

## 14<sup>th</sup> Sarnet International RWH Conference – Mpumalanga, South Africa

### **Title    Rain Water Harvesting and Biogas production working together synergistically for Empowerment of Rural Households and Climate Change Mitigation**

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#### **Abstract**

Next to air, the three most essential elements for human existence are arguably water, food, and energy – normally in that order. This paper considers not only how harvested rainwater can produce food in a garden, but also how it can facilitate liquid fertilizer and energy, via a bio-digester. This energy is both renewable and reduces green house gasses.

At the start of the system is a RWH tank/cistern, which is used to irrigate a vegetable garden. The vegetables are harvested and prepared in the kitchen, and all preparation waste and leftovers become ‘raw material’ for the bio-digester. This may be supplemented with cow manure, or virtually any type of organic matter. These are added via the digester’s inlet together with an equal quantity of water from the RWH tank, but grey water can also be used, so that more of the rainwater can go to the garden.

Inside the digester bacteria consume the organic material, and in the process produce ‘biogas’, a 65/35 combustible mixture of methane and carbon dioxide. This gas is accumulated in the top half of the bio-digester’s reactor chamber, and a pipe takes the gas to the kitchen to cook the garden produce (or any other food) as and when required. The water that goes into the bio-digester eventually exits on the other side, from its ‘outlet’, and by now it has been enriched into a high grade non toxic liquid fertilizer which may be dispersed onto the garden. ‘Digestate’, a relatively small proportion of undigested residue that settles in the digester, also has fertiliser value, and when mixed in with the soil improves its texture and water retention. Together the liquid fertilizer and digestate enrich the soil with nitrogen, potassium and phosphates. The synergy of the system is therefore evident with each element complementing the other.

Other benefits include: (a) a reduction in deforestation; (b) reduced respiratory problems related to smoke inhalation from wood fires (methane is clean burning); (c) by burning the methane it does not escape into the atmosphere. (All rotting organic vegetation in garden and landfill dumps produces methane, which is 21 times more potent than CO<sub>2</sub> as a greenhouse gas). Clearly this, along with reduced deforestation, mitigates climate change.

*Note to the technical adjudicators: This paper fits in with Sub theme 2: Livelihood based innovations and community empowerment for climate change adaption and mitigation.*

## **Rain Water Harvesting and Biogas production working together synergistically for Empowerment of Rural Households and Climate Change Mitigation**

### **Back ground**

Next to air, the three most essential elements for human existence are arguably water, food, and energy – normally in that order. This paper considers not only how harvested rainwater can produce food in a garden, but also how it can facilitate both a liquid and solid fertilizer together with a combustible gas for cooking, via a biodigester. By 2005 there were over 25 million small-scale operational biogas systems of various kinds worldwide – with over a million now being installed each year<sup>(7)</sup>.

**Scope:** Owing to space restrictions (12 pages), the discussion will be limited to one type of RWH system, one type of biodigester, with one application for the biogas (cooking), based on experience gained by the authors over the past two years in the construction of four biodigesters made with ferrocement, although it is accepted that there are numerous possibilities for each of these cases. Furthermore only limited explanation of the bio-chemistry and various processes will be possible.

### **Overview**

The approach in the paper will be to explain the various elements of a fixed dome biodigester, some typical ‘raw material’ inputs, the bio-chemical processes that occur within the dome chamber that produce biogas and two other end products. Thereafter, an explanation is given of how the biodigester can function synergistically together with rain water harvesting, and the benefits that may be derived from this. Finally some costs are given relating to limited work done in South Africa.

## **Fixed-Dome Biodigester**

In China, millions of small-scale fixed-dome biodigesters have been constructed, mainly since 1950. These plants are generally constructed from brick and mortar, and since there are no moving parts, the structures are potentially maintenance free. These plants operate on the principle of the ‘continuous process’, whereby biomass (organic matter) and water are added to the plant on a daily basis. Typically the biomass consists of grass, leaves, kitchen leftovers, various types of dung, and even human waste.

