SEDV 625
Interdisciplinary Research Project

Title of project:

Low cost biodigester as a sustainable energy solution for developing countries: Jiudai Yakou village, China, a case study.

Student: Blanca Elizabeth Romo-Rábago
Supervisor: Dr Irene Herremans
Content advisor: Dr Patrick Hettiaratchi
External supervisor: Renay Eng-Fisher

Low cost biodigester as a sustainable energy solution for developing countries: Jiudai Yakou village, China, a case study.

List of Tables

List of Figures

Figure 5.1. CO_2 emissions from fuels commonly used in rural areas

List of Abbreviations

AD: Anaerobic Digestion

ALRI: Acute Lower Respiratory Infection

BOD: Biological Oxygen Demand

BSN: Biogas Support Programme

CDM: Carbon Disclosure Mechanism,

CH_4: Methane

CO_2: Carbon Dioxide

COD: Chemical Oxygen Demand

C/N: Carbon-Nitrogen ratio

COPD: Chronic Obstructive Pulmonary Disorder

EVHS: Eco Village of Hope Society

FAO: Food and Agricultural Organization of the United Nations

FDB: Fixed Dome Biodigester

FLDB: Floating Drum Biodigester

GHG e: Green House Gas Emissions

GWP: Global Warming Potential

HHV: High Heat Value

H_2S: Hydrogen Sulphide

K: Potassium

LHV: Low Heat Value

Lm: Lumen

MC: Moisture Content

N: Nitrogen

NPV: Net Present Value

PM: Particular Matter

R: Radius

RET: Renewable Energy Technologies

RT: Retention Time

T^o: Temperature

TPB: Tubular Polyethylene Biodigester

TS: Total Solids

VD: Volume of digester

VG: Volume of gas storage

Glossary:

Biocapacity: measures the natural resources' regenerative capacity.

Biodigester: the technology used to generate biogas from organic matter.

Bioenergy: energy produced from biomass.

Biofuel: a renewable source of energy derived from biomass.

Biogas: a combustible gas produced by anaerobic digestion of organic matter. It normally contains 60 percent of methane and 40 percent of CO_2.

Biolatrine: an appliance that is able to capture biogas generated from human waste decomposition.

Biomass: biological material from living or recently living organisms.

Climate sensitivity: Amount of warming for a doubling of CO_2 concentration.

Ecological Footprint: Measures the impact that an individual has on the natural resources, including the amount of land and water used for living as well as carbon emissions that are needed to maintain his/her lifestyle. This estimated consumption also considers Earth's regenerative capacity.

Fuel wood: also known as firewood is wood used as a fuel.

Lumen: amount of visible light emitted by a source. One lumen is equivalent to 0.06 W.

Mantle lamp: an old device (19^{th} century) which produces a flame for illumination.

Night soil: a mixture of human feces and urine, which sometimes also refers when these residues have undergone putrefaction.

Radiative forcing: the difference between the energy received by the Earth and the energy reradiated to the space.

Retention Time: the average of time that the digesting sludge stays within the digester.

Septic tank: a sealed pit located underground which substitutes a sewage facility.

Sewage: waste water with a high concentration of organic material.

I. Introduction

The development of renewable energies is becoming more important as the use of fossil fuels is turning unsustainable. Renewable energies, especially energy obtained from biomass, which refers to any biological material that comes from living or recently living organisms, could also contribute to poverty abatement. According to the United Nations Development Program, biomass energy is recognized as the prime source of energy for the poor (UNDP, 2006); It is estimated that by 2050, sustainable biofuel and biomass production could add 100 EJ (ExaJoule) to the global energy supply with little or no net CO_2 emissions. However, there are many challenges to developing biomass as an effective sustainable source of energy. One of them is to implement effective and affordable technology that is best suited to the end user and location. It is well known that the lowest income populations spend a substantial share of their income and time on low quality energy supplies (Daisy & Kamaraj, 2011). Over 3 billion people worldwide use solid fuels, such as wood, to supply their energy needs, which is four times less efficient than biogas. The use of wood among other inefficient sources of energy is one of the factors that keeps a large population in the developing world trapped in the vicious circle of poverty (WHO, 2009).

Biogas is one of the most versatile energy sources. It can provide sustainable development and access to clean energy. Since biogas is generated by anaerobic degradation of human and animal waste, it can be a promising and affordable energy solution to abate poverty (UNDP, 2005; Rowse, 2011; Daisy & Kamaraj, 2011).

Study objective

This research draws from a broad base of international case studies to evaluate the feasibility of implementing a low cost biodigester at the Jiudai Yakou village, Yunnan province, south western China. I compare the three most popular low cost biodigester technologies currently used in developing countries to generate biogas. These technologies are assessed in terms of cost effectiveness, social, and ecological benefits, as well as the potential for biogas production at the Jiudai Yakou village. Currently this village does not have a reliable source of electricity, and it has an inefficient latrine system to manage human and animal waste. My working hypothesis is that by using a low cost biodigester at the Chinese village, it can provide the villagers with a sustainable source of renewable energy that is safe, more efficient and provides more ecological and sanitary benefits than a traditional latrine.

Jiudai Yakou: Current situation and context

The Jiudai Yakou village is a leprosy community with 93 inhabitants located in south western China at the Yunnan province (Figure 1.1). This province is part of China's western provinces in which most of the poor people in the country live. The region comprises widely dispersed rural communities that have little infrastructure and low levels of access to modern energy services. At present, around 4.6 million households, mostly in remote areas that are far away from power grids, do not have access to electricity (Ying et al., 2009). Even though Jiudai Yakou is connected to the power grid, the village commonly has power outages leading to periods of blackouts.

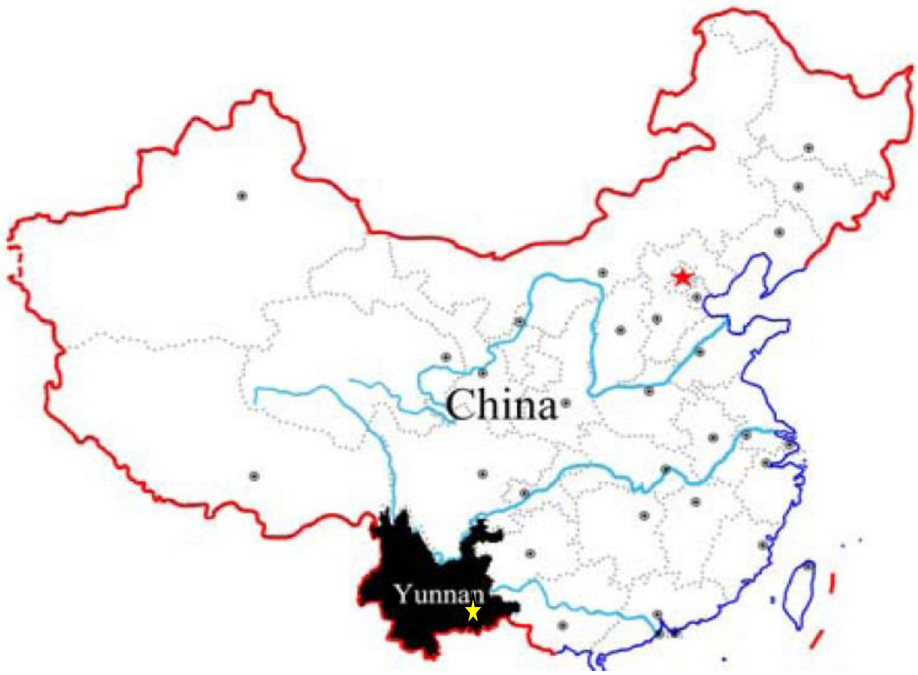


Figure 1.1 Location of the Jiudai Yakou village, Yunnan province, China

Similar to most areas rural in China, Jiudai Yakou villagers use biomass (wood, agricultural wastes, crop residues, animal waste, and forestry residues) as an alternative source of energy, which is mostly used for cooking and heating. They usually spend half of the day collecting these sources of biomass, especially wood. Kerosene is also employed for their lamps (EVHS, 2012).

Each household head owns an average of three hectares of land that is primarily used to grow corn, which represents the source of their main income. In 2011, the village suffered two long droughts that in addition to increasing soil erosion has contributed to making the land less fertile, impacting importantly their harvests and as a result their income. It is estimated that the average adult villager earns annually about $80.37 CAD. Considering that about 30 percent of the population are children and 10 percent are seniors, this income is extremely low for a household that has on average three children and a senior and annual income per household of $241.11 CAD.

Their food is mainly based on corn, rice, Chinese leafy vegetables. For the villagers that have farm animals, their diet additionally includes pork, chicken and beef, which represent extra income for their families.

Physical characteristics

Jiudai Yakou is located in the Yunnan province, 800km from Kunming city, its capital. The average temperature and rainfall graphs are presented in Figure 1.2 and 1.3 respectively. These graphs were taken from Quibei County, which is close to Jiudai Yakou with similar conditions as there is no information for the village itself. According to these graphs the average temperature is 17.45 ^{o}C but ranges from 6 to 25 ^{o} C. The annual precipitation is 1740 mm.

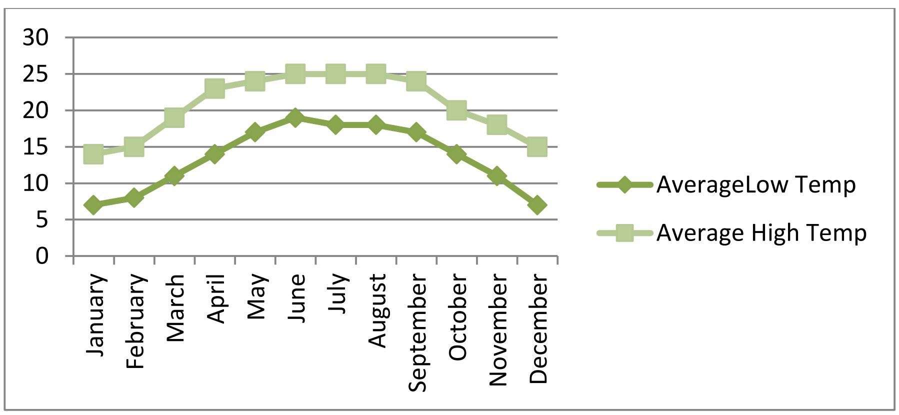


Figure 1.2 Average Temperature (^{o}C) from Quibei County

(Source: World weather online, 2012)

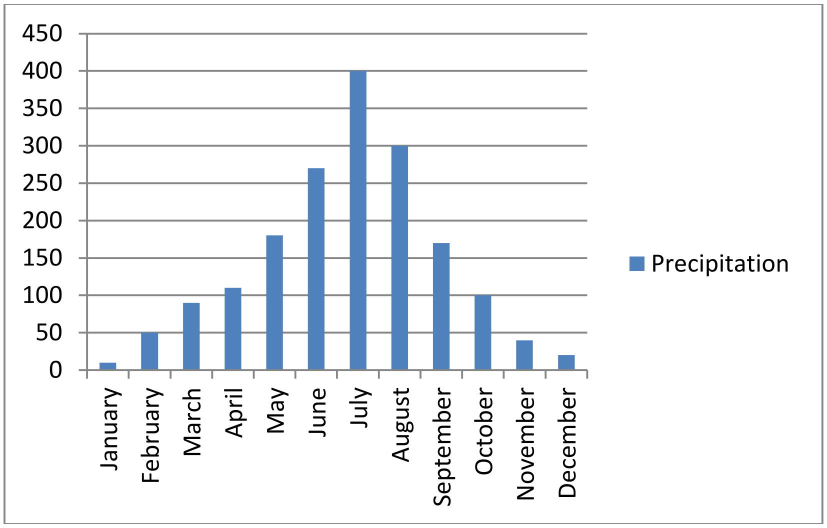


Figure 1.3 Average Rainfalls (mm) from Quibei County

(Source: World weather online, 2012)

Sanitary conditions

Jiudai Yakou has a very simple latrine system that currently is full and is in need of replacement. The current latrine is in very poor conditions (See Appendix A). It occupies and area of 10 m^2 and has three rectangular shaped inlets, so human feces are mixed with urine and other watered materials which have shortened the latrine's lifespan. There is no doubt that the village needs an improved sanitation system to overcome this problem. Moreover, untreated human and animal waste contains high concentrations of viruses and bacteria, which can cause infection and disease when in direct contact with people, or when water supplies are contaminated (Rowse, 2011).

Water situation

The main concern of the residents of Jiudai Yakou is water. Since this village does not have running water, their water sources come primarily from rainwater capture devices installed throughout the village. This water is used for cooking and watering corn crops through a cistern that each family has. Attempts to hand drill for water have so far been unsuccessful because of the soil characteristics (limestone formation). Furthermore, buying water from external sources is very expensive. For this reason, the optimum biodigester for the village has to use the least amount of water.

Culture and community involvement

Although, the villagers communicate via local dialect, they can speak standard Chinese (Putonghua). However, the children who have not attended school do not speak Putonghua. Unfortunately, less than four percent of the children study at school.

The Eco Village of Hope Society have been training the women on sewing activities; however, most of the women are usually busy with weeding and corn fertilization and do not have time to improve their sewing skills or to improve the quality of their products.

There are about 15 households with an average of 6 family members per household. Each family member usually takes care of his/her own family but if community work is needed they are willing to participate. Recently, they started working together looking for underground water by drilling wells. It is expected that during the construction of the biodigester the villagers will also assist and collaborate on the project. Actually, one of the villagers, Xiang Wei Yi has built a biodigester for his family and he would be willing to assist during the construction and operation of the biodigester.

Yunnan: A provincial perspective

Yunnan is classified as one of the world’s biodiversity hotspots and China's most diverse province, biologically as well as culturally. The province has snow-capped mountains and tropical environments that support an important variety of species. Although, Yunnan province covers less than four percent of the land of China, it contains about half of China's bird and mammal species, and it also has the largest diversity of plant life in the country. One of the characteristic ethnic groups is the Hani, who live in the mountainous area and have a long tradition of rice terrace agriculture (Liang, 2011).However, Yunnan's natural resources are under threat because its population highly depends upon the local ecosystem for its food and resources (Ying et al., 2009). Therefore, the region's sustainability is threatened. In fact, it is reported that since the 1990s the ecological footprint of Yunnan changed from a surplus into a deficit and has increased rapidly during the last decades (Table 1.1 and Figure 1.4).

Table 1.1The Ecological footprint (EF) of Yunnan (Unit: gha)

Year	Arable land	Pasture	Forest	Built up land	Fossil energy	EF per capita	Total EF of Yunnan
1991	0.3636	0.1526	0.0219	0.0096	0.3738	0.9462	3.58
1995	0.4042	0.2182	0.0290	0.0105	0.3675	1.0557	4.21
2000	0.4798	0.3341	0.0208	0.0141	0.3612	1.2587	5.34
2006	0.5186	0.4687	0.0390	0.0293	0.9763	2.1129	9.47

Source: Ying et al., 2009.

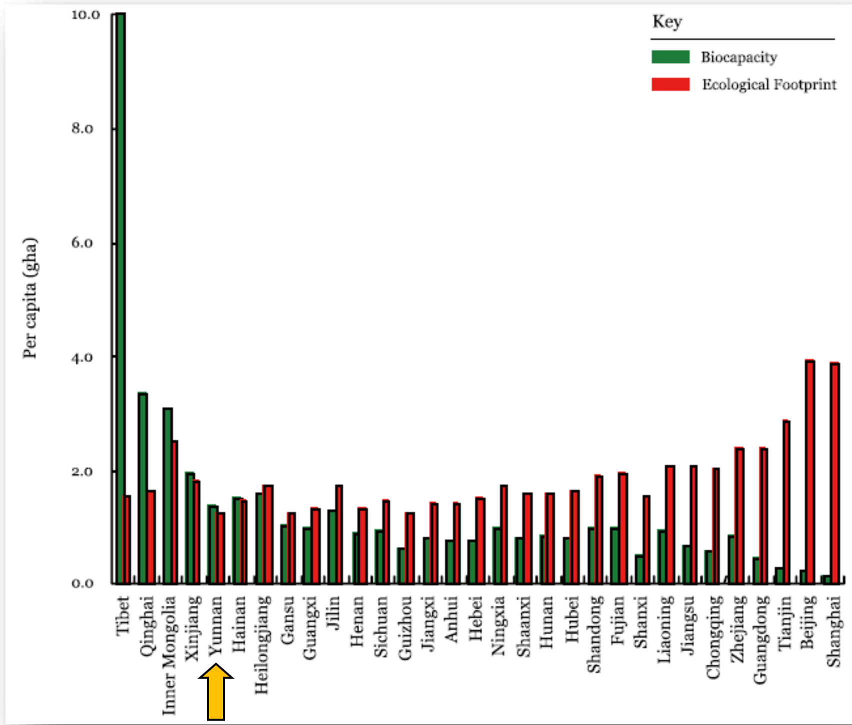


Figure 1.4 Chinese provincial Ecological Footprint and Biocapacity

(Source: WWF, 2012).

Some of the unsustainable practices that have contributed with an increasing ecological footprint are:

- Heavy wood collection for fuel and building supplies,
- Animal poaching, including the Yunnan golden monkey, that is used for food and income, and
- Increases in energy consumption.

Fuel wood collection alone contributes to the loss of more than 120, 000 hectares of forest each year in Yunnan (Ying et al; 2009).

However, and as can be seen in Figure 1.5, Yunnan compared with the rest of China's provinces, still has a biocapacity surplus that is in jeopardy if current unsustainable practices, such as wood collection, continue.

