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Biomass torrefaction for energy purposes – Definitions and an overview of challenges and opportunities in Brazil

Carlos Miguel Simões da Silva[a,*], Angélica de Cássia Oliveira Carneiro[a], Benedito Rocha Vital[a], Clarissa Gusmão Figueiró[a], Lucas de Freitas Fialho[a], Mateus Alves de Magalhães[a], Amélia Guimarães Carvalho[b], Welliton Lelis Cândido[a]

[a] Departamento de Engenharia Florestal, Universidade Federal de Viçosa, Viçosa 36570-000, Minas Gerais, Brazil
[b] Instituto de Ciências Agrárias, Universidade Federal de Uberlândia, Monte Carmelo 38500-000, Minas Gerais, Brazil

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ABSTRACT

Torrefaction is a thermal treatment with high potential to be applied in the production of solid fuel from lignocellulosic biomasses. This treatment promotes an increase in the energy quality of the raw material, making it a more attractive and competitive source within the primary energy matrix. However, the production of torrefied biomass on a commercial scale is still at an early stage of development with only a few industrial facilities around the world. Although not one of the pioneering countries in biomass torrefaction, Brazil has a great potential for large-scale deployment in this sector due to its availability of agroforestry biomass in quantity and diversity. The Brazilian agricultural and forestry production is one of the largest in the world with favorable conditions to expand it sustainably. The aim of this study was to evaluate the application potential of torrefaction in the solid fuel's production from lignocellulosic biomasses in Brazil. In the first part, it showed the definitions, use for energy purposes and the Brazilian production of agroforestry biomass. In the second part, it reviewed the definitions of thermal treatments, differences between dry and wet torrefaction process, biomass hydrolysis and torrefaction technologies. In the third part, the challenges and opportunities of the Brazilian commercial torrefaction are discussed.

1. Introduction

Humans depend on energy sources to supply basic needs and to obtain the desired quality of life. Energy consumption exists in several human activities such as from the primordial uses in foods preparation to the industrial activities with high technological advances. The population growth and the economic development of any country inevitably result in an increase of overall energy consumption. This growing demand must be an important subject matter in government planning.

Several criteria have to be considered for the choice of energy sources that will make up the power matrix, such as: I) Cost – Viability in obtaining or producing energy with the economic conditions of the population. II) Availability - Diversification of types and preference for local procurement sources for increased trade safety, and independence. III) Quality - The properties of energy sources must meet the necessary quality indexes to be used in the available equipment. IV) Socio-environmental issues - The impact potential must not exceed acceptable limits.

Many countries do not have power matrices observing all these criteria because they are composed mainly of fossil fuel sources. This unfavorable scenario increases the demand for research and investments in obtaining and developing alternative energy sources. The focus is on renewable sources that can be obtained locally. The main alternatives are hydropower, solar, wind, and those from the processing of several agroforestry biomasses.

Biomass was once the primary fuel used by humans, mainly because of the traditional use of firewood. This energy source has lost its standing as a result of the beginning with the exploration and consumption of fossil fuels that undoubtedly have a higher energy quality. The raw biomass presents undesirable indexes in the main properties of energy purpose, such as high values of moisture, hygroscopicity and heterogeneity, as well as low values of bulk density, carbon/oxygen ratio and calorific value.

To overcome this situation, there is a current process of modernization of all stages of production, processing and consumption chain of biomass to make it a higher quality fuel, more competitive, and attractive within the energy trade. This process includes the development

* Corresponding author.
E-mail address: karmiguel@yahoo.com.br (C.M.S. da Silva).

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of more efficient burner technologies, thermal, chemical and biological conversion routes, and pre-treatments. One of the most promising technologies is the torrefaction process.

Torrefaction is a thermal treatment that presents satisfactory results according to several researchers working with different agricultural and forestry biomasses. The treatment consists of a mild pyrolysis of the raw material with higher mass yields than traditional pyrolysis. The torrefied biomass is characterized by a homogenous solid fuel with higher carbon and energy contents and lower hygroscopicity than the raw biomass. This fuel source still depends on advances of all stages of its production and marketing chain to be consolidated within the global matrix of energy production.

Brazil has favorable conditions for the development and consolidation of a productive chain of torrefied biomass on the commercial scale. The potential comes from the availability of arable land and the favorable edaphoclimatic conditions that enable the sustainable production of lignocellulosic biomass in large quantities and diversity. However, the participation of biomasses and other renewable sources in primary energy production has been declining recently in Brazil. Torrefaction is an alternative to be used to reverse this scenario, making biomass a more attractive and competitive fuel source on the energy market.

In light of this, the aim of the study was to present definitions and an overview of the biomass torrefaction potential for energy production in Brazil. The study was divided into three approaches: (I) Lignocellulosic Biomass – Characteristics as fuel source and context of the Brazilian production; (II) Biomass Torrefaction – Definitions, production and technologies; (III) Challenges and Opportunities in Brazil. At the end of this study, a conclusion is made connecting the three previous sections summarily.