Figure 1 illustrates a version of a fixed dome biodigester. The principle components of the system are an *inlet pipe*, *dome chamber*, *2<sup>nd</sup> stage chamber*, *expansion chamber*, *outlet pipe* for liquid, outlet leading to a *gas pipe*. It is evident that the 2<sup>nd</sup> stage chamber and expansion chamber are separated by a platform and trapdoor.

The three chambers are all made with ferrocement – which consists of a sand/cement mortar applied to a frame made from 4mm fencing wire overlain with chicken mesh (see figure 2). The wire & chicken mesh give the structure tensile strength, mitigating the development of unwanted cracks. Any such cracks would result in liquid and gas escaping.

Furthermore, building the plant largely below the ground surface (see figure 1) means that the backfilled ground will apply forces that tend to make the structure go into a state of compression, and this further mitigates crack development. Also, by building below ground, the gas plant is substantially insulated from rapid temperature variations – which would upset the microorganisms involved in digesting the biomass and producing biogas.

## **How the Gas Plant Works**

Biomass is added via the inlet pipe (see figure 3). To this an equal mass of water is added. The contents of the pipe are then pushed down into the dome chamber using the plunger.

Note that in the case of 'green' biomass (i.e. vegetation such as leaves, grass, vegetable off-cuts) it is advantageous to pre-silage the biomass in a drum (this can be done simply stomping on it to compress it, and remove as much air as possible, adding a little water if required) and then leave it for some days before adding it to the digester. This will get the first stages of the digestion process underway, reducing the overall retention inside the digester.

Once the biomass is inside the digester, it tends to float upwards, as it is usually lighter than the watery liquid (hereafter called supernatant). The space above the supernatant is filled with biogas, which is typically 60/65% methane (CH<sub>4</sub>), and 40/35% carbon dioxide (CO<sub>2</sub>). It is therefore evident that the biomass that was pushed down the pipe finds itself in an environment that is essentially without oxygen. A range of microorganisms that thrive under such oxygen depleted conditions feed on the biomass, in the process reducing it in four stages to methane and CO<sub>2</sub>, together with a fraction of a percent of ammonia, NH<sub>4</sub>, and hydrogen sulphide, H<sub>2</sub>S. This complete process is referred as 'anaerobic digestion', or AD, and is illustrated in figure 4.

As AD proceeds and more and more biogas makes its way to the surface, a pressure builds up in the upper dome area. This pressure pushes down on the surface of the supernatant, so that it moves downwards, displacing supernatant into the 2<sup>nd</sup> stage chamber, and on into the hollow pipe that goes through the trapdoor, into the expansion chamber. If this process carries on long enough the level in the expansion chamber will eventually reach the outlet, as indicated in figure 5. By this time the supernatant has been enriched with nitrogen in the form of ammonia, and may be used as a liquid fertilizer. The difference in the level in the *expansion chamber* and that in the *dome chamber* is the 'hydrostatic head' and is normally between 0.8m and 1.5m, depending on the design of the gas plant. The corresponding gas pressure is 8kPa and 15kPa. When the gas is turned on in the kitchen, the pressure gradually

reduces in the dome chamber, and hence the supernatant will slowly migrate back from the expansion chamber to the 2<sup>nd</sup> stage chamber and then back to the dome chamber.

### **How a RWH and Biogas can work together synergistically**

Figure 6 illustrates the various elements of the system, while figure 7 shows a working example in Pretoria. A brief description follows:

The *RWH cistern (a)* collects rain water runoff from the available catchment (which may either be roof runoff, or ground runoff, or both). The water is used to irrigate the vegetable *garden (b)*. The produce of the garden is taken to the kitchen for preparation and cooking. Normally a considerable amount of ‘*biomass*’ (*c*) is generated in the preparation process (e.g. carrot tops, potato skins, outer leaves of cabbage, etc.) and this is fed into the inlet pipe of the *biodigester (d)*, together with water from the *cistern*. If the preparation waste from the kitchen is inadequate, this may be supplemented with cow manure, or virtually any type of organic matter. The *biogas (e)* from the plant is piped to the burner in the kitchen and the produce from the garden is thus cooked.