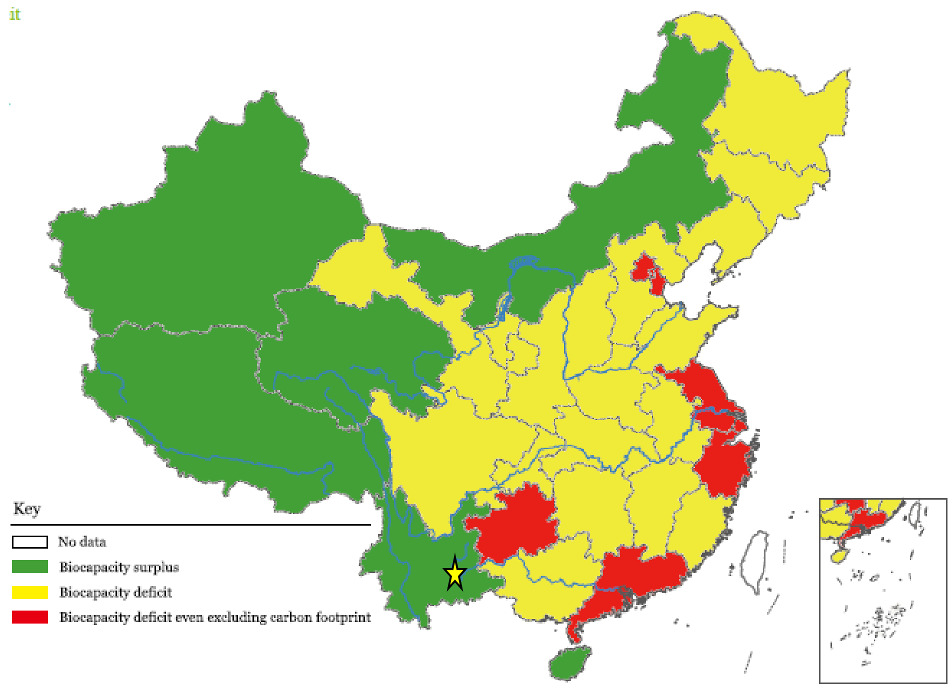


Figure 1.5 Biocapacity Surplus

(Source: WWF, 2012).

China: A national perspective

Although China has the world's largest hydroelectric generation and is the second worldwide producer of wind energy, its energy consumption is dominated by coal and oil as is clearly observed in Figure 1.6 (EIA, 2012).

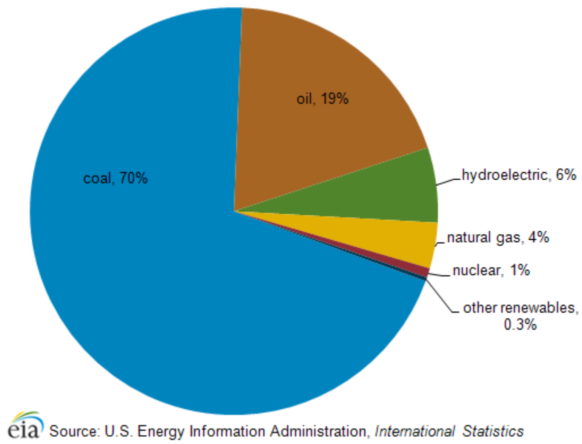


Figure 1.6 Total Energy Consumption in China by type, 2009

(Source: EIA, 2012)

China has a lot of potential for renewable energy, especially in the western provinces, where 70 percent of the population live and 40 percent of the primary energy is demanded (Deublein & Steinhauser, 2008). If we consider that biomass is satisfying most of rural China's energy demands, mainly in the traditional forms of agricultural wastes and forestry residues, more attention should be given to efficient use (GNESD, 2002).

In terms of biogas production it is estimated that in the future biogas plants from agricultural residues will provide 145 billion m^3, equivalent to 950 TWh (Deublein & Steinhauser, 2008). This scenario is feasible as China has the goal to generate at least 15 percent of renewable energy by 2020, which means that about 200 million of biogas plants have to be built (Deublein & Steinhauser, 2008; EIA, 2012).

The Chinese government has paid great attention to research and development of biogas since the late 1970s, a period in which a global oil crisis occurred. Ever since, biogas technology has advanced continuously. In fact, the first dissemination of household biodigesters started in China. At the beginning the costs were significant and with a long construction time. However, these efforts were compensated by an additional income from fuel savings and from selling the fermented residue as fertilizer (Deublein & Steinhauser, 2008; Kossmann & Pönitz, 1998; Shrestha, 2010).

The "China dome" bioreactor has become standard construction and an example for other developing countries. In 1978, about 6 percent of all households in China were using this bioreactor. The following years several plants were set up and an important objective to disseminate the technology was established (Deublein & Steinhauser, 2008; GNESD, 2002). Universities started to get interested in improving the technology and in 1980, the Institute of Biogas Research (IBR), was created, which is the only international centre in China for research and training on biogas technology (IBR, MOA, 2012). By the end of 2002, more than 11 million households were using biogas to improve their income (Figure 1.7), (Deublein & Steinhauser, 2008; Kossmann & Pönitz, 1998; Bensah, & Brew-Hammond, 2010).

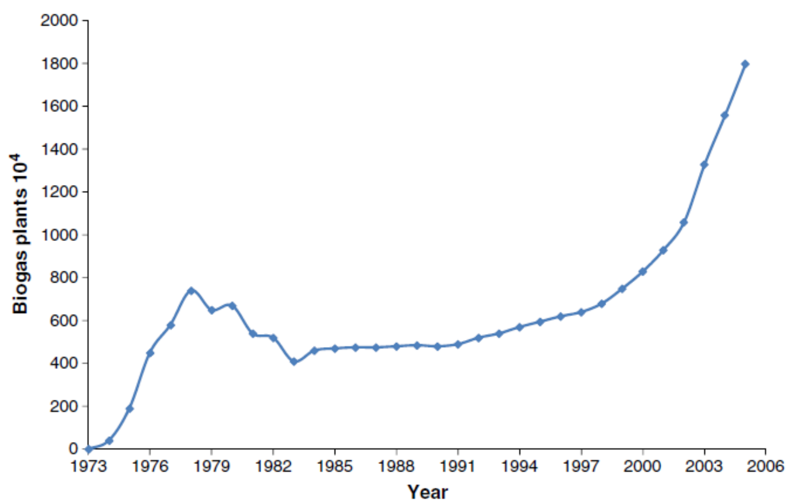


Figure 1.7 Number of biogas plants in China

Source: Chen et al, 2010; Zeng et al, 2007.

From 2003 to 2010, China established the "National Rural Biogas Construction Plan" with the goal to increase the number of biogas plants to 20 million by 2005. Since 2006, the Chinese Energy law created the Special Renewable Energy Fund which formally started supporting the development and use of renewable energy technologies (Deublein & Steinhauser, 2008; GNESD, 2002).

According to the Ministry of Agriculture of China, the policies that the government has established in rural areas have been successful. In 2010, for example, 3.2 million biogas households were installed and about 1,000 large and medium-scale biogas plants (MOA, 2012). This trend is expected to continue and, hence, biogas will play a more significant role in developing a more efficient and competitive renewable source of energy for rural China.

II. Energy Analysis

Energy plays an important role in the economic and social development of our societies. It has the power to improve quality of life, including education, health, and sanitation. Having access to electricity for example, allows people in rural areas to extend their productive time into the night. The correlation between energy consumption patterns and the level of economic development of a given society is also well known. While developed countries use excessive amount of energy, developing countries, mainly in rural areas, rely on inefficient sources of energy, such as fuel wood to meet their basic energy needs, which has environmental and health concerns that mainly affects the lives of women and children. In most developing countries women and girls are responsible for cooking, as a result they are more exposed to indoor air pollution from burning fire wood while cooking (Karki et al., 2005; WBCSD, 2004).

In 2000, only 17 percent of the population had access to the energy needed to provide high living standards, consuming 50 percent of the world’s energy supply (WBCSD, 2004). It is expected that by 2100 the world's energy consumption will be three times higher than in 1990 (IPCC, 2011); as a result, more efficient sources of energy as well as more sustainable practices are today's most serious issues in both developed and developing countries.

Renewable energy technologies (RETs) can be used not just for developed countries but also for developing countries to face and lessen these issues. Renewable energy technologies can provide the poor with an affordable and efficient source of clean energy that creates business opportunities and stimulates local economies (GNESD, 2002). Unfortunately, wind, solar, geothermal and hydro generally require an important investment and high technical skills to operate and maintain them, characteristics that are difficult to find in developing countries and especially in rural areas. Therefore, currently biogas energy can be an interesting and economically feasible source of energy that can be scalable and developed in any place (Shrestha, 2010).

Throughout this chapter biogas technology will be presented as one of the most versatile RETs. The first part describes the process of anaerobic digestion as an effective alternative for biogas generation, as well as presents a list of parameters recommended for a high methane yield. The second part presents the physical and chemical characteristics of biogas, its flammability and possible uses. Finally, estimation of biogas production at the Jiudai Yakou village is discussed.

Anaerobic Digestion definition

Several authors agree that anaerobic digestion (AD) is the most suitable alternative for biogas generation (Bonnett, 2009; Dennis et al., 2001; Ferrera et al, 2008; Rowse, 2011). AD is a biological process that happens naturally when bacteria break down organic matter in environments with little or no oxygen (Bonnett, 2009; Dennis & Burke, 2011). The anaerobic bacteria used in this process are similar to those found in swamps, marshes, ocean depths, or even digestive tracts of humans and most animals (Bonnett, 2009). The process has many benefits: it stabilizes the organic matter, reduces pathogens, flies and odours, and reduces the total solids and sludge quantities by converting part of the volatile solids fraction to biogas (Burke, 2001; Dennis et al., 2001; Manvit, 2010; Rowse, 2011).

AD process

AD has two major stages, acidogenesis (waste conversion) and methanogenesis (waste stabilization). The process is illustrated in Figure 2.1.The AD process also includes other reactions, in which, nitrogen compounds are converted to ammonia, sulphur compounds are converted to hydrogen sulphide, phosphorus to orthophosphates, and calcium, magnesium, and sodium are converted to a variety of salts (Dennis et al., 2001 & Rowse, 2011).

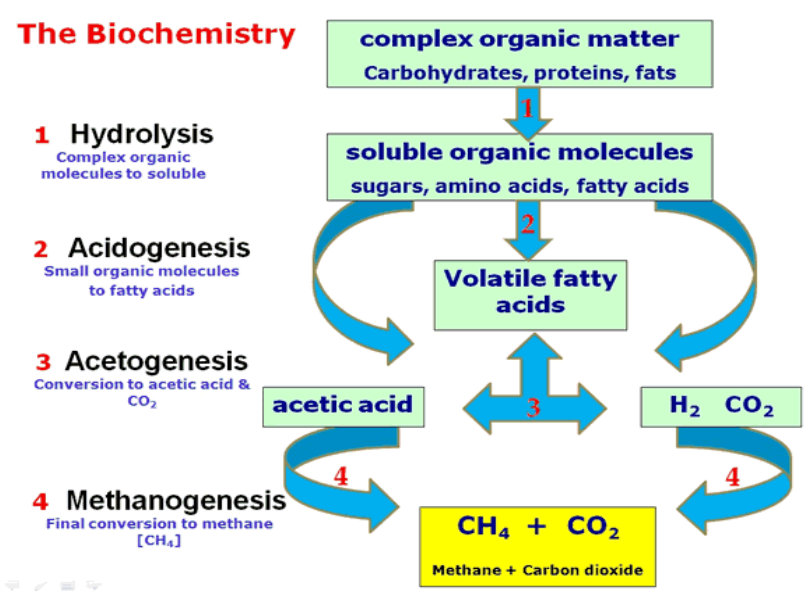


Figure 2.1 Anaerobic digestion processes

AD feedstock

Almost any organic material can be processed with AD, including human and animal waste, grass clippings, leftover food, etc. However, each waste is not equally degraded or converted to gas through AD. For example, anaerobic bacteria do not degrade lignin as well as some hydrocarbons, and dairy wastes have been reported to degrade slower than swine or poultry manure (Dennis & Burke, 2001).

Each feedstock produces different biogas yields depending, among other things, on the Carbon (C) and Nitrogen (N) ratio (C/N ratio). The optimum C/N ratio for anaerobic digestion is 30. If the C/N ratio is very high, nitrogen will be consumed very fast and the rate of reaction will decrease. In contrast, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia, which is toxic under certain conditions. Therefore, the C/N ratio is a very important aspect to consider before feeding the biodigester (Karki et al., 2005).

Table 2.1 presents the C/N ratio of different substrates which are available at the Chinese village and can be used in the future as a feedstock for biogas production:

Table 2.1 Substrates characteristics

Substrate	Mass of material (Kg)	Gas yield (m^3/Kg)	% N (Dry weight)	% C (Dry weight)	C/N ratio	Moisture Content (%)
Pig manure	16	3.6 – 4.8	3.1	43.4	14	80
Cow manure	56	0.2 – 0.3	2.4	45.6	19	81
Chicken manure	0.96	0.35 – 0.8	8	48	6	69
Human excrement	46.5	0.35 – 0.5	6	48	8	78

General straw	Seasonal	0.18	0.7	56	80	12
Corn silage	Seasonal	0.25 – 0.40	1.3	52.65	40.5	66.5
Sawdust	Seasonal	19.53	0.43	204.25	475	42

Sources: Bond et al., 2011; Chen, 2004; Karki et al., 2005, Richard & Trautmann, 2005.

According to the Cornell Waste Management Institute, the formula used to calculate the C/N ratio for the mixture as a whole is:

$$R = \frac{Q_1(C_1 \times (100 - M_1) + Q_2(C_2 \times (100 - M_2) + Q_3(C_3 \times (100 - M_3) + \ldots}{Q_1(N_1 \times (100 - M_1) + Q_2(N_2 \times (100 - M_2) + Q_3(N_3 \times (100 - M_3) + \ldots}$$

In which: R = C/N ratio of compost mixture Qn = mass of material n ("as is", or "wet weight").Cn = carbon (%) of material n. Nn = nitrogen (%) of material n. Mn = moisture content (%) of material n.

In order to know the corresponding C/N ratio of the mixture of pig, cow, chicken manure and human excrement available at the Jiudai Yakou village, the above formula was used with the values from table 2.1; therefore the formula is as follow:

R= 16 (43.4 * (100 – 80)) + 56* (45.6 (100 – 81)) + 46.5* (48 (100 – 78)) + 0.96 *(48 (100 – 69)) / 16 (3.1) *(100 – 80)) + 56 (2.4 *(100 – 81)) + 46.5 * (6 (100 – 78)) + 0.96 (8* (100 – 69))

R= 12

In the case of the village, the C/N ratio mixture is 12, which is a very low value if we consider that the optimum C/N ratio is 30. Therefore, it will be necessary to consider other substrates with a higher C/N ratio such as saw dust that can also be collected at the village. For this scenario, the C/N ratio mixture will need, in addition to the animal and human waste available at the village an extra 16.64Kg/day of saw dust. This number was calculated using the following formula:

$$Q_5 = \frac{RQ_1N_1(100-M_1)+RQ_2N_2(100-M_2)-Q_1C_1(100-M_1)-Q_2C_2(100-M_2)}{C_5(100-M_5)-RN_5(100-M_5)}$$

Q_5 = 30*16*3.1 (100 – 80) + 30*56*2.4 (100 – 81) + 30*0.96*8(100 -69) + 30*46.5*6(100 – 78) – 16*43.4(100 – 80) – 56 *45.6 (100 – 81) – 0.96*48(100 – 69) – 46.5*48(100 – 78) / 204.25 (100 – 42) – 30*0.43(100 – 42)

Q_5 = 16.64 Kg

This can be feasible if a pile of saw dust is located in the latrine area, where users can add about 100 grams after using the latrine or they can also fill the bottom of the biodigester with saw dust upon which latrine waste is discharged; this is a common practice in many biodigesters in China (Karki et al., 2005; Richard &Trautmann, 2005; Satyanarayana, 2008).

AD optimum parameters

In addition, to the feedstock characteristics and C/N ratio, biogas yield can be affected by other factors as well, such as: temperature, pH, retention time, moisture content, total solids, alkalinity or even how effectively the biodigester is enclosed (Behrendt et al., 1978; Friends of the Earth, 2007; Karki et al., 2005; Rowse, 2011). Some recommended operation parameters are listed in table 2.2:

Table 2.2 Biodigester recommended parameters

Operation parameters	Optimum	Sources
Digestion temperature	20 – 40^{o} C	Lansing et al., 2010; Karki et al., 2005; Behrendt et al., 1978.
pH	6 – 7.6	Tchobanoglous et al., 2003, Rowse, 2011; Karki et al.,2005; Behrendt et al., 1978.

Retention time	15-30 days 70-90 days (night-soil digester)	Lansing et al., 2010, Behrendt et al., 1978; Karki et al., 2005.
Moisture content& Total Solids	70 -85 %(MC) 5-10 % (TS)	Behrendt et al., 1978; Karki et al., 2005; Mata-Alvarez et al.,2000.
Alkalinity	500 – 900 mg/L $CaCO_3$	Rowse, 2011; Rittmann& McCarty, 2001.
C/N ratio	20 - 30	Karki et al.,2005

Dry and fibrous material takes longer to digest than fine-structured and wet substrate. In order to keep the optimum total solids, it will be necessary to mix the feedstock with an equal volume of water or urine. Since, the Jiudai Yakou village does not have enough water, urine can be used instead, or if the animals at the village consume enough water, no additional water is required for the biodigester (Sasse et al., 1991). To avoid a low pH on the fermented chamber due to urine, the addition of 500 – 900 mg/L of lime, sodium hydroxide or ammonia can keep the alkalinity required in the biodigester. Furthermore, these chemical are the least expensive (Rowse, 2011; & Sasse et al., 1991).Researchers have found that an addition of less than 30 percent of urine can increase biogas yields up to 31.6 percent (Satyanarayana, et al., 2008).

