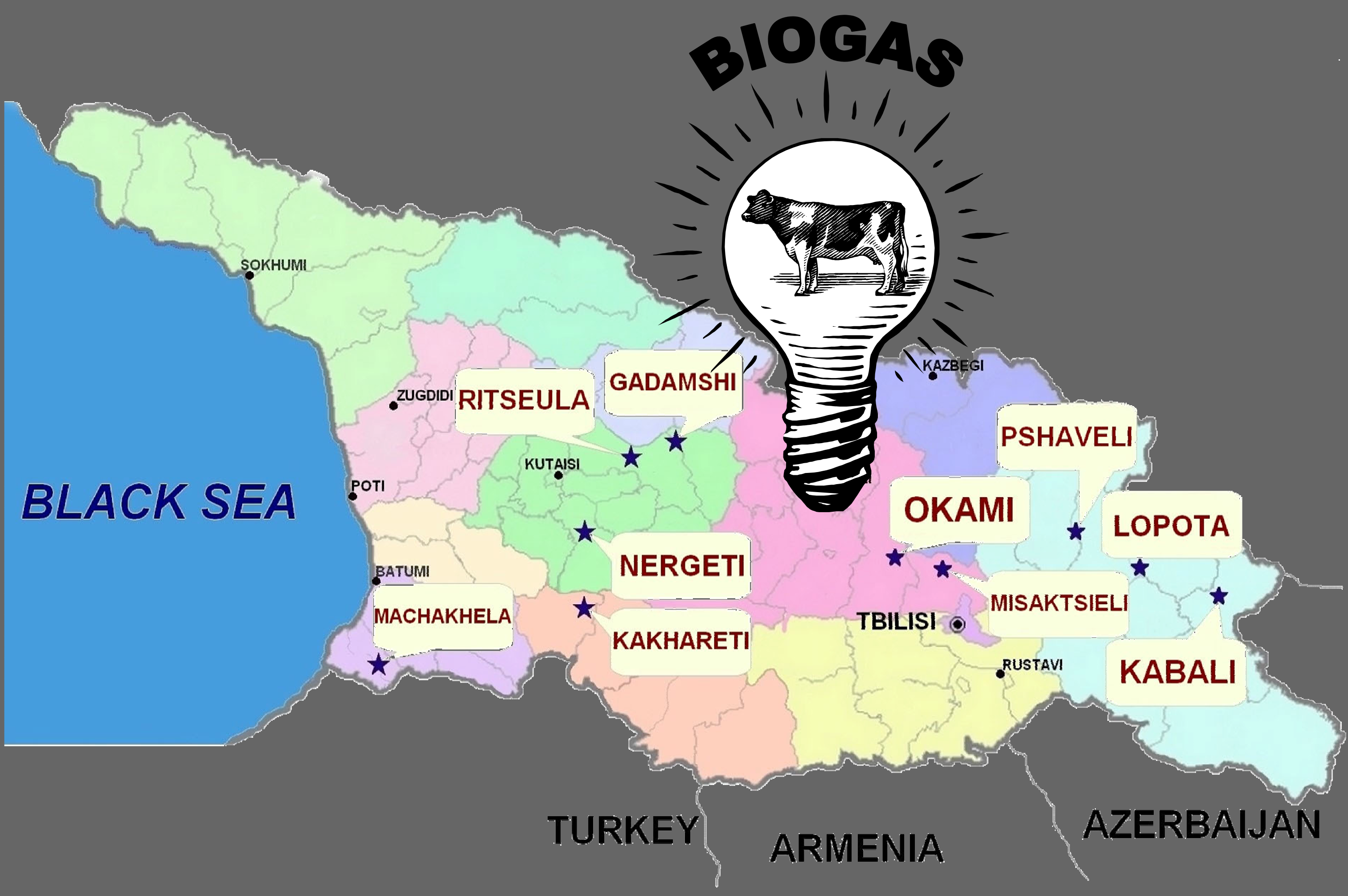
Biogas: Retrospect and Prospects
Georgia, Rural Energy Program

July 2007



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ACKNOWLEDGEMENTS

Several sources including site visits to different regions for on-site observations, discussions with a wide range of experts from the industry, the World Bank, the UNDP, NGO's and others were held. An in-depth search of the literature was also conducted to gain international perspective. These sources have been acknowledged in the report. However, any omissions are regretted.

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ABBREVIATIONS AND ACRONYMNS

%	Percent
$	Dollar (US)
AD	Anaerobic Digestion
ARET	Agriculture Research, Extension, and Training Project (World Bank funded)
BOD	Biochemical Oxygen Demand
BTC	Baku-Tbilisi-Ceihan (Oil Pipeline)
^oC	Degrees Celsius (or Centigrade)
CBO	Community Based Organization
CDM	Clean Development Mechanism (of Kyoto Protocol)
COD	Chemical Oxygen Demand
DFES	Debt-for-Environment Swap
EBRD	European Bank for Reconstruction and Development
EE	Energy Efficiency
e.g.	For Example
EU	European Union
^oF	Fahrenheit
FRP	Fiberglass Reinforced Plastic
Ft^3	Cubic Feet
GEF	Global Environment Facility
GEL	Georgian Currency Lari (US $1 = 1.67 Lari (2007)
GHG	Greenhouse Gases
GoG	Government of Georgia
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Development Agency/Technical Arm)
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulfide (gas)
KVIC	*Khadi* Village Industries Commission (A village development body in India)
kW	Kilowatt
KWh	Kilowatt Hours
LPG	Liquefied Petroleum Gas
M&E	Monitoring and Evaluation
MENR	Ministry of Environment and Natural Resources
mg/l	Milligrams/liter
MoD	Ministry of Economic Development
NH_3	Ammonia
No.	Number
N_2O	Nitrate Oxide (a GHG)
O & M	Operation and Maintenance
pH	Measure of acidity or alkalinity of a solution
R&D	Research and Development
RE	Renewable Energy
REP	Rural Energy Program (USAID Funded)
RT	Retention Time
TS	Total Solids
UNDP	United Nations Development Program
USAID	United States Agency for International Development
VAT	Value Added Tax
VS	Volatile Solids
WB	World Bank

EXECUTIVE SUMMARY

Proper manure management is crucial to energy and resource recovery from livestock manures. Good manure management also minimizes environmental contamination by preventing pollutants such as nutrients, organics, and pathogens from migrating to surface and groundwater. Among the available options, anaerobic digestion (AD) is an alternative solution to livestock waste management that offers economic and environmental benefits. Furthermore, AD technology lends itself to most developing-country rural settings.

AD offers sustainable alternative to treat the solid and liquid fraction of livestock manure, providing major benefits in terms of energy production, waste stabilization, odor control, and pathogen reduction, while conserving the fertilizer value of manures. During anaerobic digestion of manure and other biodegradable wastes, microbes "digest" the organic materials, producing combustible biogas, containing 55-65% methane suitable for direct combustion and/or to produce electricity. In many rural areas, biogas produced is used for home cooking,[1] light and for small-scale agro-processing applications.

The residue of the AD process, a nutrient-enhanced organic fertilizer, has shown increased crop yields over raw manure. The technology has also been instrumental in improving rural income and rural health in many countries. At present, China, India and Nepal are the world leaders in biogas production from animal manures using small-scale, (based on 4 or more cattle) family-size biodigesters. Where larger quantities are available—small digesters can be enlarged to accommodate larger number of animals—biogas has been economically converted to electricity for use and/or sale. In the developed world, many farms profitably sell excess biogas electricity and reap cash benefits through carbon trading under the Kyoto Protocol. Such initiatives also help reduce greenhouse gas emissions.

In Georgia, the AD technology, mostly under the sponsorship of international donors—primarily the World Bank and UNDP—has made some important strides. For example, the bank, as of 2007, under its Agriculture Research Extension and Training Project (ARETP) has funded installation of 272 family-size biodigesters in western Georgia. The major objective of the project is to help reduce nutrient loading to the Black Sea. Other donor initiatives have also installed biodigesters including in Georgia's colder regions. The demand for biodigesters rural areas remains strong, and there appears to be no technical barriers to its wider deployment.

The above study found that the small-scale bio-digester (e.g. 6 m^3 volume) based on 4-6 cattle is considered suitable for most Georgia rural areas. On the average, digester operating under mesophilic temperature range (i.e. 25^0-40^0 C) produce 0.2-0.4m^3 per m^3 of installed biodigester volume. Higher operating temperatures (thermophilic range, 50-55^0 C) produce higher yields such as 2-6 m^3 per m^3 of installed biodigester volume. To achieve thermophilic range often requires external heat input. In Georgia, heat to the biodigester is provided with the use of circulating hot water—water heated with use of biogas, wood etc.), insulation with straw, soil etc., providing direct heat to the biodigester or other measures, as outlined in this study under Section 3.3.

Notwithstanding the high digester demand, the biogas technology in Georgia has not taken a foothold. The primary reason is the high upfront costs, ranging from US $1,500 to $2,500 for the more popular Chinese Fixed Dome or the India Floating Dome designs. Such costs are beyond the reach of most Georgia farmers and the cash-strapped government is also constrained by other competing priorities. Other limiting factors to wider dissemination are the lack of organization and

[1] Estimates show that as of 2006, there are 2.3 million cattle in Georgia. An average east European cow produces 8-9 Kilogram (kg) of dung/day. One kg of dung can produce 0.5 m^3 of biogas considered enough to meet the cooking needs of one person (in most developing countries).

infrastructure support, lack of awareness of the technology's benefits and poor private sector interest. At present, there is no organized effort or entity for developing biogas.

This study is based on a 2 ½ week field study in Georgia. It included visit to key regional bio-digester sites, discussions with the local industry experts, key private vendors, international donors including the World Bank, and UNDP, the Georgian ministries, NGO's and others. Based on critical analysis of various data, information and observations and review of relevant international experience, recommendations are made on applicability of suitable designs and other requirements.

For all sites, Chinese Fixed Dome design with some modifications, as being practiced, is recommended. The design appears to be technically suitable, has performed well in Georgia and can be constructed with easily available materials such as bricks and concrete. The local industry, though limited, is also familiar with its design and installation. Nevertheless, site-specific situation would determine the final selection. The study provides information on this aspect. Included are recommendations to improve performance in colder regions. It is hoped that the REP's proposed installations will be an additional catalyst to further development and strengthening of the AD technology, in particular, small-scale digesters, in Georgia.

In developing countries, where biogas technology has taken a strong foothold, the governments have played a major role by providing subsidies and/or affordable financing and supporting policies enabling market development and private sector investments and participation. If the Georgian government wants to develop a sustainable national biogas program, it should develop a strategy plan. The plan should be based on a centralized approach and include potential funding sources, policy coordination, defined targets, capacity building, customer knowledge and active participation of stakeholders including women, NGO's and the private sector.

As a start, it may be useful to establish a small "Biogas Cell" (or Unit) at the national level (e.g. at the Ministry of Energy) solely responsible for promotion of biogas technology from the national perspective. Institutionally, the focus should also include: (a) strengthening the technical and managerial capability of the few existing construction companies, (b) enabling the local government bodies at district and village levels to assume the responsibility for planning and implementation the biogas program in their respective areas, (c) developing an integrated biogas program

The government should also coordinate on-going biogas initiatives and both existing and potential funding streams. There appears to be a need to create fundamental policy incentives and regulatory mandates (such as for manure management and others) will encourage market development of AD. While technical and investment aspects get priority attention, it is important to note that without sound institutional support, biogas program will not survive. Countries such as India, China, Zaire, Denmark and Germany have taken this approach.

Provision of investment subsidies will help create demand and also encourage innovation as well as private sector interest and participation. Innovation is needed to develop Georgia-specific sound designs especially for colder regions where biogas production, in absence of mitigating measures goes down in winter months. The government's approach and actions must mitigate technical institutional and investment barriers. While providing details of specific measures are beyond the scope of this study, some information is provided under Section 4.0.

1.0 INTRODUCTION

Under its multi-year, 2005-2009, Rural Energy Program (REP), the US Agency for International Development (USAID) is assisting Georgia to develop and deploy indigenous sustainable energy systems. Biogas development, based on anaerobic digestion (AD) of animal manure[2], is one such intervention. AD of manures (and other organic substrates) is a proven technology that lends itself to most rural settings.

Given the existence of over 2.36 million animals in Georgia, one study[3] estimates the daily biogas production potential of 2.4 million m^3, offering a significant potential to improve rural energy cooking needs. The program provides small grants where a project's potential feasibility is established. In addition, to develop an integrated approach, the program coordinates various activities with various other donors.

Anaerobic digestion of animal manures produces biogas containing 55-75% methane suitable for cooking, heating, lighting, (and electricity production, where economically feasible), 30-40% carbon dioxide (CO_2) and trace amounts of hydrogen sulfide (H_2S) and other gases. Compared to air, biogas is about 20 percent lighter, and has an ignition temperature in the range of 65^0 to 75º C. Biogas is an odourless and colourless. It burns with a blue flame similar to that of Liquefied Petroleum Gas (LPG). Appendix A: *Energy Content of Biogas from Various Animals,* displays various values.

The digestion process also produces environmentally stable, nutrient-rich residual slurry that provides an excellent source of organic fertilizer. During digestion, there is a small shift of about 5% of the organic nitrogen to ammonia (NH_3). It is therefore (more) useful to apply the residual slurry right away since during storage the ammonia may volatilize. Also, nutrients tend to settle out of the anaerobic effluent, and there may be as much as 5 to 8 times less nutrients in the top layers of the effluent storage compared to the bottom sludge. These factors are important for residue storage and utilization.

In addition to animal manures, anaerobic digestion can utilize a large number of other organic materials such as human wastes, crop residues, food processing and other wastes, or mixtures of one or more of these residues and wastes. Animal manures however, exhibit good nutrient balances, are easy to slurry, and are relatively biodegradable.[4] The range of biodegradability reported varies from 28-70%; variation is partly due to the diet of the animals and amount of (animal) bedding included in the feedstock. Also, fresh manure produces more biogas than stored manure.

Human excreta (also called night soil) are an important AD feedstock especially in China. It is especially viable where this feedstock can be integrated with other excreta disposal systems. This process in a country's context should, therefore be evaluated keeping in view its contribution towards hygienic excreta disposal and biogas and fertilizer production. There may however be cultural barriers to the use of night soil.

At the farm level, anaerobic digestion has proven to be one of the best manure management practices and has gained worldwide acceptance and good traction. At many farms, the technology is being utilized as

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[2] Included are: livestock (cows, buffaloes), pigs, sheep, goats, poultry, ducks and horses. AD is the most efficient method of capturing energy from manure. It can also benefit processors of milk, meat, food, fiber, brewery and other industries as well as crop residues.

[3] Adapted from TACIS (1997), Assessment of Market Potential for Homemade and Industrial Biogas Equipment in Georgia, TACIS, Tbilisi, Georgia.

