Resources, Conservation and Recycling 110 (2016) 99–114

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Review

Evolution of palm oil mills into bio-refineries: Literature review on current and potential uses of residual biomass and effluents

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ARTICLE INFO

Article history:
Received 7 July 2015
Received in revised form 4 March 2016
Accepted 23 March 2016
Available online 6 April 2016

Keywords:
Palm oil mil (POM)
Palm oil mill biomass
Biorefinery
Empty fruit bunches (EFB)
Palm kernel shell (PKS)
Fiber

ABSTRACT

The palm oil agroindustry not only produces the most consumed vegetable oil in the world, but also a significant quantity of residual biomass. This waste represents real opportunity to create a variety of products. In the context of sustainable oil production, the use of biomass to generate value-added products can be addressed through the evolution of existing palm oil mills (POMs) into biorefineries. In this manuscript, the authors present a literature review of potential uses for biomass generated in palm plantations and at the POM, including the main properties, quantities, and current practices. After this, a review of novel, less traditional is made. Finally, strategies for the synthesis and analysis of POM biorefinery concepts are discussed. This review highlights the need for development of high-value products from POM waste and the urgency to incubate these emerging technologies for gradual transition into biorefineries. Based on short term economic performance, biomass pelletization and anaerobic digestion of POME are the most promising technologies. Furthermore, the production of biochar has great potential when the environmental performance is taken into account. More work is needed to evaluate the long term economic, social, and environmental impact of other new technologies both now and in the future.

Contents

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http://dx.doi.org/10.1016/j.resconrec.2016.03.022

1. Introduction

Unlike crops that are grown in temperate climates, the oil palm is a perennial crop that grows in the tropical regions of the world where production continues throughout the year. In 2014, the world's total oil palm production area was 16,472,000 ha, of which 77.5% was located in Indonesia (8,150,000 ha) and Malaysia (4,620,000 ha). The remaining areas were Thailand (720,000 ha), Nigeria (440,000 ha), Colombia (354,000 ha), and other countries (2,188,000) (Fedepalma, 2015). The two main products of this industry are crude palm oil (CPO) and the solid palm kernel (PK). Palm oil is the most produced vegetable oil worldwide, with production reaching 59.23 million tons (t) in 2014 (Fedepalma, 2015). The main use of CPO is for food; however, it is recently being used for the production of biodiesel and oleo-chemical derivatives. Palm kernel meal (PKM) and palm kernel oil (PKO) are obtained from the PK. In 2014, the production of PKO worldwide was of 6.52 million t, and that of PKM was 7.81 million t (Fedepalma, 2015). While PKO is mainly used for the manufacture of oleo-chemical products, PKM is used mainly for animal feed (Fedepalma, 2015).

Besides CPO and PK, the palm oil agroindustry generates a significant amount of residual biomass, which in 2010 was estimated globally around 87 million t/y (wet basis) (Ng et al., 2012a). The types of residual biomass generated in this agroindustry are: (i) Empty Fruit Bunches (EFB), which result from the removal of fruits from the sterilized Fresh Fruit Bunches (FFB); (ii) fiber resulting from the pressing of the fruit; (iii) Palm Kernel Shells (PKS) from the nuts; (iv) ash produced by burning the fiber and PKS in the boilers; (v) Palm Oil Mill Effluents (POME) from the process of oil extraction in the Palm Oil Mill (POM); (vi) sludge removed from the anaerobic lagoons in the wastewater treatment systems and; (vii) logs, roots and palm leaves left behind in the fields after replanting, once they have met their production cycle which is nearly 25 years.