Finally but not less important is to have an effective enclosed biodigester to avoid leakage. This is also a very important aspect to consider because if the digester has gas leakage and the biogas concentration in the air is between 6 to 12 percent it could be explosive and may cause damage to human life and property (Bensah et al., 2010).

Biogas characteristics and composition

Biogas is a combustible gas produced as explained above by anaerobic digestion of organic matter (Karki et al., 2005). This gas is principally composed of methane and carbon dioxide. Table 2.3 provides the approximate composition of biogas, which could vary according to the experimental condition:

Table 2.3 Biogas composition

Gas	Composition (%)
Methane (CH_4)	50 - 70
Carbon dioxide (CO_2)	30 - 40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water vapor (H_2O)	0.3
Hydrogen sulphide (H_2S)	Traces

Source:Karki et al., 2005; &Yadava et al., 1981.

Methane is an odourless and colorless gas that when it is burned produces a non toxic, smokeless clear blue flame (Shrestha, 2010). "The specific gravity of methane (relative to air) is 0.55; critical temperature is equal to 82.5°C and pressure for liquefaction 5000 psi. Air requirement for combustion (m^3/m^3) is 9.33 and the ignition temperature is 650°C" (Karki et al., 2005: 18).

Biogas uses

Biogas can be used for cooking, lighting or heating. In China it is usually used in greenhouses for agriculture and in Finland it is even used to run cars, it is also commonly used to heat the biodigester during cold weather. Although in the later case, energy is not gained, the biodigester still offers an important solution for waste disposal as the organic material will decrease in size by around 50 per cent and can easily be transported and spread over farmland (Buxton et al., 2010; Hilkiah et al, 2007; Karki et al., 2005).

Biogas energy content

The energy content of biogas is 6kWh/m^3 which is equivalent to providing a family of 6 members with enough biogas to cook 3 meals, or to light a 60 – 100 watt for 6 hours, or it can even run a one horse power motor for 2 hours and can generate 1.25 kilowatt hours of electricity (Buxton & Reed, 2010; Karki et al., 2005).

Methane has a high heat value (HHV) of 55.5 MJ/Kg and low heat value (LHV) of 50MJ/Kg which is equivalent to 15kWh and 13kWh respectively. It produces more heat than kerosene and is four times more efficient than burning wood and five times more efficient than burning cow dung (Drewko, 2007; Karki et al., 2005). Table 2.4 presents some biogas equivalencies.

Table 2.4 1 m^3 of biogas is equivalent to:
0.5 Kg diesel or kerosene
1.3 Kg wood
1.2 Kg cow dung
1.3 Kg plant residues
0.7 Kg hard coal
0.24m^3 propane

Source: Drewko, 2007.

If biogas is used to generate electricity or for cooking the biogas, needs a filter to remove hydrogen sulphide (H_2S). The filter is usually made of iron oxide and reduces H_2S

concentration from 500ppm to 1ppm.It is easy and affordable to buy and it can last for at least 5 years (Friends of the Earth, 2007 & Viquez, 2009).

Potentiality of Biogas at the Jiudai Yakou village

The Jiudai Yakou village consists of about 15 households. Each household has between 2 to 8 villagers. For our calculations we assume that each household has an average of 6 villagers, three adults and three children. In table 2.5 an estimation of the biogas requirements at the village is presented.

Table 2.5 Biogas requirements for household at the Jiudai Yakou village

		Total (m^3/day)
Lighting	2 lamps* 4hrs/day*0.105m^3/h	0.84
Cooking	A family with a double stove for 1 1/2hrs: (0.22m^3/h + 0.11m^3/0.5hr + 0.44m^3/h + 0.22m^3/0.5hr)	0.99
	Total energy use per household	1.83
	Total energy use at the village	27.45
	Total annual energy use at the village	10,019.25 m^3

Source: EVHS, 2012.

The current sources of energy at the village are mainly based on wood for cooking, electricity for lighting and when a black out occurs fuel is used for their simple kerosene lamps. The estimated costs and energy use are shown in table 2.6.

Table 2.6 Energy use for household at the Jiudai Yakou village

Source of energy and amount of energy use (m^3/ day)	Cost per unit	Total ($CAD)/year	% of total income

Wood (3.96)	4hrs/day = $7.86	2,870	
Electricity 1.31 kWh*8hrs = 10.48	$0.048 CAD/kWh	183.6	76.18
Kerosene (0.2 L/ for 2 lamps producing 37 lumens for 4 hours per day)	$ 0.53 CAD/ L [3]	38.69	16.05

[1]Average salary at Yunnan is $15. 73CAD/day, [2]Electricity price at Yunnan is in average $0.048 CAD/kWh,[3]Kerosene cost estimation is $0.53 CAD /L

Source: Buxton & Reed, 2010 & Karki et al., 2005

As can clearly be observed in table 2.6, the villagers energy expenses represent between 16 to 76 percent of their annual income, which unfortunately is the same situation that most developing countries face. The high cost occurs mainly in rural areas where villagers pay for a low and inefficient sources of energy (GNESD, 2002).

The villagers main sources of income come from farming and selling their produce in the market, and some villagers have farm animals. Table 2.7, provides a description of the type of animals as well as other substrates which can be used for biogas production and that are available at the village:

Table 2.7 Potential biogas production at the Jiudai Yakou village

Amount of animals, plants or people (individuals)	Type of substrate	Biogas yield m^3 /substrate/day (DM)	Total Biogas yield m^3/substrate/day a (DM)
7	Cow manure	0.32	2.24
8	Pig manure	1.43	11.44
12	Chicken manure	0.01	0.12
93	Human excrement / sewage	0.04	3.72

16.64 Kg	Saw dust	$0.651 m^3$/ Kg	10.83
		Potential biogas yield at the village	28.35
		55% methane	15.73

DM = dry matter. a = based on mean biogas yield (m^3/kg DM). b = calculated from methane yield based on biogas of 55% methane.

Source: Barnett et al., 1978; Bond et al., 2011; Buxton, et al., 2010; Chanakya et al., 2005; Hervie, 2000; Karki et al., 2005; Quazi, et al., 2008; Sasse, et al., 1991

If the energy needs at the village are $27.45 m^3$/day and the potential for methane production is$15.73 m^3$/day; then, the villagers could meet 57 percent of their fuel demands by using biogas for cooking and lighting. However, the implementation of a biodigester has some implications that will be important to address before its installation at the village, such as:

- Health and safety concerns about using a biodigester.
- Social and technical issues arising from using human waste in the biodigester.
- Biodigester environmental, social, and economic benefits.
- Efficient community engagement to operate and maintain a communitarian biodigester.
- Biodigester efficiency, location, functionality, reliability, size, costs, and other aspects related to its construction and maintenance.

In the following chapters, these and other implications for installing a biodigester at the Jiudai Yakou village will be discussed.

III. Technology Assessment

Biodigester technology has a long history. It probably goes back 2,000 – 3,000 years ago in ancient Chinese literature. The technology has had a wide variety of applications, such as, industry, agriculture, wastewater treatment plants, landfills, etc. (Ding et al., 2010). In the early 1900s India started developing biodigester systems for leprosy colonies. However, the high cost and the time consuming nature for constructing a biodigester were among the important factors limiting its distribution. It was not until the late 1970s that low cost biodigesters were developed. Today this technology is growing in popularity and provides developing countries with a sustainable source of energy that could improve their quality of life. Some important characteristics of a low cost biodigester is that it does not require a heating system or mobile mixing mechanisms such as those used in large scale biodigesters. Therefore, the costs for building this type of biodigester are generally low. In addition to these advantages, a low cost biodigester can provide a community with important environmental, economic and health benefits (Bennett, 2009; Deublein & Steinhauser, 2008; GNESD, 2002; Harris, 2012). Figure 3.1 shows the design of a typical low cost biodigester, which includes an inlet structure that feeds the biodigester, an airtight fermentation chamber that converts organic matter into biogas and slurry and finally the outlet structure required to remove the digested organic matter (Karki et al., 2005).

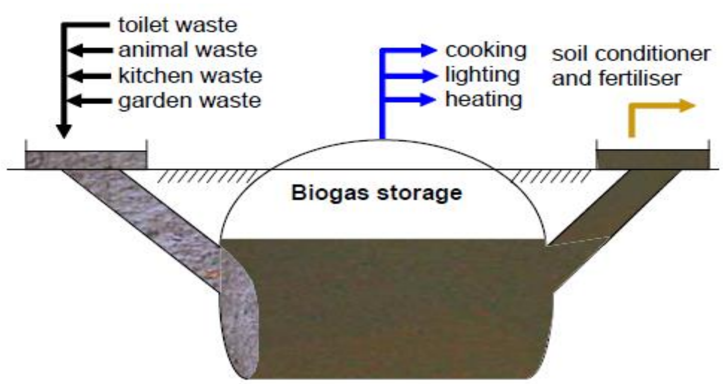


Figure 3.1 Design of a typical biodigester

Source: Behrendt et al., 2006.

Biodigester materials, location, size, feedstock used and the cost among other aspects are determined by the type of biodigester used. In this chapter, the three most popular biodigester designs commonly used by developing countries will be described and discussed to determine which would be appropriate for implementation at the Jiudai Yakou village.

Fixed Dome Biodigester (FDB)

This biodigester consists of an underground fermentation chamber with a dome on the top for gas storage (Figure 3.2). This underground system has several advantages. It provides protection from physical damage and it keeps stable temperatures even during cold seasons which have a positive influence in the bacteriological processes. It is a low cost plant because it does not need moving parts for mixing purposes. It can last for more than 35 years because it is made of concrete and does not have rusting steel parts. In fact, China has the oldest fixed dome biodigester that is still in operation after 65 years (Butare & Kimoro, 2002). However, the construction of this plant is labour-intensive and difficult to build because it needs to be supervised by experienced biogas technicians. Table 3.1 summarizes advantages and disadvantages of this biodigester (Barnett, 1978; Daisy & Kamaraj, 2010; Rowse, 2011; GNESD, 2002).

Table 3.1 Summary of the Fixed Dome Biodigester (FDB)

Advantages	*Disadvantages*
Low construction cost	Frame not gas tight
No moving parts	Gas pressure fluctuates
No corroding steel parts	Digester has low temperature
Constructed underground, doesn’t waste space	

Create employment locally	

Source: Hervie, 2008.

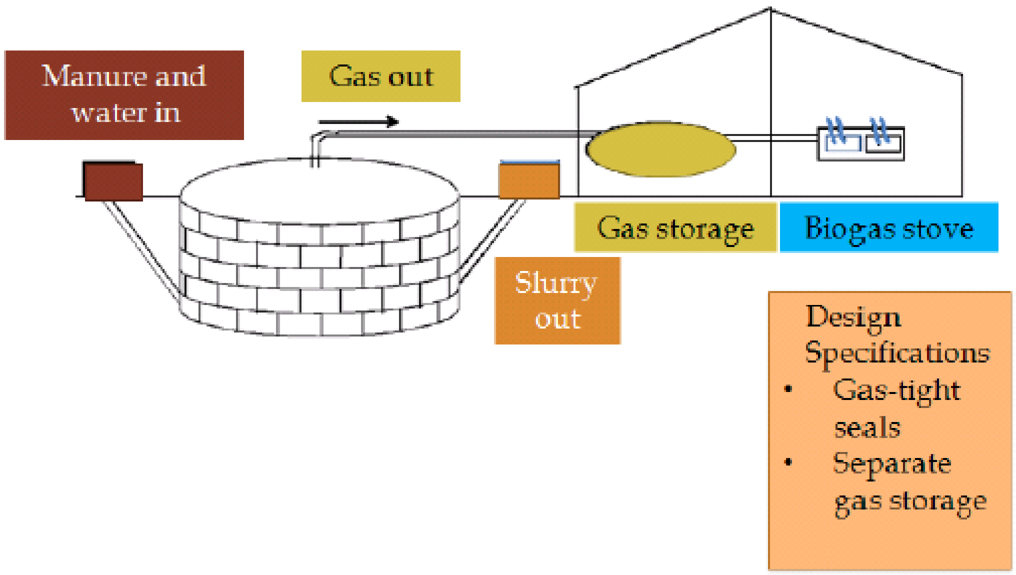


Figure 3.2 Fixed Dome Biodigester

Source: Rowse, 2011.

Floating Drum Biodigester (FLDB)

This biodigester consists of a digester chamber made of brick masonry in cement mortar (Figure 3.3). A steel drum is placed on top of the digester to collect the biogas produced from the digester. Thus, there are two separate structures for gas production and collection. The drum floats either in a water jacket surrounding the digester or directly in the digesting slurry. When biogas is produced, the drum moves up as it fills. This is an advantage because the operator can visually see and better understand the biodigester mechanism. However, the steel drum is expensive and requires frequent maintenance.

The drum needs protection against corrosion and coating needs to be applied carefully. Floating drums always require a guide that keeps the drum upright and provides stability. This biodigester has a design life of 5 – 15 years. Table 3.2 summarizes advantages and disadvantages of this biodigester (Drewko, 2007; Karki et al., 2005; Rowse, 2011; SD, 1997).

Table 3.2 Summary of the Floating Drum Biodigester (FLDB)

Advantages	*Disadvantages*
Very simple	High cost
Operation easy to understand	Steel parts could be corroded
It has a constant gas pressure	High maintenance and paint is needed
Volume gas is visible	
Few mistakes during construction	

Source: Buxton & Reed, 2010; Hervie, 2008.

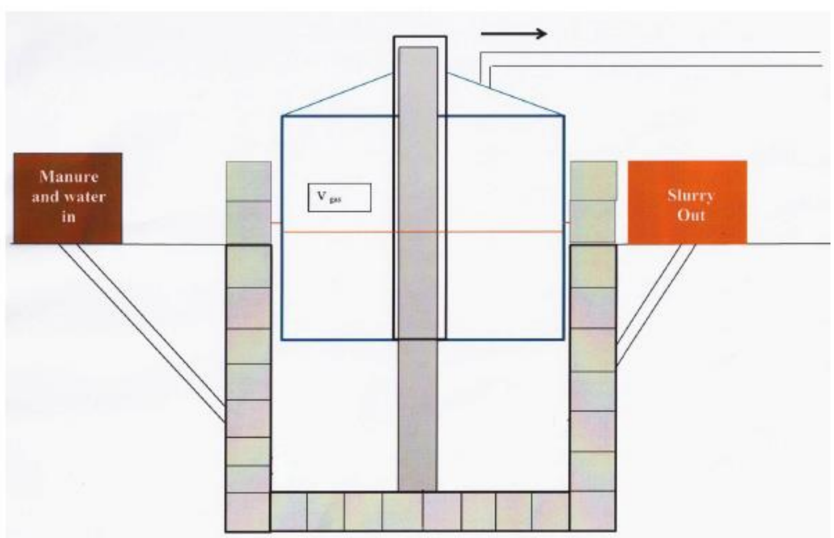


Figure 3.3 Floating Drum Biodigester

(Source: Rowse, 2011)

Tubular Polyethylene Biodigester (TPB)

It consists of a tubular PVC or polyethylene geomembrane (Figure 3.4). This digester is semi buried in an open trench in the ground. This type of biodigester is recommended for areas with high temperatures. The construction and installation time is two days. The biogas is stored in a reservoir made of plastic that is similar to the traditional cylinder used for butane. Studies have shown that an increase of pressure inside the digester is required as well as the availability of welding facilities during digester construction to avoid future damages. However, these conditions are difficult to have in most rural areas. This biodigester can last from 5 to 6 years and it is the most inexpensive digester but also the least durable; Table 3.3 summarizes advantages and disadvantages of this biodigester (Drewko, 2007; Marti, 2012; SD, 1997).

Table 3.3 Summary of the Tubular Polyethylene Biodigester (TPB)

Advantages	Disadvantages
Standardized prefabrication at low cost	Low gas pressure may require gas pumps
High digester temperature in warm climates	Scum cannot be removed during operation
Uncomplicated cleaning, emptying and maintenance	Very few local craftsmen are in a position to repair a damaged TPB.

Source: Hervie, 2008.

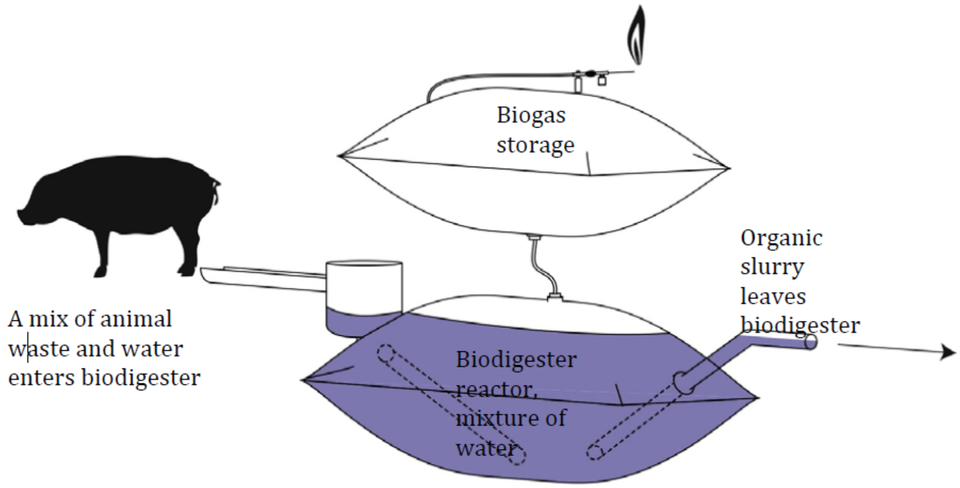


Figure 3.4 Tubular Polyethylene Biodigester

(Source: Bennett, 2009).

