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Status and prospects for household biogas plants in Ghana – lessons, barriers, potential, and way forward

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Abstract
Ghana is a country faced with pressing developmental challenges on energy, sanitation, environment and agriculture. The development of a large scale, enterprise-based biogas programme in Ghana will improve sanitation, produce clean energy, reduce greenhouse gas emissions, promote nutrient recovery, and create jobs. While aforementioned benefits of biogas are known, the biogas industry is still not growing at rates that would enable its impact on sanitation, agriculture and energy usage to be felt, owing to challenges such as low awareness creation and poor biogas supply chain, lack of well-trained personnel, poor follow-up services, and high cost of biogas digesters – USD 235- 446 per cubic meter. This paper looks at the chronology of biogas developmental in Ghana, technical and market potential of household biogas plants, strengths and weaknesses of main biogas service providers, human resource development, quality issues, and risks involved in developing a large scale household biogas programme. From the paper, the technical and market potential of dung-based, household biogas digesters in Ghana are estimated at 162,066 and 16,207 units respectively. In order to take full advantage of biogas technology, the paper recommends the development of standardized digesters, increase in awareness programmes on the life-long benefits of biogas systems, introduction of flexible payment schemes, and stepping-up of follow-up services. Finally, there is an urgent need for a 'promoter' who will engage all stakeholders to ensure that a national action plan on biogas technology is initiated and implemented.

Keywords: Biogas technology; Energy; Sanitation; Environment; Ghana.

1. Introduction

The potential of biogas technology as a sustainable energy source, as a medium for improving sanitation, and as a source of rich organic fertilizer has been clearly shown in several studies in Ghana [1-6]. Despite the aforementioned benefits, Ghana's biogas industry is still at an infant stage; while Ghana has just over 250 biogas plants constructed, sister nations such as Kenya and Tanzania have over 2000 [7] and 5000 plants constructed [8] respectively. A myriad of challenges are faced by biogas service companies, notably, high costs of biogas digesters, poor image of biogas as a modern energy source, and socio-cultural hindrances on the use of 'faecal gas' for cooking and 'faecal fertilizer' in agriculture.

Other major factors include low commitment from government, low follow-up services on the part of biogas companies, lack of concrete policy on biogas, lack of well-tested standardized designs, and lack of microfinance schemes for cattle farmers interested in biogas digesters [1]. The current supply chain for biogas digester is weak and is characterised by few entrepreneurs located in Accra, the national capital. In addition, the manpower base (the number of trained technicians/artisans) is also weak and is woefully inadequate to handle any large demand for digesters.

The direct involvement of government and state institutions in biogas promotion is an important factor for countries – such as China [9], India [10], and Nepal [9, 11] – that have achieved success in biogas technology. Cooperation between the state and the private sector has led to the development of favourable policies and regulatory frameworks that have ensured a sustained growth of the biogas sector. In addition, there has been government support for research and development leading to the development of structurally stable and user-friendly digester models that have received wide acceptability.

The absence of a favourable climate for biogas systems in Ghana explains why most biogas plants have been constructed in institutions such as schools and hospitals, and in relatively wealthier households in the major cities for treatment of nightsoil. Construction of biogas plants is costly and is far above the means of most rural households where the presence of biogas facilities would make a big difference in their way of living, via the provision of a sustainable source of clean energy for cooking and rich organic fertilizer for agricultural activities. It is obvious that biogas technology will not thrive in rural agricultural communities in Ghana without government support in the form of subsidies and flexible payment arrangements. It is also true that the decision to invest in the biogas technology should not only be based on the profitability of the investment since the non-direct financial benefit to the beneficiary and the overall benefits to the society at large provide economic justification for public intervention. Thus, a social business model focusing on technical training, business development, financing and market facilitation as its main components and based on the concept of private-public partnership should be developed in order to deal with the challenges facing Ghana's biogas sector.

This study is aimed at providing guidelines and strategies for prospective firms and investors interested in entering into Ghana's burgeoning biogas industry. It discusses trends in the biogas sector, proposes market segments to target, analyzes the strength and weaknesses of major biogas service providers, and evaluates the technical and market potential of household biogas plants. It further outlines potential risks that would be faced in developing a large scale biogas programme and suggests mitigation strategies that should be employed to address the risks. Finally, it discusses measures that should be put in place in order to develop a solid enterprise-based biogas programme in Ghana.

