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A techno-economic analysis of using mobile distributed pyrolysis facilities to deliver a forest residue resource

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HIGHLIGHTS

- A model of harvesting forest residues using mobile pyrolysis facilities is created.
- Delivered feedstock costs are examined against conventional woodchip delivery.
- Transport requirements are reduced when using mobile facilities.
- Delivering torrefied wood is the lowest cost pathway when using mobile facilities.
- Using mobile facilities can be cost competitive with woodchip delivery.

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ABSTRACT

Distributed mobile conversion facilities using either fast pyrolysis or torrefaction processes can be used to convert forest residues to more energy dense substances (bio-oil, bio-slurry or torrefied wood) that can be transported as feedstock for bio-fuel facilities. Results show that the levelised delivered cost of a forest residue resource using mobile facility networks can be lower than using conventional woodchip delivery methods under appropriate conditions. Torrefied wood is the lowest cost pathway of delivering a forest residue resource when using mobile facilities. Cost savings occur against woodchip delivery for annual forest residue harvests above 2.5 million m^3 or when transport distances greater than 300 km are required. Important parameters that influence levelised delivered costs are transport distances (forest residue spatial density), haul cost factors, and initial moisture content of forest residues. Relocating mobile facilities can be optimised for lowest cost delivery as transport distances of raw biomass are reduced.

1. Introduction

Climate change concerns and government policies aimed at reducing greenhouse gas emissions from fossil fuels continue to contribute to an increasing demand for fuels from biomass sources. Forestry residues are an underused biomass resource that have considerable potential for increased utilisation – at present, most are burned on-site at the end of commercial forestry operations. However, like many biomass feedstocks, forest residues suffer from low spatial and energy densities. Typically, forest residues are spread-out over wide areas of land, thus large distances are travelled for collection and delivery to bio-fuel production facilities. If forest residues are transported in their raw form or as woodchips, truck capacity is limited by volume rather than weight and, as a result, more delivery trips are required than if the truck were transporting a more energy dense substance at full weight capacity (Sultana and Kumar, 2011). The combination of low spatial and energy densities of biomass results in high transport costs which, in turn, elevate the final bio-fuel production cost.

One proposed method to reduce the cost of delivering a biomass resource is to implement a network of distributed biomass conversion facilities near the location of forest residues (Badger and Fransham, 2006). These conversion facilities convert raw biomass to a more energy dense substance, which is then transported longer distances to a centralised bio-fuel production facility. Mobile facilities are of particular interest as forest residues are not consistently available at the same location for long periods of time. Mobile distributed conversion facilities (‘mobile facilities’) can be moved from a depleted region and relocated to a region with abundant forest residues. Relocating mobile facilities reduces transport distances of raw biomass material.

Two processes that are suited for mobile facilities are fast pyrolysis and torrefaction. These are both forms of pyrolysis, which is the thermal decomposition of materials in the absence of oxygen.

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Fast pyrolysis involves high heating rates and short reaction times producing primarily a liquid bio-oil product (Bridgwater, 2012). Torrefaction occurs at lower temperatures than fast pyrolysis and the principal product is a solid char-like substance known as torrefied wood (Acharya et al., 2012). The energy and mass densities of the liquid and solid products are typically higher than that of forest residues or woodchips.

Fast pyrolysis has been the focus of many recent studies (e.g. Oasmaa et al., 2010; Bridgwater, 2012), including techno-economic analyses (e.g. Bridgwater et al., 2002; Wu et al., 2010; Rogers and Brammer, 2012). However, most studies focus on permanent distributed fast pyrolysis facilities and few have considered mobile distributed fast pyrolysis facilities. Research addressing torrefaction technology and its economic advantage for biomass applications is garnering attention (e.g. Uslu et al., 2008; Chew and Doshi, 2011; Phanphanich and Mani, 2011; Acharya et al., 2012), although no literature has been identified that focuses on mobile distributed torrefaction facilities.

This paper investigates the technical and economic impact of using mobile facilities to deliver a forest residue resource to a bio-fuel facility. A model is created to simulate four pathways (Fig. 1a) of delivering a forest residue resource to a bio-fuel facility gate: (i) woodchips (ii) bio-oil (iii) bio-slurry (i.e. a mixture of bio-oil and bio-char) and (iv) torrefied wood. Furthermore, the model includes two point-of-delivery scenarios (Fig. 1b) to account for situations when the bio-fuel facility is either located within or at a distance from the forested region. The model is described in detail in Section 2.