Biodigester materials

As mentioned above, usually the FDB and the FLDB are constructed with brick, masonry, stone masonry, Ferro-cement, mild steel sheet and fibre-reinforced plastic (high costs). Normally FDB is made of concrete and steel, whereas FLDB is constructed with various materials available, such as bricks. Tubular polyethylene biodigesters are fabricated from folded polyethylene foils, with porcelain pipes as inlet and outlet (Behrendt et al., 2006; Bond & Templeton, 2011; Karki et al., 2005). Considering that a family sized- fixed dome biodigester was built by one of the villagers at the Jiudai Yakou, it is expected that the masonry skills and materials required to build any of those biodigesters will not be a problem, especially if cement and sand are used as main construction materials. However, a training program has to be implemented before the construction of the biodigester to obtain a good masonry work and to train more villagers which can help during and after the construction of the biodigester.

Comparison of biodigesters

Table 3.4 presents a comparison between these three biodigesters in terms of construction, operation and maintenance.

Table 3.4 Comparative analysis between the three biodigesters

	Fixed Dome Biodigester	Floating Drum Biodigester	Tubular Polyethylene Biodigester
Materials	No rusting parts needed	Drum is hard to obtain	Easily accessible, low cost, materials can be reused after lifespan is over
Construction	Special masonry and skilled laborers, excavation in rock can be difficult, Low reliability due to high construction failure (gas-tightness)	Skilled labor depends on materials used because FLDB can be made of steel, plastic	Two days of construction and the household owner complete the work
Simplicity	Not easy to understand by households	Easy to understand because the drum rises and falls	The user can easily see inside the digester and gas storage.
Gas Pressure	Pressure is not maintained and leaks are common	Constant gas pressure	Pressure can be regulated by adding weights
Maintenance	Daily stirring of the system, managing inflow and outflow, complicated maintenance if a leak is found	Regular removal of rust and paint, managing inflow and outflow	Repairs can be done by the household, managing less inflow and outflow than FDB or FLDB
Damage possibilities	Scum can reduce gas pressure, the system is protected underground	Drum will rust and it can become misaligned	Easily damaged by sun and animals

Source: Bennet, 2009; Drewko, 2007;Ocwieja, 2010

As table 3.4 shows a number of issues for each technology can arise during and after construction. Therefore, it is very important to have mitigation measures in order to overcome and address these issues. These mitigation measures will be presented once the technology to be implemented at the village is chosen. Other important aspects to consider before selecting the best technology are the biodigester's location and size.

Biodigester location

The biodigester has to be safe for children and animals. Although the final decision to locate the biodigester will be determined by a consensus among the villagers, it is recommended that the biodigester be located close to the animals and the point of gas consumption. This is to avoid collecting the animal waste from different locations and to reduce cost for transporting the biogas. Because usually a biodigester is underground, it has to be located far from heavy machinery that is frequently moving. It also should be distant from trees making sure that roots will not grow into the brickwork, and it needs to be located about 15 m far way from sources of water to prevent contamination. If it is possible, it is suggested to locate the livestock in a stable and to have them penned most of the time. This will facilitate animal waste collection and will reduce grazing from the natural flora (Sasse et al., 1991). I will talk about this aspect as one of the benefits of having a biodigester in Chapter V, Ecology and Environment.

Biodigester size

The size of the plant depends on the volume of daily feed and retention time. If any of the three biodigester designs are installed at the Jiudai Yakou village, the daily input will be about 137 Kg, and it will receive human waste from a latrine plant attached to the biodigester. Table 3.5 presents different plant sizes depending on daily loading and biodigester location.

Table 3.5 Loading rate for various Plant sizes

Plant Size (m^3)	Daily Loading Rate (Kg)	
	Hills (cold weather)	Terai(warm weather)
4	24	30
6	36	45
8	48	60
10	60	75
15	90	110
20	120	150

Source: Karki et al, 2005.

According to the Biogas Support Programme (BSP) the recommended retention time to reduce pathogens for human waste is 90-100 days and for cow dung is 70 days in the hills and 55 days in the terai (Bensah & Brew-Hammond, 2010; Karki et al., 2005).

In addition to the feedstock's volume and biodigester retention time, the amount of biogas used per day may also be considered. It is estimated that about 15.73 $m^3$of methane will be generated by the biodigester per day. In order to save space inside the biodigester a compost pit and an effluent tank should be located beside the biodigester to store the slurry and organic matter before using it as fertilizer (Karki et al., 2005 & Sasse et al., 1991). Figure 3.5 shows what a tubular polyethylene biodigester system without a latrine looks like.

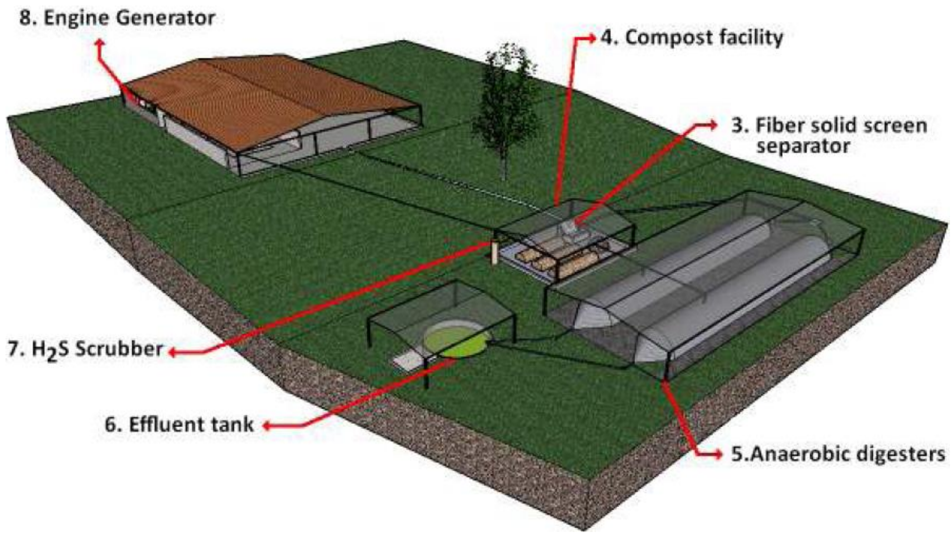


Figure 3.5 Tubular Polyethylene Biodigester system diagram

(Source: Viquez, 2009)

This biodigester has two tubular PVC membrane bags of 20.11 m each with 2.5 m in diameter. This biodigester is commonly installed in the ground and the retention time is 40 days. The digester can hold 123, 026 L of liquid volume and can store 76.45 m^3 of biogas (Viquez, 2009). For the Jiudai Yakou village the daily volume loaded will be 16,000 L with 100 days retention time if human waste is used as feedstock or 6,215 L with 55 days retention time if the animal waste available at the village is used. This represents about 13 percent and 5 percent respectively of the materials' sizes used in the biodigester shown in figure 3.4. However, this type of biodigester is not recommended for the Jiudai Yakou village because this system works much better in warm temperatures. Since the Chinese village is located in the mountains, the temperature can drop during nights, affecting the biodigester optimum conditions.

For the FDB and the FLDB a biodigester size of $10m^2$ and 1.5 m deep can hold $15m^3$ of material, which will be adequate to treat a daily loading rate of 160Kg of saw dust, human and animal waste (See Appendix B). These substrates are available at the village and could be used to feed the 15m^3 biodigester (Still, 2002).

Biodigester with a latrine plant attached

Since the main purpose of building a biodigester plant is to have an alternative waste disposal method, the gas gained should be seen as a bonus. Considering that the Jiudai Yakou village lacks a sanitary system that can handle and efficiently manage human waste, a biodigester with a latrine plant attached(biotoilet) is very promising because it can replace a septic tank (Bensah et al., 2010; Buxton & Reed, 2010). Studies have shown that anaerobic digestion technology is one of the most appropriate methods for treating human waste because it can destroy more than 95 percent of the pathogens found in human feces. Hence biogas installation can significantly improve the health of users. This phenomenon has been observed in rural China after biotoilets have been installed with reductions in schistosomiasis and tapeworm of 90 percent and 13 percent respectively. In addition biogas gains, and stabilized manure are obtained as a by product of the anaerobic digestion process. Furthermore, there are many worldwide examples of successful biodigester projects with a latrine system that continuously feeds the biodigester (Drewko, 2007; Karki et al., 2005).

Although, in China the use of biogas produced from human and animal waste decomposition is not an issue as in other countries or cultures, biogas is considered dirty and unhygienic when it is produced from human waste. It is still, therefore very important to have a community training program that considers that a change in excreta disposal practices is challenging. Therefore the program should include:

- A committee responsible for the operation of the biodigester and a person in charge for cleaning and keeping the latrine in optimum conditions.
- A strong interaction between the community members and the service providers that clearly communicate the qualitative and quantitative sanitary benefits of using a biotoilet in terms of savings, environmental protection as well as community benefits.
- A manual to use the latrine in a safe and hygienic manner.
- A list of contact information in case of any technical problems with the latrine as well as with the biodigester (Bensah & Brew-Hammond, 2010; Buxton & Reed, 2010; Drewko, 2007).

Biotoilet with urine diversion

According to the literature a dry toilet biodigester with urine-diversion has several benefits, such as the use of urea as fertilizer, dry excreta compost quickly; it has lower volume, the dry conditions speed up the killing of the germs and with no urea in the dry toilet it reduces the possibility of having a low pH at the fermentation chamber. However, it has also been documented that one of the main concerns about not using water in the biolatrine is that it can generate bad odors because of aerobic decomposition of feces entrained in the inlet pipe. Moreover, poor connections between the toilet seat and the inlet pipe of the biodigester can cause feces to get stuck to the inlet pipe. Therefore, the use of water to flush the toilet will be recommended when possible as well as perfectly sealed connections must be used between pipes during the construction phase to avoid leaks (Bensah & Brew-Hammond, 2010; Quazi& Islam, 2008).

Table 3.6 presents the composition of human feces and urine. The greater part of the nutrients in human waste are contained in urine and it also contains the largest proportions of plant nutrients as can be observed in the table, due to an important concentration of Nitrogen (N) and Potassium (K) (Daisy & Kamaraj, 2010; Still, 2009).

Table 3.6 Quality and Composition of Human Feces and Urine		
Approximate Quality	**Feces**	**Urine**
Water content in the night soil (per capita)	135 -270	1- 1.3 L
Approximate composition	**Dry basis**	
pH	5.2 -5.6	
Moisture (%)	66 - 80	93 -96
Solids	20 -34	4 -7
Composition of solids		
Organic matter (%)	88 – 97	65 - 85
Nitrogen (%)	5 -7	15 -19
Potassium (%)	0.83 – 2.1	2.6 – 3.6
Carbon (%)	40 – 55	11 – 17
Calcium (%)	2.9 – 3.6	3.3 – 4.4
C/N ratio	5-10	0.6 – 1.1

Source: Daisy & Kamaraj, 2010

Table 3.6 shows the importance of urea diversion in terms of the amount of Nitrogen, and Potassium (NK) that can be recovered in excreta per year in China in comparison with other countries. "On average each person produces 30 L of biogas and 1-1.5 L of urine per day, which contains enough nutrients to fertilize 300 – 400 m^2 of land" (Drewko, 2007: 57). However, the concentration of nutrients can vary depending of the diet, country and even between individuals.

Table 3.7 Comparison of estimated excretion of nutrient per capita in selected countries			
Country		Nitrogen Kg/capita yr	Phosphorus Kg/capita yr
China	Total Urine Feces	4 3.5 0.5	0.6 0.4 0.2
Haiti	Total Urine Feces	2.1 1.9 0.3	0.3 0.2 0.1
India	Total Urine Feces	2.7 2.3 0.3	0.4 0.3 0.1
South Africa	Total Urine Feces	3.4 3 0.4	0.5 0.3 0.2
Uganda	Total Urine Feces	2.5 2.2 0.3	0.4 0.3 0.1

Source: Drewko, 2007.

Besides the savings from installing a biotoilet instead of building isolated latrines or septic tanks, the use of multiple substrates usually has more benefits improving biogas production and slurry characteristics (Barnett, 1978; Lansing et al., 2010). Although a septic tank can be connected with a biodigester after several years in use, fresh human excreta is better for biogas production (Bond et al., 2011). Therefore if a biodigester is planned to be installed at the Jiudai Yakou village, it is recommended that it is connected from the beginning (construction phase) with the new latrine system.

The FDB or the FLDB are the two most suitable technologies that can be connected with a latrine system. On one side the FLDB offers a gas with a constant pressure, which is easier to use than a FDB (Drewko, 2007). On the other hand, a FDB is most popular for biolatrine construction. In both cases, two compost pits (1m x 1.2 m x 0.8m) are recommended to be built beside the biodigester. A layout is presented in Figure 3.6 showing the dimension of a 15 m^3FDB and a construction of six latrines (five for females and one for males) together with four urinals for males.

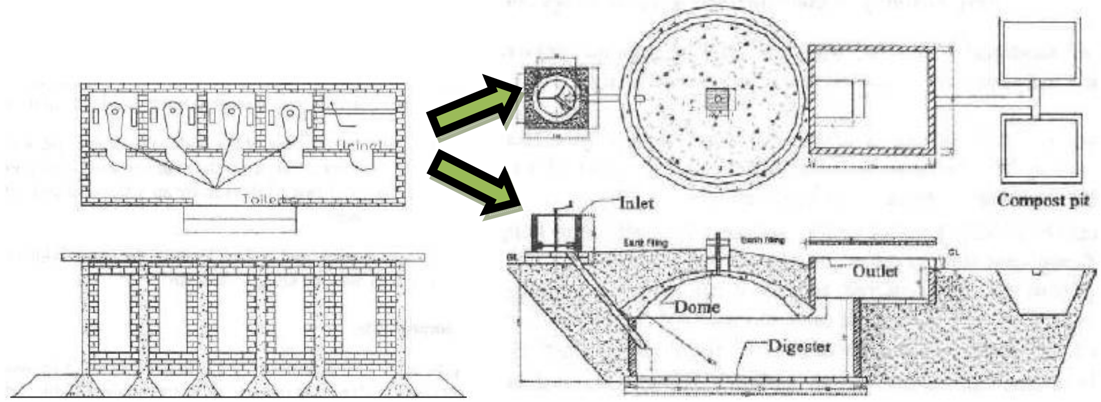


Figure 3.6 Layout showing FDB with a latrine attached plant

(Source: Karki et al., 2005).

Finally Figure 3.7 shows an integrated community biolatrine diagram, which includes two main inlets, one from the latrine plant and the other from animal waste. This scenario is very similar to the one expected to be implemented at the Jiudai Yakou village.

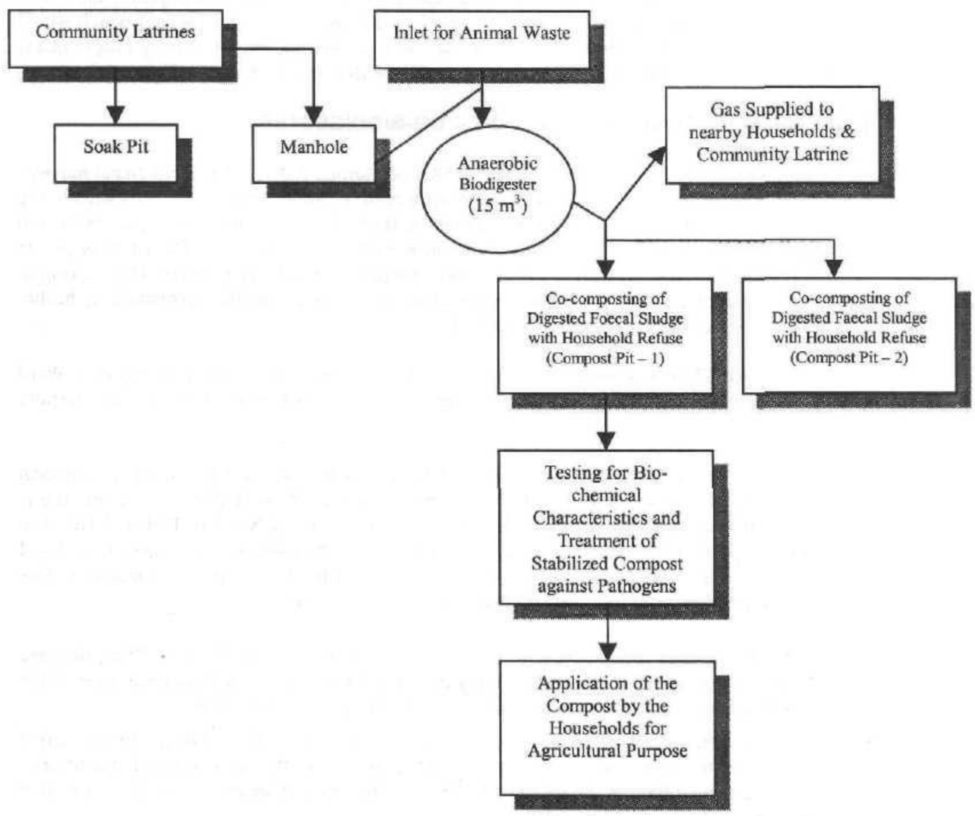


Figure 3.7 Diagram of a Community Biolatrine System

(Source: Karki et al., 2005).

