2015-08-11

A Comparative Technological Review of Hybrid CSP-Biomass CHP Systems in Europe

C. M. Iftekhar Hussain
Technological University Dublin, iftekhar.hussain@mydit.ie

Aidan Duffy
Technological University Dublin, aidan.duffy@tudublin.ie

Brian Norton
Technological University Dublin, brian.norton@tudublin.ie

Recommended Citation

Iftekhar Hussain, C.M. Duffy, A. & Norton, B. (2015), A Comparative Technological Review of Hybrid CSP-Biomass CHP Systems in Europe, *International Conference on Sustainable Energy & Environmental Protection,* Paisley, UK, 11-14 August.

A COMPARATIVE TECHNOLOGICAL REVIEW OF HYBRID CSP-BIOMASS CHP SYSTEMS IN EUROPE

C. M. Iftekhar Hussain, Aidan Duffy, Brian Norton

Dublin Energy Lab, Focas Institute, Dublin Institute of Technology, Dublin 8, Ireland

Abstract

This paper aims to explore different solar technologies and its suitability for hybridization with biomass for combined heat and power (CHP) generation in Europe. Although hybrid solar-biomass research and demonstration is in its infancy, it has the potential to provide dispatchable renewable energy at a significant scale over many areas in Europe. Therefore, this review examines the technical and economic reported performances on hybrid systems in order to assess the technical and economic viabilities of newly-emerging projects. Three different combinations of solar and biomass technologies are discussed in this paper: solar tower (ST) - biomass, parabolic trough (PT) - biomass and linear Fresnel (LF) - biomass systems. Using findings from literature, case studies and industry sources, this review compares each of these systems with respect to their technical and economical parameters.

The paper shows that, of the three concentrated solar power (CSP) technologies, ST provides the best overall efficiencies for both heat and power generation. However, complex installation requirements and high capital cost may explain poor uptake of this technology. Of the three systems, LF suffers from relatively high optical and thermal losses and also to greater cosine effect losses; which may explain why this technology is also poorly deployed. Only one solar-biomass hybrid power plant is currently operating in Spain; this uses PT technology due to its comparatively easy installation process compared to ST and relatively higher heat and optical gain than LF.

Keywords: CHP, Hybridization, Termosolar Borges

1 INTRODUCTION

Standalone solar energy plants suffer from intermittent energy output due to day/night cycles and also from reduced irradiation periods during winter and cloudy days or transients [1-3]. Although biomass power plants can operates continuously, they can have high initial cost, uncertain supply chain security and require bulk transportation [4]. Hybrid solar/biomass plants will become an increasingly attractive option as the price of fossil fuel and land continue to rise and the cost of solar thermal technology falls [5].

There is one CSP-biomass hybrid power plant ‘Termosolar Borges’ currently in operation in Spain. This paper explores the possibility of more use of such power plants in European and Mediterranean climates.

The Termosolar Borges plant uses parabolic trough + biomass combustion + natural gas system for hybridisation. Other systems combine different technologies [6, 7]. This review paper collects information from a range of literature reviews and presents a number of system combinations in order to identify the most promising system for solar-biomass hybridization in Europe.

2 TECHNOLOGY OVERVIEW

CSP and biomass technologies suitable for hybridization include the Stirling dish which is one of the most prominent CSP technologies and offers a better system efficiency over all other CSP. The system consists of a Stirling engine at each focal point of the parabolic dish which generate electricity. The unique technical characteristics of Stirling Dish does not allow sharing of plant equipment like cooling systems and power blocks as with other CSP technologies when integrated with biomass. The same is true of hybrid PV systems. Due to this reason the system capital cost of biomass hybridization with Stirling Dish and PV being high, is less economically viable.

The most proven technologies for power and heat generation are biomass combustion and gasification. Therefore this paper only considers combinations with Solar Tower (ST), Parabolic Trough (PT), Linear Fresnel (LF), Biomass Combustion (BC) and Biomass Gasification (BG).

2.1 Solar Tower

Solar towers (central receiver technology) use heliostat dual-axis sun-tracking mirror to reflect the sun's heat onto a single receiver point. The heliostats reflects direct normal irradiance of sun to a central receiver. This cumulative Direct Normal Irradiance (DNI) generates a high temperature to produce superheated steam through heat transfer fluid. This superheated steam is eventually fed into a Rankine Cycle to operate a steam generator to produce electricity. Heat could be used for industrial processes, such as steam production for process heat (around 1000 °C) and the charging of energy storage [8-10]. This technology is preferable for large scale heat or power production.

