REVIEW ARTICLE

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Review of Hybrid Solar-Biomass Power Generation System

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Abstract

The present paper reviewed the studies of the hybrid solar-biomass power plants. Based on renewable energy, several configurations of hybrid power cycles are discussed and summarized. It includes the technical, economical, and environmental aspects of the hybrid solar-biomass plant, how the hybrid power plant works, and the essential resources required for the setup and running of the hybrid solar biomass plant. The advantages and disadvantages associated with the single renewable resource-based power plants are also discussed. The hybrid power plants help rectify the disadvantages over single resource plants, improve the power production rate of the plant, and helps it run over seasonally. The present paper also discussed the solar and biomass potential in the Indian context and compared the progress of the hybrid solar-biomass power generation system with other countries.

Keywords: Biomass, Environmental aspects, Hybrid Power Cycles, Solar Energy.

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Introduction

In the 21st century, the demand of human beings for the utilization of energy has increased more than ever. Demand for energy in every field, from energy production to energy distribution, and most of the energy products used for this development, causes the main effect on the non-renewable source of energy. According to the International Energy Agency's (IEA) New Policies Scenario (NPS), global 45 total primary energy consumption grew by roughly 39% between 2000 and 2017, with another 27% rise expected by 2040. [1] Many developments have been done to improve and improvise renewable sources of energy, and the hybrid power plant cycle is one of the important steps in this cause. With the depletion of the non-renewable resources of power, technological advancement has been made to increase renewable resources. The hybrid power generation plants solve many of the problems in a single source power generation system, like the resource management throughout the year, the condition required to produce power, and the cost of setting and running the power plant.

The use of solar radiation and biomass for power generation is overgrowing, particularly in areas of the globe where these resources are plentiful, like Mediterranean countries. However, solar energy plants suffer from the intermittency of day/night cycles and reduced irradiation periods (winter, cloudy days, short transients). Biomass power plants have to confront the logistic problems associated with the continuous supply of vast amounts of relatively scarce and seasonal fuel. Hybrid systems may provide:

- The solution to these limitations.
- Maximising the energy potential of these resources.
- Increasing process efficiency.
- Providing greater security of supply and reducing overall costs.

This paper reviewed the hybrid solar-biomass plants provides over a single-source power plant, the current condition of the hybrid power plants in India, and the government expectation from this technology. It also discussed the technical and economic aspects of the solar biomass hybridization and effect of location and resources on installing the hybrid power plant.

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Hybrid Power Plant

A hybrid power plant generally combines two or more power generation cycles to generate more power than the single power generation system and minimizes the drawbacks of single power cycles. The power generation cycles can be solar, biomass, wind, and other possible renewable and non-renewable cycles. The more popular hybrid power generation system is used at this time is the solar-biomass power generation system. As two forms of renewable energy, solar and biomass energy hybridization provides a smart approach of complementing one other to overcome their particular disadvantages.[2] Hybridization with more stable renewable sources, such as biomass, is a cost-effective approach to satisfy energy demands on a consistent basis.[3] The hybrid solar and biomass power (HSBP) plant, with its low levelized cost of electricity (LCOE) and excellent dispatchability, will become a more appealing fossil energy option in the future.[4]

Solar Power Generation Plant.

Solar energy is the most encouraging renewable energy source of power generation globally. At present, electrical energy has become one of the primary needs in our daily lives, making it accumulative demand. As a leading source of electrical power generation, fossil fuels are decreasing day by day, and also its usage supplement a severe environmental problem. These reasons force the modern world to develop new energy sources which are renewable and safe. The renewable sources include wind, solar, water, biomass, and geothermal, ocean energy sources. By comparison, solar energy has remarkable capacity in the long term and is expected to have a significant role in upcoming years. Photovoltaic technology and thermoelectric technology are two ways for directly converting solar energy into electric energy.[5] It is also the cheapest method of power generation among other renewable energy sources (Figure 1 a and b).[6, 7]

Solar photovoltaic (PV) cells/modules

Solar PV cells generate electricity from sunlight, which can be fed into the mains electricity supply of a home/industry/building or sold to the public distribution company connected to the grid. It will reduce the need for power generation through fossil fuel technology. More and more solar energy systems on the rooftop will help create jobs, enabling home and industrial buildings to save money, cut greenhouse emissions, and reduce pollution.

PV modules use semiconductor materials (usually silicon) to generate DC electricity from sunlight. A large area is needed to collect as much sunlight as possible, so the semiconductor is either made into thin, flat, crystalline cells or deposited as a skinny continuous layer onto a support material, usually glass. The cells are wired together and sealed into a weatherproof module, with electrical connectors added. Modern modules for grid connection usually have between 48 and 72 cells and produce dc voltages of typically 25 to 40 volts, with a rated output of between 150 and 300 Watt peak solar panels.[10] Then these panels are combined to give a specific voltage and current to be fed to an inverter which will then convert DC to AC electricity to be further used for the energy/power needs of a home/industry/commercial building.[11]

A typical solar power plant consists of solar cell collectors, turbines, generators, condensers, and an electricity distribution system shown in Figure 1 (b) . Energy collected from the sunlight is used to heat the water coming from the condenser and convert it into high-pressure, high-temperature steam. This steam is used to rotate the turbine, which powers the generator, generates electricity, and completes a typical solar power plant process.

