Torrefied Biomass Pellets: An Alternative Fuel for Coal Power Plants

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***Abstract*—This paper aims to make a comparison between the logistics costs of buying Wood Pellets (WP) and Torrefied Biomass Pellets (TBP) produced in Portugal and exported to the major consumer markets of Northern Europe. The starting point is to determine the value of a shipload of WP and TBP delivered to a North European port and loaded in Aveiro, the main Portuguese WP expeditor port. Torrefaction implies higher energy and bulk density pellets, which contributes to increase the logistics costs associated with them. The loss of mass is greater than the loss of energy. These changes in bulk and energy densities are an advantage in terms of logistics: more tonnes per unit of volume and more energy per tonne will decrease the transportation cost per energy unit. The analysis carried out in this paper determines the energy in gigajoules (GJ) per tonne and all the comparisons are based on the cost per energy unit. This analysis is supported by real data collected in the Argus Biomass Markets report.**

***Index Terms*—Torrefied biomass pellets (TBP), torrefaction, wood pellets (WP), energy costs.**

I. Introduction

The search for alternative sources for the production of thermal energy with less environmental impacts means that biomass has started to reach a very important role compared with other forms of renewable origin energies. Biomass therefore has great importance for the production of thermal energy, and most of this biomass comes directly from forest and forestry operations in all their several forms, mainly being processed into wood chips after the falling of the trees [1].

Actual society development, providing increasing levels of comfort to the people, inevitably leads to an increase in energy consumption in all its forms, requiring a constant and permanent supply. This demand mainly for fossil fuels, traditionally more available and also cheaper, caused a gradual but effective increase in market prices, making it a key factor for competitiveness between countries, since companies competitiveness depends on the energy cost [2].

This factor directly interferes with the balance of external transactions, giving advantages to countries or industry sectors that were able to bridge the differential production cost with sustainability measures, using alternative energy sources, improvements and modernization in production processes and measures of energy efficiency control [3].

In addition to the direct energy consumption costs, the costs associated with environmental damage related to fossil fuels consumption are also under the spotlight, mainly those related to greenhouse gases emissions released into the atmosphere through the combustion of these fuels, especially CO_2, as the most recognized by the public, but the list extends to other, equally or more harmful to the environment and the health of populations than the aforementioned [4].

Use of wood pellets (WP) as a sustainable energy alternative is an effective instrument in the fight against climate change [3]. It represents a positive globalization of wealth and local employment creation. Wood as a primary energy source responds to available evidence and to a need for energy, especially relevant at a time of deep economic crisis, which has forced many to rethink future strategies [4].

The most important obstacle in the use of such resources is the high cost of production, supply and homogenization of use if problems in the various energy conversion technologies are not to be caused [2].

During the last few years, several companies have invested in WP plants that will be used for heat and electricity production. Global WP production reached 23.6 million tonnes in 2013. As for 2014, according to related research study, the global production capacity of wood pellets increased by 8% and the global capacity of wood pellets reached 25.5 million tons [5].

In 2013 the European Union remained the largest wood pellet supplier and producer, and produced 12.0 million tons, with Germany, Sweden, Latvia, and Portugal as the top producers. Wood pellets in Portugal are produced mainly for export and the country has increased its production since 2008, exporting almost the entirety of its pellets to the United Kingdom, Netherlands, Belgium and Denmark [6].

The Portuguese pellet market consists of small direct consumers with small and medium peaks in the winter period from October to April [7].

The main consuming sectors for pellets in Portugal are the domestic sector and public services and industries with thermal energy needs. This includes large building heating systems, i.e. bakeries and other similar facilities. In this sector, the largest consumers are mainly elderly care centres, schools and sports facilities.

The wood pellet market in Portugal is at an early stage of development, as it is not well structured, lacks domestic consumption and most of the production is exported abroad to northern European countries like England, Denmark, Belgium or Sweden [7].

Torrefaction is a process used to produce high-grade solid biofuels from various streams of woody biomass or agro residues. The end-product is a stable, homogeneous, high quality biofuel with far greater energy density and calorific value than the original feedstock, providing significant benefits in some logistics activities such as handling and storage, as well as opening up a wide range of potential uses [8–9].

Torrefied biomass and torrefied biomass pellets (TBP's) have several benefits over untreated biomass, such as higher calorific value, more homogeneous product, higher bulk density, increased grindability, durability, a hydrophobic nature and increased resistance to biological activity (Fig. 1). This results in a high-grade biofuel that can be used as a replacement fuel for coal in electricity and heat generation and as a raw material for gasification processes in the production of high-value bio-based fuels and chemicals [10].

Wood pellets are often seen as a solution to some of the major disadvantages of using biomass as a sustainable alternative fuel [11].

Figure 1. Torrefied biomass pellets.

Wood pellets have a higher energy density, higher calorific value, and lower moisture content than wood chips or untreated biomass.

