Renewable and Sustainable Energy Reviews 72 (2017) 801–820

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Current status of bioenergy technologies in Germany

Rafal Strzalka*, Dietrich Schneider, Ursula Eicker

University of Applied Sciences Stuttgart, Research Center Sustainable Energy Technologies, Schellingstrasse 24, 70174 Stuttgart, Germany

ARTICLE INFO

Keywords:
Bioenergy
ORC (Organic Rankine Cycle) process
Renewable cogeneration
Biomass conversion

ABSTRACT

Bioenergy conversion technologies have been frequently described and analysed in the literature, but a comprehensive and detailed comparison between the complex individual characteristics of each technology is still lacking. Therefore, the paper contains a description of the technical, economic and environmental properties of each technology with a special focus on the German bioenergy sector. The study presents an analysis of different bioenergy applications with regard to their specifications, power/heat output range and their areas of application. Due to the fact, that biomass combustion applications are the most widespread and market proven renewable conversion technologies, a detailed analysis of decentralised, biomass-fired CHP plants is presented in the paper.

The overview of the individual characteristics of different biomass conversion routes shows that biogas plants achieve high electrical efficiencies, are available with a broad range of capacities and belong to the established technologies. Although the investment costs of biogas plants are relatively high, biomass conversion with anaerobic digestion can be seen as one of the most promising option for a sustainable energy supply in Europe.

1. Introduction

The worldwide energy consumption is constantly growing and the utilization of primary fossil energy sources is already approaching their natural limits. The actual, mostly fossil-fuel based energy generation is linked with emissions of large quantities of pollutants, causing serious negative environmental effects. The limited potentials and availability of petroleum, natural gas and coal as well as growing environmental concerns provided the impetum for a massive development of renewable energy applications in recent years, as a promising alternative for sustainable global energy supply [1–3].

Among alternative energy sources, biomass plays the most important role, accounting for about 80% of the energy generated by renewable energy carriers worldwide. The main difference between biomass and other renewables is the possibility of its utilization as a fuel. Biomass is the only carbon-based renewable energy source which can directly substitute fossil fuels. Biomass is also the only renewable energy source that can be stored and applied to produce heating, electricity and fuels when they are needed. The environmental benefit of using biomass as an energy source is the ability to reduce CO_2 emissions compared to fossil fuels. The liquid or solid biomass feedstock can be directly used to provide energy or converted to more convenient energy carriers.

The promotion of the use of renewable energies is a major objective of the European energy policy together with energy savings and increased energy efficiency. Especially the promotion of decentralised energy production from biomass and other renewables is an important part of the EU energy policy, because of its many benefits, including the utilization of local energy sources, increased local security of energy supply, shorter transport distances and reduced energy transmission losses. Biomass is an integral part of the development of the European renewable energy sector with the policy goal of a 20% target for the overall share of energy from renewable sources and a 10% target for energy from renewable sources in the transport sector until 2020. Biomass can also contribute a significant part to the development of district heating and cooling, which is an integral objective of the EU Directive on the promotion of the use of renewable energies [4].

The above mentioned EU Directive obligates each Member State to adopt a national renewable energy action plan. These action plans should take into account national measures related to achieving defined minimum levels of energy from renewable sources for district heating and cooling. These priorities provide a good basis for the future development of modern decentralised bioenergy systems and their implementation within communal and municipal energy supply concepts. However, research and development activities are still needed to develop efficient bioenergy supply schemes, because biomass conversion technologies should achieve conversion efficiency of at least 85% for residential and commercial applications and at least 70% for industrial applications [4].

Bioenergy is already a significant contributor to the European

* Corresponding author.
E-mail address: rafal.strzalka@hft-stuttgart.de (R. Strzalka).

http://dx.doi.org/10.1016/j.rser.2017.01.091

Nomenclature

APH	Air preheater
CON	Condenser
E	Emission factor
EBU	Efficiency of biomass utilization
EVA	Evaporator
EXF	Exhaust fan
e	Physical exergy
ε	Exergetic efficiency
FBCB	Fixed bed combustion boiler
GEN	Generator
h	Enthalpy
IAF	Intake air fan
M	Motor
ORC	Organic Rankine Cycle
REC	Recuperator
SOP	Silicone oil pump
S	Entropy
TOECO	Thermal oil economiser
TOP	Thermal oil pump
TUR	Turbine
y	Ratio

