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Review Article

Biomass and biogas for energy generation: recent development and perspectives

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Biogas from biomass appears to have potential as an alternative energy source, which is potentially rich in biomass resources. This is an overview of some salient points and perspectives of biogas technology. The current literature is reviewed regarding the ecological, social, cultural and economic impacts of biogas technology. This article gives an overview of present and future use of biomass as an industrial feedstock for production of fuels, chemicals and other materials. However, to be truly competitive in an open market situation, higher value products are required. Results suggest that biogas technology must be encouraged, promoted, invested, implemented, and demonstrated, but especially in remote rural areas.

Keywords: biomass resources, biogas application, sustainable development, environment.

Energy is an essential factor in development since it stimulates, and supports economic growth, and development. Fossil fuels, especially oil and natural gas, are finite in extent, and should be regards as depleting assets, and efforts are oriented to search for new sources of energy. The clamour all over the world for the need to conserve energy and the environment has intensified as traditional energy resources continue to dwindle whilst the environment becomes increasingly degraded. The basic form of biomass comes mainly from firewood, charcoal and crop residues. Out of the total fuel wood and charcoal supplies 92% was consumed in the household sector with most of firewood consumption in rural areas.

The term biomass is generally applied to plant materials grown for non-food use, including that grown as a source of fuel. However, the economics of production are such that purpose-grown crops are not competitive with fossil-fuel alternatives under many circumstances in industrial countries, unless subsidies and/or tax concessions are applied. For this reason, much of the plant materials used as a source of energy at present is in the form of crop and forest residues, animal manure, and the organic fraction of municipal solid waste and agro-industrial processing by-products, such as bagasse, oil-palm residues, sawdust and wood off-cuts. The economics of use of such materials are improved since they are collected in one place and often have associated disposal costs.

Combustion remains the method of choice for heat and power generation (using steam turbines) for dryer raw materials, while biogas production through anaerobic digestion or in landfills, is widely used for valorisation of wet residues and liquid effluents for heat and power generation (using gas engines or gas turbines). In

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addition, some liquid fuel is produced from purpose grown crops (ethanol from sugarcane, sugar beet, maize, sorghum and wheat or vegetable oil esters from rapeseed, sunflower oil oilpalm). The use of wastes and residues has established these basic conversion technologies, although research, development and demonstration continues to try and improve the efficiency of thermal processing through gasification and pyrolysis, linked to combined cycle generation. At the same time considerable effort is being made to increase the range of plant-derived non-food materials. To achieve this several approaches are being taken. The first is to provide lower cost raw materials for production of bulk chemicals and ingredients that can be used in detergents, plastics, inks, paints and other surface coatings. To a large extent these are based on vegetable oils or starch hydrolysates used in fermentation to produced lactic acid (for polylactides) or polyhydroxbutyrate, as well as modified starches, cellulose and hemicellulose. The advantages are biodegradability, compatibility with biological systems (hence, less allergic reaction in use) and sparing of fossil carbon dioxide emissions (linked to climate chance). Associating an economic value to these environmental benefits, linked to consumer preferences has contributed to increased production in this area. The second expanding activity is the use of plant fibres, not only for non-tree paper, but also as a substitute for petroleum based plastic packing and components such as car parts. These may be derived from non-woven fibres, or be based on bio-composite materials (lingo-cellulose chips in a suitable plastic matrix). At the other end of the scale, new methods of gluing, strengthening, preserving and shaping wood have increased the building of large structures with predicted long-lifetimes. These include a wide range of natural products such as flavours, fragrances, hydrocolloids and biological control agents. In spite of decades of research and development, engineering (recombinant DNA technology) is being widely investigated to achieve this, as well as to introduce new routes to unusual fatty acids and other organic compounds. In addition such techniques are being used to construct plants that produce novel proteins and metabolites that may be used as vaccines or for other therapeutic use. Processing of the crops for all these non-food uses will again generate residues and by-products that can serve as a source of energy, for internal use in processing, or export to other users, suggesting the future possibility of large multi-product biomass-based industrial complexes.

Technical Description

Bacteria form biogas during anaerobic fermentation of organic matters. The degradation is very complex process and requires certain environmental conditions as well as different bacteria populations. The complete anaerobic fermentation process is briefly described below as shown in Table 1, and Figure 1. Biogas is a relatively high-value fuel that is formed during anaerobic degradation of organic matter. The process has been known, and put to work in a number of different applications during the past 30 years, for rural needs such as in [1]: food security, water supply, health cares, education and communications.

