Transportation Research Part A 49 (2013) 48–61

Contents lists available at SciVerse ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Cost analysis for high-volume and long-haul transportation of densified biomass feedstock

Daniela Gonzales, Erin M. Searcy, Sandra D. Ekşioğlu *

Department of Industrial and Systems Engineering, Mississippi State University, P.O. Box 9542, Mississippi State, MS 39762, United States

ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form 12 December 2012
Accepted 3 January 2013

Keywords:
Densified biomass
Barge transportation
Rail transportation
Truck transportation
Regression analysis

ABSTRACT

Using densified biomass to produce biofuels has the potential to reduce the cost of delivering biomass to biorefineries. Densified biomass has physical properties similar to grain, and therefore, the transportation system in support of delivering densified biomass to a biorenery is expected to emulate the current grain transportation system. By analyzing transportation costs for products like grain and woodchips, this paper identifies the main factors that impact the delivery cost of densified biomass and quantifies those factors' impact on transportation costs. This paper provides a transportation-cost analysis which will aid the design and management of biofuel supply chains. This evaluation is very important because the expensive logistics and transportation costs are one of the major barriers slowing development in this industry.

Regression analysis indicates that transportation costs for densified biomass will be impacted by transportation distance, volume shipped, transportation mode used, and shipment destination, just to name a few. Since biomass production is concentrated in the Midwestern United States, a biorefinery's shipments will probably come from that region. For shipments from the Midwest to the Southeast US, barge transportation, if available, is the least expensive transportation mode. If barge is not available, then unit trains are the least expensive mode for distances longer than 161 km (100 miles). For shipments from the Midwest to the West US, unit trains are the least expensive transportation mode for distances over 338 km (210 miles). For shorter distances, truck is the least expensive transportation mode for densified biomass.

1. Introduction

Several studies focus on the feasibility of increasing renewable energy production in response to the Energy Independence and Security Act (EISA) of 2007. As stated in the Renewable Fuel Standard (RFS) program, the minimum level of renewable fuels used in the US transportation industry is expected to increase from 9 billion gallons per year (BGY) in 2008 to 36 BGY in 2022 (EPA, 2012). Renewable energy should supplant conventional fossil fuel use and consequently decrease US dependence on foreign oil. A number of issues make attaining those goals a challenge including the lack of an efficient technology to convert biomass to biofuel, the uncertainty of biomass supply, and the high logistics costs for delivering biomass to biorefineries (Petrolia, 2008; Hess et al., 2009).

In order to minimize logistics costs, the production of first generation corn- and soybean-based biofuels has mainly relied on local biomass resources. Raw biomass, such as baled herbaceous biomass, is bulky, aerobically unstable, and has poor flowability properties, all of which pose logistics challenges and increase supply chain costs. In order to minimize transpor-

* Corresponding author. Tel.: +1 662 325 9220; fax: +1 662 325 7012.
E-mail address: sde47@msstate.edu (S.D. Ekşioğlu).

0965-8564/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tra.2013.01.005

tation related costs, the traditional supply chain model used by corn-based biorefineries locates biorefineries within an 80 km (50 mile) radius of corn farms (Aden et al., 2002). The limited amount of biomass available within this collection radius does not justify investments in large-scale biorefineries. Consequently, traditional biorefineries have low production capacities and do not benefit from the economies of scale associated with high production volumes (Searcy and Flynn, 2008). This is one of the reasons why biofuels have not been cost competitive with fossil fuels. The production of first generation biofuels has also initiated a nation-wide debate on food versus fuel.

Second generation biofuels utilize agricultural and forest residues, and energy crops as feedstock. Yet, first and second generation biofuels have different properties than conventional fossil fuels, such as high acidity, high moisture content, or high oxygen content. Due to these properties, fuels with a high concentration of ethanol, such as E85, can corrode some types of metal and can make some plastics brittle over time. As a consequence, today's vehicles cannot run on highly concentrated ethanol blends. Additionally, the pipeline system currently in place for fossil fuel transportation cannot be utilized for transporting biofuels. The next generation of biofuels, referred to as drop-in fuels, is expected to overcome those challenges and will become interchangeable with conventional fossil fuels.

