SUSTAINABILITY WITH BIOGAS AS A FORM OF ALTERNATIVE ENERGY

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Abstract

There are quite a number of different alternative energies but in this paper Biogas will be analysed as a form of alternative energy in the context of sustainable development. A number of aspects need to be investigated if biogas is used as a form of energy supply. Criteria to consider include the availability of water and the area of agricultural land that needs to be used to supply the reactors with enough substrate to operate. Should energy crops be cultivated for the reactors, or is there enough other forms of substrate already available? There are factors to be taken into consideration such as whether to use the crops for food or fuel, area, water, labour and sustainability of the farmers.

Keywords: Biogas, Alternative Energy, Substrate, Energy Crops, Food or Fuel.

1. INTRODUCTION

If one considers the resources available to generate energy, there are a number of aspects that compete for the same amount of resources. A more sustainable way should be found to go about generating these energies from the existing resources available to ensure that there will be resources available for generations to come. The diagram below (Figure 1) represents a flow diagram illustrating the flow of resources to energy.

It can be seen that there is a lot of competition between food production, energy production for heating, cooking, factories, transport, resources to build infrastructure as well as the use of ground for these activities. One way to address the problem is to ensure that the biomass which is normally available is used to its optimum. A way of doing this is to use the fermentation process to generate heat and electricity from the waste from animals, humans and food, which is currently just left to ferment. There are many advantages to having the fermentation occur in a controlled environment.

Biogas, a clean and renewable form of energy, could very well be a substitute (especially in the rural sector) for conventional sources of energy (fossil fuels, oil, etc.), which are causing ecological environmental problems (Balat, M & Balat, H. 2009). Biogas production is mainly based on anaerobic digestion of biomass – typically using single energy crops. Maize, sunflower, grass and sudan grass are the most commonly used energy crops (Balat 2009).

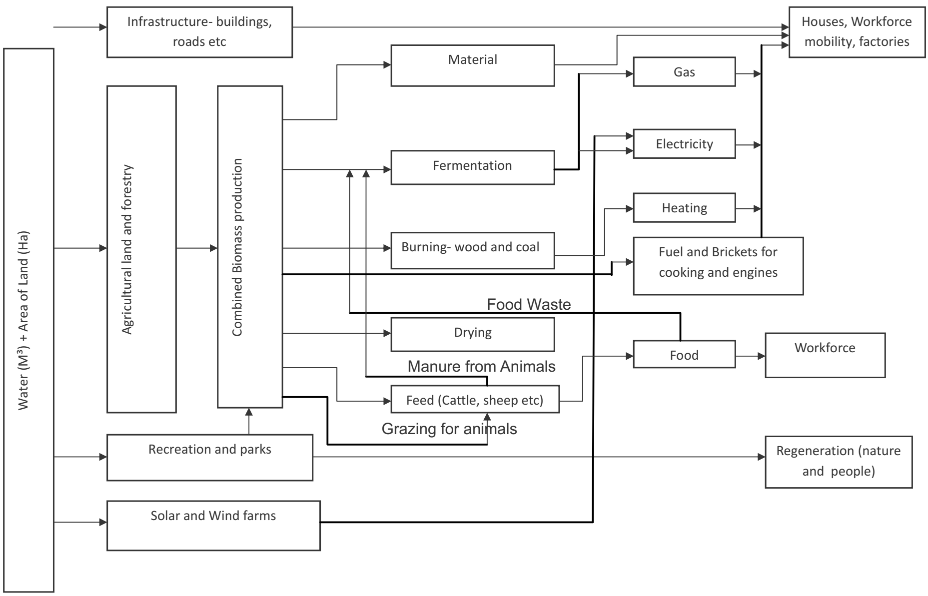

Figure 1: Flow of Resources to the Final Use

A combination of energy crops and other substrates can also be used. In the future, biogas production from energy crops will increase and requires to be based on a wide range of energy crops that are grown in versatile, sustainable crop rotations (Bauer et al., 2007). In 2006 the growth rate of energy exploitation of biogas in the EU was around 13.6% according to Faith Demirbus.

