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Small-Scale Biogas by Lake Victoria

Analyzing and implementing the biogas technology for cooking in rural African households

Master of Science Thesis in the Master Degree Programme of Biotechnology

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Småskalig biogas runt Victoriasjön
Förutsättningar för och implementering av biogasteknik för matlagning i lantliga afrikanska hushåll

1 Sammanfattning på svenska

Den här studien är ett steg på vägen att försöka införa småskaligt biogasbruk, huvudsakligen för matlagning, på den fattiga landsbygden runt Victoriasjön i Östafrika. Den behandlar förutsättningarna för, och de möjliga effekterna av detta.

Några olika rötningsmaterial presenteras: Vattenhyasint, vild solros, kogödsel och mänsklig avföring. Att använda mänsklig avföring kan ha positiva effekter på folkhälsan, eftersom biogasprocessen till stor del hygieniserar den.

En biogasreaktor byggdes på en gymnasieskola i Kenya. Den kostade runt 200 euro, inklusive isolering med lerhalm. Ingen kvalificerad arbetskraft var inblandad, och slutsatsen drogs att denna typ av reaktor (även om just den här läckte vid projekttidens slut) kan vara väl lämpad för den oftast fattiga befolkningen runt Victoriasjön, att bygga och använda. Målet är att när väl den första reaktorn är igång ska tekniken spridas från användare till användare.

Den konstruerade reaktorn uppskattas kunna ersätta runt 40 % av dagens spisbränslebehov, och hela gödningsbehovet, för en familj av 5 personer. Om familjen i nuläget betalar för spisbränsle betyder detta att deras investering betalar sig på ungefär 200 dagars användning av reaktorn. Vidareutveckling av tekniken kan komma att ge ännu bättre resultat.

Uppsatsen innehåller även ett kapitel om hållbar utveckling, och biogas fanns ha positiv effekt på denna på flera sätt. Den bidrar till jämställdheten, då den gör situationen lätare för kvinnorna, och ger dem en bättre möjlighet att t.ex. skaffa sig en inkomst, och därmed öka sin status. Biogas minskar också fattigdomen, dels genom minskade utgifter och dels genom ökad kontroll över mat- och bränsleförsörjningen. Den kan även spara träd.

Slutligen finns ett kapitel med rekommendationer för hur tekniken ska kunna spridas i området. Den viktigaste rekommendationen är att försäkra sig om ett genuint intresse från användarna. Subventioner rekommenderas att användas försiktigt, eller inte alls, då dessa tenderar att motverka ett verkligt engagemang. Andra rekommendationer är grundlig utbildning och tillgänglighet till teknisk support.

Denna uppsats föreslår att användarna betalar för byggnadsmaterialen till reaktorn, och att de även bygger den själva, för maximalt ”local ownership” och spridning från användare till användare.

2 Abstract

This study is a step on the way to try and introduce small-scale biogas, mainly as cooking fuel, into the poor rural areas around Lake Victoria, in East Africa. It deals with the conditions for doing so, and the possible effects thereof.

Some different feed materials are presented: Water hyacinth, wild sunflower, cow dung and human faeces. Using human faeces can have good effects on public health, since the biogas process hygienizes the faeces to a large extent.

A biogas digester was built at a secondary school in Kenya. It cost around 200 euro, including insulation with clay-straw. There was no skilled labour involved, and it was concluded that this type of digester (although this one leaked by the end of the project time) could well be suitable for the, mostly poor, people around Lake Victoria, to build and use. The aim is that once the first digester is up and running, the technology will spread from user to user.

The constructed digester is estimated to be able to replace around 40 % of the present cooking fuel needs, and the full fertilizer needs, for a family of 5. If the family at present has to pay for cooking fuel, this means that they will have their investment back in around 200 days of using the digester. Future development may yield even better results.

There is also a chapter on sustainable development, and biogas was found to have a positive effect on it in several ways. It contributes to gender equality, since it eases the situation for women in rural homes, and gives them a better chance to for example earn an income, thus raising their status. Biogas also reduces poverty, both by cash savings and by increased control over energy and food supply, and it can spare trees.

Finally there is a chapter with some recommendations for how to spread the technology in this kind of area. The most important recommendation is to make sure that there is a genuine interest from the users. Subsidies are advised to be used with care, or not at all, since it tends to work against a genuine commitment. Other recommendations are thorough education, and accessible technical support.

This thesis suggests that the users pay for the materials used to build the digester, and that they also build it themselves, for a maximized local ownership and a user-to-user distribution.

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3 Foreword

This study is a step on the way to try and introduce small-scale biogas, mainly as cooking fuel, into the poor rural areas around Lake Victoria.

It is based to a large extent on my own experiences from two Kenya journeys, each one of the length of two months, when I did some preparation work on local biogas implementation, and also tried to form an opinion of how feasible the idea was and what factors could promote it better. The first journey was spent mainly on building insulation structures of straw and clay around two existing biogas digesters: one in the rural village Orongo, and one in a secondary school, Nyasanda Community High School, in the small town Ugunja. The second journey was dedicated to constructing a family size biogas digester using only affordable and locally available materials and technologies. This work was done as a project, again at Nyasanda High, where I worked together with a group of eight students who formed a biogas club that would maintain and cultivate the knowledge at the school after the project time was over. The design we used for the digester was mainly the design of Swedish biogas expert and high school teacher Björn Martén, who has been promoting biogas in the area for many years, and we only adjusted the design slightly to the materials and tools that were available.

On top of this, I have also done my best to find knowledge and experience achieved by others who have worked in this field. For example I have looked into China's long and extensive biogas program, as well as experiences from e.g. India and Nepal, to gain relevant inputs on how biogas can succeed or fail in a context very similar to that around Lake Victoria. To find information on the biogas process itself I have found that Swedish research has been a useful resource, although much of the vast information that can be found there has a low relevance to the rural African conditions considered here, since it holds a level of technical advancement which is just ridiculous in this context.

The focus of my work has been on the digester design – including the chapter on how biogas can win popularity in this area – and the description of the biochemical process. For the sake of a holistic view, so that this thesis can be used on its own for those willing to try the technique, I also included chapters about safety, economy and stoves. These – especially the latter – are more superficial regarding their scientific content. I did take a university course in Development Theories once, and this knowledge I have implemented in the chapter on Sustainable Development.

It is important to stress that this study is not the only work that has been done in this field. For example, Björn Martén, my supervisor, recently sent another team of master students from the Development Assistance Engineer program (Biståndsingenjörsprogrammet) at the University of Skövde, to Kenya to work on biogas, together with University of Nairobi. Some of the better off private people in Kenya are also starting to use biogas digesters, mostly of the expensive Chinese design, and there is a sector doing research on biogas at the Kenya Agricultural Research Institute, K.A.R.I. My thesis is meant to fit in within this larger picture, and provide some kind of summary of the available knowledge.

4 Introduction

Lake Victoria was declared "Threatened Lake of the year" in 2005, by Global Nature Fund[1]. It is in fact so threatened that it might turn into a dead lake within a few decades. This is frightening, since the lake is of great importance to the area in a number of ways – even influencing regional weather and climate.

Some of the key problems of the lake are the ecological imbalance caused by the introduction of invasive species – mainly the Nile perch and the Water Hyacinth – and the significant eutrophication, caused by untreated sewage and waste from a growing population, as well as by pollution from expanding industries. The problems include also the surrounding land areas, with issues such as a vast deforestation, destruction of wetlands and a sprouting practise of chemicalized agriculture. The deforestation is to a significant extent caused by the use of firewood for cooking, and by the clearing of farmland. Together with the heavy rains in the area, it leads to extensive soil erosion, which, among other things, transports large amounts of earth into the lake.

The population in the area is very poor, and in fact most of them are believed to live below the poverty line[2]. Thus they often have no choice but to keep cutting down the trees, or pulling up the fish, even when they can clearly see that the stocks are decreasing. The necessary solution is to provide them with an alternative, which can allow them to meet their current needs, without jeopardizing the needs of the future.

An idea that could provide such an alternative, in at least three different areas, is biogas!

The biogas technology is the anaerobic treatment of organic material, such as cow dung, human feces, fresh plants or kitchen waste, by the use of bacteria. The process has three major outcomes:

1. It produces a combustible gas that can be used as cooking fuel
2. It produces a so-called "biofertilizer" that with good results can be used on crops
3. It improves hygiene by killing off many parasites and other pathogens that may be present in the raw material

It is easy to see that the gas in itself could ease the pressure on the forest, by serving as an alternative cooking fuel, but at least *as* important could be the high quality biofertilizer, that could be an alternative not only to chemical fertilizer, but since it improves the health of the soil and therefore of the crops, it could to some extent even replace chemical pesticide. If this kind of fertilizer would move in now, before the society has made a full shift into chemicalized agriculture, a lot of future damage could be prevented. The last of the above points, hygienization, is also very important, in an area where many children die each year from diarrhea, caused by human fecal pathogens in their drinking water.

Now, the beautiful little dream for the future, on which this thesis rests, is that almost all the rural families in this area would have their very own little biogas digester, producing cooking fuel for their meals and fertilizer for their crops, all for free and environmentally friendly. The feed for the digester could differ between the families; those with many cows could use cow dung, others living by the lake could use the (invasive) Water Hyacinth, a long known biogas material, and more inland the Mexican sunflower, Tithonia, which is also very common in the area and yields a lot of biogas, could be used. In all those cases, the human toilet should also be connected to the biogas digester, to increase gas production, and solve the hygiene problem of the sewage.

For this idea to win success in the area, the following points should be considered, when developing and introducing the biogas system:

- Local ownership
- Low cost
- Simple construction – no skilled labour
- Simple, comprehensive operation and maintenance
- Much gas produced
- Water access sufficient (though it could be partly recirculated, and the digester run differently in dry seasons)
- Caution! Consider the risk of an explosion

Eventually, for a faster and easier spread, it would also be very helpful if the countries would set up national biogas organisations, where biogas users could get technical help and advice. A Chinese biogas document claims that ”a favourable policies and legal environment is crucial”[3], but on the other hand, other studies show that if the cost is low enough, and the construction and maintenance simple, so that the technology can spread on a user-to-user basis without subsidies, the spread can actually precede the institutional attention[4].

It was with roughly these points in mind that the Swedish biogas expert and high school teacher Björn Martén, my supervisor, developed his plug flow digester, made by the use of some welding but no lathing, out of plastic water drums. I took his design to Kenya for further development on the spot, and managed to construct it in only plastics (using bottlenecks for bolt and nut, etc)! Although my digester was not yet made perfect during my stay (we had a problem with leaking bearings) it is clear that this design idea has a very interesting potential.

In this thesis, I will describe this digester model – hereby called the Nyasanda Digester – and compare it to other potent variants, some of which have been used in underdeveloped countries for a long time. Then an interesting method to insulate the digester with a clay and straw construction – another one of Martén’s ideas – will be introduced. In the later chapters of the thesis I will also discuss the sustainability aspects of introducing biogas technology in this area, and then we will have the very important section of how the biogas technology can come to win a vast regional spread. Like with sustainability this includes social and other factors, and comparisons will be made with success stories and failures in other similar parts of the world.

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5 What is Biogas?

The biogas technology is the technology to anaerobically treat organic material, such as cow dung, human feces, fresh plants or kitchen waste, by the use of bacteria. The process has three major outcomes:

1. It produces a combustible gas that can be used as fuel
2. It produces a so called “biofertilizer” that with good results can be used on crops
3. It improves hygiene by killing off many parasites and other pathogens that may be present in the raw material

Let me talk a little bit about each one of these outcomes.

5.1 The combustible gas

Biogas consists mainly of 50–70 % methane, 30–40 % carbon dioxide and a low amount of other gases[13]. Its heat value, LHV, ranges from 17.96 MJ/Nm^3 – 25.15 MJ/Nm^3 depending on the methane content[5], and it has many applications. It can be used for example to fuel a car or other vehicles, to produce electricity using a gas or steam generator or a biogas fuel cell[6], for lighting of a biogas lamp or as cooking fuel, using a biogas stove. Biogas burns without smoke or soot, and experience has shown that health of lungs and eyes has improved significantly for people who switch from firewood to biogas, as cooking fuel.[7] It can be used in a conventional LPG stove[8] that can be bought in the supermarkets, although these stoves require that the gas first be compressed into a cylinder, which, according to some verbal sources, can be considered commercial use and therefore require a license[9]. Most poor rural users use home-made burners with a low working pressure, so that the gas can be used without any intermediate steps.

As a rule of thumb 1 m^3 of methane has roughly the same energy content as 1 l of petrol, and so one 1 m^3 of biogas corresponds to 0.5–0.7 l of petrol. Some examples of what can be done with 1 m^3 of biogas are shown below.

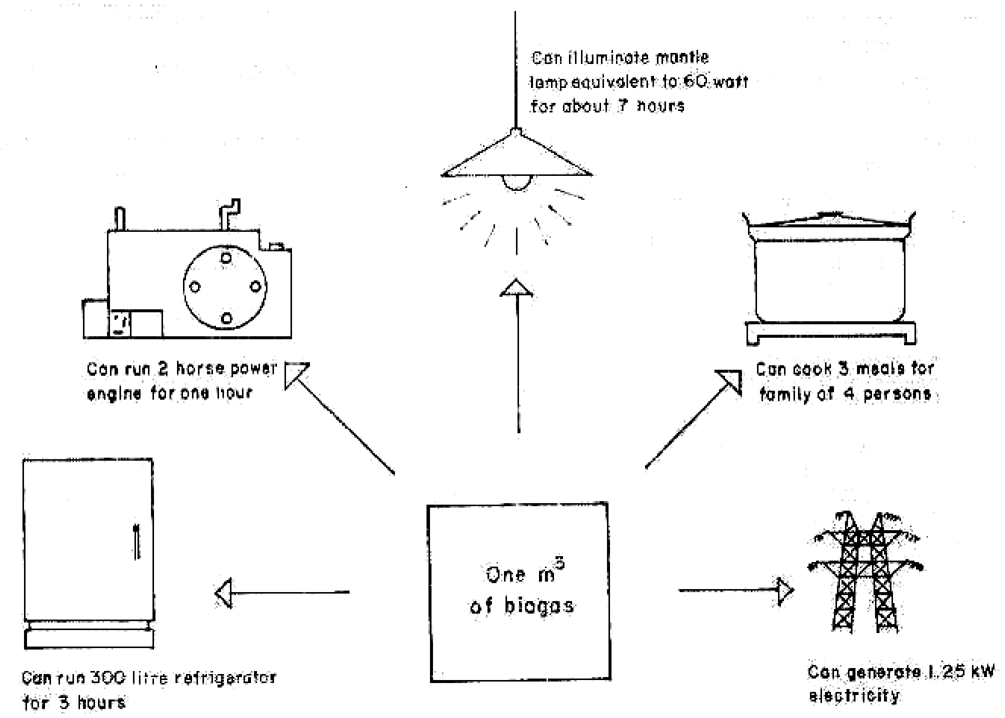


Figure 1: Possible applications of biogas. Source [22]

Using biogas for lighting is justifiable only if electricity is not available, as lighting consumes gas inefficiently and regular attention is required to keep the lamp burning well[22].

5.2 The residue – a biofertilizer

"The value of the effluent can be of even greater benefit than the value of the gas. This is not usually emphasized enough." This was stated in Guidebook on Biogas Development, printed by the United Nations in 1980[22], and many other sources say the same.

The residue from the biogas plant contains virtually the same plant nutrition as the material once put in the plant[10]. All that has left the material is some carbon, hydrogen and oxygen. Left in the residue are all the macro and micro-nutrients, such as nitrogen, phosphorus, potassium, and an undetermined number of minerals and trace elements, of which many are essential to the growth and health of crops. This makes the biogas residue much more nutritious than chemical fertilizer, which often contains only a few nutrients. Of course the exact composition of the residue varies with the type of feed used.

The nitrogen of the slurry has been mineralized, meaning that it has taken the form of ammonia, NH_4^+, rather than nitrate, NO_3^{2-} and nitrite, NO_2^-, which are common forms in cow dung. The NH_4^+ is more readily absorbed by the plants, and, because of its positive charge, it binds to the soil colloids in the ground, likely lowering the nitrogen leakage compared with cow dung. The biogas residue is also more hygienic than cow dung.