Two ‘by products’ are obtained alongside biogas. The first is a watery ‘*liquid fertilizer*’ (*f*), the second is a residue, referred to as *digestate (g)*, which settles out on the floor of the gas plant. It consists of difficult-to-digest organic material such as recalcitrant carbohydrates (cellulose, lignites, etc). When mixed in with soil it adds an organic content, which improves both the soil’s texture and water retention characteristics. Together the liquid fertilizer and digestate supply nitrogen, phosphates and potassium. Studies have shown that the combined effect of (*f*) and (*g*) result in improved crop yields of between 10% and 30%. (ref). However, the digestate also contains inorganic substances in the form of minerals and metallic elements (which cannot be digested by the microorganisms) – these substances are beneficial in moderate proportions, but inhibiting to biogas production at higher concentrations..

Generally the digestate and liquid fertilizer will not result in toxic elements in the vegetables that are grown and consumed by humans in the case where 'green' biomass is the predominant input material. More caution should be exercised where various types of animal dung are used. Where human excrement is inputted, the liquid fertilizer and digestate will have some toxicity. To combat this, the liquid fertilizer should be exposed to UV radiation from sun ponds and made to pass through appropriate reed beds, followed by testing. The solid digestate can be dried and then detoxified by heating it for one hour at 70 degrees C.

### Benefits of a RWH/Biogas system

The main benefits of a RWH/Biogas system have been summarised in Table 1. In this table the benefits have been arranged under four headings, 'Social', 'environmental', 'health' and 'economic'. In each case the predominant benefit is indicated with a red star, but it is evident that most of the benefits are multi faceted.

| Table 1 - Benefits of RWH/Biogas System                          |          |                |        |          |
|--|----------|----------------|--------|----------|
| ★ designates primary benefit<br>☆ designates auxiliary benefit/s | BENEFITS |                |        |          |
|  | Social   | Environ-mental | Health | Economic |
| - fewer trips for wood & water - allows other activities         | ★        | ☆              |        | ☆        |
| - quicker cooking - allows to other activities                   | ★        |                |        | ☆        |
| - reduced deforestation & desertification                        | ☆        | ★              | ☆      | ☆        |
| - disposal of household organic waste & manure                   | ☆        | ★              | ☆      | ☆        |
| - fewer/smaller landfill disposal sites                          | ☆        | ★              |        | ☆        |
| - cleaner living environment                                     | ☆        | ★              | ☆      | ☆        |
| - reduction of potent greenhouse gas                             | ☆        | ★★★            | ☆      | ☆        |
| - clean drinking water (only for roof RWH)                       | ☆        | ☆              | ★      | ☆        |
| - RWH water mosquito free (covered RWH tanks)                    | ☆        | ☆              | ★      | ☆        |
| - clean burning flame = reduces respiratory infections           | ☆        | ☆              | ★      | ☆        |
| - reduction in adverse affect of pesticides                      | ☆        | ☆              | ★      | ☆        |
| - less decaying organics = fewer flies                           | ☆        | ☆              | ★      | ☆        |
| - more money for food, education, medicine                       | ☆        |                | ☆      | ★        |
| - construction teams required to build gas & RWH                 | ☆        |                | ☆      | ★        |
| - liquid fertilizer rich in nitrogen                             | ☆        | ☆              | ☆      | ★        |
| - solid fertilizer that improves texture & water retension       | ☆        | ☆              | ☆      | ★        |
| - low maintenance gas production                                 | ☆        | ☆              | ☆      | ★        |

## Costs

The cost of building small structures cost effectively is very linked to scale. For example the cost of building one system is likely to be two or three times the unit cost of building 100.