Biogas appliances

Biogas appliances may include: gas cookers/stoves, biogas lamps, radiant heaters, incubators, refrigerators and engines. However, in developing countries the most popular and well developed biogas appliances are stoves used for cooking (Figure 3.8).This is because biogas burns with a clean and blue flame which makes biogas for cooking the perfect means of exploiting biogas in rural areas. Since biogas is similar to butane and propane gas sold in cylinders, appliances for cooking and lighting are easily adapted to biogas (Behrendt et al., 2006; Herrero, 1990; Karki, 2005). In order to cook 1.2 Kg of rice, 120 -140 Litres (L) of biogas are needed and to cook 0.5 Kg of legumes will require between 30 -40 L of biogas (Drewko, 2007).

The water pressure needed for biogas burners or stoves for domestic cooking are between 75 to 85 mm. There are different types of stoves depending of the number of burners that it has and the size of these burners. Table 3.8 shows some of them as well as some sizes and types used for biogas lamps (Karki et al., 2005; Widodo, 2009).

For the Jiudai Yakou village it is recommended to use stoves of 0.22 and 0.44 $m^3$of capacity which are the most popular stoves used in China. Furthermore, it is important to buy the best burners or stoves that can guarantee safety, reliability and efficiency because ultimately a good stove can maximize the use of the biogas that is being generated by the biodigester and avoid biogas losses. To avoid the combustion of toxic chemicals contained in the biogas it is important to use a method that can remove H_2S and CO_2 which are commonly cheap as well as easy to install and operate (Barnett, 1978).

Another important reason for the popularity of biogas use for cooking is the strong support from government and non-profit organizations that have encouraged the development and improvement of stoves in remote communities. In 2010, for example, the United Nations announced the Global Alliance for Clean Cook stoves, which has the target of delivering worldwide 100 million clean cook stoves by 2020 (Bond et al., 2011; Smith 2010).

Regarding the use of biogas for lighting, there are different types of lamps which are easy to manufacture and simple to operate. A mantle lamp usually requires 0.23 m^3/hr and a pressure of 45 mm H_2O. Table 3.8 describes different type of lamps which are usually made of clay by Chinese fanners (Widodo, 2009). The energy use for lighting at the village is based on the assumption that each household has one mantle lamp for indoor uses and one or two mantle lamp for outside illumination, which use in total 0.84 m^3

biogas per day. Biogas lamps should be placed right below the roof to avoid fire hazard because these lamps are not energy-efficient and they get very hot. The light output is measured in lumen (lm). The equivalent of 400-500 lm is 25 – 75 W light bulb and one lamp consumes about 120 -175 L of biogas per day (Drewko, 2007; Karki et al., 2005).

Table 3.8 Biogas requirements for various appliances

Description	Size	Rate of gas consumption (m^3 / h)
Stove	2" diameter	0.33
	4" diameter	0.44
	6" diameter	0.57
Lamp	1 mantle	0.07
	2 mantle	0.14
	3 mantle	0.17

Lighting equal to 60 watt mantle lamp ≅100 candle power ≅ 620 lumen.

Source: (Barnett, 1978; Karki et al., 2005; Widodo et al., 2009)

Finally but not least important is the gas line connections between the biodigester and the appliances used. This gas line should be located 30 cm underground with a slope to drain out the moisture that biogas usually contains. This gas line can be made of ¾ inch galvanised pipes (Butare & Kimaro, 2002). The meters of material needed will depend on the distances between the biodigester and the location of the appliances, which for the village will be the biogas used per household for lighting two lamps and for biogas used in stoves with two burners for cooking.

Figure 3.8 Utilization of biogas for gas stove and mantle lamp

(Source: Behrendt et al., 2006; Widodo et al., 2009)

IV. Social Assessment

In most biodigester developments, designers and administrators pay enough attention to the construction process, however, if effective final users training, follow up management, operations, daily maintenance and repair work are not well designed and carried out, it will result in inadequate technical services and support. This can result in the paradoxical situation of progress with the biodigester's construction because the household is being unable to actually benefit once projects are completed (Pulamte & Abrol, 2003).

If social aspects are considered, the biodigester project can bring many benefits to the community, such as:

1. - Energy generation through methane production that can be used for cooking, heating or even for electricity generation.

2. – Production of odourless slurry for use as a renewable fertilizer, that could improve the quality and quantity of crop productivity, because it contains nitrogen and phosphorous that are traditionally extracted from finite mining processes.

3. – Improvement in family health because biogas does not release toxic gases, such as carbon monoxide, found in burning fuel wood.

4. - The empowerment of women because in most developing countries women and girls are responsible for cooking, as a result they are usually the end users and, thus, a key element in the operation of the biodigester.

5. - Animal hygiene is improved because animal manure can be disposed safely, reducing smells, flies, and the spread of diseases.

6. - Environmental benefits because there is no need for cutting down trees for cooking and it also reduces GHG emissions.

7. - Work load and cost are reduced because the time needed for loading the biodigester with fresh manure is less than that required for collecting woodfire and the cost is lower than buying fuel.

8. – It is a sustainable technology because it is simple and it uses local materials, reducing the operational and maintenance costs.

To maximize these benefits it is important that before choosing the best and most suitable biodigester, local conditions are well understood, including social and cultural dimensions which are generally ignored (Pulamte & Abrol, 2003).

Technology transfer

Technology transfer is an interactive process between the technology specialists and the final user(s). Although this step is essential for the successful implementation of a technology, it is complicated to achieve because often there is a gap between technology development and its application as well as a weak interaction among scientists, external experts and users (Pulamte & Abrol, 2003). For a biodigester to be a sustainable project it requires a holistic approach that considers the biosocial system, such as human capital and natural resources. Therefore, this transitional stage is about changing and understanding social structures. As Ehrenfeld (2008) mentions, if we want something to change we need to look at the structure that creates action.

In order to successfully implement a low cost biodigester at the Jiudai Yakou village it is necessary to consider the culture of the residents and identify which actions are causing unsustainable practices in terms of water, energy and waste management. The installation of a low cost biodigester at the Jiudai Yakou village attempts to contribute with a more efficient waste management system and with biogas generation for cooking, among other benefits as cited above. This potential solution will have some hazards and stresses such as biogas flammability, waste availability, inefficient management, maintenance and operation as well as waste disposal reframing. Using Kofinas & Chapin's (2009) "adaptive capacity" framework (Figure 4.1), the immediate impacts of these hazards will be the biodigester's poor management and not enough waste to generate biogas for the village. However, effective instructions for the installer, operator and the end user about safe operation of the equipment and its maintenance could improve the biodigester's management and eliminate or reduce the danger of biogas flammability. In order to have enough waste to generate biogas a diversification of waste is recommended. Kofinas & Chapin (2009, p. 67) mention that "diversity provides the raw material or building blocks on which adaptation can act"; therefore, it is suggested that other sources of waste, such as human and animal waste as well as crops by-products will be needed to generate sufficient biogas. Finally, in regards to the waste disposal reframing process, it is recommended that social learning, networks and local knowledge are well understood. Usually, early negative experiences with biogas plants due to lack of experience using the technology causes lack of credibility of the process (Switzenbaum, 1995). One advantage that the Chinese village has is that one of the residents has built a biodigester for his family, and he would be ready to assist in the construction and operation of the biodigester. Moreover, the residents are willing to change current beliefs and norms for something new that is socially desirable.

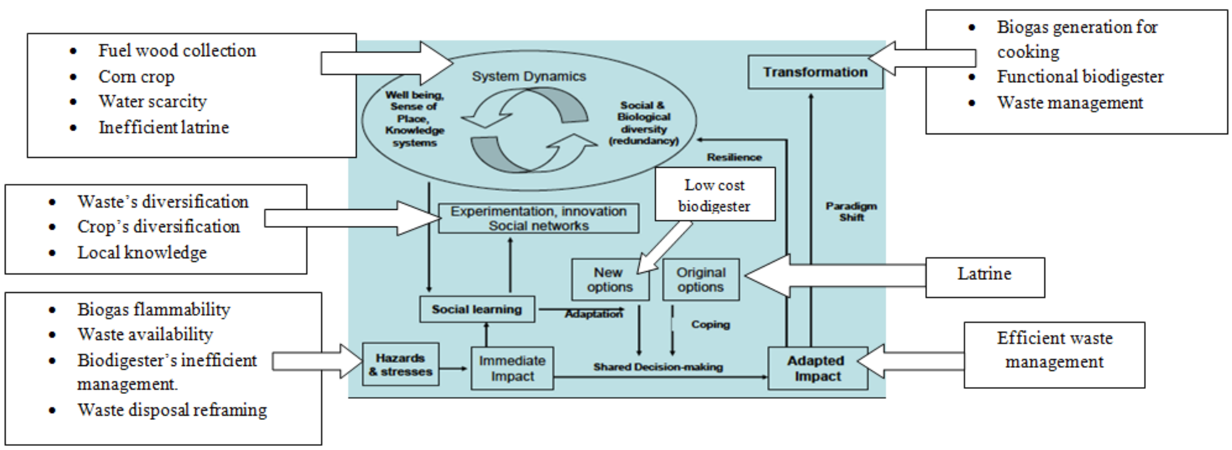


Figure 4.1 Adaptive capacity framework

Source: Romo-Rábago, E., 2013.

Gender benefits

The literature mentions a strong connection between biodigester developments and empowerment of women and girls. Since all domestic works, such as cooking, cleaning vessels, collection of fuel wood, and agricultural production is exclusively done by women in most rural areas in developing countries, a biodigester could reduce the time they spend doing these activities, especially because deforestation is increasing the time for collecting wood. Furthermore, cooking with biogas has less harmful effects on health than fuel wood. Women and girls have a high exposure to indoor air pollution from combustion of fuel wood and they are more likely to develop chronic health problems related to exposure to particulate matter (Karki et al., 2005 & Rowse, 2011).

Because the women are the most benefited group by biodigesters and because they play an important role in the household hygiene, it is recommended to consider them from the beginning of the project. Successful case studies have reported that an efficient training program needs to have women on the committee board to improve understanding of the technology and speed up its dissemination (Edward, 2002; Lauridsen, 1998; Karki et al., 2005; Ocwieja, 2010; Rowse, 2011).

Time saving and workload reduction

It is estimated that the Jiudai Yakou's villagers spend about half of the day collecting fuel wood that is used for cooking. However, the exact amount of time needed to collect fuel wood per household as well as the time for cooking, cleaning utensils, etc. are data not registered at the Chinese village. Table 4.1 presents the data from a field survey made in Nepal to estimate the amount of time needed for cooking before and after a biodigester was installed.

Table 4.1 Analysis of average time for daily works			
Daily works	**Average time in minutes per day**		**Average time saved per day (minutes)**
	Biogas households	**Non Biogas households**	
Fuel wood collection	25	60	+35
Cooking	145	195	+50
Fetching water	70	45	-25
Cleaning utensils	30	60	+30
Livestock caring	40	30	-10
Dung collection	15	-	-15
Slurry mixing	15	-	-15
Total	340	390	50
			+Shows saved time due to Biogas plants

(Source: Shrestha, 2010)

Table 4.1 shows that the amount of time saved per household is 50 minutes per day. According to the calculations made in Chapter II about the potentiality of biogas at the Jiudai Yakou village, biogas can replace 57 percent of cooking needs. Therefore, if the village is integrated by 15 households, and assuming that the villagers work seven days a week for wood collection, the time saved per week will be 50 hours; equivalent to an annual time saving of 2,600 hours at the village. Assuming that this time can be employed in productive activities earning at least the minimum wage payment at Yunnan, which is $1.96 CAD/hr, the village will have extra income from time saving of $5,096 or $339 CAD/household. This represents about 150 percent increase in the current annual income that each household has.

Health improvement

A biodigester development improves the health of community members by reducing indoor air pollution and providing proper sanitary conditions by efficient use of human and animal waste into the biodigester. In the next paragraphs, reduction of indoor air pollution by using biogas for cooking as well as water quality and sanitation by handling human and animal waste will be discussed as key elements to improve the health of the villagers.

Indoor air pollution

When fuel wood is burnt for cooking, it releases toxic substances, such as, carbon monoxide, particular mater (PM) and hydrocarbons. As observed in Figure 4.2, biogas releases the lowest amount of toxic substances compared to the rest of the fuels commonly used in rural areas (Bennet, 2009; Karki et al., 2005).

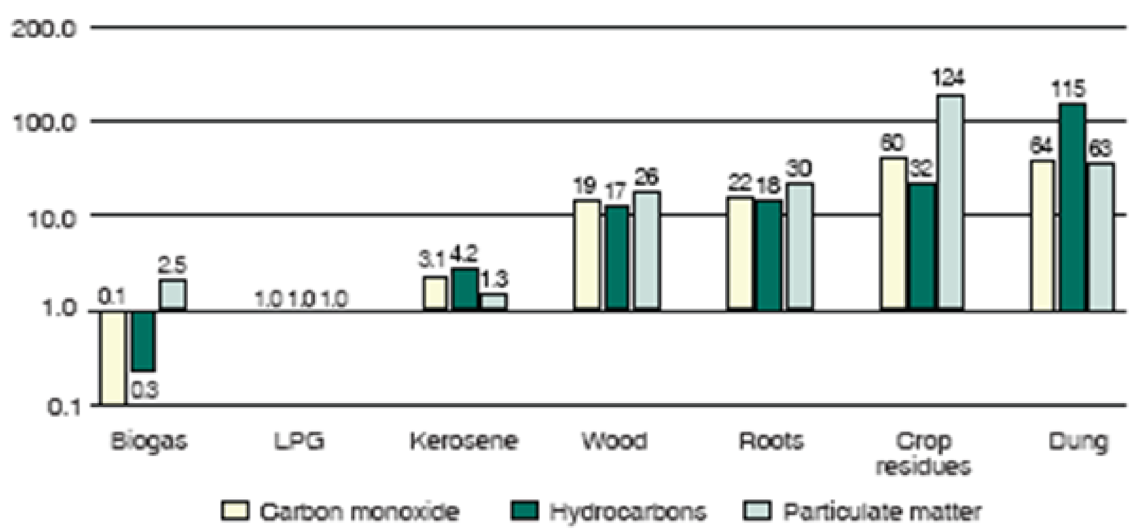


Figure 4.2 Ratio of emissions from different fuels[1]

Source: Smith 2006.

[1]*The values are shown as grams per mega joule of energy delivered to the cooking pot (g/MJ/day)*

The inhalation of this harmful smoke can cause Acute Lower Respiratory Infection (ALRI), eye illness, eye burn, lung problems, asthma, headaches and intestinal/diahorrea problems. Biomass fuel has also been associated with tuberculosis, cataracts and low birth weight in babies and it has been classified by the International Agency for Research on Cancer as a possible carcinogen. Furthermore, ALRI has been reported as the number one killer of children worldwide. The Chronic Obstructive Pulmonary Disorder (COPD) affects women health which is exposure to indoor air pollution for cooking on unvented fires. COPD is responsible for more than 2.4 million lives each year. Therefore, cooking with biomass accounts for 3.5 percent of the global disease burden (Smith, 2006).

There is strong evidence that shows a health improvement by cooking with biogas instead of burning biomass (Bennett, 2009; Mata-Alvarez, 2000; Ocwieja, 2010; Shrestha, 2010; Smith, 2006; Zelelke, 2008). One of the main benefits of using biogas is the reduction of indoor smoke which also reduces health-related expenses (Shrestha, 2010).

Water quality and sanitation

When there is a lack of an efficient human and animal waste disposal, water bodies can easily be contaminated. This can bring negative consequences to the community. For example, many large agricultural farms in China, India and Mexico, water their crops with contaminated water, which can cause an important number of diseases such as, diarrhoea, cholera, typhoid, gastric ulcers, anaemia, giardiasis and amoebiasis among the consumers of these crops (Mohapatra, 2011). According to UNESO, 2006, "1.5 million children die of diarrhoeal diseases in a year due to inadequate sanitation facilities. One child dies approximately every 20 seconds from diarrhoea. Provision of safer water, sanitation and hygiene practices could prevent about 90 percent of those deaths".

Collecting human and animal waste into the biodigester could provide a community with an effective waste management system, which can improve sanitation and avoid water contamination. Since these residues and mainly human waste have an important amount of pathogens, a biodigester with an adequate retention time can reduce more than 95 percent of pathogens while recycling nutrients from urine and feces (Karki, 2005).

In addition to the health benefits, a village that has good sanitary conditions in place and has access to clean water and energy will attract educated professionals to remain in a rural setting as well as provide the villagers with an improved quality of life and with better opportunities for their rural community.

V. Ecology and Environment

In addition to the social benefits, the installation of a biodigester can bring environmental benefits as well, such as GHG emission reductions, deforestation reduction, a sustainable waste management system at the village, agricultural improvement by the production of slurry that can be used as a fertilizer for different types of crops and even avoidance of cattle grazing by having the livestock penned most of the time for easy animal waste collection.

Climate change

It is well documented that GHG emissions play an important role in protecting the atmosphere from climate instability. During the industrial revolution an important increase in these gases has been documented. Methane, for example, has increased by 30 percent in the last 25 years and it is estimated that 70 percent of these emissions are anthropogenic (IPCC, 2007). This has augmented radiative forcing affecting global climate patterns. Since biodigesters can reduce GHG emissions by capturing methane emissions from organic waste and destroying the methane through combustion, anaerobic digestion of biomass is of increasing interest to reduce these emissions (Bennett, 2009; Mulugetta, 2007; Thompson et al., 2009; Weiland, 2010).

GHG emissions at the Jiudai Yakou village

When biomass, such fuel wood, at the village is burnt, much of its carbon content is converted to carbon dioxide and methane, a potent greenhouse gas with 25 times the global warming potential of carbon dioxide (IPCC, 2007). In fact, fuel wood is one of the main sources of GHG emissions in rural areas (Xavier et al., 1990). Therefore, substitution with biogas can importantly reduce GHG emissions and obtain value from the carbon by producing energy and by using it as a source of organic carbon in soils (Garfia et al., 2012). Additionally, human and animal waste can produce methane and nitrous oxide during anaerobic decomposition. If these residues are treated in a biodigester, biogas can be used as one of the cleanest fuels available in rural areas because it has the lowest warming potential per energy unit delivered as can be observed in Figure 5.1. Furthermore, the slurry obtained as by product through the biodigester process can substitute chemical fertilizers.

