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# Opportunities for solar assisted biogas plant in subtropical climate in Australia: A review

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**Abstract**

Household waste generation has become a serious environmental issue in recent years. However, some technologies are available to convert household domestic waste into energy. One of such techniques is the biogas generation using household waste. The biogas generation technique is not a new method of energy generation, but its production efficiency is questionable. Biogas yield from domestic waste are influenced by pH level, temperature, HRT and C/N ratio. Moisture and the temperature levels in the biogas generation systems are very critical to its production efficiency, especially this is highly affected in the colder weather condition. Solar assisted biogas plant may provide better production efficiency compared to the traditionally designed biogas plant. In this paper, the scopes and opportunities of solar assisted biogas generation are reviewed. Possible benefits and challenges associated with the solar assisted biogas generation are highlighted.



*Keywords:* Biogas; anaerobic digester; biogas system performance; solar in biogas; solar assisted biogas.

## 1. Introduction

Australia produces about 64 million tons of waste [1]. From the Australian national waste report 2016, it was found that the waste produced from household is 13.3 megatons (Mt) where it was recycled only 5.6 Mt and the remaining 6.5 Mt was landfilled [1]. Fig.1 shows the comparison of waste generation and population growth in Australia from 1996 to 2015. Among the domestic waste sectors, the households waste sector continues to grow with the population and thus affects the pollution and as well as the economy. Approximately 2.1 million Mt of food waste is landfilled in Australia every year and 85% of Australian household put hazardous waste in the rubbish bin. The average garbage bin contains 60% organic material waste where 40% is food waste and 20% is garden waste. The introduction of food/garden organic bins in many council areas will go a long way to achieving the targets for the household sector [2].


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New technologies in composting and anaerobic digestion accelerate organics diversion. Moreover, the security of the energy supply is a crucial challenge because most of the natural energy resources like oil and gas reserves are found to be depleting. In this perspective, the production of biogas from waste can play an important role in future energy generation. Biogas is a mutual renewable energy source that can substitute conventional fuels to produce heat and power. I can be used as gaseous fuel in automotive applications. Althothe ugh biogas based on house waste is a promising substitution for, or contribution to, the natural gas the network, the amount produced is limited in comparison with the annual global consumption. The necessity for global sustainable waste management has led to research interest in alternative fuels based the on Agri-waste and bio-waste [1].

Australia enjoys extensive solar as well as large biomass energy potential. In Australian subtropical region where the average annual temperature is 21.6 °C. Typical temperature ranges are 22 to 32 °C in the summer and 9 to 23 °C in the winter in Queensland [2]. Meanwhile, biogas production in Australia in 2009 was equivalent to 16231 TJ and gross electricity production by biogas was 1265 GWh. The temperature inside the digester has a major effect on biogas production. Anaerobic fermentations are best suited in the mesophilic (30–40ºC) and thermophilic (50–60ºC) temperature. In winter time a solar assisted community biogas has been suggested to meet the difficulties in biogas yield due to its cold temperature where solar energy provides the heat which helps to maintain the maximum temperature of 35ºC. The solar energy is also the medium of radiant energy to internal energy [3]. In addition, the length of the fermentation period is dependent on temperature. It is possible to obtain a substantial increase in gas yield by using solar energy to heat biogas digester. So, digester heating by the concept of solar assisted biogas can play a vital role in the regional area. Moreover, the Australian government announced a climate change plan including a wide-ranging package of clean-energy proposals and the introduction of a carbon price mechanism accompanied by significant levels of financial support for innovation in clean-energy technologies. It can be seen from Figure 1 that in the period of 1996 -2015 the population increased by 28% whereas the waste generation increased by 170% and the growth rate of waste is 7.8% from the report of national waste policy 2010 by Federal Government. The trend was nearly proportional until 2000. After the year 2000 -2001 until 2015 the population increased normally where the waste generation increased in the high margin. The aim of this paper is to show the overview of the necessity of biogas, their opportunities and methods, the proposed solar assisted biogas system and its benefits and challenges in a subtropical climate in Australia.