[4] The range of biodegradability reportedly varies from 28-70 percent; large variation is partly due to the diets of the animals and amount of (animal) bedding included in the feedstock. Also, fresh manure is much more biodegradable than aged and/or dried manure because of the substantial loss of volatile solids over time. Furthermore, where cattle are fed agricultural wastes, the manure is less biodegradable than where cattle are fed ground grains or commercial feed.

both an alternative energy source *and* an environmental conservation tool. Experience in many developing countries shows that at macro level, the national programs have proven to be profitable even when taking into account the costs of the program; however, at the household level, the program is relatively less attractive.

It is estimated that, at present over 22 million households worldwide receive energy for lighting and cooking from biogas produced in household-scale biogas digesters. This includes 18 million households in China,[5] 3.7 million households in India, and 140,000 households in Nepal; all three countries are world leaders in biogas development and deployment. At the rural, small-scale level, the experience in Nepal exemplifies AD's benefits. Its use has shown a reduction of workload for women and girls of 3 hours/day/household, annual savings of kerosene of 2.5 liters/household, and annual savings of fuelwood, agriculture wastes and dung of 3 tons/household. Larger installations have generated income-producing opportunities and based on anecdotal evidence, have also improved rural health. Appendix B: *Energy Content of Various Fuels* shows various values for comparison.

Like larger digesters, small-scale digesters are profitable in terms of money if they yield considerable savings on conventional sources of energy such as firewood, kerosene or bottled gas (further assuming that they are not subsidized) and effective crop yield from by-product use. In some cases, small-scale digesters have also created home-based income-generating opportunities in rural areas. Nevertheless, small-scale digesters retain a following despite the costs and operating skills requirements.

However, biogas development in developing countries has required government financed investment subsidies and/or affordable financing (for construction and/or maintenance of biogas plants) particularly for small and lower-income farmers. In addition, to provide sustainability and optimize operational performance, measures such as establishing a well-designed after-sales service program and joint responsibility by owners, installers, and program staff (such as in Nepal), providing training to grassroots-level engineers in technical and managerial skills for construction of biogas digesters (as in India), and establishment of a network of rural biogas centers to provide necessary infrastructure to support dissemination, financing, and maintenance as in China have also been needed.

Nepal also provides market development support for household scale (4-20 m^3, with the most popular being 6 m^3); a permanent market facilitation organization, Biogas Sector Partnership/Nepal has been created. As of 2005, over 60 private biogas companies not only increased their technical and market capabilities but also their business as well. In China, a government program provides over $130 million in annual subsidies to (trained) farmers who build their own digesters.

1.1 Biogas Development in Georgia

Until 50 years ago, biomass was the primary source of thermal energy in Georgia. Energy was obtained by burning wood (38.7% of Georgian territory is covered by forests), hay, peat and other materials. The first biogas device in Georgia was built in Krtsanisi, near Tbilisi, shortly after the World War II.

Given the high potential and good demand for household digesters in Georgia, several groups, including international donors, are active in the development and dissemination of biogas technology. The current

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[5] 1. Source: Li Jingong. 2005. *Rural Biogas Development in China, Director, Division of Energy, Ecology nd Environment Center for Science and Technology Development, Ministry of Agriculture, Beijing.* About 70%of China's 1.23 billion people live either on farms or in villages, where no formal waste management system exists for these people. Since, for most part, food wastes are consumed by pigs and chickens, usually human and animal wastes, grain stalks (primarily rice—do not easily breakdown in the biodigesters and tend to form crust), sweet potatoes vines and weds are most common biogas feedstock. Also, most biodigesters are built in conjunction with the construction of new pigsties and toilet facilities, often located directly under the floor of the pigsties and the drain from pigsty as well as toilet feed directly into the biodigester.

designs—deployed with varying degree of success—generally are modifications of the popular Chinese digesters, and in some cases of the Indian Floating Dome design. Most installations have been funded by international donors—in particular, USAID and the World Bank—and in limited cases, cost-shared (with farmers through their labor and/or cash, combined usually 20% of the total cost). Some of the domestic organizations such as the National High Technology Center of Georgia, and local ministries including the Ministry of Economic Development, and the Ministry of Energy also provide some research and development (R&D) and program support.

However, currently, the private sector participation in AD in Georgia currently is very limited, given lack of developed markets and high investment risks. Of the few companies, one, Bioenegy Incorporated seems to have the most business. The result is high installation costs and lack of innovation and design improvements adversely impacting the development of biogas. The cash-strapped Georgian Government, given competing priorities, has also not yet taken an active role but is striving to do so.

Currently, the major players and perhaps the only players in AD of manure in Georgia are the international donors. For example, as part of its multi-year Agriculture Research Extension and Training Project (ARETP), the World Bank has installed over 292 digesters in selected villages in Western Georgia. These installations have included limited design testing and evaluation through pilot projects, farmer awareness and training including through the use of study tours, farm visits, seminars/workshops and other outreach methods. The project also trained technicians to assist farmers with biodigester installations; anecdotal evidence however indicates the trained technicians, in absence of relevant opportunities, found jobs in other sectors.

The major aim of ARETP however, is to reduce Black Sea non-point pollution through environmental management of manures through the use of bio-digesters rather than biogas production. Program's districts covered include: Khobi, Chkhorotsku and Tsalenjikha in Samegrelo region[6] around the Khobi River. ARETP also financed development of a cost-effective pump to help farmers with messy (manual) unloading (such as for cleaning) of the digester, when needed. The farmers had indicated that digester cleaning is a major O&M issue. Some pilot projects to assess feasibility of larger, 10 m^3 biodigesters are also currently underway.

ARETP used improved Static Dome (Chinese) design (for example, in Chkhorotsku, Khobi, Tsalendjikha, Zugdidi and Kobuleti regions), and to a limited extent, for warmer areas, the mobile dome (Indian) biodigester Since the program showed good success and wider acceptance with a number of international and national development agencies, as well as the Government of the Autonomous Republic of Achara, which allocated some public resources for co-financing of the biogas digester (BGD) dissemination program.[7] Few digester failures occurred either due to weather conditions or failure of the beneficiary farmers to fully provide their own contribution in the amount of 20% of the total cost of a biogas digester.

In terms of the benefits, according the World Bank, the participating farmers annually generated around 180-200 m^3 of methane per farm, substituting 900-1000 m^3 of firewood; 6.9-7.8 tone of organic fertilizer annually per farm in the form of residual slurry. The slurry provides an excellent substitute for expensive, environmentally polluting mineral fertilizers. Majority of the farmers, based on a survey, rated biogas much better than the project's other intervention, Manure Storage Facility (MSF). The major reason cited is the biogas's economic benefit given firewood cost savings and/or liquid gas and/or brand fertilizers. However, the study found very low acceptance for community-based biodigester.

[6] Samegrelo region has the highest concentration of livestock in Georgia.
[7] Source: The World Bank, Tbilisi, Aide Memoirs, Environmental Pollution Control Program; October 2006.

The beneficiary households report making up to 600 GEL (approximately US $364) annual savings from the reduced use of mineral fertilizers, firewood and liquid gas. The GoG supported the program through the 2006 Guidebook for Georgian Farmers, published under the National Program for Delivery of Extension Services to Farmers and Agro- producers, sponsored by the President of Georgia. Cattle manure is the most common feedstock used in small digesters in Georgia. Also, few farmers mix poultry manure with animal manure. Poultry manure has higher carbohydrate[8] content (poultry feed contains more carbohydrate-rich ingredients) often produces greater volumes (as compared to other manures) of biogas and over longer time; in addition biogas is produced earlier.[9] ARETP has been highlighted in this study since to date, it has been the only structured manure management-energy system initiated in Georgia.

In general, it can be stated that biodigester are most appropriate where most manure is recoverable (such as under complete confinement), and sand bedding in animal stalls is not used. Other variables, such as water content, type of bedding used, storage, and treatment, should also be taken into consideration since they have a direct bearing on the economics of Anaerobic Digestion (AD). Among these, bedding (for confined animals) is the biggest single factor that affects a digester input. Generally speaking, sand bedding is the least compatible with cost effective digesters since excessive sand, if not removed efficiently, will rapidly plug most digester designs.

The current 2 ½ -week study, in line with its scope, attempts to review the status of biogas technology with particular emphasis on bio-he digester designs, and their appropriateness to develop recommendations on which types of biogas projects, if any, the REP program should support. In addition, the study includes few cost-effective design improvements, assesses market potential of biogas and suggests interventions to improve its potential.

The study is based on in-depth review of pertinent reference materials, field visits to representative biogas digester sites field visits, consultations with officials of government of Georgia (GoG), NGO's, international donors including the World Bank's ARET project staff, UNDP farmers and others. Based on the study's recommendations, REP will review the recommendations to cost-share up to 80% of the total cost of digesters installation at the recommended farmer site in the 9-village, REP's small hydropower project area, following USAID guidelines.

1.2 Environmental Aspects of Manure

Of the large quantities of animal dung produced in Georgia, most remains unused, piled in open areas, often near households or farms. This is because the manure has no immediate use (crop land available often is limited). The result is manure flowing into rivers, lakes, ponds or area creeks. The accumulated manure (and other organic matter) gets fermented or digested and partly released as methane and carbon dioxide (both GHG's) to the atmosphere or ionized to minerals, which leach into the ground.

The result is an economic loss and environmental and human health dangers due to potential contamination of area streams and groundwater. During site visits, numerous large and small piles were noticed, some in the vicinity of drinking water wells. It was also indicated by the interviewees that such

[8] Carbohydrates are one of the most important substrates in biogas production; a greater availability to *methanogenic* bacteria enhances their microbial activity and consequently methane production.

[9] However, poultry manure is dry and has higher nitrogen impacting the desirable 20-30 C:N ratio (represents relationship between carbon and nitrogen of the feedstock) for bio-digestion. If co-mixed in larger quantities, given its drier state, special pre-treatment may be needed before digestion. During the study's field visit, a number of farmers inquired about its use as a feedstock for biogas. In some countries such as Moldova, poultry manure is discharged into open anaerobic lagoons, leading to the direct release of methane (CH_4) and N_2O into the atmosphere as a result of AD that takes place inside. The disposal approach presents a serious environmental problem.

piles are much larger in winter when animals are confined. Across the EU, livestock has also played a significant role in polluting surface water and agriculture soils with nutrients, metals, and pesticides. For instance, a major source of Black Sea pollution has been the Danube River, the EU's largest, which drains 817, 000 kilometers into the Black Sea. The World Bank estimates that within the Danube watershed, approximately 60% of the nitrogen compounds and about 66% of the phosphorous compounds originate from non-point sources such as agriculture and livestock operations. As a result, the Black Sea littoral states (Romania, Bulgaria, Turkey, Georgia, Russia and Ukraine) have suffered major ecological degradation and heavy economic losses. Applying the anaerobic digestion process can help mitigate this problem, in addition to providing an indigenous renewable source of energy.

In the context of manure-nutrients, it is also important to note that nutrient excretion is a necessary by-product of digestion and metabolic processes in any animal.[10] Nutrients along with gaseous losses and odor problems are a major manure management and environmental issues; dust and flies are considered main nuisances. Animal manure contributes to both water and air pollution by emitting or releasing methane, ammonia, (excess) nutrients, pathogens, dust, bio-aerosols, odors, and volatile organic compounds, as well as increasing the biochemical (or biological) oxygen demand (BOD).[11]

Manure is also a potential source of salts and trace metals, antibiotics, pesticides, and hormones (used to fatten animals). Potential sources of manure pollution at livestock farms include open feedlots, pastures, treatment lagoons, *manure stockpiles* or storage, and land application. It seems that the installation of manure storage facilities should go hand in hand with installation of biogas digesters.

Livestock and livestock wastes also produce gases. Gaseous losses can occur at any stage of manure handling with continued exposure to air. Some of the losses are localized, such as ammonia (NH_3), whereas others, such as carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O). Such losses could be significant. Manure should therefore be transported when fresh to closed storage to minimize NH_3 loss.

Following independence from Soviet Union, Georgia has made some important strides towards environmental conservation. For instance, the Ministry of Environment and Natural Resources has made important progress in strengthening the legal and regulatory instruments such as through the enactment of

[10] For example, nitrogen excreted by dairy cows in directly related to nitrogen intake, and approximately 71% of nitrogen consumed is excreted. For example, in the U.S., a mature Holstein cow, on the average produces about 210 pounds of total nitrogen, 84 pound of phosphorous, and 168 pounds of potassium per year according to USDA. Nutritional options with no effect on a cow's performance are available, and where feasible should be used.

[11] BOD is measured through a chemical procedure that determines how fast biological organisms use up oxygen in the body of water. Most pristine rivers may have a BOD value in the range of 1 mg/l; moderately polluted rivers, 208 mg/l.

major environmental legislation.[12] A number of environmental initiatives are underway to bring environmental improvements through better manure management. Included is the World Bank's ARETP which through its environmental component—Environmental Pollution Control Program.[13]

[12] These include the "Environment Protection Law," (1996), the "Law on Environmental Permits" and the "Law on State Ecological Expertise." Georgia has also ratified the Bucharest Convention for the Protection of the Black Sea Against Pollution (1992), the Odessa Ministerial Declaration (1993).

[13] The Program has invested $1.17 million over a period of five years (2002-2007) in the Khobi River watershed area

2.0 BIOGAS TECHNOLOGY

Anaerobic digestion of organic materials such as from animal manure, night soil (human excreta), pieces of vegetation (crop stalks, straw, grass clippings, leaves etc.), whey, slaughterhouse wastes, biodegradable garbage and wastewater can be used to produce biogas. During the process, acid-producing bacteria break these down into volatile acids, which in turn are converted by the anaerobic methanogenic bacteria into a gas (biogas).[14] During Biodigestion, half of the carbon is released as methane and carbon dioxide. Moisture contents greater than 85% or somewhat higher are suitable for AD.

Oxygen-free is the primary requirement of AD to occur. Other important factors, such as temperature, moisture and nutrient contents, and pH are also critical for the success of AD. AD best occurs at two temperature ranges: the mesophilic (30-40°C) and thermophilic (50-60°C). In general, AD at mesophilic temperature is more common even though digestion at thermophilic temperature has the advantages of producing greater quantities of gas and reducing reaction time, which translates into reduced digester volume.

The AD process converts between 40 and 60 percent of the organic matter to biogas. The process significantly depends on the biological activity of relatively slowly reproducing methanogenic bacteria. Gas generation consumes about one-fourth of the dung, but the available heat of the gas is about 20 percent more than that obtained by burning the entire amount of dung directly. This is mainly due to very high efficiency (about 60%) of utilization compared to the poor efficiency (11 percent) of burning dung cakes directly. The process simultaneously reduces Biological Oxygen Demand (BOD) as well as Chemical Oxygen Demand (COD) and is effective against pathogenic bacteria. The call out box, *Factors to Consider in Installing Digesters*, lists key considerations that should be taken into account.