Following are some factors that help us to understand why solar energy power generation is crucial:

- Solar energy is free for use and available in immense amounts, and its supply is continuous for most of the year.
- The solar power plant's capital and running cost is low compared to other power generation plants.
- Energy produce by solar power is very clean and efficient (Table 1) when compared to other sources of energy.
- The process involved in producing the power generation is not very complex as fewer resources are required, so the operation becomes simple.
- The rate of energy production is fast in solar power plants compared to other plant power generation capacities.[7]

Figure 1: (a) Concentrated solar-power plant.[8]

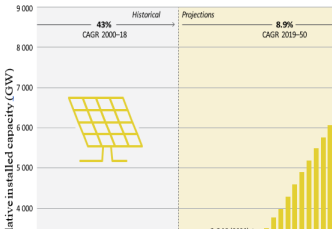

Figure 1: (b) Schematic of CSP generation technology system.[9]

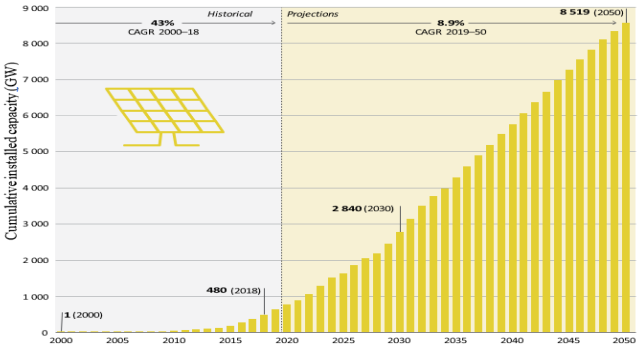

Figure 2: Future projections based on IRENA's analysis (2019[14]

Table 1: Efficiency of some of the solar cells[12]

Name Of cell	*Type of cell*	*Energy conversion efficiency (%)*
Crystalline silicon cell	• Conventional cell specially structured cell	16-18
	• Heterojunction with intrinsic thin layer (hit)	20-23
	• Back contact Chemical cell	20-21
	• Cadmium telluride (cdte)	9-11
	• Copper indium gallium selenide (cigs)	13-15
	Crystallite silicon (c-si) cell and amorphous silicon (a-si) cell	9-10
Thin-film solar cell	Amorphous silicon (a-si) cell	
	• Single junction	5-6
	• Double junction	6-8
	• Multi junction	8-12
Concentrator solar cell (csc)	Low concentration	30-40
	High concentration	65-75

The energy efficiency of most present-day photovoltaic cells is only about 15 to 20%, and, since the intensity of solar radiation is low, to begin with, extensive and costly assemblies of such cells are required to produce even moderate amounts of power (*Solar Energy - Electricity Generation*, n.d.).

The photovoltaic power potential of the world is different for the different regions. Hence, the potential for solar power generation is better for the countries that lie on the equator line than other countries.

Solar photovoltaic modules convert solar energy directly into electricity and are expected to account for 11% of global power output by 2050.[13] Renewable energy deployment has accelerated in recent years, hitting new highs and exceeding yearly conventional power capacity increases in several locations.

Solar PV power installations have dominated the renewables sector for many years, outperforming all other renewable technologies. The worldwide capacity of installed and grid-connected solar PV power reached 480 GW at the end of 2018 (Figure 4), indicating a 20% year-on-year increase over 2017 (386 GW) and a compound annual growth rate (CAGR) of approximately 43% since 2000.[14]

Solar PV is projected to continue to drive total renewables growth in numerous countries over the next decade, due to abundant resource availability, considerable market potential, and cost competitiveness.

From today's levels, IRENA's remap analysis shows that solar PV power installations could grow almost six-fold over the next ten years, reaching a cumulative capacity of 2840 GW globally by 2030 and rising to 8519 GW by 2050 (Figure 2).[14] When comparing between the CSP and PV technology, the initial cost of the system is the major cost component in both situations. According to the International Energy Agency (IEA), PV plant starting costs vary from 2000 to 5200 US$/kW, whereas CSP plant initial costs range from 4200 to 8400 US$/kW.[15] PV also has a maintenance cost of 1% of the initial investment. This amount is equal to around 2% of the initial CSP cost. The difference in such expenses is related to the CSP system's complexity.

Even after accounting for the initial and ongoing costs, the economic returns and incentives of CSP facilities are larger than those of PV plants. PV technology is only accessible throughout the day and is completely unavailable during peak power usage hours. CSP technology offers the potential to shift output to peak consumption hours, allowing it to take advantage ofhigher tariff rates at certain times.