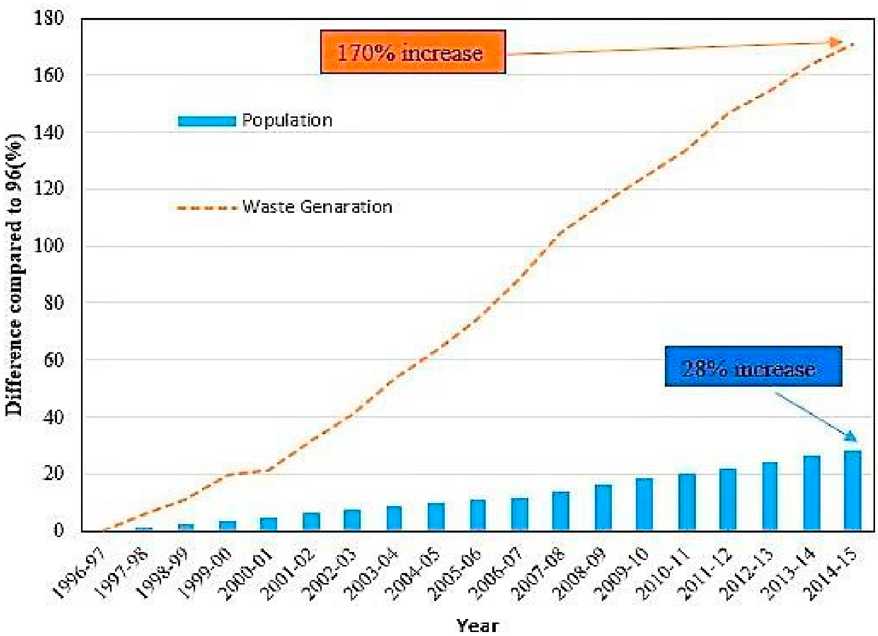


Fig. 1. Comparison of waste generation and population growth in Australia [1].

## 2. Conventional biogas generation process

Biogas is produced by bacteria with the help of biodegradation of organic resources under the anaerobic condition. It can be used everywhere in either rural or urban area. This biogas process produces different gasses. Firstly, it produces methane with some carbon dioxide and then some small proportions of hydrogen sulfide. During the filtration, by opposing the hydrogen sulfide it can be burned as heating sources and when it is compressed it can be used as fuel in transport sectors. To produce biogas by decomposing from different types of Anthropogenic anaerobic bioreactors make use of this biochemical processes.[4]. Moreover, for the large-scale biogas can generate electricity and by more refining, it can be used in the gas grid. Biogas generation methods from biomass involve 3 steps and the results of 3 different classes of bacteria who working together. The first process is hydrolysis and acidogensis. The first group of bacteria secretes extracellular enzymes which can hydrolyze long chain/Polymeric materials to simpler monomers like glucose and fructose. Later this glucose is converted to acetate, ethanol, lactate etc. The second process is Acetogenesis and dehydrogenation which helps the formation of acetate and a small amount of methane ($CH_4$). Finally, in Methanogenesis process the methanogenic bacteria converts to acetate and hydrogen converts to methane and carbon dioxide ($CO_2$) [5].

### *2.1. Waste classification and processing*

As increasing the population, the wastes are also increasing. There are 5 types of wastes are found. All these wastes are commonly found both in households as well as in industries. One of them is a liquid waste like dirty water, organic liquids, wash water, waste detergents and even rainwater. Solid waste is commonly found in a household with the industrial and commercial places such as plastic waste, paper waste, tins and metals and ceramic and glass. Organic waste is most common in a household like food waste, manure and rotten meat and these wastes can’t be inclined anywhere. Recyclable rubbish items like paper, metals, furniture which can be converted into new products. Hazardous waste includes all types of toxic, corrosive and flammable which is very harmful to the environment [6-8]. Our major concentration is to utilize the waste for biogas generation, however, all kinds of waste are not suitable for biogas generation. The waste which is quick enough to decompose or specified levels of moisture content especially the domestic household waste is suitable for biogas generation. Fig.2 showing the overview of the biogas system from different sources.