Factors to Consider when Installing Biodigesters

- The specific benefits to be derived.
- The number and kind of animals to be served.
- Where the system might be placed?
- How the manure and other inputs will be collected and delivered to the system?
- How the required temperatures will be maintained?
- How all the risks associated with the process, some of which are substantial, will be mitigated?
- How the outputs will be handled?
- The amount of monitoring and management time required.

The resulting residue averages 40 to 60 percent by weight of the feedstock (the dry matter content decreases and the digested slurry has a high viscosity than cattle slurry in particular) can be separated into a liquid and a solid phase. This residue is an effective soil conditioner and fertilizer[15], with research suggesting that the micro-flora present in digested manure may lead to increased crop yields. During the digestion process, manure nutrients are "pre-mineralized"[16] in the controlled environment of the digester, making them readily available to growing plants. Furthermore, manure viscosity goes down during the digestion process helping in its movement.

[14] See also Section 2.2; Conversion Process and Digester Designs.

[15] In the residue, the organic nitrogen (e.g. in proteins) is converted into a mineralized form (released as ammonia or nitrate NO_3 nitrogen) that being directly available can be absorbed more quickly by plants. Soil bacteria must mineralize the rest of the nitrogen before it is available for crops, which is the reason why organic fertilizers have a lower efficiency compared to mineral (or chemical) fertilizers. By timing of the plant's ammonia and nitrate nitrogen absorption rates, and comparing them to the rates resulting from commercial fertilizers, the rates of the mineralized form are more predictable than the plant absorption rates of organic nitrogen from raw manure.

[16] Mineralization is when the elements in organic matter decompose into plant accessible forms. Mineralization is the alternative to immobilization where the decomposed organic matter is retained by microorganism.

Pathogenic organisms are greatly reduced in a digester. The reduction is observed to be in excess of 99% for fecal indicator organisms. Weed seeds are also greatly reduced, though the decimation rate is not known. There is also a significant reduction in the number of flies in waste management facilities handling digested manure. A study found a yield increase of 10 percent (on average) over commercial fertilizer[17]. Since AD on the average converts 50% or more of the labile[18] carbon into methane, the process also results in a positive solution to pollution problems. The process also eliminates manure odor problems by as much as 97% versus fresh manure.

2.1 The AD Process

Biodigestion involves various reactions and interactions that take place among the methanogens, non-methanogens and substrates (e.g. animal manures) that are fed into the digester as inputs. Inorganic solids, and hard to digest organic material however comes through the digestion process intact.

Methane and carbon dioxide are the primary gaseous end products of the anaerobic digestion process. The quality of the digester off-gases is dependent upon feed composition. Mixed feeds normally yield biogas with higher methane content, approximately 65 percent, as compared to normal feeds; the yield increases with proteins and lipids. In addition, the product gases contain small volumes of hydrogen sulfide and nitrogen. The generation of methane occurs as the last step of a series of biochemical reactions. Several operating parameters such as temperature, pH, and C:N ratio are important for the AD process. Appendix C: *Optimizing Factors for Anaerobic Digestion and Digested Slurry,* lists various factors.

2.1.1 <u>The Conversion Process</u>

Biodigestion is a complex physio-chemical and biological process involving different factors and stages of change. This process of digestion (methanization) is summarized below in its simple form. The reactions are divided into three groups, each mediated by heterogeneous assemblages of microorganisms, primarily bacteria. The call out box, *Digestion of Manure Solids in the Biodigester* synopsizes various changes.

> ***Digestion of Manure Solids in the Biodigester***
>
> The anaerobic digester digests the solids in the manure. The solids can be divided into total solids (TS), which include the volatile solids (VS), typically 70% of the TS, and the remaining inorganic fraction. The volatile solids can be divided between biodegradable volatile solids, typically 50%, and non-biodegradable solids. Typical dairy manure entering the digester at 12% total solids will leave with about 8% solids. That is, one half of the volatile solids, the biologically degradable ones, are converted to methane and carbon dioxide. Typical solid separation of the effluent will remove 4% of the solids from the effluent. About one third of the solids are converted to gas, one third can be separated out mechanically, and one third remain in the separated liquid effluent.

The three stages of Biodigestion are as follows:

Stage 1: Hydrolysis: The waste materials of animal (and plant) origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilized into simpler ones with the help of extra cellular enzyme released by the (liquefying) bacteria. This stage is also known as polymer breakdown stage. For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

Stage 2: Acidification: The monomer such as glucose that is produced in Stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid-forming bacteria break

[17] As reported in Philip Lusk, "Methane Recovery from Animal Manures: The Current Opportunities Casebook, "Department of Energy, National Renewable Energy Lab. (DOE/NREL), 1998.

[18] readily undergoing change or breakdown

down molecules of six atoms of carbon (glucose) into molecules of less atoms of carbon (acids), which are in a more reduced state than glucose. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Stage 3: Methanization: Methanogenic bacteria to produce methane process the principle acids produced in Stage 2. The reaction that takes place in the process of methane production is called Methanization.

The methanogens are much more sensitive to pH and temperature changes, cannot tolerate oxygen, and need the simple organic acids (produced in step 2) for food. The range of pH methanogens prefer is from 6 to 8 with optimum pH of 7. The acid formers are much more robust. They grow faster than the methanogens, are less sensitive to temperature fluctuations and pH changes, can tolerate oxygen and can feed on a wide variety of organic material.

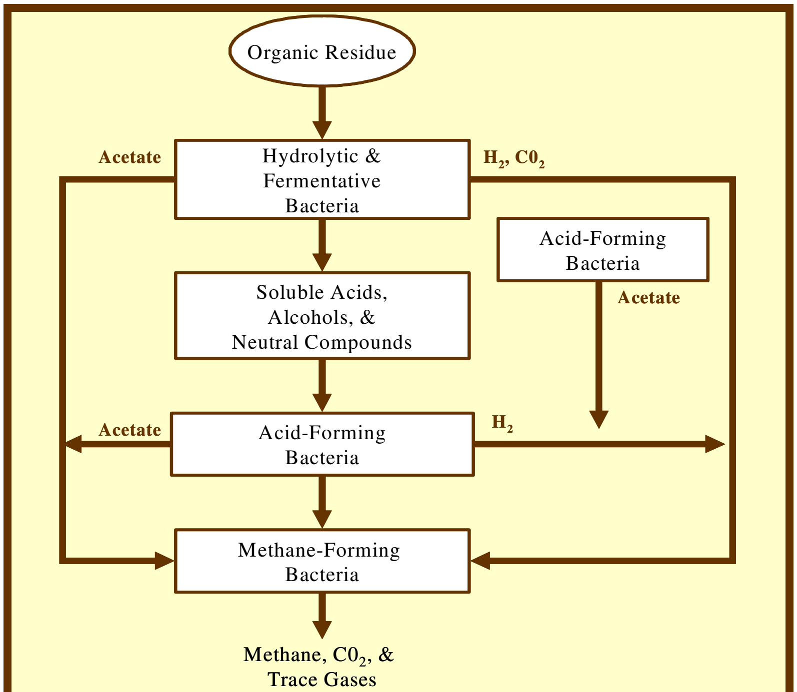

Figure 2-1. The Anaerobic Digestion Process

It is important that the digesters design and its operating environment must be able to retain enough methanogens to complete the breakdown of the acids and produce the methane. The operating environment includes such parameters, as pH, temperature, and retention time[19] must be appropriate for the population of methanogens to survive and thrive.

There are three temperature regimes that methanogens grow in. The lowest temperature range, less than 25^0 C, is called the psychrophilic range; covered lagoons in colder areas for most part operate within this temperature range. Methanogens in this range grow slowest and produce the least biogas per unit of time. The mesophillic range that centers at an optimum of about $25\text{-}40^0$ C is the most common temperature for methane digesters. Thermophillic operation at about $45\text{-}65^0$ C may be able to produce more biogas per unit of time, provide better pathogen control, and shorter retention times, but the difficulty of getting and holding the high temperatures steady has so far prevented livestock operations from adopting this temperature range.

There are advantages and disadvantages of various temperature ranges. The use of mesophilic temperature allows the process of production to be more stable by helping to inhibit excessive ammonia (NH_3) production, but these temperatures also do not destroy potentially harmful bacteria. On the other

[19] It typically takes 20-25 days to allow time for the methanogens to grow and reproduce in sufficient quantities to replace the ones that are removed on a daily basis. Shorter retention times are possible under conditions of high growth. Thermophillic conditions have often been thought to foster faster growth. Providing a media that the bacteria cling to can also retain more bacteria. Systems that take a portion of the effluent, concentrate the bacteria and then recycle it back into the influent end of the digester can increase the solid retention time allowing for more growth of the slower growing organisms.

hand, thermophilic temperatures, while destroying bacteria and allowing increased loading rates due to faster degradation, also cause greater instability because of increased free ammonia load. Though some of ammonia is necessary for biogas production, the combination of two (thermophilic temperature and excessive ammonia) can inhibit and destroy bacteria that are necessary for biogas production.[20]

Why Digesters Fail

Poor Digester Design (No. one reason)

- Incompatibility
- Each Farm is Unique

Poor Equipment

- Digester
- Engine Generator (where electricity is generated)

Toxic Substances

- Excessive NH_3 (such as from urine)
- Harmful feed additives

Poor Management

- Biological System
- Lack of knowledge/training/interest

Poor Rate of Return

- Low electricity (sale) price for generated electricity; poor economic return for slurry

2.2 Key Biogas Digester Designs

The primary requirement for anaerobic digestion (AD) to occur is a closed reactor, with sufficient volume for the biological reactions to occur without stress. In this context, many different shapes and styles of biogas plants have been experimented with: horizontal, vertical, cylindrical, cubic, dome shaped and other configurations.

Based on external limitations, such as capital outlay, treatment efficiency, net energy yields and operational skills, the available technology ranges from rudimentary systems (costing as low as US dollar sixty) to commercial systems suitable to treat manure from dairy farms with up to 5,000 or more cattle. The technology can be tailored to meet a plant's specific situation. Past failure of AD of manure (mostly in 80's) are related to lack of capital and low operational skills, as indicated in the call out box to the right. Some general guidelines are provided below.

Several design goals have been used to size biodigester. Such goals have included: maximizing biogas production (with minimal capital investment), achieving targeted pollution control, and reduction of pathogens in the feedstock, such as manure or production of a reasonable amount of gas with minimal operational attention. Optimal gas production, per m^3 however, must allow a margin of safety in size, equal to several days' additional retention beyond "optimum", to ensure viable growth for the methanogenic microbes. A clear understanding of AD is crucial to achieve the performance goals. This aspect overall is missing in Georgia.

Designing a properly sized digester to obtain the maximum biogas production per unit of reactor volume is important in maintaining low capital construction costs. Also, the digester should be sized to achieve desired performance goals in both winter and summer, and must be large enough to avoid "washout." Thus, a designer must determine the desired results before making sizing decisions. For larger plants (e.g. for 400 or more cattle), a number of empirical methods are available while small family-size digesters have primarily relied on trial and error and judgments.

Biogas digester designs should also give sufficient time to the slowly reproducing methanogenic bacteria to reproduce so that they can replace cells lost with the effluent sludge, and adjust their population size to follow fluctuations in organic loading and the generation of volatile acids and other substrates from the earlier steps of the AD. If the bacteria lost from the digester with the effluent slurry exceeds the methanogenic growth rate, the bacterial population in the digester will be "washed out' of the system.

[20] See: David Parker, West Texas A&M University, Canyon, Texas 79019; Presentation made at Western Regional Biomass Energy Program, (USDOE award no. 55008) on May 31, 2000; Email: dparker@mail.wtamu.edu

Washout can be avoided by maintaining a sufficient residence time for solids, and thus bacterial cells remain in optimal concentration within the digester.

Costs of biodigester installations vary according to the type and size of the plant, type of livestock operation and site-specific conditions; in the context of an average Georgia farmer, they are high.[21] Labor costs are only a small percentage of the total costs. In addition, there are also variations from State to State and District to District. There is an effect of economy of scale in both digester types. A comparison of cost may be made on the basis of cost per m of digester volume. For the same hydraulic retention time (HRT), the *Janata* plants (based on Chinese fixed dome design[22]) are cheaper by 40-45 % or more than KVIC digesters of comparable sizes. It is important to establish criteria prior to an installation.

Like larger digesters, a small-scale digester are profitable in terms of money if it yields considerable savings on conventional sources of energy like firewood, kerosene or bottled gas (further assuming that they are not subsidized) and effective crop yield from by-product use or sale of the residue as fertilizer. In some cases, small-scale bio-digesters have enabled creation of income-generating opportunities in rural areas by providing an energy source such as for cheese making. Nevertheless, small-scale digesters retain a significant following in developing countries, despite the costs and complications of operating the plants.

In Georgia, the major goal of AD seems to be the *production of biogas* with least capital investment. An exception seems to be the World Bank's ARETP bio-digesters where the major aim has been *to lower the nutrient loadings to the Black Sea*. As the study shows, Chinese Fixed Dome design with slight modifications is the most common design used.

For larger quantities of organic wastes such as animal manures and agriculture residues several types of digester designs are used. Key digester types include: Covered Lagoon, Batch Digester, and Plug-Flow Digester. In the US, these three types are recognized by the US Department of Agriculture's (USDA's) Natural Resource Conservation Service (NRCS) in the form of "National Guidance provided to States." For family-size (4-25 cattle) the most important designs are: The Chinese Fixed Dome, the Indian Floating Dome and various modifications of these. Key ones are synopsized below.

2.2.1 Fixed Dome (Chinese) Design

In the Chinese design, organic wastes (such as manures) fermentation chamber consists of a gas-tight chamber constructed of bricks, stone or poured concrete. Both the top and bottom are hemispherical and are joined together by straight sides. The fermentation chamber and the gasholder are one unit. The inside surface is sealed by many thin layers of mortar to make it gas-tight; earlier designs showed gas leakages. The inlet pipe is straight and ends at mid-level in the digester. There is an inspection plug at the top of the digester to facilitate cleaning, and the gas outlet pipe exits from the inspection cover.

The digester is fed semi-continuously (i.e. once a day. There is a manhole plug at the top of the digester to facilitate entrance for cleaning, and the gas outlet pipe exits from the manhole cover. In the standard design, the headspace volume above increases slightly with increasing pressure since the effluent port liquid level moves up and down with pressure changes. Additionally, if effluent is not removed from the system, the liquid volume in the bio-digester increases reducing the headspace volume. As a result, gas delivered into home varies. This causes variations in heat produced by cooking elements and variation of

21 For example, Bioenergy in 2002 installed an 8-m3 biodigester at a cost of $2,600 (Source: Bioenergy Inc.). Such costs are high and often beyond the reach of an average farmer in Georgia.