Apart from nutrients, the residue contains much humus, even though 40–50% of it has been converted into the gas. Humus improves the quality of the soil, by increasing soil porosity and water-holding properties. The residue also supports the microbiological activity in the ground, which helps keep the crops healthier and more resistant to different kinds of pest, thus lowering the demand for chemical pesticides, compared with chemical fertilizer.[11]

With all this in mind, it is not surprising to find an increase in crop yields when biogas residue is used as biofertilizer. A study from China found a 30 % increase in crop yields compared with chemical fertilizer[11], and a study from Vietnam found a 25 % increase compared with cow dung[12]. The first study also found a marked improvement in soil structure indicators.

5.3 Hygienization of organic waste and sewage

To, again, quote the UN biogas guidebook from 1980, now on hygienization: “For this reason alone certain governments are actively encouraging the construction and use of biogas plants as a means of promoting better village health. It is not the ultimate hygienic standard, but it is a realistic and greatly improved standard, which can be paid for and maintained by a village.”[22]

When the residue comes out from the biogas plant, it is a practically odourless slurry that does not attract flies. The environment inside the digester is very special due to the lack of oxygen, and it is quite rough for any organisms that are not highly specialized for such conditions. Here is the change in some pathogens and conditions found in a low-cost tubular digester with a long retention time:

Differences between waste water and slurry of biodigesters

	Input	Output
COD *(mg/litre)*	2 998	978
Escherichia coli (10^3/cell/ml)	52 890	75
Coliforms *(10^3/cell/ml)*	266 780	236
pH	6.8	7.2

Note: COD = chemical oxygen demand (the amount of oxygen consumed for the oxidation of the reductive substances contained in 1 litre sample of liquid waste by a strong oxidizer).
Source: [21]

A Swedish governmental study on hygienization of biological waste, stated that biogas processing treatment in the thermofilic range (50–60° C) fulfilled the criteria to be approved as a hygienization method, whereas the process in the mesophilic range (35–40° C) did not. The criteria were: 1. No salmonella bacteria must be found after treatment, 2. No viable parasite eggs must be found, 3. The number of fecal streptococcus bacteria must be less than 100 per gram. It was found that some parasite eggs spent the full 8 days in the mesophilic digester without being harmed at all, and there was still some salmonella left, although there had been a strong reduction.

However, it is likely that the results get better if the retention time is prolonged. After all, parasite eggs are meant to survive the conditions inside a stomach (very similar to those inside a biogas plant) for some time, but not forever. The intended retention time for the Nyasanda digester is around 40 days. The hygienization can also be improved if the residue is subsequently composted, before being spread on crops[22].

6 The Biogas Process

The biogas process is very similar to that of a cow stomach. In fact, biogas is indeed produced in the stomachs of cows, and that is where the bacteria used for the process are usually taken from, by using cow dung to first start up the digester. Therefore it is only natural that the process has an optimum at roughly those conditions usually prevailing in a cow-stomach. It is generally agreed that there is a biogas production optimum at around 35 °C, pH 7–8 and in an aqueous solution with a DS (dry substance) content of around 10%. (This optimum is called the mesophilic optimum. There is also a thermophilic optimum around 55 °C and a psychrophilic optimum around 20 °C.[10])

It is not one type of bacteria doing the job in a biogas process, but a mixture of many different species in a complex collaboration. Some of them are only facultative anaerobes (meaning they can use oxygen should it be present, but can also live without it) and others are obligate anaerobes (meaning they will be poisoned by oxygen). Some of them produce methane (methanogenes) and others don't. Of those that don't, most of them produce substances that in their turn serve as substrates for the methanogenes. The details of this collective digestion that will turn the complex organic compounds of the feed materials into biogas are nicely described in a biogas training manual from Nepal[13]:

Stage 1: Hydrolysis. The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilized into simpler ones with the help of extracellular enzyme released by the 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 which 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 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: The principle acids produced in Stage 2 are processed by methanogenic bacteria to produce methane. The reactions that takes place in the process of methane production is called Methanization and is expressed by the following equations (Karki and Dixit, 1984).

CH3COOH Acetic acid	-->	CH4 Methane	+	CO2 Carbon dioxide		
2CH3CH2OH Ethanol	+	CO2 Carbon dioxide	-->	CH4 Methane	+	2CH3COOH Acetic acid
CO2 Carbon dioxide	+	4H2 Hydrogen	-->	CH4 Methane	+	2H2O Water

The above equations show that many products, by-products and intermediate products are produced in the process of digestion of inputs in an anaerobic condition before the final product (methane) is produced.

The reactions shown above is just a selection from all the many reactions that take place in the biogas digester, with a focus on those reactions forming methane as an end product. Many of the other reactions form carbon dioxide as an end product, to give the final gas composition of roughly 60% methane and 40% carbon dioxide.

The biodiversity of the process is likely to make it less sensitive, and more able to adapt to a wide range of different feeds. It has shown that the biogas technology can be used to purify many kinds of industrial waste, and even such tough waste as the sludge water from leather industries[14]. This is impressive, since the very purpose of this industry is to prevent biological decay.

6.1 What factors can affect the process?

Although the process is thus adaptable and robust, there are many factors that can prevent it from working optimally, that is, lower the gas yield, and there is also always the risk that the whole process just dies, and one has to start it all up again from the beginning. What one especially needs to remember is that this is a biotic process, and as all biotic processes, it will tend to optimize itself to any given circumstances. That means that it works best in stabile conditions, and is sensitive to sudden changes in its physical or chemical environment. Since this process is also anaerobic, the bacteria can not get very much energy, so they develop relatively slowly. This makes them extra sensitive to changes that happen fast.

Some factors that can affect the process:

- **Oxygen:** As mentioned before, many of the involved bacteria are obligate anaerobes, so it is very important that the digestion chamber be very gastight, to prevent oxygen from the surrounding air to leak in. Small amounts of oxygen ending up in the digester together with the feed, however, will quickly be consumed by those bacteria that can respire oxygen.[13]
- **Temperature:** The optimum temperature is around 35° C, but more important is that it be kept stabile. For example, a sudden drop in the slurry temperature by even 2° C may significantly affect the bacterial growth and gas production[13]. It is possible to increase gas production rate by running the digester at temperatures around 55° C (thermophilic process), but that requires extra warming and more sophisticated techniques, and is probably not suitable for poor rural conditions. In China, biogas digesters have been known to produce small amounts of gas at temperatures as low as 12–13° C, but if it falls below that, the production virtually stops[14].
- **Loading rate and dilution:** If the plant is overfed, acids will accumulate and methane production will be inhibited. If the plant is underfed, the bacteria will starve, and gas production will also be low. A proper feeding rate should be 4–6 kg DS per day and m^3 digester volume. Since plants and fresh cow dung usually have a DS content of around 20 %, and the optimum DS content is 10 %, that means 8–12 kg of plants or dung, mixed with as much water.[15,13] The stiffer and stronger the feed material, the more water should be added to it[15].
- **pH:** Although it is usually very hard to judge the pH of the slurry without the proper means, it is of some significance to the process so I will mention it. The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7.13 During the digestion, the pH of the slurry will change. In the

acidification step pH will decrease, and this may inhibit or even stop the digestion or fermentation process, as the methanogenes will not thrive below a pH of 6.5. In the later digestion steps, NH^{4+} is formed through the digestion of nitrous compounds, thus increasing the pH of the slurry again. A pH value above 8, especially if caused by a high NH^{4+} content, can also inhibit the bacteria[10]. In the phase where methane production is stabile, the pH remains buffered between 7.2 and 8.213. At least this is the case in a batch digester and in a tube digester of sufficient length (see the chapter Biochemical reactor technology).

- **Toxic compounds:** Certain compounds can be strongly inhibiting or toxic to the process. Such compounds are for example detergents (soap, organic solvents, etc), disinfectants, antibiotics (perhaps from cattle that has been treated, or human feces) and strongly oxidized compounds such as nitrate, NO_3^{2-}. Salt in small quantities can help the process, but in large concentration such as that of seawater, it is toxic. Many metals are in small quantities essential to the bacteria, but especially heavy metals are strongly toxic in higher concentrations. [10,] 13, 22 With the origin of the bacteria in mind, it is a good idea to assume that everything toxic to humans and other animals, is also toxic to the biogas bacteria.

Generally, one should care for ones biogas digester like one cares for ones stomach. Any changes should be introduced slowly, to give time for biotic adaptation.

6.2 Feed materials

A wide range of organic materials can be used for biogas production. The feed material dominating biogas reports from poor rural areas is cow dung or dung from other livestock, probably mostly because it is available and would have to be taken care of anyway. The second most frequently featuring feed material is probably human feces, where the biogas technology can do a lot of good for the social hygiene. But although dung should be used where available, it is a waste of biogas potential to use material that has already been partly digested. Plant material, especially pasture plants which are often used in organic farming for their ability to fix nitrogen, can yield more gas per kilogram of feed. Plant based feed also makes the technology available for families without cattle, which, since cattle-raising often presents a severe pressure on the environment, might make it better regarding sustainability, as well as targeting the poorest families better. In any case, it is always best to use a material which is already readily available, rather than producing it especially for the biogas production, and of course, if there is a hygiene problem that can be solved at the same time, that opportunity should not be missed!

Although most organic materials treated in a biogas digester will yield some gas, there is a great optimization potential in finding the best composition of the feed. Like most living organisms, the biogas bacteria prefer a complex diet of many different nutrients, and many trace elements are essential for their growth. Even though the feed should not change rapidly over time, it is therefore often an advantage to have a complex (but constant) composition of the feed. In putting together the feed, the concentrations of the different trace elements etc are of course often not known, but one factor that has a great impact on the efficiency of the process, and that one should therefore try to pay some attention to, is the so-called C/N ratio. Again, I will quote the excellent biogas training manual from Nepal[13]:

C/N Ratio. The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH4). NH4 will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population.

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta has a C/N ratio as low as 8. C/N ratio of some of the commonly used materials is presented in Table 3 (Karki and Dixit, 1984).

Table 3. **C/N Ratio of some organic materials**

Raw Materials	C/N Ratio
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Pig dung	18
Sheep dung	19
Cow dung/ Buffalo dung	24
Water hyacinth	25
Elephant dung	43
Straw (maize)	60
Straw (rice)	70
Straw (wheat)	90
Saw dust	above 200

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. In China, as a means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged. Similarly, at Machan Wildlife Resort located in Chitawan district of Nepal, feeding the digester with elephant dung in conjunction with human waste enabled to balance C/N ratio for smooth production of biogas (Karki, Gautam and Karki, 1994).

In the table above, observe especially that cow dung and Water hyacinth is right in the middle of the recommended C/N ratio. The C/N ratio of dung is absolutely dependent on the diet of the animal, and therefore especially human feces can be unpredictable in this aspect. Those who eat much protein and little fibre will have a lower C/N ratio of their feces than others.

The above recommended C/N ratio of 20–30, agrees roughly with the recommendations from other sources, although this depends a lot on in what form the carbon is present. If the carbon is for example in the form of lignin, it cannot be digested by the bacteria, and so a higher C/N ratio is needed, but in some cases, even a value as low as 10 can be found.

To approximate the C/N ratio of plant material, a useful rule of thumb is that harder and stiffer materials have a higher C/N ratio, whereas softer and pulpier materials have lower values. Nitrogen is an important component in proteins and enzymes that the plants use for their life supporting processes in for example leaves and flowers, whereas carbon often is used for structure tissues such as stems and trunks. Straw from e.g. rice therefore has a higher C/N ratio than grass.

6.2.1 Water hyacinth (Eichhornia crassipes)

By Lake Victoria, making use of the invasive Water hyacinth (Eichhornia crassipes) could of course be a gold-mine, and many people are trying to do so in different ways with some good results. For example, it has been showed to be an excellent material for wickerwork. As feed for biogas production it also has a good potential, and in fact Water hyacinth has a long history of usage for this purpose[22]. Its composition is highly depending on the nutrients present in the water in which it grows, but if the conditions are good, the weed will be rich in both macro and micro nutrients, and its strong ability to absorb those from the water has even made it useful in water purification applications.

As shown in the Nepalese table above, the C/N ratio of Water hyacinth (probably referring to this species, which is an invasive weed also in Nepal) is around 25. Other minerals that Water hyacinth has been found to contain are, in percent of dry weight: P 0.31 %, K 3.81 %, Ca 1.66 %, Mg 0.56 %, and Na 0.56 %[16]. The high nutrient content of the Water hyacinth will not only help the bacteria of the biogas process, but will also improve soil fertility and soil condition, by serving the microorganisms of the soil, and thus increase crop yields and crop quality, when the effluent from the biogas digester is used as fertilizer.

To use the Water hyacinth as biogas feed, one should first allow it to rot in the sun for two days to break down air pockets. Then it is chopped up into small pieces. Even after this processing it may float, causing a scum layer in the digester. Therefore, a stirrer that can break this layer, or a batch digester, must be used for this feed[22] (see the chapter Biochemical reactor technology).

The access to this feed might be unreliable, as the Water hyacinth is known to appear very suddenly in huge numbers, and then, just as suddenly, the floating emerald mats may be gone, pushed away by the wind. Therefore, when the weed appears, it should be fenced in, so that it could not escape[8]. Harvesting it requires caution and proper equipment, as it is known to harbour decease and snakes[17].

6.2.2 Wild sunflower (Tithonia diversifolia)

This large shrub of the Asteraceae, or sunflower, family is also abundant in the Lake Victoria region, as in all the humid and subhumid tropics of Africa. A boundary hedge of sole Tithonia can produce about 1 kg biogas (tender stems + leaves) per meter and year, on a dry weight basis. It regrows quickly after cutting, and it is tolerant to soils which are acidic and low in fertility. Its leaves are high in nutrients, with an average nitrogen content as high as 3.5 % on a dry matter basis. Assuming a carbon content of around 50 % (which is common to biomass), this gives a C/N ratio as low as 14. If this should prove to be too low for satisfactory biogas production, one could try to raise it by picking withered Tithonia plants, or mixing Tithonia with other withered leaves or some of the examples from the Nepalese C/N ratio table shown earlier. Other nutrients in Tithonia leaves are 0.37 % phosphorous and 4.1 % potassium, and there have been experiments with using it as a crop fertilizer, with some good results.[18,19]

In some cases, it may be beneficiary to pre-treat plant material by for example some kind of composting, before feeding it into the biogas digester[22]. This can be done in order to break down structures of the plants that may make it difficult for the bacteria to access the nutrition, e.g. long, linear molecules, firmly stuck together, or wax layers on the surface. It can also break down air pockets, as mentioned earlier concerning the Water hyacinth. Tithonia is, however, known to degrade very quickly[18], and does therefore probably not need any pre-treatment before being fed into the digester. People having used Tithonia for biogas production, without pre-treatment, report that it works well and yields more gas than does cow dung.

6.2.3 Cow dung

Most people living in this area seem to have a few cows. They are used to handling cow dung, since this resource is being used for fertilizing fields, clay plastering of houses and in some areas as cooking fuel, dried into cakes. Hence, using it also for biogas production seems like an attractive prospect to many. Unlike the traditional usage on the fields, or burning the dried cakes, this provides fertilizer *and* cooking fuel, all from the same piece of dung!

Cow dung has also been extensively used for biogas production, and it has the advantages that it hosts the bacteria responsible for the biogas process, thus adding a constant supply of these to the digester. It also works well even without a stirrer, usually not forming any disturbing scum layers. On the downside, it is already partly digested. Cows with their four stomachs have a very efficient digestion, and volatile fatty acids and other more easily degradable substances have been thoroughly removed from the original feeds. Therefore, dung from animals with only one stomach is slightly better as biogas feed.[10]

The composition of the dung is of course dependent on the cow's diet, but a Swedish study shows that the VS (volatile solids) content – that is the fraction of the solid content that the bacteria can digest – is about 80 % of the dry matter. Cellulose was 24.5 %, hemicellulose 54.1 % and lignin 17.9 % of the dry matter. [10]

Also mixed dung can work very well in biogas plants, and each type of dung seems to help the other to produce more gas[22], maybe because of the more complex diet that the mix offers to the bacteria.