Concentrating Solar Power (CSP)

The availability of fossil fuels and the hazardous pollutants created by combustion are the major concerns for traditional power plants. These difficulties, which are major challenges in the current context, may be mitigated once conventional power plants are linked with solar cycles. With the usage of various technologies for power production, interest in CSP plants is always rising due to better efficiency, reduced operating costs, and tremendous up-scale potential (Figure 3).[16] The use of a concentrator to collect solar energy to heat the heat transfer working fluid to a certain temperature, through heat exchange equipment to transfer heat to the working fluid in the power loop or directly generate superheated steam, and finally into the turbine generator set to do work and output power is referred to as concentrator solar thermal power technology. Solar thermal collecting system, heat absorption and transit system, heat storage

system, steam generating system, and power generation system are the five elements of a concentrated solar thermal power generation system. It primarily incorporates optics, thermodynamics, materials science, mechanical engineering, and other disciplines, with important technologies such as concentrated solar energy technology, sun tracking technology, heat storage technology, and operation control technology being developed and used.

There are various type of technologies used in the CSP generations among which the most matured ones are these

- Parabolic Trough Collector (PTC);
- Solar Power Tower (SPT);
- Linear Fresnel Reflector (LFR);
- Parabolic dish collector (PDC).

Line focus CSP collectors, such as PTC and LFR, focus concentrated sunlight on a linear receiver and have a lower concentration ratio than other CSP collectors. Despite the fact that SPT and PDC are point focus types, they may attain concentration ratios of 300–3000. The PTC, LFR, and SPT are appropriate for power generating capacities of 10–200 MW, whereas the PDC is suggested for smaller generation levels of 0.01–0.4 MW.[17]

The global cumulative installed capacity of CSP rose by 22.5 percent from 1,092 MW in 2010 to around 6000 MW in 2018. The growth of the CSP market has slowed in the last 4–5 years as prices for rival technologies like as solar PV have plummeted.[20] CSP is regaining popularity in research and development (R&D) to enhance efficiency, expand storage capacity, and lower prices. The requirement for reliable and consistent power is becoming increasingly important as more nations embrace ambitious renewable objectives.

By 2040, the total installed CSP capacity will be around 715 GW, with a capacity factor of 45 percent (3900 hours per year), generating 2790 TWh per year. Solar energy accounts for 85 percent of total power output, or 2370 TWh, or 8.3 percent of total electricity generation.[21]

Biomass Power Generation Plant.

The word biomass refers to the mass of living organisms, including microorganisms, plants, and animals. From a biochemical perspective, it is cellulose, fats, lignin, sugars, and proteins. People have used biomass energy ever since the first cave-dwelling person thought of making a fire out of wood. Today, biomass power plants use everything from animal waste to wood pellets to create electricity. There are lots of advantages to biomass energy, which is a renewable energy source. Resources can be found easily in rural areas, making them a good energy source for developing and underdeveloped countries. Biomass is used for facility heating, electric power generation, and combined heat and power through several methods. Direct combustion is the most used technique used for power production. However, there are some other processes also which are used for power production. These are anaerobic digestion and pyrolysis.[22]

The direct combustion of biomass the most commonly used technique for biomass power generation, in which biomass is burned in a combustor or furnace to generate hot gas, which is fed into a boiler to generate steam, which is expanded through a steam turbine or steam engine to produce mechanical or electrical energy as shown in figure 4, instead of using the direct combustion process, with the help of some developing technologies that gasify the biomass to produce a combustible gas, and others process that produces pyrolysis oils that can replace the liquid fluid.

Biomass energy production currently contributes about 14% of the total energy supply worldwide, and developing countries use most of this energy (38%), predominantly in the rural and traditional sectors of the economy.[24] India is a tropical country blessed with sunshine and rains and thus offers an ideal environment for Biomass production. Further, the vast agricultural potential also makes available huge agro-residues to meet the energy needs. With an estimated production of about 460 million tonnes of agricultural waste every year, biomass can supplement the coal to the tune of about 260 million tonnes, resulting in a saving of about Rs. 250 billion every year.

As seen in Table 2 and 3, the primary agricultural residue in India for the biomass is straws and pulses consisting of more than 60% of the total production of biomass from residue.

In 2020, the government estimated the biomass potential of the country based on the biomass production in India to be about 19500 MW, and it is likely to increase in the upcoming years with the implementation of new technologies and policies.