2. Chronology of biogas technology in Ghana

Developments in Ghana's biogas industry are usually grouped into three main periods: before 1990, from 1990 to 1999, and from 2000 to date. The first period saw government sponsored research and development activities in biogas technology, and training of local technicians and engineers in the design, construction, and management of biogas plants. The period also witnessed state-funded, community-type biogas projects in several cattle growing communities, including the Appolonia Household Programme in 1986 which involved the construction of nineteen fixed-dome biogas plants for nineteen households in Appolonia, a rural community in Greater Accra Region [1].

In the second period (1990 – 1999), the involvement of government reduced considerably and the main promoters of the technology were the German Agency for Technical Assistance (GTZ) and the Catholic Secretariat. GTZ trained and built the capacity of local personnel, and funded several biogas plants, notably, two plants at slaughterhouses in Ejura and the Department of Animal Science of the Kwame Nkrumah University of Science and Technology (KNUST). The Catholic Secretariat initiated and funded a number of biogas plants in Catholic-administered hospitals in Battor, Akwatia, and Nkawkaw [1].

The third period (2000 – date) is characterized by the growth of private companies in biogas dissemination in Ghana. Two major companies - Biogas Technology West Africa Limited (BTWAL) and Beta Civil Engineering Limited (BCEL) – have been at the forefront in biogas promotion in Ghana. According to Bensah and Brew-Hammond [1], BTWAL and BCEL have achieved success in biogas dissemination owing to their marketing strategy which focuses on the ability of biogas digesters to replace septic tanks especially in new buildings. Patrons are satisfied with the sanitation improvement aspect of the biogas digester and thus care less for the use of the gas or the digested slurry.

3. Biogas digester models successfully disseminated in Ghana

The fixed-dome and the floating-drum are the two main digesters widely promoted by biogas companies in Ghana. Both digesters come in several designs and the four most common models are illustrated in Figure 1.

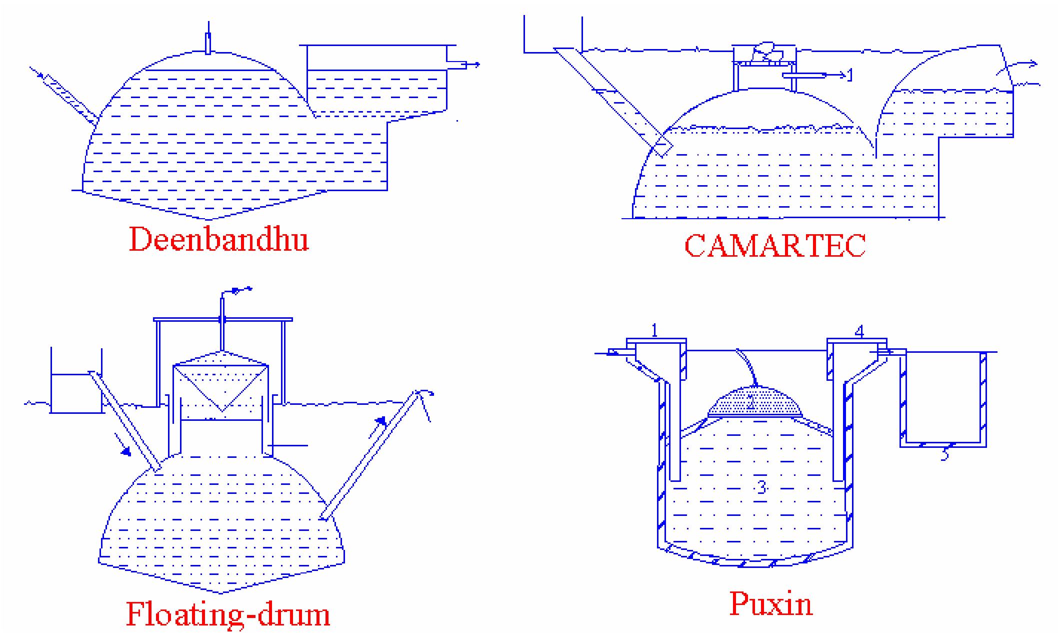

Figure 1. Digester models widely constructed in Ghana [12]

