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Review

Biogas technology research in selected sub-Saharan African countries – A review

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This reviews aims to provide an insight and update of the state of biogas technology research in some selected sub-Saharan African countries in peer reviewed literature. This paper also aims to highlight the sub-Saharan countries' strengths and weaknesses in biogas research and development capacity. An attempt is made to pinpoint future research in critically reviewing the biogas technology research. The methane-producing potential of various agriculturally sourced feedstocks has been researched, as has the advantages of co-digestion to improve carbon-to-nitrogen ratios and the use of pretreatment to improve the hydrolysis rates. Some optimisation techniques associated with anaerobic digestion including basic design considerations of single or two-stage systems, pretreatment, co-digestion, environmental conditions within the reactor such as temperature, pH, buffering capacity have been attempted in some of the researches in Nigeria, Tanzania, and Zimbabwe. However, there appears to be little research in biogas technology in many sub-Saharan African countries in internationally peer reviewed literature. Biogas production from large quantities of agricultural residues, animal wastes, municipal and industrial wastes (water) appears to have potential as an alternative renewable energy for many African countries if relevant and appropriate research is carried out to adopt the biogas technology to the local conditions in African countries. African scientists are urged to carry out research in biogas technology to locally demonstrate the feasibility, application, and adaptation of this technology and help improve the quality of energy supply in their respective countries.

Key words: Biogas research, renewable energy, anaerobic digestion, sub-Saharan Africa.

INTRODUCTION

In Africa, water pollution and access to energy resources present challenges to human health, environmental health, and economic development. In 21 sub-Saharan African countries, less than 10% of the population have access to electricity. The need for alternative renew-able energy sources from locally available resources can not be over emphasised. Appropriate and economically feasible technologies that combine solid waste and wastewater treatment and energy production can simultaneously protect the surrounding water resources and enhance energy availability. Biogas technology in which biogas is derived through anaerobic digestion of biomass, such as agricultural wastes, municipal and Industrial waste (water), is one such appropriate technology Africa should adopt to easy its energy and environmental problems. Anaerobic digestion consists of several interdependent, complex sequential and parallel biological reactions in the absence of oxygen, during which the products from one group of microorganisms serve as the substrates for the next, resulting in transformation of organic matter (biomass) mainly into a mixture of methane and carbon dioxide (Parawira, 2004).

Africa is a continent with abundant, diverse and un-exploited renewable energy resources that are yet to be used for improving the livelihood of the vast majority of the population. The production of biogas via anaerobic digestion of large quantities of agricultural residues, municipal wastes and industrial waste (water) would

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Table 1. African countries with biogas producing units (Akinbami, 2001; Karekezi, 1994; Laichena and Wafula, 1997; Omer, 2005).

Country	Number of small/medium (100 m^3)	Number of large digesters (>100 m^3)
Botswana	Several	1
Burkina Faso	>30	-
Burundi	>279	-
Egypt	Several	Few
Ethiopia	Several	>1
Ghana	Several	-
Cote D'Ivoire	Several	1
Kenya	>500	-
Lesotho	40	-
Malawi	-	1
Morocco	Several	-
Nigeria	Few	-
Rwanda	Several	Few/several
Senegal	Several	-
Sudan	>200	-
South Africa	Several	Several
Swaziland	Several	-
Tanzania	>1000	1
Tunisia	>40	-
Uganda	Few	-
Zambia	Few	-
Zimbabwe	>100	1

