

BIOGAS USE IN RECONSTRUCTION

PRACTICAL ACTION
Technology challenging poverty



Introduction

Biogas is a mixture of approximately 60% methane and 40% carbon dioxide, produced by the breakdown of organic materials such as human excrement, dung or vegetable matter by bacteria. The process of anaerobic digestion takes place in a sealed tank known as a digester, occurring at slightly elevated temperatures; the most effective ranges are between 30 - 40°C for mesophilic bacteria and 50 - 60°C for thermophilic bacteria (US Dept. of Energy, 2011), whilst it is far less effective outside of these. Biogas is a clean, high grade fuel used for cooking, lighting and generating electricity. It can be produced on a scale varying from a small household system to a large commercial plant of several thousand cubic metres.

The bio-digestion of animal and human waste yields several benefits:

- The production of methane for use as a fuel, which reduces the amount of woodfuel required and thus reduces desertification.
- The waste is reduced to slurry that has a high nutrient content, making an ideal fertiliser which can be utilised as a commercial product or to improve the fertility of local arable land.
- During the digestion process, dangerous bacteria in the dung and other organic matter are killed, which reduces the pathogens dangerous to human health.

Biogas is a well-established fuel for cooking and lighting in a number of countries. China has over 7.5 million household biogas digesters, 750 large- and medium-scale industrial biogas plants, and a network of rural 'biogas service centres' to provide the infrastructure necessary to support dissemination, financing and maintenance. India has also had a large programme, with about three million household-scale systems installed (Martinot, 2003). Other countries with active programmes include Nepal, Sri Lanka, Kenya, and several in Latin America. As carbon emission levels are becoming of greater concern and as people realise the benefits of developing sustainable, low carbon energy supplies, then biogas becomes an increasingly attractive option.

Relation to People-Centred Reconstruction

The production and use of biogas by various methods has three general benefits (as described above); the production of biogas can either compliment or replace traditional woodfuel or biomass, helping to reduce local environmental damage, with increased energy security. People producing their own energy supplies can reduce dependency on external sources, making them less vulnerable to outside risks and shocks. Additionally, the production of fertiliser can improve the condition of agricultural land, leading to increased food production and the possibility of improved livelihoods.

As well as helping people to become more independent and productive, the replacement of smoke-producing woodfuels and the safe containment of harmful bacteria can have a significant positive effect on wellbeing. All of these potential benefits are directly related to key aspects of PCR. This technical brief provides an overview of various technologies to produce and use biogas. It will discuss the practical applications of biogas technology and details some examples of where it has benefitted a reconstruction scenario. The relevance and applicability of the technologies to the three stages of reconstruction are discussed.

For the original document see Practical Action's technical brief [Biogas](#).

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Uses of Biogas

Biogas and the waste it is produced from have a wide variety of applications. They can be used in household appliances or larger, community-based systems, providing energy services both essential to everyday living in a reconstruction context and as a means of improving livelihoods after a disaster. Some of the general uses include:

- Direct use for cooking, lighting and heating
- Fuel for combustion engines to drive an electricity generator
- Transport fuel
- Fertiliser (waste)

Some typical consumption rates for applications are given in Table 1 below:

Application	Consumption L/min	Consumption m ³ /hour
Gas lamp	2.4	0.14
Refrigerator burner	2.4	0.14
Domestic cooking burner	4-15	0.2-0.9
Commercial burner	20-50	1-3
Duel fuel engine (per kWh)	9	0.56
Spark ignition engine (per kWh)	11.5	0.7

Table 1: Typical consumption rates for biogas appliances (FAO, 1992).

Biogas Plants

Biogas plants are sealed containers built specifically to create the anaerobic conditions necessary for digestion and controlled production of gas. Most common biogas plants must be fed daily with feed material or slurry to ensure continuous gas production. The slurry is a mixture of organic material and water, usually in equal proportions. Many types of organic materials can be used. The aim of the digester is to provide a sealed vessel that allows input of feedstock and removal of gas whilst being built of locally available construction materials.