22 In Nepal, the Gobar (Hindi/Nepal word for dung) Gas and Agriculture Equipment Development Company (GGC) has also developed a design—based on Chinese Fixed Dome biodigester—which is very popular in the country. The concrete dome is the main characteristic of GGC design. Likewise, an Indian version—Deenbandhu Model—made of brick masonry work with a spherical shape gasholder at the top and a concrete bottom is comparable with GGC model in performance and costs.

gas lap intensity. Some systems use separate gas storage or a floating dome as in the Indian design (helps to maintain constant gas pressure).[23]

The gas produced during digestion is stored under the dome and displaces some of the digester contents into the effluent chamber, leading to gas pressures in the dome of between 1 and 1.5 m of water. This creates quite high structural forces and is the reason for the hemispherical top and bottom. The design has been developed in respect of: (a) the four important horizontal lines; (b) gas pressure; (c) average rate of gas production; (d) gas storage; (e) digester size; (f) geometric forms, loads and forces. The inside water level at ambient pressure is 95% of total volume. The gas pressure in the fixed-dome digesters is equal to, or below, 100 cm of water (range can be 0-100 cm or higher). The basic design keeps the ratios of key dimensions constant, e.g. diameter to height of the cylinder is 2:1

The hydraulic retention time (HRT), for both cow and pig manure, is 35-40 days at total solids concentrations of 5-8% and 4-7% respectively. The bio-digester produces 0.1-0.2m^3 biogas/m3 of biodigester volume/day or approximately 0.25 – 0.3 m^3 biogas/kg of total solids (total solids: volatile solids ratio equals 1:3)

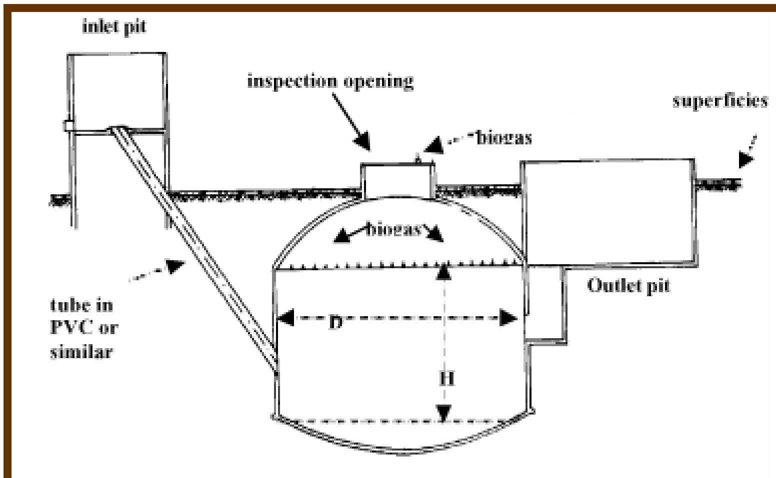

Figure 2-2. Chinese Type Digester

Much is known about Fixed Dome (Chinese) digesters in terms of materials, methods of construction, cost, suitability of various feedstock and gas production rates. High-quality materials and trained (likely to be expensive) human resources are needed to build this kind of digester. In China, the construction of family-sized digester is standardized and the government puts emphasis on sound work and quality construction.

In terms of absolute numbers, Chinese design digester by far appears to be the most common digester type in use in most developing countries). For example, in China, over 5 ½ million family-sized fixed dome plants of 6, 8 and 10 cu meter digester volume is currently operating. Larger digesters such as for farms, distilleries etc. also exist.

In Georgia, Fixed Dome (Chinese design, also called *Drumless Design*) or its modifications is the most popular design in use. Often, construction materials and technique (e.g. brickwork, lime-mortar, cement-mortar, concrete cast-in-place, liquid glass etc.) are selected at the site to keep costs low. In some cases, a brick dome is constructed on an umbrella-shaped framework or a concrete cast-in-place digester used. Gas produced is mostly used for cooking and where excess available, for making cheese for sale.

2.2.2 Floating Dome (Indian or KVIC) Digester Design

This design basically consists of a drum, a gas meter, a feed pit and an outlet pit. Conceptually, it can be viewed as a large underground straight or domed circular (brick or concrete) tank with a smaller

23 Often the floating dome or cover is a cup-shaped concrete storage container floating up side down in a tank of water. The cup moves up and down in the tank with changes in gas volume. Another advantage of this type of storage systems is that during cold weather, moisture in the gas condenses in the storage container rather than gas lines. Condensate in the supply lines can block the lines or cause oscillating pressure. (See also: www.cityfarmer.org)

cylindrical opening on the top (usually between 1.5 to 5.0 meters in diameter for a household unit). Overall, the tank is in the shape of a *buried bell* with the top cut off and the bottom sealed. Floating in the cylindrical top of the tank is a large metal gas drum of a slightly smaller diameter than the tank opening.

This drum is like a large upside-down pot and it floats on top of the digesting sludge and captures the gas. It is usually made of mild steel or sometimes fiberglass-reinforced plastic (FRP). The gas produced is trapped under this floating cover, which rises and falls on a central guide. The pressure of the gas available depends on the weight of the gasholder per unit area and usually ranges from 4 to 8 cm of water pressure.

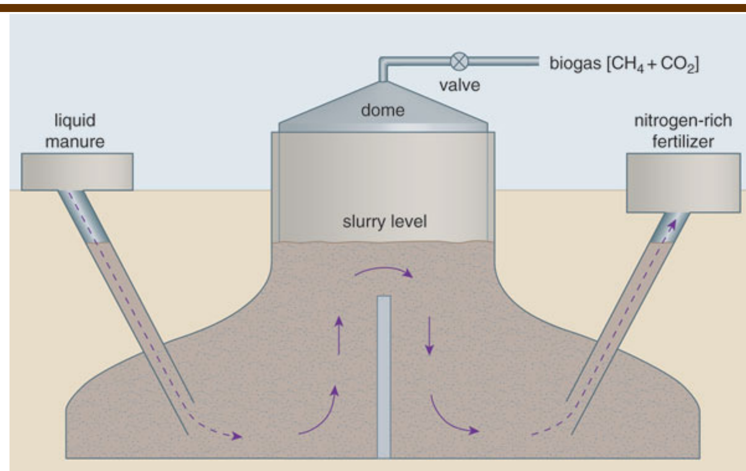

Figure 2-3. Floating Dome (Indian Design) Type Digester

The reactor wall and bottom are usually constructed of brick, although reinforced concrete is sometimes used. The reactor is fed semi-continuously (e.g. once a day) through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe. The underground tank has a large inlet and outlet pipe for the waste material and fertilizer and the gas pipe come out of the top of the floating drum. The big advantage of this design is that the gas is kept at constant pressure—controlled by adding weights to the floating drum which helps maintain consistent gas pressure for better combustion and to keep uniformity of light intensity in biogas lamps.

Construction costs vary according to ambient temperatures, the size of biodigester, manure management system used at the farm and other factors. The cost of a mild steel gasholder is approximately 40-50% of the total cost of the plant. More recently, the steel drum has been replaced by fiberglass-reinforced plastic (FRP) to overcome the problem of (steel's) corrosion. However, FRP gasholders are 56-12% more expensive than the steel drum.

A slightly modified design called KVIC typically has reactor wall and bottom usually constructed of brick, though reinforced concrete is sometimes used. The volume of the gas cover is approximately 50% of the total daily gas production. The pressure of the gas available depends on the weight of the gasholder per unit area, and usually ranges from 4-8 cm of water pressure. Figure 2-4, Floating Dome Type Digester, gives another view of the design.

The bio-digester is fed semi-continuously through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe. When the bio-digester has a high height to diameter ratio, a central baffle is included to prevent short-circuiting. Most KVIC type digesters are operated at ambient temperatures, thus retention times (RT) depend on local conditions. For region with ambient temperatures of 20-40^0 C, 30-40 days RT is considered; for lower ambient temperatures, 35-45 days of RT is considered adequate.

Typical feedstock for floating dome or KVIC is cattle manure although such substrates as agricultural residues, night soil and aquatic plants have also been successfully used. In general, Floating Dome (or KVIC) design is considered suitable for warmer climates such as those in India. In order to adapt KVIC digesters to the various ambient temperatures, they are designed for three different retention times to produce the same volume of gas.

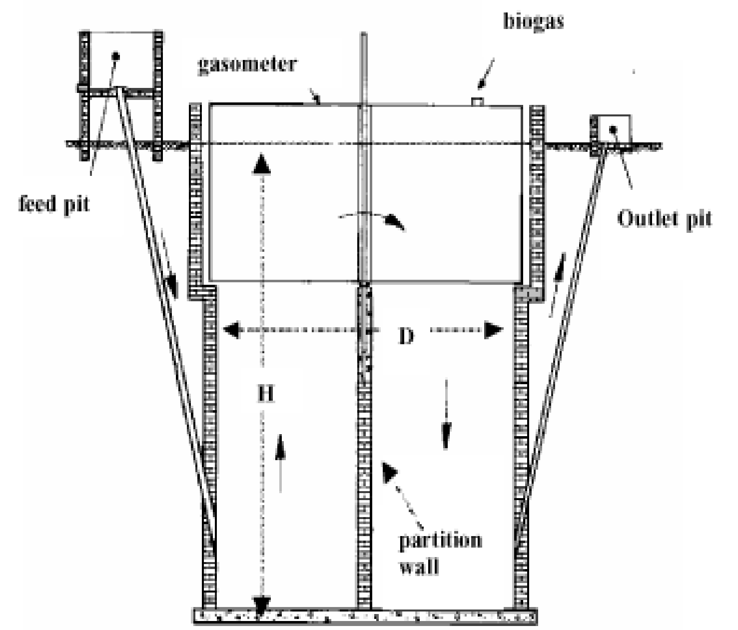

Figure 2-4. Floating Dome Type Digester

Source: www.scielo.br/pdf/sa/v60n1/14562.pdf

The advantage of this model, in spite of expensive steel gasholder, is that since the daily flow of slurry goes up the first side, where the insoluble matter rises, and down the second, where this matter naturally tends to fall, the outgoing slurry daily draws out with it any sludge found at the bottom. Thus having to clean out the pit becomes a comparatively *rare necessity*. Sand and gravel however may build up on the bottom of the digester and will have to be cleaned from time to time depending on your location. The digester life has averaged about 25 years in tropical environments.

2.2.3 Fixed Dome versus Floating Dome

Each of the two widely used designs offers differing advantages. However, it appears that the Chinese designs are resource conserving, compact, and adaptable to whatever building materials is locally available. For example, the design uses bricks and stones, often locally available with relatively low-cost cement; in few cases, digesters are even carved out of solid rock. Of particular interest are also the built-in self-pressurizing mechanisms in the Chinese designs, which eliminate the need for costly metal covers in the Indian designs.

However, attempts to replicate the Chinese results outside the (People's Republic of China (PRC) have yielded very uneven results. Building materials, such as cement, lime and quarried stones, which are produced locally on Chinese communes, are unavailable or very expensive in many other countries.

The design requires skilled installers. Also, while underground plants are simpler and less expensive to construct and can be gravity-fed, bio-digesters built above ground and made of steel can withstand the pressure of the slurry. In earthquake-prone zones of Georgia,[24] concrete construction could pose problems. In these regions, a steel gasholder (instead of concrete one), covered with insulation, and later with bricks is used. Each potential site must be reviewed in terms of its needs including climate, soils, water table levels, skills required, costs etc. before installing a bio-digester.

Chinese bioreactors are also difficult to clean. Some installations in Georgia (such as those by Bioenergy Inc.) use a 3-kW pump (cost: $180). The firm provides digester-cleaning services at a cost as part of its business. Depending upon the type of feedstock (animal manure, poultry manure, agricultural residues

[24] Except for Black Sea areas (Western Georgia), most of the country is prone to earthquakes of varying intensity and frequency.

etc.) and the level of maintenance, a digester may need cleaning every 1 to 2 year. The above-surface models are easier to maintain and, if painted black, may be partially heated by solar radiation.

2.2.4 GGC Nepal Design

The Nepali biogas plant design, modification of the Chinese design, uses an airtight underground digester, where dung is put in and then stirred with some water. In Nepal, fixed dome design, GGC 2047 model, is the popular design.[25] Popular sizes range from 4-20 m^3. It is considered to be reliable, well functioning, simple, requires low maintenance and is durable. Within the dome, bacteria that occur naturally in cow dung break down the raw materials to produce methane. At the top of the dome there is a gas outlet pipe that is transfers biogas for potential end-uses.

Figure 2-5. GGC Nepal Design: The Dome will be Covered with Compacted Earth

Cost of a small size plant without subsidy is said to be around $350 with farmer providing labor. The current subsidy policy is applicable to only GGC 2047 Model of capacity 4-10 m^3. In Georgia, Bioenergy Inc. has installed some digester using the above design**.** However, research is needed to establish their potential for wider use and deployment

Nepal is also benefiting from Carbon Trading by using biogas after the Kyoto Protocol came into force (in Nepal) in December 2005. By using biogas Nepal is saving 700,000 tons of CO_2, offering an earning potential of up to $3.5 million per year[26] through the Clean Development Mechanism, under the United Nations Framework Convention on Climate Change. The industrialized nations can buy such credits to compensate for the extra greenhouse gases they produce over the allowances set by the Protocol.

The sale of 1,000,000 Emission Reduction (ER) credits to the Community Development Carbon Fund (CDCF) will allow for the full implementation of Phase IV, and will reduce reliance on donor assistance for future phases of the program..

2.2.5 Bags or Tubular AD Digester

The bag digester was developed in the 60's in Taiwan to solve the problems experienced with brick and metal digesters; bag digester is made of PVC or red mud and basically is a long cylinder. However, experience has shown that a Bag Digester could be successful where PVC is easily available, pressure inside the digester is increased and welding facilities are easily available. At present, such conditions are difficult to meet in most rural areas of Georgia.

A similar design using low-cost (less than US $60 for a family size unit) plastic biodigester based on the use of tubular polythene film is in use in Vietnam (22,000 installed to date) and to a limited extent in Georgia.[27] Given the low costs, the design does not require subsidies. The simple means of installation has facilitated farmer-to-farmer extension of the technology. Notwithstanding these benefits, given the

[25] Nepal Biogas Plant: Construction Manual; Biogas Support Program, P.O. Box 1966. Kathmandu, Nepal; Telephone No. 552 1742, 553 4035; Email: snvbsp@wlink.com.np
[26] Website: http://www.bspnepal.org.np/introduction.htm
[27] Few tubular bio-digesters have been installed by JSC Eris Imedi, Email: Sanikidzerm@gmail.com, Cell/Tbilisi: 899 97 0257

lack of experience and possible weather and other damage such as by stray animals have limited its wider use.

A modification of the low-cost plastic biodigester system to help the durability of the digestion chamber involves constructing it from bricks and concrete. The design is a cross between an underground fixed dome (Chinese) model and a plastic-bag model. The main digestion chamber is a rectangular (flat-topped) low-depth underground concrete tank. There is no pre-digestion / mixing chamber, but instead a siphon-type input with active and continuous scum-breaking action is used. The effluent is gravity fed to a secondary chamber. This design facilitates the integration of the livestock pen and household latrine with the biodigester, thus saving space and reducing the overall costs of construction. Nevertheless, these designs need more research especially country-specific before they can be recommended for potential wider use.