Like TBP's, they are also uniform in size and more homogenous regarding fuel quality. Wood pellets are made up of small particles, and, unlike biomass of larger particle size, can be readily crushed in coal mills, resulting in particles that can be fed into pulverized-fuel burners just like coal powder [12]. However, there are also some disadvantages to wood pellets. Despite their lower moisture content, wood pellets retain the hygroscopic nature of wood and remain vulnerable to water, although to a lesser extent than chips and other untreated biomass [13].

The possibility of biological degradation can cause storage problems and implies that special precautions need to be taken in the logistics chain in general. Another disadvantage is that pellets production has traditionally been limited to only a few types of feedstocks, mainly sawdust, shavings, and bark, which are by-products of the wood processing industry, although lower- quality industrial pellets that are suitable for large-scale use can also be made from wood chips and other types of wet biomass [14]. The potential feedstock for TBP's is larger than for wood pellets, and does not rely as heavily on the wood processing industry [15].

Torrefaction of biomass is a promising and widely discussed pre-treatment method to reduce the costs for bioenergy chains, especially logistics costs. Different studies have indicated that the supply chain for fuel pellets made from torrefied biomass is more cost-efficient compared to conventional wood pellets [16].

The utilization of torrefied biomass in coal-fired power plants has been tested and reported by some major European power producers and its utilization in existing handling and storage facilities has been reported recently in several studies and publications [17].

Combined torrefaction and pelletizing produces an energy-dense biomass fuel with properties similar to those of bituminous coal. The high calorific value and high energy and bulk densities of TBP's may lead to significant cost savings in the biomass-to- energy chain when compared to state-of-the-art biofuel chains, especially in logistics [18], because the higher the energy density of a fuel is, the more energy a truck, train, or ship carrying that fuel can transport. At the same time less storage space is required, also leading to cost savings.

A high energy density also brings other benefits, such as improving the functionality and decreasing the energy use of conveyors and mills at the power plant [19]. In addition to the possible savings in logistics that can be achieved when switching from untreated biomass or WP to TBP's, higher grindability is one of the key properties that make torrefied biomass and TBP's so attractive for co-firing in existing coal-fired power plants.

Co-firing is the simultaneous use of two or more fuels in the same furnace. Co-firing biomass with fossil fuels is one of the solutions to reduce the greenhouse gas emissions of existing power plants [21].

The low moisture content of TBP's facilitates storage, allowing longer storage periods than those of woodchips or wood pellets, for example, and is also expected to lead to reduced stack losses and a higher power plant efficiency compared to conventional co-firing. Despite their many good fuel properties, TBP's are still a new fuel, and, unlike the case of wood chips and wood pellets, there is not yet much experience of their large-scale handling and use [21].

The aim of this study is to make a comparison between the logistics costs of buying Wood Pellets (WP) and Torrefied Biomass Pellets (TBP) produced in Portugal and exported to the major consumer markets of Northern Europe, such as Belgium, England, Denmark or Sweden [22].

II. MATERIALS AND METHODS

For this study, the necessary data were collected from different sources. To obtain the prices of WP and TBP, the major domestic WP producers were contacted, being mainly those with export experience to the countries of northern Europe, such as England, Belgium, Denmark or Sweden. In the case of TBP there is only one producer active in Portugal and is unable to provide these quantities for exportation, since a single load corresponds to its annual production capacity (Fig. 2). However, there is an ongoing project with a production capacity of 100,000 t/y of TBP and which should be operational by mid 2016 (Fig. 3), so the values may serve as a reference or a starting point for future analysis.

Details of the types of vessels used in the transportation of pellets were collected in the Captaincy of the Port of Aveiro [23]. Shipping companies with experience in this transportation were also consulted in order to understand the logistic operations involved in exporting WP, since it is assumed that one of the main advantages that TBP presents over WP is related to the logistics, since, having better hydrophobic properties does not require so much care in storage, but as well its higher bulk density associated with the higher heating value. This combination will allow a higher energy dense product, being this the main advantage of TBP presented by all the producers active worldwide.

Figure 2. Biomass torrefaction pilot-plant located in Portugal.

Figure 3. Biomass torrefaction plant with an annual capacity of 100,000 t/y being built in Portugal.

Data on transportation costs from the port of Aveiro to the main ports of northern Europe were collected in the Argus Biomass Markets Report [24] and were compared with the information provided by the exporting companies that were contacted directly in this research in order to obtain more realistic information as well as more accurate and precise costs. The port of Aveiro is the main exporting port of WP from Portugal to the northern European countries, with several infrastructures of storage and handling. These are the type of logistic costs that are expected to avoid with TBP production once that are hydrophobic and can theoretically be handled without complex storage facilities like silos.

