Bioresource Technology 215 (2016) 2–12

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives

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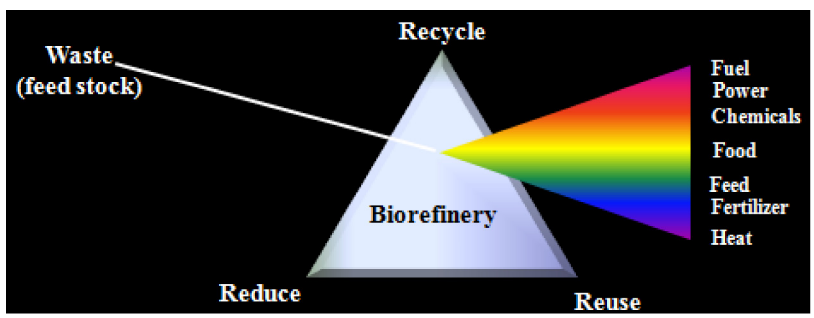
HIGHLIGHTS

- Resource recovery of bioenergy and platform chemicals from waste.
- Biorefinery as a sustainable approach for waste mining.
- Exploitation of waste would enhance biorefinery competitiveness & social acceptance.

GRAPHICAL ABSTRACT

Conceptualizing waste biorefinery for recovery of value added products.



ARTICLE INFO

Article history:
Received 6 February 2016
Received in revised form 23 March 2016
Accepted 24 March 2016
Available online 29 March 2016

Keywords:
Biofuels
Biobased products
Eco-footprints
Low carbon technology
Circular Bioeconomy
Life cycle assessment (LCA)

ABSTRACT

Increased urbanization worldwide has resulted in a substantial increase in energy and material consumption as well as anthropogenic waste generation. The main source for our current needs is petroleum refinery, which have grave impact over energy-environment nexus. Therefore, production of bioenergy and biomaterials have significant potential to contribute and need to meet the ever increasing demand. In this perspective, a biorefinery concept visualizes negative-valued waste as a potential renewable feedstock. This review illustrates different bioprocess based technological models that will pave sustainable avenues for the development of biobased society. The proposed models hypothesize closed loop approach wherein waste is valorised through a cascade of various biotechnological processes addressing circular economy. Biorefinery offers a sustainable green option to utilize waste and to produce a gamut of marketable bioproducts and bioenergy on par to petro-chemical refinery.

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http://dx.doi.org/10.1016/j.biortech.2016.03.130
0960-8524/

1. Current scenario

The world is undergoing a new wave of urbanization, especially in the emerging developing countries leading to multiple impacts over natural resources and the environment. Metropolitan infrastructure, as the interface between the human consumption and natural resources/environment, poses various challenges and opportunities for sustainable resource management at urban scale (Clark and Deswarte, 2008). Concerns over dependence on fossil fuels alongside increasing levels of carbon dioxide (CO_2) in the atmosphere have led to a global drive for renewable and eco-friendly technologies. In this context, biorefinery has emerged as a potential alternative of petroleum based refinery where biomass of non-edible feedstock/biogenic waste is used as raw materials and a range of products, such as biofuel, industrial biochemicals and biomaterials including commercially important biopolymers are produced (Clark and Deswarte, 2015; Venkata Mohan, 2014a).

Concepts such as the 'biorefinery' create stretching aspirations towards increasingly integrated technologies (Aresta et al., 2012). Municipal Solid Waste (MSW) is the one amongst the most abundant organically bound carbon produced each year that could be useful resource for biobased technologies. In India, MSW is >150 million tonnes with more than 50% bio-waste; on top of that, it covers 60 thousand ha of landfills emitting landfill gas (GHGs). Sewage is mounting 40 billion liter/day resulting in >10 million ton of extra sludge and >20 million ton CO_2-emissions upon incineration (http://www.sahyog-europa-india.eu/inventories). From this standpoint, humankind has not exploited biogenic waste to even a fraction of its potential. Waste as a prime target substance in the biorefinery, shows up in a wide range of opportunities for mercantile interests rather than utilitarian reasons. On the other hand, creating a categorical scheme for describing the technologies for valorising waste is immensely difficult (Tuck et al., 2012; Zondervan et al., 2011).

This review comprehensively describes the biorefinery models that are being explored for the utilization of biogenic wastes as a resource in the framework of circular economy. The most popular microbial and photosynthetic processes are widely deployed for many different technological solutions. Integrating different models involving unit operations and bioprocesses gives a much more holistic outcome through an updated 'product versus energy' explored in the bioeconomy.

2. Bioprocess based technological models in nexus with biorefinery

2.1. Acidogenic model

2.1.1. Biohydrogen

Acidogenesis is the biologically mediated process where organic compounds are converted mainly into various bio-based products viz., hydrogen (H_2), volatile fatty acids (VFA) and other trace by-products (Sarkar et al., 2016). Oxidation of organic substrates results in generation of short chain VFA as by-products. Pyruvate, the end product in glycolysis, is oxidized to acetyl CoA and then to acetate via acetyl phosphate resulting in ATP generation. The reduced ferredoxin during pyruvate oxidation to acetyl-CoA is oxidized by the enzyme hydrogenase, which generates ferredoxin and releases electrons that bind with protons to form molecular H_2 (Fig. 1). Hydrogen has highest energy content per unit weight of any known fuel (143 GJ $tonne^{-1}$) and is the only fuel that is not bound to any carbon. An appropriate inoculum selection significantly influences the acidogenic process efficiency and substrate degradation towards value addition (Kapdan and Kargi, 2006). Mixed consortia as biocatalyst is generally preferred because of its low cost, non-sterile conditions requirement, operational stability and flexibility, effective on diverse substrates, diverse biochemical functions, ease of process control and up-scaling (Nikhil et al., 2014; Li and Fang, 2007). Selective enrichment of biocatalyst by pre-treatment of mixed inoculum enhances the overall H_2 evolution rate (Venkata Mohan et al., 2008a). Various physiological microbial groups present in the mixed consortia, lead to diverse metabolic functions, having the advantage of producing a mixture of bio-based products rather than that are not only specific to single product (Amulya et al., 2014; Venkata Mohan, 2009). This would make the process cost-effective when compared with the well-established chemical and electrolytic H_2 production process (Azwar et al., 2014).

2.1.2. Biohythane

During acidogenesis, H_2 along with methane (CH_4) is produced in low quantities because of fluctuations occurred in bioprocess conditions. H_2 and CH_4 produced through a separate two-stage process leads to a potential high-value solution for the valorization of waste biomass (Venkata Mohan et al., 2008c). Mixture of CH_4 and H_2 is referred as biohythane, which can have a composition of 46–57% H_2, 43–54% CH_4 and 0.4% CO_2. A proper blend of both H_2 and CH_4, can have impact on the transition of fossil