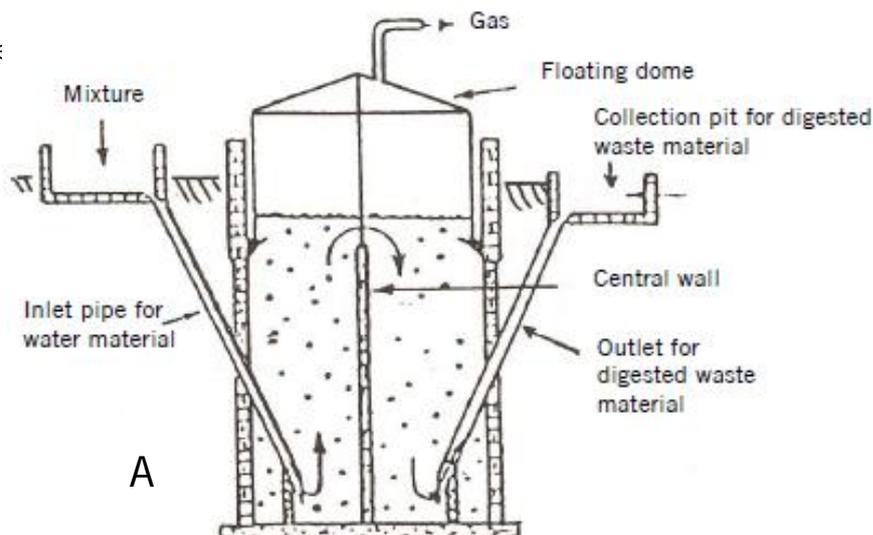
Domestic Biogas Plants

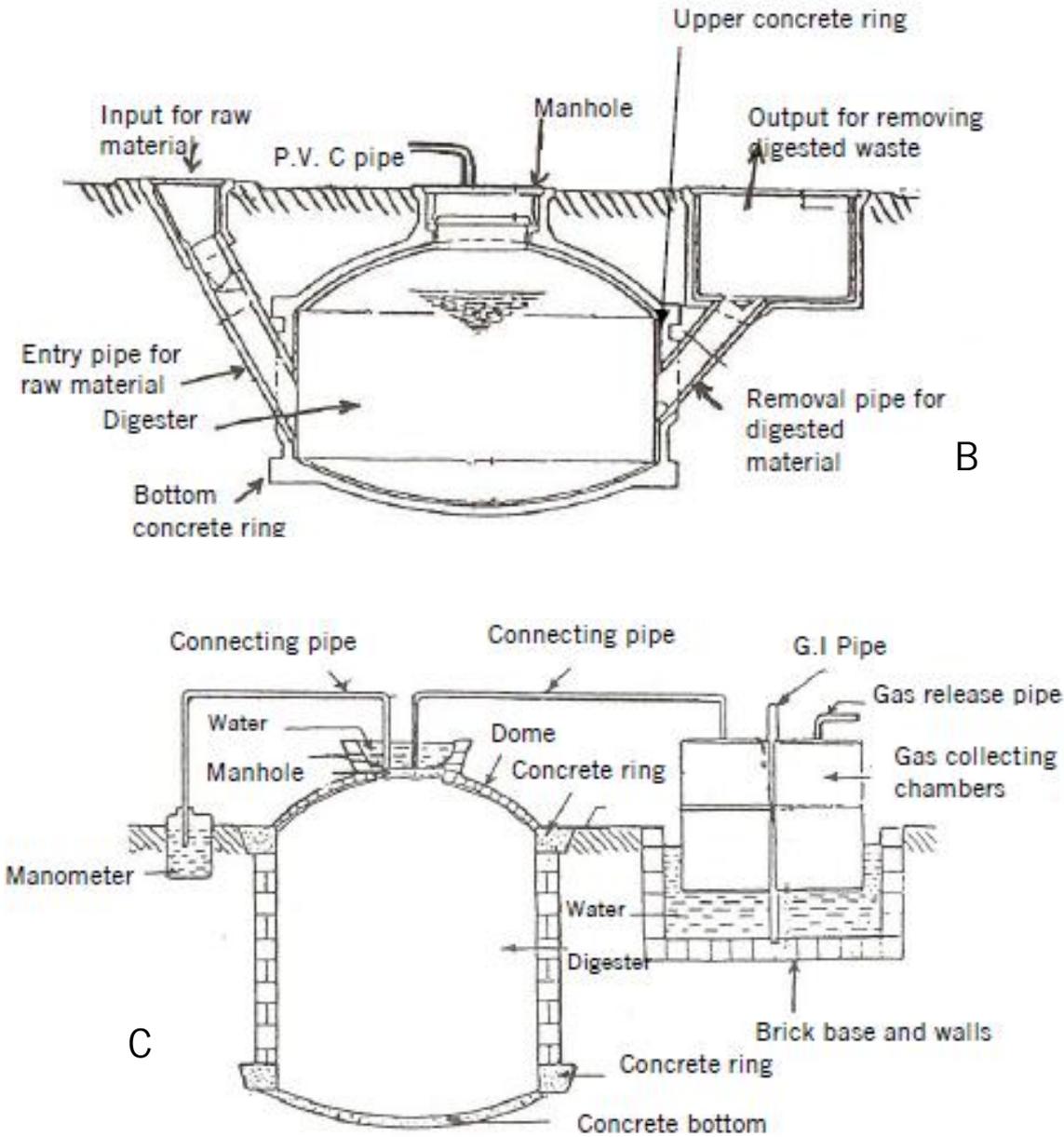
The most common types of digester are the floating dome (or Indian digester), the fixed dome (or Chinese digester) and the Sri Lankan digester. These plants are predominantly for use with cattle and/or pig waste, requiring regular ‘feeding’ and daily maintenance.