III. RESULTS AND DISCUSSION

This study assumes that the buyer pays the same base price per GJ for TBP as is usually paid for WP. Using an assumed price of 132€ per metric ton and the incoterm FOB (Free on Board) Aveiro port (Portugal) for WP, and using the energy densities presented in Table 1, a value of 7.80€/GJ FOB is obtained. This value is in line with reference values described in the available literature and technical reports analyzing the emerging market of TBP. It is expected that initially the TBP buyers do not be available to pay more than usually pay for WP, at least until the advantages that TBP present over WP be totally clarified and understood, including higher grindability, hydrophobicity and higher energy density [25-30].

The most common vessel size used in the Aveiro port is 2,990 tonnes, with an approximate volume of 4,750 m^3 [23]. For both types of pellets, the bulk carrier is always filled up entirely before reaching a maximum volume limit. Table 1 shows the energy content that may be loaded in a 4,750 m^3 bulk carrier (Fig. 4). An average shipping cost of 15€/t from Aveiro port to any of the main North European ports was estimated.

In Table 1 it is possible to verify that the amount of energy loaded may be 25% higher when the shipment is TBP instead of WP. This means that less energy content in a fully loaded vessel results in a higher cost per energy unit, more precisely €0.88 /GJ for WP and € 0.71/GJ for TBP. It can also be extrapolated that the larger the boat is, the greater the difference between WP and TBP will be.

In Table 2 the cost per GJ of the delivered fuel is presented based on a FOB value of € 7.80 /GJ plus the shipping costs. As shown in Table 2 the FOB Aveiro price is € 396,474 for WP and € 489,762 for TBP that results in a cost for the buyer of € 8.68/GJ for WP and € 8.51/GJ for TBP. The cost of a delivered shipload with a higher energy density fuel such as TBP is slightly lower than for WP but, as shown in Table 1, the amount of energy loaded is 25% higher.

Figure 4. Ship being loaded with WP in the port of Aveiro.

Table 1. Energy and bulk densities for WP and TBP and estimated costs for shipping per GJ.

	WP	TBP
Energy (GJ/t)	17	21
Bulk density (kg/m^3)	650	750
GJ/m^3	11.05	15.75
Vessel capacity	4,750 m3 2,990 t	
GJ loaded	50,830	62,790
Shipping cost (€/GJ)	0.88	0.71

Table 2. Cost per GJ in destination.

	WP	TBP
Aveiro FOB total price	€ 396,474	€ 489,762
Cost of shipping	€ 44,850	
Total price in buyer's port	€ 441,324	€534,612
Cost per GJ for the buyer	€ 8.68/GJ	€ 8.51/GJ

IV. Conclusions

Torrefaction is a thermal pre-treatment technology, which produces a solid biofuel product that has superior handling, milling and co-firing capabilities compared to other biomass fuels. The advantages of torrefied biomass are widely recognised (higher energy density, grindability, hydrophobic, etc.). Interest in biomass torrefaction has grown significantly in recent years, as has knowledge of its processes and properties. The process of torrefaction is dominated by the thermal break- down of hemicellulose to a combination of gases, condensable liquids, and solid components that, together with the cellulose and lignin present in the raw material, comprise a product suitable for utilization as fuel. Torrefied products can substitute charcoal in a number of applications such as fuel for domestic cooking stoves, residential heating, manufacture of improved solid fuel products such as fuel pellets, compacted fire place logs and barbecue briquettes for commercial and domestic uses. Important advantage of torrefied wood compared to untreated wood is its uniformity. Torrefaction has the potential to become an important biomass pre-treatment technology that can improve the biomass to a high quality solid fuel with good characteristics in terms of energy density, homogeneity, grindability, and hydro- phobic behavior. The main advantage of torrefaction is the improvement of energy density and grindability. Torrefaction is seen as a breakthrough technology to decrease the handling and storage costs and reduce investment for co-firing application. Expectations are high especially from industrial users' point of view, but the technology and product quality are still surrounded by some uncertainties. However, it is expected that TBP suppliers will use the same logistics and transport means as for WP. This will lead to supply costs being slightly reduced due to the higher bulk density. From the current state-of-the-art, TBP can be an alternative to WP, but the pre-treatment process is much more expensive, meaning that cost benefits only arise in long-distance transportation. Due to the low moisture content of torrefied wood the transport cost is lower and the quality as a fuel better. It is easily packaged and transported, and thus constitutes an efficient fuel. From the obtained results, it is possible to conclude that TBP is advantageous compared to WP because the cost per GJ is lower. Although the total cost for the TBP is higher when the unit costs are analyzed, it is seen that these are lower for TBP, making it more advantageous from the standpoint of the final cost per unit of energy. Despite this, it is mandatory to pursue further research concerning other costs or benefits associated to the properties of each type of fuel, such as hydrophobicity and grindability, in order to perform a deeper analysis and include these costs and benefits at the purchasing value of the products.

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