benefit African society by providing a clean fuel from renewable feedstocks and help end energy poverty. There is a consensus that achieving the Millennium Development Goals (MDGs) in Africa will require a significant expansion of access to modern and alternative renewable energy. Biogas is a renewable, high quality fuel, which can be utilised for various energy services such as heat, combined heat and power, or a vehicle fuel. This would reduce the use of fossil-fuel-derived energy and reduce environmental impact, including global warming and pollution, improve sanitation, reduce demand for wood and charcoal for cooking and provide a high quality organic fertiliser. Biogas technology can serve as a means to overcome energy poverty, which poses a constant barrier to economic development in Africa. Biogas production from agricultural residues, industrial, and municipal waste (water) does not compete for land, water and fertilisers with food crops like is the case with bioethanol and biodiesel production. Currently there is serious shortage of food in developing countries which will continue into the future. Therefore, food production is much more important and should compete out completely the production of energy crops for bio-diesel and bioethanol. Unlike other forms of renewable energy, biogas production systems are relatively simple and can operate at small and large scales in urban and rural locations, there are no geographical limitations to the employment of this technology nor is it monopolistic.

In Africa the interest in biogas technology has been further stimulated by the promotion efforts of various international organisations and foreign aid agencies through their publications, meetings and visits. To date, some digesters have been installed in several sub-Saharan countries, utilising a variety of waste such as from slaughterhouses, municipal wastes, industrial waste, animal dung and human excreta. Small-scale biogas plants are located all over the continent but very few of them are operational. In most African countries, for example, Burundi, Ivory Coast and Tanzania, biogas is produced through anaerobic digestion of human and animal excreta using the Chinese fixed-dome digester and the Indian floating-cover biogas digester, which are not reliable and have poor performance in most cases (Omer and Fadalla, 2003). These plants were built for schools, health clinics and mission hospitals and small-scale farmers, in most cases by non-governmental organisations. Most of the plants have only operated for a short period due to poor technical quality. Table 1 gives a list of the African countries with biogas production units as at 2007. There is thus a need to introduce more efficient reactors to improve both the biogas yields and the reputation of the technology. The development of large-scale anaerobic digestion technology in Africa is still embryonic, although the potential is there. There is a need to learn from the past experiences, adapt the biogas technology from Europe and Asia for local circumstances through research. In developing countries, biogas energy research should be planned and conducted as part of the main factors leading to its contribution to the solution of energy problems. Keeping this in mind, the results of the research should be applicable on a nation-wide scale and constitute a part of the country's development plan. In many of the developing countries, there is still need for some basic research mostly on the quantity and potential biogas yield of fermentable organic wastes available, and the size and type of biogas digesters which can be economically viable for the potential consumers of the biogas technology.

In this paper we review the biogas technology research as published in peer reviewed journals from selected sub-Saharan African countries. It must be pointed out clearly that there is little or no information (laboratory research-based) on biogas technology research in most African countries. Lack of basic and advanced research in biogas technology by African scientists could be one of the factors contributing to poor biogas technology application in Africa.

BIOGAS TECHNOLOGY RESEARCH IN SELECTED SUB-SAHARAN AFRICAN COUNTRIES

Biogas technology research in Nigeria

Nigeria is an energy rich resource country in terms of both fossil fuels such as crude oil, natural gas, coal, and renewable energy resources like solar, wind and biomass. The urban poor and the rural households however, still depend on biomass for their energy needs. In Nigeria, identified feedstock substrate for an economically feasible biogas production includes water lettuce, water hyacinth, dung, cassava leaves and processing waste, urban refuse, solid (including industrial) waste, agricultural residues and sewage (Akinbami et al., 1996, 2001; Okagbue, 1988; Ubalua, 2008). It has been estimated that Nigeria produces about 227,500 tons of fresh animal waste daily. Since 1 kg of fresh animal waste produces about 0.03 m^3 biogas, then Nigeria can potentially produce about 6.8 million m^3 of biogas every day from animal waste only. In addition, 20 kg of municipal solid waste (MSW) per capita has been estimated to be generated in the country annually (Mathew, 1982). By the 1991 census figure of 88.5 million inhabitants, the total generated MSW will be at least 1.77 million tonnes every year. With increasing urbanisation and industrialisation, the annual MSW generated will continue to increase (Akinbami et al., 1996). Biogas production may therefore be a profitable means of reducing or even eliminating the menace and nuisance of urban wastes in many cities in Nigeria (Akinbami et al., 2001).