2.2 Parabolic Trough

Parabolic trough collectors are made of long parabolic shaped mirrors consists of the receiver with the same length which is located on focal point of the mirror [11]. This is a one axis tracking technology typically aligned on an east-west axis. The north-south axis harvests more energy in summer where east-west produces more in winter [12]. The tracking system rotates the collector on its single axis throughout the day to track the DNI of sun's energy, which reflects on to the receiver tube containing either synthetic thermal oil, molten salt or pressurized water. The temperature reaches 400° C for thermal oil, 550° C for molten salt and 500° C for pressurized water. This produced heat is then transferred to either heat exchanger to fed it to Rankine cycle to produce electricity

2.3 Linear Fresnel

Linear Fresnel collectors are one of two viable line-focus CSP technologies, along with the parabolic trough [13-15]. Linear Fresnel collectors utilize an array of low-profile, flat or nearly flat primary reflectors and a fixed receiver assembly that includes one or more linear receiver tubes and an optional secondary reflector. The primary reflectors track the sun in the daytime while the receiver assembly remains fixed. The low profile reflector architecture allows increasing concentration ratio without increasing wind loads, which is otherwise the case for parabolic troughs and large-sized heliostat mirrors for central-receiver systems. Historically, most linear Fresnel collectors were used or developed for low- or medium-temperature heat generation. A linear Fresnel collector typically includes an array of mirror panels, so its design may differ in terms of the individual mirror dimensions and the overall arrangement. In addition, the fixed nature of the receiver assembly provides considerable design freedom. On the other hand, linear Fresnel collectors have lower optical/thermal efficiency than parabolic troughs because the combination of a fixed receiver and the one-axis tracking mirror panels in a horizontal plane results into greater cosine losses than troughs [16-18]. The lower cost collector components are often required to compensate this optical penalty

2.4 Biomass:

As shown in figure 1, two major biomass conversion routes are biochemical and thermochemical.

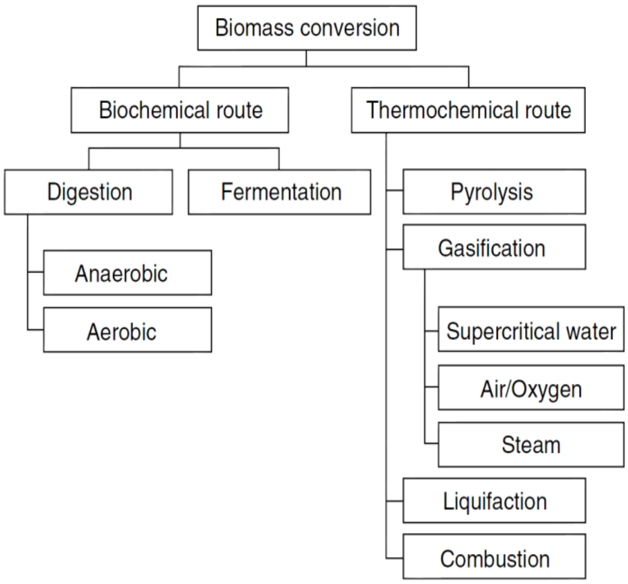

Figure 1. Biomass conversion route.

In biochemical processes there are two more routes mostly known as digestion (anaerobic and aerobic) and fermentation [19]. However, in this review only the two most important process of thermochemical conversion route will be considered.

Biomass combustion involves complete conversion of biomass in excess oxidant (usually air) to CO_2 and H_2O at high temperature. Gasification converts biomass in an O_2 deficient environment. Pyrolysis takes place at a relatively low temperature in the total absence of O_2 [20].

2.4.1 Biomass Combustion

Combustion is a chemical reaction in which a fuel is oxidised releasing a large quantity of energy. Hot gas produced by burning biomass in a combustor or furnace is fed into a boiler in order to generate steam. The steam drives a turbine or steam engine to produce electricity [21,22].

Biomass combustion is ideally suitable for commercial process heat/district heat, CHP, and electricity generation ranging from a few MW up to 50-100 MW. This technologies adopts either Fixed Bed (underfeed stoker & fixed or moving grate) or Fluidised Bed (bubbling & circulating fluidised bed) or Entrained Flow or Dust Combustor to convert energy from biomass. Technology selected depends on the type & quantity (plant scale) of biomass fuel available.

Combustion plant consists typically of:

- Furnace/boiler
- Heat recovery/steam generation
- Steam engine/turbine with generator (power generation plant)

2.4.2 Biomass Gasification

Gasification is a thermochemical process in which a carbonaceous fuel is converted to a combustible gas known as syngas, consisting of H_2, CO, CH_4, CO_2, H_2O, N_2, higher hydrocarbons and impurities (e.g. tars, NH_3, H_2S and HCl) [19]. The process occurs when a controlled amount of oxidant (pure O_2, air, steam) is reacted at high temperatures with available carbon in a fuel within a gasifier. Gasification converts biomass to a gas, which can then be utilised in advanced power generation systems such as fuel cells thus achieving higher electrical efficiencies compared to combustion based technologies. For this reason, gasification is considered the enabling technology for modern biomass use [23,24]. Furthermore, it offers greater flexibility in terms of applications to electricity, heat, transport fuels and chemicals.

