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Hybridisation optimization of concentrating solar thermal and biomass power generation facilities

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Abstract

Recently, the first concentrating solar power–biomass hybrid power plant commenced operation in Spain and the combination of both energy sources is promising to lower plant investment. This assessment investigates 17 different concentrating solar power–biomass hybrid configurations in regards their technical, economic and environmental performance. The integration of molten salt thermal storage is considered for the best performing hybrid configuration. While thermal storage can increase plant output significantly even 7 h full-load thermal storage plants would generate the majority of the electricity, 70%, from the biomass resource.

Only mature technologies with references >5 MWe are considered in this assessment to ensure that the scenarios are bankable. The concentrating solar power technologies selected are parabolic trough, Fresnel and solar tower while the biomass systems include grate, fluidised bed and gasification with producer gas use in a boiler.

A case study approach based on the annual availability of 100,000 t of wood biomass is taken to compare the different plant configurations but the results are transferable to other locations when updating site and cost conditions. Results show that solar tower–biomass hybrids reach the highest net cycle efficiency, 32.9%, but that Fresnel-biomass hybrids have the lowest specific investment, AU$ 4.5 m/MWe. The investment difference between the 17 scenarios is with up to 31% significant. Based on the annual electricity generation CSP–biomass hybrids have an up to 69% lower investment compared to standalone concentrating solar power systems. The scenario with the best technical performance, being solar tower and gasification, is at this point in time not necessarily the best commercial choice, being Fresnel and fluidised bed, as the lower Fresnel investment outweighs the additional electricity generation potential solar towers offer. However, other scenarios with different benefits rank closely.

Keywords: Concentrating solar power–biomass hybrid plants; Energy from biomass; Parabolic trough; Fresnel; Solar tower

1. Introduction

Concentrating solar power (CSP)–biomass hybrid plants are a well accepted solution for comparatively low cost base-load/dispatchable renewable energy but are a niche market considering the limited areas with a sufficiently high direct normal irradiance, >1700 kW h/m^2/

Abbreviations: CSP, concentrating solar power; PPA, power purchase agreement; PT, parabolic trough; ST, solar tower; F, Fresnel; IRR, internal rate of return on investment; TO, thermal oil; DSG, direct steam generation; MS, molten salts; TS, thermal storage; DNI, direct normal irradiance; AU$, Australian Dollar (AU$/US$ = 0.96).

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year, and biomass resources. Countries such as Australia, Spain, Italy, Greece, Thailand, India, and Brazil are, amongst others, prime candidates for such projects as these countries have locations that meet both criteria. To maximize the commercial viability and efficient biomass use the power plant concepts should be as efficient as possible considering the economic realities of obtaining finance for such projects.

Recently, the first CSP–biomass hybrid plant commenced operation near Barcelona, Spain (Protermosolar, 2012), which proves that such concepts work technically and are bankable solutions. Despite other CSP–biomass configurations being investigated in the past, including Fresnel and tower systems, no other projects commenced construction at this point in time.

This paper investigates different possible CSP–biomass hybrid configurations with the aim of identifying the best in regards to technical, economic, and environmental performance, such as cycle efficiency, investment, and CO_2 abatement potential. The efficient use of biomass is not only necessary to maximize plant output, but also to optimize usage as biomass has to be purchased competitively against other users, such as pulp and paper industry. Understanding the different CSP–biomass hybrid options will enable project developers to concentrate on the most promising ones therewith increasing chances to successfully implement such projects.

All scenarios investigated in this paper assume that the biomass boiler is operating constantly at full capacity, that the CSP system provides additional capacity during the daytime when electricity demand/prices are typically higher in Australia (Lekovic et al., 2011), and that the CSP and biomass systems can operate independent of each other by providing identical steam flows/parameters to the joint turbine. To minimize plant investment molten salt thermal storage is considered only for one high temperature scenario as its cost are still comparatively high and the biomass component can generate electricity at lower cost during the night and extended cloud coverage. Future work could investigate CSP–biomass hybrids with thermal storage in more detail by considering other storage media, such as pressurized water or steam, and tank configurations, such as single tanks.

2. Current hybrid proposals

First proposals to combine CSP with biomass/waste materials using dish systems were investigated briefly in the 1980s (McDonald, 1986). However, due to technical and financial issues no plants were built. It took more than two decades before the first commercial CSP–biomass hybrid plant, Termosolar Borges 22.5 MWe (Morell, 2012), commenced operation near Lleida, ca. 150 km west of Barcelona, Spain, see Fig. 1. The plant is located further north than any other CSP project in Spain and uses the mature trough technology with thermal oil (Cot et al., 2010). The solar field generates saturated steam at 40 bar and the biomass boilers superheat this steam to 520 °C (Morell, 2012). The steam temperature is well selected to avoid high-temperature corrosion on the superheaters from this type of fuel, wood see Fig. 1. To further optimize the concept its steam pressure could be raised >40 bar (Morell, 2012).

Several other studies investigated the hybridisation of parabolic trough plants with biomass considering capacities from 2 MW_{th} to 107 MWe but no other project has yet commenced construction (Pérez and Torres, 2010; Schnatbaum, 2009; Nixon et al., 2010; California Energy Comission, 2008). These studies concentrate on integrating a biomass fired steam boiler into the CSP plant's water-steam cycle but also consider a biomass fired heater in the thermal oil or molten salt cycle.

Alternatively, Fresnel systems have been investigated for hybridisation with biomass and waste materials (Peterseim et al., 2012; Rojas et al., 2010; Spliethoff et al., 2010; Nixon et al., 2012). The benefit of using Fresnel would be steam temperatures up to 500 °C (Fluri et al., 2012) and subsequent higher conversion efficiencies. However, no reference plants yet exist for this CSP configuration.

Solar towers with direct steam generation (DSG) and molten salts are being investigated in combination with biomass (Peterseim et al., 2013) as are solar towers using a volumetric air receiver (Coelho et al., 2012). Due to the limited reference situation of high-temperature air tower systems and the higher complexity of such a system it is expected that solar towers with DSG or molten salts are easier to finance. Another option to combine high-temper-

Fig. 1. First CSP–biomass plant under construction near Lleida, Spain (left) and biomass fuel (right).