Although biogas technology is not common in Nigeria, various research works on the science, technology and policy aspects of biogas production has been carried by various scientists in the country. Some significant research has been done on reactor design by some Nigerian scientists that would lead to process optimisation in the development of anaerobic digesters. For instance, the Usman Danfodiyo University, Sokoto, designed a simple biogas plant (with additional gas storage system) that could produce 425 L of biogas per day which could be sufficient to cook meals for one person (Dangogo and Fernado, 1986). Similarly, an engineering design and economic evaluation of a family-sized plant was carried out at the Technology Planning and Development Unit, Obafemi Awolowo University, Ile-Ife (Adeoti, 1998). Igoni et al. (2008) provided a synthesis of the key issues and analyses concerning the design of a high-performance anaerobic digester. Ezekoye and Okeke, (2006) designed and constructed a plastic biodigester and used it to produce biogas from spent grains and rice husk mixed together. The digestion of the slurries was undertaken in a batch operation and good biogas production was reported.

Many other raw materials available in Nigeria have been critically assessed for their possible use in biogas production by (Odeyemi, 1983). They include refuse and sewage generated in urban areas, agricultural residues and manure. It was concluded that poultry manure generated in Nigerian homes and in commercial poultry farms could be economically feasible substrates for biogas production. The potential to utilise poultry, cow and kitchen wastes for biogas production was demonstrated by other workers including Akinluyi and Odeyemi (1986), Abubakar (1990), Lawal et al. (1995), Matthew (1982), Ojolo et al. (2007) and Zuru et al. (1998). Atuanya and Aigbirior, (2002) reported the feasibility of biogas production using a UASB reactor of 3.50 L capacity.

Ilori et al. (2007) investigated production of biogas from co-digestion of banana and plantain peels using a 10 L laboratory scale anaerobic digester. The highest volume of biogas was obtained when the banana and plantain peels were in equal proportions as feedstock. Seeding of co-digested pig waste and cassava with wood ash was reported to result into significant increase in biogas production compared with unseeded mixture of pig waste and cassava peels (Adeyanju, 2008). Fariku and Kidah (2008) reported good biogas production from anaerobic digestion of waste shells of *Lophira lanceolata* fruit. The potential use of local algal biomass for biogas production in Nigeria was recognised by Weerasinghe and Naqvi (1983). Odeyemi (1981) compared four other substrates, namely *Eupatorium odoratum*, water lettuce, water hyacinth and cow dung as potential substrates for biogas production. *Eupatorium odoratum* gave the highest yield of biogas and cowdung was the poorest substrate. He concluded that *E. odoratum* was a cheap source of biogas in Nigeria because of its luxuriant and ubiquitous growth. These laboratory studies demonstrated the potential of biogas production from agricultural waste, industrial and urban waste and animal waste in Nigeria. It appears that some groundwork for biogas research and development have been initiated in Nigeria.

Biogas technology research in Sudan

Sudan is an agricultural country with plenty of water resources, livestock, forestry resources, and agricultural residues besides municipal and industrial wastes. The supply of agriculture was estimated at 44.5 x 10^6 kg, animal dung was 900 x 10^6 kg and baggasse 840 x 10^6 kg in 2005 (Omer, 2005). However, it is an energy importing country and the energy requirements are supplied through imports that cause financial problems. The oil import bill consumes more than 50% of the income earnings of the country. In Sudan there were 200 installed biogas units for family, community or industrial uses in 2005 and the main sources of feedstock were agricultural and animal wastes (Omer, 2005). There is need for research on the potential to utilise the large quantities of biomass for biogas production and improve the biogas yield. Typically different variants of anaerobic digesters need to be used to treat each different feedstock optimally. There have been some efforts to research on the potential to utilise water hyacinth as a feedstock for biogas technology by Dirar and El Amin (1988) and El Amin and Dirar (1988). Water hyacinth biomass is abundant in White Nile and 2400 tons of fresh biomass were estimated to pass the town of Malakal every day in April and increasing to 5 000 tons daily in summer. These researchers optimised the anaerobic digestion of water hyacinth focussing on the effect of solids concentration, temperature, and retention time and inoculum source in batch experiments.