Fixed-dome digesters are mostly constructed because it is relatively cheap. The Deenbandhu digester has a dome structure forming both the digester and the gasholder and is constructed of bricks. The Puxin digester has a digester made of concrete and gasholder made of carbon fibre, and is being promoted by BCEL. Water-jacket floating-drum digesters are ideal for digesting fibrous feed materials such as slaughterhouse waste since the gasholder can always be removed to remove scum whenever it forms. They are relatively expensive to construct and maintain due to the high cost of the steel-drum [13]. Advance plants such as the Upflow Anaerobic Sludge Blanket (UASB), the lagoon and the Continuous Stirred Tank Reactor (CSTR) are ideal for treatment of industrial and municipal wastewater [14]. Two UASB reactors have so far been constructed in Ghana for the treatment of wastewater from Guinness Ghana Limited in Kumasi and nightsoil at the Korle Gonno wastewater treatment plant in Accra.

4. Biogas service providers

Table 1 lists active biogas service providers in Ghana. BTWAL and BCEL are the leading companies in Ghana in terms of the number of plants installed annually. The Institute of Industrial Research (IIR) is the only state agency involved in biogas plant construction, and most of their plants are community biolatrines where biogas plants are directly attached to improved pit latrines. The other companies are relatively small and are owned by people who have other commitments.

BCL and ABCL are based in Obuasi in the Ashanti Region and most plants constructed by the two companies are patronized by AngloGold Ashanti Limited, which prefers construction of biogas digesters to septic tanks. BEL was founded by Dr Elias Aklaku, a senior lecturer at the Agricultural Engineering Department, KNUST, and has not been very active of late due to founder's involvement in academia.

Apart from aforementioned companies, there exist small, one-man-owned, and less organized biogas companies in Ghana. Their activities are difficult to monitor and most of them are either not registered or do not keep good records of the plants they construct. The strengths and weaknesses of the major service providers are outlined in Table 2.

All companies depend solely on profits that come from the plants they construct for individuals and institutions. Since the biogas industry is still at a developmental stage, offers that come are low due to poor awareness creation and the high cost of digesters. Government support is absent and there are no flexible payment arrangements for interested people to patronize biogas plants. Apart from BCEL that promotes concrete-based Puxin digester, all other companies disseminate brick-based digesters. BCEL imports most equipment – gas stoves and pipes (rubber), gas meters and manometers, gasholder (glass fibre reinforced plastic), generators, lamps, CO_2 and H_2S filters – from Shenzhen Puxin Science and Technology Company Limited in China. The company has also been using pozzolana produced from the Building and Road Research Institute (BRRI) in Kumasi.

On the contrary, BTWAL designs and fabricate their stoves and manometers, and are conducting research into kaolin as a major raw material in biogas construction. They, however, import balloon gasholders from Walter Krause GmbH, biogas meters from Krom Schroder Elster Group, and generators from Hans-Jurgen Schnell Anlagenbau, all German companies. Lately, IIR and a few other companies have been constructing plants using pavement bricks which are made of quarry dust, cement, and dust.

Table 1. Profile of some biogas service providers in Ghana

Company/location	Date founded	Type of digester/system installed	No. of plants installed
Biogas Technologies West Africa Limited, Accra	2000	Fixed dome and effluent treatment plants	56
Beta Construction Engineers Limited, Accra	2006*	Puxin Biogas Digesters	53
Biosanitation Company Limited (BCL), Obuasi	1998	Fixed-dome, floating-drum	35
Institute of Industrial Research, Accra	1986*	Fixed-dome, biotoilets	22
Biogas Engineering Limited (BEL), Kumasi	2002	Fixed-dome, biotoilets	18
Abu Biogas Construction Limited (ABCL), Obuasi	2008	Fixed-dome, floating-drum	6

* Started biogas plant construction in that year

5. Target market

Due to the high cost of biogas plants, biogas companies have only been able to construct plants for wealthy individuals in Accra and Tema, and institutions such as universities, real estates, hospitals, and hotels. Most community plants constructed in rural areas have been funded from the Social Investment Fund or by donor support. Awareness creation on the benefits of the biogas plant is very low. Most companies submit proposals to various organizations and institutions for them to consider biogas digesters for treating blackwater from their toilet systems.

In order for patronage of biogas systems to increase, the following promotional guidelines should be considered:

- Media sensitization;
- Development and distribution of leaflets on biogas plants and their associated benefits.
- Community forums involving community-based organisations;
- House-to-house awareness creation especially in target communities;
- Development of demonstration plants; and
- Involvement of a champion in biogas awareness creation;

6. Product quality

Well-engineered biogas plants last for over 25 years irrespective of the raw material used – concrete or bricks [13, 15]. However, the structural integrity of the design adds extra durability to the digester. A detailed comparative study on digester models constructed in Ghana was analyzed by Bensah [12] and a modified form of the Deenbandhu digester (Figure 2) was recommended for large scale promotion in Ghana.