Gasification plants typically consists of:

- Gasifier
- Syngas cleaning units (engine/turbine requirements)
- Gas engine/turbine with generator (power generation plant
- Heat recovery/steam generation
- Steam engine/turbine with generator (combined cycle plant)

3 SYSTEM SELECTION

A good number of research have been conducted on working characteristics and performance of different CSP plant in different scenarios [25-29]. Peterseim. J. H *et.al* [3] examined 17 different combinations of CSP-biomass and storage systems in his study. Among various combinations of system this paper considers three best performing combinations of CSP technology. The study therefore, will compare those technology selections to identify better system for both power and heat generation in Europe.

3.1 System 1: Solar Tower : Biomass

Among all other concentrating solar power technologies, Solar Tower (ST) or Central Receiver Systems (CRS) is able to produce highest temperature >500°C and steam pressure (up to 130bar) and provide better efficiencies in electricity and heat production [30]. Solar tower system can operate with Direct Steam Generation (DSG) or Molten Salt for storage system in terms of power generation. DSG is particularly preferable for its higher efficiency, on the other hand molten salt enables power plant to produce electricity during insufficient DNI. Solar tower with molten salt is also and commercially available from different suppliers.

Among 17 different combinations which had been studied previously [3,31], solar tower (ST) with direct steam generation (DSG) as primary CSP working fluid combining with biomass gasification gave the highest peak net efficiency of 33.2% followed by the combination of solar tower, molten salt (primary CSP working fluid) and gasification with optimum net efficiency 32.9%. Both systems are able to produce 540°C temperature at 130bar steam pressure. On the other hand at 525°C and 120bar steam pressure ST/DSG/biomass combustion system can provide 33.0% of pick efficiency followed by ST/molten salt/ biomass combustion of 32.8% efficiency. From the above information it appears that biomass gasification gives marginally higher efficiency comparing with combustion system when it merge with CSP. Within the CSP, molten salt as the working fluid is slightly less efficient than DSG. In terms of heat storage, usually molten salt may be best in present time for solar tower technology.

On the same research it was found the economically the internal rate of return of DSG with combustion and gasification system is 10.8% and 10.9% respectively in comparison to molten salt with combustion and gasification both 10.5%. The payback period of the first case is 9.7 and 9.6 and the second case gives 10.2. The reason behind the better economic performance of DSG than molten salt is the capital expenditure of setting up a large storage facilities for molten thermal energy storage (TES) system.

3.2 System 2: Linear Fresnel: Biomass

Linear Fresnel is also an option for hybridization with biomass resource and this systems has also been investigated in various research [31, 32]. Although LF systems is capable of obtaining from 400°C to 500 temperature at steam pressure from 90bar to 110bar which is less than ST technology, however no such power plant had been found which combines linear Fresnel with molten salt for heat storage. At 500°C temperature and 110bar steam pressure LF with DSG as primary working fluid can provide net plant efficacy of 32.5% when it combines with biomass combustion system [3,32].

Among all CSP biomass hybrid system, LF use to give the best economic performance. The same system can give an IRR of 11.5% with only 8.6 years of payback period. The research also indicates that Fresnel technology offers much lower investment cost in comparison to other two CSP technology.

3.3 System 3: Parabolic Trough: Biomass

Parabolic Trough (PT) technology hybridized with biomass is most mature system among all of the hybrid technologies as there is one such plant is currently operating in Spain. It had been found that PT with DSG in combination with biomass combustion system at temperature 450°C and 100bar steam pressure can obtain pick net efficiency of 31.5% [3]. On the other hand PT with molten salt at 525°C and 120bar can give the efficiency of 32.7%. If the biomass technology adopts gasification, the same combination with PT and molten salt can provide slightly more efficient system of 32.8% and able to obtain temperature of 540°C at 130bar steam temperature. It indicates clearly that gasification has higher conversion efficiency it is although not very significant [33, 34]. The economic scenario is not however, as competitive as other two CSP technologies. PT, DSG and biomass combustion will see 8.9% of IRR on investment with 14.6 years of payback time. Other two combinations will give a little better IRR which is 9.0% and 9.1% respectively. The payback period is also marginally better which is 14.4 years and 14.3 years. No LCOE had been presented in this particular research. LCOE of PT-biomass hybrid system could be more useful in understanding the suitability of this system for electricity and heat generation.