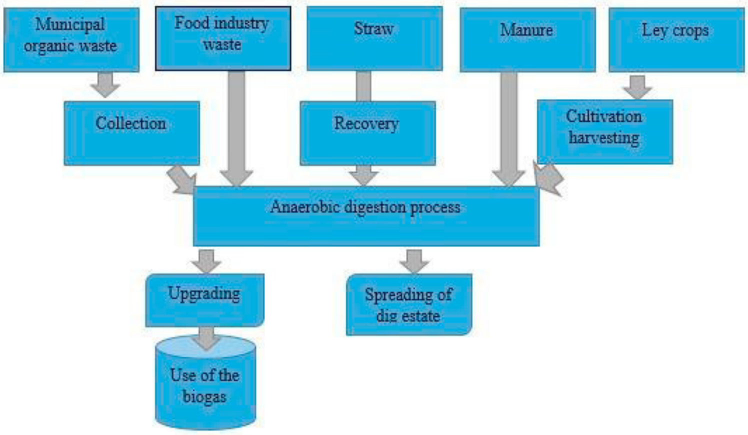


Fig. 2. Biogas systems process from different wastes (Berglund, 2006).

### *2.2. Types of digesters for biogas productions*

Biogas installations and processing from different substrates become the most important application of anaerobic digestion today. There are different types of digesters can be determined according to the type of raw materials used shown in Table 1 [5]. Batch process dry fermentation is another single step process where the methane produced in the same digester. This technique is engaged when the TS of the substrate is high Substrate is added together with the inoculum and it's left to the digest until the end of HRT [9]. Though different wastes are used in biogas production there is a various plant of biomass can be used for biogas generation. The most conspicuous part of any wetland is vegetation like Submerged vegetation, free-floating plants, trees, emergent vegetation

### *2.3. Biogas generation methods*

There are two types of methods for biogas generation. One of them is anaerobic digestion and other is Aerobic digestion. The anaerobic digestion is a sustainable method to transform organic waste materials into renewable energy. It occurs in the environment no molecular oxygen and from food source due to microbes. The advantages of anaerobic digesters biogas can be used as an alternative fuel source, easy to dry, low cost and odours removed from the system. Low rate digesters and high rate digesters are the two common anaerobic digesters. Aerobic digestion is a process to decrease the volume of sludge and suitable for the sequent use. In this process, the initial sludge mixed by with waste activated sludge. There are two types of aerobic digesters such as batch operated aerobic digesters and continuous flow of aerobic digester.

Table 1. Digester types

| Types of digesters | Features |
|---|---|
| Covered lagoons | Used for liquid waste |
| | Mostly found in the underground, covered by the airtight lining. |
| | HRT time 30-40days |
| | Temperature is above 200C. |
| | Produce methane |
| | Can be used as compost as |
| | High in nutrient content |
| Complete mix digester | Made of concrete. |
| | Best for the substrate which has 3-10% TS. |
| | HRT is low (10-20 days). |
| | It is conducive for the large-scale dairy waste treatment. |
| Plug flow digesters | Long and narrow constructed underground to minimize the heat loss. |
| | The TS is 14% |
| | HRT is 15-20 days. |
| | Used both for mesophilic and thermophilic digestion. |
| Fixed film digesters | It is formed in the inert plastic media to grow bacteria. |
| | HRT of this kind of digester is very low, around 3-4 days. |
| | Typically fixed film digesters are around 100,000 gallons. |
| | Reduce odour-related problems. |

The chemical reaction associated with anaerobic digestion can be given by:

Organic matter +combined O2→new cells + energy + CH4 + CO2 + end products (1)
anerobic microbes

Sources of combined: $O_2$ , $CO_3$, $SO_4$, $NO_3$, $PO_4$

End Products: $H_2S$, $H_2$, $N_2$

The chemical reaction associated with aerobic digestion can be given by:

Organic matter+$O_2$→ new cells+ energy+ $H_2$ 0+ $CO_2$+ other end products (2)
aerobic microbes