6.2.4 Human feces

This is the one source of biogas feed that is always available to humans, rich or poor, wherever they live, and it is very beneficial to use it for this purpose, as it also helps solving a hygiene problem. As biogas feed, human feces works well. Humans have only one stomach, which makes our feces more nutritious than for example cow dung, and this serves the biogas process. The C/N ratio of human feces is generally a bit too low, but it can be raised by mixing it with e.g. toilet paper! In Africa, many people use leaves instead of toilet paper, but even those could be of some help to the process, although in this case, some more carbon rich material probably needs to be added. The exact content of the feces is of course dependent on what the people eat, and those who eat much meat and little fibre will have a much lower C/N ratio than those who do the opposite. Perhaps one should also be a bit careful with eating things that could be toxic to the biogas bacteria, such as antibiotics.

When one works with human feces, one will want to be sure of good hygiene, first of all. It is good if the feces is handled in such a way that it does not come in direct contact with people. On the other hand, it would be good if the feces could be mixed rather thoroughly with water, before entering the digester. Sometimes the material can stick rather firmly together, and it can be difficult for the water, and therefore also for the bacteria, to penetrate it. This means that material could go almost untreated through the whole digester, and it might therefore not be hygienized when it comes out again. The Skövde engineer group[20] built a mixing device before their digester, right after the toilet. The device is covered, and one simply turns a handle to mix the feces in the water, and break larger pieces into small ones. Then a hatch is opened and the mixture can enter the digester. This way, no direct contact with the feces is needed.

A tube or batch reactor should be used for human feces, to ensure reliable hygienization (See the section Biochemical reactor technology).

7 Biogas Digesters for Underdeveloped Countries

Biogas digesters for underdeveloped countries have been constructed in innumerable varieties, but there are a few major types, with different basic features that are common to them. A biogas digester is of course a type of chemical reactor, since a lot of chemical reactions take place in it. It is usually called a digester, or a biodigester, since it digests organic material through a biotic process, but in many ways it follows the same principles as a general reactor.

7.1 Biochemical reactor technology

7.1.1 Tank or tube

There are two major types of reactors that are used for any kind of chemical or biological reaction. That is the tank type and the tube or plug flow type. What characterizes a tank reactor is that its contents are (in the ideal case) evenly mixed in the whole tank. That means that the outflow has the same composition as any volume element within the tank, whereas the inflow is of a rather different composition. In a tube reactor on the other hand, the composition of the contents changes gradually all the way from the inlet to the outlet. There can be radial mixing of the content, but there is little axial mixing. For this to be true, the reactor's length must be much greater than its width and height, or else the contents will intermix through diffusion. For the same reason, a tank is more compact in shape.

Except in some very special cases, the tube is more efficient than the tank. This is partly because the reactions can go quicker in the beginning of the tube, when the concentration of the substrates is high – in the tank they immediately get diluted – and partly because in the tube, they can go all the way. In the tank, since every volume element has the same composition, thus a mixture of old and new material, a percentage of the fresh feed material is always washed out through the outlet without time to first react. In the biogas case there will be different bacteria active at different stages of the tube, so that they can specialize on the conditions at that stage. This is not possible in the tank where there aren't any different stages, and so this may be an extra benefit with the tube in the biogas case. A definite benefit with the tube in the biogas case is that it makes sure that no pathogens from the feed can go quickly through to the outlet, and thus the hygienization gets more effective. The reasons why one sometimes wants to choose a tank version are usually that they may be simpler or cheaper to construct, or that the composition of the feed varies significantly with time. In the latter case, the impact on the composition inside the reactor will be smaller in a tank than in a tube.

7.1.2 Continuous or batch

Reactors can also be grouped by some general ways to operate them. The two major ways are continuous operation and batch operation. With a batch reactor (which is always a tank) there are three phases: First one fills the reactor with all the materials, then one leaves it to perform its reactions, and finally one empties the reactor, harvesting the products and usually cleaning the reaction chamber. A continuous reactor on the other hand, is constantly fed with, and emptied of, a certain amount of material, usually much smaller than the total active reactor volume. Unless there is anything accumulated in the reactor (or if it is slowly depleted of something), what goes in equals what comes out. Only the forms are different between inlet and outlet.

In the case of biogas, a batch reactor can be useful if the main purpose is hygienization, and maybe the production of biofertilizer for a certain time, but if the main purpose is to use the gas produced, of course there is a problem when the gas access is periodically interrupted. Methane is also quite difficult to store for long periods, as it is a small, non-polar gas that easily diffuses through most bag materials, although it could be quite satisfactorily stored if compressed into a metal cylinder. However, a continuous reactor is probably more useful in this case.

There is also a middle version of those two types called a fed-batch. In such a reactor one starts with a little bit of material, and then more material is added but none is taken out. At a certain point the reactor is emptied, cleaned and started anew, just like the regular batch reactor.

7.2 Common digester designs in underdeveloped countries

7.2.1 Chinese design – fixed dome

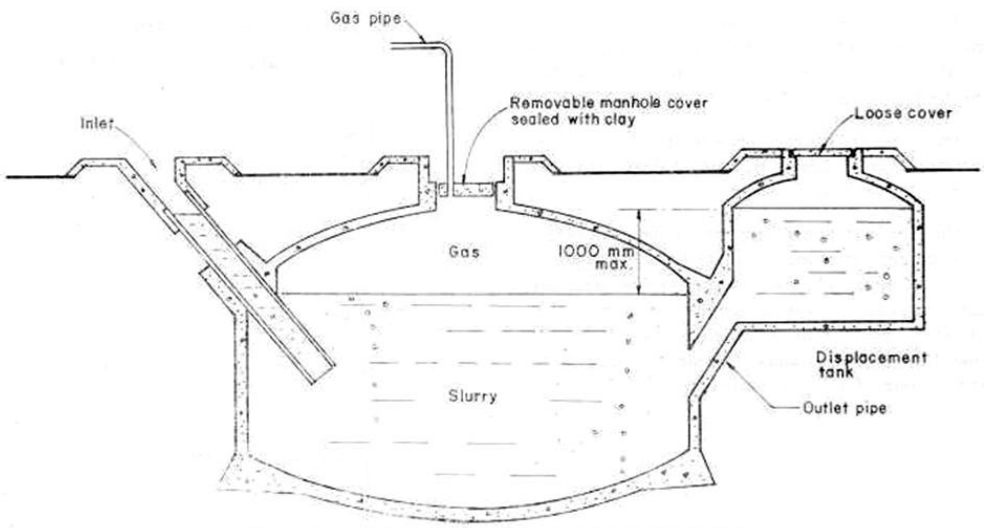


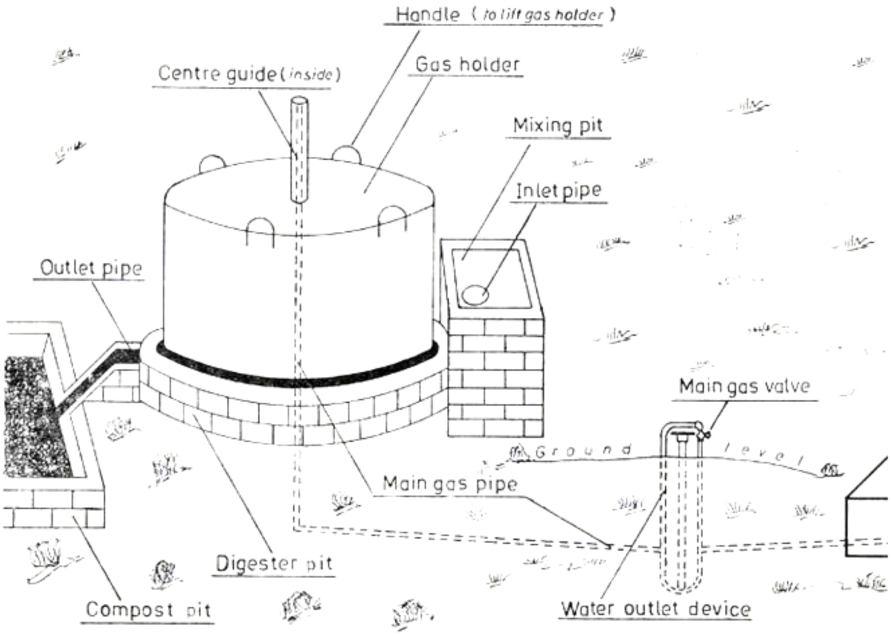
Figure 5. Common circular fixed dome digester (China)

Picture from: source [22]

This digester was built in China as early as 1936[13]. It is constructed underneath the ground out of concrete or brick masonry with several layers of plastering. The main chamber is a combined reaction chamber and gas holder. When the gas is produced, the pressure builds up and displaces some of the slurry out to the inlet pipe and the displacement tank, and when the gas is used, the pressure falls again, and the slurry sinks back. It is usually operated on a batch basis, but with a little daily input of animal dung and human feces, though not so much as to call it a fed-batch. A few times a year the digester is emptied to remove any floating scum layer and bottom sludge layer. A small amount of the slurry is kept as starter culture for the next batch. In this type of digester, the emphasis is on producing fertilizer and removing pathogens and parasites, and the retention time is very long: 30 – 100 days. There is no gas available around emptying, or for a while thereafter.

This type has not won any great popularity outside China, mainly due to a high investment cost and scarcity of labour skilled in masonry and plastering. It has also had a lot of technical problems, especially since the pressure is constantly fluctuating. There has been gas leakage, combustion difficulties and domes caving in, ruining the digester. This type was huge in China in the beginning of the 1980s (subsidized by the government), but towards the end of the 1980s most of them were disused, and China has now have moved over to better, more advanced varieties.[3,14,22]

7.2.2 Indian design – floating dome



Modified picture from: source [22]

This digester could be called a semi-continuous tank. It consists of a chamber, usually constructed of brick, or sometimes reinforced concrete. On top of the chamber there is a drum, originally made of mild steel but later replaced by fibreglass reinforced plastic (FRP) to overcome the problem of corrosion. The gas produced is trapped under the floating cover which rises and falls on a central guide. The pressure of the gas available depends on the weight of the gas holder per unit area and usually varies between 4 and 8 cm of water column. The digester is fed semi-continuously, one or a few times a day, through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe. In some versions there are stirrer blades placed on the inside of the floating dome, so that the slurry can be stirred by turning the dome around.

Also this digester type is rather expensive to build, and requires skilled labour and special equipment which might be difficult to access. None of these two is therefore a favourable option for the poorer farmers. [21,22]

7.2.3 Soft polyethylene tube

This digester is using a whole new approach, since the two previous ones were found economically out of reach for most of the poor framers that would need them. It is a long tube digester, made from double layers of soft tubular polyethylene. It is usually placed in a trench in the ground, but if one has access to a pond or other water reservoir, it can be practical to place it there. The details for in- and outlet etc, are from sewage equipment, or other easily accessible materials such as sliced up bicycle rings for wrapping.

This digester is made all in cheap materials that are highly available in most developing countries. The total cost is around €30. The techniques used are also simple, and the technology has been found to spread on a user-to-user basis, once the first digester has been put in use. A study from Vietnam of introducing this digester type showed that over the first three years, less than 12 % of the 800 installed digesters had had technical problems. The problems encountered were mostly damage caused by stray animals, and most of the repairs had been carried out by the farmers themselves.[21]

On the downside, this digester, like the Chinese one, offers no possibility for stirring. Therefore plant material cannot be used, since plant material is known to float to the surface and form a scum layer, which, when it goes thicker, loses contact with the aqueous solution, and so digestion stops. That means that only those farmers who have enough cattle to, together with the human feces, produce enough gas, can find this digester very useful. That means that it helps the “richer poor” more than the very poorest. There may also be a problem if a lot of sand from the cow dung enters the digester, since this will accumulate at the bottom. That problem can be solved by a mixing device before the inlet, where the sand can be separated. Of course the low durability of the plastic also means that the digester needs to be replaced within a few years, especially if the polyethylene is exposed to the sunlight. If a digester breaks in a pond, or if the slurry is allowed to leak into the ground water, there may also be a hygienic problem.

7.2.4 The Lysekil design – polyethylene drum tube

Left: The Lysekil digester with its designer Mr Björn Martén. Right: An earlier version in Orongo Village.

High school teacher and biogas expert Björn Martén has, together with his high school pupils in Lysekil, developed a biogas digester to be suitable for the needs of the rural Lake Victoria region. It is a tube digester, made from polyethylene water drums (only one in the pictures, but they can be combined by screws and, if possible, hot-air welding to make a longer digester), some plastic pipes and a welded iron stirrer. The gas is taken out by a hose-pipe in the roof, and led into a soft PVC gasbag, which is quite durable and cannot burn. The people in the targeted area are skilful welders, but there is usually no access to a precision lathe, for which reason the bearings for the stirrer was made from a piece of pipe with an inner diameter just larger than the outer diameter of the stirrer axis. The joint, however, had to be made tight using an o-ring, for which a trace was made using a lathe, so that it would stay in place.

This digester is especially developed for using plant material, since that yields more gas and makes the technology available also to cattleless farmers, thus providing an alternative to the often environmentally hazardous stock-raising. The stirrer is to be turned a few times a day, and breaks any scum-layer formed by plant material floating to the surface, but is designed with flat blades to avoid axial mixing of the slurry. Since this digester is meant to be placed above the ground, it is easier to empty and clean it (which needs to be done every once in a while to get rid of inert material) but also means that it needs to be properly insulated, since the temperature is likely to vary more above ground than underneath it. The drums are more expensive to purchase than the soft polyethylene mentioned above, but are also more durable. On the other hand, the soft polyethylene version is easier to make very long, since with the drum version, there will likely be tensions in a very long digester if the ground is not absolutely flat, and that might make the joints between the drums leak.

8 The Nyasanda Digester – Implementation Project in Kenya

During a six weeks project in a Kenyan high school, the author, together with a group of high school pupils, designed and constructed a biogas digester to be suitable for the local needs. The aim was to make it as cheap and simple as possible, using only locally available materials, so that it could be spread on a user-to-user basis. (For more details on what makes a digester suitable to this area, see chapter 15 How Can Biogas Win Popularity In This Area?)

Starting from the Lysekil design, the result of our project was a plug flow biogas digester made all in plastic. It was constructed using only simple tools and fire, and there was no skilled labour involved. The digester was built within the project time, but it leaked from the bearings and there was not enough time to fix this problem, and so it was never actually tested in practise. From the day when the actual construction work was started, it took two weeks to complete the digester, working only a little more than one hour each day.

8.1 Description of the digester

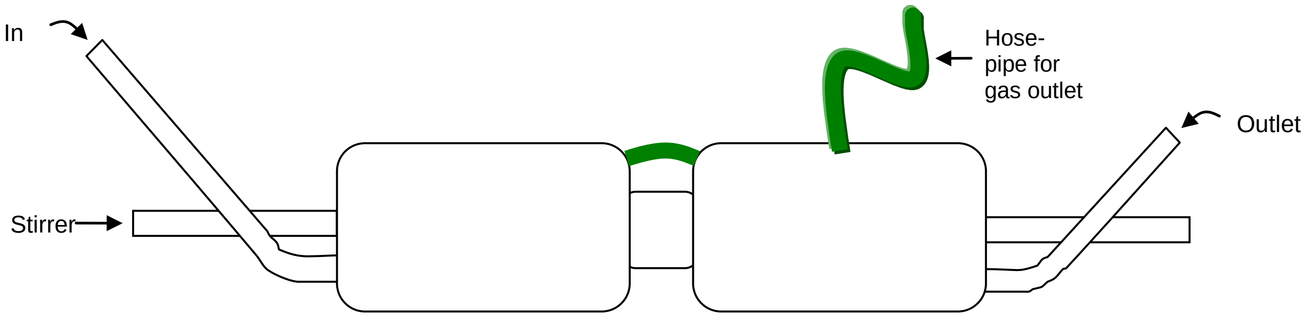


Figure 2: Principle sketch of the Nyasanda digester. The length, excluding protruding pipes, is roughly 2 m.

The chamber was made from two 210 l polyethylene water drums, connected at the openings by a sawed open 20 l water jug (“jerrican”). Through the whole digester ran a stirrer, made from a 1.5 inch PVC sewage pipe, with plastic bottles attached to it as stirrer blades. The bottles were attached by burning a hole in the pipe with an iron pipe that had been heated in the fire.