The construction of these plants requires significant investment and planning, and they are therefore not generally suited to emergency responses. The permanent reconstruction phase, where families and individuals are building long-term housing solutions, gives the most appropriate opportunity to consider these technologies.

Figure 1: Sections of domestic Biogas plant designs.

- (A) Indian digester
 - (B) Chinese dome digester
 - (C) Sri Lankan digester
- Source: Practical Action





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Specific details on the construction and operation of these plants are available in the Practical Action technical brief [Using a Biogas Digester](#). For more details and case studies on how individuals have benefitted from these technologies see the Practical Action [biogas homepage](#).

An alternative to the above is a 'compact' biogas digester, which can produce a usable fuel from the degradation of waste foodstuff. This can be particularly useful in scenarios where the owner and operator of the machine does not have cattle or other animal stock. The technology has been developed by the Indian Appropriate Rural Technology Institute, and can produce gas from a variety of feed stocks, including waste flour, vegetable residues, waste food, fruit peelings, rotten fruit, oil cake and rhizomes of banana (ARTI, 2006). Details of this solution are covered in the [Biogas](#) technical brief, with a specific building manual [ARTI Floating Dome Biodigester](#) also available.

Alternative (short-term) Biogas Plants

However, in more short-term scenarios other digesters such as the bag or balloon digester (a type of Plastic Bio-Digester) and the plug flow digester (a type of Earth-pit plant) may be appropriate, since they are easier and quicker to construct. This corresponds with a shorter useful life span compared with more advanced technologies.

Bag or Balloon Digester

A balloon plant is a type of Bio-Digester that consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin and therefore safety valves are required; if higher gas pressures are needed, a gas pump is required as well.

Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), trevira and butyl. The useful life-span does usually not exceed 2-5 years. Balloon biogas plants are recommended if local repair is or can be made possible and the cost advantage is substantial.

Advantages: Standardised prefabrication at low cost, low construction sophistication, ease of transportation, shallow installation suitable for use in areas with a high groundwater table; high digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance; difficult substrates like water hyacinths can be used.

Disadvantages: Low gas pressure may require gas pumps; scum cannot be removed during operation; the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon. There is only little scope for the creation of local employment and, therefore, limited self-help potential.

Variations: A variation of the balloon plant is the channel-type digester, which is usually covered with plastic sheeting and a sunshade (fig.2-E). Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high.