End Products $NH_4$, $NO_2$, $NO_3$, $PO_4$

Cell reduced by decay by following equation

$$C_5 H_7 NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_20 + NH_3 \quad (3)$$

From the auto oxidation process the ammonia is produced using the following the equation

$$C_5 H_7 NO_{2\,+}\, 7O_2 \rightarrow 5CO_2 + 3H_2\, O + H + NO_3 \quad (4)$$

### *2.4. Advantages and drawbacks of conventional biogas systems*

The main advantages of the conventional systems are their lower operational system, minimal maintenance and *low* costs. In conventional biogas plant, biogas is produced by anaerobic digestion with anaerobic bacteria of biodegradable materials like municipal waste, green waste, manure sewage and crops. There are two types of biogas plant named fixed dome and floating drum biogas plant. The performance of the conventional BGS plant can be controlled by monitoring the variation in parameters like temperature, pH, loading rate, agitation, etc. The temperature inside the digester has the major effect on biogas production. Different temperatures range for psychrophilic is less than 30 °C, mesophilic between the ranges of 30–40 °C and thermophilic between 50°C to 60 °C during the anaerobic process [10]. The pH value of the digester should be kept in the range of 6.8-7.2 by serving the optimum loading rage. Moreover, in the anaerobic digestion process to increase the methane yield, pre-treatment is required for the feedstocks. The pre-treatment could be done by pre-treating the feedstock with alkali or acid, thermochemical way, Ultrasonic and ensilage way. Particle size, C: N ratio, agitation, seeding of biogas plant, organic loading rate, hydraulic retention time (HRT) and solid concentration are the major parameters which influences gas production [11, 12]. Though all these factors depend on the climatic, biological and the operational conditions, the temperature is the major concern which can affect the performance of the anaerobic digestion. This temperature range is difficult to achieve during the cold atmosphere. To achieve the optimum temperature for good production of biogas, external thermal energy is required for the slurry in the digester. So, to achieve the heat from an external source the following methods might be considered.

- Using the exhaust heat from the biogas running engine.
- Using electrical heating.
- Utilize the heat resulting by the combustion part, biogas output or fossil fuel and other renewable sources.

## 3. Proposed solar assisted biogas system (SA-BGS) for sub-tropical climate in Australia

Electricity, fossil oil and the biogas from the process might be used for the desired temperature but the excessive use of the natural energy leads the heating cost and will be uneconomical. The length of the fermentation period is dependent on temperature. It is possible to obtain a substantial increase in gas yield by using solar energy to heat biogas digester. Utilization of solar energy for biogas reactor heating has been demonstrated in several projects and research in developing countries, in addition, produced hot water from the solar system is used to heat the reactor. Recently, many studies have shown that using solar energy to improve the fermentation temperature is an attractive approach for improving biogas production. G. Kocar & A. Eryasar experienced with their research of the insulation thickness and solar energy systems for different cities in Turkey where the solar energy is a highly desirable alternative for biogas and also found the system is an attractive economic investment [13]. Dayal et al [14] found that conventional and the solar-assisted greenhouse coupled biogas plant that the temperature of the slurry can be raised from 20 °C to 35°C in the conventional plant, the optimal temperature for anaerobic fermentation. Lawand et al. found a new architecture of green house had developed during the cold season [15]. It has been shown that the use of solar energy reduces the period to achieve the optimum temperature for biogas production. So due to lower temperature biogas production decreases and might be stoped. Thus for increasing biogas production it requires to increase the digester temperature than the ambient temperature. Also for a required production rate of biogas, the period to achieve the optimum temperature should be reduced. Researchers revealed that if the temperature of digester could be maintained at 40ºC then it is possible to reduce the HRT (Hydraulic Retention Time) by over 40% and solar ponds to be helpful in maintaining digester temperature at the desired level at night. Kumar et al [16] have experienced an average of 11.5% more biogas production with solar greenhouse assisted biogas plant in a region where yearly temperature variation was 2°C to 25°C. Yuan et al [10] calculated digester's heat load based on weather data and concluded that at that particular region, in October, the heat absorbed by 2 $m^2$ solar collectors could meet the heat demand of 6 $m^3$ digester. Alkhamis et al [17] showed that solar collector is an attractive option to maintain a 40°C constant digester temperature as internal rate of return of the investment .Vinoth et al [16] found that the gas yield recorded solar assisted biogas plant was 11.5% higher than the control biogas plant during winter time in India. So the low ambient temperature in the winter is an important factor that may affect the performance of anaerobic digestion, therefore, the biogas plant should be built with the heating system. It is obvious that the use of solar energy increases the reactor temperature. Dong &Weatherford et al experimented a simulated solar thermal collector system to heat the river water and ultimately improve the inside temperature of digesters and they recommended some parameters to the affordable biogas digesters in cold climates [18]. Thus, these comparative studies showed that solar energy could be utilized to improve the fermentation temperature of biogas digesters both the hot climates as well as in cold climates.