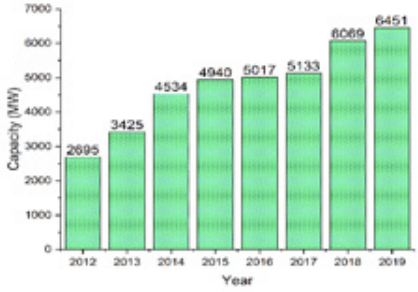

Figure 3: Concentrated solar power global total installed capacity[19]

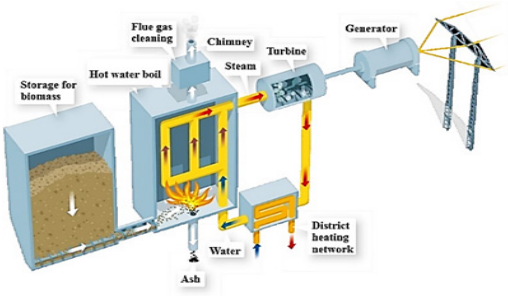

Figure 4: Direct combustion process of biomass plant [23]

Table 2: Agriculture residue quantity/annum in India[24]

Type of Agro Residues	*Quantity (Million Tonnes / Annum)*
Straws of various pulses & cereals	225.50
Bagasse	31
Rice Husk	10
Groundnut Shell	11.1
Stalks	2
Various Oil Stalks	4.5
Others	65.9
Total	350

Table 3: Estimated potentials of biomass based renewable energy in india.[24]

Types of energy options	*Capacity*
Biomass energy	16,000 Mw
Bagasse cogeneration	3,500 Mw
Total	19,500 Mw

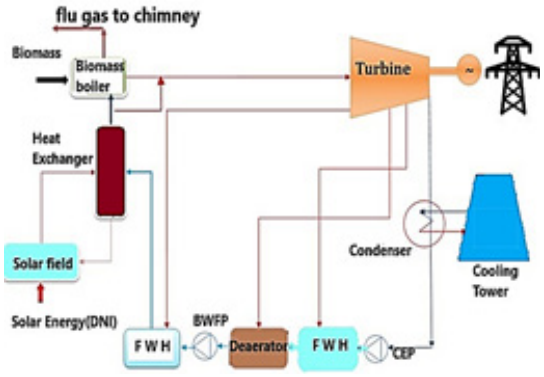

Figure 5: Block diagram of a hybrid cycle[26]

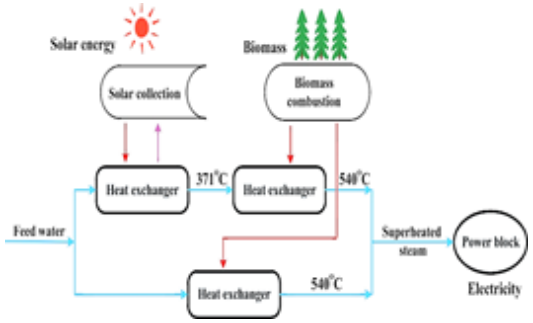

Figure 6: A schematic of the hybrid solar-biomass concept for steam power plant[13]

Table 4: Biomass potential and installed capacity in key indian states.[25]

State	*Power potential (mwe)*	*Installed capacity (by 2011)*	*Tariff*
Punjab	2413.2	74.5	@Rs 5.25 Per unit, (2010-11)
Uttar pradesh	1594.3	592.5	@Rs 4.70
Haryana	1120.8	35.8	@Rs 5.24 Per unit
Rajasthan	1093.5	73.3	@Rs 4.72/Unit water cooled (2010-11)
Karnataka	631.9	365.18	@Rs 3.66 Per unit (ppa signing date)
Gujrat	457.7	0.5	@ Rs 4.40 Per unit
Chhattisgarh	248.5	231.9	@Rs 3.93 Per unit

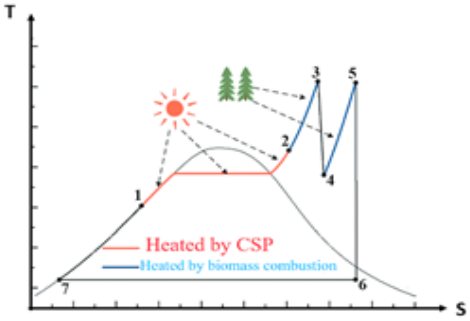

Figure 7: The T-S diagram of the solar-biomass hybrid power plant.[13]

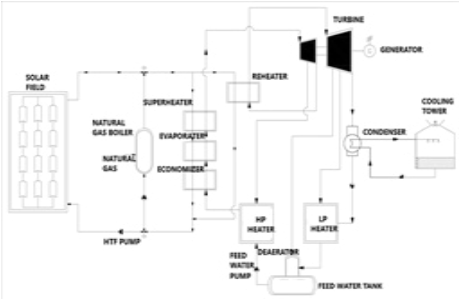

Figure 8: Basic process flow diagram of a CSP power plant[27]

As the potential of Biomass energy increases, the price is also increasing in almost every part of the world where biomass energy is being used. If we talk about India with the increasing potential and capacity, the tariff per unit also has increased. In the Table 4, the installed capacity of some of the Indian states are mentioned during the 2011 and the tariff plans