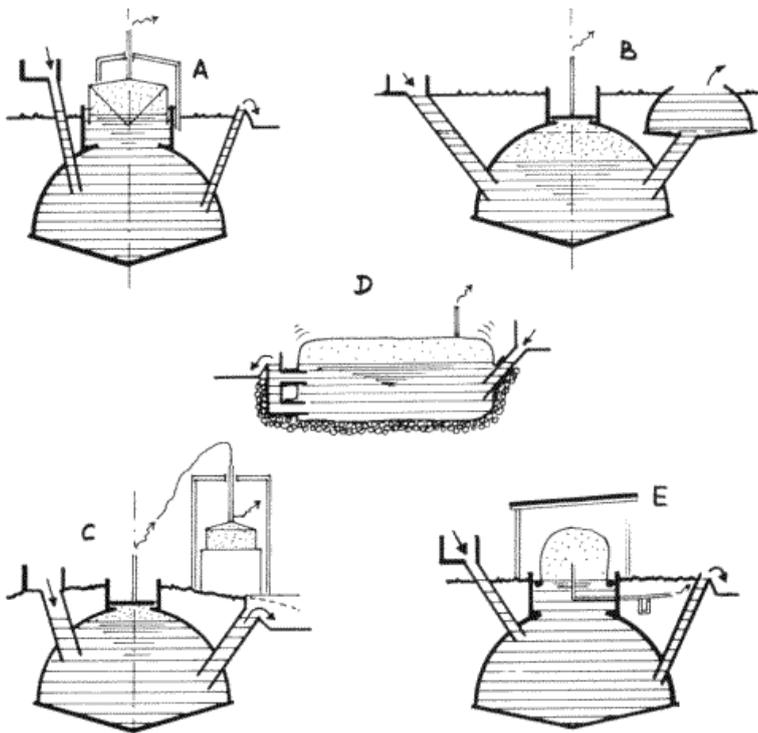


Figure 2: Sections of various biogas digester plant concepts:
 (A) Floating-drum plant
 (B) Fixed-dome plant
 (C) Fixed-dome plant with separate gas holder
 (D) Balloon plant
 (E) Channel-type digester with plastic sheeting and sunshade.
 Source: Biogas Plants, L. Sasse, GATE, 1988, p. 14

Plug Flow Digester

This is a type of Earth-pit plant, therefore appropriate in stable soil (e.g. laterite), where masonry digesters are not necessary. Earth-pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gas-holders.

For earth-pit plants, it is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as anchorage for the gas-holder. The gas-holder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gas-holder. An overflow point in the peripheral wall serves as the slurry outlet.

Advantages: Low cost of installation (as little as 20% of a floating-drum plant); high potential for self-help approaches.

Disadvantages: Short useful life; serviceable only in suitable, impermeable types of soil.

Plug flow digesters (Figure 3) constitute a type of earth-pit plants that have long, narrow concrete tanks with either a rigid or flexible cover. The vessel is a long narrow (typically a 5:1 ratio; 5 times as long as the width) insulated and heated tank made of reinforced concrete, steel or fiberglass with a gas tight cover to capture the biogas.

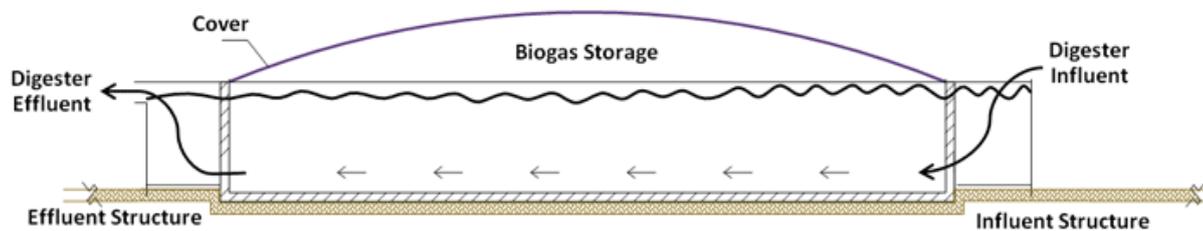


Figure 3: cross-section diagram of a plug flow digester. Source: <http://www.plugflowdigester.com/>

The plug flow digester (tank) is built partially or fully below grade to limit the demand for requiring additional heating. Plug flow digesters are used only at dairy operations that collect manure by scraping. In theory, manure in a plug flow digester does not mix longitudinally on its trip through the digester but can be imagined to flow as a plug, advancing towards the outlet whenever new manure is added.

When the manure reaches the outlet it discharges over an outlet weir arranged to maintain a gas tight atmosphere but still allow the effluent to flow out. In actuality the manure does not remain as a plug and portions of the manure flow through the digester faster than others and some settles or floats and remains in the digester. Biogas produced by the digester is used to heat the digester to the desired temperature.

Excess biogas can be used to run an engine generator. Heat can also be recovered from the engine generator and used for space or floor heating, water heating or steam production to offset the cost of purchased electricity, propane, natural gas or fuel oil used on the farm for daily operations.

Products of Biogas Plants

Biogas: The digestion of organic matter in the biogas plant forms methane commonly referred to as biogas. This is a combustible gas that burns with a hot blue flame. Biogas is neither poisonous nor as flammable as other gases used for cooking or lighting. In some countries such as Kenya, biogas is mainly used for cooking and lighting. It is also used, to a limited extent in community systems, to run refrigerators, and diesel and petrol engines.

Sludge: The residue or sludge from the fermentation process in the biogas digester is the main product of the plant. It is a fertiliser of better quality than undigested waste because the nitrogen previously unavailable to crops is transformed into water-soluble ammonia which is readily taken up by plants.