4. COMPARATIVE ANALYSIS

CSP/biomass hybridization can lower the capital cost by sharing the plant equipment such as steam turbine, condenser and auxiliary equipment [1-6]. The following presents technical comparisons between different CSP and biomass technologies.

4. 1 Comparison of CSP Technologies

Table 1 shows that LF have better opportunities for large scale power plant development in terms of land use. However, there are very few such type of reference power plant had been developed because of less favourable technical features of LF in comparison with its closed technically similar system PT collector.

Table 1: Comparison of different CSP technology [38]

System	Peak Solar to Electricity Conversion Efficiency	Annual Solar to Electricity Conversion Efficiency	Land Use m²/ MWh
Solar Tower	23 -27%	15-17%	8-12
Linear Fresnel	18-22%	8-10%	4-6
Parabolic Trough	21-25%	15-16%	6-8

It was found from other researches that in comparison with PT, LF requires 35% smaller solar field due to smaller row-to-row distance [35-38].However, it has higher heat loss due to its receiver design. Parabolic trough vacuum receiver has much lower heat losses than the atmospheric Fresnel receiver leaving this technology less suitable for large scale heat generation.

Moreover LF observes higher optical losses caused by horizontally placed collectors which observes higher cosine losses. The cosine losses generally occurs if the surface is not normal to the sun, the solar irradiance falling on it will be reduced by the cosine of the angle between the surface normal and a central ray from the sun [36,39]. The shading of a linier Fresnel to adjacent collector array further reduce optical efficiency. The cosine loss and shading effect carouses supplying significantly less thermal energy to the power block, especially in the early morning and late afternoon which causes lower dumping rate of thermal energy. However at mid-day with high irradiation, LF is well capable of produce thermal energy which exceeds the power block capacity causing higher upper dumping as shown in Figure 4. To optimize these problems the operating time for linear Fresnel system reduces which increases the costs per kWh.

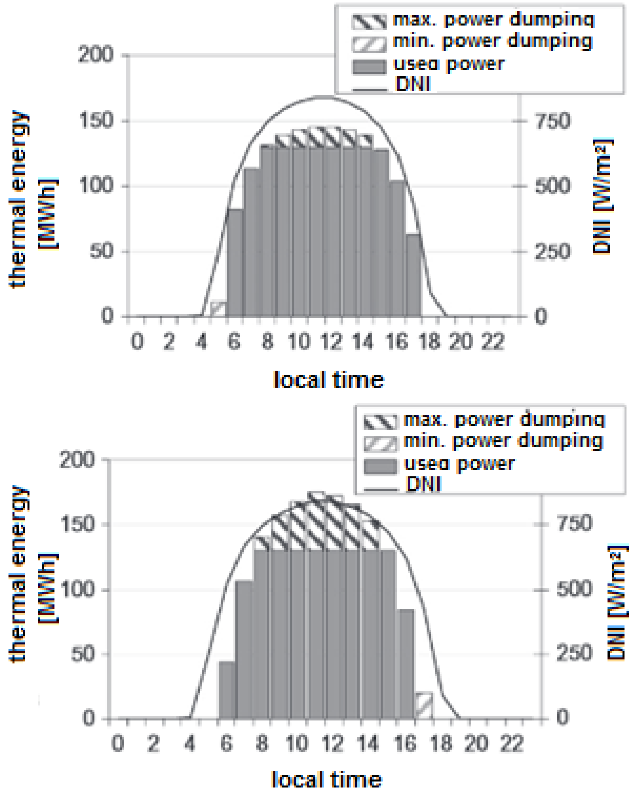

Figure 4: Dumping effect of parabolic trough and linear Fresnel [39]

In case of PT and ST, few more research have been carried out to evaluate the performance of each systems [35, 40]. Simulation studies have shown that solar tower performs well in heat generation which allows better cycle efficiency [35]. Figure 5 shows the performance of ST and PT in four different systems in a given day in July and January to understand the performance characteristics in summer and winter time.

Systems which have been considered in the model are Solar Rankine Cycle Parabolic Trough Collector (SRC--PTC), Solar Rankine Cycle Solar Tower (SRC_ST), Integrated Solar Combined Cycle Parabolic Trough Collector (ISCC_PTC), Integrated Solar Combined Cycle Solar Tower (ISCC_ST).