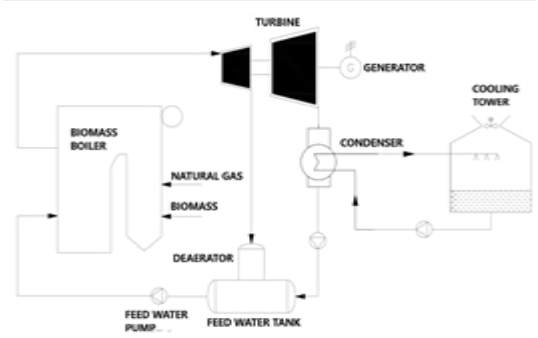

Figure 9: Basic process flow diagram of a biomass combustion power plant[27]

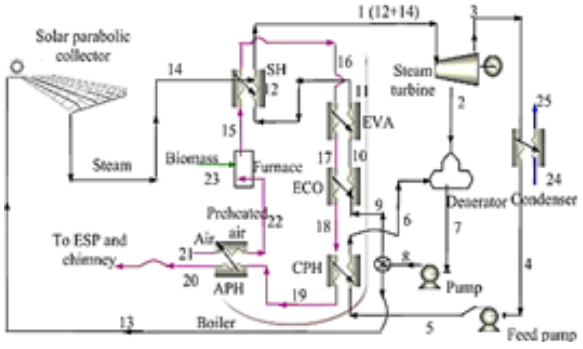

Figure 10: Basic process flow diagram of a hybrid power plant[28]

for that year, comparing the tariff plans to that year to the current plans ,a hike in the price of the tariff can be seen in every Indian states with the increases of 20–25%.

However, the biomass power generation system's biggest problem is that it is not operational throughout the year because of its biomass supply chain. Biomass from agriculture waste can only be available after the harvesting period and only last for about 3 to 4 months,[25] and other sources are not in quantity to run the power system properly and functionally, so to avoid this particular problem the concept of merging two or more power generation cycles comes into existence. The most common power generation system that has been merged is the solar biomass. However, with many technological advancements, numerous other power generation cycles have also emerged.

Similarities between Solar Plant & Biomass plant.

There are few similarities exist in between the solar and biomass power generation system, both the system uses the renewable energy source to produce power. Both have an advantage to the current environmental condition with almost no harmful emission of any dangerous substance in the environment. The resources that are used for the power generation is very and/free, so the operation cost of the plants is very less compared to other power generation plants, due to which most of the developing countries which depend on agricultural activities are showing more and more interest in this hybrid power generation system as it can solve their problem of power issue with less capital invested in it.

Taking the power plant design of both the solar and biomass, few pieces of equipment are the same in both these plants, such as turbines, electricity distribution system, and condenser. So, merging these two cycles will only make the capital cost less, with the main advantage being that the plant now can run on both the source of energy and its working would not depend upon the season of one resource.

Figure 5 shows a block diagram of the simple hybrid solar-biomass cycle. In this cycle, two different energy sources are merged to produce power, and they can work separately and in combination both. A typical turbine is used for power production, and the means of power production can be done either by solar energy, biomass energy, or both.

Using a hybrid power plant instead of a single resources power plant gives an edge in both the capital costs spending and the power generation capacity, it can produce power with the use of sunlight or biomass or using both, and also various equipment are utilizes in both the cycle which decreases the overall cost of the plant.

A concept diagram of a typical solar-biomass hybrid power plant (with steam Rankine cycle as the power cycle) and a T-S diagram of its power cycle are shown in Figures 6 and 7, respectively. The data under the T-S diagram helps to understand how the hybridisation of the solar-biomass takes place to increase the cycle's efficiency.

From the diagram, it is known that from 1-2 the heating is done through the CSP energy and from 2-4, it is done through the biomass combustion, it helps to reduce the load on the particular energy source so that the efficiency can increase as compared to the single-source energy system.

Techno-economic and Environmental Aspects of Hybrid Power Generation

Technical Aspect

The technology used for the hybrid solar-biomass plant is merging two individual power generation cycles to cover the power production for each other seasonally. The advancement in the technical field have made this possible and more effective than an individual cycle.

Figure 8 shows a process flow diagram of a solar power plant. Energy absorbed by the solar cell is used to convert the water in the boiler to steam, and this high-pressure steam is used for the turbine to generate power. In addition, various additional equipment like economizer, reheater, evaporator is installed to improve the efficiency of the power plant so that more and more power can be generated by the power cycle.

Figure 9 shows the process flow diagram of the biomass combustion power plant. The biomass boiler heat is produced by the biomass, which leads to the production of high-pressure steam. This steam is used for turbine functioning and generates power, and the steam is then condensed and used again.