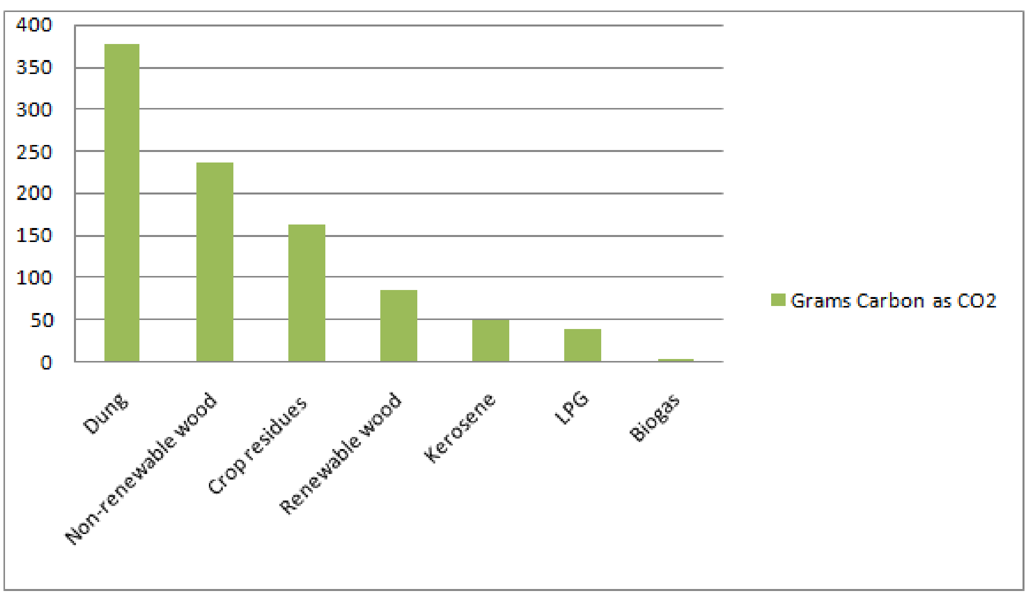


Figure 5.1 CO_2 emissions from fuels commonly used in rural areas

(Source: Eaton, 2009).

Studies have shown that the use of biogas can reduce global anthropogenic methane by around four percent and 60 percent of nitrous oxide, which has 300 GWP. If the slurry obtained through the biodigester substitutes for the chemical fertilizers and displaces traditional disposal of animal waste on crops, which currently are the largest individual contributors to GHG emissions, an important amount of nitrous oxide can be reduced (Bond et al., 2011; EPA, 2010).

Since the main sources of GHG emissions from the village come from burning wood for cooking and using kerosene for lighting, the production and capture of biogas from the human and animal waste from the village contributes to GHG reduction through two processes: emission reduction and fuel substitution. Emission reduction can be achieved through the capture of the emitted methane from human and animal waste. Fuel substitution applies to the use of biogas to replace kerosene and fuel wood. Since GWP of methane is 25 times CO_2 and it has a value of 2.75 tonnes of CO_2 equivalent, fuel substitution will be used to calculate CH_4 and CO_2 emissions. Since biogas efficiency is 55 percent in stoves and only 3 percent in lamps, the biogas generated at the Chinese village will be used only for cooking. The following calculations estimate the energy off-set for fuel wood substitution:

- Atmospheric emissions from burning biomass:

One mole of $C_{760}H_{1980}O_{874.7}N_{12.7}S$ produces 760 moles of CO_2

Therefore, one tonne (VS) produces 760*44/25,305 (or 1.32) tonnes of CO_2

= 49.7 tonne (0.75) (0.9) (1.32) = ***44.3 tonnes of CO_2/year***

•Avoided atmospheric emissions from burning fuel wood:

If one mole of $C_6H_{10}O_5$ produces six moles of CO_2

So, one Kg (VS) produces: 6 * 44/ 162 Kg CO_2= 1.63 Kg CO_2

Therefore, 36.86 Kg of fuel wood/day from the Jiudai Yakou village * 0.9(MC)*0.95(Ash) =31.52 Kg CO_2/ day = ***11.51 tonnes of CO_2/year***

•Avoided emissions from biomass decomposition of human and animal waste;
Considering that one tonne of biomass waste produces 0.1tonnes of CH_4
Therefore, human and animal waste biomass at the village produces
0.1*49.68tonn/day = 4.97 tonne of CH_4/year
Since CH_4GWP = 25, this amounts to 25 *4.97 = ***124.19 tonnes of CO_2***

•Net result

Reduction in CO_2 equivalent emissions: 11.51 + 124.19 – 44.3 =

91.4 tonnes of CO_2 equivalent/year

•Economic benefit:

Considering that Carbon (Credit) value is = $15/tonne of CO_2 equivalent,

therefore, 91.4 tonnes of CO_2eq = **$ 1,371**

Fuel substitution seems to contribute more with GHG reductions than emission reduction. Therefore, biogas production from human and animal biomass waste contributes with significant amount of GHG reductions and, thus, carbon credits. This might improve the cost of biogas production and the sale of the produced CO_2 for carbon credit (Salim Abboud, 2010).

Table 5.1 Deforestation and tree savings at the Jiudai Yakou village

Amount of wood needed (Kg/year)	Amount of trees saved
If 1m^3 biogas = 1.3 Kg wood then, 28.335 m^3 = 36.86 Kg/day = 13,452 Kg / year	If a tree with 10cm diameter (*Castanopsis indica* or *Schima wallichi*) weights 60Kg; Therefore, 13, 452 Kg wood / 60Kg **= 224.2 trees/ year.**

Environmental degradation

As discussed in Chapter I, Yunnan is one of the most privileged provinces in China. It has a rich variety of ecosystems with the largest diversity of plant life in the country (Liang, 2011). Its preservation and sustainable development will depend upon adequate management of their resources. This will include an important reduction on fuel wood dependency and cattle grazing that have significantly affected the health of the forests.

As cooking is the primary cause of fuel wood consumption, it is one of the major causes of deforestation and forest destruction (Garfia et al., 2012). Furthermore, free grazing for cattle in rural areas have also contributed with erosion and environmental degradation of the natural surroundings. With the installation of a biodigester, farmers and villagers are more likely to stall feed their cattle to optimize dung collection; allowing regeneration of pasture and forest land (Karki et al., 2005; Zelelke, 2008).

If the entire biogas generated at the Jiudai Yakou village is used for cooking, 100 percent of their cooking needs will be met. Table 5.1 shows an estimation of deforestation reduction at the village if a biodigester is installed:

As presented in table 5.1, implementation of a biodigester at the village will help alleviate demand for fuel wood and save a considerable amount of trees, while covering 100 percent of their fuel needs for cooking, leading to more than 50 percent decrease in fuel wood consumption. The remaining 50 percent (16.64 Kg) will need to continue being collected to feed the biodigester and to keep optimum C/N ratio in the fermentation chamber as discussed on Chapter II.

Agricultural improvement

Among the multiple benefits that a biodigester brings to a community, singular production of a solid (biosolid) and liquid residue (slurry) which can be used as a soil conditioner to fertilise land is one of the most important outputs of the system.

The slurry can be used in a liquid or solid form; if pathogen levels are low enough and the slurry is well-decomposed (dark brown in color with friable consistency), biosolids can be directly poured onto the crops or the slurry can be sprayed on leaves. Studies have shown an increase in crop yields, a 400 percent increase for tomatoes and wheat, and 300 percent increase for the weight of root vegetables. (Barnett, 1978; Herrero, 1990; Karki, 2005; Morris et al., 1980).

This natural fertilizer is also used to feed fish, cattle, poultry, birds, and as a pesticide to control insects and pathogens. In fact, in China, the slurry is commonly used as a supplement to feed cattle, hogs, poultry and fish (Karki, 2006). Because of the valuable nutrient content of nitrogen and phosphorus, biosolids and slurry can also correct the overuse of chemical fertilizers, increase water holding capacity of soils, stabilize water content, control root pathogens and replenish the soil nutrients (Barnett, 1978; FAO, 1996; Rowse, 2011).

Slurry has more nutrients than conventional fertilizers, including compost, because in these cases nutrients such as nitrogen are lost by volatilization due to exposure to sun and heat. It has been reported that nitrogen from dung escapes 30 – 50 percent while after digested, only 15 percent escapes. Slurry and biosolids are also rich in micronutrients needed for plant growth and because of the long retention time, pathogens and weed seeds get destroyed in the fermentation chamber. Furthermore, these natural fertilizers have 260 percent more ammonia than composted manure. Karki (2005) also mentions “that soaking the seeds with slurry can induce germination of the seedlings faster and promotes resistance to diseases”.

Table 5.2 provides an estimation of the amount of fertilizer used by the Jiudai Yakou villagers as well as potential annual savings resulting from using slurry for their crops, which are usually corn (irrigated area).

Table 5.2 Fertilizer use and savings at the Jiudao Yakou village

Amount of fertilizer use (Kg/ Hectare)	Savings for using slurry ($ CAD)
If 10 tonne of fertilizer is needed for 1 Ha of irrigated area or 5 tonnes/Ha of dry farming[1] hence, 22.3 Ha of farming land area at the village needs = 111.5 tonnes for dry farming = 223 tonnes for irrigated areas	If 35.23 L of fertilizer for corn = $4.5 CAD[3]; then, 24,840 Kg = **$3,172.86**
If organic matter received by the biodigester is reduced by 50 percent [2]; consequently daily slurry production = 68.05Kg/day/village = 24.84 tonne/year/village = 11.14 percent of total fertilizer needs	

[1]FAO, 1997;[2] Lansing et al., 2010; [3] Bain, 2012.

According to table 5.2, the slurry produced at the village can meet more than 11 percent of the villagers land fertilizer needs. This translates into an annual saving at the village of $3,172.86, which is equivalent to 34 percent of a villager annual income.

VI. Economic Analysis

Until this chapter, different technologies have been explained and discussed as feasible alternatives for the Jiudai Yakou village in terms of technical, social and environmental aspects. However, before deciding which is the best technology for the village, it is very important to consider an economic analysis because it will provide these technologies with a monetary value not just for their capital investment but for their socioeconomic, and environmental benefits. "The simple decision rule is that if the benefits exceed the costs, the project is worth undertaking; otherwise not" (Karki et al., 2005: 111).

In this chapter, economic benefits will be calculated taking into account social and environmental benefits discussed in previous chapters. As well the capital cost for each technology, operations and maintenance costs, time savings for reducing fuel wood collection, the payback period and the net present value of each technology will be considered to choose the best and most affordable technology for the Jiudai Yakou village. Finally, financing opportunities will be evaluated to leverage the total costs of the most appropriate technology for the Jiudai Yakou village as well as risks and mitigation strategy for the preferred technology.

Technology costs

The capital cost is the most expensive part of any biodigester. The construction cost alone amounts to 70 and 80 percent for plants of 20 and 4 m^3 respectively (FAO, 1996). Assuming that the village will need a 15m^3 biodigester, figure 6.1 presents approximate capital and maintenance costs for each low cost biodigester that has been discussed in previous chapters, as well as the total cost of a latrine with a urine diversion toilet unit (biotoilet).

6.1 Technologies costs for a 15 m^3 biodigester

Technology & Lifespan	Components	Capital Cost	Operation and maintenance cost (O & M costs)	Total cost
FDB (20 – 50	Construction materials Biogas appliances	$1,400 - $3,500	$600 - $1,500	$2,000 – 5,000

years)	Pipe and pipe fitting Reinforcement steel Labor			
FLDB (5 – 15 years)	Same components than FDB plus a steel drum, coating and painting as well as a guide for the floating drum	$1,750 - $4,200	$750 - $1,800	$2,500 – 6,000
TPB (2 – 6 years)	Accessories Reactor Reservoir Stove Additional material	$245 - $350	$105 - $150	$350 - $ 500 / household
Biotoilet (10 – 20 years)	Excavation and earth work Concrete work Walling work Roofing Carpenter and joinery Wooden stair	$70 - $140	$30 - $60	$100 – 200 / toilet

Sources: Bennett, 2009;Drewkon, 2007;FAO, 1996;Goethert et al, 2003.

(Source: Shrestha, 2010)

Payback period

To be able to estimate the payback period for each technology, it is important to evaluate the energy benefits that using biogas will bring to the village economy. If estimated biogas generation at the village will meet 57 percent of their energy needs, table 6.2 presents average savings for replacing fuel wood, electricity, and kerosene with biogas. Therefore, the annual energy needs that can be replaced with biogas at the village are 3,089 m^3 for cooking and 2,621 m^3 for lighting.

Table 6.2 Annual economic benefits for using biogas at the Jiudai Yakou village		
Source of energy	Amount replaced by biogas	Money saved ($CAD)
Wood[1] (3,089 m^3)	4.015tonne of wood = 4, 562 hours *0.57[a] = 2,600 hrs * $1.96 [4]	5,096
Electricity[2] (2, 621 m^3)	3, 276.25kWh *0.57 = 1,867.46 kWh * $ 0.048[5]	89.64
Kerosene[3] (2, 621 m^3)	1,310L * 0.57 = 746.99*$ 0.53[6]	395.90
Total savings from fuel wood collection and kerosene		**5,491.9**

[1] 1.3Kg of wood = 1m^3 of biogas, [a] 0.57 represents the percentage of energy needs at the village, [2] 1.25 kWh = 1m^3 of biogas; [3] 0.5 L of kerosene = 1m^3 of biogas
[4]Average salary at Yunnan is $1.96CAD/ hr; [5] Electricity price at Yunnan is in average $0.048 CAD/kWh; [6]Kerosene cost estimation is $0.53 CAD /L

Source: Buxton & Reed, 2010 & Karki et al., 2005

According to EVHS 2012 survey, the annual per capita income at the village is $80.37 CAD. If each household has three adults, then each household has an annual income of $241.11. Assuming that biogas production at the village will provide 57 percent reduction in the village energy expenses. The savings per year will be $5,491.9 CAD for replacing 57 percent on kerosene use and for time saving by using biogas.

Table 6.3 presents the payback period for the three technologies under two different scenarios, one scenario considers only kerosene savings ($395.90 CAD) and the other scenario considers kerosene savings and time savings from fuel wood collection ($5,491.9 CAD). In order to calculate the payback period for each technology, the equation shown below will be used:

$$\text{Payback period} = \text{Total investment} / \text{Savings per year}$$

Table 6.3 Payback period for each technology		
Technology	**Payback period (years)** (Savings from kerosene = $395.9 CAD)	**Payback period (years)** (Savings from kerosene & fuel wood collection= $ 5,491.9 CAD)
FDB	Low investment: 2,000 / 395.9 = 5.05 High investment: 5,000/ 395.9 = 12.63	2,000/ 5,491.9 = 0.37 5,000/ 5,491.9 = 0.91
FLDB	Low investment: 2,500 / 395.9 = 6.3 High investment: 6,000 / 395.9 = 15.16	2,500 / 5,491.9 = 0.46 6,000/ 5,491.9 = 1.09
TPB	Low investment: 350 / 80.3[1]= 4.36 High investment: 500 / 80.3[1] = 6.22	350 / 596.16[2]= 0.59 500 / 596.16[2]= 0.84

[1]If 0.5L kerosene = 1m^3 of biogas, then 0.84m^3 of biogas needed for lighting per household = 0.42 L kerosene*$0.53 CAD/L kerosene = $0.22/day * 365 = **$80.3 CAD/ year**

[2] If 50min/day are saved by avoiding fuel wood collection, then, 304.17 hours/year * $1.96CAD/hour = **$596.16/year** extra income per household.

According to the calculations presented in table 6.3, the payback period significantly declines when fuel wood collection is measured. If we consider that the free time that each household will have for avoiding fuel wood collection will be employed for economic activities, then this will represent a direct economic income to the village. Under this scenario, the shortest payback is for the FDB which is between 0.37 or 0.91 of a year which is equal to about 4.5 or 10.92 months. Furthermore, the FDB also has the longest lifespan (20 – 50 years).Therefore, after the investment is paid back, the cost savings continues for the remaining life of the FDB.

Net Present Value (NPV)

The NPV estimates the value of a project over its productive lifetime. NPV considers all future values and provides an equivalent to the present value. According to the Food and Agriculture Organization of the United Nations (1996), “the NPV technique measures the worthiness of a project by converting the annual cash flow to a single present value. A positive NPV indicates that the benefits are higher than the costs that accrue over the project life”.

The formula used to calculate NPV is:

$$\mathrm{NPV}(i) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where,

NPV = present sum of money

R= Net cash flow

i = Discount rate

t = time

In order to calculate the net cash flow, savings from biogas use, workload reduction, fertilizer and carbon credits where considered for the three technologies.

The NPV of the technologies that can be installed at the Jiudai Yakou village are presented on table 6.4:

Table 6.4 NPV for each technology		
Technology	**Values**	**NPV**
FDB	**R** =$1400-3500 CAD **i** = 6% **t** = 6 years	NPV_{max} = 2,999.91 NPV_{min} = 2,564.87
FLDB	**R** = $1750-4200 CAD **i** = 6% **t** = 6 years	NPV_{max} = 2,927.4 NPV_{min} = 2,419.86
TPB	R = $245 - 350 CAD **i** = 6% **t** = 6 years	NPV_{max} = 2,528.62 NPV_{min} = 2,202.34

When solving for the NPV of the formula (See Appendix C), the three technologies would be estimated to be valuable projects, especially for the installation of a FDB, which could have a NPV between $94,404.5 and $106,827.5 during its 20 years of lifetime.