2.2.6 Plug-flow AD Design

Many anaerobic digesters for typical dairy manure in the developed world are plug flow systems. The first documented use of this type of design was in South Africa in 1957. In this design, manure is added to one end of an insulated impermeable container. Each day a new "plug" of organic wastes is added, slowly pushing an equal amount at the other end of the digester. Plug-flow digesters are usually operated with a total solid concentration of 11%-13% at the mesophilic temperature range, with a HRT[28] from 20-30 days. Plug-flow digesters are often built below ground and may not require stirring/mixing.

The plug flow digester is similar to the bag digester. It consists of a trench (trench length has to be considerably greater than the width and depth) lined with concrete or an impermeable membrane. The bio-digester is covered with either a flexible cover gasholder anchored to the ground, concrete or galvanized steel top. Plug-flow required good management skills. In many setting they have shown good results.

2.2.7 Batch AD Digester Design

This is the simplest of all the AD processes. The operation involves merely charging (single charge) an airtight bio-digester with the substrate, seed inoculums, and in some cases a chemical (normally a base) to maintain almost neutral pH. The bio-digester is then sealed and the fermentation is allowed to proceed for 35-180 days, depending upon the ambient temperature. During this period, the daily gas production builds up to a maximum and then declines. The fermentation can be conducted at “normal” solids content (6-10%, such as in animal manures) or at high concentrations (> 20%), which is then known as “dry” fermentation. At the end of the digestion cycle, the Batch Digester is emptied, cleaned, recharged and restarted for a new cycle then left until done.

Operating the batch digestion system requires that you have two or more digesters to be able to have a more or less continuous gas supply. Three is more practical. Batch digesters have the quality of predictability because once started they are not disturbed or interrupted

2.2.8 The Complete Mix AD Digester

The complete-mix digester is a large, vertical poured concrete or steel circular container. The complete-mix digester can handle organic wastes with total solid concentration of 3% to 10%. Complete-mix digesters can be operated at either the mesophilic or thermophilic temperature. They offer a wide range with a hydraulic retention time (HRT) as brief as 10-20 days. Popular forms of Completely Mix Digesters are: (i) Complete Stirred Tank Reactors (CSTR), (ii) Completely Mixed Flow Reactors (CMF), and (iii)

[28] HRT is the average time that a liquid stays in a reactor before it is discharged. It is equal to the active volume of the tank divided by the flow rate of the liquid entering it, i.e.. (HRT=V/Q). HRT is usually expressed in days, but may be as short as few hours

Continuous Flow Stirred Tank (CSTR).[29]They can be used at dairy or swine farms using scrape or flush (manure management) systems. However, these systems are expensive, require skilled operator and show poor biomass immobilization (HRT = SRT), they are suitable for Georgian.

2.2.9 Covered Lagoons for AD

Covered lagoons are an option that can be used in many parts of Georgia.[30] A covered lagoon is an earthen lagoon fitted with a floating, impermeable cover that collects biogas as it is produced from the organic wastes such as animal manures. The cover is constructed of an industrial fabric that rests on solid floats laid on the surface of the lagoon. It should be constructed from a substantial material designed to withstand the rigors of weather.

The cover floats on top of the lagoon, trapping the biogas produced during the decomposition of the manure and, in most cases, as the cover is generally constructed of an impermeable plastic membrane, preventing the dilution of the manure by rainwater. The cover can be placed over the entire lagoon or over the part that produces the most methane. An anaerobic lagoon is best suited for organic wastes including animal manures with a total solid concentration of 0.5% - 3%.

Covered lagoons, since they operate at ambient temperatures, (thus not heated) break down solids more slowly than other types of anaerobic digesters, but they are the least expensive system to implement and operate. Covered lagoon digester O&M is simple and straightforward compared to other digester designs. However, it should be noted that at colder winter temperatures, neither the manure's bio-digestion, nor the lagoon itself functions properly. This will result in an accumulation of solids, an overloaded lagoon, and potential odor problems when lagoon temperatures rise in the spring.

Key disadvantages of Covered Lagoons are: maintenance issues related to the cover, lagoons leave large footprints and solids and nutrient accumulation, unless managed properly. Also, covered lagoons can cause environmental pollution. To collect methane, a floating lagoon cover and a gas pump to move the gas is required.

The capital cost for covered lagoon can be less than those required for other bio-digester designs. However, a key issue for covered lagoon is that digestion is dependent on (ambient) temperature; therefore biogas production varies seasonally if the lagoon is not externally heated. This means that methane production is greater in summer than in winter. In general, a daily biogas production in summer could be averaged 35% higher than in winter. The large fluctuations may make end-use applications more problematic than larger manure quantity bio-digester designs such as plug flow and completed mix bio-digesters. Another concern is that it can take an anaerobic lagoon as long as 1-2 years to achieve its "steady state" biogas production potential.

Given the large quantities of manure available in Georgia and the low level of skills required to install and operate covered lagoons, it is recommended that their feasibility such as through pilot projects at suitable sites in warmer regions be explored.

2.2.10 Small-Scale Digester Designs in Europe

In Europe, over 70% of biodigesters are small-scale, 20 m^3 to 75 m^3 or more, and use cattle manure (sometimes mixed with straw and slurried), pig and chicken manure, food industry wastes such as oils and fats and slaughterhouse wastes. The digester is either horizontal steel or the vertical concrete digester. The biogas is stored in balloons and protected in containers, silos or protected huts. Biogas end-use varies from site to site and depends on the quantities produced and end-users needs. A number of them are used

[29] For Additional information See: www.tanks.org and other sources.
[30] Covered lagoons are suitable for regions with temperate to warm climates such as in western Georgia.

to produce electricity. Appendix D: Small *Digester Designs in Europe* provides additional information on these designs.

2.2.11 Community Anaerobic Digesters

Centralized or Community AD systems make it possible to develop an economically successful venture by combining the manure from several cattle farms within a region. These systems might also be considered in areas where dairy, swine, or poultry farms are too small to support a cost-effective on-farm facility. A Centralized system may be designed and operated by a community group, a corporation, a cooperative, or a third party such as an energy company, depending on community consensus. The potential advantages of centralized biogas production include:

- Economy of scale —Experience demonstrates significant economic benefits as biogas production capacity increases;
- Marketing leverage — the ability to provide a significant supply of energy may be an advantage in negotiating contracts such as for the sale of electricity, where feasible, to the local utility and/or sale of nutrient-rich byproduct where markets exist;
- Financing —Due to the scale of the project, additional sources of venture capital may be available as well as assistance from grants, tax credits, or renewable energy programs; and
- Third party management —Livestock producers can realize the environmental and economic benefits of biogas production without the responsibility for day-to-day operation of the system—operation and/or management can be contracted out.

In some EU countries, such as in Denmark, most, including community digesters, are thermophilic operations due primarily for sanitary reasons rather than to increase biogas production[31]. The digester design is based on Continuous Stirred Tank Reactor (CSTR) design. The common feedstock including for community digesters are a mixture of cattle, pigs, chickens, meat-pickings wastes and sludge, fats and oils and others, often requiring thermophilic temperature digestion. Co-digestion of such wastes allows use of organic wastes that otherwise would be problematic for bio-digestion. In addition, commercial reactors for digesting (biodegradable) municipal wastes are also being used. These range in capacity from 70 m^3 to 5,000 m^3.

For Georgia centralized (or community-based) systems, given the availability of large quantities of (unused) manure in many villages offer great potential to provide cooking gas, organic fertilizer and strong likelihood of creating income-producing opportunities. At present, large piles of unused manure in most Georgia villages are presenting a serious health and environmental danger, in addition to an economic loss.

Notwithstanding these, it is unlikely that community digesters will be established in the foreseeable future. The biggest constraint is (strong) unwillingness on the part of farmers to cooperate with each other. It was mentioned repeatedly during this study's fieldwork in all villages when the option was discussed. It seems anything related to collective approach, given the negative experience during the communist rule, is shunned. This situation can be mitigated through appropriate pilot projects, community education and awareness and other means, as needed. Experience has shown that women are more receptive than men to such education and awareness campaigns.

[31] For additional information on Anearobic Digestion in Europe, see: (i) www.biogas.ch (for Switzerland), (ii) www.iea.org (For France), (iii) www.r-p-a.org.uk/home.fcm (for U.K.) (iv) www.biogasdk.dk, www.dkbiogas.com, www.biogasinfo.org, www.lr.dk (for Denmark), www.biogas.Se (for Sweden), and www.biogas.it (for Italy).

Community digesters, potentially, can also generate rural employment opportunities such as for local masons, unskilled laborers, supervisors, turnkey workers and biogas accessory manufacturers; all roles women can fulfill as well as men. In this way, rural communities have greater opportunities to earn a living and become self-reliant and in turn conserve and protect their local environment'

2.3 Key Approaches to Manage Cold Weather Designs

Georgia's climate being marginal for operating biogas digesters may require specific designs and measures in many areas to keep biogas generation during the colder months. In hot weather, it is relatively easy to hold the temperature of a bio-digester at ideal operating levels by shading a biodigesters, maintaining the same ideal temperature in a cold climate is somewhat more difficult and often challenging. Cold temperature occurring in winter months can be an important risk factor for the success of a biodigester. The digester temperature must be maintained at a level sufficiently high enough to ensure maximum microbiological activity, or at least at a level that permits the minimum required degree of activity for AD.

In cold weather manure can freeze; a situation that exists in Georgia's northern and higher elevations during winter months. Frozen manure, which is solid, may not be loaded into the digester since it will not be digested and thus will not contribute to energy production. Animal manure barns should be constructed to reduce the incidence of (manure) freezing.

Clearly, the digester design should consider two basic heat requirements: bringing of incoming fresh manure to digester temperature, and replacement of heat lost through the digester walls, floor and roof. Here, two important considerations are insulation of the digestion vessel and adequate sizing of the digester heating system. While the digester must be airtight, it should also be situated so that it can be heated. Also, where economical (such as for larger digesters), the frozen manure can be heated through use of a gas boiler.

The airtight requirement of the digesters, in addition to creating anaerobic conditions, also helps in heating such as with hot-water piping running in and out of the digester tank. The digester tank should also be insulated to help it retain optimal operating temperatures. To heat water several options are available and have been effectively used. These include: heating the water using the methane produced by the digester, woodfuel, and solar thermal systems where feasible and others, as feasible and economical.

Heating supports the metabolic requirements of the anaerobic organisms. Several approaches can be employed as technically and economically feasible for a particular situation. In many colder regions, insulation of digester such as with straw, wood shavings, or similar materials has been employed. A layer about 50-100 cm thick, coated with a waterproof covering is a good start. Installers in Georgia and many other countries take advantage of the soil's insulating effect by at least partially burying the digester tank in a pit or piling the soil up against the tank's sides. If this still proves to be insufficient in winter, then the following options for small-size digesters such as for 4-35 cattle may be used:

(i) **Supplying heat from outside sources:** burning commercially available fuel, wood or biogas can do this. A biogas-heated boiler is a good idea since it allows the bio-digestion process to feed back on itself, thus increasing its efficiency. In either case efficient combustion and heat recovery is desirable; and

(ii) **Use of heating coils:** A biodigester culture can be easily heated by circulating hot water through a coil immersed in the digester's contents. When hot water is regulated by a thermostat and circulated through coils built into a digester, the fermenting process may be kept at an efficient gas producing temperature quite easily. Where coils are placed in the digester, a ratio of 1 ft^2 coil area per 100-ft^3 digester volumes is recommended.[32] Usually, for Georgia weather, it should be sufficient to circulate the heating for a couple of hours in the morning and again in the evening. Biogas produced by the biodigester can be used for this purpose. It is especially interesting to note that using a portion of the gas generated to heat the water is entirely and economically feasible. The small quantity of gas "wasted" on heating the digester will be more than compensated for by the greatly increased biogas production in the thermophillic digester temperatures.

Also, it is relatively simple to keep the biodigester at the ideal temperature if hot water, regulated with a thermostat, is circulated through the system. In the US and a number of EU countries, boiler and co-generator design for maximum heat recovery are used to assure adequate quantities of heat to support the biological process in the digester. A number of large (for 1,500 or more number of dairy cattle) bio-digesters (Plug-flow or completely mixed biodigesters designs) have been successfully working in very cold regions of the US. All are heated with hot water brought to temperature by burning biogas and some cases where electricity is generated through biogas, via use of generator heat.

2.4 Safety Issues in Biodigestion

During the site visit to key digester sites and discussions with relevant individuals, it was clear that health and safety issues are not getting the needed attention. It appears that precautions are not being observed during the maintenance of the system and utilization of biogas. Use of biogas poses dangers similar to gasoline or bottled gas use.

It is important to recognize that anything that can cook meals (and fuel an engine) can also burn users. Biogas can be explosive when mixed with air in proportion of one part of biogas to 8-20 parts of air in an enclosed container. This situation can occur when a biodigester is opened for cleaning, when biogas is released to repair a gas storage tank, or when there is a gas leak in a poorly ventilated room. Use of open candles to look into the biodigester (or smoking cigarettes) must be avoided. Thus, precautions are important during the maintenance of the system.

Gas leaks can cause an explosion. Gas leaks can also occur in plastic pipes, joints, clamps, and gate valves. Use of lead in Brass gate valves and pipes must be avoided. The hydrogen sulfide in the biogas over time will degrade or destroy lead causing gas leaks. Rats have been known to bit holes in plastic pipes. Stoves and gas mantle lamps should be placed with fire safety in mind. At one location during the site visit, use of lead pipes and plastic tube to transport biogas was noticed. Another important safety relates to prevention of negative pressure in a biogas system. Negative pressure will pull air into the biogas system; the mixture of biogas and air potentially can explode. (If that does not happen, the oxygen in the air will kill most of the (anaerobic) bacteria, potentially lowering the gas production.

Negative pressure occurs when force created by the weight of the gases outside the biogas system is greater than force inside the system. In a normal operation, the pressure inside the system is always greater than outside. However, when an individual farmer wants more gas from a biodigester than it can (safely) produce or there is an unnoticeable leak, negative pressure can result.

Another key safety issue is the need to use a flame arrester A flame arrester is a safety device that should be added to *every* gas line since in case of fire, it can prevent the flame from traveling down the gas pipe into the gas storage tank or digester and causing an explosion. However, based on discussions with some installers, it was clear that some design modifications do not include the use of a flame arrester especially for smaller (3-5 cattle) systems.

[32] Imhoff K et al., 1971 “Disposal of Sewage and other Waste-borne Wastes”. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, USA.

The arrester can be a ball or roll of mesh copper wire (avoid iron and steel since they can rust) inserted into a gas pipe. Flame arrester should be placed in a length of a pipe of slightly larger diameter than gas pipe. For example, for a 1.27 cm-pipe, use of a 1.90-cm arrester pipe is recommended. It is also recommended that the current use of sponge by Bioenergy should be substituted with better materials such as meshed copper wires for better protection.