Table 5: Economical comparison of single resource and hybrid power plant.(Rs/kW)27

CSP Plant		*Biomass Power Plant*		*Hybrid Biomass-CSP Plant*	
Solar field	165600	Biomass treatment plant	28800	Biomass treatment plant	28800
Heat recovery bioler	14400	Biomass boiler	57600	Biomass boiler	57600
				Solar field	165600
Heat transfer system	14400			Heat recovery bioler	14400
Turbogenerator set	54000	Turbo generator set	54000	Heat transfer system	14400
Heat storage	21600			Turbogenerator set	54000
BOP	32400	BOP	32400	Heat storage	21600
Evacuation line	3600	Evacuation line	3600	BOP	32400
Civil works	28800	Civil works	28800	Evacuation line	3600
Assembly + commissioning.	25200	Assembly + commissioning.	25200	Civil works	28800
				Assembly + commissioning.	25200
TOTAL	360000	TOTAL	230400	TOTAL	446400

Table 6: Installed capacity of power generation in energy sector of India[36]

Fuel	*MW*	*% of Total*
Total Thermal	2,34,728	61.3%
Coal	2,02,675	53.0%
Lignite	6,620	1.7%
Gas	24,924	6.5%
Diesel	510	0.1%
Hydro (Renewable)	46,209	12.2%
Nuclear	6,780	1.8%
RES* (MNRE)	95,013	24.8%
Total Capacity	382,730	

In the flow diagram of both solar and biomass power plant, we can see that various components are common. When designing a hybrid power plant, it is kept in mind how to utilize these components to achieve our target both technically and economically. The process of the hybrid heat exchanger is designed in such a way that both the processes use a single turbine system, generator, and condenser. There are some additional types of equipment that are added for merging both the power cycles.

In figure 10 shows a basic process flow diagram of a hybrid power plant. A hybrid power plant equipped with an air preheater, economizer, evaporator and other auxiliary equipment are installed in the above process flow diagram. Both solar energy and biomass energy are used to produce steam to produce more steam, resulting in more power production. The cycles also do not have the limitation that both energy sources have to exist simultaneously. Therefore, this cycle will work on either solar energy or biomass.

With the ongoing research on the technical aspect of the hybrid solar-biomass plant, this technology is being made easily available to most parts of the world. The development does not hinder the account of power generation.

Economical Aspect

The economical aspect of the hybrid solar-biomass power generation system is majorly considered by most countries (especially the developing countries). The economical aspect of the hybrid solar-biomass power plant is dependent on many factors. Some of them are:

- The location of the plant setup
- The availability of the plant resources (such as irradiation of sunlight, biomass resources, water bodies)
- The current policy of the government of that country where the plant is being installed
- The workforce of the given location
- As the technology evolves, the technological advancement of the plant increases the efficiency of the plant for energy production, which helps to decrease the plant running cost.
- Benefits from having a flexible input source, including solar and bioenergy[29]

When we talk about the capital cost of the investment for the hybrid solar-biomass plant, it is more than the single resource power generation cycle. We can see that difference in the cost invested in different fields of the power plant below.

With the help of Table 5, the comparison of the electricity generation and the cost of the electricity of a CSP, biomass power plant and a hybrid solar-biomass plant, it is clear that the one time capital for the hybrid is higher than the single

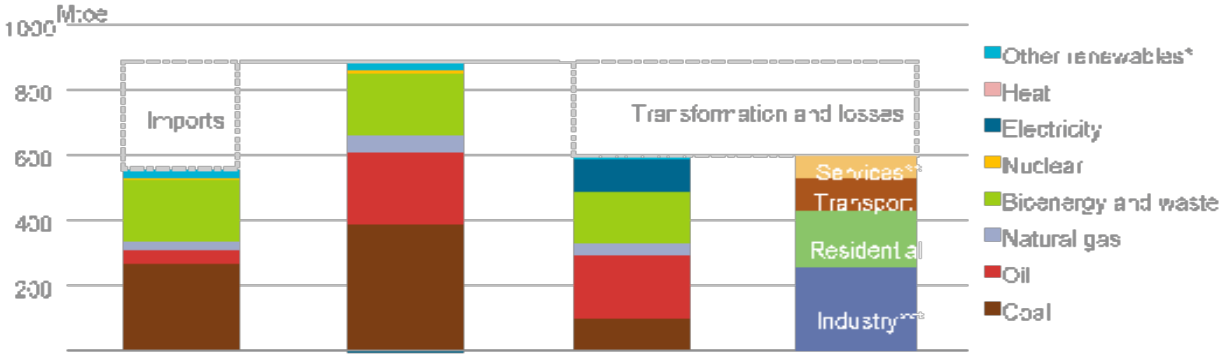

Figure 11: Overview of India's energy system by fuel and sector, 2017.[21]

source power plant. However, with the installation of the power plant, the efficiency and running cost of the hybrid power plant is less than both the single source power plant, which makes the hybrid power plant superior.

Although the cost invested in the installation of the plant is more than the single sources plant, the technological aspect of the hybrid power plant comes into play, which helps to reduce the running cost of the power plant. In the long term (power plants are supposed to run at least 20 years), they cover these extra expenses but also helps provide clean energy and for most of the year compared to the single resource plant, which provides the power production seasonally.