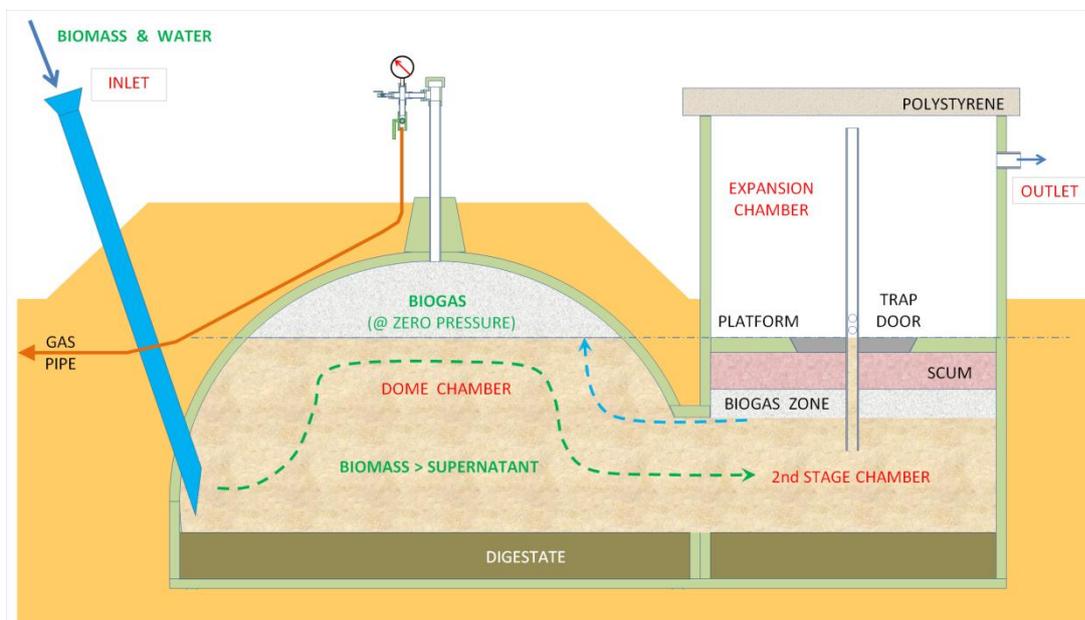
The main reason for this is all the time spent negotiating the contract, investigating the soil conditions and other site specific parameters, putting together a construction crew, and setting up on site. Added to this is the engineer's design time, and the time he will need to supervise/train a relatively unsophisticated contractor – who will most probably have no experience in building RWH/biogas systems.

Although the authors have been involved in the design and construction of four 6000 litre bio gas plants – all made with ferro-cement, there was a substantial degree of inefficiency in the construction process, as they were all built at different times in different places with inexperienced workmen requiring intensive supervision. Furthermore a number of technical problems were encountered, as may be expected when doing something new with unfamiliar technology. For example the waterproof coating proved to be ineffective and had to be removed and the work redone. Problems were experienced with leaking gas pipes. For all these reasons no clear picture has emerged with regard to the unit cost of building a ferrocement biodigester, other than the cost of the raw materials which is approximately R8700.

On the other hand the cost of installing readymade plastic bio-digesters and rain water harvesting systems has sufficient history to make more accurate estimates. In South Africa the company Agama Energy has installed approximately 70 units over a number of years, and is currently gearing up for substantial expansion. The ex-works cost of a 6000 litre domestic digester is R20000, while installation varies considerably, from R5000 to R25000, depending on distance and soil conditions.

In terms of RWH systems, the company Rural Integrated Engineering has installed well over a 100 RWH systems in South Africa since 2008. The system consists of 3 x 5000 litre plastic underground cisterns, and 1 x 5000 litre above ground plastic tank, together with gutters, and to total installed price is R40000.

Based on these prices, it is believed that a ferrocement digester and RWH cistern system could offer significant cost savings, which was main reason the authors undertook the exercise set out in this paper. However, more analysis is required in this regard, especially in terms of the effect of how scale will reduce costs.



