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Economic evaluation of decentralized pyrolysis for the production of bio-oil as an energy carrier for improved logistics towards a large centralized gasification plant

Konstantinos Braimakis [a], Konstantinos Atsonios [a,b], Kyriakos D. Panopoulos [b,*], Sotirios Karellas [a], Emmanuel Kakaras [a,b]

[a] Laboratory of Steam Boilers and Thermal Plants, National Technical University of Athens, 9, Heroon Polytechniou Street, 15780 Zografou, Greece
[b] Chemical Process and Energy Resources Institute, Centre for Research and Technology Hellas, 6th Klm. Charilaou - Thermi Road, GR - 570 01, Thermi, Thessaloniki, Greece

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ABSTRACT

In the present study, the potential of biomass-to-bio-oil conversion as an intermediate process step to increase product energy density and subsequently decrease transport-related costs is examined. The scheme under investigation consists of two steps; (1) decentralized bio-oil production from biomass gathered from a certain area and (2) transportation of the produced bio-oil to a central destination (bio-refinery, power plant, etc.). The supply chain is compared to one based on direct solid biomass transportation from the circular source to the central plant. The best case scenario of the biomass-to-bio-oil conversion scheme involves an 80 dry t/h fast pyrolysis unit and utilization of the by-product char for electricity production, while the bio-oil is transported by pipeline. For central transportation distances ranging from 100 to 500 km, the centralized unit yard cost of woodchips-derived bio-oil is equal to 0.030–0.035 €/kWh$_{th,}$ while the respective cost for directly transported biomass varies between 0.015 and 0.024 €/kWh$_{th}$. It can therefore be concluded that the capital and operating costs of fast pyrolysis units are still high, hindering any benefits from cost-effective transportation of the bio oil.

Contents

* Corresponding author.
E-mail address: panopoulos@certh.gr (K.D. Panopoulos).

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1. Introduction

The upgrade of low energy density solid biomass to liquid bio-oil from 0.1 to 0.8 t/m^3 [1,2] to 1.2 t/m^3 [1–4] and from 1.5–14.8 GJ/m^3 [1,2,4] to 20.4–26 GJ/m^3 [1,2,5–7] through the fast pyrolysis process has become extensively investigated. The use of biomass as a fuel for bio-refineries and power plants is associated with high transportation costs, mainly due to its relatively low energy density [2,8,9], which is approximately 1/8th of that of coal [9]. Kumar et al. [10,11] have shown that the cost of biomass transportation in a biomass-to-ethanol conversion scenario is between 25% and 50% of the total production cost. For the production of electricity, transport costs can reach values from 25 to 45% of the total electricity production cost [9].

A much discussed way to overcome this issue is the decentralized conversion of the locally produced solid biomass to bio-oil, a liquid product of much higher energy density (up to 7 times [2]) and better fuel quality, through the fast pyrolysis process [1,2,12,13]. Apart from its higher bulk density, ranging between 8 and 12 times that of biomass, bio-oil exhibits some additional advantages such as better handling and storing efficiency at a lower cost [2,14]. In [2] it is shown that the land requirements of a bio-oil handling facility are significantly lower than those of a woodchip handling system (1.8 in contrast to 3.9 ha for a 50 MW$_e$ plant), with a subsequent impact on the land costs. Furthermore, it is shown that bio-oil handling systems have less moving equipment and labor associated with them, resulting in lower operation and maintenance costs.

In addition to this, bio-oil is considered an appealing feedstock for biorefineries owing to its high versatility, since it presents a potential for a wide range of uses. Certain utilization pathways encompass the upgrade and refining of the fuel through technologies such as gasification and synthesis, fluid catalytic cracking, hydroprocessing, and steam reforming. The possible final products include biofuels (biohydrogen, bioethanol, transportation fuels, etc), chemicals and other materials [5,14–17]. Other options are the heat and power production [15,18,19]. It should be noted that although bio-oil has been tested as a fuel for electricity production in properly modified gas turbines and diesel engines [20], it still cannot be used as a transportation fuel in its present form [7]. This is mainly due to its high acidity, low thermal stability and calorific value, high viscosity and poor lubrication compared to light and heavy fuel oils [7,20,21]. Other disadvantages include the higher content of solid particles and ash present in bio-oil mixtures, which is detrimental to the efficiency of combustion processes [21]. A possibly viable method to ameliorate the problematic properties of bio-oil investigated by Ikura et al. [22] regards its mixing with No. 2 diesel fuel. On the other hand, certain studies have shown that bio-oil could replace light and heavy fuel oils in industrial boiler applications [18,23].

The purpose of the present study is to estimate the production cost of fast pyrolysis bio-oil for different biomass species and reactor capacities and to investigate the potential of the decentralized fast pyrolysis process to reduce the increased costs related to biomass transportation to central plants. The parameters taken into consideration are the biomass annual feed to the pyrolysis plant, its purchase price, surface density, chemical composition and energy content.

The biomass-to-bio-oil conversion and transportation scenario is compared to a scenario involving direct biomass transportation. For the more accurate calculation of fast pyrolysis product yields, composition and energy content with respect to the biomass

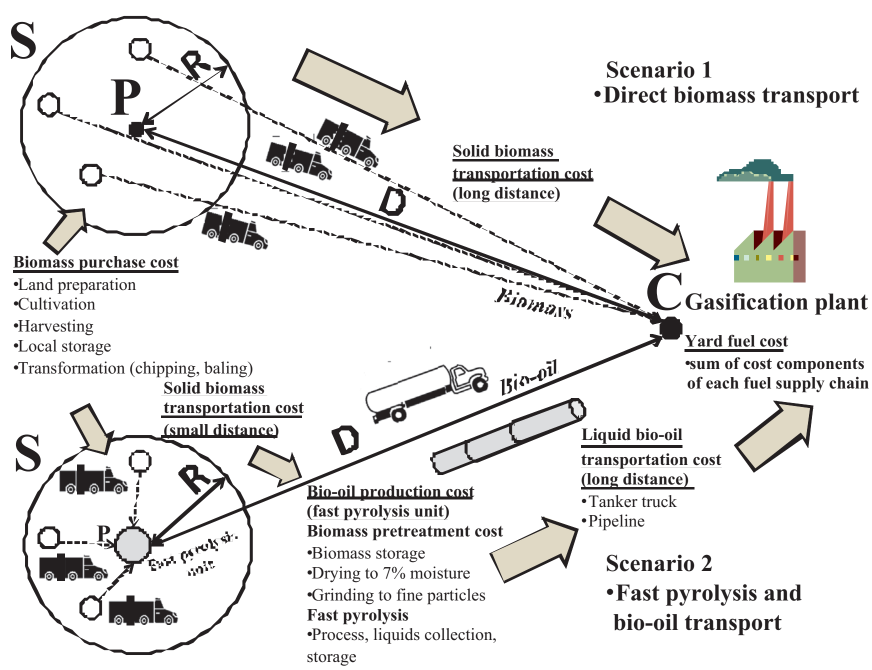

Fig. 1. Overview of biomass-to-bio-oil conversion though fast pyrolysis as a concept to reduce fuel transportation costs from a biomass source area to a central gasification plant. The cost components of each fuel supply scenario are also included.