During the last decades thousands of biogas units were built all over the world, producing methane CH_4 for cooking, water pumping and electricity generation. In order not to repeat successes in depth on local conditions and conscientious planning urged [2]. The goals should be achieved through:

- Review and exchange of information on computer models and manuals useful for economic evaluation of biogas from biomass energy.
- Exchange of information on methodologies for economic analysis and results from case studies.
- Investigation of the constraints on the implementation of the commercial supply of biogas energy.
- Investigation of the relations between supplies and demand for the feedstock from different industries.
- Documentation of the methods and principles for evaluation of indirect consequences such as effects on growth, silvicultural treatment, and employment.

Table (1) Anaerobic degradation of organic matter [3]

Level	Substance	Molecule	Bacteria
Initial	Manure, vegetable, wastes	Cellulose, proteins	Cellulolytic, proteolytic
Intermediate	Acids, gases, oxidised, inorganic salts	CH_3COOH, $CHOOH$, SO_4, CO_2, H_2, NO_3	Acidogenic, hydrogenic, sulfate reducing
Final	Biogas, reduced inorganic compounds	CH_4, CO_2, H_2S, NH_3, NH_4	Methane formers

Biogas technology cannot only provide fuel, but is also important for comprehensive utilisation of biomass forestry, animal husbandry, fishery, agricultural economy, protecting the environment, realising agricultural recycling, as well as improving the sanitary conditions, in rural areas. The introduction of biogas technology on wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and development funds [4].

Biogas is a generic term for gases generated from the decomposition of organic material. As the material breaks down, methane (CH_4) is produced as shown in Figure 3. Sources that generate biogas are numerous and varied. These include landfill sites, wastewater treatment plants and anaerobic digesters. Landfills and wastewater treatment plants emit biogas from decaying waste. To date, the waste industry has focused on controlling these emissions to our environment and in some cases, tapping this potential source of fuel to power gas turbines, thus generating electricity. The primary components of landfill gas are methane (CH_4), carbon dioxide (CO_2), and nitrogen (N_2). The average concentration of methane is ~45%, CO_2 is ~36% and nitrogen is ~18%. Other components in the gas are oxygen (O_2), water vapour and trace amounts of a wide range of non-methane organic compounds (NMOCs).

For hot water and heating, renewables contributions come from biomass power and heat, geothermal direct heat, ground source heat pumps, and rooftop solar hot water and space heating systems. Solar assisted cooling makes a very small but growing contribution. When it comes to the installation of large amounts of PV, the cities have several important factors in common. These factors include:

- A strong local political commitment to the environment and sustainability.
- The presence of municipal departments or offices dedicated to the environment, sustainability or renewable energy.
- Information provision about the possibilities of renewables.
- Obligations that some or all buildings include renewable energy.