2. Lignocellulosic biomass

2.1. Definition and utilization for energy purposes

Biomass is any organic material derived directly or indirectly from the process of photosynthesis by plants and algae, except for fossilized materials. The range of possible uses of biomasses is quite heterogeneous due to the infinity of existing materials that fit this definition [1]. Currently, emphasis is given to its use as a fuel input in the sectors of energy production [2]. The main types of biomass targeted for these purposes are lignocellulosic materials of agricultural and forestry origin, including energetic plantations and residues from the stages of processing, and use of the other products within the sector.

Lignocellulosic biomass is a complex fibrous structure with a heterogeneous chemical constitution. The chemical compounds present in this biomass can be classified into two groups as described by Acharya et al. [3] and Anukam et al. [4]. The first one is constituted by organic macromolecules with structural function in the plant such as lignins and polysaccharides – cellulose and hemicelluloses, which are present in major proportions in biomass. The second group consists of the low molecular weight compounds with physiological, protective or reserve functions. It is subdivided into organic (extractive) and inorganic (ash) compounds [1,5]. The chemical composition of the lignocellulosic biomass is variable by factors inherent to the material itself, such as species, age and position on the stem of the plant, besides the soil and climatic conditions and management to which they were subjected during their growth.

Lignocellulosic biomass is a solid fuel with high potential for use within the world's power matrix. It is a source in agreement with most of the environmental and social precepts, such as being renewable, with a carbon-neutral cycle, and generating high amounts of direct and indirect jobs throughout its production chain [3]. In addition, it can be obtained in almost all the habitable regions of the planet with a relatively low cost of production [6,7]. Despite the mentioned advantages, the biomass presents low participation within the power matrix, replaced mainly by the fuels of fossil origin. The low energy quality indexes of the raw biomass compared to the other fuels are one of the main causes for this scenario [8–10].

Heterogeneity, high moisture content, and low energy density are some of the main undesirable characteristics of the raw biomass for use as fuel [8–11]. Physicochemical heterogeneity and high water content present in the biomass bring operational disruptions and reduce the efficiency at all stages of the biomass processing from the obtaining to the conversion into thermal energy in the combustion systems. The moisture of biomass is associated with its hygroscopic qualities, defined as its capacity of absorbing and retaining moisture from the environment. Besides that, lignocellulosic biomasses have a low calorific value due to the high O/C atomic ratio of their main chemical constituents [12], and low bulk density.

Brito [13] states that, to increase the participation of biomass in the power matrix, it is necessary to invest in new technologies and in the improvement of the existing processes to obtain greater efficiency and quality in direct burning, treatments and conversion routes. Some of these treatments are performed in order to alter and homogenize the physical characteristics of biomasses, such as drying, reduction in chips and particles, and densification like the production of pellets and briquettes. Other treatments significantly alter the chemical properties of the material, converting it into other higher added-value fuels. These treatments can be performed through thermal processing such as torrefaction, carbonization, gasification and fast pyrolysis, or biochemical processing like biofuel production [11,14].

2.2. Brazilian production

According to the Brazilian Energy Company's report [15], the average production of primary energy in Brazil was made up of 54.2% non-renewable sources and 45.8% of renewable sources between 2006 and 2015 (Fig. 1). These renewable sources were hydroelectric power (13.4%) and biomasses such as sugarcane products (18.1%) and firewood (10.7%). The IEA Bioenergy Task 40 report [16] mentions Brazil as the country that uses the most biomass for energy generation, with approximately 16% of total world consumption, followed by the United States (9%) and Germany (7%).

Brazil has an economy strongly dependent on the primary sectors of agricultural and forestry production, explaining the significant representativeness of biomass within the national power matrix. Biomasses come from plantations with exclusively energetic purposes, or as residues from some agricultural production chain. Table 1 shows the Brazilian production data of crops according to the database provided by the FAOSTAT (*Food and Agriculture Organization of the United Nations - Statistics Division*). Sugarcane was the main crop, grown in millions of tons, followed by soybean and maize. About the Brazilian representation inside the world production, sugarcane ranks first in

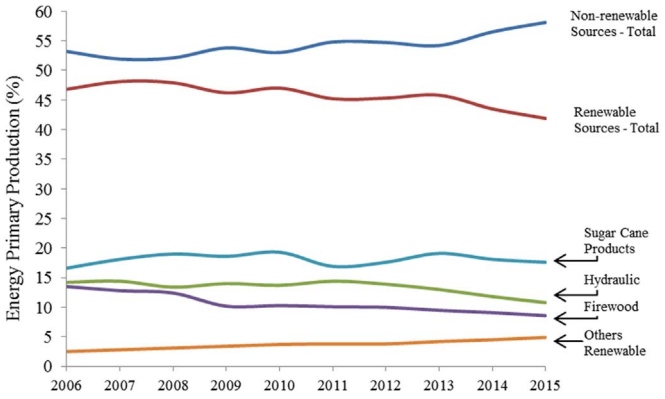

Fig. 1. Brazilian primary energy production in the period from 2006 to 2015. Adapted from the Brazilian Energy Company's report [15].