed as linear.

$$\phi = \mathrm{b}\, N. \tag{3}$$

Nutrient Replacement Cost *Q*

Studies have shown that removal of agricultural waste results in increased use of fertilizers to compensate for the loss of soil nutrition and to maintain SOC [16]. Therefore, farmers expect compensation for the biomass in proportion to the increased cost of fertilizer. The fertilizer price index is obtained from the U.S. Department of Agriculture, and normalized for consumer price inflation data obtained from the U.S. Bureau of Statistics. Assuming a 2015 nutrient price of \$15 t^{-1} for corn stover [16], the variation in nutrition replacement costs resulting from the variation in fertilizer price can be modelled (see Figure 4).

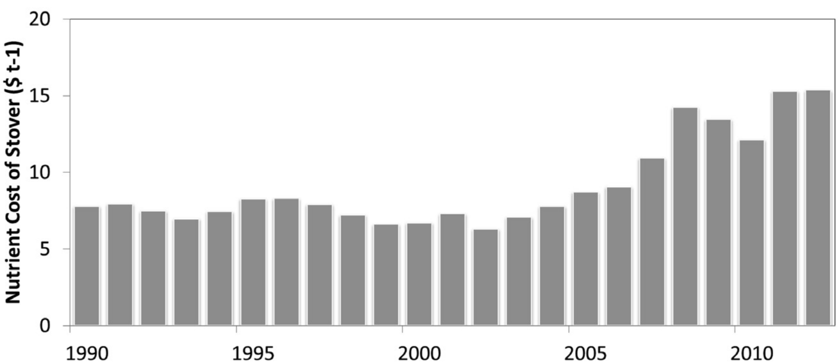

Figure 4. Variation in nutrient replacement cost of corn stover.

MINIMIZING BIOMASS COST

Equations 2 and 3 show that the variable components of biomass cost are linked by an intricate relationship, such as:

$$Biomass\ Cost = \underbrace{\left(0.75\, \tau\, \beta \left(\mathrm{M}\,(\mathrm{b}_1\, N)\right)^{-0.5} \mathrm{S}^{0.5}\right)}_{A} + \underbrace{N}_{B} + \underbrace{(Q)}_{C}, \tag{4}$$

Where:

Term A: Transport cost
Term B: Incentive to Farmer
Term C: Nutrient Replacement Cost and Fixed Cost

Equation 4 is simulated for different values of incentive ***N*** and biomass yield ***M*** (Figures 4 and 5).

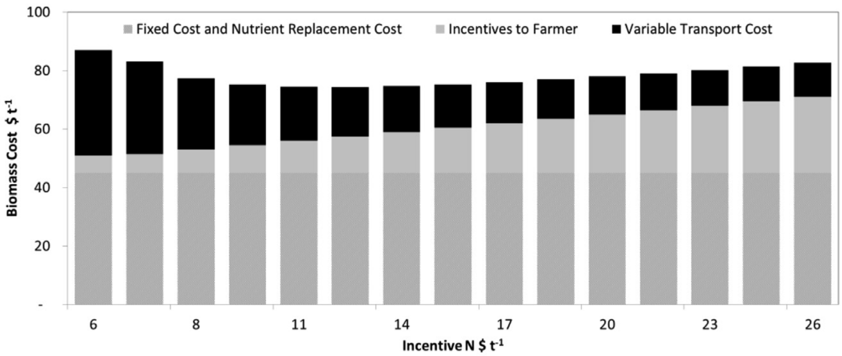

Figure 5. Biomass cost simulated for different values of incentive *N* (constant biorefinery size of 500 kt yr^{-1}, constant biomass yield density *M* of 2.5 t ha^{-1}).

Results in Figure 5 shows that a trade-off exists between biomass transport cost and incentives offered to farmers, and there is an incentive ***N*** that will result in the lowest biomass cost. Managers who only focus on minimizing biomass transport cost (right end of Figure 5), or managers who only focus on minimizing incentives (left end of Figure 5), will ultimate pay 15 to 20% more for biomass.

CONCLUSIONS

Biorefineries and farmers venturing into the cellulosic biofuel industry will require supply market strategies, supply contracts, and supply chain designs that minimize biomass costs. Previous studies have focused on optimizing biomass cost, without considering the relationships between biomass transport costs and farmer incentives. This study determined that an intricate relationship exists between biomass transport costs and farmer incentives, and that minimal biomass costs can be achieved by considering these relationships between the variables. Managers who only focus on minimizing biomass transport costs or managers who only focus on minimizing incentives, without considering the relationships among the elements will ultimately pay 15 to 20% more for biomass. In developing long term supply contracts between biorefinery and farmers, managers should consider optimizing the trade-offs between biomass transport costs, incentive to farmers, farmer participation, variation in stover supply, biorefinery size, and alternative feedstock availability.

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Rajdeep Golecha is an industry expert in bioenergy. His expertise is in business portfolio development for a sustainable biofuel businesses, and commercial optimization to reduce input costs. He has served as the commercial manager for a major energy company's multi-billion dollar biofuel portfolio, where he led the development of cellulosic biofuel projects, and instituted improvements to capital efficiency and reduction in feedstock (biomass) costs through effective feedstock supply and business strategies. His current focus is on developing optimal market structures for cellulosic biofuel programs. He has an MBA from Michigan State University, and a Mechanical Engineer. E-mail: rajdeep.golecha@gmail.com.