Figure 3: Experimenting with attaching bottles as "stirrer blades" in a test pipe. Later, the strings were not used, as the attachment turned out to be strong enough anyway.

The same sewage pipe (they could be bought in one piece of specific length) was also used for inlet and outlet, after it had been bent by first heating it over the fire. The inlet opening needs to be the highest point of the construction, and the outlet opening on the same height as the slurry level inside the digester, or higher, if there is extra pressure (ΔP) inside the digester. E.g. 10 cm water column of extra pressure means the outlet opening should be 10 cm higher than the slurry level inside the digester.

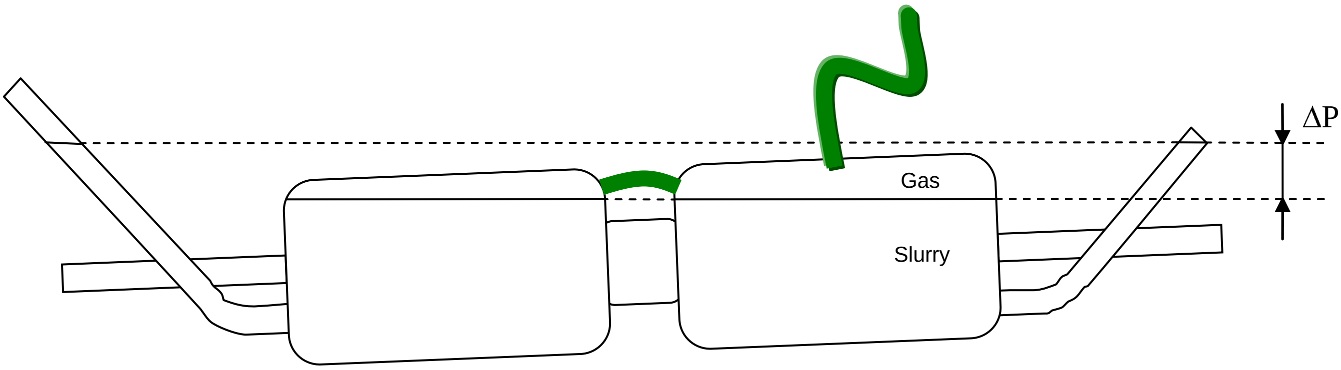


Figure 4: Principle sketch of the digester, showing slurry levels with a back pressure of ΔP on the gas side. This digester leans slightly towards the inlet, which can be favourable. It should not lean towards the outlet as material could then slide too quickly through the digester.

Both the in/out-let pipes and the stirrer pipe were attached in the sides of the digester by PVC pipe adapters, secured by a plastic nut from sewage equipment. There were two “correct size” adapters for the in and out-let, and two larger ones as bearings for the stirrer, so that the stirrer pipe could go fully through the narrow piece of the adapter. The narrow part of the larger adapters had to be widened slightly for this purpose, and this was done first by the use of round files, and then,

when we were more pressed for time, by heating the inside with an iron pipe until it melted, and then scraping the melted bits out before they cooled down (holding our breath to the toxic chloro-organic smoke). The resulting rough surface was smoothed by a round file. This contact surface between the insides of the adapters and the stirrer pipe – a surface the size of a roughly 3 cm broad band around the pipe – smeared with grease, was all that would hold the slurry back from leaking out by the stirrer bearings, but as was later shown, the bearings did leak. This design is therefore not satisfactory.

The holes for the adapters were burned into the drums, using some iron junk and a curry powder can, respectively.

The gas would be taken out at the top of the digester by a regular PVC hose-pipe. To attach the hose-pipe home-made "pipe nipples" were made from bottlenecks. The small flange just below the threads of the bottleneck, above the larger flange, was removed by knives, saws and files, and the top of the cap was taken off, leaving the threaded part to be used as a nut. A hole was burned in the superdrum and then the bottleneck was screwed/pushed through from the inside, all the way to the remaining flange, while the edges of the hole were soft. The cap nut was immediately attached from the outside. The hose-pipe just fitted *inside* the bottleneck, and so to make it stay, and to make the joint tight, it was agreed to tie soft plastics and strings around it, like a local biogas user had been seen doing. But first the hose-pipe was fixed inside the bottleneck with the PVC pipe cement.

Figure 5: Bottleneck pipe-nipple

Figure 6: Experiment bottleneck pipe-nipple attachment

8.2 Discussion about the design

8.2.1 Techniques used

The techniques were incredibly simple to use. The attachment of the bottles to the stirrer was also very strong and stable, whereas the adapters, especially for the stirrer, had a tendency to let themselves be screwed out, and therefore need to be securely fastened. It seemed clear that all techniques needed should be possible to learn while doing for any reasonably handy person in this area.

8.2.2 Digester

Björn Martén had estimated that the size of a family digester should be around half a cubic metre (500 l). This one was not quite that, but almost. The dimensions should be such that the length-to-width relationship be more than 2:1, and this one indeed was. The joint between the superdrums, however, was perhaps not great. It had the advantage that it was simple, flexible, would not wear out quickly (although it needed a lot of silicon paste in order to stop leaking) and could easily be taken apart to clean or make adjustments on the inside. But, on the other hand, it had the disadvantage that all components of the slurry must be able to lift from the bottom or sink from the surface in order to pass to the second drum. This may not be a huge problem if used only with plant material (which doesn't hold any sand like cow dung does, although it will, on the other hand, tend to float) and the stirrer is always turned while, or just before, feeding the digester. Besides, all the components of the slurry would in any case have to be able to get to the location of the outlet in order to finally escape the digester. In order to ease both those passages, it is probably better if the DS (Dry Substance) content of the slurry is rather high, so that the slurry cannot separate into a floating scum layer, a bottom sludge layer and a watery middle layer, but be rather evenly mixed when stirred by the stirrer.

Perhaps it would have been better to join the two drums with the help of a superdrum fundi. He or she could either make a permanent seal with melted plastics around the jerrican, where we now had silicon paste, or we could go with another plan that I had, but that we didn’t try, which was this: The superdrums have bands, about three cm broad, where they are slightly wider (a design thing). We could take off the tops of both superdrums, one a bit over the top band and the other one just *at the top* of the top band, so that the opening of this last superdrum would be slightly larger. Then maybe that one could be slipped outside the other one, creating an overlap of about 3 cm. Then the joint could be sealed with melted plastic, as mentioned before. This would of course make the total volume smaller, but there would be no obstacles for the material to pass inside, which could make the active volume larger. Also, if this works, a third drum could be added after the second, etc. Another problem though, with both those ideas, is that there would be no easy way to open the digester to do some work inside it, or to clean it all out, once the joint would be sealed.

A way to solve this last problem of not being able to open the digester, could be to make a hatch in the side of one (or more) of the drums. A rectangular opening of suitable size could be made in the side of the drum, and maybe the envelope area of a jerrican (20 l plastic water jug) could be used to cover it, attached by screws. The screws would rust with time but could be replaced after some period without too high a cost. The hatch would need to be sealed by silicon paste, preferably in an overlap between opening and cover. The hatch should be located fully underneath the slurry level while the digester is in use, so as to avoid biogas leakage out, and oxygen leakage in. After having been opened and closed many times the holes for the screws could go larger, but then one could change to larger screws, thus prolonging the life length of the digester for yet another while. Also, the jerrican cover could be replaced after some time, since it is not so expensive. This hatch type has not been tested in this project using the mentioned materials, but it was used in Björn's design which I tested in Sweden before the project, and with those materials it worked well. However, in that case we were using a slightly harder type of plastic drum, and the cover was of the same material as the drum (in fact it was cut out from an identical drum that had been discarded).

8.2.3 Bearings and stirrer

Something obviously needs to be done about the leaking bearings for the stirrer. I discussed the issue with a friend who then pointed out that for one thing, we don't need to have bearings at both ends. Only one end of the stirrer pipe needs to stick out so that it can be turned from the outside. The other end just needs something to hold it in position, which is an easier task than to allow it to go through and turn. Also, the pipe adapter which was used for bearings looks like this:

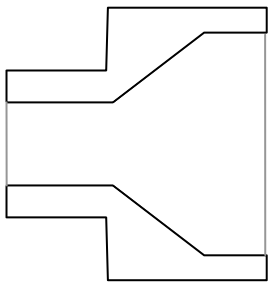


Figure 7: Cross-section of PVC pipe adapter, not quite to scale

In the project we used the side which is to the left in the picture (and which is threaded on the outside, though it doesn't show here) to be pointing inwards to the digester, and the larger part to be on the outside. However, since the larger part has a funnel-shaped interior, if you instead turn that end inwards, then a conical collar of some kind could be made for the stirrer pipe:

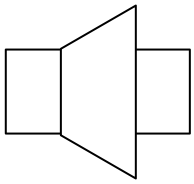


Figure 8: Conical collar for the stirrer pipe

And when the cone is pushed into the funnel, a rather good seal against leakage would be created. Maybe one could even actively pull the stirrer outwards and fasten it there somehow whenever the stirrer is not used. Then the digester could be allowed to leak slightly, just around feeding and stirring time, but be tight during the largest part of the day.

There is also a slight possibility that the type of bearings that we did use could still work, if we had only done the job better. We were running out of time, and so when we had finally made the adapters large enough for the pipe to go through them, there was a crude and quite deep unevenness along the insides that was well visible with the eye. But the PVC pipe that we used as stirrer was slightly flexible, and thus could maybe tolerate some smooth unevenness and still make the joint tight. Then the pipe should be pushed through with force, and the grease should be water proof, and of a type that would make the plastic surfaces really slippery against one another (the type that we used wasn't great).

In the Lysekil digester, the stirrer axis and the bearings were made of two pipes of different dimensions, one just small enough to go inside the other one, and to make the joint tight, an o-ring was used. A track was made on the inside of the bearing where the o-ring was fitted to stay in place, and then the axis was pushed through. This bearing kept tight despite a rather high water pressure. Probably it could work also for this plastic version. The track could maybe even be made with a simpler tool than the lathe that was used in Lysekil, since plastic is easier to handle.

Figure 9: O-ring to tighten bearings with

The stirrer in itself was a great construction, although I now think it would be better to keep the caps on the bottles, so that they will not get filled up with slurry which is now the case (since the attachments are not tight and so the axis will be filled with slurry). It is not a great problem if the bottles do get filled with slurry, but it doesn't help either, and it probably makes the stirrer heavier to turn. Since it was never tested with real slurry, we don't know yet if it will be strong enough to handle the force.

8.2.4 Bottleneck pipe-nipples

Another perhaps week spot in the design was the many bottleneck pipe-nipples. Those offer many places for biogas to leak out and oxygen to leak in. Altogether there were three pipe-nipples in the digester, and at least one for the gas container. If the design were to be changed so as to exclude the jerrican joint as previously described, the pipe-nipples in the digester could be reduced to only one. In any case, one should really make an effort to make the pipe-nipples gastight, using any material available to seal them with.

8.2.5 In and out-let pipes

The in and out-let were constructed from the same sewage pipe as the stirrer axis. This was done in order to keep the cost down by having to buy only one pipe instead of two. However, it may very well so be that they are too narrow for the material of the slurry to pass well, especially since they were attached to the digester by an adapter which, in its most narrow part, was only around 3 cm wide. Another way to attach the same pipe to the digester would be to use the larger kind of adapter which was used for bearings, and even in this case let the pipe go through the narrow part, rather than stay in the wider part. Of course, we all know that that didn't work very well for the bearings, but in this case the pipe would not need to be able to turn, and so the joint could be sealed with cement and silicon. Or else, a larger pipe could be bought, and in fact they were only 300 KES (around €3) a piece after all. But perhaps it should be mentioned that the pipe adapters of the larger size used were not as readily available as the smaller one, and in fact one of them even had to be bought in Maseno.

8.2.6 On the whole

Regardless of the leaking bearings, the Nyasanda digester is an almost functional biogas plant, with only locally available materials, no skilled labour involved and at the cost of only around 220 Euro! It seems clear that if only that bearing problem could be satisfactorily solved, at a low cost, it would be very feasible for a large number of families and other groups of people in rural Kenya to set up and use their own biogas digesters, roughly of the design that we have drawn up here.

9 The Gas Container

In the case with a plug flow digester made of drums, it is almost necessary to have a separate gas container, even though some gas could be stored in the digester itself. (Whenever there would be a low or no consumption of gas, the gas would push the slurry down, causing it to overflow and the pressure to build up. Then when the gas would be used, the pressure would fall, and the slurry sink back again from the in- and outlets, raising the slurry level inside the digester. If a lot of gas would build up inside the digester though, it would mean a smaller active reactor volume for digestion, and at some point the gas would reach down to the slurry outlet, and start to come out.) Experience has shown that, if used for cooking and lighting, the gas container should be able to store around 60 % of a day's gas production.[22]

There are two main types of separate gas containers: The flexible bag type and the floating dome type.

The type that Björn Martén[8] has used before in his projects, as well as the one the Skövde engineers[20] are using is the flexible bag. It has the advantages that it is easy to use and to move, and when one wants to cook with the gas, one just puts something heavy on the bag for the correct pressure. The pressure will stay constant, unless the weight on the bag is altered (unlike the case when the gas is collected inside the digester itself, where the pressure will fluctuate).

As a disadvantage with the bag type could be mentioned that rodents have been known to bite and destroy the plastic bag[22], and it may also be fragile to sharp objects. It must either be strong enough to withstand the pressure build-up required to push the gas out "through the back door" via the slurry outlet as described before, or it should be provided with a safety valve to prevent the bag from bursting, and of course it should not in any way be combustible or able to melt in heat, in which case a hot object fallen onto the bag could cause an explosion. But the major draw-back with this type, in the author's own view, is the very poor availability. The author was unable to find a proper gas bag in Kisumu, even in the special laboratory equipment shops, and to have one made especially is bound to be expensive.

The choice was therefore made to work with a floating dome type, made of polyethylene water drums.

This biogas container is constructed simply out of two plastic drums, one inside the other, where the inner one is turned up-side-down. It is held down by rocks or similar attached to its lower end, so that it will not tip and let gas out. The larger drum is filled with water, and when there is no biogas in the container, the smaller drum should be fully submerged in the water, so as to be completely emptied from air. The gas is then led into the container at the top end by a hosepipe, attached by the same type of bottleneck pipe-nipples as were used for the digester. (If the gas would be led into the container from underneath, there would be a high water column of pressure for the gas to overcome.) Another hose-pipe will lead the gas from the container to the stove. The pressure will roughly equal the weight of the stones minus the weight of the water they displace, divided by the surface area inside the smaller drum, and remain fairly constant at all times.

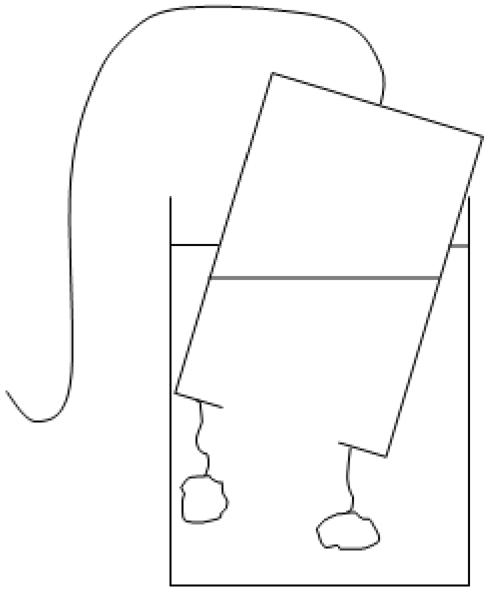


Figure 10 Gas container made from two plastic drums, one inside the other which is filled with water. Stones are used to weigh the gas drum down.

9.1 Discussion about the gas container

The gas container made of two superdrums is of very simple design and should be able to work well. It should be kept away from the sunshine in order to last longer and for the gas not to expand with the heat and maybe escape. The water would probably remove some of the carbon dioxide from the gas which would make the heat value of the remaining gas higher. The water could maybe go slightly acidic from this, but since the resolved carbon dioxide can continuously escape to the air along the sides, it shouldn't reach any higher concentrations.