However, all types of biobased energy will continue to face biomass feedstock transportation and other logistics challenges, mainly due to physical characteristics of raw biomass. Recent reports published by the Idaho National Laboratory (INL) propose a commodity-based, advanced biomass supply chain design concept to support large-scale production of biofuels (Hess et al., 2009; Searcy and Hess, 2010). This design concept is substantially different from the feedstock logistics model utilized by conventional biorefineries and moves preprocessing of raw biomass, e.g., operations such as drying and densification, to earlier stages in the supply chain. Preprocessing increases the bulk density of the material, resulting in a densified, pellet-like product. This paper refers to the product as densified biomass as opposed to pelletized biomass, since the latter is a specific process. Handling and transportation costs for densified biomass are lower than for raw biomass. Thus, using high capacity transportation for long-hauls becomes an option worth investigating. High capacity transportation gives biorefineries the opportunity to increase the biomass collection radius past 80 km (50 miles), and as a consequence, increase biomass availability and reduce feedstock supply risk. A recent study by Searcy and Flynn (2008) indicates that the theoretical optimum size for an ethanol plant using corn stover as a feedstock, assuming a yield of 0.32 metric tons per hectare, is approximately 220 million gallons per year (MGY). These results are consistent with Wright and Brown (2007), which states that, depending on the conversion technology used, the theoretical optimal size for corn-based ethanol plants is 79 MGY and 240–486 MGY for lignocellulosic-based ethanol plants. Wright and Brown (2007) assume: (a) a typical/average biomass yield per acre, and (b) biomass yield and availability are consistent within the plant-draw radius. Due to very high capital costs compared to conventional biorefineries, advanced biofuel plants should operate at high capacity in order to be economical. The annual biomass processed by such a plant is expected to be 4.7–7.8 million tons annually. This corresponds to receiving 513–852 truck shipments of biomass daily, the equivalent of receiving 120–200 rail cars daily or 9–15 barges daily. In order to supply so much biomass, transportation modes that are economical for shipping large volumes of densified biomass over long distances, such as rail and barge, should be utilized. Additionally, using barge and rail does not impact traffic in the communities around the biorefinery and consequently does not raise traffic-safety challenges.

Fig. 1 presents the distribution of population and biomass by US states. The figure presents only those 14 states with a big gap between the amount of biomass available and the population size. For example, 12% of the nation's population lives in California, yet only 0.59% of the available biomass for production of biofuels is found in California. Only 0.97% of the country's population lives in Iowa, yet 13% of US biomass is available in Iowa. Fig. 1 shows that the majority of the population lives in the East and West US; however the majority of the biomass is available mainly in the Midwest and South. As a result, long-haul delivery of biomass or biofuels is needed to satisfy fuel demand.

Locating biorefineries closer to demand rather than supply is not a new concept. Pacific Ethanol, for example, is located closer to demand in California, and Oregan. The company receives shipments of corn by rail from the Midwest. Using high capacity transportation modes such as unit rail and barge, for high-volume and long-haul shipment of biomass results in increased biomass supply at biorefineries. Increases in cost due to the long-haul transportation of biomass should be compensated by the savings coming from the economies of scale in biofuel production, savings resulting from shorter transportation distances to deliver biofuel to customers and the reduced risk innate to having access to a larger pool of suppliers.

The goal of this paper is to analyze the impact of rail, truck and barge transportation on transportation costs of densified biomass. The existing literature details transportation-cost analysis for densified biomass in the form of pellets, cubs and bales when shipped by trucks (Sokhansanj and Turhollow, 2004, 2006; Badger and Peter, 2006; Rogers and Brammer, 2009). Literature discussing pipeline transportation (Searcy et al., 2007; Ileleji et al., 2010; Judd et al., 2011), and rail transportation of biomass (Mahmudi and Flynn, 2006; Searcy et al., 2007; Bonilla et al., 2009; Sokhansanj et al., 2009; Ileleji et al., 2010; Judd et al., 2011) has also been explored. Rail transportation studies mainly discuss distance-based fuel costs and load/unload costs per ton of biomass. However, our research suggests that no studies exist on transportation of densified biomass by barge. Our research contributes to the existing literature by providing a thorough analysis of the main factors which impact transportation cost for densified biomass in the US through barge and rail. Some of the biggest factors affecting cost include railcar ownership, railway service provider, competition with other transportation modes, and shipment origin and destination. This paper proposes a number of regression equations which can be used to estimate rail transportation costs. These equations are developed using actual tariffs charged by railway companies for products which have similar characteristics to densified biomass. This is important because the data set used consist of existing tariffs similar to what biofuels industry will be facing.