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Review

Technologies for the utilisation of biogenic waste in the bioeconomy

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ABSTRACT

A brief review has been done of technologies involved in the exploitation of biogenic wastes, in order to provide an introduction to the subject from the technological perspective. Biogenic waste materials and biomass have historically been utilised for thousands of years, but a new conversation is emerging on the role of these materials in modern bioeconomies. Due to the nature of the products and commodities now required, a modern bioeconomy is not simply a rerun of former ones. This new dialogue needs to help us understand how technologies for managing and processing biogenic wastes – both established and novel – should be deployed and integrated (or not) to meet the requirements of the sustainability, closed-loop and resource-security agendas that evidently sit behind the bioeconomy aspirations now being voiced in many countries and regions of the world.

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1. Introduction

Human utilisation of biogenic materials or biomass is not new; indeed, it is a very old practice. Prior to the industrial revolution biomass was the main source of energy and materials. Biomass

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utilisation declined following the exploitation of fossil fuels during the 1900s, except for in a few cases, e.g., the timber and fibre industries (Gallezot, 2008), during the 1930s agricultural surplus in the USA (Gallo, Bueno, & Schuchardt, 2014) and during World War II petroleum shortages in Europe (Suarez & Meneghetti, 2007). There is now a renewed interest in biomass, sparked by the aim to reduce society's climate footprint and other environmental burdens, achieve a more secure supply of resources and to encourage the bioeconomy. Activities designed to achieve those aims are already underway, although the recent food versus fuel and deforestation debates reveal that the source of the biomass being exploited is an important consideration. It follows that attention should be paid to the effective exploitation of unavoidable organic wastes that might otherwise go unused or potentially be landfilled or cause disposal problems.

Historically it is likely that some organic wastes have been spread to land since ancient times, often for utilitarian reasons rather than for commercial interests, e.g., the spreading of manure (Golueke & Dias, 1996). The composting of municipal solid waste (MSW) for land-spreading in Europe apparently began through the efforts of the Dutch government in the 1920s, but this was later followed by much wider interest in utilising MSW (Slater & Frederickson, 2001).

More recently, many nations have produced roadmaps or strategies setting out how they plan to approach the bioeconomy in their own country or region. There are undoubtedly new opportunities, exploitation of biogenic wastes being one important prospect. The English and other UK Governments (waste is devolved in the UK) have discussed this question, noting the opportunities likely to arise from utilising waste (HM Government, 2015). A desire to valorise wastes and to move waste treatment (and resources) up the waste hierarchy should contribute to a renewed vitality that is likely to nurture the bioeconomy. The valorisation of waste is an emerging subject going beyond energy applications. For example, there is interest in generating higher value substances and products from biogenic waste, such as pigments, phenolics and nutrients. A good selection of recent ideas may be found in Brar, Soccol, and Dhillon (2014).

One obvious question to ask is – "how much biogenic material and biogenic waste is there?" From one perspective the answer is "a great deal!". Cellulose, a useful polysaccharide and platform chemical, is the most abundant organic polymer on Earth. Annually the amount of cellulose generated is about 40 times greater than the amount of starch produced by crops for food and feed, and every ton of cereals harvested is usually accompanied by production of 2 or 3 tons of cellulosic crop residues that are often burned or wasted (You et al., 2013). From this standpoint humankind has not exploited biogenic material to "even a fraction of its potential" (Gajalakshmi & Abbasi 2008). In nature cotton fibres show a particularly high concentration of cellulose (>90%). Not surprisingly, cellulose, a prime target substance in the bioeconomy, shows up in a wide range of biogenic materials and wastes, an obvious example being wood. However, biogenic substances for use as feedstocks will be more or less easy to obtain depending on the form of the waste materials or products in which they are found, and depending on how effective we are at collecting and separating them. In a bioeconomy, this latter issue is not just about separate household collections and waste management processes. Detection and separation issues occur in various layers of the bioeconomy. For example, technologies will be required to separate cellulose, antioxidants, amino-acids, or any other target substance away from the waste matrix or composite in which it is presented. Indeed, substance-separation processes account for well over half of the process costs for many chemical operations. Whereas distillation delivers substance separation in the petro-refinery, the chemical constituents of biomass are generally less volatile. Therefore, in the cognate biorefinery, appropriate solvent extraction methodologies will have to be developed to provide the chemical separation functions (Ragauskas et al., 2006). Consequently, not all of the large amounts of biogenic material in nature and the waste sector will yet be readily available or extractable using current methods, and this is without factoring in the influence of pricing signals and markets (Howes et al., 2011).

Therefore, it's not surprising that estimates of the amount of biogenic material vary widely. There may be as much as 60 billion tons of organically bound carbon produced each year (Lew, 2013). This is not of course all available for human use. A recent debate in the UK concluded that although there is no clear source of information on the amount of waste biogenic material available in the UK, the figure could be in the order of about 100 million tonnes each year (House of Lords Science & Technology Select Committee, 2014). Viewed from the bioenergy perspective (modelling only forestry biomass, agri-residues, energy crops and biofuels supply), the UK has been projected to have access to about 1800 PJ (1 petajoule = 10^6 gigajoules) annually of bioenergy supply (from all possible sources) by 2020 (Howes et al., 2011).

In some respects the amount of available biomass need not be viewed as a fixed value. Biomass for the bioeconomy could be increased through genetic modifications that create bigger plants, change the ratio of lignin and cellulose to favour the latter, enhance plant resistance to diseases and to stressors, minimise plant losses, or modify plant cell walls so that the cellulose is more readily processable (Ragauskas et al., 2006).

What kinds of technological approaches are helping us to exploit this biogenic waste? This review briefly describes many of the key technological ingredients in the bioeconomy that are being explored for the utilisation of biogenic wastes as a resource. Creating a categorical scheme for describing these technologies is increasingly difficult for wastes. Some biotechnologies, such as microbial fermentation processes, are widely deployed into many different technological solutions. Wastes (especially those not source-segregated) are often quite complex matrices, and effective management and processing may entail several technological objectives. Moreover, economic pressure to valorise wastes is intense; due to the relatively low value of many wastes, the premium technologies do more than simply extract materials, or provide energy or treat the waste – there's not much room in a waste bioeconomy for one-trick ponies. Concepts such as the 'biorefinery' create stretching aspirations towards increasingly integrated technologies. There is a major research need to integrate unit-processes to give a much more holistic outcome than would be possible through an outdated 'material versus energy' economy. Therefore, this article introduces material recovery technologies as far as possible but, for energy technologies in particular, links these endeavours to the integrated multi- and by-product objectives that often accompany them.

Analytical procedures, necessary for various process control and management activities in the bioeconomy, are not covered, since they are not centrally involved in any bulk processing. However, reviews of relevant analytical chemistry procedures, e.g., chromatographic techniques for analytical separation of biomass reaction products, have been done (Murzin & Holmbom, 2013, chap. 7). Also not covered is bioremediation, wherein plants and microbes in particular are used to remove pollutants from contaminated sites or from contaminated material removed from polluted sites, although such technologies are sometimes used to recover or clean up biogenic wastes.

This is not a critical review, since unravelling the detailed strengths and weaknesses of such a wide range of technologies cannot be done in the form of a single article. However, many of the key challenges associated with the various technologies are indicated. One departure from the technology message is an initial