This construction seems to be more durable and much more available than a decent bag type of container. For the pressure to be able to rise high enough to cook with, though, there needs to be enough space for the water to rise along the sides as the gas drum is pulled down by the stones. If that is not the case, an extra step is needed between the gas container and the stove, to create a higher pressure. However, biogas stoves can be made for quite low working pressures, so that is probably a better way to approach this problem. The bigger superdrum could also be replaced by a pit or similar, containing water. With this type of gas container, the pressure would remain (fairly) constant at all times, which makes it much easier to use the gas, than in a system with fluctuating pressure.

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10 Insulation of the Biogas Digester

10.1 Why insulation?

Bacteria have a so-called lag phase, which takes place just after they have encountered new conditions, for example if they have been cultivated in the laboratory in a medium with a certain nutrient composition, and are then being moved to a different medium with a different nutrient composition. In the lag phase, the bacteria do not grow (reproduce) or produce their usual products, but instead they produce new enzymes for themselves and otherwise regulate their systems, so that they can function optimally in the new environment. When the lag phase is over, they quite abruptly enter the growth phase, where they grow exponentially, digest the nutrients and produce their products.[23]

Also a sudden temperature change can make bacteria enter their lag phase. For methanogenes (the bacteria producing biogas) the fact that they don't have access to oxygen means that they can get rather little energy out of their feed, which in turn means that they cannot afford to produce heat, and this makes them extra sensitive to temperature changes. Therefore, if the temperature in the biogas digester fluctuates very much over the day, the bacteria could remain in an almost constant lag phase, and one would never get any gas.[23]

Although many sources agree that a constant digester temperature is desirable, it has been difficult to find data of just how stabile the temperature must be for the process to work well, but Mr Björn Martén[8], with his long experience in the field, has stated that a fluctuation of ±1° C from the mean value should be acceptable. This was therefore the goal when the insulation project in this thesis was started.

10.2 Insulation project with clay-straw in Kenya

The author spent two months in Kenya in 2005, to experiment with digester insulation, using a building technology with clay and straw. Half of the time was spent in Orongo village and the other half at Nyasanda High.

In Orongo, a clay-straw insulation structure was built around a 200 l digester of Lysekil design, and the plan was to build another similar structure around a similar digester in Nyasanda, but this second structure was never finished, due to practical problems and lack of time. The first structure, which was built by the author and her contact person John Ombwayo, with help from sporadic primary school pupils and some paid labour (friends and relatives of John's), took three weeks to construct, counted from the very first day the author put her foot in the village. When tested, the temperature inside the filled digester varied with ± 2° C from the mid temperature, despite a variation of ± 8° C in the outside temperature. A comparison between the air temperature inside the insulation structure and the outside air temperature was not made.

Figure 11: Clay-straw insulation structure, built around a 200 l biogas digester in Orongo village

Before starting this project, the clay-straw building technique (which is a special technique among many using clay and straw) was studied by reading a master thesis in architecture called "About houses made of earth and clay-straw"[24] (author's translation), and by verbal instruction and some demonstration by Ms Maja Lindstedt[25], but the author had never actually tried the technique in reality. This, however, never presented any problem, as both the constructors (the author and John) found the technique comprehensible and easy to learn while working.

10.2.1 The insulating clay-straw structure

All that is needed to build this type of insulation structure is: Clay, straw, sand, cow dung, basins (or other) in which to mix clay and water, a home-made wooden frame and perhaps some thin wooden sticks as armouring. It is also necessary to have or build a roof over the structure, to protect it from rain and direct sunlight. This roof should not get too hot in the sun, for which reason an iron-sheet roof might not be ideal. In this project, a thatched roof was used. Such a roof works well concerning the temperature, but needs regular maintenance not to leak.

The house is to be built in two steps: First blocks of clay-straw are made, and allowed to dry in the sun for a few days. Then the blocks are joined together to form a box-like house, which is to be covered with 3–12 cm of plastering as shelter from weather and insects, as well as for stability. The walls excluding plastering were in this project 30 cm thick. (The thickness depends on the climate, and can be thicker where the climate favours quick drying.)

3 hand-carts of rice straw were used for the Orongo house, which corresponded to about 4 m^3 of loosely packed straw. At Nyasanda a maximum of 12 m^3 thinner grass straw was ordered before the author left the project site, but since the construction was never finished, I do not know if it would have been enough. It was clear that much more grass was needed per unit of structure, using this type of straw.

3 hand-carts of clay were used for the Orongo project, and probably something similar would have been used in Nyasanda.

The total cost for the construction of the Orongo structure was 20,520 KES (226 Euro[26]) including some costly mistakes, a little labour and transport of materials.

For more detailed information and building instructions, see Appendix B – Building an Insulating Clay-Straw Construction.

10.2.2 Achieved insulation

When the structure was finished and the digester had been filled, the insulation effect was measured using an indoor/outdoor thermometer, of which the "outdoor" probe (which is in the end of a long cord, coming out from the thermometer) was placed inside the digester chamber. The thermometer itself (which also holds the "indoor" probe) was placed so that it could measure the outdoor temperature in the shade. The thermometer can save a maximum and a minimum value, and was read and reset once a day, in the morning.

It would of course have been nice to measure the temperature difference between the air inside the insulation house, and the air outside it, or to compare with a similar digester without insulation, so as to isolate the effect of the insulation structure, but none of this was done, mostly because there was only one thermometer.

The following days of measurements showed that although the outdoor temperature varied with ±8° C from the middle value, the variation inside the digester was only ±2° C. Much of this stabilizing effect which was found is likely due to the amount of water in the digester, but it is still significantly better than the effect that had been reached earlier, with other methods[8].

10.3 Discussion about insulation with clay-straw

My supervisor, Björn Martén, is full of ideas of how the temperature could be maintained high and constant inside the digester, with passive or hand pumped water loops etc, but to my mind those techniques seem too complicated for the people to be likely to take them at heart. The insulation with clay-straw, on the other hand, is utterly simple, built in materials which are familiar to the people, and seems to provide enough efficiency to the process, if also not maximum.

In this project, the structure did not meet the target of ±1° C, but stopped at ±2° C. However, I believe that this could be improved on with more practice. The weak spot in the design was probably the roof. It was agreed to make a thatched roof of the same kind that was used for the huts and houses in the village, but when the roof was built, it was clearly of much lower quality than those, and could not have given much insulation.

On the whole, insulation with clay-straw seems to be a very good idea for the Nyasanda digester, and other digesters above ground level.

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11 The Biogas Stove

In China, as a source from 1980 narrates, a variety of stoves were made and used, some of which were approved by the government and some of which were not. Many people were constructing them and modifying the design, which was sometimes all in metal, sometimes in a mixture of metal and ceramics, and sometimes even all in ceramics. There was an over-all recommended air-to-biogas ratio of 10:1.[14]

Biogas can burn even from just an open pipe-end, but the challenge is to make it burn economically, lest it will be difficult to make the gas suffice. An inventor and biogas user that the author met in Kenya said that the number one trick is to make the nozzle for the flame as narrow as one possibly can. He was himself using used up ballpoint pens, from which he had removed the ball. Over this nozzle he placed an outcurved metal disc with holes in it, to split the single flame into several flames.[27]

Figure 12: Kenyan biogas burner, made from a ballpoint pen, a spray can and some iron junk. The outcurved disc to the right will be placed over the nozzle to spread the flame.

If a narrow nozzle is the first trick, then the second trick must be insulation. This seems to have been much ignored historically, but in Kenya nowadays many people are starting to insulate their cooking places with a pottery clay device, or a brick or stone hearth, with only a small opening in which to put in the firewood. They have found that this saves cooking fuel and reduces the disturbing smoke. It will probably be helpful just to place the biogas burner inside one of these clay or brick fireplaces, but Mr Martén[8] has designed a biogas stove in clay-straw. As explained earlier, this material insulates excellently and is not combustible.

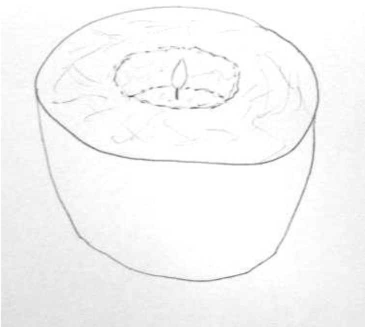

Figure 13 Biogas stove made from clay-straw, a material which insulates well and cannot burn (see the chapter Insulation of the Biogas Digester).

This stove insulates not only the flame but also the pot, and it should therefore be possible to use a very tiny flame to maintain the heat at boiling temperature, once this temperature is reached. This would have a large impact on the amount of gas used in this area, where food stuff (such as beans) is often boiled for very long times in a go.

To turn the gas on and off, there are taps that can be bought in the hardware stores, although they are quite expensive. Between the stove and the gas container there should also be a waterlock, to prevent the flame from following the pipe back into the gas container, although, at normal use, this should not be possible anyway. More about this will be said in the chapter Safety Aspects nedan.

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12 Safety Aspects

The UN biogas guidebook[22] has the following to say about biogas and safety: "Biogas, when used as instructed, is safer than other gases used in houses. It can only explode when there is 6 to 25 per cent biogas mixed with air. If all the air is removed from the gas holder and pipes before use /…/ the gas plant cannot explode." In fact, even within this span, 6–25 %, the gas mixture might not be able to explode, depending on the amount of methane in the biogas. A more exact illustration of this is given in Figure 14 nedan.

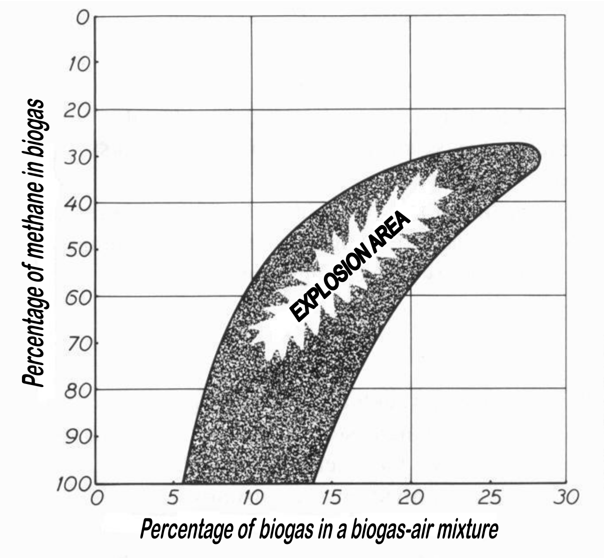

Figure 14: The mixing conditions under which biogas can explode, if exposed to a spark or flame.
Source: Swedish Institute of Agricultural Engineering, 1982[10]

For example, if the methane content in the biogas is 60 % (a quite common value), the amount of biogas in air must be between 8–18 % for the mixture to be able to explode.[10] That means that a lot of air must have leaked into the gas container or digester, before there is any risk, and in this area, where the plants and gas containers are likely to be kept outdoors or in well ventilated spaces, the concentration of biogas leaking out from the plant is not likely to be able to reach such levels.

Still, if the gas is stored in a fragile bag, in a space where there is sometimes a fire, and the bag for some reason breaks, it seems very much possible that the critical conditions might emerge, and therefore a fragile gas bag should never be kept in such a space. One should also be careful with air that might be trapped in the system right when the plant is started up for the first time, or after having been emptied and cleaned. This air might intermix with the first biogas produced, so that when the gas is ignited, the flame can follow the pipe back to the gas container and cause an explosion. The safest way to avoid that to happen is to have a waterlock between the stove and the gas container, so that no flame can pass from the stove to the container, under any conditions.

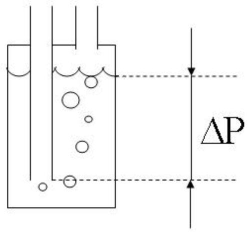

Figure 15: Waterlock. The left pipe should be connected to the gas container, and the right one to the stove. The waterlock will create an extra pressure of ΔP (mm water column) for the gas from the gas container to overcome, before reaching the stove, but will make the usage of the gas very safe.

It has also been said that the first 4 – 6 container fulls of gas at up-start, or re-start, should not be burned but allowed to escape to the air[22].

Apart from the risk of explosion there can also be a risk of suffocation or poisoning. These risks are largest in connection with digesters of Chinese type or similar. None of the major components of biogas is poisonous, but if a person breathes only biogas, he or she will suffocate due to lack of oxygen. A biogas digester of Chinese type will keep producing gas, even if it is opened, as long as there is slurry in it. If the slurry is removed, there is likely to be a lot of carbon dioxide lying at the bottom of the digester, and therefore no one should enter the digester to do any work or inspection until the digester has been well ventilated for a long time. The carbon dioxide could even be removed by lifting it in buckets and pouring it out, away from the digester, like water. When a person does enter the digester, he or she should be attentive to dizziness or any type of breathing discomfort, and if such are experienced, he or she should immediately come out from the digester again.[22]

As for poisoning, the main risk factor is the hydrogen sulphur, H_2S, which may be present in the gas in low quantities, and higher if the feed is of animal origin. Hydrogen sulphur is poisonous even in very low concentrations, giving symptoms such as irritation in nose and eyes, later head-aches, nausea and psychological disorders, and a concentration of 0.1 volume-% (1000 ppm) leads to immediate unconsciousness and death.[10] The positive side of hydrogen sulphur is that it also has a very distinct smell, even that in very low concentrations, which resembles that of rotten eggs. When a person detects that smell, he or she is not yet in any great danger, but the smell should not be ignored, rather action should be taken to stop the gas leak.[28]

13 Economy

As mentioned before, and will be further discussed later, there are many non-monetary benefits that come out of the use of a biogas digester. However, especially in an area like this where money is in very short supply, it is absolutely crucial to consider the actual monetary aspects by themselves. One cannot expect people to transfer money from their other expenditures into this one just because they value it so much, when many of them live from subsistence farming, and in fact don't have any other expenditures to take from. For example, many of them would probably prefer to spend a few shillings on cooking fuel, rather than spend the average 5–8 hours a day collecting it[29], but even that simple choice is out of their reach. Therefore this chapter will deal with the monetary issues only, of starting to use the Nyasanda Digester.

13.1 A cost estimation

Since the Nyasanda Digester was not perfect by the end of the project – it leaked from the bearings – it is difficult to give a definite answer to how much it would cost to build a functioning digester of the same type. It depends on how much it would cost to make the bearings tight. If, however, we assume that that cost falls roughly within the uncertainty limit caused by variations in price, and we add a little bit of margin on top, then we can estimate that building a biogas plant of the Nyasanda type would cost:

	Kenyan shilling*	Euro**
Digester	5,300	58
Gas container	2,500	28
Insulation structure	12,400	137
Tools	900	10
Sum	**21,100**	**233**
Rounded off	**21,000**	**230**

**By the time of the project, Feb–Mar 2007*
***By Swedish Forex exchange rates 2007-11-19*

Table 1: Estimated cost to build a Nyasanda type biogas plant. A complete budget can be found in Appendix A

The largest uncertainty in this estimation is in the insulation structure, the cost of which depends greatly on how much needs to be paid for pottery clay, straw and the transport of these to the digester site. Among the tools are some basic tools like hammer and saw which might already be available, and some are things that could be found on scrap yards, so this entry might be near zero in some cases. The other two are probably quite certain, save for the bearings issue.

13.2 How much money can be saved?

(The facts in this chapter are from the author's own observations and interviews with people during her projects, unless otherwise stated.)

How much money can be saved depends on how much money the people presently spend on cooking fuel, fertilizer and perhaps lamp fuel, if the biogas will be used for lighting. (It is not common to pay for hygiene services.) Secondly, it depends on how much of these resources can be replaced, using the biogas technology, and if there are any additional costs caused by the biogas technology. A problem here could be if the people have to pay for their water, in which case it will be difficult to achieve a good economy in the project.

Most people in Kenya nowadays have to pay for their cooking fuel, even if they top it up with some collected firewood, millet stalks and other. The most common types of commercial cooking fuel are firewood, charcoal and some kerosene, although the latter is mostly used for lighting. Some people have started using gas stoves with LPG gas, but since these are expensive to buy, it is mostly the richer people doing so.

Most people do not pay for fertilizer, but use the dung from their own cows and goats. However, chemical fertilizer is becoming more popular, and is being advertised here and there. Most people in the Lake Victoria basin, more than 75 %, are involved in some kind of agriculture[30].