Biogas technology research in Tanzania

Tanzania is a tropical country and agriculture is the main stay of her economy. Tanzania imports all its fuel oil and it cost the nation over 60% of the meagre foreign currency earnings (Nkonoki and Lushiku, 1988). Given such a situation which will continue for unforeseeable future, Tanzanian government has formulated an energy policy which emphasize on renewable energy development (Sheya and Mushi, 2000). Amongst renewable energies in Tanzania include, biomass, solar, wind, geothermal, hydro, biogas etc. Like many tropical countries, Tanzania has plenty biomass resources that can be efficiently exploited in a manner that is both profitable and sustainable for bioenergy such as biogas production. These biomasses include municipal solid wastes, agricultural, agro-industrial wastes, human excreta (Kivaisi and Rubindamayugi, 1996; Sheya and Mushi, 2000; Mbuligwe and Kaseva, 2004; Chaggu et al., 2007). Also huge quantities of animal manure suitable for biogas production are generated from animals each year. Bearing in mind that Tanzania has 18.8 million cattle population, this makes it the third country with largest cattle population in Africa after Ethiopia and Sudan. In total, livestock population in Tanzania stands at 40 million animals.

Biogas technology utilizing animal waste is not new to Tanzania; it was introduced in as early as the 1950s by private stakeholders. In 1975, the government through the Small Industries Development Organisation introduced the Indian design (floating gasholder digester) in primary and secondary schools, rural health centres and a number of other institutions. In 1983, the Ministry of Industries and Trade through its Centre for Agriculture Mechanisation and Rural Technology (CAMARTEC) initiated a biogas development programme. This programme was supported by the German Agency for Technical Cooperation (GTZ). Under this programme, the Chinese fixed dome biogas digesters were adapted to local conditions (Sheya and Mushi, 2000). In mid 1993, the first simple low-cost polyethylene tubular biodigesters were introduced into the United Republic of Tanzania as part of the FAO/TCP/URT/2255 project. The polyethylene tubular digester technology, aimed at reducing the production cost by using local materials and simplifying its installation and operation (Bui-Xuana et al., 1997). However, at present these technologies are based only on use of animal manures as feedstocks for the biogas digesters. There is, therefore, a tendency to limit the technology to cattle rearing areas. Therefore, there is a great need for biogas research and development aimed at enhancement of biogas process using efficient cost effective high rate bioreactors and different biogas feed stocks other than conventional used animal manures in traditional digesters currently used in Tanzania. To this effect there has been scientific research going on the anaerobic digestion for biogas production for the past twenty years in Tanzania. The biogas research and development has been centred mainly at the University of Dar es Salaam in collaboration with counterparts in foreign Universities.

Digested material from an established reactor or similar materials such as ruminant manure is often used to seed a new bioreactor, reducing the start-up time. Many bioreactors use methods of inoculating the fresh material with either digested material or the liquid fraction from the bioreactor, thus reducing washout of microorganisms. The microbial populations available in rumen fluid have been used as a seeding material in anaerobic digestion lignocellulosic feedstocks often to increase the production of fatty acids, which subsequently enhanced biogas production. The potential application of rumen microorganisms to anaerobic digestion of agricultural, agro-industrial, water hyacinth rich lignocellulosic material singly or in combination was found to improve biogas production in batch and continuous culture experiments in UASB reactors (Op den Camp et al., 1988; Kivaisi et al 1990, 1992; Kivaisi and Eliapenda, 1995; Kivaisi and Mtila, 2001).