To transport gas, some biodigesters (e.g. in Batumi region, under the ARETP) in are using plastic tubes; polyethylene tubes are considered better and safer. Their use should be discouraged since over time, the plastic can degrade and biogas can leak creating safety hazards. An alternative is to bury biogas pipeline in the ground. Likewise, recognition of the health issues is also important. While bio-digestion will kill over 99 percent of the enteric bacterial pathogens and the enteric group of viruses,[33] proper care including good hygiene practices should be exercised in handling the raw manure.

In Georgia, while the interest in biogas development seems to be exponentially increasing—and the limited number of installations gaining traction, albeit, very slowly—the health and safety aspects appear to be getting overlooked. The knowledge and awareness, on the part of the existing few installers, seems limited; seems there is no money to be made here. Given their significance, it is suggested that information on health and safety issues need proper dissemination including on the part of NGO's and through use of local language. Any accidents apart from human health and property damage will also provide adverse publicity to the program, potentially hindering its much needed use and dissemination.

[33]Using bio-digestion time of 14 days and at 35 degree C.

3.0 CURRENT STATUS OF BIOGAS IN GEORGIA

Efforts to install bio-digesters in Georgia, with assistance from GTZ, the German Development Agency, date back to 1993-1994. The first biodigester was constructed in Sasireti, Kaspi in 1994. Later, other digesters were installed in Gurjaani, Dedoplistskaro, Gardabani, Tsalka and Chakvi**, so**me with USAID assistance. The volumes of biodigesters ranged from 2-20 cubic meters.[34] The reactor designs used were primarily Floating Dome (heat-insulated, where necessary), horizontal fixed-dome type (Chinese Design) and locally improved versions of fixed dome type. These designs continue to be the mainstay of the biogas program.

Under the World Bank-funded ARETP project, to date, 272 digesters have been installed in the Western Georgia with the major aim to reduce pollutant loading in the Black Sea. The construction of bio-digesters is also planned along the Baku-Tbilisi-Ceihan (BTC) oil pipeline under the BTC Social Investment Program.

A grant recipient team working on metallic biogas digesters reported that they have isolated two bacteria, which could increase the digestion capacity of a bioreactor by 30 percent.[35]This is an excellent research contribution of this project, which further needs to be strengthened. It could possibly result in a much higher gas production with similar manure feeding rates to the biogas digesters.

Based on experience with other country-specific evaluations of biodigesters it has been found that biodigesters are sensitive to local environmental, social, and economic conditions. Consequently, biodigester research and development in one area, while valuable in a general sense, may not be directly applicable to biodigesters in other regions.

3.1 Site Visits

During the 2-½ week period of study, a total of eight biodigester sites representing the South, Southwest, southeast, and Western Georgia were visited. Included were three sites under the World Bank's ARETP project in Western Georgia. For these sites, one or more individuals from the local staff of Winrock International accompanied the author on all site visits.

At most places, either Fixed Dome (Chinese design) or the design somewhat modified has been installed. The feedstock used is cow manure and the sizes range from 4-10 m^3. Gas produced is used for home cooking and for making cheese, sold profitably as per the plant's owners, in the local markets. Cooking stove used is 2-3 burners. In wintertime, gas yield are said to decline unless outside heat source is provided to the biodigester. During discussions, in addition to other issues, farmers were advised against extracting gas when the pressure is low to avoid potential build up of negative pressure (See: Section2.4), which can result in stoppage of the process (through entry of air/oxygen) and sometimes an explosion.

A list of the sites visited along with synoptic view of the digester is provided under Appendix D*: Biodigester Sites Visited,* and Appendix F*: Persons/Organizations Contacted lists various individuals contacted* to get information regarding this study.

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[34] Few exceptions included a 30-m^3-volume bioreactor in Sachkhere with financial scope from United Methodist Committee on Relief (UMCOR).

[35] World Bank AIDE Memoire, October 2000. World Bank, Tbilisi.

3.2 Key Bio-digester Designs in Use in Georgia

Currently, Chinese Fixed Dome and the Indian Floating Dome and their site-specific, usually with minor design modifications are popular in Georgia. Of the two designs, the Chinese Fixed Dome and/or its modifications are more common. An example of modification is to install a separation wall (with space, depending on the size of the digester, left at the bottom) to facilitate flow. The concrete gasholder is sometimes covered with plastic sheets and (subsequently) with soil. Appendix E: *Daily Input of Cattle Manure and Urine Recommended for Georgia* shows various input quantities that are currently used.

Also, during the site visit, the farmer and the installers indicated that both the inside of the digester and the gasholder is layered with mortar to prevent escape of generated biogas. Except for the overflow tank, the entire system is covered with a thick layer (30 cm or more) of soil; soil is a good insulator since it has slow heat transfer. The practice seems to be working well at the visited installations.

Some of the installations visited use the floating dome design with some modifications. The steel-floating gasholder is covered with plastic sheets. Currently six such biodigesters, with sizes ranging from 7-9 m^3, are planned for the Ajara region. A feasibility study for a larger plant, 25 m^3, based on manure from 22-25 cattle in the Ajara region is also under implementation for a private firm. Since the area has high water table, the floating dome design is considered suitable. The sponsoring firm is involved in trucking milk to urban areas. The company will use biogas for its dairy operations, primarily for heating. For the proposed larger digester size, there is no experience in Georgia.

In rocky areas, such as parts of the Ajara region, GGC Nepali (from Nepal) design (See: Section 2.2.4) has been used. Currently, 18 such digesters of varying sizes, based on 5-15 cattle are under planning. The Nepali design is a modification of Chinese fixed dome design and has proven successful in Nepal. In Georgia, no monitoring and evaluation data exists on its performance.

To maintain appropriate temperatures inside the digester in colder Georgian areas, depending on the site and its geographical location, currently two key techniques are being used in Georgia. These are: (i) of hot water to warm the influent manure, and (ii) f thermal insulation (one or more layers of soil, straw, hay, glass wool of thickness as required) the digester. Hot water is heated initially with the use of firewood and later with the generated biogas. For thermophillic conditions, inside temperature should be 45-65^0 C, a temperature difficult to maintain in colder climates without an outside heat source.

In addition to installing the Chinese, the Indian or their modified designs, three tubular biodigesters using polymers have also been installed[36] in 2007 in the Ajara region by a Georgian vendor. Each of these digesters is 6 m^3, and per digester cost is $1,300. The gasholder is also made of polymer and the entire unit material was imported from Turkey. Other tubular bio-digester planned range from 10-25 m^3. Given the lack of data on their functioning it is too early to reflect and/or recommend these designs for areas under the 9-village REP.

3.3 Cold weather Designs in Georgia

A 2001 review by the World Bank/Tbilisi[37] indicates that the heating system(s) required for retaining optimal temperature within bioreactors developed so far is not satisfactory for either metal, or for concrete, digesters. However, based on discussions with installers, farmers and digester owners/operators, it appears that this situation has considerably improved. It is suggested that proposed methods of addressing heating problem should be resolved before procuring these types of works for the REP.

[36] Installation by JSC Eris Imedi; Email: sanikidzem@gmail.com
[37] See World Bank/Tbilisi AIDE MEMOIRES, October 2001

Current approaches seems to be working well. However, in absence of monitoring and evaluation of the system(s), it cannot be stated with certainty.

The current winter-weather designs incorporate with varying degree of success include: (i) a wood stove at the bottom of the digester, (ii) use of biogas and/or electricity to do the same, (iii) limited use of solar panels, (iv) use of glass wool, straw, hay or other similar insulation around the digester, and (v) and others. The use of one or more of these options primarily depends upon the heat requirements in winter, the local availability of the material and the individual farmer's economic resources. In terms of temperature requirements, the Chinese design (dome) is more commonly used (often with some modifications, in Georgia) loses more heat than the floating dome (Indian) design. Thus, better insulation techniques and cost-effective, possibly locally available, materials are required.

To elevate the temperature of the circulating water, use of solar energy, particularly for smaller systems represents an interesting and viable possibility in Georgia regions where it is technically and economically feasible. The key element of such a system is a solar panel that has a black backing and over which water is trickled. (The face of the panel is oriented to receive maximum exposure to the sun). In its passage over the "face" of the panel, the trickling water becomes increasingly warmer. The heated water collects in a reservoir positioned at the base of the panel. The heated water can be transferred from the reservoir and circulated through the digester-heating coil. Digester temperature however needs careful monitoring to help optimize the digestion process.

Bioenergy Inc., the leader biogas designer/installer in Georgia, recommends adding hot water to manure to improve its temperature and placing 2-3 m haystack (excessive quantities may cause problems in the biodigester) on it and periodically adding hot water to the influent. In addition, the firm recommends weatherization of cattle-shed: installing double window frames, plastering the walls, and weatherizing the ceiling with dry soil to help improve winter performance. These appear to be relevant to Georgia.

Given the limited experience with cold-weather digesters, lack of baseline data, including no monitoring and evaluation (M&E) of the existing biodigesters, varying climatic conditions, no conclusive recommendations can be made on the best approach. However, among the number of options cited in the study, use of soil, straw, polyethylene as insulating materials and use of hot water to provide direct heat to the digester have proven successful. Their use should be continued until Georgia-specific R&D can develop alternate materials. .

For larger systems (for example, dairies with 200 or more cattle), often generator heat from biogas-to-electricity system has proven economical for many settings. Use of firewood should be avoided due to potentially adverse environmental consequences costs. If needed as a starter, it should be substituted with (generated) biogas.

3.4 Potential Design Improvements for Georgia

As stated earlier, much of the developmental work on biodigester has been approached from the engineering viewpoint with emphasis on design and construction with the aim of maximizing gas production and efficiency of conversion of feedstock to biogas. There has been little change in the basic designs of the floating canopy (as developed in India) and liquid displacement (developed in China) systems. The relatively high cost and need for skilled artisans in their construction have been major constraints to widespread adoption, which has had to be supported by subsidies from Government or Aid Agencies.

Furthermore, in addition to design considerations, to optimize AD benefits, the manure biodigester must be integrated into the overall livestock operations of a farm. In this context, given the diversity of site-specific variables no single farm can serve as a model for AD and/or manure management. For instance, the designated operation of the livestock farm (such as dairy) will determine the various parameters, such as digester loading and the overall energy generated from the system. The anaerobic system must therefore be designed to meet the individual characteristic of each livestock farm. Furthermore, livestock farmers need thorough and accurate information before starting methane production on their farm, in addition to long-term interest and training.

A review of the resume of biogas technology in Georgia indicates that local innovations and design modifications need greater field experience for wider dissemination (and long-term successful) use. This is because while millions of biogas digesters have been constructed worldwide, it is well recognized that the experience of (pioneering, country-specific) individuals and organizations has been the guiding principle rather than a defined scientific approach or replicating another country's approach.

In particular relevance are: the issues related to sizing the system to fit the energy needs, operational efficiency, use of appropriate construction materials (e.g., instead of steel). An improved coordination and feedback are also important towards development of Georgia-specific digester designs. There is a need to develop and implement an M&E program.

In Georgia, the few local vendors have made some improvements in installing the digesters. There is no monitoring of their performance. Thus, biodigester performance information or any long-term impacts of biodigester is not known. At the government level, the High Tech Center has come up with 1-2 designs and a review indicated that in view of their high-tech gadgetry and potentially high costs, they are considered unsuitable for most rural needs.

3.5 Market Potential for Biogas in Georgia

Based on this study, there appears to be a significant demand for small-scale, family-size (4-20 m^3) biogas digesters in Georgia. Currently, based on anecdotal evidence, it is estimated that over 500 biodigesters exist in Georgia against a potential near-term (2007-2011) demand of 1,500 or more digesters spread over different regions.

The potential demand is based on the large quantities of currently unused manure, the need of an alternate cooking fuel to replace environmentally damaging fuelwood use, and to prevent water pollution from piles of manure that exist in and around the rural villages. At present, most manure is piled outside and uncovered, used as raw fertilizer in the field (where land is available) or for cooking, when dry, or in some cases, is put in a hole for composting. The piled manure flows into area water-bodies including nearby drinking water wells[38] with potentially serious health and environmental consequences.

Potential unmet biogas demand however is seriously constrained primarily by the lack of funds to meet the high upfront digester costs. Donor funding has installed most existing digesters in Georgia; ironically, such funding,

> ***Nepal: Biodigester Success Story***
>
> Nepal has over 125,000 mostly family-size biogas digesters installed through a dedicated marketing approach. At present, over 45 companies market, construct, and install biodigesters, and also provide guarantees for the biodigesters. The Agriculture Development Bank or one of the approximately 59 Micro-finance Institutes (MFI's) including savings and credit cooperatives, rural development banks, and others biodigester loans. MFI's provide loans for 18-24 months, using group collateral and interest rates not exceeding 16 percent. An 8-m^3 digester is generally considered suitable for a family of 5-8 people. The GGC-Model, a modified Chinese dome design, is the most popular biogas plant design with capacity range of 4-20 m^3. Over 60% of all digesters are also connected to a latrine. Over 90-94% of all digesters are operational.

[38] Even for a biodigester, there should be no manure pit within 13-15 meters of a well or spring used for drinking water.

under almost non-existent competition has kept the installations costs high.

Contributing factors to this situation are: (i) lack of access to affordable credit, (ii) lack of know-how and awareness at the farmer level, (iii) lack of supporting policies and infrastructure such as robust and tested standards, (iv) most communities unwillingness to participate in community digesters, where feasible, (v) weak private sector interest and participation, given real and/or perceived high risks and lack of relevant regulatory support and (vi) others such as affordable and accessible biogas appliance (valves, stoves, lamps etc.) at low prices. To access this potential, it is recommended that a well-designed market survey is initiated at the start followed by review of current constraints and development of effective mitigation measures.

A commercial market for household digesters can be created by mobilizing commercially viable number of biogas plants, ensuring long-term commitment by stakeholders and, building consumer confidence such as through pilot-projects, supportive government policies and by providing one-time construction subsidies. Pilot projects should accompany a well-designed information campaign about energy, fertilizer and cleanliness of biogas.

If the GoG plans to develop a national program it needs to spearhead an initiative to focus on areas with livestock density, temperature, availability of water, scarcity of alternate energies particularly for cooking, while implementing policies that are conducive to private sector investment and participation. Government should help create an enabling environment for market development, including by providing subsidies, supportive tax policies, develop technical and operating standards, and other measures to legitimize the program. The private sector can help mobilize the supply side for biodigester plants. Commercial success of the business can lead to its sustainability. The call out box, *Nepal: Biodigester Success Story,* highlights such support; the resulting positive outcomes are well recognized.[39]

3.6 Biodigester Design(s) for the Proposed Sites

Under the 9-village REP area, currently, Kabali, Kakhareti, Machakhela and Ritseula villages are identified as potential areas for the proposed biodigesters (Appendix H: *Geophysical and Other Characteristics of the Proposed Digester Sites,* provides more details on these sites). The widespread rearing of cattle by the area's largely rural households combined with the need to find an alternative, sustainable fuel to firewood for cooking in these households makes biogas a potentially viable source. The program will promote and support the installation of quality biogas plants using experienced and reputed installers.