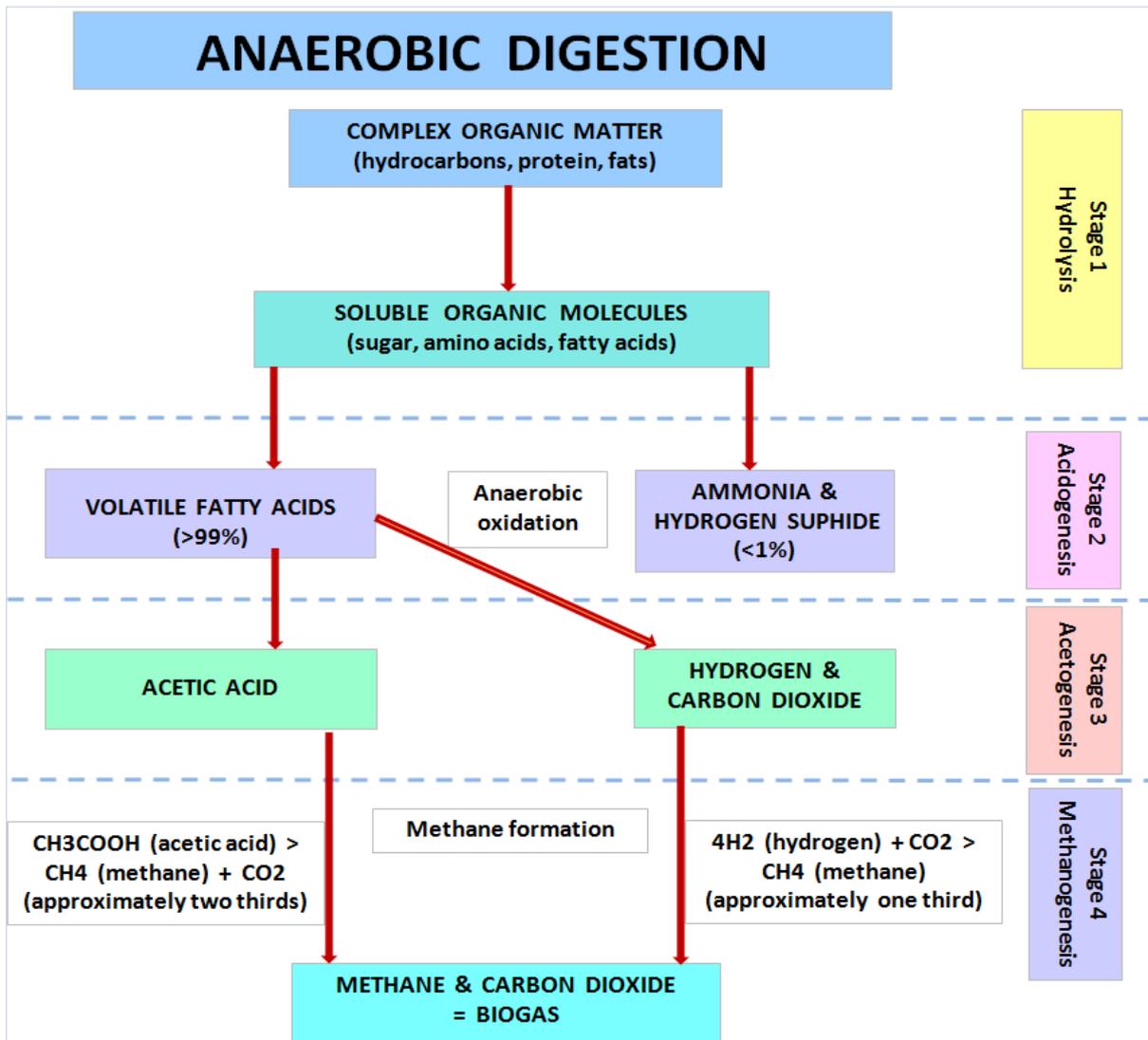
**Figure 1** – The diagram shows the various elements of a biogas plant. It may be seen that in the ‘zero pressure’ configuration the level of the supernatant is flush with the top of the platform. This allows someone to stand on the platform, remove the trap door, and remove some digestate via a bucket.