According to Bensah [12], it has the most structurally sound base to counter uplift forces, of all fixed-dome digester models; moreover, the positioning of the expansion chamber in relation to the digester allows easy access for cleaning and maintenance, without compromising on the structural strength of the dome.

Table 2. Strengths and weaknesses of major biogas service providers in Ghana

Biogas service provider	Strength	Weakness
Biogas Technologies West Africa Limited (BTWAL)	• Passionate and inspirational CEO/founder • Well-known within and outside Ghana • Large workforce (150 comprising engineers, designers, artisans and labourers) • Strong partnerships with firms in Germany • Manufacture of own appliances such as gas meters • Good number of plants working	• Poor/inappropriate design of series digesters • Low community participation in biolatrine dissemination, e.g. biotoilet at Oshiuman/Abeman • Failed to develop CDM projects • Plants are relatively expensive • No follow-up services
Beta Construction Engineers Limited (BCEL)	• Good civil engineering works • Puxin digesters are easier to construct • Well-known in Ghana • Strong partnership with Shenzhen Puxin Company Limited in China • Good number of plants working	• Poor/inappropriate design of series digesters • Use of low retention times (10 – 15 days) in design of mesophilic digesters • Failed to develop CDM projects • Plants are relatively expensive • All biogas appliance imported from China • No follow-up services
Institute of Industrial Research (IIR)	• Parastatal research institution/ government support • Team comprising engineers, industrial designers, etc. • Relatively inexpensive plants • Over 20 years of experience in biogas plant construction	• High rate of failure of biolatrines constructed (at least 60 %) • Lack of initiatives • Failed to develop CDM projects • No follow-up services
Biogas Engineering Limited (BEL)	• Over 20 years of experience in biogas plant construction • Founder well-known in Ghana • Relatively inexpensive plants	• Founder not into full scale biogas plant dissemination due to other commitment • Failed to develop CDM projects • High rate of failure of biolatrines • No follow-up services

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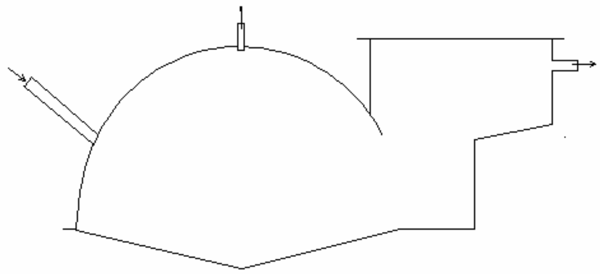

Figure 2. Proposed fixed-dome model for large scale promotion in Ghana [12]

7. Market potential of household biogas plants in Ghana

7.1 Household plants based on cow dung

Cow dung is mostly used as organic fertilizer. Some communities in northern Ghana use dung for trapping termites for low fowls and for plastering mud houses. A survey by Kumasi Institute of Technology and Environment (KITE) [6] has shown an overwhelming majority of farmers are in favour of dung being used in biogas plants. The technical potential for dung-based plants is estimated based on data from the Ghana Statistical Service (GSS).

From the fifth round of Ghana Living Standard Survey (GLSS 5), a total of 2,750,185 cattle are raised by 216,088 agricultural households, yielding an average cattle holding per agricultural household of 12.73 [16]. It should be noted that 84 % of cattle population are raised in the rural savannah terrains of the country, comprising Northern and Upper Regions of Ghana. A household biogas plant usually requires a daily supply of at least 20 kg of dung in order to produce considerable gas for daily cooking. The minimum amount can be generated by seven (7) local breeds of cattle such as the Short-horn, the Crosses, and the Zebus, according to scientists at the Animal Research Department of University for Development Studies (UDS), Navrongo. Since the standard deviation of the number of cattle own by agricultural households is unknown, it is assumed that each agricultural household possesses at least seven (7) cattle, enough to generate the daily minimum requirement of dung needed to produce enough gas for cooking.