For all biodigesters, climate plays an important consideration particularly in the type and design of a biodigester. Georgia's extremely diverse climate encompasses several climatic zones from humid subtropical to eternal snow and glaciers. Georgia is located on a rather low latitude, has moderate cloud cover, with an average annual length of sunshine ranging from 1,350 to 2,500 hours, and a significant total rate of solar radiation amounting to approximately 115 to 150 kcal/cm² between sea level and 500 meters elevation. For each of the site, careful attention should be paid to the local year-around weather.

Also, for all villages selected some factors are common. These include: (i) the availability of animals (for manure); (ii) interest of the farmer, and (iii) ability to cost-share (through labor and/or cash). While these factors are conductive to digester installations, they need to be supported by making sure that the plants

[39] Critical elements of the Nepal program include: innovative financial engineering and judicious application of consumer subsidies. For the private sector, all participating companies must meet strict production quality and service standards for their biogas plants. As a result of growing competition, technical design modifications, and better quality control measures, the overall cost of biodigesters have declined about 38%.

are installed appropriately, providing appropriate training to the farmers, and to the extent possible after-installation support such as contracting through the installer(s) is also important.

Moreover, selection of a competitively selected vendor(s) is important. The individual or entity must also provide digester documentation that should specify the type of digester and include a process diagram with the following minimum information. The digester should also meet the manure requirements of the farmer and include information on: (i) Flow rates, influent and effluent, (ii) Design total and volatile solids content of influent and effluent, (iii) Digester volume, (iv) Retention time, (v) Type of heating system, control and monitoring (where needed), (vi) Methane yield, and has (vii) Process Control and monitoring. Later, as regulatory requirements are developed in Georgia, specific needs may also have to be included.

As a recommendation, it is suggested that the Chinese design be given preference over the Indian Floating Dome Design provided adequate cost-effective measures are included in the design to keep required digester temperature in the colder months. Several techniques, economical and feasible for these areas, have been suggested under Sections 2.3 and 3.3 of this study.

The major reasons for recommending Chinese design with modifications, as currently being practiced in Georgia, are that: (i) the design is considered technically suitable because it has demonstrated its suitability elsewhere for similar settings, (ii) uses easily available materials, (iii) the local industry, though very limited, is experienced in the design and its installations, (iv) avoids the (difficult) issues related to transporting (and also procuring) the steel (or reinforced fiberglass, as steel substitute) such as for the Indian design, and (v) has relatively cheaper costs.

The GGC Nepali design (basically a modification of the Chinese design), given very limited experience, is not recommended in spite of its potential suitability. However, it is also recommended that where a potential site is highly rocky and in a high seismic area, the Indian Dome Design should be reviewed for its suitability. This design requires lesser digging and potentially can better withstand impact of earthquakes.

Furthermore, several factors are important in locating a biodigester at a particular site. For example, the digester should le located away from the drinking water supply (such as well), located in a sunny area—preferably should not receive any shade during the day—close to the source of the manure, close to a source of water, and close to the point where the gas will be used. If it becomes necessary to choose among these factors, it is most important to keep the plant from contaminating drinking water source(s). Next, as indicated above, as much sun as possible is important for the proper operation of the digester.

The other variables are largely a matter of convenience and cost: transporting the manure and the water, piping the gas to the point of use, and so on. Nevertheless, manure transportation should not involve excessive time. Also, it is of relevance to note that fresher the manure, the more methane is produced as the final product and the fewer problems with biogas generation will occur. Also, it is important to make sure that there is enough space to construct the digester. A plant that produces 3 cubic meters of methane requires an area approximately 2 X 3 meters; proportionate adjustments can be made for larger plants.

While a digester can assume any shape, in general, the shape of the tank is determined by the soil, subsoil, and water table. For areas where the earth is not too hard to dig and the water table is low—even in the rainy season—for a 7.0 cubic meter circular tank a diameter of 1.5 meters and a depth 4.0 meters is considered suitable. Where water table is high, it is useful to apply an extra coating of cement to prevent contamination of groundwater.

Often it has proven useful to put an iron or wire strainer (copper screening) with 0.5 cm holes at the upper end of the input and the output pipes to keep out large particles of foreign matter from the pit. Likewise, a flame arrester should be placed in the gas pipe. Likewise, a moisture trap for biogas should be used. For the Indian design, a center wall that divides the pit into two equal compartments has shown better results. The wall can be built to a height two-thirds from the bottom of the digester (226 cm).

All these are generalized recommendations. While these are important, the bio-digester's designer/installer should apply professional expertise based on a bio-digester's site-specific needs such as the end-use of biogas and byproduct and other factors as applicable. For instance, a rocky earthquake prone area may require use of the Floating Dome Design. Beyond design and installation, it is suggested that, with an oversight from GoG, an NGO or other suitable entity, an installer should be required to provide training and implement monitoring and evaluation of the project for such factors as its performance, biogas utilization and any problems arising. M&E may involve the use of a local NGO or other suitable entity. The REP should provide a checklist of parameters to be monitored and how they should be evaluated to gauge performance.

4.0 RECOMMENDATIONS

It is recommended that the proposed digesters under the REP use the Chinese Fixed Dome design and/or its modifications as are currently used. The design appears to be technically suitable and uses construction materials that are easily available and local installers, though limited, have experience with their installations. The Floating Dome (Indian) design should be kept as an option for the rocky and earthquake prone areas especially for the warmer zones. An alternative would be the GGC biodigester for rocky areas (Section 2.2.4). The Bags or Tubular biodigester is not recommended given its limited experience.

To manage the digesters during colder months, several options are provided under Section 2.3 of this study. The current practice of warming the influent manure with hot water, and the use of glass wool, straw, hay, soil or other similar insulation materials (Section 3.4), is considered appropriate and cost-effective. Insulation with the use of composting or similar innovative approaches, while technically feasible are not recommended due to lack of experience and other limitations.

To provide direct heat to the bio-digester, use biogas is recommended. Other options include use of producer gas or solar panels. However, at this time, such options may not be practical for Georgia, given limited resources and experience. In all cases, site-specific conditions and cost considerations will determine the type of insulation material used and the digester design selected. These recommendations are provided as guidelines.

The study indicates that there is a large demand for biogas digesters in Georgia. If the GoG wants to meet this demand, the study has made several recommendations. Key ones include: (i) The need to establish a (small) specialized unit, such as a "Biogas Cell", at the central level (e.g. under the Ministry of Energy); (ii) Coordination of the existing and future funding streams that take into account measures to increase overall investment in the program; (iii) Providing subsidies to meet the high upfront costs, and/or easy access to credit, (iv) Working with key stakeholders—NGO's, international donors, farmers, key ministries including agriculture, education, and environment and private sector to develop appropriate policies; and (v) The development and implementation of training, education and awareness campaigns.

Table 4.1 provides Summary of Key Recommendations. These can be implemented as near-, short- or long-term strategies, based on a feasibility study and biogas program's goals and objectives. Successful implementation of the above measures combined with research, development and demonstration (RD&D) has helped develop a market-oriented and commercially viable biogas industry in China, Nepal and India. The GoG, it is suggested, review this and other relevant experience to further develop its biogas program.

Table 4.1: Summary of Key Recommendations

Problem	Suggested Strategy	Remarks
Which Digester Design(s) for the REP?	1. Use Fixed Dome Design and/or its modifications, as currently used. 2. Competitively procured installer must provide (and implement) details as listed in the study (Section 3.6) 3. Use site-specific (See Appendix G) and other information.	Use Floating Dome design for rocky and (highly) earthquake prone areas; provide good insulation if used in colder climates.
Colder Weather Strategies/D-esigns	1. Use hot water (heated with fuelwood, biogas etc.) to warm influent manure, where needed. 2. See section 3.3 for measures to insulate and/or heat bio-digester. 3. Use locally available insulation materials such as hay,	Newer, automated designs are not recommended due to potential technical, economic and other

	straw, soil and others. 4. Monitor biodigester temperature in winter weather.	limitations.
Biogas Development is Not Prioritized	1. Integrate biogas into national energy development plan. 2. Provide policy support. 3. Establish Biogas Cell at National Level. 4. Seek funding: domestic/international donors 5. Address Capacity-building issues including entrepreneurial development and training of farmers, installers etc.	Work with the Ministry of Energy and local NGO's; gain from international experience
High Upfront Costs	1. Provide construction subsidies. 2. Facilitate access to credit such as via micro-finance and through use of low-interest, long-term loans 3. Motivate private sector through tax incentives, loan guarantees etc.	Work with rural finance institutes, rural banks and others
Limited Investment and Financial Support	1. Create confidence among banks; provide some kind of collateral; develop enabling policies; work with rural banks. 2. Install (non R&D) pilot projects to demonstrate demand. 3. Experience shows that the above helped (i) banks to provide soft loans; and (ii) generate commercial biogas markets.	Seek assistance from (i) international donors and (ii) domestic resources
In adequate R&D	1. Create action plan to scope, develop and demonstrate biogas technology. 2. Focus on colder climates and low cost approaches. 3. Improve technical reliability	At the start, pilot project should not be R&D-oriented.
Weak Private Sector Interest	1. Provide incentives e.g. accelerated depreciation, subsidized credit etc. 2. Make biogas eligible for micro-finance.	Address barriers that limit access to micro-finance and easy credit.
Low Public Awareness	1. Enhance via mass media, exhibits, conferences, farm campaigns etc., as prioritized	Work with NGO's e.g. EEC and other ministries.

APPENDIX A:
ENERGY CONTENT OF BIOGAS FROM VARIOUS ANIMALS

Material	Swine (per head)	Swine (per head)	Beef (per head)	Poultry (layers) (per bird)
Design Criteria				
Animal weight (kg)	62	64	364	1.9
Total fresh manure & urine (gal/day)	1.35	12.5	6.1	0.032
Solids content (%)				
Before dilution	10.0	15.0	15.0	25.0
After dilution	6.7	8.0	8.0	8.0
Total waste volume after dilution (gal/day)	2	24	12	0.1
Volatile solids production (VS kg/day)	0.45	5.45	2.3	0.018
Digester loading rate (kg VS/ft^3 digester/day)	0	0	0	0.056
Digester volume (ft^3/head)	5	47	19	0.3
Retention time (days)	20	15	13	22.5
Probable VS destruction (%)	50	35	45	60
Anticipated Gas Yield				
Yield (per ft^3 digester volume)	1	1	1	1
Yield (ft^3/head/day)	4	46	28	0.29
Gross energy content (Btu/kcal/head/day)	2,300/580	27,800/7,006	16,600/4,183	180/45.4
Net energy content (Btu/ head/day) (Uses 35% of gross to operate digester)	1,500	18,000	10,700	110

Source: Barker, James C. 2001. Methane Fuel Gas from Livestock Wastes: A Summary. North Carolina State University Cooperative Extension Service, Publication #EBAE 071-80

APPENDIX B:
OPTIMIZING FACTORS FOR ANAEROBIC DIGESTION AND DIGESTED SLURRY

Temperature
- Mesophilic = 95°F (35°C) ± 5°F (2.8°C)
- Thermophilic = 140°F (60°C)
- Each -6.7°C or 20°F decrease cuts gas production in half.

Loading Rate
- Semi-Continuous Batch Loaded
- Digester Retention Time = 15 - 30 days
- Manure Solids Content = 6 - 10 %
- Digester Design Range = 0.045-0.136 kg (0.1 - 0.3 lbs) volatile solids / ft^3 / day

Process Stability
- Recommended pH Range = 7.0 - 7.5
- Anaerobic digestion process tends to become acidic (lowered pH).
- Digester failure may occur if pH gets below 6.5.
- Hydrated lime may be added to stabilize pH.

Digester Mixing
- Prevents settling and maintain contact between bacteria and manure
- Maintain uniform temperature
- Prevent surface scum formation
- Facilitate release of the biogas

Nutrients
- Good digestion requires carbon: nitrogen ratio 15:1 to 30:1 range
- Most fresh animal manures fall within this range and need not adjustment.
- Excessive bedding or exposed feedlot manure may present a nutrient imbalance.

Toxic Substances
- Oxygen
- Ammonia
- Abnormal dosages of antibiotics, disinfectants, or cleansing agents

Digester Start-up
- Fill tank with water and warm to desired operating temperature.
- Add seed sludge such as from municipal sewage treatment plant to 15% of digester volume to reduce start-up time.
- Add fresh manure beginning gradually and increasing over a 3-week period to desired loading rate.
- Good gas production should occur in about 4 weeks of start-up.
- Unassisted, bacteria may require 2 - 3 months to multiply to an efficient population.

APPENDIX C:
SMALL DIGESTER DESIGNS IN EUROPE

In EU, the small-and medium-sized farm plants represent about 70% of the existing plants (and, as of 2006, about 80% of the actual annual growth). They have been in use for about 60 years, and the oldest plant (located in southern Germany) has been operating for 36 years.

Most plants in Switzerland, Austria, France, and Great Britain are small farm plants. About half of the existing 38 plants in Denmark are small or medium-sized plants. About 205 of the plants in Germany are small-or medium sized. Germany has seen the strongest growth of such plants during the past 2 years, with 29 new plants built during this period.

The main substrate of German plants is liquid slurry from cattle, pigs, and chickens. One-third of the German plants also use solid manure that includes straw and is liquefied in special mixing devices with slurry or water. In Germany and U.K., increasingly, food industry wastes—oil and fat from frying, slaughterhouse wastes and spoiled food—is being added to the manure.

Two main plant types digesters have been developed in Europe. These are: (i) Horizontal follow-through steel digester, using a standard steel tank, often previously used as a gasoline tank, (ii) Vertical storage digester, using standard slurry storage tank as the digester.

The horizontal steel digesters generally range from 50 to 100 m^3, and occasionally to 150m^3. A stirring axle and arms reach each square foot, making this digester usable for all substrate types. Because of its limited volume and time-consuming construction, it is currently used mostly for problematic substrates such as chicken and other solid manures.

The vertical concrete digester is based on a standard concrete slurry tank as used in southern Germany. These tanks are series products that provide low-cost volume. They can be insulated and made gaslight, and are often built underground, thereby reducing space demand. The volumes range from 250 to 600 m^3, but some are 800 to 1200 m^3 and range in depth from 3 to 6 m and measure 8 to 16 in diameter.

The gas is stored in balloons and protected in containers, silos, or shelter huts: The storage capacity is 60-100 m^3. The biogas is stored at night, when the biogas engine is not running. The 2004 cost of a self-constructed plant for 100 cows (a typical size for southern Germany) is $120,000-$140,000 (U.S.). Also, in a number of EU countries, subsidies are granted, that, for example, in Germany range from 20%-25% of the total cost. A reasonable return on investment can be achieved under these conditions. Also, only a few company-built plants are built because they cost 50%-100% more than self-constructed ones.