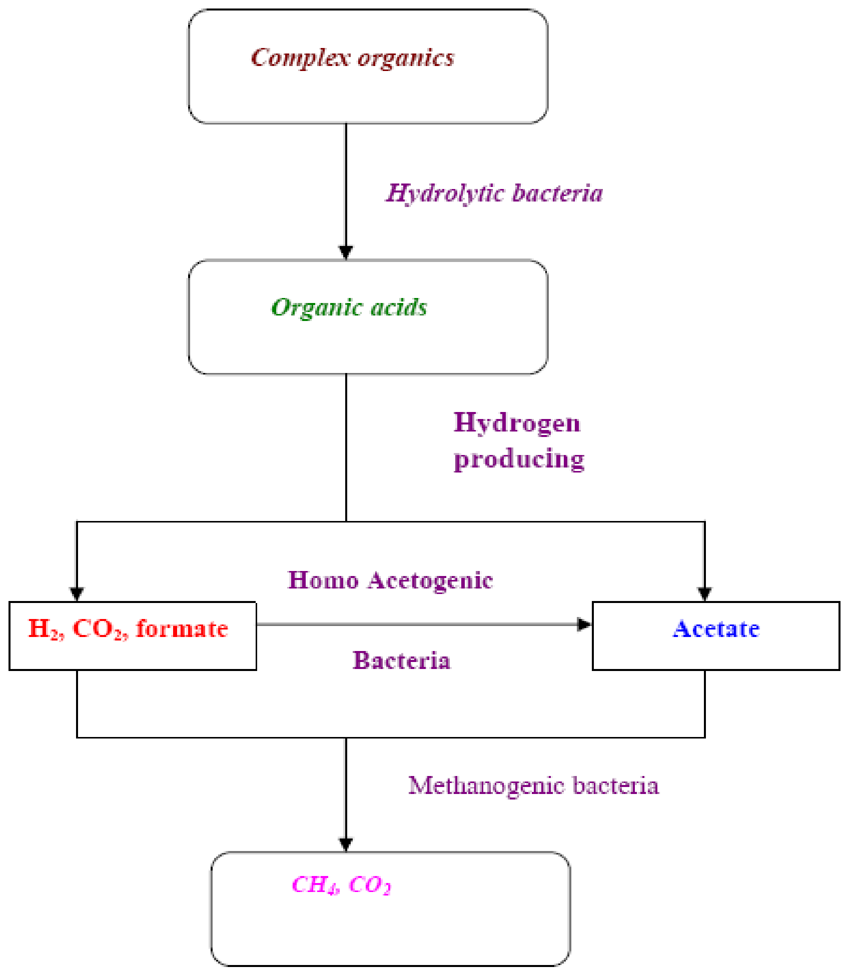


Figure 1. Biogas production process

Biogas Utilisation

The imporatance and role of biogases in energy production is growing. Nowadays, a lot of countries in Europe promote utilisation of renewable energies by guaranteed refund prices or emission trading systems. A general schematic of an agricultural biogas plant, with the anaerobic digester at the 'heart' of it as shown in Figure 2. Pre-treatment steps (e.g., chopping, grinding, mixing or hygienisation) depend on the origination of the raw materials.

In the past two decades the world has become increasingly aware of the depletion of fossil fuel reserves and the indications of climatic changes based on carbon dioxide emissions. Therefore extending the use of renewable resources, efficient energy production and the reduction of energy consumption are the main goals to reach a sustainable energy supply. Renewable energy sources include water and wind power, solar and geothermal energy, as well as energy from biomass. The technical achievability and the actual usage of these energy sources are different around Europe, but biomass is seen to have a great potential in many of them. An efficient method for the conversion of biomass to energy, is the production of biogas by microbial degradation of organic matter under the absence of oxygen (anaerobic digestion). It is now possible to produce biogas at rural installation, upgrade it to bio-methane, feed it into the gas grid, use it in a heat demand-controlled CHP and to receive revenues.