Pre-treatment of feedstocks can increase biogas production and volatile solids reduction due to increased solubilisation. The use of pre-treatments is particularly useful in the digestion of biomass feedstocks, as these tend to be high in cellulose or lignin. Pre-treatment can break down these recalcitrant polymers physically, chemically or biologically. These have been shown to be effective in anaerobic digestion of lignocellulosic wastes such as baggasse, maize bran, coconut fibres, water hyacinth, sisal fibre and sisal leaf decortications residues leading to significant increase in methane yield compared to the untreated (Kivaisi and Eliapenda, 1994, 1995; Katima, 2001; Mshandete et al., 2005a, 2006). Additives enhances the production rate of a bioreactor or increase the speed of start up, which ultimately improves biogas plant performance significantly. Soybean curd residue, *Okara* as an additive was reported to enhance methane production from pretreated woody waste (Take et al., 2005).

Co-digestion of organic wastes is a technology that is increasingly being applied for simultaneous treatment of several solid and liquid organic wastes. The main advantages of this technology are improved methane yield because of the supply of additional nutrients from the codigestates and more efficient use of equipment and cost-sharing by processing multiple waste streams in a single facility. Co-digestion of organic fractions of municipal solid waste, sisal leaf decortications residues, coffee hulls with chicken manure or fish waste or cow dung manure improved the digestibility of the materials resulting in increased methane productivity and methane yield (Kivaisi, 2002; Kivaisi and Mukisa, 2000; Mshandete et al., 2004a).

There are several types of reactor in use today, and the design is related to the material to be digested. Immobilisation of microbial biomass can take advantage of the natural tendency of cells to form dense granules which settle in the digester, for example the UASB bioreactors or can involve the use of an inert (pumice, glass beads) or degradable (sisal fibres wastes) medium to which the microbial populations attach, for example in packed bed bioreactors, solid state stratified bed bioreactors. These high rate anaerobic bioreactors have been demonstrated to allow for a continuously high and sustainable organic load rate, a short hydraulic retention time (to minimise reactor volume) and to produce the maximum volume of methane from semi solid sisal leaf decortications and leachate, potato leachate and agro-industrial wastes and wastewater (Rubindamayugi et al., 1989, 1992; Mshandete et al., 2004b, 2005b, 2008).

Biogas research technology in Zimbabwe

Zimbabwe is faced with serious shortage of electricity, resulting in imports soaring to about 50% of total energy needs at time. Given that it is expensive to invest in new thermal and hydroelectricity generation facilities and the fact that the government and power utility authority cannot raise the necessary capital, a role has been opened for renewable energy such as biogas to contribute to the energy needs. Zimbabwe's economy is based on agriculture and therefore large quantities of biomass residues from agricultural activities, industrial residues and wastewater from food processing companies and municipal solid wastes and wastewater are generated which possess energy potential not currently being utilised. Total biomass energy theoretically available in Zimbabwe has been estimated at 409PJ (Hemstock and Hall, 1995). The Zimbabwe government has a national energy strategy which includes renewable energy development with the aim to replace fossil fuel. This goal can be partly achieved if there is substantial effort in research, development and application on renewable energy such as solar, wind and biofuels such as bioethanol, biodiesel and biogas of which Zimbabwe has a high potential. Some efforts have been done to carry out research on the biogas potential from some biomass resources in Zimbabwe as discussed below.

Millions of tons of solid waste are generated each year from municipal, industrial and agricultural sources in Zimbabwe. Total biomass energy theoretically available in Zimbabwe has been estimated to 409PJ of which 48.5% is from agriculture, 29.8% from forestry and 21.7% from livestock (Hemstock and Hall, 1995). Five assessments of Zimbabwe's biomass standing stock estimated the total standing stock to be between 321 and 1502 million tons and mean annual increment varied between 9 and 47 million tons. Municipal solid waste from households, industry, institutions and municipal authorities is a potential feedstock for anaerobic digestion for biogas production. Per capita municipal solid waste generation has been estimated at 0.5 kg/day and given the estimated urban population of 3,392, 144 in 2002, Zimbabwe has a potential to about 1696 tons of municipal solid waste per day (Jingura and Matengaifa, 2008). The sewage sludge is being treated via aerobic and anaerobic digestion but most of biogas digesters have been lying idle for years now. The estimated agricultural crop residues are over 10 million tons in Zimbabwe, which are currently disposed through different inefficient energy conversion ways.