Thus, the theoretical potential of biogas plants based on cow dung is estimated at 216,088 digesters. The technical biogas potential is calculated following the method used by Netherlands Development Organization (SNV) where the theoretical potential is multiplied by a Cattle Holding Factor (CHF) [17]. The CHF denotes the average cattle holding of a country; a CHF of 0.75 is applicable to countries with average cattle holding of more than three heads per agricultural household [17]. Since Ghana has more than 12.7 heads per agricultural household, the technical biogas potential for Ghana is thus estimated at 162,066 digesters, which is relatively low compared to SNV's estimate of 278,000 [18]. The market potential will be lower because a considerable number of households would not be able to afford the cost of biogas plants or may not be willing to pay. Taking effective demand for biogas installations at 10 % of the technical, the market potential is estimated at 16,207 which is quite large considering the estimated number of biogas plant constructed in Ghana which stands at a little over 250.

Dung based plants usually require equal volumes of dung and water for optimal digestion of the slurry [15]. Water availability is another main factor that influences the location of biogas plants. Access to water is defined in terms of time taken to reach the nearest water source – usually less than 30 minutes for a suitable water source [17]. From GLSS 5, access to water for Ghana is estimated at 94 % which means a large scale, dung based biogas programme is unlikely to suffer from general water scarcity. Moreover, conserving and mixing of cow urine with dung will reduce the quantity of water needed and would create better conditions for generation of gas with higher methane content. Inclusion of standardized kraals linked to biogas plants would enable urine to be effectively used as feedstock for biogas plants and thereby increase gas production.

7.2 Household plants for other livestock waste

It is unknown whether biogas plants have been constructed to handle other livestock waste aside cow dung in Ghana. GLSS 5 gives the following estimates of livestock in Ghana as well as households raising livestock.

The average livestock per household for all farm animals shown in Figure 3 lies within the range 9 – 14. Considering the fact that the aforementioned livestock other than cattle generate little waste per household and the fact that livestock are raised using the extensive (free range) system of animal husbandry, it can be reasonably concluded that household-based biogas plants would not be feasible due to inadequate feed material. Opportunities however exist for households that raise cattle in addition to other livestock due to the possibility of mixing different manure and achieving good feeding material for the biogas plant.

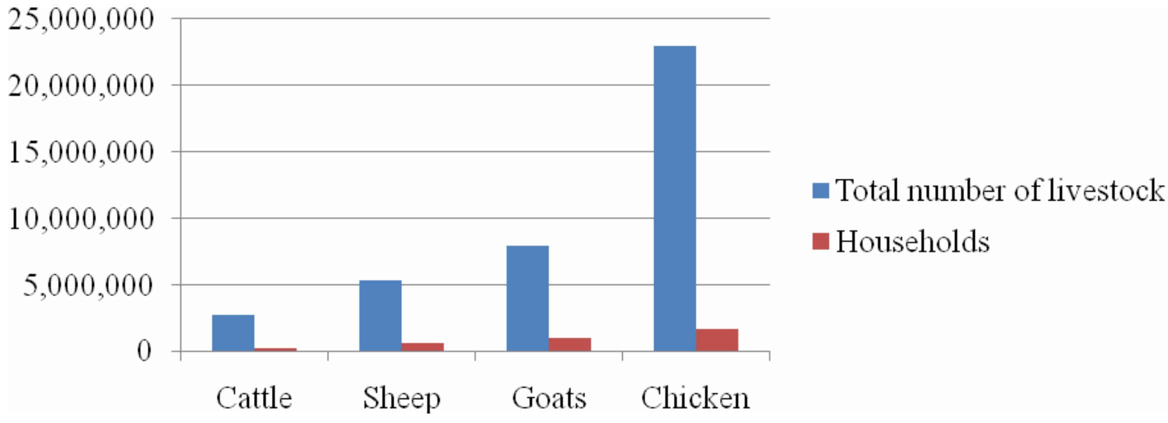

Figure 3. Estimated number of households raising different livestock and the number of livestock [16]

7.3 Household plants for nightsoil

The market potential for nightsoil-based plants is gargantuan. A good number of offers for biogas plants come from wealthy households in the major cities. Biogas plants are gradually being incorporated into designs of new buildings as replacement to septic tanks. Even though the cost of digesters are far higher than septic tanks of equal volumes, replacing septic tanks with digesters offer a good way of reducing the financial burden in building biogas digesters.