The proposed schematic diagram of the solar assisted biogas plant is shown in Figure 3. Hot water from collector will flow through the jacket of the digester so that heat from an external source will enter into the digester. There will be several temperature sensors and controller to the system according to the temperature requirement within the digester. Further research will be commenced with the design of digester, followed by calculation of energy consumption. The organic fraction of domestic waste can be considered as feedstock for the digester. The process will be achieved by regulating parameters which affects the performance of the system. This research could be the best option in subtropical climate region in Australia as there is a significant temperature variation within a year. This biogas technology can be applied for a wide range of capacities as a local source of green energy and offers flexibility to handle the wastes generated by isolated communities. In addition, the outcome of this project will help glean and disseminate the ideas pertinent to the application of solar energy for biogas production in other subtropical climatic conditions as well.

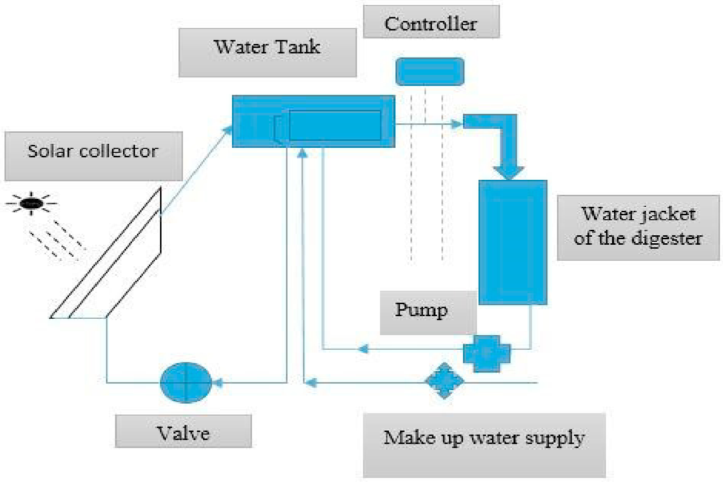


Fig. 3. Schematic diagram of the solar assisted biogas plant

## 4. Benefits and challenges in using SA-BGS

There are several benefits of solar assisted biogas generation system. It improves the energy yields of biogas generation systems. It helps in regulating the moisture and temperature levels in the biogas digester system. Solar energy is a free source when compared to other auxiliary fuels.

There are many challenges also associated with the solar assisted biogas generation system. The solar energy infrastructure is quite cost-intensive and its integration with biogas generation is an added capital investment. Operation and maintenance of the solar energy system especially in the dirt situation is quite a tedious one. Solar energy systems are highly variable in delivering the energy outputs, and sometimes the efficient control is needed as the biogas performance parameters are highly sensitive.

## 5. Conclusion

Biogas plants can be operated in many different ways, depending on the influent feedstocks, the applied temperature and reactor configuration. Temperature is an important factor that affects the performance of anaerobic digestion. Thus, solar assisted biogas offers a higher amount of gas yield by increasing digester temperatures and possibilities for recovering energy from waste. The development of solar energy systems is associated with a few challenges, a further technical study on the solar energy assisted biogas plant to overcome these challenges are required, so that this system can handle the wastes generated by local communities.

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