Experiments have proved that sludge is a better fertiliser than commercial, inorganic fertiliser. It improves crop yields when and if properly used, and farmers can save considerable amounts of money that would otherwise be spent on purchasing commercial fertilisers.

Selection Criteria for Biogas Plant in a PCR Context

When building a biogas digester, certain criteria must be met if it is to be successful, and the ones below apply specifically in a post-disaster context:

Technical:

- The temperature has to be high enough to cause the digestion process to work.
- For fixed-dome type digesters, the quality of the building materials must be high as the biogas is held under pressure within the dome.
- Skills and know-how are needed both to build and to maintain biogas plants; this must be transmitted to the local population in-line with a PCR context.

Social:

- Providing operators with a financial stake in the system they are using could encourage greater responsibility for operation and maintenance, being directly linked to earnings and investments.
- Handling animal and human wastes is a sensitive cultural issue and even the use of the gas may be unacceptable in some societies, although this is only very occasionally.
- Promotion and dissemination of the benefits of biogas will be needed if it is to be accepted by communities not used to the concept.
- The use of human waste appears to be more successful when it is associated with an institution such as a hospital or a communal facility such as a refugee camp, rather than an individual home, as the amounts of waste available tend to be much higher.

Financial / political:

- Government promotion and involvement can assist in dissemination. This can be a win-win solution as it provides clean energy and reduces problems associated with waste; significant government investment early on in reconstruction may reduce /prevent problems from occurring later on.
- Private sector investment will support long-term sustainability, but is more suited to individual family units.
- Set-up costs are relatively high but in some cases a special budget and aid located for post-disaster reconstruction can be used to introduce biogas, which can continue to provide clean fuel during and after reconstruction.

Using Biogas units to reduce waste

In a post-disaster scenario it is likely that toilet provision will be limited to pit latrines, at least until more advanced solutions can be implemented. The pit can fill up quickly, which can easily lead to pollution, contamination and unsanitary conditions unless either a new pit is dug or the existing pit is emptied. In rural settings it is generally easier to construct a new latrine, but this is probably not possible in a confined urban setting.

Therefore, in urban reconstruction contexts there is a requirement for latrines to be emptied as they become full of waste sludge. Currently this is dominated by manual methods, which are inefficient and expose the operators to severe health risks. Practical Action’s technical brief [Pit Emptying Systems](#) examines some of the advanced mechanical emptying solutions that are being developed.

Another option is to combine biogas digester technology with the latrines; this gives the opportunity to control human waste and reduce pollution, whilst providing useful fuel and by-product in the process. Despite the several benefits that this can achieve, there are certain barriers to implementation that must be considered, including ‘soiling-up’ (a hard irretrievable layer grows with use), social acceptance and logistical constraints. Refer to the Practical Action technical brief [Using Biogas Technology to Solve Pit Latrine Waste Disposal Problems](#) for a detailed study on this.

A combination of both shallower pits and permanent suction pipes could be beneficial to solving fluidity/emptying issues and soiling up in pits, but also provide hygiene benefits to the emptier and fresher feedstock for the digester. The critical factor when assessing digester placement is space, because without it there will be no other problems. Regarding pressure issues, the use of a storage vessel is proposed rather than just a comprehensive maintenance program because it provides the user with the ability to alter the pressure, however further assessment would be required.

The issues regarding technology when using biogas to reduce waste can be split into *collection*, *haulage*, *disposal* and *treatment*:

Collection: the sludge will be partially degraded upon emptying therefore decreasing the maximum methane yield. This means, to make the system feasible the frequency of pit emptying will have to increase. Pit emptying frequency is inversely proportional to the operational life of the pit. Dismantling is often required when emptying a pit.

A solution proposed is to fit an in-situ pipe to the pit that has an exit outside the super structure (Figure 5). This addition will limit the disruption caused by emptying as well as making the whole process more hygienic because the hose will no longer have to be dropped into the faeces. The addition will also help deal with the problems regarding viscosity and *soiling up* in pits because emptying will happen from the bottom and water can be added through the pipe to decrease the viscosity.