8. Financing biogas plants

In Ghana, the cost of building biogas plants range from GH¢ 2,200 – 4,000 (USD 1,549 – 2,817) for a 6 m^3 digester, and from GH¢ 3,000 – 6,000 (USD 2,113 – 4,225) for a 10 m^3 plant. From the preceding information, the unit cost of biogas plants roughly lies within the range Gh¢ 333.3 – 633.3 (USD 235 – 446) per cubic meter. Quotations from the two leading companies – BTWAL and BCEL – usually lie close to the maximum limit while others including the IIR and the smaller companies construct plants at costs closer to the lower bracket. It must however be emphasized that the exact costs is influenced by the ground conditions of the location, inclusion of facilities such as gas meters, H_2S removers, among others, and the cost of labour. Since the cost of raw materials take-up between 45 – 60 % of the total cost of biogas plants in Ghana, most companies have developed capacities in brick and appliance manufacture: for example, IIR manufactures their own pavement bricks for use in biogas plant construction.

Unlike countries such as China, India and Nepal, there are no flexible payment schemes for biogas plants. There is the need to develop a financing facility to assist end-users who cannot make full payment for the cost of the biogas plant. For a biogas programme targeting agricultural households, flexible microfinance schemes are needed in addition to some level of subsidies. Financial support may be obtained from donors based on target users: for example, a biogas programme targeting girls schools in rural communities is likely to receive financial and logistical support from the Ghana Education Trust Fund, Ministry of Women and Children Affairs, Ministry of Education, metropolitan, municipal and district assemblies, traditional authorities, and international organizations such as GTZ and SNV.

9. Human resources and management

A successful implementation of a large scale biogas construction programme in Ghana will be determined by the quality of human resource that would be trusted with the planning and management of the programme. Personnel will be needed to perform the following functions:

- Management and building working partnerships with government, microfinance companies, academia, and international institutions and organizations;
- Awareness creation and planning of programme;
- Technical duties: design and construction of appliances and plants;

- Research and development (R&D), training of engineers, technicians and artisans, and follow-up services (extension, maintenance and monitoring); and
- Project development and proposal writing

There is the need for technical assistance in order for Ghana to build capacity on the design, construction, installation, operation and maintenance of biogas plants. Large scale diffusion of biogas systems will require a pool of technical experts in order to deliver quality installations and post installation services on demand. In addition comprehensive training programmes for artisans and technicians should be designed and organized to ensure the availability and readiness of skilled labour as and when needed.

10. Quality assurance

Quality issues are essential for the success of a large scale biogas programme. The following quality issues should be given maximum attention:

- For construction of simple biogas plants such as fixed-domes and floating-drums, standardized designs of digesters are very essential for large scale promotion where numerous engineers, artisans, technicians and labourers will be involved;
- Plants must be designed using retention times that ensure adequate treatment of feed slurry, and such that effluent parameters such as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) meet Ghana Environmental Protection Agency (EPA) standards. Bensah and Brew-Hammond [1] recommend the following retention times for used in designing biogas plants under mesophilic conditions (21 – 30 ^{0}C): 60 days for plants handling nightsoil and slaughterhouse waste, and 40 days for dung and other livestock waste;
- Step-to-step procedures for building digesters must be outlined in simple, easy-to-follow language for artisans to understand;
- Materials of construction such as bricks, sand, stones, concrete and pozzolana must always pass quality standards in order to ensure durability of digesters; and
- Biogas appliance that would be manufactured or imported as part of the programme must be of high quality, durable, and convenient to use.

A complete manual that addresses aforementioned issues and others must be developed and all biogas companies should adhere to standards set in the manual.

11. Extension, monitoring and maintenance

Lack of follow-up services is a major problem hindering a wider promotion of biogas technology in Ghana. Biogas companies do not have funds for follow-ups. Moreover, users also fail to report problems to service providers leading to break down of installations.

Routine maintenance programmes and guarantees spanning a reasonable number of years on the plant, pipes, fittings and appliances, should be factored into a national biogas programme.

12. Critical risk factors and risk mitigation

Risk factors and mitigation strategies that should be employed to address the risks in the development of a large scale biogas programme in Ghana are outlined in Table 3.

13. Research and development (R&D)

R&D should focus on the development of well-engineered digesters at costs that will engender a profitable and a sustainable domestic biogas market. There is the need to identify suitable design models for the Ghanaian context and develop more efficient appliances such as stoves, lamps, refrigerators, and generators. Premium must also be given to development of local materials such as bamboo for use in digester construction. Equal attention should be focused on socio-cultural and financing considerations that are relevant to the success of a national biogas programme.