The most cost-efficient process for biogas use is the direct use thereof for cooking/heating, lighting or even refrigeration, rather than converting it to electricity before use (Stegmann 1996, Strachan et al. 2006). The problem with direct use of converted biogas is that the equipment to use the biogas should be close to the reactor and if possible with a continuous demand. For direct end use the quality of the gas is not that critical. Electricity generation can take place by using the Methane gas as fuel for an engine to drive an electricity generator.

But what makes biogas distinct from other renewable energies is its importance in controlling and collecting organic waste material and at the same time producing fertilizer and water for use in agricultural irrigation. Unlike other forms of renewable energy, biogas neither has any geographical limitations and required technology for producing energy and it is either complex or monopolistic (Taleghani and Kia, 2005).

2. BIOGAS AS A RENEWABLE ENERGY SOURCE

Especially in developing countries like China, India, and Africa thousands of simple small-scale reactors are operational and will still, in future, have their benefit of waste management combined with decentralized energy production (Hartmann and Ahring, 2005). Traditionally, biogas has been burned in internal combustion engines for electricity production and heat, but its potential use in fuel cells could increase its electric efficiency (Benito et al.,2007). Composition and biodegradability of source material are key factors for the methane yield from energy crops and animal manures. Crude protein, crude fat, crude fibre, cellulose, hemi-cellulose, starch and sugar markedly influence methane formation (Amon et al., 2006). Photosynthesis is the most effective route to convert solar energy into biomass, while biomass is the most convenient form to store solar energy. For this reason, energy from biomass is now considered as having the potential to provide the major portion of the projected renewable energy needs of the future (Andrea Schievano 2009).

The use of Biogas has many advantages. Abandoned agricultural land can be used to grow energy crops. Other examples of positive environmental impacts are carbon and nutrient supply to soils, erosion and desertification prevention. Biodiversity and the increase of landscape values will also accrue to the area. Furthermore, the energy crops completely utilize the land and the agricultural resources, while the food crops require just a partial use of land (INTUSER, 2007). Globally, photosynthesis stores energy in biomass at a rate roughly ten times the present rate of global energy use. However, today less than 1.5% of this biomass is used for energy, estimated to be between 40 to 50 Exajoules per year. Biomass is mainly used as a traditional fuel (e.g., fuelwood, dung), contributing to about 38±10 EJ/year, and modern biomass to about 7 EJ/year (Hoogwijk et al., 2003). It is estimated that in its widest sense, biomass accounts for a minimum of 15% of total world energy supply, and that within some developing countries biomass accounts for between 35-50% of domestic supply. It is worldwide assumed that between 12.5% and 30% of total available manure can be recovered for energy production (Kocar 2007). Suitable substrates for the digestion in agricultural biogas plants are: energy crops, organic wastes and animal manure. Maize, herbage, clover grass, sudan grass, fodder beet and others may serve as energy crops (Chynoweth et al., 1993).

There are many different types of bioreactors but they all work on the basis where the feedstock is fed into the container where the anaerobic digestion of biomass can take place. There are a few factors in the design that play a role in the functioning of the reactor. These factors are pH, temperature, C/N ratio and retention time. The pH should be between 5.5 and 8.5 with a temperature in the reactor between 25°C and 40°C. The C/N ratio should be 20-30:1 due to the microbes that utilise carbon faster than nitrogen. A retention time of between 30 and 60 days are needed to digest the material (Ostrem et al., 2004). If these factors are not borne in mind, the efficiency of the reactor will not be as high as it could be.