Figure 4: Pit latrines in the Kibera informal settlement (slum) in Nairobi, Kenya. Photo: Karen Robinson / Practical

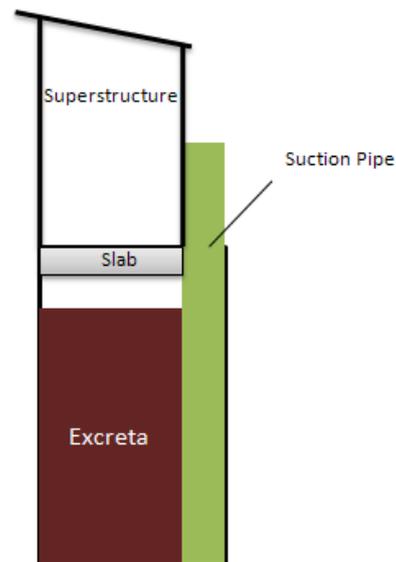


Figure 5: A diagram conveying the use of an in situ pipe. Source: Practical Action

technical brief

Haulage: for sustainability reasons and to limit costs the push is to combine the system with manually operated emptying technologies (Boot N., 2006). These technologies are also more feasible in urban settings where access is an issue for vacuum pumps. When using these technologies it is not the distance from the latrine to the disposal point that is the defining factor but the time it takes.

Disposal: is essentially about the placement of the digester which is governed by three main factors:

- Space and land tenure; for example in slum areas space is sparse and they live on land they do not own so improving sanitation facilities is not high on their priority list
- Not in my back yard (NIMBY); people do not want waste dumped where they live however this is a very context specific area
- Use of the gas; whether it be a communal facility or private household

Treatment: there are essentially two main issues regarding treatment. The first is problems surrounding pressure of the gas. One solution would be to ensure that the digester is correctly maintained. Another physical solution, highlighted by Kossmann et al. (1999), is the use of a separate gas holder. Floating drum digesters allow the user to alter the pressure of the gas by applying weight and pushing the moving "drum" down.

Research has highlighted maintenance issues surrounding these digesters and that fixed dome digesters provide better results. Therefore a possible solution is to take the benefits from both technologies and use them to their full advantage by using the fixed dome design for the batched digester setup while connecting a floating drum design in series to act as storage, so when/if the user does experience pressure complications they can apply an amount of weight to the top of the drum and increase the pressure.