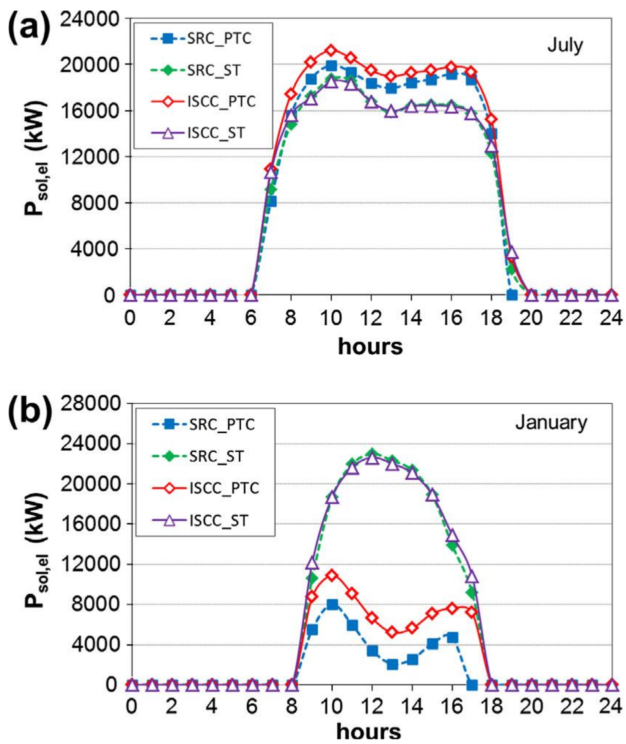

Figure 5: Hourly solar power production (Psol,el) on a day in July (a) and January (b) [35]

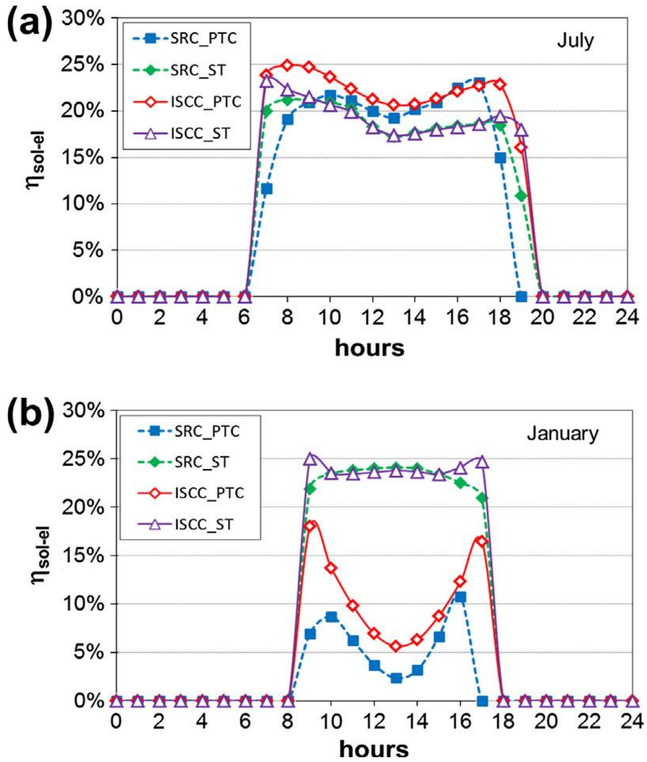

Figure 6. Hourly solar-to-electric efficiency (ηsol-el) on a day in July (a) and January (b) [35]

The simulation results in Figure 5 show that, in summer time both systems of PT performs better than ST systems. However, parabolic trough energy generation reduces dramatically in winter due to cosine effects and incident angle modifier effects and heat losses.

An ST performs through-out the year giving superior yearly solar to energy conversion efficiency. In Figure 6, the efficiency curve of both ST and PT are presented.

Values of η_{sol-el} as high as 25% are obtained by solar tower plants in winter time (Fig. 6b), when low ambient temperatures make the condensing pressure fall, thus increasing the steam/bottoming cycle efficiency. The solar-to-electric efficiency of the PTC plants is strongly affected by the cosine effect: η_{sol-el}, whose values are lower than 10% in the central hours of a January day, increases up to 23% (SRC) or 25% (ISCC) in July.

Pitz Paal *et.al* [38] compared different CSP technologies from where he presented a correlation between temperature vs efficiency of each system. The correlation provides an understanding the maximum efficiency on different state of temperatures of each technology. The efficiency is measured as:

$$\eta_{max} = \eta_{th,\, Carnot} \times \eta_{Absorber} \qquad (1)$$

Assuming the obtained absorber temperature is equal to process temperature.

$$T_{Absorber} = T_{Process} \qquad (2)$$

Figure 7 shows that at higher temperature a Stirling dish gives higher efficiency followed by solar tower. Solar tower performs best between around 1000K (727°C) to 1300K (1027°C) which gives a fare range of options for heat and power generation.