Both fast pyrolysis and torrefaction are well suited for mobile applications. It is possible for each process to be sustained using its reaction products to meet thermal and energy requirements of the system. Therefore, the reaction can continue independently and does not require an electrical grid connection. At present there are no commercial mobile facilities available for either process, although designs for such systems have been made and several pilot projects are in operation (Preto, 2005; Renewable Fuel Technologies, 2011).

Fast pyrolysis and torrefaction are described in Sections 1.1 and 1.2, respectively. The current status of each process and the specifications for the mobile facilities used in this study are also provided.

1.1. Fast pyrolysis

Pyrolysis is the thermal decomposition of materials in the absence of oxygen (Mohan et al., 2006). The products of pyrolysis reactions comprise solid char, liquid bio-oil and syngas, which is a mixture of H_2, CO, CO_2, and CH_4. The relative quantity and composition of each product depend on operating conditions, such as reaction temperature, residence time, use of catalysts, as well as the feedstock type.

To obtain a high liquid product yield, fast pyrolysis is used. Fast pyrolysis requires temperatures of 500–650 °C and feed particles less than 3 mm in diameter (Mohan et al., 2006; Rogers and Brammer, 2012). The feed particles are resident in the reactor for 2–3 s, and the vapours produced are condensed into bio-oil. High bio-oil yields of up to 80 wt% can be achieved (Xiu and Shahbazi, 2012).

There are many types of reactor systems that perform fast pyrolysis including fluidised bed, circulating fluidised bed, auger, rotating cone and ablative, of which the first three have a strong technical grounding and are most attractive for commercial development (Butler et al., 2011). Auger pyrolysis has been selected as the reactor for this study because it has been suggested as an option for mobile facilities (Sorenson, 2010).

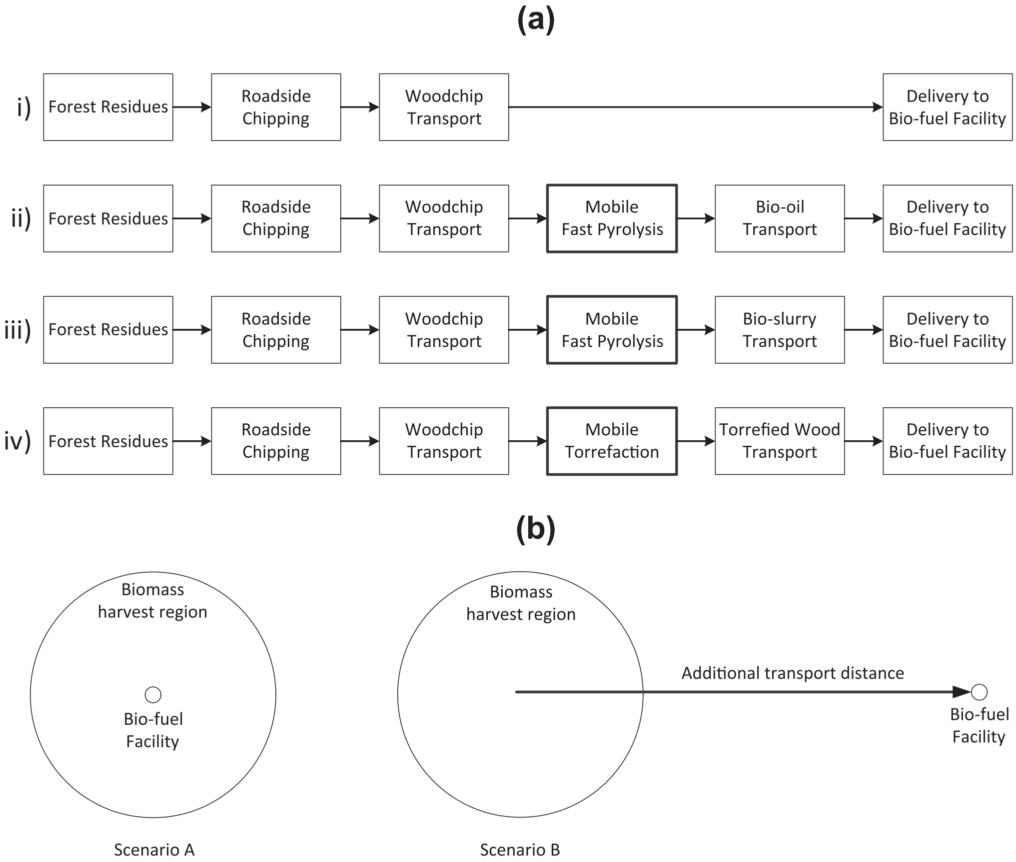

Fig. 1. (a) The four pathways to deliver a forest residue resource to a bio-fuel facility considered in this study. (b) Point-of-delivery scenarios.