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A supply chain network design model for biomass co-firing in coal-fired power plants

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ABSTRACT

We propose a framework for designing the supply chain network for biomass co-firing in coal-fired power plants. This framework is inspired by existing practices with products with similar physical characteristics to biomass. We present a hub-and-spoke supply chain network design model for long-haul delivery of biomass. This model is a mixed integer linear program solved using benders decomposition algorithm. Numerical analysis indicates that 100 million tons of biomass are located within 75 miles from a coal plant and could be delivered at $8.53/dry-ton; 60 million tons of biomass are located beyond 75 miles and could be delivered at $36/dry-ton.

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1. Introduction

Co-firing biomass with coal is an attractive energy generating option for several reasons. First, co-firing increases renewable energy production without major capital investments. For example, biomass is typically used for production of cellulosic biofuels. However, investment and processing costs necessary for production of cellulosic biofuel are very high (Wallace et al., 2005). Biomass co-firing uses the existing coal-fired power plant infrastructure. This results in savings on investments in the infrastructure which is necessary to supply biomass. Second, co-firing is a low-risk option for production of renewable energy since the risk associated with major capital investments and uncertain raw material supplies is much smaller as compared to other alternative uses of biomass. Third, co-firing results in reduced emissions of oxides of sulfur (SO_2), nitrogen (NO_2) and fossil carbon dioxide (CO_2) per unit of energy produced as compared to using coal only. Coal combustion contributes significantly to air pollution through emission of SO_2, and NO_2, which lead to acid rain and ozone depletion. On the other side, woody biomass contains virtually no sulfur. Biomass absorbs CO_2 during growth, and emits it during combustion, thus, biomass has a zero net greenhouse effect (Demirbas, 2003). Fourth, co-firing minimizes waste (such as, wood waste, agricultural waste) and the environmental problem associated with its disposal. Finally, co-firing is a near term market for biomass. It is expected that biomass will be used to produce electricity in the near future for a number of reasons. Coal plants can handle co-firing of biomass in amounts equivalent to displace 10% of their capacity without having to replace existing boilers. This fact and the numerous policies and incentives at the Federal and State level are expected to increase generation of electricity from renewable resources, such as biomass. Policies at the Federal level such as the renewable

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energy production tax credit (PTC) provide an income tax credit of 2.2 cents/kW h. At the State level policies such as the California's renewable portfolio standards (RPS) "requires investor-owned utilities, electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33% of total procurement by 2020." As of January 2012, 30 States and the District of Columbia have enforceable RPS or other mandated renewable capacity policies (EIA, 2013).

A number of studies support co-firing of biomass. For example, Baxter (2005) shows that biomass-coal co-combustion at 25% biomass is a low-risk, low-cost, sustainable, renewable energy option that reduces greenhouse gas (GHG) emissions. Goerndt et al. (2012) estimate that co-firing, using the physically available woody biomass, could replace 11% of the electricity generated in northern USA. Heller et al. (2004) estimate that co-firing at 5% and 15% levels reduces CO_2 emissions by 5.4% and 18.2% respectively. Tillman (2000) demonstrates that a moderate coal-biomass co-firing ratio can mitigate the risks associated with slagging and fouling of the combustor. Tillman (2000) and NETBIOCOF (2006) show that the impact of low levels of biomass co-firing on conversion efficiency is modest. The Annual Energy Outlook (EIA, 2013) projects that, electricity production from using biomass will increase from 37.26 billion kW h in 2011 to 131.89 billion kW h in 2040 (see Fig. 1). Hansson et al. (2009) argues that biomass co-firing will become a major contributor to meeting the renewable energy production goals of European Union. In summary, generating electricity from biomass co-firing has potential.

Although co-firing of biomass is a cost-efficient option for production of renewable energy, it does not eliminate the logistics and transportation costs associated with supplying biomass to a coal plant. Transportation and logistics costs of biomass supply are high due to the physical characteristics of biomass. Biomass has low density and poor flowability properties; it is bulky, heterogeneous, and unstable by nature. In addition, biomass suppliers are typically small or medium sized farms, which are widely dispersed geographically. For these reasons, processes such as loading, unloading and transportation of biomass are challenging and expensive.

Biomass has been identified as a source of renewable energy which will contribute to achieving the goals set by the Energy Independence and Security Act 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 9.0 billion gallons per year (bgy) in 2008 to 36 bgy in 2022 (EPA, 2012). The production of renewable energy comes with challenges, one of which, as in the case of co-firing, is managing biomass supply. In response to these challenges, researchers are looking into minimizing biomass supply costs by improving biomass supply chain and logistics related activities.

The goal of this paper is to identify the amount of coal that can be displaced efficiently in the USA using biomass, and estimate the corresponding costs. For this purpose a framework that integrates two supply chain design models. One of the designs allows a coal plant to receive biomass shipments from suppliers located nearby, i.e. within 50–75 miles. This model is consistent with that used to supply corn to ethanol production plants. The second design allows coal plants to receive shipments from suppliers located nearby using trucks, and suppliers located further away using rail. Such a model will enable the delivery of high volume of biomass. This model is consistent with the biomass delivery system proposed by the Idaho National Laboratory (INL) (Hess et al., 2009). This system relies on densifying biomass at local preprocessing facilities. Densified biomass refers to biomass that has undergone preprocessing to increase the bulk density of the material. Although densification can result in either a liquid or solid material, in this paper we will assume that the densified product is a bulk solid, such as a pellet and briquette. Densifying transforms biomass into a stable, dense, and flowable commodity, which is easier to load, unload and transport. Densified biomass is delivered by trucks to a centrally located depot – a consolidation point – from where high-volume shipments are delivered to biorefineries. Depending on the distance traveled, rail or trucks can be used to deliver densified biomass to a biorefinery (Hess et al., 2009). We use an extension of the hub-and-spoke network design problem (Aykin, 1995) to model this biomass supply system.

The hub-and-spoke biomass supply system relies on using the existing high-capacity infrastructure that is in place for transport of products that have similar physical properties to densified biomass, such as, grain and wood chips. In-bound shipments of biomass from nearby suppliers rely on truck transportation. Suppliers located further away use unit train

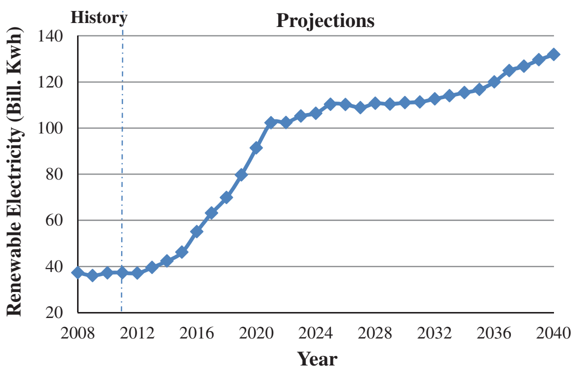

Fig. 1. Production of electricity from using biomass (EIA 2013).

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