The use of residual biomass from the palm oil agroindustry has gained attention in recent years since it can be converted, through the use of different technologies (cogeneration, composting, pelletizing, briquetting, pressing, pyrolysis, enzymatic digestion, etc.) into value-added products (Chiew and Shimada, 2013; Prasertsan and Sajjakulnukit, 2006; Mekhilef et al., 2011). The gradual integration of these technologies within the POMs, transforming them into biorefineries, is also an area of growing interest (Chiew and Shimada, 2013; Chang, 2014; Kasivisvanathan et al., 2012; Chew and Bhatia, 2008a). There are several meanings for "biorefinery" available in the literature (Van Ree and Annevelink, 2007). For example, the National Renewable Energy Laboratory, NREL (NREL, 2014), defines a biorefinery analogous to oil refineries: in the case of the biorefinery, the raw material is biomass, which produces fuels, power and chemical products through conversion processes and the use of specific equipment. The DOE (Department of Energy of the United States) mentions that an integrated biorefinery uses various combinations of raw material feedstock and conversion technologies to produce a spectrum of products, with the main focus on energy production (US Department of Energy, 2011); co-products include chemicals, animal feed, heat, and energy (US Department of Energy, 2011).

The enormous growth potential of this agribusiness coupled with the environmental and social impacts of palm oil producers led to the emergence of the Roundtable on Sustainable Palm Oil (RSPO) in 2003. The principles and criteria of the RSPO are currently the most ambitious sustainability standards for the palm oil agroindustry (Roundtable on Sustainable Palm Oil, 2013). Globally, countries producing CPO have adjusted environmental standards to comply with the recommendations of the RSPO. In the case of Colombia, the Ministry of Environment and Sustainable Development has set environmental regulations regarding the emissions of particulate matter from stationary sources (such as boilers using biomass as fuel) and pollutant discharges into bodies of water. In the first case, the requirement of particulate material leaving new boilers is 50 mg m^{-3} (Ministerio, 2008). Regarding POME, the new regulations require changing reduction percentages of organic matter by fixed values on BOD (Biological Oxygen Demand), COD (chemical oxygen demand), TSS (Total Suspend Solids), chlorides, sulphates, and cadmium (Ministerio de Ambiente y Desarrollo Sostenible, 2015). These new values cannot be achieved with the conventional systems for the treatment of POME comprising anaerobic and facultative lagoons. The gradual evolution of POM into biorefineries is as an opportunity not only to comply with the new strictest environmental standards, but also to enable the creation of new products and improve the overall economic, environmental and social performance of these systems.

There are several good reviews of POM residual biomass utilization (Prasertsan and Sajjakulnukit, 2006; Mekhilef et al., 2011; Prasertsan and Prasertan, 1996; Tantitham et al., 2009; Shinoj et al., 2011). Some reviews focus on the current status of specific conversion technologies. Biomass utilization in Malaysia including POM biomass focusing on the production of biofuels and bio-power has been described (Mekhilef et al., 2011). In Thailand, Prasertsan and Prasertan (1996), carried out a survey about the use of POM biomass and identified potential uses of this biomass. Tantitham et al. (2009) discussed the status of three biogas projects in this country and (Prasertsan and Sajjakulnukit, 2006) reported biomass and biogas energy uses from POM biomass. Shinoj et al. (2011) published a review on the use of EFB fiber for composites. Singh et al. (2010) reviewed the techniques for composting POM biomass. The review published by Gobi and Vadivelu (2013) focused on the production of polyhydroxyalkanoates and bio-hydrogen from POME. The use of palm oil biomass for decentralized electricity generation was reviewed by Bazmi et al. (2011).

Reviews dealing more closely with biorefineries concepts have also been published (Chiew and Shimada, 2013; Chang, 2014; Kasivisvanathan et al., 2012; Chew and Bhatia, 2008a). Chiew and Shimada presented a paper reviewing seven technologies for using only EFB and making a comparison through life cycle assessment tools (Chiew and Shimada, 2013). Chew and Bhatia (2008a) presented a very comprehensive review about the use of catalytic routes for the production of biofuels from palm and oil palm biomass-based biorefinery. Chang (2014) wrote an extensive literature review about the use of EFB for the production of bio-oils focusing on the major challenges and the perspectives of the use of this biomass. Kasivisvanathan et al. (2012) carried out a fuzzy optimization study to convert a POM into an integrated biorefinery.

This paper aims to review the existing literature on the main alternative uses of residual biomass from the palm oil agroindustry, and the work that had been done to use this information in the synthesis and analysis of POM biorefineries.