Renewable and Sustainable Energy Reviews 40 (2014) 964–998

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Competing uses of biomass: Assessment and comparison of the performance of bio-based heat, power, fuels and materials

S.J. Gerssen-Gondelach [a,*], D. Saygin [a], B. Wicke [a], M.K. Patel [b,1], A.P.C. Faaij [c,2]

[a] Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] University of Geneva, Institute for Environmental Sciences and Forel Institute, Energy Group, Route de Drize 7, 1227 Carouge/Geneva, Switzerland
[c] Energy and Sustainability Research Institute, University of Groningen, Nijenborg 4, 9747 AC Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 19 November 2012
Received in revised form
23 July 2014
Accepted 30 July 2014

Keywords:
Biomass value chains
Bioenergy
Biomaterials
Technology review
Production costs
GHG abatement costs

ABSTRACT

The increasing production of modern bioenergy carriers and biomaterials intensifies the competition for different applications of biomass. To be able to optimize and develop biomass utilization in a sustainable way, this paper first reviews the status and prospects of biomass value chains for heat, power, fuels and materials, next assesses their current and long-term levelized production costs and avoided emissions, and then compares their greenhouse gas abatement costs. At present, the economically and environmentally preferred options are wood chip and pellet combustion in district heating systems and large-scale cofiring power plants (75–81 $US\$_{2005}/tCO_2\text{-eq}_{avoided}$), and large-scale fermentation of low-cost Brazilian sugarcane to ethanol (-65 to -53 $\$/tCO_2\text{-eq}_{avoided}$) or biomaterials ($-60$ to -50 $\$/tCO_2\text{-eq}_{avoided}$ for ethylene and -320 to -228 $\$/tCO_2\text{-eq}_{avoided}$ for PLA; negative costs represent cost-effective options). In the longer term, the cultivation and use of lignocellulosic energy crops can play an important role in reducing the costs and improving the emission balance of biomass value chains. Key conversion technologies for lignocellulosic biomass are large-scale gasification (bioenergy and biomaterials) and fermentation (biofuels and biomaterials). However, both routes require improvement of their technological and economic performance. Further improvements can be attained by biorefineries that integrate different conversion technologies to maximize the use of all biomass components.

Contents

Abbreviations: AD, anaerobic digestion; BTX, benzene, toluene, and xylenes; BC, biochemical; CBP, Consolidated Bioprocessing; CC, combined cycle; CFB, circulating fluidized bed; CHP, combined heat and power; DDGS, dried distillers grain soluble; DLUC, direct land use change; ECH, epichlorohydrin; ETE, ethanol-to-ethylene; FAME, fatty acid methyl ester; FT, Fischer–Tropsch; GHG, greenhouse gas; GT, gas turbine; HHV, higher heating value; HTU, hydrothermal upgrading; ICE, internal combustion engine; IGCC, integrated gasification combined cycle; IGFC, integrated gasification fuel cell; ILUC, indirect land use change; IPCC, Intergovernmental Panel on Climate Change; LHV, lower heating value; LR, learning rate; MSW, munical solid waste; MTBE, methyl tertiary butyl ether; MTO, methanol-to-olefins; NG, natural gas; NGCC, natural gas combined cycle; NGGT, natural gas–gas turbine; NOP, natural oil polyol; O&M, operation and maintenance; ORC, organic Rankine cycle; PA, polyamide; PBR, photobioreactor; PBT, polybutylene terephthalate; PC, pulverized coal; PDO, 1,3-propanediol; PE, polyethylene; PET, polyethylene terephtalate; PHA, polyhydroxyalkanoates; PLA, polylactide; PP, polypropylene; PS, polystyrene; PTT, polytrimethylene terephtalate; PUR, polyurethanes; PVC, polyvinylchloride; R&D, research & development; SC, steam cycle; SHF, separate hydrolysis and fermentation; SNG, substitute/synthetic natural gas; SRC, short rotation crops; SSCF, simultaneous saccharification and co-fermentation; SSF, simultaneous saccharification and fermentation; TC, thermochemical; TOP, torrefied and pelletized biomass; WTW, well-to-wheel

* Corresponding author. Tel.: +31 30 253 5446; fax: +31 30 253 7601.
E-mail addresses: s.j.gerssen-gondelach@uu.nl (S.J. Gerssen-Gondelach), saygindeger@gmail.com (D. Saygin), b.wicke@uu.nl (B. Wicke), martin.patel@unige.ch (M.K. Patel), a.p.c.faaij@rug.nl (A.P.C. Faaij).
[1] Formerly with Copernicus Institute of Sustainable Development, Utrecht University; since September 2013 with University of Geneva, Institute for Environmental Sciences and Forel Institute, Energy Group, Route de Drize 7, 1227 Carouge/Geneva, Switzerland.
[2] Formerly with Copernicus Institute of Sustainable Development, Utrecht University; since April 2014 with University of Groningen, Energy and Sustainability Research Institute, The Netherlands.

http://dx.doi.org/10.1016/j.rser.2014.07.197
1364-0321/

1. Introduction

In the last decade, biomass use for the production of modern bioenergy and biomaterials grew significantly in order to oppose the depletion of fossil resources (and associated increasing energy prices) and to reduce greenhouse gas (GHG) emissions [1]. For both energy and material application of biomass, it is expected that this growth will continue or even accelerate. For example, the Intergovernmental Panel on Climate Change (IPCC) reviewed recent literature and scenarios on long-term biomass deployment potentials and biomass demand for bioenergy [2,3]. In 2008, global bioenergy use accounted for a primary biomass supply of 50 exajoule (EJ_p) per year. By 2050, the global biomass demand for bioenergy is projected to reach about 77 EJ_p/year in the absence of climate policies (median case of baseline scenarios) and about 155 EJ_p/year under the most stringent GHG mitigation scenarios [3]. In addition, Saygin et al. [4] estimate an economic potential of biomass use of almost 20 EJ_p/year for substitution of synthetic organic material in the chemical industry in 2050. Hence, a total biomass supply of 100–175 EJ/year would be required to meet the projected demand for both bioenergy and biomaterials in 2050. By the same year, the technical biomass deployment potential is estimated to be in the range of 100–300 EJ_p/year [2].

The increasing demand for biomass will intensify the competition between biomass feedstocks as well as their applications; not only between food and non-food uses, but also between non-food applications for energy and materials. Thus, to ensure sustainable expansion of biomass use, we need insight in which routes (biomass value chains) are the most promising for producing heat, power, fuels and materials in terms of their technological, economic and environmental performance. This requires (i) a clear view on the status and prospects of potential value chains; and (ii) assessment and comparison of their economic and environmental performance in the short and longer term. Assessment of the