Water is achieved from different sources: When it rains, many people collect the rain water. On top of that they collect water from wells or streams or from the lake. In towns there is running tap water, drawn from Lake Victoria, and achieved for a fee. There are often interruptions in the water supply, caused by a growing demand and sinking lake water levels. In the villages, people sometimes pay for the transporting of water from wells to their homes.

Example 1
Let us assume that a family cooks with only firewood, all of which they buy. They have their own patch of earth that they cultivate, but they don't buy fertilizer. They have free access to plenty of water. Now they start using biogas for cooking fuel, but not for lighting. There are five people in the family.

Firewood, if used for three meals a day, costs in Kisumu area around 50/= (0.55 Euro[26]) per person and day. (The price is slightly higher in remote areas.) For a family of five, that gives 250/= (2.76 Euro[26]) per day, or **91,000/= (1,000 Euro[26]) spent on firewood for cooking per year**. That represents the maximum amount that this family can save, if all of the cooking fuel is replaced by biogas, and no extra costs are added.

Now, let us see how much of the cooking fuel that can actually be replaced by the biogas. Another digester similar to ours has given 300 l of gas per day and m^3 digester volume[31], using only cow dung, and according to Mr Martén that means that it should be able to produce 500 l using plants. That digester is not yet insulated, so with proper insulation one should get even more gas. But let us assume for the moment that our digester will produce 500 l gas per m^3 and day, and since the active digester volume is around 0.4 m^3, that means 200 l per day. A study has it that 200 l of biogas is enough to cook three meals for just one person[21], but that is using an ordinary, non insulated stove. With an energy efficient stove and a well insulated pressure cooker, the energy consumption could be lowered by up to 70 %[8]. Let us for now assume that the family manages to lower the energy consumption with 50 % by insulating their stove. In that case, two fifths, or **40 % of the family's cooking fuel could be replaced by the biogas.**

This family would therefore save 0.4 * 91,313 = 36,525 ≈ 37,000 KES (400 Euro[26]) per year.

Example 2
We use a family of five as before, but in this case they don't pay for any of their cooking fuel. Instead they pay for chemical fertilizer, on their 3 acre patch of earth where they grow maize. They use 100 kg of chemical fertilizer a year, which, if they buy it by the kg costs around 50/= per kg, whereas if they buy it in larger quantities they can get a 50 kg bag for 2,200/=. (Also this is usually more expensive in more remote areas.) Let us assume that they buy it by the kg, and so **they spend 5,000 KES (55 Euro[26]) per year on chemical fertilizer only.**

Our type of digester should be loaded with 1.5–2.5 kg DS (Dry Substance) per day, or 550–880 kg DS per year. Assuming a C/N ratio of 25, that means 22–35 kg nitrogen in the residue (as much as in the input) per year. Chemical fertilizer usually has less than 20 % nitrogen content, and so this is well enough to cover the total need for the family patch. Thus **the full 5,000 KES (55 Euro) per year can be saved.**

This is without consideration of the expected increase in crop yield and decrease in the need for chemical pesticide.

13.3 How long time before the investment pays back?

Using the family in example 1 above, who pays for all their cooking fuel but not for fertilizer, it would take 21,000/37,000*365,25 = **207 days to earn back the investment** of 21,000/=. Using example 2, where the family pays for fertilizer but not for cooking fuel it would take 21,000/5,000 = **4.2 years to earn back the investment.**

It is therefore clear that the cost of cooking fuel is likely to be a stronger driving force in choosing to invest in a biogas digester, then the cost of fertilizer, although both of them together, is of course the best.

14 Aspects of Sustainable Development

Sustainable development, according to the Brundtland definition, is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs"[32]. It is said to rest on three interdependent and mutually reinforcing pillars: Environmental, social and economical sustainability. Although the most crucial condition for a society to go on, is of course that it stays within the limits of the system, i.e. the environmental limits, it is easy to see that also the other two pillars are important in creating a society which is pleasant for people to live in. Our question is therefore: What impact might the use of small-scale biogas have on either of these three pillars, in the Lake Victoria region? Let us start by looking at some aspects of the present state of this region.

14.1 Description of the present state of the area

This beautiful land is considered by many to be the cradle of humankind, and indeed, less than two hundred years back, it appears that human existence in this area would have been almost idyllic. The equator passes through the northern tip of the lake, and the warm weather and the plentiful rains in the rain seasons made a wide biodiversity flourish. The people survived rather easily on slash-and-burn agriculture, their perhaps biggest problem being the pests that also thrive in this kind of climate, like malaria, sleeping sickness and different kinds of parasites.[33]

Since then, however, many things have changed, different regimes have come and gone, population has doubled a few times, and as mentioned in the introduction, the area around Lake Victoria is now one of the most threatened regions of the world.

The lake itself is in fact shrinking. Some sources say the lake surface has dropped by 1.5 m, creating docking problems to the economically important boat traffic on the lake, etc[34]. The lake shrinking has many reasons, one of which being a decrease in rainfall in recent years, to which the lake size is very sensitive. The decrease in rainfall is likely connected with the extensive deforestation in the area; In Kenya for example only 2 % of the land is still covered by trees. [35] Some also argue that the global climate change has caused a greater evaporation in the area, and another politically hot issue in the matter is that Uganda has a hydropower generating plant at the lake's only outlet, the White Nile River. Cities and industry are constantly demanding more electricity from this plant[36].

Also the ecosystems of the lake are severely threatened, both by over fishing, and by invasive species like the Nile perch, introduced as a food fish to help the local fishing industry. This worked well at first. The delicious perch thrived, and was exported to Europe, Asia and North America. As with any species that grows beyond its system boundaries though, the Nile perch has now started to diminish, as it has completely or almost wiped out many other fish species in the lake and is now running out of food[1].

There is also the Water hyacinth, which, introduced as a beautiful ornamental plant, sometimes covers up to 90 % of the lake surface. This is devastating to the surrounding societies, as the impenetrable emerald mats paralyze all traffic on the lake, on which regional business, and of course food production through fishing, depend. The hyacinth also competes with the native plants, fish, and frogs for oxygen, often causing asphyxiation and massive die-offs. It even increases the evaporation from the lake, thus speeding up the lake's shrinking.[37] Fighting back this weed is therefore a necessity, and attempts have been made, by chemical treatment, biological treatment and by the physical removal of the weed.

The chemical treatment has its obvious drawbacks (the lake is also a source of drinking water etc) but also the biological treatment – although visibly effective – causes problems, as the weevils which were introduced for the purpose, eat only that part of the plant which is above the water surface. When the plant subsequently dies, it sinks to the bottom, where its decay consumes the dissolved oxygen in the water, leading to oxygen depletion at the bottom of the lake[38]. In the absence of oxygen, the further decay of the Water hyacinths likely leads to formation of methane leaking to the atmosphere. The environmentally best method to control the weed therefore seems to be physical removal, which is conducted thus: First the mats are chopped up in pieces using boats with special machines. Then the chopped up, floating biomass is collected and pulled up on land, where it is allowed to dry for a few weeks before it is burned[39]. The greatest problem with this method would be the high cost it involves. And of course the effect is somewhat temporary.

The shores of Lake Victoria have the densest rural population in the world, with 30 million people now living in the lake basin[40]. Most of them, some 75 %, are involved in some kind of agriculture[30], many are involved in fishing[41], and almost all of them use firewood or charcoal to cook[42]. These people are very poor, and as many as 60 % are believed to live below the poverty line[2]. They are therefore vulnerable to all kinds of crises such as diseases[43], not seldom caused by the poor hygiene from the wide-spread use of "pit latrines". These latrines consist simply of a deep pit dug in the ground, and a small hut built on top of it with a small hole in its floor. The latrine is used until the pit is full, and then the pit is simply covered again, the hut being moved to a new pit that has been dug. When the pit starts getting filled up the first time, however, some people throw batteries in it, and then the volume, which was full of biological activity, goes down significantly, and the latrine can be used a while longer[42]. Then when the rains come, some of the content from the many, and not always professionally constructed, pits leak out, some of it getting into drinking water, causing diarrhea and spreading cholera, typhoid and other pathogens. According to the World Health Organization, WHO, 1.9 million children under 5 years, die each year from diarrhea, almost all of them in the underdeveloped world[44]. In fact 80 % of all underdeveloped world diseases are caused by unclean drinking water[45].

Another plague of the Lake Victoria basin is the HIV epidemic, which is estimated to have infected some 10 – 40 % of the local population; a much higher number than the national averages of the three countries[46,47,48,49]. This has created many orphan children with little chance of getting ahead in life, although some secondary schools have started to accept a number of orphans without a school fee, thereby providing them with education and a meal of food each school day[50].

A great obstacle to any kind of development in the area is the corruption, infiltrating all levels of society, making it more rule than exception that any investment made, largely ends up in the pockets of who-ever is in the top position of the project. The police officers' salary is not even high enough to make a living from, unless they fill it out with bribes[42], and criminality is very high.

But despite all of these problems, this is in no way a desolate or hopeless part of the world. This is also the land of Wangari Maathai, the Kenyan Nobel Peace Prize Winner of the year 2004, and founder of the Green Belt Movement; a movement to create ecological awareness among the people, targeting especially the women, and to replant trees.[35] In 2007 the World Social Forum was held in Nairobi, Kenya, and there it was evident, as all around in the country, that an atmosphere of optimism and strength, of taking action and making a change, is penetrating all of this part of Africa. In every village and certainly in the slum quarters of the cities, people are organizing themselves in youth groups, development groups, women groups etc, that address the local problems and try to find solutions to them, e.g. the sports clubs in the slums that provide the youth with an alternative preoccupation to crime.[42] All the three countries around Lake Victoria – Uganda, Kenya and Tanzania – have a government decision that primary education should be free and available to all[51], and although this goal is not yet reached due to lack of schools and teachers etc, a large part of the population is getting primary education, and the gender distribution of this part is fairly equal. At least in Kenya, people discuss politics openly and vividly, and their news channels publish sometimes very critical news about the governance of the country. Especially the corruption is strongly criticized, and actions are being taken against it, although this huge work is bound to take time.[42]

14.2 The impact of biogas

Let us be realistic, a wide-spread use of small-scale biogas can probably do very little concerning the Nile perch. Nor is it likely to be effective against the HIV epidemic. It is probably not even rational to believe that it can have any great influence on the demands on the Ugandan hydropower plant at the river Nile, since biogas is likely to be used mainly for traditional energy needs such as cooking fuel, whereas electricity is demanded mostly for lighting, industries and different conveniences that are new and ever growing phenomena in these societies.

14.2.1 Saving trees

What the biogas use will, on the other hand, do, is to reduce the consumption of traditional energy resources such as firewood, the magnitude and importance of which should not be underestimated; especially so, given the massive population growth that this area has seen. Let us assume that an average tree in the area contains 1 m^3 of dry wood (a rather loose estimate, based on different calculations dealing with trees[52,53]) and weighs 598 kg/m^3 after seasoning[54]. In theory, such a tree could give roughly 10.8 GJ of energy[55], but with the traditional three stone cooking fires most often used in the area[42], which have an average efficiency of only around 14 %, the same tree would give 1.51 GJ of *useful* energy. A family size biogas digester like the Nyasanda digester, producing 200 l of biogas per day with a heat value of approximately 21.6 MJ/m^3 [56] would, if we assume an average stove efficiency of 60 %[57], give 0.942 GJ of useful energy per year. This could thus save 0.63 trees per year and digester. Given the population in the lake basin of 30 million people, if all families consist of five people and they all use this digester, this would mean almost 4 million saved trees per year.

As Professor Wangari Maathai has pointed out, a tree cover has many effects of great importance to a country. It influences the availability of rain and of underground water, the soil fertility and the clean air, it prevents soil erosion, and it gives beauty to the landscape. Experts even say that a forest cover of 10 % is required for a country to sustain life naturally[35]. The prevention of soil erosion is beneficial also to the lake, as the large amounts of earth otherwise being flushed into the lake with each rain present a problem. If the water flows through the landscape at a slower pace, there is also less problems with flooding, at the same time as the landscape is being kept more humid. All of these things affect the long-term sustainability of the societies, and wealth of their people.

14.2.2 Sustainable fertilizer

The fertilizer that the biogas technology gives can, as has been stated before, also be of great importance, and perhaps even greater than that of the energy produced. The mined phosphorus which is presently used in chemical fertilizer is for example estimated to be finished in about 50 – 130 years, and the peak ("peak phosphorus") was already past somewhere around 1990[58]. Therefore an increased recirculation of this nutrient is necessary. But chemical fertilizer is also known to have many disadvantages, other than just being finite. For example it contains no humus, and therefore the water maintaining properties etc of the soil, slowly go down. Chemical fertilizer has also proved to lead to an increased use of chemical pesticides, due to the lower qualities of the soil and crops. The biogas residue on the other hand, can restore and maintain the soil quality and fertility for an unforeseeable time into the future, and it is also much more nutritious than the chemical fertilizer, thus improving food quality and health of the people. (See chapter 5.2 The residue – a biofertilizer)

14.2.3 Cleaner drinking water

One of the largest problems to all of the underdeveloped world – and the denser the population, the larger the problem – is the lack of clean drinking water.[45] If a large portion of the population in this area were to start using the biogas technology to hygienize their feces, it could therefore have a great positive effect on public health, and therefore also on the economy of the society.

14.2.4 Gender issues

Biogas is also a cleaner fuel than firewood and kerosene, reducing health effects like pulmonary diseases and eye problems[7]. But this is not only a health issue; it is also a gender issue. With few exceptions it is still the women who are doing all of the cooking and the collection of firewood. Therefore it is they who are primarily getting sick and dying from the kitchen smoke, and they who spend 5–8 hours each day collecting firewood. With biogas, much less work could be spent for cooking fuel.[59] It is also the women who traditionally do all the farming, and so an increased crop yield could further decrease the work load on women. With less time spent on these things, some women could use the time to bring in an extra income through perhaps some handicraft, thus raising their power, self-dignity and status towards the men. It has also been found that when cooking becomes easier, as it does when shifting from firewood to biogas, the men take more part in the cooking[59]. All of this improves gender equality, and studies have shown that gender equality is a crucial condition for positive development of any society[60].

14.2.5 Empowering the rural poor

Another aspect of social character is the fact that small-scale biogas puts the individual family in a much stronger control of the three crucial matters house-hold energy needs, food production and to some extent personal health. Modern definitions of poverty all emphasize powerlessness and the consequent vulnerability as the most important parts of poverty, much more important than the lack of convenience or money.[60] If the family can fulfil all or most of their energy needs with resources that are freely and abundantly available in the surrounding, and some of them in fact being disturbing weeds, then that is a very large step towards control over their own situation. No longer would they be helpless victims to fluctuating fuel prices, or to both fossil fuels and trees running up. The fertilizer that gives them good crop yields and, more importantly, keeps their soil fertile and healthy year after year, means that they can sustain themselves even without much income, and they will not need to go in search of a new patch of land in a few years time (a practise which is already quite impossible in this area nowadays, given the density of the population). This improved self dependence also means that there is less likely to be conflicts over energy and food resources, and hence the biogas use could improve the long-term political stability of the region, as resources is a very important cause of conflicts in this world[61].

14.2.6 Reducing Water hyacinth

And, although it may have to give in to the Nile perch, the use of biogas could very well prove to be of help against that other invasive species, the Water hyacinth. If run by only Water hyacinth, the Nyasanda digester producing 200 l of biogas per day, would require roughly 10 kg of Water hyacinth per day, or 3652.5 kg of Water hyacinth per year. This corresponds to a Water hyacinth cover of roughly 150 m^2. To harvest the plant directly from the lake is of course preferable to planting it in e.g. a pond, from environmental point of view, since the former brings some of the nutrients, that have been lost to the lake through soil erosion, back to the land where it came from, thus closing the nutrient cycle between land and lake.