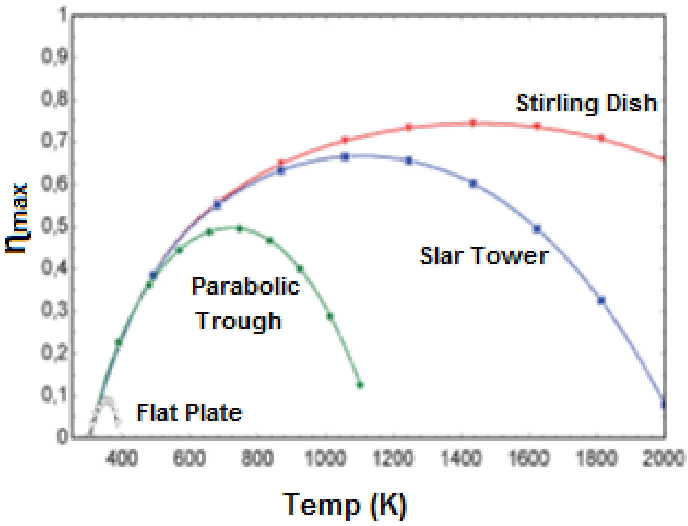

Figure 7: Temperature vs Efficiency curve of CSP system [38]

In comparison to that the parabolic trough gives a smaller window for CHP generation with optimum efficiency. Maximum efficiency spectrum is in between 700K (427°C) to 750K (477°C). The obtainable maximum efficiency is better in solar tower where it offers around 65% in comparison to 50% efficiency of parabolic trough. The flat plate solar concentrators are the least in producing heat and thus less efficient in CHP generation.

The capital costs for the solar field and receiver system are a larger percentage of the total costs in solar tower systems, while the thermal energy storage and power block costs are a smaller percentage [3]. As shown in table 1, the area used to generate per MWh for ST is relatively higher than parabolic trough and significantly higher than LF and PT, it is apparently clear that ST draws higher capital cost in comparison to other two. However, according to International Renewable Energy Agency report in 2012 there is no CSP power plants using PT and LF are using thermal storage system, which means those plant only can generate electricity during day time. Therefore, solar tower can potentially lower the lavalized cost of energy (LCOE) by increasing the capacity factor using thermal energy storage system.

4.2 Biomass Technology Comparison

A comparison of gasification, combustion, pyrolysis and pressurised gasification and gas turbine combined cycle, IGCC for power generation was found that the feed expenditure in the combustion systems is the highest of the systems at any capacity which leads to a low system efficiencies shown in Figure 8 [41].

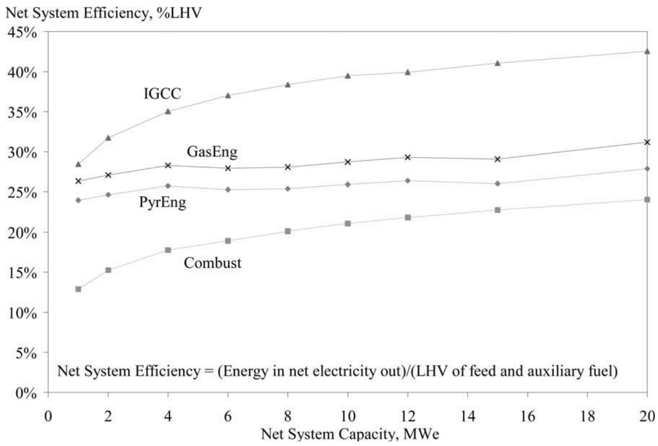

Figure 8: Comparison of efficiencies for biomass to electricity systems. [41]

This high feedstock expenditure is countered by low capital expenditure as a result of the low total plant costs shown in Figure 9.

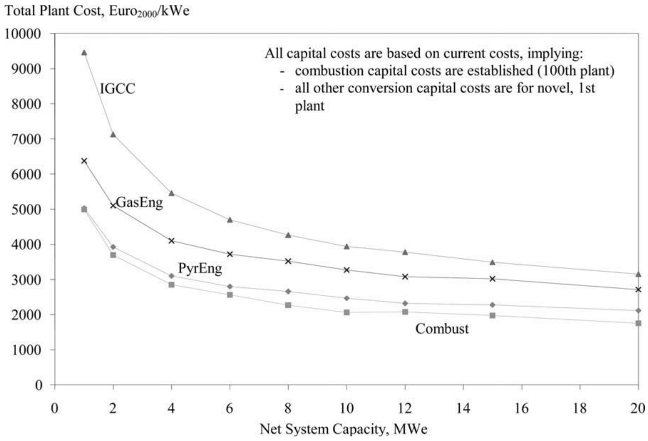

Figure 9: Comparison of total plant costs for biomass to electricity systems. [41]

Low capital payback costs along with low overheads and maintenance costs and relatively lower labour costs are also the advantages of combustion system. Both low capital costs and low labour requirements are the key drivers of various well established power plants using biomass combustion technology. It appears from the study that despite lower system efficiency of biomass combustion, this technology is widely adopted and well proven in the market for power generation due to its economic competitiveness over other biomass systems.