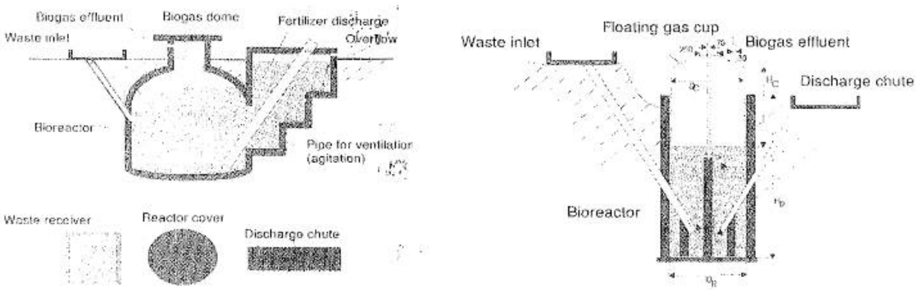

Figure 2 Sectional view of a bricked tank. Gasdome left and Floating cup right (Deublein, 2008).

3. BENEFITS OF A BIOGAS PLANT

Biogas has a wide variety of uses, but, as it is derived from biomass, it is a renewable energy source. There are many other benefits:

- Biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits (Chynoweth, 2004) and is an additional potential source of income for farmers. Many farmers are forced to give up their occupation, since their land no longer brings sufficient yield;
- Biogas production from corn or grass could contribute to the maintenance of the structure of the landscape with small farmyards;
- Biomasses that are not needed are often left to natural deterioration, but energy can be generated from it;
- Reduction of landfill areas and the protection of the groundwater: the quantity of organic waste materials can be reduced down to 4% sludge when the residue is squeezed off and the waste water from the biogas plant is recycled into a waste water treatment plant;
- Substantial reduction of the disposal costs of organic wastes, even including meaningful re-use (e.g., as fertilizers);
- Less mineral fertilizer needs be bought and nitrate leaching is reduced. Plant compatibility and plant health are improved;
- $CO2$ –neutral production of energy (especially electrical power and heat) is achieved (Deublein, 2008).
- Some of the environmental benefits are that the methane emissions during manure storage are reduced and the fertiliser quality of the digestate is high. Renewable energy is produced from biogas (Amon, 2006).

If these biogas plants can form part of any farming operation, it can make a huge difference in the cost of producing food. The cost of electricity is so high that the electricity generated in this way can be utilised to supply power for irrigation.

Currently, farmers are irrigating in off-peak times just to save on their electricity bill. If the farmers have their own electricity generation plants, electricity can be generated when needed at a reduced cost.

4. BIOGAS FEEDSTOCKS

Almost any organic (carbon-based) material is a potential source of biomass feedstock to produce biogas (Faith Demirbas 2009). Organic waste excreted by animals (e.g. manure) and industrial waste streams generated by agricultural, animal and other food processing activities are examples of historically low-value waste products that have potentially higher value when viewed as renewable biomass feedstock sources (Rutledge 2005). Possible feed stocks for anaerobic digestion are listed below:

- Agricultural feedstock materials
- Manure (e.g. swine, dairy cattle, beef cattle, poultry)
- crop residues (e.g. corn-silage, maize, sunflower, grass, sudan grass)
- Industrial organics
- Municipal solid waste
  - organic fraction of municipal solid waste (OFMSW)
  - municipal solid waste (MSW) (Faith Demirbas 2009)

On most of the farms in the Free State, most of the above feed stocks are available. Depending on the area in the Free State, varying quantities are available. On all farms and small holdings, the sewerage systems are functioning on french drain systems which in any case are not safe for the environment as the drains often crack and raw sewerage seeps out of the drains and can contaminate the ground water. Therefore, if this material can be used to generate biogas, it can have a positive impact on our environment.

5. EVALUATION OF FEEDSTOCKS

There are various feedstocks available in the Free State. There are the traditional crops, field grass, grass next to roads, grass in parks, animal manure and also human waste, to mention a few.