Financing opportunities

In order to have a successful and sustainable biodigester project at the Juidao Yakou village it has to be economically feasible. As a result, short and long term funding has to be considered. For the short term funding, the Eco Village of Hope Society (EVHS) is constantly training the young adult villagers on different activities, such as creating goods that can be sold at markets, bringing economic benefit to the community. Furthermore, savings from using the latrines, as well as from selling biogas can be collected for a community fund. These community funds will be used to help purchase necessary supplies and materials to maintain the biodigester. For the long term, a community fund will be based on small charges that can be either goods or services rendered for the use of the biodigester. The funds will cover the cost to hire someone to maintain the biodigester as well as future maintenance costs and training of the people.

Regarding the capital cost, which as discussed above is the highest cost of the entire project, two main supporters are considered to subsidize the capital cost of the project. One is the EVHS's fundraisers who generally provide approximately $10,000 per year, with strong support from the Chinese community and others in Calgary, Alberta. It is expected that at least ten percent will be directed to the biodigester project. At the most recent fundraiser held in February, 2013, approximately $1,000 was collected to cover the installation costs of the biodigester. The second supporter is the Fig Tree Foundation, who could provide about $5,000 to cover expenses during the first phase of the biodigester project. Some of these funds, along with a potential corporate sponsor, will help cover the capital and installation costs of the biodigester project, including a latrine attached plant.

It is also important to mention that the biodigester project will mainly provide a sanitary solution to the villagers, therefore a net energy gain is not considered. Because of that, each household will be charged for the service that the latrines will offer, generating an extra income to pay for the person that will be responsible for cleaning and maintaining the latrines. The biogas is expected to be sold to the villagers at the equivalent kerosene cost ($0.25 CAD/$m^3$), which will also have more advantages than kerosene, such as environmental, health, and time saving benefits. The slurry generated by the biodigester will be given back to those who supplied the pig and cow manure in proportion to the number of animals owned. It is important to mention that the expected income from biogas generation has been left out of the analysis to present a more conservative analysis.

The expected short and long term funds from each biodigester project are described on table 6.5:

Table 6.5 Financing opportunities at the Jiudai Yakou village

Technology	Annual O & M costs	Long term funding $ CAD/year	Short term funding
FDB	$600 - $1,500	• EVHS selling of goods that the villagers make [1]=$1,095CAD • Biogas income[2] = $1,434.45 CAD • Latrines use[3] = $90 CAD **Total = $2,619.45**	EVHS fundraiser = 1,000 Fig Tree Foundation = 5,000
FLDB	$750 - $1,800		
Latrine system (6 latrines and 4 urinals)	$300 - $600		
TPB	$105 - $150	EVHS selling of goods that a family makes = $73 CAD Biogas income = 2m3* $0.25 CAD*365 days = $91.25 **Total = $164.25 CAD**	

[1]Assuming that 30 percent of the villagers' annual income comes from crafts that they make, this income is = $ 0.2 CAD/ day / household * 365 days =73 *15 household = $1,095 CAD year/ village.

[2] Potential for biogas generation at the village = 15.73 m^3 * $ 0.25 CAD/ m^3 = $3.93 CAD/day * 365 = $1,434.45 CAD.

[3] Assuming that each household will be charged $0.5/ month for the use of the toilets, therefore, annual income = $90 CAD / year/ village.

As clearly presented in table 6.5, the proceeds from selling of goods, biogas and latrine incomes will provide any of the technologies with about $2,619.45, enough funding to leverage maximum expenses of $2,400 for operation and maintenance costs.

The community savings will be more than future operation and maintenance costs. Furthermore GHG emission credits for each ton of carbon recycled can be invested in this community fund as well as royalties from better yield crops. Moreover, EVHS will train villagers as well as new volunteers with technical expertise to guarantee effective use of the biodigester.

Risks and mitigation strategies

According to the economic analysis presented here, the fixed dome biodigester has more socioeconomic and environmental advantages than the floating drum biodigester and the tubular polyethylene biodigester. Furthermore, it has the highest net present value and the shortest payback period when compared with the other two low cost biodigesters. Moreover, the fixed dome biodigester can be connected with the latrine system, providing the entire village with an effective waste management system and with a clean source of energy and a natural fertilizer. However, this technology, as any other, has some risks that should be considered before its implementation.

Table 6.6 provides a list of risks that the FDB technology could have for the Jiudai Yakou villagers. It also presents a list of mitigation measures that will be considered for the FDB's mitigation strategy.

Table 6.6 Fixed Dome Biodigester's risks and its mitigation measures

Risks	***Mitigation measures***	***Sources***
1. High costs: • High capital cost due to larger biodigester and infrastructure to capture biogas for energy use and for installing dry toilets.	• External funding to leverage capital costs. • Selling of goods, biogas and latrine incomes to leverage operational and maintenance costs	Casillas, 2011; Quazi & Islam, 2008; Rowse, 2011.

2. Construction impacts: • Long term impacts: permanent land occupancy and impacts on soil, air, water and flora and fauna. • Short term impacts: temporary land occupancy, water pollution during construction, noise and air pollution, sediment loading • Aesthetics: a biodigester is not usually aesthetically pleasing.	• Use as less land as possible • Reuse excavated material during the construction process or dispose properly. • Plant trees around the biodigester but far enough from biodigester chamber.	Yinan, 2005
3. Operational issues: • Daily feedstock collection • Biomass scarcity or fluctuations in the number of animals can damage the system and biogas production. • Scum formation • Anaerobic digestion's reactions are sensitive to temperature fluctuations and alkalinity • Anaerobic digestion takes more time to start up the process • Matchstick needed each time the stove is used • Gas bags need an important space in the kitchen • Low pressure for cooking • Lack of knowledge and skills.	• To facilitate daily feeding of waste, the biodigester has to be located close to the animals and ideally the cattle have to be in a cowshed to have them penned most of the time. • Diversify sources of feedstock • Mix manure with water from the villagers' cisterns. • Add sodium bicarbonate to keep optimum alkalinity • The biodigester should be built at least partially underground to keep an optimum temperature . • Since the Jiudai Yakou village has a small biodigester in place, it is recommended to use a sample from it to seed the new biodigester and accelerate the start up process. • To improve the operational use of stoves, it is recommended to see what the Global Alliance for Clean cook stoves could offer for the Chinese village. • The technology is well known by one household owner at the village, so he will be a key element to assist during the construction, operation and	Bennett, 2009; Buxton & Reed, 2010; Chanakya, 2005; Daisy & Kamaraj, 2010; Gautum, 2009; GNESD, 2002; Karki, 2005; Rowse, 2011; Sasse et al., 1991; UNF, 2013.

	maintenance of the biodigester. Furthermore, volunteers from the EVHS will be also willing to participate and to train the villagers.	
4. Emissions: • Hydrogen Sulphide emissions • Bad odour from H_2S (rotten egg)	• Use of a sulfur filter made of steel wool or iron shavings to remove H_2S.	Fox, 2011; Nelson, 2002; Rowse, 2011; Schwegler, 2007; Weiland, 2010.
5. Sanitation issues: • Pathogens in animal and human waste still detectable for more than eight weeks. • AD is more vulnerable to upsets from toxic compounds found in waste, and corrosive gases. • Increased amounts of mosquitoes because there is no more smoke inside the house • Slurry has to be stored before being used.	• A retention time longer than 70 days is recommended when using human and animal waste. Well-decomposed slurry should be dark brown in color with friable consistency. • Slurry can be dried before applied on land, which is easier to transport than in its liquid form. • Identify and control potentially contagious diseases. • Stop application of slurry if there is outbreak of animal disease. • Consider enough space to store slurry.	Barnett, 1978; Behrendt et al., 2006; Bensah & Brew-Hammond, 2010; Daisy & Kamaraj, 2010; Deublein & Steinhauser, 2008; Karki, 2006; Morris et al., 1980; Ogunmokun et al., 2006; Rowse, 2011; Satyanarayana et al., 2008; Yinan, 2005.
6. **Safety:** • Biogas leakage is odorless without H_2S and is extremely dangerous because, if not detected, it can cause asphyxiation at high concentrations. • Biogas concentration in the air between 6 – 12 percent can be explosive.	• During the construction phase, assure an effective enclosed biodigester to avoid leakage. • Biogas containers should be stored away from the biogas stove to reduce explosion hazards and also far away from flames, matches, lighters and cigarettes. • Warning signs placed around the plant are recommended to inform the villagers about the flammability of the biodigester.	Bensah & Brew-Hammond, 2010; Deublein, & Steinhauser, 2008; Fox, 2011; Hervie, 2008; Rowse, 2011; Schwegler, 2007; Shrestha,2010;

Once these risks are well understood and the mitigations measures are addressed, the biodigester final design as well as operation and maintenance plan can be developed. In order to construct the biogas plant according to Chinese standards, and with local material, the final phase should be developed in collaboration with a Chinese organization such as a rural energy company or a governmental research institute. Since China has a lot of experience on biogas technology and development of biodigesters, especially in rural areas, the following institutions are considered as potential expertise advisors:

Table 7.2 Directory of Chinese biogas' organizations

Organization name	***Contact information***
BioEnergy Engineering and Low Carbon Technology (BEELC)	Dr Renjie Dong rjdong@cau.edu.cn
International Renewable Resources Institute	Alexander Eaton alex@irrimexico.org
Xunda Science and Technology Group Co. Ltd.	Wen Feng 706531207@qq.com
China Association of Rural energy industry (CAREI)	Chen Xiaofu chwiaofu@126.com www.carei.org.cn
Global Environmental Institute	Chongying Chen cychen@geichina.org www.geichina.org
The Nature Conservancy China Program	TNC China Program china@tnc.org www.nature.org/china/ 77 Xichang Road Kunming, Yunnan Phone: 86871 418 2111

VII. Research summary and recommendations

Based on the literature reviewed and the analysis made in this study, the installation of a low cost biodigester at the Jiudao Yakou village has the potential to provide the villagers not only with a renewable source of energy that has multiple environmental and socio-economic benefits, but it will also provide them with an efficient sanitary system that is relatively affordable and easy to operate and maintain. Moreover, these benefits can be maximized through the installation of a FDB. In summary, implementation of a FDB at the Chinese village will bring the following benefits:

- Gender benefits. Because women and girls are usually responsible for cooking and cleaning activities, construction of a biodigester at the village could improve their quality of life. Therefore, the engagement of women in the biodigester project will facilitate the dissemination of the technology and will contribute with a proper operation of the biodigester.
- Time savings by using biogas for cooking instead of collecting fuel wood. It is estimated that a total of 2,600 hours will be saved per year at the village by avoiding the collection of fuel wood. If this time is spent on economic activities, a 150 percent increase on the villagers' annual income is expected.
- Health benefits. Although the analysis does not present a dollar value on health improvements, it is expected that using biogas for cooking will reduce the amount of toxic emissions as well as contributing to zero production of solid waste. Moreover, a biodigester offers an efficient waste management system which can also reduce the risk of water contamination.
- Reduction of GHG emissions. Implementation of a biodigester will lower GHG emissions by avoiding the production of CO_2 from burning fuel wood and the

production of CH_4 from the natural decomposition of organic matter, including agricultural residues, human and animal waste. Biogas could annually avoid 91.4 tonnes of CO_2 equivalent emissions which otherwise will be generated. Moreover, under CDM, royalties from carbon credits for fuel replacement represents an extra income for the village.

- Reduction in deforestation. Deforestation reduction is very important because the wood that is collected for fuel comes usually from full-grown trees which are regarded as better for burning. It is estimated that up to 224 matured trees could be saved annually by using biogas for cooking.
- Reduction of soil erosion generated by free grazing. Cattle and other herding animals will be located in a cowshed constructed besides the biodigester, in order to facilitate animal waste collection. This will potentially reduce overgrazing and soil erosion.
- Energy benefits. Establishment of a FDB at the Chinese village could meet 100 percent of the villagers energy needs for cooking or 57 percent of their total energy needs including cooking and lighting.
- Waste management. A biodigester provides a constant recycling of organic waste, the slurry that is generated through the process can be used as a fertilizer to improve crop yields. Some studies have reported an increase up to 300 percent on their wheat and vegetables crops. Furthermore, due to its nutritional value the slurry can be even used to feed cattle and poultry. If this slurry is used as a fertilizer or for animal's food substitution, the villagers could save more than 34 percent of their annual income.

- Short payback period. The payback of a FDB is between 4 and 10 months, with a lifespan of at least 20 years.
- High net present value. The FDB has the highest NPV when compared with a TPB or FLB. Considering the 20 years lifespan of a FDB, the NPV is between $94,400 to $106,828.
- Although the FDB has also the highest capital cost a short and long term financing plan has been developed to leverage total costs, including operation and maintenance costs.

After this feasibility study, the next stage of the project will be the technical design and the action planning for the biodigester's implementation at the village, preferentially in collaboration with Chinese technical experts in the field.

In order to successfully disseminate the technology at the village and offer a clear guide for operating and maintaining the system, it is necessary to develop a communitarian manual as well as a Health and Safety Plan. These sources of information will provide the villagers with the fundamental background for safe and hygienic waste use. At the same time, this knowledge will create job opportunities for local entrepreneurs who can help to disseminate and train others on how to create a self-sustaining biodigester's system. If successful, this project will be replicated at other villages throughout China as an effective approach for sustainable energy development.

References

Abanyie, S. A. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Applicability of passive and low energy cooling techniques in Ghana (pg.98). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Addison, K. Biogas from m3 to L. http://journeytoforever.org/biofuel_biogas.html

Alvarez, R., & Lide, G. (2008). The effect of temperature variation on biomethanation at high altitude. Bioresource Technology 99, 7278–7284.

Amrago, D., Hassan, A., Commeh, M. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Efficient cook stoves – R & D to date (pg.132). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Angelidaki, & Ellegaard, L. (2003). Codigestion of Manure and Organic Wastes in Centralized Biogas Plants. 103, 95-105.

Bain, B. (2012). Fertilizer trends. Retrieved March 3rd, 2013 from Nomura Global Chemistry Leaders Conference: https://www.nomura.com/events/global-chemical-conference/resources/upload/fertecon-barrie-bain-presentation.pdf

Barnett, A., Pyle, L., & Subramanian, S. K. (1978). Biogas Technology in the Third World, A Multidisciplinary Review. International Development Research Centre, Ottawa.

Beijing Antaike Information Development Co., Ltd. The leading China metals provider: Yunnan releases new electricity prices. http://www.antaike.com/content.php?id=55002

Bensah, E. C. & Brew-Hammond, A. (2010). Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. International journal of Energy and Environment 1(2), 277-294.

Behrendt, J., Deegener, St., Meinzinger, F., Gajurel, D.R., Shalabi, M., Wendland, C., Otterphl, R. (2006). Appropriate De-central Wastewater Technologies for Low Income Regions. Retrieved October 15, 2012 from Institute of Wastewater Management and Water Protection: http://www2.gtz.de/Dokumente/oe44/ecosan/en-appropriate-de-central-wastewater-technologies-for-low-income-regions-2006.pdf.

Bhattacharyya, S. C. (2012). Review of alternative methodologies for analyzing off-grid electricity supply. Renewable and Sustainable Energy Reviews 16, 677– 694.

Bolzonella, D., Pavan, P., Mace, S. & Cecchi, F. (2006). Dry anaerobic digestion of differently sorted organic municipal solid waste: a full-scale experience. 53(8) 23-32.

Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. Energy for Sustainable Development 15, 347–354.

Butare, A. & Kimaro, A. (2002). Anaerobic technology for toilet wastes management: the case study of the Cyangugu pilot project. World Transactions on Engineering and Technology Education 1(1), 147 – 152.

Buxton, D. & Reed, B. (2010). Disposal of latrine waste: Is biogas the answer? A review of literature. EWB-UK National Research Conference. Loughborough University, Leicestershire, UK.

Casillas, C. E., & Kammen, D. M. (2011). The delivery of low-cost, low-carbon rural energy services. Energy Policy39, 4520–4528.

Chanakya, H. N., Bhogle, S., & Arun, R. S. (2005). Field experience with leaf litter-based biogas plants. Energy for Sustainable Development 9(2), 49 – 62.

Chen, H. C. (2004). Reuse of activated sludge biomass: equilibrium studies for the absorption of basic dyes on biomass. Textile Research Journal ,

Chen Y, Yang G, Sweeney S, Feng Y. (2010). Household biogas use in rural China: a study of opportunities and constraints. Renewable and Sustainable Energy Reviews;14 (1):545–9.

Dairy Farmers Cooperative: http://www.adelaide.edu.au/biogas/anaerobic_digestion/casestudy.pdf

Dairy Australia. (2004). Eco-effi ciency for Australian dairy processors. Fact-Sheet 5: Biogas. Retrieved March 3rd, 2013 from Dairy Australia: http://dmsc.com.au/wp-content/uploads/2011/03/Ecofact05.pdf.

Daisy, A. & Kamaraj, S. (2010). The Impact and Treatment of Night Soil in Anaerobic Digester: A Review. Retrieved January 1st, 2013 from: http://www.omicsonline.org/1948-5948/JMBT-03-043.php?%20aid=1171

Dennis, A. & Burke, P.E. (2001). Dairy Waste Anaerobic Digestion Handbook. Environmental Energy Company. Retrieved January 1st, 2013 from: www.makingenergy.com.

Deublein, D. & Steinhauser, A. (2008). Biogas from waste & renewable resources. Germany: Wiley-vch Verlag GmbH & Co. KGaA.