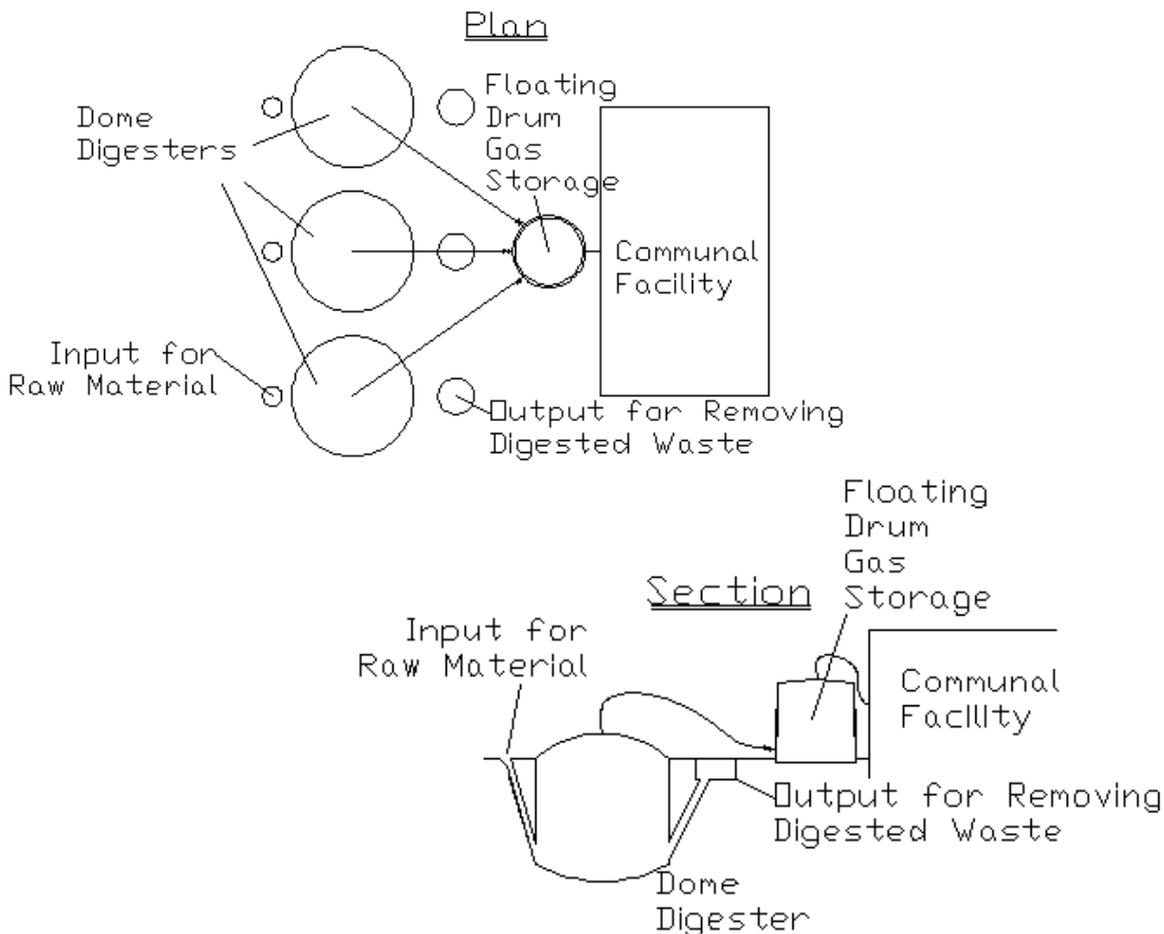


Figure 6: Possible digester setup to deal with pressure issues - Source: Practical Action

Case Study: Communal biogas latrines in Nairobi

The use of biogas technology to assist in urban waste disposal solutions has been demonstrated in Kenya, in the informal settlements of Kibera, by the use of standard pit latrines combined with digesters.

Kibera is a large slum on the outskirts of Nairobi, with a dense urban population and hundreds of people sharing each toilet cubicle. The Umande Trust, a Kenyan rights-based NGO, has developed a 'BioCentre' which incorporates biogas technology into a latrine block with sanitary facilities, and is managed by community-based groups that are trained by the organisation.

The construction can be built anywhere where space allows in the slums as does not require sewage infrastructure, instead treating human waste on-site. This helps to combat the pollution of pathways and drains by faecal matter, reducing the spread of disease and particularly, infant mortality rates.

The management of the facility by the local community ensures that hygiene is a priority, and the biogas produced can be used for energy needs such as cooking. More details of the project can be found on the Urban Health Updates website [here](#).



Figure 7: BioCentre in Kibera, Nairobi.
Source: © Buckminster Fuller Challenge

Case Study: Biogas promotion in Kenya

Practical Action's East Africa office undertook a survey of the use of biogas in Kenya in 1995, with the aim of highlighting the critical factors that affect the adoption of the technology in the country. The original manual can be found on the Practical Answers website at [Biogas Promotion in Kenya](#).

The survey discovered that in areas where the first installed biogas plant performed well, word of mouth from satisfied users encouraged other potential users to install their own plants; where plants failed, the failure created a negative impact on the technology, discouraging potential users in the process. Social influence created by successfully operated biogas plants therefore seems to have a significant effect on wider dissemination and acceptability of technology.

Another crucial factor for adoption is the high initial investment cost of biogas systems, posing a big problem to many potential users who are unable to raise money up front. The rising costs of components and adverse economic conditions in recent years have reduced disposable incomes in the country; cost therefore constitutes a serious constraint to dissemination of biogas technology.

Equally important is the maintenance and operation of the plant once installed; the survey found that only 25% of biogas plants in the area were operational, many having fallen into a state of disrepair after installation. It is possible that the organisations involved in construction failed to include the local populations to an extent where the technology was fully understood and accepted. It is also possible that the users were not experiencing the desired benefits from the system and reverted back to traditional, familiar energy supplies.

The general consensus of the study was that there is scope for wide-spread introduction of biogas use in Kenya, especially in areas of high population density. However, the lack of community involvement with planning and training, overstatement of potential benefits and poor assessment of community/household requirements can lead to plant installations that do not match the needs of the population and are poorly maintained; greater inclusion of PCR principles into the process will help to address this.

Case Study: Biogas Technology in Sri Lanka

Biogas technology has been used in Sri Lanka for nearly two decades, with many government and NGO backed projects developing various technologies at different stages. Practical Action South Asia recognised the need to look at the biogas technology in an ‘integrated’ manner (considering all possible applications, solutions, inputs and outputs and how they could interlink) to reap the multiple benefits which this technology offers.

Traditionally, biogas technology has been used in Sri Lanka as a source of energy for the rural population; predominantly for lighting. However, it was realised that it possessed several other benefits which were not being fully exploited. The main emphasis of the project was to develop and promote appropriate designs of biogas units that could address, in an integrated way, the local need for an alternative cooking fuel, the increasing cost of fertiliser, and the need to reduce solid waste, especially in poorer areas of society.