14.2.7 Green-house gases – decrease or increase?

There is however something that could perhaps prove to be a great disadvantage with a wide-spread use of low-technology biogas, and that is the leakage of methane into the atmosphere. Methane is a green-house gas with a global warming potential, GWP, of 23 over a 100 years[62], meaning it is a 23 times more potent green-house gas than carbon dioxide. As long as the gas is properly burned as intended, it does not contribute to global warming, as the combusted gas turns into carbon dioxide and water, and none of this carbon dioxide was of fossil origin. If, however, not all of the gas is combusted but some is allowed to leak into the air, that means that carbon dioxide from the air is being converted into methane, via the photosynthesis in the plants (possibly a middle step in the stomach of a human, cow or other animal) and finally the processes in the biogas digester. This is a problem that I feel has not been debated enough, given that there is bound to be plenty of gas leakage in this kind of use. In China, early users of biogas had so much problems with gas leakage from the very digester, that some stopped using their digesters because of that. Others over won the problem by covering the insides of their masonry digester with water-glass.[14] Also the soft polyethylene tube digester type probably leaks a lot of methane, since methane quite easily diffuses through thin polyethylene. But even if the digester itself does not leak, there will be methane emissions to the air, for example every time the digester is opened to be cleaned, and when it is started up again, the first three container-fulls of biogas should not be combusted for safety reasons. There will even be a little gas leaking every time someone starts to cook, just before the flame is ignited.

How large this contribution is to the total green house gas emissions however, depends largely on the source of biogas feed used. If the source is Water hyacinth, much of these would have turned into methane anyway, when decaying anaerobically at the bottom of the lake, plus the asphyxiation (oxygen depletion) that it creates[37] makes organic material also from other sources turn into methane at the bottom of the lake. Therefore using Water hyacinth as a feed might very well decrease the total emissions of green-house gases, counting not only the directly anthropogenic emissions.

If human feces is used, this also could decrease the total emissions, given the present conditions in which most people in the area are using the pit-latrines. In these latrine pits there must also be a lot of anaerobic decomposition, turning what was recently carbon dioxide into methane. When the same process takes place in a biogas digester, at least some of the methane is combusted. From the pit-latrines almost all of it must sooner or later end up in the atmosphere.

If cow dung or other dung is used, it is also likely that some of it would otherwise have ended up like methane in the atmosphere, although this depends on how the dung would have been stored and used. As long as there is sufficient oxygen present, no methane is formed, as carbon dioxide is then produced instead.

If however the feed is the sunflower, Tithonia, it seems quite clear that all the carbon which is thus converted into methane would otherwise have been converted into carbon dioxide as the plants would have withered on the ground where they grew.

As long as there are trees being replanted, and the forests spread, it could be argued that these forests are binding carbon dioxide from the atmosphere thanks to the use of biogas, replacing firewood, but in fact, these are forests that used to be there only a few decades or maybe centuries ago, and so the restoring of these should be done anyway, in order to reset the concentration of green-house gases to the levels they were before, even if no more emissions are made.

14.2.8 Changing the ecosystem?

If we look at the ecological aspects, it is possible that a large-scale out-take of biomass to use as biogas feed might eventually have an impact. If, for example, a lot of Tithonia is brought from its usual hedges by the road-sides, and eventually ending up on the crop fields, it is likely that the soil where it grows will eventually become depleted of some of the nutrients in which Tithonia is rich, and thus Tithonia may cease to grow there. As mentioned, Tithonia is rich in nitrogen. However, if nitrogen is removed from the soil by the taking away of Tithonia, probably some nitrogen fixing plant will eventually take its place[63], and perhaps even this plant might be suitable to use as biogas feed. Tithonia usually grows by roads with heavy traffic, where there is much nitrogen from the exhaust gases. Here, there might not be a problem of nitrogen depletion, but on the other hand, plants growing in these places are probably heavily polluted by for example heavy metals, and are therefore not well suited as a fertilizer for food crops.

The Water hyacinths growing in the lake are benefiting from nutrients that have to a large part ended up there by soil erosion and untreated toilet sewage. Therefore, using Water hyacinth as biogas feed and later as crop fertilizer, means that one is, to some extent, bringing nutrients back to where they came from, and also maintaining them there, if the human feces are also used as biogas feed. Even though some of the nutrients did not come from the human crop fields but rather from what used to be wild forests, taking them out of the eutrophied lake is probably going to be more of a benefit than a disadvantage, for a long time yet into the future.

14.2.9 Ecocycle contamination?

When elements are being recirculated in short cycles like this – nutrients from human feces becoming crop fertilizer, becoming crops, being eaten by humans, then turned into a fertilizer and being spread on the crops again – there is always the risk of ecocycle contamination, meaning that some harmful substances might build up in the system, their concentration becoming higher with each cycle, until they reach critical concentrations.

Such substances might be for example heavy metals or medical drugs. Perhaps some of the residue should always be discarded somewhere else than on the fields, maybe a digester-full of slurry once a year or so, and perhaps also people who are currently on medication should not use the biogas feed latrine.

At this point though, it must be pointed out that this sensitivity that the more closed system and the shorter cycles bring, can also be an advantage! With this kind of a system, the consequences of many actions become more immediately clear, and may very well reach a much more conscious level to the people. If, for example, somebody would drop a battery into the biodigester, the whole process might stop or become severely harmed, and that would mean no cooking fuel and no fertilizer for a long time. It might also become obvious that what people eat has an influence on the process, and later also on the effect of the fertilizer. This way, an awareness of how everything in nature is connected, and how every action therefore has a consequence somewhere, might arise in the people quite naturally. This is very much different from the world view of most people now living in an industrialized country, where many have never, even at quite high age, stopped to think about how the fields can keep bringing nutrition even though it is taken away with each harvest, or what happens with the remainders of the medicine having gone through our bodies after we flush the toilet. In my own view, it is very much possible that it is this awakened awareness that – if it comes now, before much of the industrializing damage has been done – will have the largest significance to the sustainable development in this area, out of all the issues that the biogas technology might bring.

14.3 Summary of the most important impacts of biogas

14.3.1 Advantages

A wide-spread use of small-scale biogas around Lake Victoria would probably:

- Save trees
- Ease work-load, especially for women
- Improve health, by providing a cleaner cooking fuel and hygienizing organic waste
- Improve crop yield and food quality
- Preserve soil quality and fertility
- Reduce the amount of Water hyacinth in the lake (and reduce eutrophication)
- Reduce poverty, by cash savings and increased family self-dependence
- Improve gender equality
- Save fossil fuels
- Create public awareness of ecocycles

And there are some more, like maybe reduce the methane flow to the atmosphere by removing Water hyacinth from the lake and replacing the pit-latrines, but I feel these are more uncertain. I was also a bit uncertain about the point “Save fossil fuels” and put it rather low on the list. This was because the biogas will mainly replace firewood as cooking fuel, and traditionally fossil fuels are only used as lamp fuel, where biogas is not such a good replacer. But in the end I felt I had to put that point on the list, because as trees are becoming so utterly scarce, fossil fuels are becoming more used also as cooking fuel.

14.3.2 Disadvantages

A wide-spread use of small-scale biogas around Lake Victoria might lead to:

- Increased green-house effect, by carbon dioxide being converted into methane and leaking to the atmosphere
- Altered ecosystems, when new plants start being used for cooking fuel
- Ecocycle contamination, if human feces is used to eventually fertilize human food crops
- Increased poverty, by people investing in biogas technology and failing

15 How Can Biogas Win Popularity In This Area?

The UN Guidebook on Biogas Development from 1980[22] (from now called the Guidebook) gives a chapter of advice for biogas programmes of a country. A red thread through the whole chapter is the commitment from the people themselves, who are to use the technology, and especially from the women, as they are likely the ones to be the most affected. (In numerous development programs world-wide, men have been given instructions and knowledge about new technologies, and then in fact it was the women doing the actual work in the field. Some of the knowledge was of course passed on to those women, but most of it was lost, and so the programs largely failed.[64]) The best way to promote biogas, says the Guidebook, is to have a functional biogas digester for demonstration in a regular home, preferably demonstrated by a woman. The home should be an average home, rather than the home of a very rich family. The Guidebook also says that one should emphasize the benefits that the use of biogas could bring, to all these three levels: The nation, the community and the individual family.

There is also a word of warning:

> In some countries large numbers of [biogas] plants were installed but failed because of various reasons such as:
>
> (i) Inappropriate design;
>
> (ii) Too strong a campaign to install plants at subsidized prices, before people were genuinely interested and had a realized need for them. People did not operate or maintain their plants properly;
>
> (iii) Lack of technical support.

The Guidebook states that direct subsidies, although they may cause many plants to be built quickly, usually result in many of these plants going out of use within a few years. This has also been told by sources in China, where a huge biogas program was started up in the 1960s, and during the 70s the number of households using the technology increased from 6,000 to 723,000!, but by mid-80s most of them were disused again[3]. Eventually China has managed to overcome these problems, through determined continued education and development of the technologies, as well as continued investments and support from the government, and so by the end of 2005, 18 million households had adopted biogas technologies. They produce annually 7 billion m^3 of biogas, or 1 m^3 biogas per household and day.[3] Still, the road to this success was costly, and paved with disappointment.

The UN Guidebook therefore says that an alternative to direct subsidies is to take it more slowly, to let the farmer pay the full price of the plant, and perhaps to give support in an indirect way by providing low interest loans for biogas installations. Experience shows that farmers do not value hand-outs[59], and hence they might not take the proper time to fully learn how to operate their plants well if it is given to them for free. If they have invested in it on the other hand, it is very much in their own interest to see the investment pay off. With free hand-outs, those who receive them also might not feel inclined to tell the promoter about the problems with them, as they feel it might hurt the promoter's feelings[65]. If they have paid for it however, they have to tell the problems if they are not to lose money, and the investment they have put into it makes them fully in their right to do so.

The Guidebook also points out that the following three facilities must be available to the people, or else biogas is not feasible:

- Sufficient suitable input materials;
- Sufficient water;
- Reasonably high temperatures throughout the year.

Farmers are not advised by this book to make themselves dependent upon other farmers by, for example, arranging to get cow dung for their digester from them. The other farmer might later want to build her own digester, or indeed start selling her dung to those who have.

The Nepalese training manual[13] gives some advice on how to choose the right digester for the conditions. According to this manual the main factors are as follows[66]:

- **Economic**
  - The digester should be as low-cost as possible per volume of gas produced
- **Simple design**
  - Both for construction and for operation and maintenance, especially where literacy and the availability of skilled human resources are low
- **Utilization of local materials**
  - This will ease the spread of the technology and the replacement of broken parts, especially where transport systems are not well developed
- **Durability**
  - Even a digester with a short life-length might be cost effective, but in a situation where people are yet to be motivated for the adoption of the technology, and the necessary skill and materials are yet not readily available, it is better to construct plants that are more durable, although this may require a higher initial investment
- **Suitable for the type of inputs**
  - If plant material is used as feed, it is necessary to have a digester with a stirrer, or to use a batch version
  - If the feed material is likely to contain much sand or other heavy, inert matter, it is important that the digester can easily be opened and emptied regularly
- **Frequency of using inputs and outputs**

It is also, of course, important to look at the alternatives to biogas technology that are available in the area. For example, in India, biogas from cow dung has failed in some projects, because the people were used to burning cow dung as cooking fuel, after having dried it into cakes. To burn the whole volume of cow dung of course gives much more heat energy than to convert only some of it into methane that is subsequently burned, and probably those people did not have need for the slurry as a crop fertilizer, or maybe they had not realized this value of the slurry.[67]

Especially Chinese sources point out the blessings of creating a national biogas organisation like the one they have in China, with a national level, a regional level and a local level where people can quickly get advice and technical support[3,14]. They also stress, as does the UN Guidebook, the benefits of education about biogas, and information on all levels, preferably over the radio, as newspapers and leaflets are usually not available in remote village areas.

Having said all this, there is one issue that in the author's own mind has not been properly discussed, at least not in the biogas literature concerning underdeveloped countries (the Swedish sources are much better at it), and that is the safety aspects! With a gaseous fuel there is always the risk of an explosion. There can also be a risk of suffocation or poisoning, although this risk appears to be low, the way the gas will likely be handled in the Lake Victoria region. On the other hand, the risk of an explosion, when a gas is used as cooking fuel, probably together with other fuels, in an area where safety regulations are generally sparse, and even more sparsely respected, where literacy is low and technology is immature, is obvious! And few things could probably be worse publicity than some people having such an accident, at an early state of the biogas spread. The idea to use biogas as cooking fuel, in my idea should therefore never be mentioned, without at the same time mentioning the slight risk that it might explode, and safety should be built in with the very construction of all utensils from the beginning (while people are still aware of it).

But as with anything that is going to change the habits of people, the key factor is to have a strong enough driving force. Habits, culture, taboos, anything can be altered if the incentives are good enough, but only then. Therefore, before starting up a project anywhere, one should always probe the possible incentives, and in this area, they seem to be quite favourable. Most people grow their own food, and would therefore be very much helped by a good fertilizer that would keep their soil healthy. And even more important: The traditional fuel, firewood, is now very, very scarce, and most people therefore have to buy cooking fuel at a cost which is quite noticeable to them, or spend very long hours to go in search of it. In my interviews with people, it seemed that this incentive would be the strongest one, even though, on a community level, the third benefit of improved hygiene will likely have quite an impact.

15.1 Suggestions

This area thus has the driving force needed to introduce this new technology and the new habits to the people. There is also the benefit of the warm temperature, and several suitable input materials. But there are also obstacles, the two most important ones probably being the limited availability of money and that of water.

To lower the need for water, where the availability is poor, some of it could be recirculated. All which is needed is a sieve on which to put the slurry, and some vessel underneath it to collect the water, which will then be mixed with the new feed for the digester. Some new water must, however, always be added to the feed, because otherwise the concentration of rest products from the process, e.g. ammonia, will build up in the slurry, and eventually inhibit or stop the process[68].

Mr Björn Martén[8] has also suggested an alternative way to operate the digester in dry seasons, if water is then only temporarily scarce, which is often the case in this area. His advice is that during these dry seasons, the feed material is chopped into pieces as usual, and then simply fed to the digester without any addition of water. This way the process will be slower, but on the other hand, the retention time will be longer, due to the lower volume fed. Still the gas production will be lower in these periods, but at least the bacteria will be kept alive for when the rains start again, and the digester can be run optimally again.[15]

To approach the problem of scarcity of money, besides making the technology as low-cost as possible, one could make use of the system of collective saving, which is widely used in this area[42], as in many parts of Africa. This could also be combined with the benefit of targeting women, by promoting the idea to a women's group which practices collective savings. They could for example pay for the materials for one biogas plant which they would then build, preferably together with their husbands and children (because projects tend to work better the larger part of the population they involve), and with the supervision of someone who has built one before. Then, one of the members could rent the plant from the group, by paying more to the collective savings, until they would have enough money to buy the materials for the next plant, which they could also build together. Now they would have two biogas plants to rent out, etc, until every member in the group would have their own biogas digester. This system requires a lot of mutual trust and community, but these are resources which are usually abundant in constellations like these, and the local ownership would be maximized. Other possible targets for this kind of spread are e.g. village councils and church congregations.

Otherwise the digester described in this thesis is consciously designed to fit with many of the criteria mentioned in the section above. Thus it is cheap and made only in locally available materials, and the construction is simple. To make also the operation simple, the temperature stabilization is acquired by passive insulation. Mr Martén has a few other ideas of how to level out the temperature differences between night and day, by e.g. passive or hand-pumped water loops etc, but it is quite possible that, even though these methods might yield more gas, the pure insulation method might win a greater popularity, due to its utter simplicity, and familiarity to the people (they build houses with similar techniques).

As has been stated in the previous section, it would be very beneficial to the biogas spread if the countries would put up a biogas organisation, like the one they have in China, and at least the Kenya Agricultural Research Institute (K.A.R.I) already has a sector that deals with biogas[69], even though this is not yet well known to the people. This is however no topic that I have planned to get deeper involved in, as it is something that I feel should come from the people themselves. But it is of course likely that, if this technology would be able to spread well on a user-to-user basis, the interest of starting such an organisation, and also education, in the future will be greater.