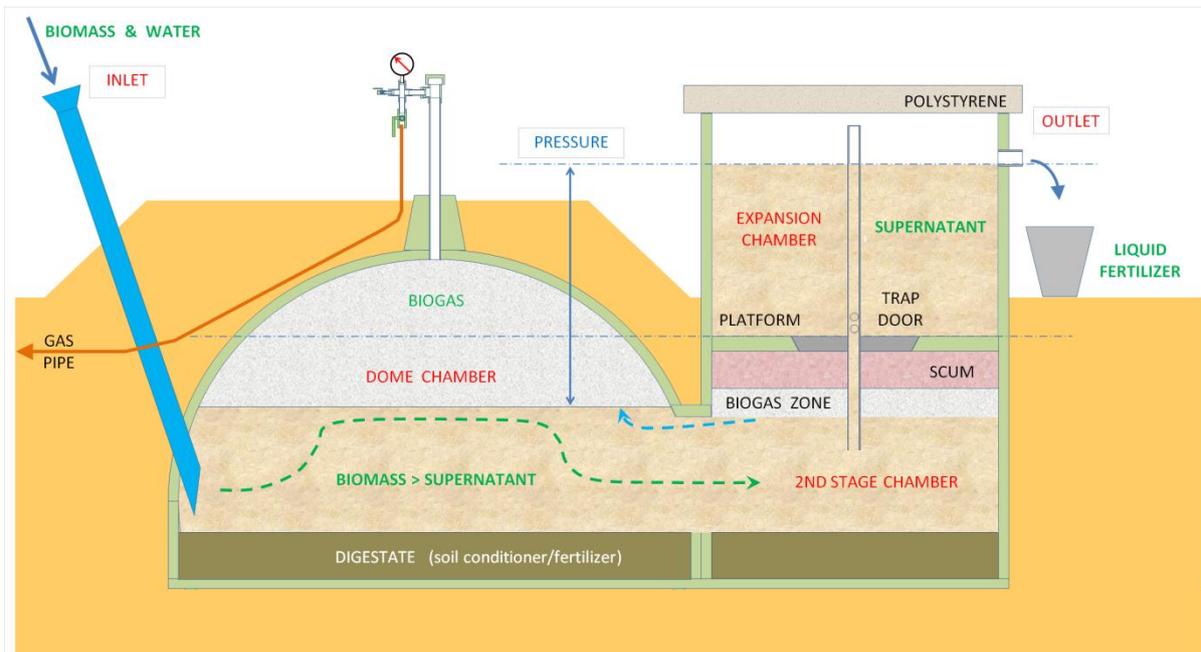
**Figure 2** – Ferrocement consists of chicken mesh fastened to a wire frame (see bottom left), and to this a cement-sand mortar is applied in two stages. On day one a thin skin of about 1cm thick is applied (see top left). Bottom right indicates how the mortar has only just moved past the chicken mesh. By day two the thin mortar skin will have stiffened the shell sufficiently for a final application of 2cm on the inside (see top right), followed by a similar application on the outside.



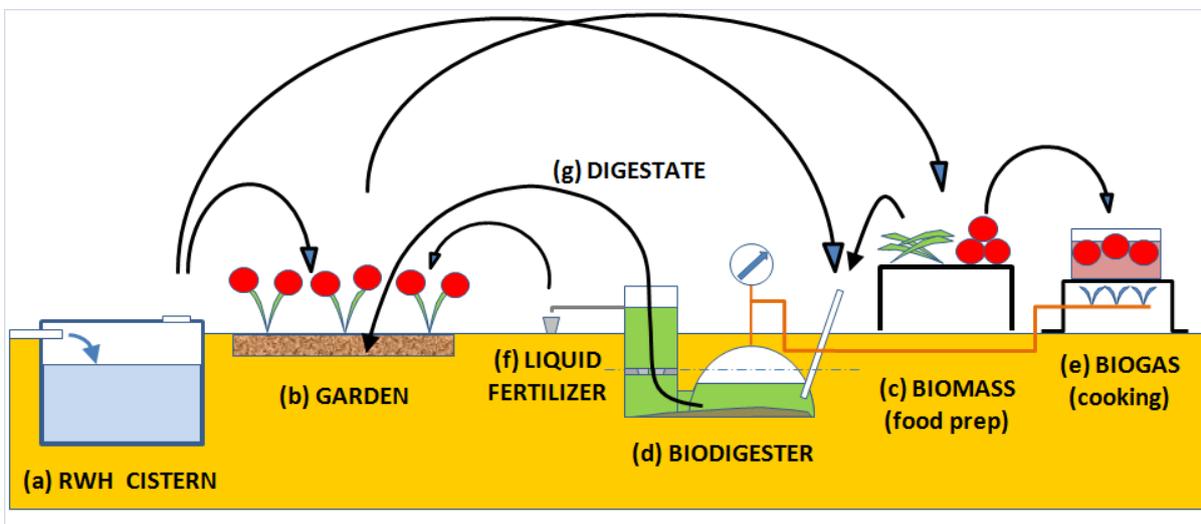
**Figure 3** – Loading biomass into the inlet pipe. The procedure is to push few handfuls of biomass into the pipe, followed by water, followed by using the plunger to push the load own into the dome chamber.