It is recommended that a biogas research centre is set-up as part of the programme for practical research. Strong collaboration with research institutions such as Council for Scientific and Industrial Service (CSIR), academia, and leading Non-governmental Organizations (NGOs) such as the Centre for Energy, Environment and Sustainable Development (CEESD) that specialises in applying engineering solutions to problems related to energy, environment, and climate change.

Table 3. Critical risk factors and risk mitigation strategies

Risks	**Mitigation strategy**
Market risk factors	
Poor quality and unreliability of biogas installations	Use of standardized digesters Accurate waste estimation and optimum sizing of plants Good workmanship and use of quality materials Quality control and regulatory frameworks
High cost of biogas plants may discourage most households from using biogas systems	Use of standardized digesters Accurate waste estimation and optimum sizing of plants Subsidies for relatively poor households Flexible microfinance schemes
Households collecting firewood may see little financial benefits from the biogas plant; or Households already using dung as fertilizer may not see the additional benefits of the bioslurry	Biogas system integrated into productive activities of households: e.g. use of bioslurry in growing vegetables, growing fodder grass, or in used as feed material in fish ponds Education and awareness creation on the benefits of the biogas plant Subsidies for relatively poor households Flexible microfinance schemes
Non-payment of loans from users benefiting from micro-credit financing schemes	Education and awareness creation Beneficiaries must provide guarantors before loans are approved
Development of monopolies and cartels	Promotion of competition Level playing field for all competitors Subsidies should be transparent
Environmental risk factors	
Leakage of biogas (CH_4) due to poor design and construction of digester, worn-out external gasholders, and poor piping network Release of biogas into atmosphere without flaring	Use of standardized digesters Good workmanship and use of quality materials Training of users on operational and maintenance requirements Proper operation and maintenance of biogas plants Follow-up services
Discharge of partially-treated bioslurry (effluent) into water bodies and public drains, or for reuse in flushing toilets (This is the case of most biogas companies in Ghana)	Use of standardized digesters Accurate waste estimation and optimum sizing of biogas plant Incorporation of post-treatment facilities such as filter tanks Periodic tests on effluent quality
Social-cultural risk factors	
Socio-cultural and religious taboos on the use of gas and bioslurry from nightsoil-based plants. (This is a major factor especially in Islamic communities in Ghana.)	Education and awareness creation Use of post-treatment systems such as filter tanks for further treatment of bioslurry Use of bioslurry in growing fodder crops
Reluctance to change traditional ways of doing things: e.g. the switch from firewood to biogas may be rejected if it affects the style of cooking	Education on the benefits of using biogas: reduction in women workload, reduction in indoor pollution, more time to do other important activities such as attending adult education classes, etc.

14. Conclusion

This paper assessed the state of Ghana's biogas industry and considered issues that should be given attention in developing sustainable market for biogas plants. The study has shown that there is enough room for biogas companies to expand their services by developing more effective awareness creation strategies, standardized digester models, and good financing schemes.

The following key conclusions can be drawn from the feasibility study

- A technical biogas potential household, dung-fed biogas installations in Ghana stands at about 162,066; taking effective demand for biogas installations at 10 % of the technical potential based on current demand and ability and willingness to pay, a market potential is estimated at 16,207 which is still large. However, there is the need to embark on awareness creation among cattle holding households on the benefits of the biogas plant. This is because most households have no knowledge of the functions and economics of the biogas plant; and
- The cost of biogas plants are relatively high – GH¢ 2,200 – 4,000 (USD 1,549 – 2,817) for a 6 m^3 digester, and GH¢ 3,000 – 6,000 (USD 2,113 – 4,225) for a 10 m^3 plant – and beyond the capabilities of most households; there is therefore the need for service providers to develop innovative financing schemes for their products. Micro-financing will be critical to the successful implementation of a large scale, enterprise-centred biogas programme in Ghana; and

This study indicates that biogas has a considerable potential, both as a household energy source and as a commercial venture. There is, however, the need to set-up a national biogas programme that makes adequate provision for capacity building in the design, construction and operation of biogas systems, research and development, and awareness creation. Finally, there is a need for a 'promoter' who will engage all stakeholders to ensure that a concerted national endeavour on biogas technology is initiated and implemented.

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