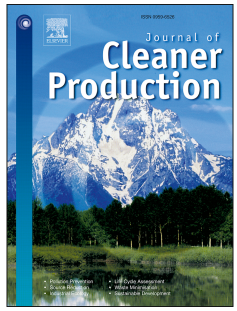

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Reducing the Cost and Environmental Impact of Integrated Fixed and Mobile Bio-Oil Refinery Supply Chains

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Abstract **Wordcount: 8,784**

The call to decrease reliance on fossil fuels to reduce impacts on the environment and improve energy independence has created new duties and responsibilities within society. As one approach, mobile bio-oil refineries have been developed to facilitate the production of bio-oil near the source of underutilized forest harvest residues. These mobile refineries are expected to improve the robustness of woody biomass to bio-oil supply chains by reducing overall supply chain costs and environmental impacts. The use of mobile refineries in combination with large-scale non-mobile refineries, however, must be examined to better understand the potential economic and environmental benefits and drawbacks of such a supply chain. The research presented herein develops a mathematical model capable of helping decision makers in determining the optimal combination and location of fixed refineries and mobile refineries for a known quantity of woody biomass and a given set of harvesting locations by considering capital, operational, and transportation costs. A hypothetical case for northwest Oregon, USA is applied to verify the mathematical model. The supply chain environmental impacts are assessed by considering the carbon footprint of the transportation activities and the bio-refinery infrastructure. The results indicate that the use of a mobile refinery along with a fixed refinery is more suitable when transportation costs and distances increase. It is also found that the capital intensity of mobile refineries can influence the importance of their role. High capital cost can be detrimental to their application within a mixed-mode bio-oil supply chain.

Keywords: Supply Chain, Bio-oil, Woody Biomass, Environmental Impacts, Mobile Refinery, Carbon Footprint

1. Introduction

Due to the increasing cost of fossil fuels, their impacts on the environment, and an increasing call for energy independence, many countries are focusing on technology and policy mechanisms for substituting fossil sources with renewables, e.g., biomass, wind, and hydro, to achieve improved energy sustainability performance. According to the U.S. Energy Information Administration, the fossil fuel share of total energy use will decrease from 82% in 2011 to 78% in 2040, while the renewables share, including bio-fuels, is expected to increase from 9% to 13% in the same time period (USEIA, 2014). Bio-oil can be produced from forest harvest residues (FHR). Bio-oil from woody biomass (WB) is a potential energy source in terms of reduced social, environmental, and economic impacts since it is a by-product of harvesting, represents a fire hazard, impedes planting of seedlings, harbors rodents that eat seedlings, and its combustion is considered carbon neutral (Page-Dumroese et al., 2009; Steele et al., 2012), particularly when compared to conventional disposal methods using fire. The main applications of bio-oil include combustion in engines, turbines, and boilers, as well as production of chemicals, transportation fuels, and hydrogen (Czernik and Bridgwater, 2004; Bridgwater, 2012; Kersten and Garcia-Perez, 2013). Optimization of biomass to bio-oil supply chains (SCs), however, is required to assist industry in supplying the market with a product cognizant of the three domains of sustainability, i.e., economic, environmental, and social (Mullaney et al., 2002).

The research herein is motivated by the premise that bio-oil can be considered an economically and technically feasible alternative for fossil fuel-based applications. Current bio-oil output is not sufficient to meet societal demand, however, due to high costs of FHR transportation and the scarcity of bio-oil refineries (Searcy et al., 2007). A recent comprehensive study concluded that the conversion process itself, in addition to the SC barriers, is inhibiting commercialization of bio-refineries (Sharma et al., 2013). The application of small scale and transportable bio-oil refineries has been investigated in recent years to more economically produce greater quantities of bio-oil. Mobile refineries (MRs) have been fabricated to be placed in the forest to produce bio-oil from FHR (Badger and Fransham, 2006). It is posited that if MRs can be utilized in a SC along with fixed (non-mobile) refineries (FRs), the limitations of producing a sufficient volume of bio-oil can be overcome, and this source of renewable energy can be deployed more effectively and efficiently.

To improve the robustness of bio-oil SC networks and to be able to respond to rapid growth in fuel consumption, different SC schemes consisting of combinations of current technologies and techniques are required. As such, mixed-mode bio-oil SCs, including the utilization of both FRs and MRs, can be part of the solution to meet increasing consumer fuel demands, while mitigating the impacts associated with fossil fuels. Previous research has proposed approaches to improving biomass