**Figure 4** – The four stages of Anaerobic Digestion showing how biomass is progressively broken down into simpler compounds by microorganisms and eventually converted to methane and carbon dioxide.



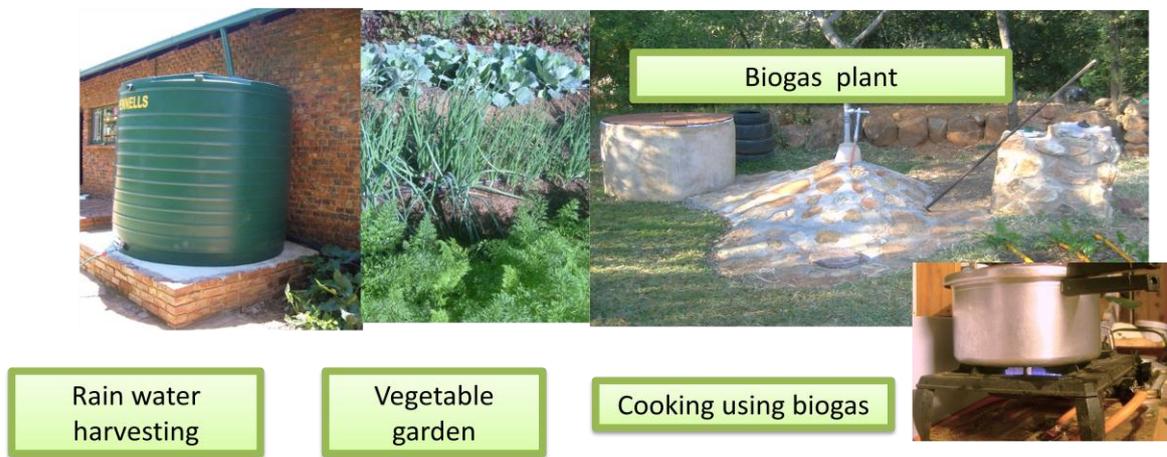
**Figure 5** – With continued AD, the gas pressure pushes the level in the dome chamber down, forcing the supernatant into the expansion chamber. The greater the difference in these levels the greater is the gas pressure.



**Figure 6**- The synergies of a RWH/Biogas system include a garden that is irrigated with water, fertilized with liquid fertilizer, with soil that is improved with digestate, resulting in an improved harvest for the kitchen. The food-preparation waste from the garden is fed into the gas plant, resulting in biogas that is used for cooking.

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The restoration of communities across southern Africa by the Word of the Almighty and sustainable economic development.



**Figure 7** – Example of a RWH / Biogas plant working synergistically

### References and Reading

- (1) Ludwig Sasse. Biogas Plants. Deutsches Zentrum für Entwicklungstechnologien – GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH – 1988.
- (2) Mansour-Al Sadi, Design and building of biogas digester for organic materials gained from solid waste, Thesis submitted to Faculty of Graduate Studies, An-Najah National University, Nablus-Palestine, 2010.
- (3) Christian Muller - Anaerobic Digestion of Biodegradable Solid Waste in Low and Middle-Income Countries - Overview over existing technologies and relevant case studies, Eawag Equatic Research, Dubendorf, May 2007.
- (4) The Biogas Technology in China (1989). Chengdu Biogas Research Institute, Chengdu, China.
- (5) Khandelwal, K, C; Bio-Energy and Rural Development; Love4Cow Trust, New Delhi, 2010.
- (6) Bioenergy and Biomass Frequently asked questions;  
<http://bioenergy.ornl.gov/faqs/index.html>
- (7) Agama Energy; Introduction to Biogas; <http://agama.co.za>, 2009.