Unmanaged organic waste fractions from farming, industry and municipalities decompose in the environment resulting in large scale contamination of land, water and air. The wastes not only represent a threat to environmental quality, but also possess a potential energy value that is not currently being utilised despite the abundance of the solid wastes. These organic solid wastes can be treated using anaerobic digestion for biogas production as was investigated by Parawira et al. (2004a; b), Parawira (2004), Parawira et al. (2005a; b), Parawira et al. (2006), Parawira et al. (2007), Parawira et al. (2008), Misi and Forster (2001a,b). These studies were concerned with some important aspects of anaerobic digestion of agricultural, food and industrial organic wastes digested singly or in co-digestion. Co-digestion of different agricultural wastes resulted in improved methane yield by 60% compared with that from digestion of separate substrates in batch and pilot scale studies. Studies were performed using batch, one-stage and two-stage processes using laboratory-, pilot-, and full-scale anaerobic bioreactors. Anaerobic digestion is a complex biochemical process carried out in a number of steps by several types of microorganisms in the absence of oxygen. Methane and carbon dioxide (biogas) are the principal end products with minor quantities of nitrogen, hydrogen and hydrogen sulphide. For improved understanding of the anaerobic digestion, some of the aspects investigated were the profiles of the hydrolytic enzymes (Parawira et al., 2005a) and production of volatile fatty acids during the hydrolysis/acidification stage (Parawira et al., 2004b), and methane yield under various reactor configurations and reactor conditions. The results from these studies demonstrated that agricultural and industrial waste and wastewater are potential substrates for anaerobic digestion for the production of biogas and environmental protection.

The large quantities of wastewater (containing high organic load) from industries could also be treated using anaerobic mesophilic treatment. A study of the industrial anaerobic treatment of opaque beer brewery wastewater using a full-scale UASB reactor was carried out over a period of two years by Parawira et al. (2005b). The anaerobic treatment of the opaque beer wastewater enabled the brewery to meet the requirements for wastewater discharged into the municipal sewage system of Harare, and therefore the costs of wastewater discharge to the company. The UASB reactor generally reduced the organic load to permissible levels during the period of the study, although there is need to improve its performance in terms of organic load removal. Further benefits from the plant could be realised by taping the energy generated by the anaerobic process in the form of biogas. The methane could be used to heat the steam boiler at the brewery or converted to electricity via a motor generator. The installation of this UASB reactor by the brewery is an attractive economic and environmental alternative considering that we are in era of critical energy shortage, substantially higher energy prices and high demand on environmental protection. Manhokwe (2007) evaluated the biological treatment methods for potato wastewater produced by a potato processing plant in Harare. Anaerobic treatment was found to enable the plant to meet the required effluent quality for discharge into municipal sewage system.

Biogas research technology in Republic of Congo (ROC)

Congo's hydrocarbon industry is the country's primary source of economic growth. According to the World Bank, the oil sector accounts for roughly 65% of the country's gross domestic product (GDP), and oil exports account for around 90% of total export revenues. Congo is the fourth largest oil exporter in sub-Saharan Africa after Angola, Nigeria and Equatorial Guinea and in 2006; Congo was the fifth largest crude oil producer in Sub-Saharan Africa following Nigeria, Angola, Sudan and Equatorial Guinea. Congo's energy consumption is dominated by oil (78%), with the remainder coming from hydroelectricity (22%). Natural gas, coal, nuclear and other renewables are currently not part of the country's energy consumption mix. Congo contains the fourth largest proven natural gas reserves in Sub-Saharan Africa. Despite Congo's natural gas reserves, the country does not commercially produce or consume any natural gas, due to the lack of proper production infrastructure.