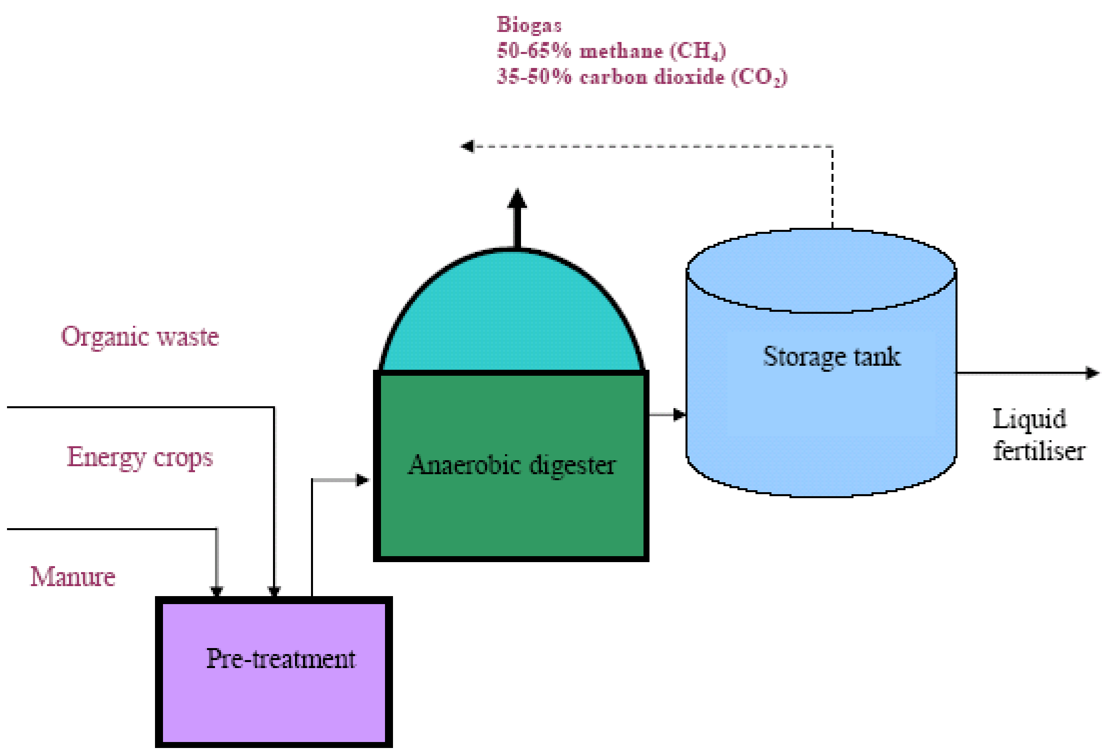


Figure 2. General schematic of an agricultural biogas plant

Biogas is a mixture containing predominantly methane (50-65% by volume) and carbon dioxide and in a natural setting it is formed in swamps and anaerobic sediments, etc., due to its high methane concentration, biogas is a valuable fuel. Wet (40-95%) organic materials with low lignin and cellulose content are generally suitable for anaerobic digestion (Figure 3). A key concern is that treatment of sludge tends to concentrate heavy metals, poorly biodegradable trace organic compounds and potentially pathogenic organisms (viruses, bacteria and the like) present in wastewaters.

These materials can pose a serious threat to the environment. When deposited in soils, heavy metals are passed through the food chain, first entering crops, and then animals that feed on the crops and eventually human beings, to whom they appear to be highly toxic. In addition they also leach from soils, getting into groundwater and further spreading contamination in an uncontrolled manner. European and American markets aiming to transform various organic wastes (animal farm wastes, industrial and municipal wastes) into two main by-products:

- A solution of humic substances (a liquid oxidate).
- A solid residue.