While energy and fertiliser remain the main uses of biogas at household level the project is being increasingly recognised as a waste disposal technology by the local government authorities for whom garbage is a severe environmental problem.

So, at the national level in Sri Lanka, biogas technology has a number of benefits as described:

- Generation of useful fuel
- Production of fertiliser
- Clearance of waste

An example of the work undertaken was the biogas plant installed at the home of Sakunthaladev Kathiravetpillai and her family in a rural district of the country. The waste from their cows was transformed into an energy source supplying the family’s needs, and meant that they could spend their time more productively instead of gathering wood for cooking and heating.

Additionally, Sakunthaladev’s husband became skilled at installing and maintaining the biogas plant, making him crucial for the development of other plants in the area. This is directly in line with the PCR principle of improving people’s independence, and increasing access to markets and skills.



Figure 8: Biogas plant installed in garden in Sri Lanka
Photo: © Steven Hunt/Practical Action

It is clear that biogas technology has undergone significant development in Sri Lanka, and efforts to integrate the various uses are seeing benefits on both individual and regional scale. The increasing acceptance and knowledge of the technology is making it more appropriate for implementation in several contexts and financial benefits are becoming more attractive, through quicker rates of return and better income-generating opportunities. Biogas technology can play a vital role in solving some of the major problems faced by the Sri Lankan societies of the present and future.

The Practical Action technical brief [Experience of Biogas Implementation in Sri Lanka](#) gives an overview of the work that Practical Action South Asia has undertaken.

Conclusion

A summary of the benefits of biogas is given below, in relation to a PCR context:

- Biogas is a clean fuel, thus reducing the levels of indoor air pollution, a major cause of ill-health for those living in poverty, and especially poorly ventilated post-disaster shelters.
- Biogas can be used to generate electricity, bringing with it the possibilities of improved communications; telephone, computer, radio and television for remote communities. This is more practical for community applications, rather than household systems.
- Fuel produced locally is not as vulnerable to disruption as external source, and can increase resilience and independence.
- Lighting is a major social asset; improved lighting can facilitate longer periods for work or study.
- If a biogas plant is linked to latrines in a sanitation programme, it is a positive way of reducing pathogens and converting the waste into safe fertiliser.
- Where biogas is substituted for woodfuel, there are two benefits: a reduction in the pressures on the forest, and a time-saving for those who have to collect wood – usually women and children.
- Where biogas is linked with sales of the resultant fertilizer, it is an excellent source of additional income, increasing access to local markets.
- China and India constitutes examples where biogas plants are produced in great numbers by local artisans. In Kenya, where biogas technology is still in its early stages of dissemination, local manufacturers have been quick to realise the potential and get involved with the production of biogas plants.

This technical brief looked at the feasibility of biogas for energy provision, particularly in post-disaster contexts as a fuel resource and as a disposal solution by examining the technological, economic and social issues regarding its implementation.

Biogas can be obtained from several different plant or digester technologies, and some of them (the balloon and plug flow digester) are more suitable for emergency shelters due to the short time needed for its construction. General criteria must be considered in the construction of a digester, and certain points of particular importance in post-disaster contexts have been presented here.

The research has highlighted a number of issues that any implementing organisation will have to face when introducing this technology, however, every programme will be context specific so a generic model would be hard to construct. Social and cultural constraints are very context specific; but the importance of keeping the public fully informed for acceptability has been identified. The products created from the biogas digestion process can have financial incentive and increase the ability of people to access markets. Therefore outlining the monetary benefit to program participants of regular and efficient use and maintenance of a plant is essential.

Biogas can be an effective way to reduce waste and provide clean, sustainable energy, which is of particular interest in post-disaster settlement planning. However, it is important to consider several technological, economic and social barriers before adopting the technology; this brief provides a range of examples, in order to recognise the necessary measures for successful implementation.

References and Resources

Practical Action documents:

[ARTI Floating Dome Biodigester](#)

[Biogas](#)

[Biogas Promotion in Kenya](#)

[Experience of Biogas Implementation in Sri Lanka](#)

[Pit Emptying Systems](#)

[Using a Biogas Digester](#)

[Using Biogas Technology to Solve Pit Latrine Waste Disposal Problems](#)

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This document was written by Mariano Gallo/Martin Bounds for Practical Action March 2012

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