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Use of vegetal biomass for biofuels and bioenergy. Competition with the production of bioproducts and materials?

L'utilisation de la biomasse végétale pour la production de biocarburants et de bioénergie. En compétition avec la production de bioproduits et de matériaux ?

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ABSTRACT

The total European bioeconomy represents 2.1 trillion euros turnover. It includes the food, feed and beverages sectors that are responsible for about half of the turnover. The bio-based industries – chemicals and plastics, pharmaceuticals, paper and paper products, forest-based industries, textile sector, biofuels, and bioenergy – contribute with 600 billion euros and 3.2 million employees. This paper will first give key figures for fossil fuel versus vegetal biomass stocks and production. The chemical composition of vegetal biomass will be described in a second part, and compared with fossil raw material. The use of vegetal biomass for energy will then be discussed, with a focus on the production of biofuels. The last part will give examples of bioproducts that could be obtained from wood in biorefineries integrated into the cellulose fiber industry.

RÉSUMÉ

La bioéconomie européenne représente un chiffre d'affaires de deux mille cent milliards d'euros. Elle inclut les secteurs de l'alimentation humaine et animale. Les industries dites « basées sur le végétal », qui fabriquent des produits chimiques, des plastiques, des produits pharmaceutiques, du papier et ses produits dérivés, l'industrie de la forêt, le secteur des textiles, les biocarburants et la bioénergie y contribuent pour 600 milliards d'euros et 3,2 millions d'emplois. Cet article compare le pétrole et la biomasse végétale en termes d'extraction, de gisement et de composition chimique. L'utilisation de la biomasse végétale pour la production d'énergie est ensuite présentée, en détaillant la production de biocarburants. La dernière partie donne des exemples de bioproduits qui pourraient être

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obtenus dans des bioraffineries lignocellulosiques (à base de bois) intégrées à la production de fibres de cellulose.

1. Introduction

A recent study evaluated the key figures for the bioeconomy in Europe in 2013 [1]. The total European Bioeconomy (the EU-28) amounted to 2.1 trillion euros turnover and 18,3 million employees. It includes the food, feed, and beverages sectors, which are responsible for roughly half of the turnover. The bio-based industries – chemicals and plastics, pharmaceuticals, paper and paper products, forest-based industries, textile sector, biofuels, and bioenergy – contributed with 600 billion euros (28.6% of total turnover in the European bioeconomy) and 3.2 million employees. Bioenergy and biofuels accounted respectively for 4 and 0,6% of the total turnover, and 1 and 0,2% of the total employees. The bio-based industry is thus already an important part of the European economy.

The objectives of this paper are to give key figures for fossil fuels versus vegetal biomass stocks and production. The chemical composition of vegetal biomass will be described in a second part, and compared with fossil raw material. The use of vegetal biomass for energy will then be discussed, with a focus on the production of biofuels. The last part will give examples of bioproducts that could be obtained from wood in an integrated lignocellulosic biorefinery and that are currently under development.

2. Key figures. Oil versus vegetal biomass

The consumption of crude oil in 2015 was 4.33 billion tons worldwide, to be compared to 2.98 billion in 1973 [2]. In January 2016, the proven crude oil stocks were 225.95 billion tons, which represents about 52 years of exploitation if one assumes that the annual consumption stays at the 2015 pace. About 10% of crude oil is used for petrochemistry to produce plastics, textiles, detergents, adhesives... Two sectors rely today most exclusively on crude oil: transportation (fuels) and organic products (mainly plastics).

Most of vegetal biomass is forest and it covers about 30% of land. The forest stock in 2015 was 531 billion m^3 spread on 4.00 billion hectares (it was 4.13 in 1990). Wood removals by human activity in 2015 were 2.99 billion m^3 (2.72 in 1990) (60% for energy, 40% for the industry) [3].

Even though most of vegetal biomass on earth comes from the forest, the estimated global biomass used by man in 2011 (11,4 billion tons of dry material) for food, feed, energy, and material was supplied first by agriculture (harvested agriculture biomass (40%), grazed biomass (31%) and harvest residue (12%)) and then by wood (18%, 2.12 billion dry tons). This biomass was used in the following sectors: feed (58%), bioenergy (16%), plant based food (14%), material use (10%) and biofuels (1%) [4].

A recent study detailed different scenarios of biomass supply and demand in Europe (EU27) and in the world until 2050, compared to the situation in 2011 [4]. The range of worldwide biomass supply in 2050 based on these scenarios would be between 12.4 and 25.2 billion tons of dry matter (wood supply would go from about 2 to about 8 billion tons of dry matter). The “low” scenario would just be able to cover the demand for food and feed, only part of the demand for materials and bioenergy and no demand for biofuels. The “business-as-usual case”, which is intermediate (about 18 billion tons of dry matter including about 5 billion tons of wood), would cover the demand for food, feed, materials, and bioenergy, and could enable an expansion of biofuels of up to 1 billion tons of dry matter of biomass. However, only the “low” supply scenario may be considered to be sustainable when one considers maintaining biodiversity. It is thus not easy to predict how much more vegetal biomass, and particularly wood, will be available in a sustainable way to increase the production of bioenergy, biofuels, biomaterials, and biochemicals. It is doubtful that vegetal biomass will be able to replace all the fossil fuel production.

3. Oil versus vegetal biomass chemical composition

Crude oil is mainly composed of hydrocarbon chains containing only carbon and hydrogen atoms (C_nH_{2n+2}), which is distilled to obtain different fractions used mainly as fuels. One fraction, called naphtha, containing molecules bearing between 4 and 8 carbons, is used for petrochemistry. It is cracked at very high temperatures in the presence of steam to obtain smaller molecules and introduce carbon–carbon double bonds. Catalytic reforming can also be applied to obtain aromatic compounds. These processes lead to the main intermediates used in petrochemistry: ethylene (C_2H_2), propylene (C_3H_6), butadiene (C_4H_6), benzene (C_6H_6), toluene ($C_6H_5–CH_3$), styrene (C_8H_8), xylenes... The four latter are represented in Fig. 1, they belong to the family of aromatic compounds.

Wood, which is the dominant vegetal biomass on earth, is composed of up to 60–70% of polysaccharides (cellulose and hemicelluloses), and 20–30% of lignin. Cellulose, which represents 40 to 45% of wood (Fig. 2), is a linear polymer of β-glucose, its degree of polymerization (DP) can reach 10 000 in wood. Hemicelluloses are heteropolymers of much

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