Although renewable sources are currently not part of the country's energy consumption mix, the country has plans to set aside part of its arable land for biofuel production. Also there has been research on biogas utilizing cassava residues as the feedstock (Cuzin et al., 1989, 2001). Cassava (*Manihot esculenta* Crantz) is grown in most parts of the ROC, where 95,700 ha are under cultivation with a total production of 861,500 ton and per capita consumption is the highest in Africa (Ntawuruhunga et al., 2007). The processing of cassava roots to produce cassava meal (fufu) in the ROC includes peeling, retting by soaking roots in water for three days and drying. During this process, large quantities of solid wastes (cassava peel) are produced. Based on the previous, data on the annual production of 700 000 tons of cassava roots, the unutilized cassava peel was estimated to 175 000 tons, which could be used to produce biogas and generate part of the energy needed for the mechanical processing of cassava (Cuzin et al., 1989, 2001).

The anaerobic digestion of raw cassava peels was studied using a 128 L plug flow digester. The results showed that a biogas yield of 0.661 m^3 per I kg volatile solids (VS) was obtained. Energy-saving calculations showed that a bioreactor of 88 m^3 is sufficient to produce the methane necessary for drying one ton of cassava meal (Cuzin et al., 1992a). Apart from producing energy in the form of biogas the 128 L plug flow digester was used to reduce cyanide levels during methanogenic fermentation of cassava peel liquor. The results showed that cyanide removal was sufficiently fast to maintain a cyanide concentration in the fermentation liquor which was non-inhibitory for the methanogenic microflora, consequently methane production was not inhibited in the anaerobic digester (Cuzin et al., 1992b). Recently, a new species of the genus *Methanobacterium*, namely *Methanobacterium congolense* sp. nov Strain CT, a non-motile, mesophilic, hydrogenotrophic, methanogenic bacterium, has been isolated from an anaerobic plug flow digester used for the treatment of raw cassava-peel waste in RCO (Cuzin et al., 2001). These results demonstrated that the presence of cyanide tolerant methanogens is vital in enhanced biogas production from raw cassava-peel waste in anaerobic digesters.

Biogas research in other sub Saharan African countries

An extensive review of literature on peer reviewed journals on biogas/anaerobic biotechnology research in other sub Saharan countries revealed scanty or no scientific publications at all. However, the potential for biogas production in those countries exists since there is availability of huge quantities biomass from agriculture and livestock, food processing, municipal solid wastes, wastewaters, agro-industrial wastes and forest wastes etc. In fact through "Biogas for Better Life" an African initiative supported by SNV /Netherlands and KfW /Germany, there is biogas technology applications based on experiences with multiple technologies (such as floating drum, plug flow, fixed dome, batch and semi-batch). Biogas for Better Life initiative, have resulted in a number of positive spin-off effects on anaerobic technology in terms production of value added products from organic wastes in the form of biogas and biogas manure production. The initiative covers a number of countries in sub Saharan Africa such as Benin, Burkina Faso, Cameron, Ethiopia, Ghana, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Niger, Rwanda, Senegal, Togo, Uganda, Zambia and Gambia etc. Nevertheless, as far as biogas and anaerobic technology is concerned South Africa is unique in sub-Saharan Africa because of its high level of economic development and many universities with state of the art research capacities. This review would not do justice to cover the wide biogas technology research in South Africa together with other sub-Saharan African countries. It has a wide range of energy options and advanced anaerobic biotechnology research not available to other African countries.

Renewable energy resources of major importance in Botswana are biomass, solar, and wind. Like other countries in southern Africa, Botswana, depends on biomass for its energy requirements, with wood constituting the major (60 - 70%) primary energy source (Gwebu, 2003). Currently renewable energy contributes only about 1% to total energy consumption mainly from solar energy. As is the case with most other African countries, enhanced research capacity is still required to develop biogas production from animal dung, municipal and industrial wastes (Gwebu, 2003). There is limited animal and vegetable waste suitable for energy production in biogas digesters. On the assumption that the total number of cattle is about 2.5 million, the average cattle moist waste production is 12.5 million kg/daily. However, most of this resource remains unusable for energy production under the free range farming practice in place (Fagbenle, 2001). However, Diaho et al., (2005) reported good biogas production from a mixture of cow abdominal waste and its dung compared to biogas production from cow dung alone under the same conditions.