The main points that I have found for a successful biogas spread in this area, and that have already been included in my work where applicable, are therefore:

- Local ownership
- Low cost
- Simple construction – no skilled labour
- Simple, comprehensive operation and maintenance
- Much gas produced
- Water access sufficient (though it could be partly recirculated, and the digester run differently in dry seasons)
- Target suitable groups for the early spread
- Caution! Consider the risk of an explosion

Let me finish up this chapter by, again, quoting the UN biogas guidebook[22] when it states these encouraging words: “Where careful preparatory work has been carried out, along with good promotion and technical support, biogas schemes have been successful”!

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All the many people who helped me along the way with theoretical and practical issues, and all of those who made my work in Kenya so utterly enjoyable.

Thank you!

Appendix A – Full Budget for Digester Design Project in Kenya

Item no.	Item		Cost
Materials for digester			
2	“Superdrums” (200 l water drums) x2	2 x 1 450 =	2900
12	Hose-pipe x1 role		900
3	1½" PVC pipe x1		300
15	Silicon paste		300
33	Adapter 1½" x2	2 x 100 =	200
39	Adapter 1" x2	2 x 100 =	200
19	Grease		150
34	PVC pipe cement		120
9, 35	”Jerrican” (20 l water jug)		100
13	Water bottles for nipples and stirrer blades	12 x 5 =	60
14	Pipe clips	2 x 30 =	60
22	Hose-pipe joint		5
	sum		**5295**
Gas container			
24	“Superdrums” x2 for gas container	1450 + 1050 =	2500
	Water bottle for nipple (1 or 2)	2 x 5 =	10
	sum		**2510**
Insulation	structure, estimation		
	Clay + transport	0–5100	5000
	Straw + transport	0–3000	2000
	Wooden moulds	2 x 500 =	1000
	Polyethylene sheet, 15 m yellow (as both tool and roof material)		1800
	Other materials for plastic roof (poles, fitos, nails)		2320
	Tools (hammer, basins)	120 + 2 x 80 =	280
	sum		**12400**
Tools			
1	Saw		250
5	Pliers		200
26, 8	Files	100 + 50 =	150
10, 32	Curry powder cans	2 x 45 =	90
29	Iron pump ("nini") for burning holes		40
	Other (screws, screwdriver,...)		200
	sum		**930**
	Total sum		**21135**
	Rounded off		**21000**

Appendix B – Building an Insulating Clay-Straw Construction

This is my full, collected knowledge about how to build an insulation structure of clay-straw in the area around Lake Victoria. I will describe in detail what we did in my project, and mix it with recommendations of how it should be done, based both on our own experiences and on other sources.

i. The Materials

In Orongo the insulation structure was built of rice straw from Kachok rice plantation, and clay from Nyalunya village, taken from 0.5 – 1 m underneath the ground level. The rice straw was long and strong, and very suitable for the clay-straw technique. Unfortunately, it had been lying outside in the rain and started to mould, which was explicitly expressed in the instructions[24] that it must not happen, but we didn't have any other, so we had to take it anyway. The clay was rather sandy, but worked. When we took clay from more than 1 m underneath the ground level however, it did not dissolve in water, but turned into lots of fat lumps. We also had a lot of problems with people who were supposed to help us to get clay, but who brought earth or sand instead. This was both costly and time consuming, so I recommend future clay-straw builders to always go to get their clay themselves.

At Nyasanda High in Ugunja a type of grass was used, one which grew in the neighbourhood and which they used for their thatched roofs. Also this was long and strong, much thinner than the rice straw but none-the-less hollow, and they said it had been used for a similar type of insulation technique before by some foreigners at the school, so we decided to give it a try. This time we spread our grass in the sun immediately after it was harvested, and turned it around a few times, so that it dried quickly and did not have time to mould. The clay, which we took from a termite hill which happened to be under construction right then, was orange brown, smooth and absolutely lovely. It was also of just the right level of moistness, easy to work with, and dissolved easily in water, despite being very fat. We made sure to take only so much at the time that the termites would not decide to move somewhere else.

I never managed to see the Nyasanda clay-straw construction in its finished state – in fact I only had time to participate in making the first clay-straw block – but at least I could confirm that the technique swallowed a lot more grass of this thinner kind than of the rice straw, but that it however worked, and the 30x60x20 cm large block was possible to lift immediately after having been pounded together in the frame.

Three hand carts of rice straw was used for the Orongo construction, which means roughly 4 m^3, loosely packed. In Ugunja I first ordered 3 hand carts of grass, and later 3 times as much more, which together makes 12 hand carts, but here I had no possibility to check how much grass there was on each. I would however estimate that no more than 3 times as much of what we used in Orongo was used in Ugunja in the end, i.e. a maximum of 12 m^3.

In Orongo we used roughly 3 hand carts of clay, and probably around the same would have been used in Ugunja.

ii. The clay-straw blocks

We started by soaking the clay in water over night, without stirring it, since it said in the instructions[24] that one shouldn't do that. The next day it had softened up enough for us to make "clay juice" from it, which means that the clay is so well dissolved in the water that there are no perceptible lumps, and it shimmers slightly, from the tiny clay flakes, when stirred. We spread the straw on a big sheet of plastic, and sprayed the clay juice over it from small buckets, with our hands. The sand was left at the bottom of the basins. Pretty soon we noticed that the water scanty, Swedish recipe was not applicable here, under the hot, Kenyan sun, so we changed it to this:

Dilute the clay juice until it looks and feel a bit like Kenyan tea. (That is; half water, half milk, and then some tealeaves.) Pour enough clay juice onto the straw to make it feel wet, but there should not be a minor lake on the plastic sheet when the straw is lifted. Turn the straw over and over until every inch of every straw is well coated by clay juice. Cover thoroughly with the plastic sheet, fold the edges underneath the straw and cover them with rocks. Let soak overnight. This preparation should be done in evening time.

In principle, one should pour just enough juice onto the straw to make it be a little bit moist, and with a slightly sticky feeling to it, when it is to be used the next day, and the juice should be just enough diluted to make the straws stick together just firmly enough to be possible to make blocks from. Experiment until this is achieved. The more clay the blocks contain, the lesser the insulating capacity[24]. It is not a big problem if the blocks seem a bit loose and brittle, because the plastering will make the construction steady enough.

The morning after the preparation, the straw is to be uncovered from the plastic, under which it has probably already started to steam with the sun. Push it into a wooden mould, which you have wetted on the inside with water or clay juice. If the straw has gone completely dry in some places: Wet it again with water or some dilute clay juice, and turn it. Fill the mould, cover it with a wetted lid and step on the lid for a while. The lid must go inside the mould, and should leave a margin of some half inch on each side, so that straws can protrude without the lid getting stuck inside the frame. Do not step too brutally; we want the straws to maintain their hollow shape so that they can trap some air into the construction, since it is mainly this air that will insulate.

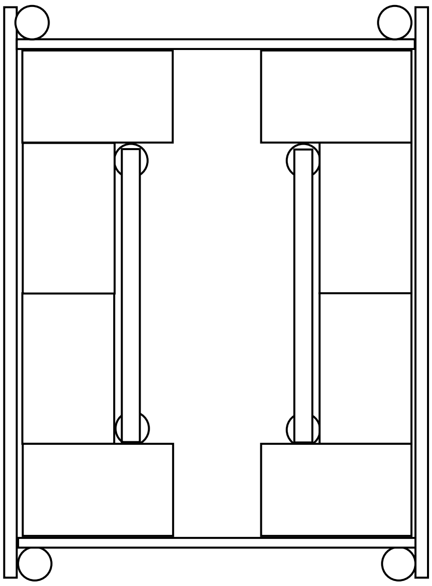
When the straw has been stepped on until it almost doesn’t bounce anymore, more straw is added. In doing this it is very important that the top straws of what has already been stepped on be roughened a bit, so that it can blend with the new straws. Otherwise the blocks will get distinct layers in a somewhat lasagne like structure, and can later easily fall apart. Keep filling and stepping until the block has reached the desired height. The frame is then immediately removed and the block is left to dry in the sun. Although it is possible to lift the block right away, it is advisable to make it in the place where you would like to have it while drying, and then leave it there undisturbed.

The newly constructed blocks should be kept in the sun and turned over every day until they dry. This will take a few days. Cover them in the event of rain.

In Orongo the blocks were made to be 30x50x20 cm. Later I however realized that there is an advantage at construction if they are twice as long as they are wide – since they can then be placed so that the joints end up in different places in each consecutive layer (a “running bond” in masonry terms) – so in Ugunja the blocks were made to be 30x60x20 cm. The Orongo blocks, as expected, started to mould even before we had started to build with them.

iii. Constructing the structure

The two structures were made in slightly different design. In Orongo (the only structure which was completed within the project time) the blocks were placed like this:



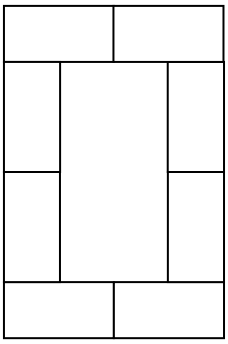
How the clay-straw blocks were placed in Orongo, seen from above

All the layers were identical, so the joints always ended up on top of one another. In the corners, both inside and outside the walls, cedar poles were therefore placed, planted firmly into the ground, and between those, thinner wood was attached by nails, for better stability of the structure. Later this would seem superfluous.

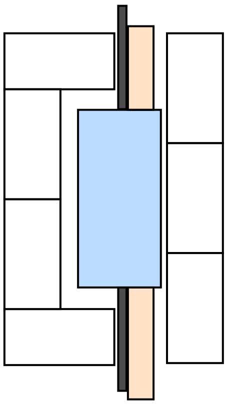
When the walls were finished, a grass roof was built over them, fastened in the wooden structure. The gables were made by millet stems, and the openings in the short walls were sealed around the in and out-let pipes with bricks and plastering. This might not have been such a great idea, since both brick and plastering are poor insulators.

It was later found that the temperature inside the digester fluctuated with roughly ±2° C from the middle value with this design.

Since the thatched roof was assumed to be the weak spot, for the next design I decided to make a kind of clay-straw lid for the structure. This would of course not withstand the rain, for which reason a separate thatched roof was built over it. The blocks were to be made slightly bigger, both to achieve the relation of 1:2 between the long and the short side, and to leave a bit more space to plaster the insides of the structure. The blocks were to be placed like this:

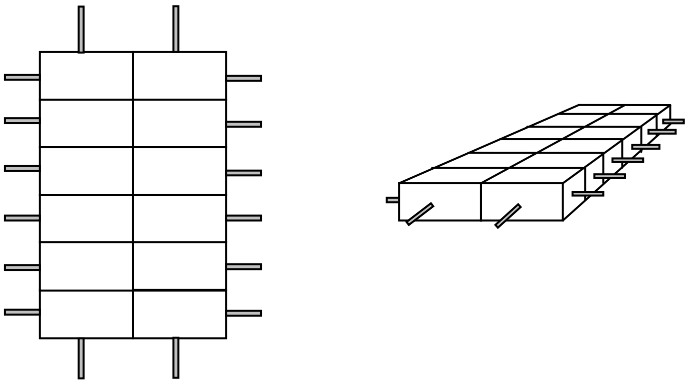


Layer 1 and 5

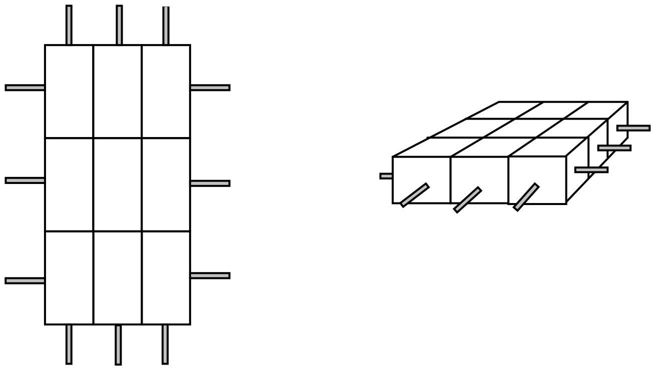


Layer 2 – 4, with an illustration of how the digester will fit, with the pipes and the stirrer sticking out through the openings

For the lid, I left two suggestions: One which would require 12 blocks, the outsides of which would be right in line with the outsides of the walls, and one which requires 9 blocks, and which would only cover half the thickness of the walls:



Lid covering the whole house, seen from above and in perspective



Lid of which the outer boundaries reach to half the thickness of the walls

For the blocks to stay in place, and not fall into the house, I was going to test reinforcing them with thin stems of wood which were to be pushed through the blocks; a technique which was taught to me verbally by Maja Lindstedt[25]. Observe that the smaller lid has a middle block which is not supported at all by a wall, but hanging only in the reinforcing wood, mortar and plastering which might cause a problem, while the blocks in the larger lid are always supported to half their size by a wall. Of course one could make a compromise between those two, e.g. two sides covering the whole walls, and two sides covering half of them, etc.

iv. Masonry

We made a mortar of clay and sand. In the instructions[24] was mentioned the ratio:

For meagre clay:
1 part clay
2 parts sand

For fat clay:
1 part clay

3 – 4 parts sand

We assumed our clay (and this is of course only in Orongo, since I never reach the masonry part in Ugunja) to be rather meagre, and we mixed sand into it until it turned into a very viscous, sticky mess. The sand is meant to reinforce the joint, and to prevent the mortar from cracking.

First we covered the ground, where we wanted to place our blocks, with a less sandy variety of the mortar, so that the blocks would be completely enveloped, and thereby better protected from insects. We should, however, have used more sand, for the next day our 3 cm foundation had cracked.

We started the masonry anyway, and did like this: The two sides which were to be joined – ground/block or block/block – were smeared with a little under 1 cm of mortar. We paid extra attention to covering all edges and corners, so as to leave no gaps. Then the smeared block was put in place onto a smeared surface, in one smooth movement, and then left. If the block came in a wrong position and we tried to move it, it just broke, since the joint was much stronger than the blocks themselves. Furthermore, clay tends to stick its best the first time. The more you disturb it, the looser it will stick to its surroundings[25]. Once a block was put in place, the next surface was smeared.

The walls were allowed to dry for about 1 day, before they were plastered. By then, the walls had set by slightly over a decimetre from the original roughly 1 meter's height.

v. Plastering

We covered the structure with 3 layers of plastering, roughly according to this recipe, given to me by Maja Lindstedt[25]:

<u>1st layer plastering, ½ – 1 inch</u>

1	part pottery-clay
2–3	parts sand
½	part cow or horse dung
1	part chopped straw (for fibre)
	water, in whatever quantity you find makes it stick the best

<u>2nd layer plastering, ½ – 4 inches</u>

1	part pottery-clay
2.5 – 4	parts sand
½	part cow or horse dung
2	parts chopped straw
1	part sawdust or other short fibre
	water

<u>3rd layer plastering, ½ – 1 inch</u>

1	part pottery-clay
2.5 – 4	parts sand
1	part fine fibre
some	cow hair (just a little bit)

The main purpose of the first layer is to make the second and third layers stick better. Therefore it should not be very smooth. Start applying at the ground, working your way upwards. Take a handful of plastering in one hand, hit it firmly onto the wall, and then smear it out in one, smooth go. Do not touch it again as it sticks its best the first time. The first layer needs to dry only for a few hours before you can apply the second layer, and if the first layer has gone completely dry, wet it with some water just before applying the second one.

The second layer needs to dry completely before applying the third one. The main purpose is stability and strength. We found that the best way to apply it was to throw it hard on the wall from a close distance, and then just leave it there. If you try to smear it, it will just fall off again. Again, we took extra care about all the corners, joints and ground parts, so that we made the layer extra thick in these areas.

The third layer is for protection. Its surface should be quite smooth. Extra care to corners, joints and ground.

When all of this was done the structure had turned into quite a stable house that seemed able to easily withstand strong winds, and even rains for some time.

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[67] Story of how biogas has also failed in India, told by A.D.Karve 2007-10-15 as a reply to the e-mail in source 65 on the Stoves e-mail list, http://listserv.repp.org/pipermail/stoves_listserv.repp.org/2007-October/007522.html, visited 2007-12-03
[68] "Förutsättningar för biogas från jordbruksgrödor" ("Conditions for, and potential of biogas from crops", author's transl.), EB 5:1998, by L Magnusson, Energy departement of Sweden, 1998
[69] Phone-call to the Kenyan Ministry of Agriculture Headquaters, made by the author's Kenyan contact Mr Wayne Wanjohi in November 2007