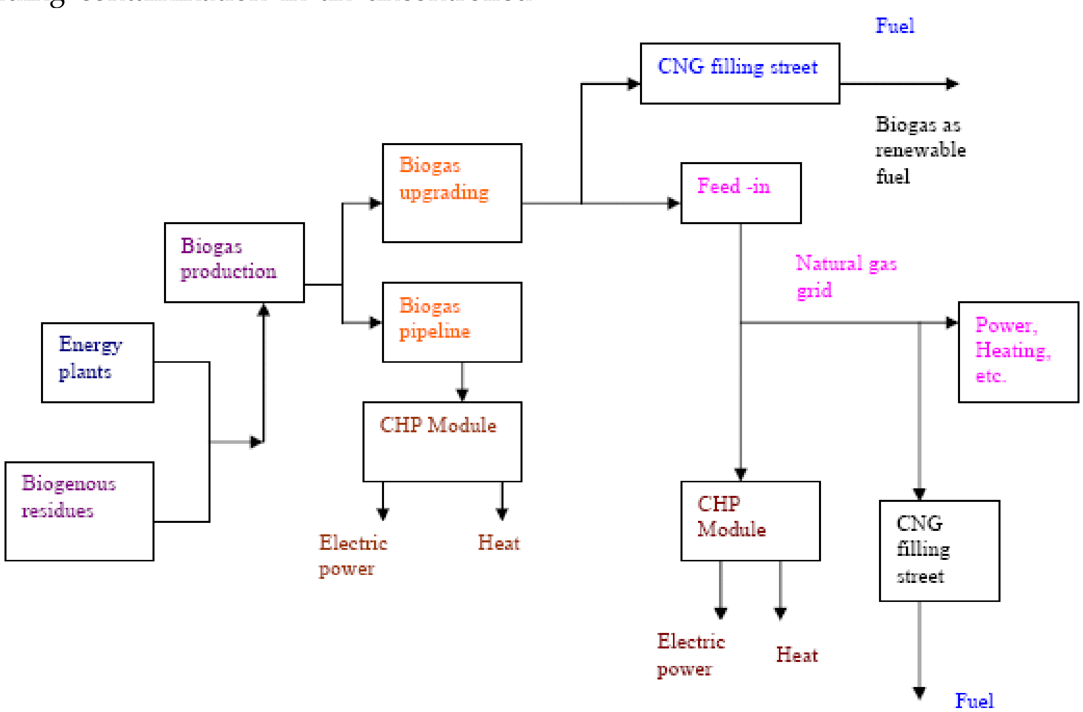


Figure 3. Overview of biogas utilisation pathways

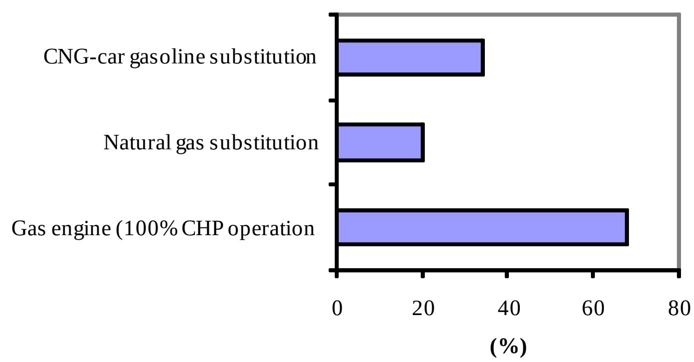
Ecological Advantages of Biogas Technology

An easier situation can be found when looking at the ecological effects of different biogas utilisation pathways. The key assumptions for the comparison of different biogas utilisation processes are:

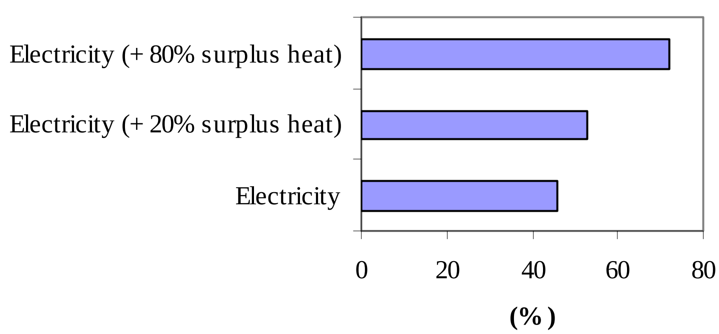
- Biogas utilisation in heat demand controlled gas engine supplied out of the natural gas grid with 500 kWe - electrical efficiency of 37.5%, thermal efficiency of 42.5%, and a methane loss of 0.01.
- Biogas utilisation in a local gas engine, installed at the biogas plant with 500 kWe - electrical efficiency of 37.5%, thermal efficiency of 42.5%, and a methane loss of 0.5.
- Biogas production based on maize silage using a biogas plant with covered storage tank - methane losses were 1% of the biogas produced.
- Biogas upgrading with a power consumption 0.3 kWhe/m^3 biogas - methane losses of 0.5.

Figure 4 presents the results of the greenhouse gas (GHG) savings from the different biogas utilisation options, in comparison to the fossil fuel-based standard energy production processes.

Biogas can be converted to energy in several ways. The predominant utilisation is combined heat and power (CHP) generation in a gas engine installed at the place of biogas production. There are mainly two reasons for this. First, biogas production is an almost continuous process; it is rather difficult or, in the short-term, even impossible, to control the operation of anaerobic digesters according to any given demand profile. Secondly, promotion of renewable energies is focused on electricity production. Because of that, biogas plant operators receive the predominant fraction of revenues from the guaranteed feed-in tariffs for electricity. Summarising the results of the eco-balances it becomes obvious that - not only by using fossil fuels but also by using renewable fuels like biogas – combined heat and power cogeneration is the optimal way for fighting climate change. From a technical point of view it can be concluded that biogas production, i.e., the conversion of renewable resources and biowaste to energy, can be seen as state-of-the-art technology.



Biogas upgrading



Local gas engine

Figure 4. Greenhouse gas emissions savings for different biogas utilisation pathways in comparison to fossil energy production

In an economic analysis, many factors have to be considered as outlined in Table 2. Due to the lack of knowledge and awareness, villagers cannot be expected to understand the benefits of solar stills, nutrient conservation, or health improvement [5].

Table (2) Factors to be considered in economic analysis

Economic factors
• Interest on loan
• Current/future cost of alternative fuels
• Current/future cost of construction materials
• Saving of foreign currency
• Current/future labour cost
• Inflation rate
Social factors
• Employment created
• Less time consumed for fetching clean water
• Improved facilities in villages; thus less migration to cities
• Less expense for buying alternative fuels
• More time for additional income earning activities
Technical factors
• Construction, maintenance and repairs of biogas plants
• Availability of materials and land required
• Suitability of local materials
Ecological/health factors
• Improved health
• Environment pollution abatement
• Improvement in yields of agriculture products