Greek symbols

Δ	delta
η	efficiency

Subscripts

0	reference point
CO_2	carbon dioxide emissions
D	destruction
EB	fossil fuel boiler efficiency
el	electrical
F	emission factor for the production of electricity from fossil fuels
i	identification number
k	system component
L	loss
P	Product
ph	physical
R	emission factor for energy generation from fossil fuels
tot	total

energy mix and it is anticipated that biomass will provide 20,000 ktoe electricity, 90,000 ktoe heat and 29,000 ktoe biofuels in 2020. The bioenergy sector in Europe is showing steady growth patterns across the different market segments and covers about 8% of the total final European energy consumption. Although biomass potentials are limited, the efficient utilization of modern bioenergy technologies will be of high importance for the future development of the European energy supply system, especially in balancing out fluctuations in energy generation from wind and solar.

Related to the actual development of alternative energy generation technologies and the role biomass is anticipated to play within the future renewable energy market, the paper analyses the possibilities of efficient biomass integration within innovative energy supply concepts. Biomass applications will be described using the example of Germany, because the German bioenergy sector is one of the most well-developed in Europe; in 2014 biomass contributed with 326.9 TWh to cover about 7,6% of the European energy demand. Energy produced from biomass contributes with 66% to the total final energy produced from renewables. The German bioenergy installations provide about 49.1 TWh of electricity and thus account for about 8% of the total electricity consumption. Additionally biomass is the most important energy source for heat generation, meeting more than 90% of renewable-based heating demand. Since 1995, the share of biofuels in the transport sector increased by a factor of nearly 120; in 2014, about 3.4 Mio t. fuels were generated from biogenic substrates, 5.1% of the total fuel consumption in Germany [5–10].

There are numerous technologies for the conversion of biomass into useful forms of energy. Bioenergy can be provided as solid, gaseous or liquid fuel and is mainly used to generate heat, as well as electricity and transport fuels and its wide application spectrum is one of the main reasons for constantly growing amounts of energy produced from biomass. Basically, the processes utilized for energy production from biomass can be divided into three main categories: thermochemical, physical-chemical and biological conversion routes. The thermochemical conversion processes of biomass include: combustion, pyrolysis and gasification. The physical-chemical conversion processes can be applied for the production of biodiesel. The biological conversion routes of biomass are used to convert biomass into biogas or bioethanol [11].

With the recent rapid development of biomass conversion technologies and increasing demand for decentralised, low-emission generation, the knowledge of efficient applications of modern bioenergy systems is important in the context of energy shortage and climate change. From technical and ecological aspects, biomass is a suitable substitute to fossil fuels, especially in the sector of power generation. While the technology for biomass-based electricity generation above 2 MW electrical power output using steam turbines are now state-of-the-art appliances, the technologies available below this capacity are less established and display several new and innovative approaches [12]. Hence, the ongoing development of these technologies and the current status of decentralised biomass power supply systems will be reviewed in the paper.

The scarcity of resources and the necessity for long-term energy security have increased the attention to the production of biofuels as an alternative fuel in the transportation sector. Biomass in the form of biofuels can be used as fuel in several kinds of vehicles and be additionally used in cogeneration plants for the generation of heat and electricity. Bioliquids offer advantageous storage and transportation characteristics which make them an integral part of most future energy scenarios [13]. Although biofuels offer several advantages as plant-based fuels from a renewable source, the utilization of bioliquids for energy purposes is not always the most sustainable option. Therefore an overview on actual issues related to production and utilization of biofuels is presented in the paper.

Over the last years a lot of information about the individual characteristics of different biomass conversion technologies has been published. However, a direct and comprehensive comparison of the specification, cost-efficiency and performance of the different bioenergy appliances is still lacking. Therefore review reports that systematically compare, analyse and evaluate the suitability of the individual biomass conversion technologies with emphasis on the relevant performance parameters and realistic commercial potential are needed. Hence, the final section of the study contains a characterisation and evaluation of the relevant parameters of the versatile biomass conversion processes.

While the development of the bioenergy sector gained momentum in recent years, the practical experience from existing plants and numerous research studies have shown that not all technologies are reliable and cost efficient. Yang et al. [14] used a cumulative exergy method for the evaluation of the sustainability of the corn-ethanol production in China and indicate that the production process is not sustainable for the conditions prevailing in China. Another study