Renewable and Sustainable Energy Reviews 15 (2011) 4042–4052

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Biorefineries from the perspective of sustainability: Feedstocks, products, and processes

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ARTICLE INFO

Article history:
Received 6 January 2011
Accepted 5 July 2011
Available online 21 August 2011

Keywords:
Biorefineries
Sustainable development
Biofuels
Biomaterials
Lignocelluloses
Economic

ABSTRACT

Today, sustainability is the buzzword in the developmental parlance. This has brought the issue of availability and utilization of energy into sharp focus. There is an urgent need to find viable alternative to fossils, mainly petroleum. It not only provides the major share of our present energy needs but also feeds the organic chemicals industry with vital raw materials. Among many alternative energy sources being explored biomass is the only one that has the potential for such dual application. Comprehensive yet judicious exploitation of biomass is, therefore crucial. The emerging concept of biorefineries is important in this context which advocates multiprocess and multiproduct biomass based industries. But everything green need not always be clean and sustainable as populism often makes it to be. Needless to say, the choices of feedstocks, processes as well as product mix are many. There is a need to critically examine them. This paper presents a status review of biorefineries from the stand point of feedstocks, products and processes.

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1. Introduction

The World Commission on Environment and Development (WECD) in its report of 1987 defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. The UN General Assembly welcomed the report in its 96th plenary

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doi:10.1016/j.rser.2011.07.034

meeting with a belief that it should become a central guiding principle of the United Nations, Governments and private institutions, organizations and enterprises [2]. This was reasserted in the 1992 United Nations Conference on Environment and Development, stating that "The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations" [3]. Dependence on fossil fuels and their exhaustive use is certainly an antithesis to sustainability and mandates search for an alternative. In continuation to such efforts, the 2002 World Summit on Sustainable Development adopted a Plan of Implementation [4] to attain the goal of sustainable development. It unequivocally identifies the importance of "access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources" and in this context "Promote a sustainable use of biomass". The common perception of biomass is one of low grade low cost energy source only meant for marginal use. Even with value addition, it is only the energy potential of biomass that is generally recognized. This view has to change. Biomass is the only carbon rich material available besides fossils. If we were to look beyond an economy based on fossils, harnessing and appropriate utilization of biomass becomes indispensible. Here comes the concept of biorefineries. The term biorefinery refers to co-production of transportation biofuels, bioenergy and marketable chemicals from renewable biomass sources [5] and aims to replace today's 'Petroleum Refineries' which produces multiple fuels and products from petroleum. International Energy Agency (IEA) Bioenergy Task 42 defines biorefinery as sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, and heat) [6]. According to American National Renewable Energy Laboratory, "biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass" [7].

Biorefineries are classified based on their system components [6]; viz. platforms, products, feedstocks, and conversion processes as explained below:

- Platforms refer to intermediates connecting biorefinery systems and their processes. More the number of platforms more complex is the system. For example, C_5/C_6 sugars, syngas, and biogas.
- Products are both energy products like bioethanol and biodiesel or material products like chemicals.
- Feedstocks can come from energy crops from agriculture (corn, sugarcane, etc.). They can also be sourced from agricultural residues, forestry residues, and industrial wastes (straw, bark, used cooking oils, paper mill black liquor, etc.).
- Currently four major groups of conversion processes are involved in biorefinery systems. These are biochemical (e.g. fermentation), thermochemical (e.g. pyrolysis), chemical (e.g. esterification) and mechanical (e.g. size reduction).

This paper critically examines the emerging idea of biorefineries in the light of sustainability.

2. The driving forces

2.1. The future of fossil feedstocks

The last century has witnessed an unprecedented growth in energy demand as the economies expanded rapidly and the living standards improved dramatically in the developed world. The other nations were soon to join the bandwagon. This quest for an open ended developmental agenda led to digging deeper and deeper into the natural resource base and stressed our natural environment. And this race is far from finished. If the recent IEA reports [8,9] are to be believed, world energy demand is growing at a rate of about 1.6% per year. It is expected to reach about 700 EJ/y by 2030, with more than 80% of worldwide primary energy production still coming from combustion of fossil fuels [8,9]. The Energy Information Administration of the US Department of Energy estimates the world energy consumption to rise by an average annual 1.4% between 2007 and 2035 [10]. While the OECD countries' energy use is likely to rise at only 0.5% per year the energy demand in non-OECD countries is projected to expand at 2.2% per year [10]. In addition to energy, we are dependent on petroleum for over 90% (by tonnage) of all organic chemicals produced [11]. Against this backdrop a reality check on the available fossil reserves, the predominant primary source of energy at present, paints a grim picture. The oil reserves are likely to last for only 40 years and natural gas for 60 years [12]. Furthermore, as only 50% of the reserves are classified as conventional, the exploration and the processing of the remaining 50% may be hiding unattractive margins [13]. Concern for energy security and availability of feedstocks for organic chemicals are major driving forces for exploring the idea of biorefineries. It is to be noted that among all the renewable sources of energy only biomass has the potential to fulfil the requirement of organic chemicals feedstock.

2.2. The environmental crisis

A second reason, and possibly the more pressing one, that warrants a changeover from fossil fuels is the damaging impact on the environment caused by them. Burning of fossil fuels is the major source of Green House Gases (GHGs) emissions and result in climate change which is an issue of grave significance [14]. To cite the IPCC report, "For the 1995 to 2005 decade, the growth rate of CO_2 in the atmosphere was 1.9 ppm per year and the CO_2 Radiative Forcing (RF) increased by 20%: this is the largest change observed or inferred for any decade in at least the last 200 years. From 1999 to 2005, global emissions from fossil fuel and cement production increased at a rate of roughly 3% per year [14]. The global mean CO_2 concentration in 2005 was 379 ppm [14]. The projected values by the coupled climate-carbon cycle models range between 730 and 1020 ppm by 2100 [14]. These are alarming projections with impacts that could be serious to catastrophic. There exists, therefore, an urgent need to address the problem. Liquid transportation fuels from petroleum are major contributors to GHG emissions. In EU alone, in the period from 1990 to 2010 about 90% of CO_2 emissions will be attributable to transport [13].

While fossil fuels release ancient carbon and other greenhouse gases into the atmosphere significantly contributing to global climate change processes, biomass fix carbon from the atmosphere [14]. Annual crops sequester carbon from the atmosphere in annual cycles, while woody biomass does so over a few decades. They are, thus, carbon neutral compared to fossils which are distinctly carbon positive. Replacement of fossil fuels with biofuels can have a major mitigating impact on CO_2 emission. In combination with CO_2 capture and storage (CCS) bioenergy can even be carbon negative [15,16]. Bioethanol in place of gasoline in transportation can potentially save the emission of 198 g CO_2 equivalent per km of vehicle travelled while electricity produced from biomass in CHP mode can save 731 g CO_2 equivalent per kWh over electricity produced from natural gas [5]. The net carbon emissions from a biomass fed power plant is estimated to be approximately 5% of the emissions resulting from a coal fired power plant after netting out the CO_2 absorbed during tree growth [17]. Studies suggest that to stabilize the CO_2 concentration at 550 ppm by the end of the 21st century, the share of the biomass derived energy has to be the same as that of fossil fuels at the beginning of the century [18]. Some prefer heat or combined heat or power generation from biomass over production