A poor rural peasant is very hesitant to enter a new venture. The negative attitude towards the use of biogas plant varies from place to place, but when it occurs, it is a major obstacle to the implementation of solar still technology. In designing the biogas technology, the following points were considered: the unit has to cost as little as possible and materials should be readily available in rural areas. Technology should be simple, within the reach of a common village man. The unit should be usable in situations of emergency, e.g., during floods and after cyclones, etc. Energy efficiency brings health, productivity, safety, comfort and savings to the homeowner, as well as local and global environmental benefits. The use of renewable energy resources could play an important role in this context, especially with regard to responsible and sustainable development. It represents an excellent opportunity to offer a higher standard of living to the local people, and will save local and regional resources. Implementation of renewable energy technologies offers a chance for economic improvement by creating a market for producing companies, maintenance and repair services. Production of bio-fuels such as ethanol from sugarcane, takes advantages of year-round cultivation potential in a tropical countries. Benefits extend from local to regional to national to global. Local rural economies benefit through new economic opportunities and employment in the agricultural sector. Urban regions benefit through cleaner air and health improvements. The nation benefits through substituting domestic resources for costly imported gasoline. The world benefits from reduced CO_2 emissions.

Bacteria form biogas during anaerobic fermentation of organic matters. The degradation is very complex process and requires certain environmental conditions as well as different bacteria population. The organic matter was biodegradable to produce biogas and the variation show a normal methanogene bacteria activity and good working biological process as shown in Figure 5-6.

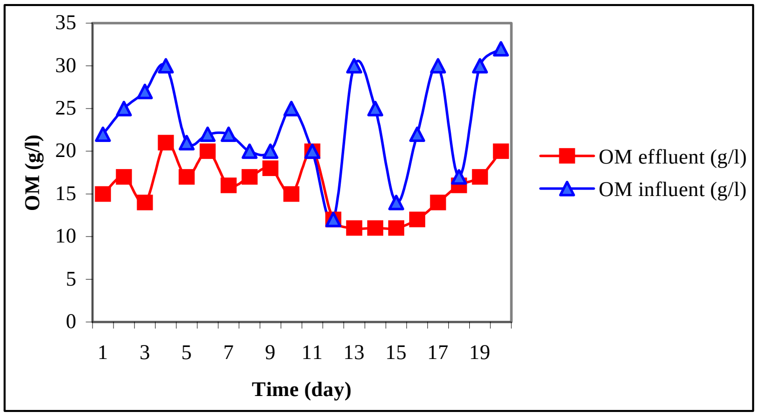


Figure 5. Organic matters before and after treatment in digester

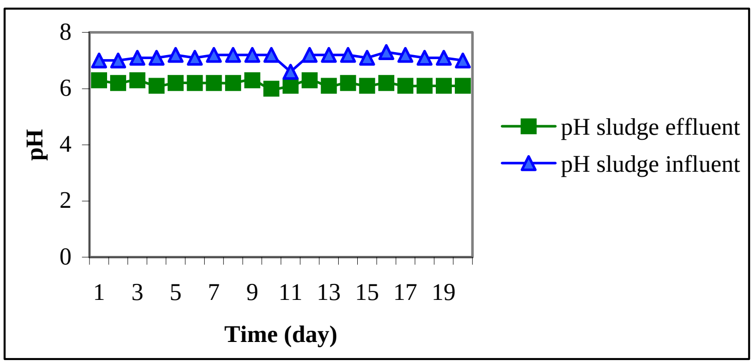


Figure 6. pH sludge before and after treatment in the digester

Table (3) Comparison of various fuels [8]

Fuel	Calorific value (kcal)	Burning mode	Thermal efficiency (%)
Electricity, kWh	880	Hot plate	70
Coal gas, kg	4004	Standard burner	60
Biogas, m³	5373	″ ″	60
Kerosene, l	9122	Pressure stove	50
Charcoal, kg	6930	Open stove	28
Soft coke, kg	6292	″ ″	28
Firewood, kg	3821	″ ″	17
Cow dung, kg	2092	″ ″	11

Gasification is based on the formation of a fuel gas (mostly CO and H_2) by partially oxidising raw solid fuel at high temperatures in the presence of steam or air. The technology can use wood chips, groundnut shells, sugarcane bagasse, and other similar fuels to generate capacities from 3 kW to 100 kW. Three types of gasifier designs have been developed to make use of the diversity of fuel inputs and to meet the requirements of the product gas output (degree of cleanliness, composition, heating value, etc.). The requirements of gas for various purposes, and a comparison between biogas; and various commercial fuels in terms of calorific value, and thermal efficiency are presented in Table 3.