APPENDIX D:
DIGESTER SITES VISITED

Lisi Village, Near Tbilisi: The 6-year old 6 m^3 biodigesters, based on cattle manure, was installed under a United Nations Development Program. The digester used an above ground steel structure and a movable gasholder (modified floating dome design). The gas was used for cooking and limited cheese making. However, for the last one year, the digester is non-operational and abandoned. The farmer indicated that he has retired from farming and his children do not have interest in biogas and farming.

Review of the Digester

Loss of interest has been an important element in such non-operational situations in developing countries. The unit appeared intact and salvageable for potential relocation and/or revival. Area farmers can be contacted.

National High Technology Center of Georgia: The center is engaged in biodigesters research for cattle manure, municipal solid wastes and other biodegradable feedstock. During the site key biogas designs were discussed. The leading design uses steel drums and incorporates some high-tech gadgetry such as electric pumps. The situation in the context of Georgia's rural settings, farmers' skills including O&M, and transportation difficulties of the unit to rural setting, many of which are connected by unpaved roads were discussed. It seems the design, in spite of its claimed efficiency in biogas production, is not practical for rural needs.

Review of the Center's Relevant Capacity.

While the technology being designed produced greater gas per unit of feedstock, it applicability, as indicated above, for rural areas at this time is limited.

Bioenergy: The Leading Independent Vendor of Rural Biogas Technology

Based on installed biodigesters, it appears that the company is the leading designer and installer of biogas digesters in Georgia. A number of meetings were held with its Director who also took our team to two of his current installations (Gadami Village, Calka Region and Saburtalo Region, Veris Kheri River area, Tbilisi outskirts; see items 4 and 5). A visit was also made to the Bioenergy's local workshop fabricating biogas digesters. The firm has been in business for over 12 years. (Contact information: Mr. Avtandil Bitsadze, Director; Telephone: (995 99) 152 705, 440822; Email: bioenergy@gol.ge

Review of Company's Capacity

The digester designs the firm uses are primarily fixed dome (Chinese) with some modifications. Its clients have included: the World Bank, the Mercy Corporation, UNDP, and others. Based on discussions with local biogas stakeholders including the international community, it was felt that the firm's business practices primarily digester costing could use some improvement and competition. Outside this, the firm seems to offer good capabilities.

Gadami Village, Calka Region (Southeast Georgia): The digester is located about 5-hour drive, mostly on dirt roads, from Tbilisi. The firm Bioenergy installed the 6 cu m digester in 2005. The digester is based on 12-15 cattle (penned only at night) and uses the fixed dome (Chinese) design. It was installed in 2005 at a cost of about $720, with the owner (Mr. Tsulukidze Guram) contributing free labor. The biogas produced is used for cooking and making cheese, which is profitably sold in Tbilisi via some cooperative arrangement.

Review of the Digester:

The farmer indicated that a number of other farmers in the village are impressed with his biodigester plant and are interested in installing it. However, in spite of the need and the very large quantities of manure available (as seen from large piles around the village), availability of funds is the limiting factor. The farmers are willing to contribute their labor and in some cases, modest amounts of cash.

Saburtalo Region, Veris Khevi River, Tbilisi Outskirts: The 50-m3 digester based on fixed dome Chinese design, is currently under construction. It will use manure from 20 cattle and about 100 pigs that will be housed in the sheds under construction. A cement manufacturing plant located in the vicinity of the site, which is located in a low-lying sloping area along a small river, will use the gas. From the nearby road, the site is not visible and the small access dirt road is sloping and curvy, and can be potentially difficult to navigate. The animals will be permanently confined.

Review of the Digester

The potential digester and its location can present some difficult problems. The site's downhill access is difficult for movement of animals, trucks carrying feed etc. during the installation and life of the digester. The site's area for the number of proposed animals also seems tight. The proposal to transport gas to over 75 meters could also cause problems of pressure, leakage and would require regular maintenance of the pipe and the associated infrastructure; burying the gas pipeline is recommended. Also, the gas might require cleaning to remove hydrogen sulfide to prolong equipment life.

Ninostmninda City, Akhalkalaki Region, South Georgia: CHF International, an organization involved in community, development and finance is assisting a local farmer install a biogas to provide heat for a 150-meter2-greenhouse plant. The site is located along a small creek behind a house in a residential area. The manure for the plant will be trucked from a cattle farm about one kilometer from the site.

On-site discussions were held with the farmer and also with the representative, Mr. Vaginak Kazarian, of CHF. The topics included: initial cost of the digester and the greenhouse (estimated at over US $15,000), the need to truck manure, potentially daily, the residential location, lack of farmer experience, lack of contractual arrangement and available market for the proposed roses to be grown. It was felt that all these issues are relevant to the potential sustainability of the digester. The visiting team did not get a satisfactory response.

Review of the Situation

The entire team visited the cattle farm and noticed large piles of manure on the ground; the manure is potentially available for the digester. The quantities piled are said to significantly increase during the winter months when the animals are confined. In the vicinity of the farm lie large (flat) (grassy) grazing areas. The suitability of installing a greenhouse near or next to the cattle farm was discussed with CHF and also the farmer. Such a location presents obvious economic and technical advantages. An option to install a biodigester inside such as for larger greenhouses was also discussed.

Farmer Nugzor Beridze, Kibuleti area, Western Georgia, ARETP Digester:

The 10 m^3 digester, based on 10-11 adult cattle and 4 calves, has been designed by Bioenergy (Mr. Avatndil Bitsadze, see item 3.0 above) and Installer Lamanzaro helped the farmer Nugzor Beridze install the digester, which uses a fixed dome, design. The all-concrete digester is spherical at the top and flat (260-meter base) at the bottom, which is connected to an 8.0-meter wide overflow tank. The installer used locally available, liquid glass, (about 10 liters); use of liquid glass is considered cost-effective for making the digester air and watertight. Over 400 bricks and 2 ¼ ton of cement was used in the construction of the biogas plant.

The gasholder is made of steel procured from Tbilisi. The daily-fed manure is manually stirred and mixed with water before feeding it into the digester. The digester took three months to construct. The biogas produced is transmitted to the house located about 12-meter away, using a long plastic pipeline, which does not have a flame arrester (See section 2.4). The gas is used for cooking and profitably, for cheese making. Farmer's cell phone no. Is: 855 140 592

Review of the Digester:

Transferring biogas over about 12-meter using a plastic/rubber pipe poses safety hazards; overtime, biogas can corrode the pipe causing gas leakage and potentially adverse safety situation. The farmer and the installer were told about the potential danger(s). The byproduct slurry is used to fertilize adjoining double-cropped corn and bean fields where it has shown improved yields as per the farmer. The farmer indicated that many farmers in the area would like to install these digesters, given the availability of manure and potential to make money. The ARETP paid 80% cost of the digester while the farmer contributed 20% by way of labor.

Farmer Gigla Lamanzaro, Kibuleti area, Western Georgia, ARETP Digester: Another area farmer using the above installer and similar design as well as similar biogas and residual fertilizer has installed a biogas digester in the same village.

Review of the Digester

A similar situation as described above for Farmer Nugzor Beridze exists and was discussed with the farmer and also the installer.

APPENDIX E:
DAILY INPUT OF CATTLE MANURE AND URINE RECOMMENDED FOR GEORGIA

Capacity of biogas facility m^3	Volume of daily input of bio mass (kg)	Daily supply of water (litre)	Number of cattle heads
4	24	24	2 - 3
6	36	36	3 – 4
8	48	48	4 – 6
10	60	60	6 – 9
15	90	90	9 – 14
20	120	120	14 and more

Source: Bioenergy Inc. 2007 Tbilisi, Georgia

APPENDIX F:
PERSONS/ORGANIZATIONS CONTACTED

A. Independent Georgian Biogas Installers/Experts

1. Mr. Avtandil Chelidze, Black Sea Area/World Bank Project, Cell: 899 517 923

2. Mr. Merab Tehirakadze, Cell: 899 9898 32; Email: chiraqadze@yahoo.com; Example of a biogas installation: 11 cu meter in village Artani.

3. Mr. Jumber Khantadze, Metallurgical Engineer, Georgian Union of Mountain Activities. Cell: 990 666; 899 539048; Email: Not available.

4. Mr. Gigla Lamanzaro, Cell: 855 140 592: Email: Not available: Has installed digesters for the World Bank under its ARETP projects in western Georgia.

5. Mr. Sanikidze Malxaz: Cell: 899 970 257; Email: sanikidzem@gmail.com; Associate of JSC, a Joint Sub Company and also of the Ministry of Economy. Works as a sub-contractor on World Bank Biogas projects.

B. Organizations

1. BioEnergy/Tbilis: Mr. Avtandil Bitsadze, President; Cell: 899 15 27 95; Email: bitsadzeavto@yahoo.com: www.bioenergy.ge (Previous name of the firm: Konstruktor Inc.)

2. CHF International/Georgia Mr. Vaginak Kazarian, Community Economic Officer, Cell: (995 99) 47 80 09; (995 8 90); Email: vjazariani@@chf.ge

3. Energy Efficiency Center/An NGO: (i) George Abulashvili, Director, (995 32) 921 640; Email: g_abul@eecgeo.org, (ii) Ms. Manana Dadiani, PhD, Head Renewable Energy Department, Cell: 995 99 531350; Email: m_dadi@eecgeo.org

4. Georgia Technical University: Professor Baadur Chkhaidze, Cell Phone: (995 93) 329169; Email: bchkhaidze@yahoo.com

5. Ministry of Economic Development of Georgia: Mr. Giorgi Nanobashvili, Head, Economic Policy Department, Telephone: (995 32) 988 441; Email: gnanobashvili@econom.ge

6. National High Technology Centre of Georgia: Dr. Tamar Dudauri, Head of Laboratory of Renewable Energy, Telephone: (995 32) 30 82 53; Email: tamaradudauri@hotmail.com

7. United Nations Development Program: Mr. Paata Janelidze, Project Manager, *Georgia, Promoting the Use of Renewable Energy Resources for Local Energy Supply*

8. The World Bank/Tbilisi: Ms. Darejan Kapanadze, Operations Officer, Environmentally and Sustainable Development. Telephone: (995 32) 91 30 96; 91 23 56

9. The World Bank/IFAD: (i) Ms. Nino Inasaridze, Head, Environmental Pollution Reduction Program, Cell: (995 99) 908 565; Email: nino.inasaridzae@adpcc.org.ge, (ii) Ms. Nino Gulua, Assistant of the Environmental Pollution Reduction Program, Cell: (995 32) 113 235; Email: nino.Gulua@adpcc.org.ge

APPENDIX G:
GEOPHYSICAL AND OTHER CHARACTERISTICS OF THE PROPOSED DIGESTER SITES

1. Kabali Village:

The Kabali region is located on the left bank of the Kabali River, eight kilometers from the village of Baisubani in the Lagodekhi district of the Kakheti Region in Eastern Georgia. The distance from the Black Sea and its orographical conditions determines the climatic factors of the Kabali River Basin. The annual average temperature is 12.60 Celsius. The absolute maximum air temperature is 380 while the absolute minimum point is - 230. The total annual precipitation averages 1076 millimeters with an average wind speed of 11 meters per second.

Various soil types are found in different parts of the Kakheti region due to differences in physical, geographical, and climate conditions. For example, on the left bank of the Alazani River, sandy, alluvial and non-calcareous soils are most common. On the lowest strip of the first upper terrace near the Alazani River flood plain, primarily meadow, alluvial, and carbonate soils. The area is also considered to be an active seismic zone[40] and flash floods are also common during heavy rains or intense snow melts. All such factors are relevant to the location and type of digester considered.

2. Kakhaeti Village

The village of Kakhareti is about 20 kilometers from Borjomi-Kharagauli Natural Park and is surrounded by wooded hills. Kakhrety is a part of the Lelovani Sakrebulo, which consists of Kakhareti plus four additional villages.

Soils vary throughout the village/region according to elevation, degree of slope and specific location. Mountain-black and carbonic soils are predominant in the lower parts of the region while clay-black and mountain-meadow soils are found in the upper parts of the plateau. Steep slopes are characterized by thin-layered soils. In the river valleys and near lakes, semi-marsh soils are common. Soil types are important considerations in a potential digester location. In terms of seismicity[41] the territory is considered to be in an active seismic zone.

The Sakrebulo has 344 households and 1,243 persons and over 338 hectares of arable land. It is estimated that as of 2006, there are 950 cattle and 250 poultry. Average annual cash income is estimated at $350. The local population uses kerosene, fuelwood, candle and power generators. Grid-power is available in some areas through UEDC's Adigeni Service Center; most rural people however do not have access to grid-power. Water supply is mostly through area springs.

3. Machakhela Region

The potential location for the biodigester is in the Adjara region (village Kedkedi, about ½ hour Southwest of the Black Sea resort town of Batumi), in the Chrokhi River Basin in western Georgia. Average altitude ranges from 2,000-2,500 meters. The mostly mountainous area has lots of cattle and limited arable land.

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[40] Seismicity of the region is rated a "nine" (9) using the MKS scale Map of Seismic Hazard Assessment of Georgia, 2006.
[41] Seismicity of the region is rated an "eight" (8) under the MKS scale (Map of Seismic Hazard

Given its location, the climatic conditions are determined by the distance from the Black Sea and the area's orographical features. Based on the information provided by REP, average temperature is 13.5^{0}C and the range of temperature is –10^{0}C to 41^{0}C. The area has high annual precipitation, reaching 2,000 millimeters in some places. The ground can be covered with snow for a couple of months in the winter in a number of places in the area.

The project area is thinly populated and, mostly divided between agriculture and pastures, is privately owned. Citrus, vineyards and orchards are major fruit crops. Overall, the region has 24,400 cattle and 1,800 sheep and goats. While grid-power is available, many rural people do not have access to it. They use kerosene, woodfuel, and petrol for cooking and power generation (via a generator). The area has both paved and unpaved roads.

Soils vary throughout the region[42] according to elevation and degree of specific location. A narrow beach is covered by sandy and sandy-alluvial soil. In some parts of the region marsh and meadow alluvial bog soils exists. Red soils predominate in the upper part of the mountain. The area, as compared to the above two villages, has comparatively lesser seismic activity. However, given heavy logging, is subjected to landslides.

4. Ritseula Region

In this region, the potential location of the biodigester is in the village of Sadmeli (region's north-central). It is mountainous; however arable land availability is greater than Machakhela region.

[42] Map of Soil types of Georgia, 1999

APPENDIX H:
CONVERSION TABLE AND CONVERSION FACTORS

Conversion Table:

Conversion from	To	Formula
Celsius	Fahrenheit	°F = °C × 1.8 + 32
Fahrenheit	Celsius	°C = (°F – 32) / 1.8
Celsius	Kelvin	K = °C + 273.15
Kelvin	Celsius	°C = K – 273.15

Conversion Factors Used:

1 cu ft	=	0.03 cu m
1 lb.	=	0.45 kg
1 gal	=	3.8 liter
1 Btu	=	0.252 kcal

APPENDIX I:
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