FUTURE RESEARCH

While there is ongoing research worldwide both in the first and second generation of bioenergy technologies, it is important to actively involve and fully engage Africa's researchers and academic communities. This would entail joint research programs between developed and developing countries with possibility for technological transfer to low technology environment world.

In order for biogas technology research to have a positive impact, the relevant and appropriate areas of research need to be identified and prioritized. Prioritization of biogas technology research activities results in the selection of the optimal research portfolio given the resource constraints. Thus, resource allocations based on identified research priorities will be more efficient and responsive to the research system objectives than when resource allocation is not based on research priorities.

Most African countries are endowed with abundant biomass resources which include agricultural, municipal and industrial waste and wastewater for anaerobic digestion and therefore biogas production. These resources consist of a wide range of forms and classes and fractions. Researchers need to focus on the resources sustainably available locally and carry out investigations that would result in optimised biogas production from them following the stages of anaerobic digestion. Co-digestion of these substrates would provide opportunities to optimise biogas production in Africa.

Anaerobic digestion of sewage sludge is already being practised in many African countries but most the digesters are being operated at far below capacity and therefore there is need to carry out research focussing on improving the performance of biogas digesters at wastewater treatment plants. The biogas currently being produced at sewage treatment plants is not being utilised since most of it is vented into the atmosphere and little is sometimes being used to heat the digesters. Therefore the biogas should be collected utilised to generate energy.

In order to promote the implementation and proper use of anaerobic digestion technology, it is important to initiate long-term anaerobic digestion and other renewable energy training and capacity-building programmes, and to perform scientific work in this field (through appropriate research). It is important to establish contacts between research and university groups and experienced contractors, and to initiate collaboration with polluting industries, that is, to interest them in the system, either for use as an environmental protection method, or for energy production. Stakeholders and partners including farmers, extension agents, academics, processors, NGOs, donors, business and policy makers must be involved in setting research and development priorities. Involvement is essential to ensure that research is relevant to the needs of the targets and that adequate research funding is guaranteed. In addition, experts should provide reliable and pertinent information about the biogas technology and its potential to local authorities, politicians, and the public in general. It demands a lot of efforts in achieving an efficient transfer of knowledge from research centres and universities to state sanitation companies, consulting engineers firms and government environmental control agencies. There is also need to obtain grants from the government or international organisations, and industry for pilot-plant and/or demonstration-scale projects (Foresti, 2001; Karekezi, 1994).

In developing countries, biogas energy research should be planned and conducted as the main factor leading to its contribution to the solution of energy problems at local settings. Keeping this in mind, the results of the research should be applicable on a nation-wide scale and constitute a part of the country's development plan. In many of the developing countries, there is remain some basic research areas mostly on the quantity and potential biogas yield of fermentable organic wastes available, the size and type of biogas digesters which can be economically viable for the potential consumers of the biogas technology.

Conclusions

Developing alternative energy source to replace traditional fossil fuel has recently become more and more attractive due to the high energy demand, the limited resource of fossil fuel, and environmental concerns as well as a strategy to survive post-fossil fuel economy era. Biogas has become more attractive as an alternative to fossil fuel because of its environmental benefits and the fact that it is made from renewable resources. This work attempted to put together most of biotechnological biogas researches in peer reviewed scientific journals that have been done in selected sub-Saharan African countries (or elsewhere by sub-Saharan African researchers together with their collaborators) for ease of reference and fostering of closer research collaborations. The optimisation of biogas production in sub-Saharan Africa through research cannot be viewed as an option only, but also imperative to improve renewable energy supply in sub-Saharan African.

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