Growth, modernisation and urbanisation in many states of Sudan have created both energy supply shortages and a growing source of free fuel: biogas. The use of biogas has been proven and is ready to be deployed in Sudan. The technology is available, it is economically feasible and it is reliable. An additional benefit of using these gases as a fuel source is minimisation of the environmental impacts that result from gas venting or flaring. The burning of such gases release air-borne pollutants, which can also enter groundwater sources and pollute farmlands. The optimum range in Table 4 is for ambient temperatures during hot seasons of Sudan tropical climates. The potential gas volumes produced from wastes vary depending on many factors, and can be expressed based in head count.

Biomass and Sustainability

There is an unmistakable link between energy and sustainable human development. Energy is not an end in itself, but an essential tool to facilitate social and economic activities. Thus, the lack of available energy services correlates closely with many challenges of sustainable development, such as poverty alleviation, the advancement of women, protection of the environment, and jobs creation. Emphasis on institution-building and enhanced policy dialogue is necessary to create the social, economic, and politically enabling conditions for a transition to a more sustainable future. On the other hand, biomass energy technologies are a promising option, with a potentially large impact for Sudan as with other developing countries, where the current levels of energy services are low. Biomass accounts for about one third of all energy in developing countries as a whole, and nearly 96% in some of least developed countries [10, 11, and 12].

Table (4) Optimum conditions for biogas production [9]

Parameter	Optimum value
Temperature °C	30-35
pH	6.8-7.5
Carbon/Nitrogen ratio	20-30
Solid content (%)	7-9
Retention time (days)	20-40

Environmental Issues of Biomass

Climate change is a growing concern around the world, and stakeholders are aggressively seeking energy sources and technologies that can mitigate the impact of global warming. This global concern is manifest in the 1997 Kyoto Protocol, which imposes an imperative on developed nations to identify feasible options by the next Conference of the Parties to the Convention (COP) meeting later in 2001. Possible actions range from basic increases in energy efficiency and conservation, to sophisticated methods of carbon sequestration to capture the most common greenhouse gases (GHGs) emission (CO_2). On the other hand, renewable energies have always been identified as a prime source of clean energies that emit little or no net GHGs into the atmosphere. Forest ecosystems cause effects on the balance of carbon mainly by the assimilation of CO_2 by the aboveground biomass of the forest vegetation. The annual emissions of greenhouse gases from fossil fuel combustion and land use change are approximately 33 x 10^5 and 38 x 10^5 tonnes respectively. Vegetation and in particular forests, can be managed to sequester carbon. Management options have been identified to conserve and sequester up to 90 Pg C in the forest sector in the next century, through global afforestation [4, and 5]. This option may become a necessity (as recommended at the Framework Convention on Climate Change meeting held in Kyoto), but a preventative approach could be taken, reducing total GHGs emissions by substituting biomass for fossil fuels in electricity production.

Simply sequestering carbon in new forests is problematic because trees cease sequestering once they reach maturity, and as available land is used up the cost of further afforestation will grow. Indeed the cost of reducing the build-up of GHGs in the atmosphere is already lower for fossil fuel substitution than for sequestration, since fast growing energy crops are more efficient at carbon removal, and because revenue is generated by the scale of electricity. Some biomass fuel cycles can also provide the additional benefits of enhanced carbon storage. The relative merits of sequestration versus fossil fuel substitution are still debated. The flow of carbon during the life cycle of the biomass should determine whether it is better left standing, used as fuel or used as long-lived timber products. Where there are existing forests in good condition there is general agreement that they should not be cut for fuel and replanted. This principle also concurs with the guidelines for nature protection, i.e., energy crops should never displace land uses of high ecological value. Where afforestation is undertaken, however, fossil fuel substitution, both by using wood fuel and using timber as a renewable raw material, should be more sustainable and less costly approach than sequestration could also be used to displace the harvest of more ecologically valuable forests. For efficient use of bioenergy resources, it is essential to take account of the intrinsic energy potential. Despite the availability of basic statistics, many differences have been observed between the previous assessments of bioenergy potential [6, and 7]. These were probably due to different assumptions or incomplete estimations of the availability, accessibility and use of by products. The biomass sources have been used through:

- Anaerobic digestion of municipal wastes and sewage.
- Direct combustion of forestry and wood processing residues.
- Direct combustion in the case of main dry crop residues.