Environmental Aspect

The depletion of fossil fuels like natural oils, gas, coal, and minerals creates chaos and many problems and conflicts in the environmental cycle, greenhouse effect, and increase in the price of the resource.[30] These are why people started looking to increase the use of renewable resources so that their harmful impact on the environment can be minimized. The hybrid solar-biomass power generation cycles use renewable resources and have a less harmful effect on the environment. Solar energy is one of the cleanest energies found, and biomass are also less carbon emission energy.

With all said and done, it affects the environment, not with the energy production part but with the setup of the hybrid plant system. The plant setup creates some harmful impact on the land and nearby water bodies. Unlike wind facilities, the opportunity for solar plants to share land for agricultural use is very less.[31] The effect on the land and water bodies due to plant construction can be hazardous as the construction of solar-biomass hybrid facilities on significant areas of land requires clearing the area, resulting in soil compaction, changing the ways of drainage channels and increase in erosion. Cooling tower systems require a massive amount of water, which is a concern as it harms the water bodies near the hybrid plant and leaks chemicals and other harmful substances from the facilities, resulting in groundwater contamination or the ground surface.[32]

Scope of a solar-biomass hybrid power plant in India.

India is the world's sixth largest energy consumer, accounting for 3.4% of worldwide energy consumption. The current fossil fuel-based power generation has such a negative environmental impact that it is unavoidable to place a greater emphasis on alternative energy sources.[33] Biomass energy has provided sustenance to humankind through the ages and attracted greater attention to India's power production. The Indian government had recognized the potential of biomass power in the Indian economy in the early stages, and since then, it has worked for the betterment of the economy. Suppose biomass is used as much as it is produced. In that case, its benefits will include its renewable nature and wide availability, neutral behavior of carbon, and the potential to provide large productive employment in rural areas. As a further outcome of the planned mix of policy and financial incentives introduced by the government, capacity has been built in the country for biomass power generation technologies, operation and maintenance, management of biomass collection, manufacturing of equipment, and resolving grid interfacing issues. Agricultural residues like stalks and stubble (stems), leaves, seedpods, rice husk, and wood processing waste inherently limit biomass power generation capacity.[34] One of the biggest challenges is providing the continuous supply of biomass waste to these plants at the right amount and right price. The price of biomass has increased in recent years due to the unavailability of biomass in India. Solar energy, among the numerous renewable energy choices, has enormous potential in tropical nations like as India, where the majority of the country receives about 1,700–1,900 kWh per kilowatt peak for more than 300 bright days per year with 8 hours of daily sunshine.[35]

On the other hand, solar thermal power plants (STPP) do not generate power continuously due to daily & seasonal variations and low levels of direct normal irradiance for at least 100–150 days in a year in most places of this country (Sahoo *et al.,* 2016). Therefore, hybridizing STPP with a Biomass power

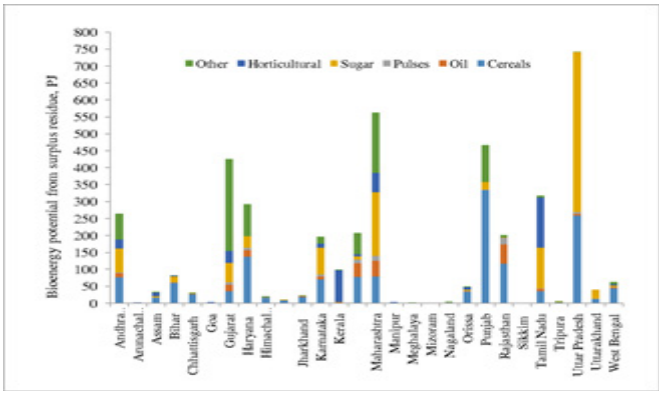

Figure 12: Bioenergy potential of different[41]

generation system is most important for continuous power generation to fulfill the energy requirements. So, biomass resources are a very good selection for hybridization with STPP for continuous power generation, which support each other seasonally. Therefore, several authors investigated hybrid solar biomass for power generation where water gets heated to a saturated state through solar thermal technologies and a superheated state through biomass boilers.

RES (Renewable Energy Sources) include Small Hydro Project, Biomass energy, Urban & Industrial Waste Power, Solar and Wind energy.

India's energy consumption has increased at a higher rate in the past decade. It is expected it will continue to follow that, all sectors, including agriculture, industry, and commercial, are running in a forward direction. With the population that India has, it is expected from then. Nonetheless, India's per capita energy consumption stands at 30% of the world's average (0.44 tonnes of oil equivalent [toe] per capita versus the global average of 1.29 toe and the International Energy Agency [IEA] average of 2.9).[37,38]

India's energy system is based mainly on coal for power generation, oil for transport and industry, and biomass for residential heating and cooking (Figure 11). Bioenergy and most coal supply are produced in the country, while oil and natural gas are mainly imported (Figure 12). In 2017 India's total primary energy supply (TPES) was 882 million tonnes of oil equivalent (Mtoe), with nearly two-thirds being covered by domestic production (554 Mtoe). Industry accounted for the largest share of India's total final consumption (TFC), followed by the residential sector, transport and the service sector, including agriculture.