Animal Manure:

Table 1: Yield from Liquid Manure per GVE (livestock unit) (Deublein 2008)

	GVE	Liquid manure (m³) per animal			Dry Mass Content (%)	Gas Production (m³/GVE/day)	Gas production per animal/day (m³/day)
		Per Day	Per Month	Per Year			
Cattle							
Feeder cattle, cow	1	0.05	1.5	18	7-17	0.56-1.5	0.56-1.5
Dairy cow, stock bull	1.2	0.055	1.65	19.8	7-17		0.616-1.65
Feeder bull	0.7	0.023	0.69	8.3	7-17		0.25-0.69
Young cattle	0.6	0.025	0.75	9	7-17		0.28-0.75
Pigs							
Feeder pigs	0.12	0.0045	0.14	1.62	2.5-1.3	0.6-1.25	0.072-0.15
Sow	0.35	0.0045	0.14	1.62	2.5-1.3	0.6-1.25	0.21-0.438
Sheep							
Up to 1 Year	0.05	0.003	0.09	1.08			0.0336-0.09
Over 1 Year	0.1	0.006	0.18	2.16			0.0672-0.18
Horses							
Up to 3 years, small horse	0.7	0.023	0.69	8.3			0.2576-0.69
Over 3 years	1.1	0.033	0.99	11.9			0.37-0.99
Poultry							
Young feeder poultry (up to 1.2 kg)	0.0023	0.0001	0.006	0.07	20-34	3.5-4	0.0081-0.0092
Laying Hens (up to 1.6 kg)	0.0030	0.0002	0.006	0.07	20-34	3.5-4	0.0567-0.0184

From the original table, the amount of gas produced per animal per day was calculated. In some cases, the production per GVE was not supplied, therefore the amount of liquid manure was used to determine the gas production per animal based on the values given for cattle.

In the above table, it can be seen that 1 livestock unit of cattle can produce 0.56 to 1.5 m³/GVE/day of biogas. In 2011 there were 8.18 million cattle, 1.58 million pigs and 23.35 million sheep and goats in South Africa (Abstract of Agricultural Statistics 2012). If the lowest biogas yield is used, it can be deduced that there is a potential of 4.5808 million m³ of biogas /day from cattle, 0.3318 million m³ of biogas/day from Pigs and 1.569 million m³ of biogas/day from sheep and goats. However, if it is assumed that only 10 % of sheep and goats are kept in sheds or in kraals, this amount drops to 0.1569 million m³ of biogas/day from sheep. This gives a total potential biogas yield of 5.069 million m³ of biogas/day for the whole of South Africa. According to the census of 2011 it can be assumed that 14.5% of all animals are located in the Free State which gives a potential yield of 0.735 million m³ of biogas/day in the Free State alone.

750 m³ Biogas is needed per day to power a 60kW generator (Agama Energy, 2008). According to Deublein & Steinhauser this figure is even higher. A figure of 1 m³ of biogas generating 2.4 kWh is mentioned. Therefore, with the 0.735 million m³ of biogas /day available in the Free State, 1764 MWh of electricity can be generated. This will mean a possible saving to the owners of R1.5876 million every day if the cost of electricity is assumed to be R 0.9 per kWh. The reason why this can be a saving is if the operators use their own generated electricity for themselves they need not buy from Eskom which will be a saving for their household or operation.

Energy Crops:

South Africa, and in particular the Free State, has a large area of under-productive land. These areas of land cannot be cultivated on an economical basis due to a number of factors such as low rainfall, low crop prices, low production, etc. and therefore farmers have stopped production. This land would be extensive farmland where no irrigation is available.If ways could be found to produce more economically on this land, farmers will be able to farm more profitable. An evaluation of the different feedstocks needs to be carried out to determine which energy crops can be used economically as feed stock for biogas production.

The total farmland in South Africa is 100 665 792 hectares and in the Free State 11 760 100 hectares. The total number of hectares of land which has not been cultivated since 1991 is 700 00 hectares for South Africa and 200 000 hectares for the Free State. The main reason for this is that the land cannot be cultivated economically (Abstract of Agricultural Statistics 2012).