- Anaerobic digestion of moist residues of agricultural crops and animal wastes.

Wood is very important raw material used by a number of industries. Its excessive utilisation as a fuel results in soil erosion, degradation of the land, reduced agricultural productivity and potentially serious ecological damage. Hence, minimisation of fuelwood demand and a national level and the increment an increase in the efficiency of fuelwood use seems to be essential. Utilisation of more efficient stoves and improvement of insulation using locally available materials in buildings are also effective measures to increase efficiency. Biogas or commercial fuels may be thought of as possible substitutes for fuelwood. In rural areas of Sudan, liquefied petroleum gases (LPGs) are strong candidate to replace firewood. Indeed, increased, LPG utilisation over the last decade has been one of the main reasons has lead to the deceleration of the diffusion of biogas technology into rural areas.

Energy from Agricultural Biomass

The main advantages related to energy, agriculture and environment problems are foreseeable both regionally and globally and can be summarised as follows:

- Reduction of dependence on import of energy and related products, and reduction of environmental impact of energy production (greenhouse effect, air pollution, waste degradation).
- Substitution of food crops and reduction of food surpluses and of related economic burdens.
- Utilisation of marginal lands and of set aside lands and reduction of related socio-economic and environmental problems (soil erosion, urbanisation, landscape deterioration, etc.).
- Development of new know-how and production of technological innovation.

A study [11] individuated on the basis of botanical, genetical, physiological, biochemical, agronomical and technological knowledge reported in literature some 150 species potentially exploitable divided as reported in Table 5. Turning to chemical engineering and the experience of the chemical process industry represents a wakening up but does not lead to an immediate solution to the problems. The traditional techniques are not very kind to biological products, which are controlled by difficulty and unique physico-chemical properties such as low mechanical, thermal and chemical stabilities. There is the question of selectivity. The fermentation broths resulting from microbial growth contain a bewildering mixture of many compounds closely related to the product of interests. By the standards of the process streams in chemical industry, fermenter is highly impure and extremely dilutes aqueous systems. The disadvantages of the fermentation media are as the following: mechanically fragile, temperature sensitive, rapidly deteriorating quality, harmful if escaping into the environment, corrosive (acids, chlorides, etc.), and troublesome (solids, theological, etc.), and expensive. Thus, pilot plants for scale-up work must be flexible. In general, they should contain suitably interconnected equipment for: fermentation, primary separation, cell disruption fractionalises and clarifications, purification by means of high-resolution techniques and concentration and dry. The effects of the chlorofluorocarbons (CFCs) molecule can last for over a century.

Table (5) Plant species potentially exploitable for production of agricultural biomass for energy or industrial utilisations [11]

Groups of plants	Number of species
Plants cultivated for food purposes that can be reconverted to new uses	9
Plants cultivated in the past, but not in culture any more	46
Plants cultivated in other world areas	46
Wild species, both indigenous and exotic	47
Total	148
Plant product	**Number of species**
Biomass	8
Sugars and polysaccharides	38
Cellulose	17
Hydrocarbons	3
Polymeric hydrocarbons	5
Gums and resins	12
Tannins and phenolic compounds	3
Waxes	7
Vegetable oils	38
Total	131

Recommendations

1. The introduction of biogas technology on wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and development funds.
2. In some rural communities, cultural beliefs regarding handling animal dung are prevalent and will influence the acceptability of biogas technology.
3. Co-ordination of production and use of biogas, fertiliser and pollution control can optimise the promotion and development of agricultural and animal husbandry in rural areas.

Conclusions

(1) Biogas technology cannot only provide fuel, but is also important for comprehensive utilisation of biomass forestry, animal husbandry, fishery, evoluting the agricultural economy, protecting the environment, realising agricultural recycling, as well as improving the sanitary conditions, in rural areas.
(2) The biomass energy, one of the important options, which might gradually replace the oil in facing the increased demand for oil and may be an advanced period in this century. Any county can depend on the biomass energy to satisfy part of local consumption.
(3) Development of biogas technology is a vital component of alternative rural energy programme, whose potential is yet to be exploited. A concerted effect is required by all if this is to be realised. The technology will find ready use in domestic, farming, and small-scale industrial applications.
(4) Support biomass research and exchange experiences with countries that are advanced in this field. In the meantime, the biomass

energy can help to save exhausting the oil wealth.
(5) The diminishing agricultural land may hamper biogas energy development but appropriate technological and resource management techniques will offset the effects.

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