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Assessing the main opportunities of integrated biorefining from agro-bioenergy co/by-products and agroindustrial residues into high-value added products associated to some emerging markets: A review

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ABSTRACT

Market implementation of integrated biorefinery requires reliable and advanced processing units combined with eco-friendly and economically profitable production chains. Future developments of integrated biorefinery systems should include either crop cultivation with selected genotypes that maximize full chain performances either the increasing use of disposable or/and underused biomass. The aim of this paper was to review the main biorefining opportunities related to agro-bioenergy co-products and agroindustrial residues potentially available on the World (as biofuel co/by-products, agricultural residues, agricultural by-products and agro-wastes), paying a special attention to high-value added products associated to some emerging markets. The current status and future perspectives of conversion from agro-bioenergy residual biomass into high-value bio-based products by innovative biorefineries have been considered. After a brief recognition on the nature and origin of the main categories of organic residuals derived from the biofuel chains and agricultural, forestry, food processing and animal activities within definitions given by the European Union, this paper has firstly focused its choice on the high-value added products associated to some chemical basic-platforms (succinic acid, cellulose, glycerin, proteins, peptides, enzymes, etc.). A special attention has also been done to high-value added bio-based products and commodities related to sustainable and renewable farming systems (soil amendment, phytosanitary drug, plant biostimulant and biofertilizer) and bio-based industries in producing innovative biomaterials (bioplastic, lignin and alginate). Finally, this paper has addressed own concern on the perspectives of integrated biorefining from organic residuals drawing particular attention to the European and Italian contexts giving and discussing some new opportunities for big players and stakeholders.

1. Introduction

The European Directive 2009/28/EC defines the term biomass as "*The biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste*". Biomass contributes to supply energy approximately for 12% of the global status on the renewable energy inputs ranging from 40% to 50% in developing countries [1].

Assessing the lignocellulosic biomass potential in developing countries [2], residual biomass is considered as a source particularly important being composed by underutilized sources which are naturally recycled into ecosystems. Agro-bioenergy co-products and agricultural residues are suitable for producing either second-generation biofuels either high-added value co-products through an integrated biorefinery approach [3]. Although such biomass might contribute only modestly to partially replace fossil sources in the longer time because inputs of agro bio-energy waste, food processing waste, animal and fishery activity and surplus of agricultural and forestry production on unused lands may be more expensive rather than creating large-scale energy plantations on arable lands, nevertheless its importance as a natural feedstock for feeding biofuel chains can increase in the near future being considered as a promising source of raw material suitable to produce high-value added bio-based products and green chemicals. Moreover, residual feedstock processing into second-generation biofuel

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has either more energy requirement because it need higher energy input for pre-treatment of recalcitrant lignocellulose, either more environmental impacts because it result from technologies that require higher water consumption.

Green chemicals and bio-based products should derive from a wide range of agro-bioenergy co-products and agricultural residues, therefore the main challenge for big players and stakeholders is to transform complex, heterogeneous and disposable biomasses into really valuable and marketable high-value added products in place of fossil sources alone. These organic residuals include mainly raw feedstock that are finely converted into many high-value added products. An important research topic is to know as a substantial part of sustainable economy based on the waste recycling is developed by biorefineries. However, an efficient conversion process depends on the gradual reconversion of the traditional fossil-based chains into innovative biomass-based chains. Enhancement of utilization of residual biomass requires effort to develop new technological systems in which conversion process, energy recovery and bio-based product are all integrated among them within an eco-friendly and efficient biorefining system [4].

High-value added product efforts development towards a new sustainable economy based on waste recycling named bio-based economy, or circular economy, or more simply Bio-economy [5]. In this context, IEA Bioenergy Task 42 affirms that *"Wood as a renewable and sustainable resource offers great opportunities for a comprehensive product portfolio to satisfy the different needs in a future Bio-economy. Worldwide many different wood based biorefining concepts are investigated and realised, of which the development status and the perspectives for implementation are quite different"*. Therefore, basing on this definition, an important research topic as substantial part of a sustainable Bio-economy are biorefineries. Substantial transition steps toward an efficient Bio-economy have been taken in recent years resulting viable to significantly reduce a reliance on imported crude oils and greenhouse gases (GHG)-emissions. Fig. 1 shows business opportunities for a circular economy based on the biofuel co-products.

Considering that the biorefinery concepts are still under development, a systematic literature review indicates how prominent feedstocks are present in the context of biorefineries. Based on 362 abstracts from articles published between 2010 and 2016, the importance of lignocellulosic feedstock is none the less obvious. About 59% of the articles mentioned lignocelluloses as main feedstock, mainly derived from dedicated lignocellulosic crops and residues. Overviews on the different biorefinery systems, current status of biorefineries, weaknesses points, opportunities and threats analysis are given in literature [6–9]. Biorefinery which uses a specific feedstock (as straw, corn and forest-based residues) are found [10,11]. There are many papers which provide information on the biorefinery concept using varied feedstock for chemical production by biochemical conversion [12]. Many of them have critically examined the current status and future technologies for converting corn or lignocellulose into fuel ethanol; or integration of lignocellulose with forest biomass; or conversion of hemicellulose from corn germ, fiber and gluten in corn-ethanol plant into value added chemicals; or detoxification of hydrolysates from fermentation processes by using bacteria; or ethanol product separation and dehydration.

Nevertheless, fewer referred papers on the biorefining opportunities from biofuel co/by-products and agroindustrial residues, including agro-waste, into a broad variety of marketable high-value added products and fine green chemicals through an approach of integrated biorefinery have been found in literature, especially in relation to some emerging technological sectors as those of the sustainable and renewable farming systems and biomaterial industry.

Fig. 1. Business opportunities for a circular Bio-economy based on the biofuel chains.
Source: [131].