In the following example, maize will be used as the hypothetical energy crop since all the figures for maize is available, however, since maize is an important food source, under normal circumstances, maize would not be used for biogas production. If the 200 000 hectares that is not cultivated is planted with maize, maize silage can produce 300 - 350 m³ Biogas/Tonne (Cropgen, 2012). Since it is under-productive land, a yield of only 1 ton per hectare is assumed (this is the total plant) then this area of land can produce 200 000 tons of biomass. This biomass can then deliver 60 Million m³ of biogas which can generate 144 000MW of electricity per season. Consequently, a saving of R 129.6 m/season can be realised in the Free State.

It can be a problem for extensive animal and game farmers to really utilise biogas unless there is some form of biomass that can be harvested. Since the animals roam on big portions of land, it would be logistically impossible to collect their dung for use in a large biogas reactor. Only the waste from the houses or accommodation can be used to feed a biogas reactor. This will only supply them with limited gas. It would not be economically viable to generate electricity from this biogas. The best would then be to use the biogas for cooking.

6. OTHER FACTORS TO CONSIDER

The other criteria that need to be considered in connection with biomass as an energy source are: Food or fuel production, water and area, labour, job creation and lastly, sustainability of farms.

Food or Fuel: This needs to be considered if agricultural land is taken out of food production to produce energy crops for biogas reactors. But as mentioned earlier, it is not the intention since there are huge areas that are currently not cultivated for various reasons. Therefore, the focus of this paper is to only look at the available land. But if a farmer should decide to erect a biogas reactor for the purpose of producing energy crops for a substrate for the reactor, the factors such as job creation and sustainability should also be considered. If the farmer finds that his soil is not fertile enough and his rainfall not high enough to produce cash crops, it is a purely economic decision to be taken to survive and to be sustainable on his farm. This decision will also mean that new jobs will be created in support of the energy drive or at least, existing jobs will not be lost. There are a number of jobs that can be created in such a plant if the farmer decides to use manual labour rather than machinery. A number of jobs will also be created in the building phase of such reactors.

If cheaper fuel and energy are also available, farmers will cultivate more and be more productive. Currently, farmers cannot irrigate in the hours of peak electricity use as this will increase their production cost. However, the fact that they do not irrigate also has a negative impact on the crop yield.

Farmers that produce kernels can still utilise the waste (maize stalks and wheat straw) for biogas production but this would produce a lower gas yield per ton of substrate. Due to the fact that any form of biomass can be used as feedstock for the reactors, it can also be used as a way of controlling weeds and other unwanted plants.

Biogas production actually make better use of land and water since two cycles of produce are taken from the same area of land. With the energy crop for biogas, the crop is cut at the milk stage of the seed production. This implies that winter crop can be planted immediately if there was a summer crop on the land. The waste from the biogas reactor (if energy crops and farm waste are fermented) is a very good fertiliser and can go directly back onto the land. There is also no need for pesticides since the unwanted plant is also biomass.

7. CONCLUSIONS

It can be seen that there is great potential for biogas in the Free State as well as the rest of South Africa. There are many advantages to making use of biogas from the fermentation of waste. It does not matter if it is waste from humans, animals or other biomass. From the above it is obvious that if we only consider the unproductive land and the use of available cattle, sheep and pig manure, there is a possible saving to the owner of the biogas reactors of around R 704.84 million per year in the Free State alone. In these calculations the capital input for the creation of the biogas plant was not taken into account. This preliminary study shows that there is potential for such an industry as a separate activity or as an integrated industry in the farmers' operations or in the community.

A further study will be done to determine what would be the capital investment for such operations. The energy crops or feedstock should be further evaluated to determine what is the yield and demand (or yield per input unit of water and area) of the different crops for the South African and Free State climate in particular. The study should also consider sustainability and ethical issues such as the use of land for fuel rather than for food production. Biogas can ensure the sustainability of farmers and create more jobs in this sector. In the extended study, the transport costs of energy crops and waste to the reactors should be further investigated so as to be able to make an informed decision on this matter.

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