5. DISCUSSION

It appears that Solar Tower (ST) is the best possible CSP technology for CHP generation hybrid system. Figure 7 shows that the effective working temperature range is very limited for flat plate solar concentrators. PT efficiency decreases dramatically after 750K (477°C). ST gives relatively better working temperature range over PT and LF. However, as ST is not as proven technology as Parabolic Trough (PT) due to its relatively higher land use and complex technical operations, PT may be the next best option for hybridization. Higher optical and heat losses of linear Fresnel (LF) may not make it due the best option for hybridization.

Biomass technology selection is heavily depended on availability of biomass resources, capital and operating cost. Deployment of biomass plant should consider a good availability of biomass resources or the plant may end up with a high operating cost. Regardless the efficiency of biomass systems different research shows that among all biomass technology, combustion system is proved to be most economically proven technology for biomass to electricity conversion.

6. CONCLUSION

Hybrid CSP and biomass power plants are interesting option for future dispatchable renewable electricity generation. The challenges are the moderate capacity factors or high TES costs, the necessity to build a large biomass collection structure, the volatility of the biomass price and low feed-in tariffs. The hybridization of these technologies increases power plant capacity factors (when compared to a solar only) and reduces biomass consumption (when compared to a biomass only power plant).

REFERENCES

[1] Peterseim JH, White S, Tadros A, Hellwig U. Concentrating solar power hybrid plants - Enabling cost effective synergies. Renew Energy; vol.67: pp178–85, 2014.

[2] Zhang HL, Baeyens J, Degreve J, Caceres G. Concentrated solar power plants: review and design methodology. Renew Sustain Energy Review, vol.22, 2013.

[3] Peterseim. J. H, Hellwig. U, Tadros. A, White.S, Hybridisation optimization of concentrating solar thermal and biomass power generation facilities, Science direct Solar Energy vol.99, pp. 203–214, 2014.

[4] Srinivas. T, Reddy.B.V, Hybrid solar -biomass power plant without energy storage, Reference: CSITE22, Appeared in: Case Studies in Thermal Engineering, 23 January 2014.

[5] Nixon JD, Dey PK, Davies P a. The feasibility of hybrid solar-biomass power plants in India. Energy. vol.46, pp. 541–54, 2012;

[6] Peterseim JH, White S, Tadros A, Hellwig U. Concentrated solar power hybrid plants, which technologies are best suited for hybridisation? Renew Energy; vol.57, pp.520–32, 2013

[7] Cot. A, Amettler. A, Vall-Llovera J, Aguilo J, Arque JM.Termosolar Borges: A Thermosolar Hybrid Plant with Biomass. Third Int Symp Energy from Biomass Waste 2010.

[8] Zhang HL, Baeyens J, Degreve J, Caceres G. Concentrated solar power plants: review and design methodology. Renewable and Sustainable Energy Review. vol.22:pp.466-481, 2013;

[9] Zhu G, Wendelin T, Wagner MJ, Kutscher C. History, current state, and future of linear Fresnel concentrating solar collectors. Solar Energy vol. 1032014 pp.639–652, 2014

[10] Baharoon DA, Rahman HA, Omar WZW, Fadhl SO. Historical development of concentrating solar power technologies to

generate clean electricity efficiently – A review. Renewable Sustainable Energy Review. 2015.

[11] Greenpeace International, SolarPACES and ESTELA. Concentrating solar power outlook 2009 – why renewable energy is hot.

[12] Valenzuela L. STE Plants with parabolic trough collectors. 2012.

[13] Morin, G., Mertins, M., Kirchberger, J., Selig, M., 2011. Super NOVA – construction, control & performance of steam superheating linear Fresnel collector. In: Presented at the 17th Solar PACES International Symposium, Granada, Spain.

[14] Morin, G., Dersch, J., Platzer, W., Eck, M., Haberle, A., 2012. Comparison of linear Fresnel and parabolic trough collector power plants. Solar Energy 86

[15] A. Heimsath, F. Cuevas, A. Hofer, P. Nitz, W.J. Platzer, Linear Fresnel collector receiver: heat loss and temperatures, Energy Procedia vol.49, pp.386 – 397, 2014.