Effect of Local Condition and Resources

India is a country where different places have very different conditions. This condition plays a very important part in the setup of the Hybrid power plant. The distribution of solar radiation in India is very different in different parts of the country, so the setup of the solar power plant is only being set in those areas where we get most solar irradiation for most of the year. Biomass is India's most important energy resource because biomass production in countries like India, which depends on the rural culture, is always more than in other countries. In addition, there are various other benefits of using biomass, as they are renewable. They provide much employment to the rural area, which is one of the concerns for developing countries.[39] The current biomass availability in India is about 500 million metric tonnes per year. Studies sponsored by the Ministry of Indian Government have estimated biomass availability at about 120–150 million metric tonnes per annum, covering agricultural and forestry residues corresponding to a potential of about 18,000 MW.[40]

The potential of biomass in India is better than many countries as the main occupation is still agriculture and the location and atmosphere of India allow it to sustain this for a longer time.

When we talk about the production of biomass resources, different states of India have different conditions. The type of biomass acquired by the different states is different in composition and crop residue changes.

The hybrid solar-biomass power generation cycle uses two power generation cycles, the preferable renewable cycles that support the power generation rate seasonally. Furthermore, in comparison to biomass, hybridization helps decrease the feedstock rate to the plant and the use of both solar energy and biomass, increasing the plant's energy production. The hybrid power plant has good potential for many industries like sugar cane, Textile, Chemical, and commercialized power plants.[39] The Ministry of renewable resources has taken many actions in recent times to promote the scale of the setup of these renewable resource plants set up so that the country's energy requirement can be fulfilled using these resources. Implementing the hybrid power plant setup is not as advanced as that many developed countries of the USA and Europe. However, the current pace and more government involvement by making better policies in its favor will cover this gap.

Major Findings

The installed power generation capacity in India's energy sector is lead by thermal energy with over 61% of total power generation with renewable energy resources at 24% (Table 6). Different types of PV cells are used in solar power plants for efficient energy conversion. The latest technological advancements in PV cell technologies are

- Bifacial solar panels (40% efficient more compared to the mono facial),
- Concentration photovoltaic cell (efficiency up to 41%),
- Multi-junction solar cells (efficiency up to 45%), and
- Perovskite solar cells (30% efficiency).

With the latest technological advancements and focus shifting toward renewable energy resources, the global capacity of the PV market is increasing rapidly, with around 950 GW capacity in 2021. The reports suggest that capacity will increase up to 2840 GW till 2030 8500GW till 2050. The huge technological advancement in CSP techniques such as

Parabolic Trough Collector (PTC), Solar Power Tower (SPT), Linear Fresnel Reflector (LFR), Parabolic dish collector (PDC) is constantly increasing the energy share of the CSP system. From 2012 to 2019, the global CSP capacity has increased from 2695 MWe to 6451 MWe, increasing over 130% in just 7 years. In addition to solar energy, Biomass energy production also contributes about 14% of the total energy supply worldwide, and developing countries use most of this energy (38%), predominantly in the rural and traditional sectors of the economy. In 2020, the Indian government estimated the country's biomass potential based on India's biomass production to be about 19500 MW. India has achieved the target of 10 gigawatts of biomass power before 2022 with the present installed capacity of 10.17 GW of biomass power. However, unlike the solar and wind power targets, the central government plans to scale up the biomass power and cogeneration target for 2030, even as the sector has potential.

From the target of having 100 GW from solar and 60 GW from wind in 2022, India has an ambitious plan of 280 GW of solar and 140 GW from wind to reach 450 GW installed renewable energy capacity by 2030. Share of Biomass is still at 10GW but with the hybrid power generation approach, and it will go higher. According to a study sponsored by the MNRE, biomass availability in India could translate to a potential of about 28 GW. In addition, about 14 GW additional power could be generated through bagasse-based cogeneration in the country's 550 sugar mills.

When comparing the cost to the power generation capacity of the single-source solar and biomass power plant to the hybrid power plant, the later have a significant advantage over the other two as the power production will be continuous and energy is produced efficiently.

CONCLUSION

Although the hybrid solar-biomass plant is still a new renewable sources power production cycle with lots of research still going on to make it more and more efficient, one can say it is one of those technologies which can cover the expense of the depletion of fossil fuels and other non-renewable resources extinction shortly. The use of the hybrid solar-biomass power plant has great potential in those countries where the rural area is dominant. It solves the problem of power production to these areas and can be a means of employment.

The scope for the utilization of the hybrid solar-biomass plant is advantageous as the resources required for the power production is satisfactory, and the government's policies related to renewable energy make the potential of hybrid solar-biomass plant bright shortly.

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