[16] Munoz, J, Martinez-Val, J.M, Ramos, A. Thermal regimes in solar-thermal linear collectors. Solar Energy vol. 85, pp.857–870. 2011

[17] Pino, F.J., Caro, R., Rosa, F., Guerra, J., 2012. Experimental validation of an optical and thermal model of a linear Fresnel collector system. Applied Thermal Engineering, 1–9

[18] European Academices Science Advisory Council (EASAC). Concentrating solar power: its potential contribution to a sustainable energy future. Available at: ⟨http://www.easac.eu/file admin/Reports/ Easac_CSP _Web-Final.pdf⟩; 2011

[19] Wayne Doherty, Modelling of Biomass Gasification Integrated with a Solid Oxide Fuel Cell System, PhD Thesis Submitted in School of Mechanical and Design Engineering, Dublin Institute of Technology

[20] Basu P. Biomass gasification and pyrolysis: practical design and theory. Brulington, MA: Academic; 2010.

[21] Nussbaumer VT. verenum Overview on Technologies for Biomass Combustion and Emission Levels of Particulate Matter. 2010.

[22] IEA Bioenergy (Task 32), Biomass Combustion and Co-firing: An Overview

[23] Kirkels AF, Verbong GPJ. Biomass gasification: Still promising? A 30-year global overview. Renewable and Sustainable Energy Reviews 2011; 15: 471.

[24] Doherty,W.,Reynolds, A.Kennedy, D. Process Simulation of Biomass Gasification Integrated with a Solid Oxide Fuel Cell Stack. Journal of Power Sources; vol.277, pp. 292-303. 2015

[25] Isabel Llorente Garcı , Jose´ Luis A ´ lvarez, Daniel Blanco, Performance model for parabolic trough solar thermal power plants with thermal storage: Comparison to operating plant data, Solar Energy 85 (2011) pp. 2443–2460

[26] Hussain.C.M.I, Muppala.S, Chowdhury. N.H, Adnan. A, Cost Analysis of Concentrated Solar Power Plant with Thermal Energy Storage System in Bangladesh, International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463, Vol. 2 Issue 4, April-2013, pp: 79-87

[27] Andrea Giostri, Marco Binotti, Marco Astolfi, Paolo Silva, Ennio Macchi, Giampaolo Manzolini,Comparison of different solar plants based on parabolic trough technology, Solar Energy 86 (2012) pp. 1208–1221

[28] Coates J, Solar T. SRP and Tessera Solar Announce 1.5MW Maricopa Solar Plant with Stirling Energy Systems SunCatcher TM Technology in Peoria, Arizona 2009.

[29] Ortega JI, Burgaleta JI, Téllez FM. Central Receiver System Solar Power Plant Using Molten Salt as Heat Transfer Fluid. J Sol Energy Eng 2008; vol: 130/024501

[30] J. H. Peterseim, A. Tadros, S. White, U. Hellwig, and F. Klostermann, “Concentrated solar power / Energy from Waste hybrid plants - creating synergies,” in SolarPACES Conference, 2012.

[31] Peterseim JH, Tadros a., White S, Hellwig U, Landler J, Galang K. Solar tower biomass hybrid plants - Maximizing plant performance. Energy Procedia vol.49, pp.1197–206, 2013

[32] Itskhokine D, Lancereau Q, Benmarraze M, Bichotte M, Dubost L. ScienceDirect LFR500 project : getting to high temperature while maintaining the cost-competitive advantage of Linear Fresnel Reflectors 2015.

[33] Peterseim JH, Tadros A, Hellwig U, White S. Increasing the efficiency of parabolic trough plants using thermal oil through external superheating with biomass. Energy Convers Manag, vol. 77, pp.784–93. 2014

[34] N.S. Suresh, N.C. Thirumalai 1, Badri S. Rao 2, M.A. Ramaswamy, Methodology for sizing the solar field for parabolic trough technology with thermal storage and

hybridization, Solar Energy vol. 110, pp.247–259, 2014
[35] G. Franchini, A. Perdichizzi, S. Ravelli , G. Barigozzi, A comparative study between parabolic trough and solar tower technologies in Solar Rankine Cycle and Integrated Solar Combined Cycle plants, Solar Energy, vol. 98 pp. 302–314, 2013
[36] Morin G, Dersch J, Platzer W, Eck M, Häberle A. Comparison of Linear Fresnel and Parabolic Trough Collector power plants. Sol Energy; vol. 86, pp.1–12, 2012.
[37] Nixon JD, Dey PK, Davies P a. Which is the best solar thermal collection technology for electricity generation in north-west India? Evaluation of options using the analytical hierarchy process. Energy; vol.35, pp. 5230–402, 2010
[38] Pitz-paal R. Parabolic Trough, Linear Fresnel, PowerTower A Technology Comparison.
[39] Pitz-paal R, Concentrators L. Line Concentrators for Power Generation : Parabolic Trough and Linear Fresnel.
[40] Sargent L. Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. Rep No NREL/SR-550-34440 2003:47
[41] Bridgwater A. V, Tof A. J, Brammer J.G. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. vol. 6. 2002.