Devakumar, C., Dev, S., Dev, U., (2011). Indicators for inclusive growth in India. The Journal of Social Environmental Research Organisation 2(1), 21 - 25.

Ding, W., Wu, Y., Wang, X., Gao, Y. (2010).Family-size Biogas Plant Using Manure and Urine Mixture at Ambient Temperature in Semi-arid Regions of Northwestern China. World Academy of Science, Engineering and Technology 41.

Drewko, A. (2007). Resource-Oriented Public Toilets in Developing Countries: Ideas, Design, Operation and Maintenance for Arba Minch, Ethiopia. A Master Thesis presented to the Hamburg University of Technology, 33176.

Eaton, A. B. (2009). The role of small-scale biodigesters in the energy, health, and climate change baseline in Mexico. A Master Thesis presented to the Faculty of Environmental Resource Engineering, Humboldt State University. Approved by the Master's Thesis Committee.

Eco Village of Hope Society (EVHS). 2012. Retrieved July 14, 2012 from EVHS: http://www.ecovillageofhope.org/project1.html.

Edward, G. (2002). Ecological sanitation practice and technology development in southern Africa and Zimbabwean case study. Retrieved August 10, 2012 from: EcoSanRes, http://www.ecosanres.org/pdf_files/Nanning_PDFs/Eng/Guzha%2023_E34.pdf

Ehrenfeld, J. R. (2008). Sustainability by design. Chapter 8, Culture change: Locating the levers of transformation (pp. 78 -98). Langley, WS: Many Rivers Press.

Energy Information Administration. (2012). Retrieved from: http://www.eia.gov/countries/analysisbriefs/China/china.pdf

EPA (2010). Methane and Nitrous Oxide Emissions from Natural Sources. U.S. Environmental Protection Agency, Washington, DC, USA.

Ferrera, I., Ponsá, S., Vázquez, F., & Font, X. (2008). Increasing biogas production by thermal (70 ◦C) sludge pre-treatment prior to thermophilic anaerobic digestion. Biochemical Engineering Journal 42, 186–192.

Food and Agriculture Organization of the United Nations (FAO). (1996). Biogas technology: A training manual for extension. Retrieved February 18, 2012 from Consolidated Management Services Nepal: http://www.sswm.info/sites/default/files/reference_attachments/FAO%201996%20Biogas%20Technology%20A%20Training%20Manual%20for%20Extension.pdf

Friends of the Earth. (2007). Briefing Anaerobic Digestion. Retrieved August, 2012 from: http://www.foe.co.uk/resource/briefings/anaerobic_digestion.pdf.

Fox, A. (2011). Student's biodigesters close the loop. BioCycle. Guatemala, 48-50.

Garfía,M., Ferrer-Martíb, L., Velob, E., & Ferrer, I. (2012). Evaluating benefits of low-cost household digesters for rural Andean communities. Renewable and Sustainable Energy Reviews 16, 575– 581.

Gautum, R., Baral, S. & Heart, S. (2009). Biogas as a sustainable energy source in Nepal: Present status and future challenges. Renewable and Sustainable Energy Reviews 13, 248–252.

Geeta, G. S., Raghavendra, S., & Reddy, T. K. (1986). Increase in Biogas Production from Bovine Excreta by addition of Various Inert Materials. Agricultural Wastes 17, 153-156.

Goethert, R., Donovan, W., Kariuki , M., Taylor, P. Davis, J., Mwanza, D. & Doyen, J. (2003).Household latrine with Pit or Septic Tank Disposal. Retrieved February 19, 2013 from The Water Utility Partnership: http://web.mit.edu/urbanupgrading/waterandsanitation/levels/provide-san-serv.html

Global Network on Energy for Sustainable Development (GNESD). (2002). Poverty reduction: Can renewable energy make a real contribution? Retrieved August, 2012 from: http://www.gnesd.org/downloadables/povertyreductionspm.pdf.

Gresens, F., & Ute, A. (2009). Closing nutrient cycles in decentralized water treatment systems in the Mekong Delta. SANSED-Project final report. German Federal Ministry of Education and Research (BMBF) & Vietnamese Ministry of Science and Technology (MUST), Reference Number: 02-WD-0620 to 02-WD-0629.

Harris, P. (2012). Beginners Guide to Biogas. Retrieved June 23, 2012, University of Adelaide, Australia: http://www.adelaide.edu.au/biogas/.

Herrero, J. M. (1990). Low cost biodigesters to produce biogas and natural fertilizer from organic waste. Innovation for Development and South-South Cooperation, 2-11.

Hervie, E. M. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Application of biogas in educational institutions for the production of cooking gas – case study at valley View University (pp. 117 - 131). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Hilkiah Igoni, A., Ayotamuno, M. J., Eze, C. L., Ogaji, S. O., & Probert, S. D. (2007). Designs of anaerobic digesters for producing biogas from municipal solid-waste. Applied Energy , 430-438.

Hopkins, J. R., Lewis, A. C., & Seakins, P. W. (2005). Analysis and applications of measurements of source dominated hydrocarbon concentrations from the PUMA campaigns in June/July 1999 and January/February 2000 at an urban background site in Birmingham, UK. Atmospheric Environment 39, 535–548.

Institute of Biogas Research of Ministry of Agriculture (IBR, MOA). (2012). Retrieved February 2nd, 2013 from Chinese Academy of Agricultural Sciences: http://english.caas.net.cn/Administration/research_institutes/56985.shtml.

Intergovernmental Panel on Climate Change (IPCC). (2011). Bioenergy. Retrieved February 4th, 2013 from IPCC: http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch02.pdf

Kalia, A. K. & Kanwar, S. S. (1990). Anaerobic Fermentation of Ageratum for Biogas Production. Biological wastes 32,155-158.

Kalia, A. K. & Singh, S. P. (1997). Horse dung as a partial substitute for cattle dung for operating family-size hilly region. Bioresource Technology 64, 63-66.

Karki, A. B. (2006). Biogas as a renewable energy from organic waste. Retrieved January 2nd , 2013 from Encyclopedia of Life Support Systems: http://www.eolss.net/sample-chapters/c17/E6-58-09-10.pdf

Karki, A. B., & Murari, K. G. (1994). Biogas refresher training for masons: a guide for trainer. Biogas support program. Netherlands Development Organization -SNV – Nepal.

Karki, A. B., Shrestha, J. N., & Bajgain, S. (2005). Biogas as renewable source of energy in Nepal, theory and development. BSP-Nepal.

Karki, A. B. (2006). Country Report on the Use of Bio-slurry in Nepal. Retrieved January 2nd, 2013 from Organic Recycling and Biogas Expert http://m.snvworld.org/sites/www.snvworld.org/files/publications/nepal_bio-slurry_use_report_2006.pdf.

Kofinas, G. P. & Chapin, F. S. (2009). Sustaining livelihoods and human well-being during social-ecological change. In F. S. Chapin, G. P. Kofinas, and C. Folke (Eds.). Principles of ecosystem stewardship (pp. 55 -75). Sweden: Springer.

Kossmann, W., & Pönitz, U. (1998). Biogas Digest. (Vol 4). Information and Advisory Service on Appropriate Technology– Country Reports. 13-16.

Krishna, N., Sumithra S. D., Viswanath, P., Deepak, S. & Sarada, R. (1991). Anaerobic Digestion of Canteen Wastes for Biogas: Production: Process optimisation. Process Biochemistry 26, l-5.

Kurvey, S. (2011). Eco-tech village. The Journal of Social Environmental Research Organisation 2(1), 5-10.

Kuteesakwe, J. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Viable strategy for scaling up the dissemination of improved stoves among the poor in Africa (pp. 58 - 62). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst

Lansing, S., Martin, J. F., Botero, Botero. R., Nogueira da Silva, T., & Dias da Silva, E. (2010). Methane production in low-cost, unheated, plug-flow digesters treating swine manure and used cooking grease. Bioresource Technology 101, 4362–4370.

Lauridsen, M. I. (1998). Evaluation of the impact on women's lives of the introduction of low cost polyethylene biodigesters on farms in villages around Ho Chi Minh City, Vietnam. Retrieved January 1st, 2013 from Livestock Research for rural development: C:\Users\HP\Documents\2013\Village of Hope\Articles\2.- Evaluation of the impact on women's lives of the introduction of low cost polyethylene biodigesters on farms in villages around Ho Chi Minh City, Vietnam.mht.

Liang, L. (2011). Biodiversity in China's Yunnan province. Retrieved June 23, 2012 from United Nations University: http://unu.edu/publications/articles/biodiversity-in-chinas-yunnan-province.html.

Mata-Alvarez, J., Mace, S., & Llabres, P. (2000). Anaerobic digestion of organic solid wastes, an overview of research achievements and perspectives. Bioresource Technology 74, 3-16.

Magessa, F. B. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Promotion and Dissemination of renewable energy technology in Tanzania (pg. 41). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Matthew, T., Agler, Aydinkaya, Z., Cummings, T. A., Beers, A. R., & Largus T. A. (2010). Anaerobic digestion of brewery primary sludge to enhance bioenergy. Bioresource Technology 101, 5842–5851.

Mbony, W. K. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), The role of renewable energy in the energy security of Cameron: A case study of Yaondo (pg. 77). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Mensah, P. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed),A study in the various solid waste management options in the Atwima Nwabiagya District (pp.133 - 134). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Mfundisi, B. K. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Constrainsts and opportunities for bioenergy production in Southern Africa (pp. 135 - 145). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Groenendaal, V., & Gehua W. (2010). Microanalysis of the benefits of China's family size bio-digesters. Energy 35, 1-10.

McConville, J.R. (2006). Applying Life Cycle Thinking to International Water and Sanitation Development Projects: An Assessment Tool for Project Managers in Sustainable Development Work. Retrieved January 15, 2013 from Masters report, Michigan Technological University, LD3300.R2006 M17: https://wiki.umn.edu/pub/EWB/UgandaCapstone/McConville_Final_Report.pdf

Mohapatra, S. P. (2011). Sustainable Sanitation for all. The Journal of Social Environmental Research Organisation 2(1), 15-20.

Morris, J. W. & Clarkson, W. W. (1980). Agricultural wastes. Journal Water Pollution Control Federation 52:6, 1342-1383.

Mulugetta, Y. (2007). Human capacity and institutional development towards a sustainable energy future in Ethiopia. Renewable and Sustainable Energy Reviews 12, 1435–1450.

Murray, A., Cofie, O., & Drechsel, P. (2011). Efficiency indicators for waste-based business models: fostering private sector participation in wastewater and faecal-sludge management. Retrieved November 2nd, 2012 from Water International: http://www.tandfonline.com.ezproxy.lib.ucalgary.ca/doi/pdf/10.1080/02508060.2011.594983.

Nelson, C. (2002). Final Report: Haubenschild Farms Anaerobic Digester Updated! The Minnesota project. www.mnproject.org.

Ngongang, A. H. T. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Production of biofuel from Jatropha Curcas: A promise for improving the socioeconomic conditions of rural population in Agrica. (pg.63). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Obeng, G. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Solar PV rural electrification: assessing the impacts on off-grid rural enterprises in Ghana (pp. 90 - 108). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Ocwieja, S. M. (2010). Life Cycle Thinking Assessment Applied to Three Biogas Projects in Central Uganda. Master of Science in environmental engineering, Michigan Technological University.

Ogunmokun, A. A., Mwandemele & Dima, S. J. (2000). Retrieved November 12, 2012 from Faculty of Agriculture and Natural Resources, University of Namibia: http://www.bscw.ihe.nl/pub/bscw.cgi/d2607905/OGUNMOKU.PDF.

Okereke, R. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Challenges and prospects of market expansion for renewable energy technology in Tanzania (pp. 80 - 87). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst.

Okunskaya, T. (2011). Human Development in Central Asia. The Journal of Social Environmental Research Organisation 2(1), 11-14.

Pereira, T. (2009). Sustainability: An integral engineering design approach. Renewable and Sustainable Energy Reviews 13, 1133–1137.

Pulamte, L. & Abrol, D. (2003). Technology transfer for rural development: Managing R and D at CSIR. Economic and Political Weekly, 38(31):3315 – 3318.

Qiubei Xian, Yunnan province http://www.chinci.com/travel/pax/q/1797478/Qiubei+Xian/CN/China/0/#

Quazi, A. R. and Islam, R. (2008). Beyond Construction. A collection of case studies from sanitation and hygiene promotion practitioners in South Asia. James Wicken, Joep Verhagen, Christine Sijbesma, Carmen Da Silva, Peter Ryan (Eds), The reuse of human excreta in Bangladesh (pp.). IRC International Water and Sanitation Centre and WaterAid.

Richard, T. & Trautmann, N. (2005). C/N ratios. Retrieved February 10, 2013 from Cornell Waste Management Institute: http://compost.css.cornell.edu/calc/cn_ratio.html

Riggle, D. (1996). Technology improves for composting toilets. BioCycle 37(4), 39-43.

Rittmann, B. E., & McCarty, P. L. (2001). Environmental biotechnology: Principles and applications (International ed.). Singapore: McGraw Hill.

Rowse, L. E. (2011). Design of small scale anaerobic digestion for application in rural developing countries. Graduate School Theses and Dissertations of the University of South Florida Graduate School at Scholar Commons, 3324.

Satyanarayana, S., Murkutea, P., & Ramakant. (2008). Biogas production enhancement by Brassica compestries. Biomass and bioenergy 32, 210 – 215.

Satyanarayan, S., Ramakant, & Shivayogi. (2010). Biogas production enhancement by soya sludge amendment in cattle dung digesters. Biomass and bioenergy 34, 1278-1282.

Sasse, L., Kellner, C., & Kimaro, A. (1991). Improved biogas unit for developing countries. A Publication of the Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Sawal1, P., Hung Huong, T., Sigvardt, M. (2008). Solution for wastewater treatment in rural school in Sarawak, Malaysia: A modified flush toilets with rural biogas system. Natural Resources and Environment Board, Malaysia & DANIDA-NREB Rural Ecosan Project, Malaysia.

Schlaepfer, A. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), Climate change- impact on developing countries and possible coping strategies (pp. 35-39). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM): Deutscher Akademischer Austauschdienst.

Schafer, W., Letho, M., & Teye, F. (2006). Dry Anaerobic Digestion of organic residues on-farm- a feasibility study. MTT Agrifood Research Finland.

Takada, M. & Ndika, A. C. (2006). Energizing Poverty Reduction a Review of the Energy-Poverty Nexus in Poverty Reduction Strategy Papers. United Nations Development Programme.

Schwegler, M. (2007). Promoting investments for renewable technology and biogas through carbon financing in China. Retrieved January 14, 2013 from Biogas Markets Asia. Singapore: http://www.frankhaugwitz.info/doks/bio/2007_06_14_China_Biogas_CDM_MarkusSchwegler.pdf.

Shrestha, A. (2010). Prospects of biogas in terms of socio-economic and environmental benefits to rural community of Nepal: a case of biogas project in Gaikhur VDC of Gorkha district. Dissertation Submitted to College of Applied Sciences-Nepal (CAS) Kathmandu, Nepal. In the Partial Fulfillment of the

Requirements for the Degree of Masters of Science (M.Sc.) In Environment Science Tribhuvan University, 521.

Singh, S., Kumar, S., Jain, M.C., & Kumar, D. (2001). Increased biogas production using microbial stimulants. Bioresource Technology 78, 313 – 316.
Still, D. A. (2002). After the pit latrine is full…What then? Effective options for pit latrine management. Retrieved August 10, 2012 from: Water Research Commission (WRC), www.wrc.org.za.

Smith KR. (2010). What's cooking? A brief update. Energy for Sustainable Development;14(4):251–2.

Smith KR. (2006). Health Impacts of fuel wood use in developing countries. Unasylva 224, Vol. 57. Retrieved March 12, 2013 from FAO; Forest and Human health: http://www.fao.org/docrep/009/a0789e/a0789e09.htm

Sørensen, P. & Thomsen, I. K. (2005). Separation of Pig Slurry and Plant Utilization and Loss of Nitrogen-15-labeled Slurry Nitrogen. Soil Science Society of America 69, 1644–1651.

Srinivasan, S. (2008). Positive externalities of domestic biogas initiatives: Implications for financing. Renewable and Sustainable Energy Reviews 12, 1476–1484.

Sushil, K., Jain, M. C. & Chhonkar, P. K. (1986). A Note on Stimulation of Biogas Production from Cattle. Biological Wastes 20, 1209-215.

Switzenbaum, M.S. (1995). Obstacles in the implementation of anaerobic treatment technology. Bioresource Technology 53, 255-262.
Themelis, N. J. (2003). An overview of the global waste-to-energy industry. Earthscan, 1-9.

Takada, M. & Charles, N. A. (2006). Energizing poverty reduction: A review of the energy poverty nexus in poverty reduction strategy papers. New York, NY: United Nations Development Programme.

Tatlidil, F. ., Bayramoglu, Z., & Akturk, D. (2009).

Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). Wastewater engineering: Treatment and reuse. New York, NY: McGraw Hill.

The American Poultry Association. (1997). Poultry Body Weights. Retrieved January 5, 2013 from Poultry Pedia: https://sites.google.com/a/poultrypedia.com/poultrypedia/poultry-body-weights.

The China Ministry of Energy (MOE). (2012). 2011 Policy Measures to Support Increase in Grain Output and Farmers' Income. Retrieved February 2nd, 2013, from the Ministry of Agriculture, the people's Republic of China: http://english.agri.gov.cn/ga/Policies/Policy/201204/t20120427_4312.htm

Thompson, S.,Sawyer, J., Bonam, R., & Valdivia, J.E. (2009). Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills. Waste Management 29, 2085–2091.

United Nations Department of Public Information. (2005). The Millennium Development Goals Report 2005. Retrieved January 1st, 2013 from: http://unstats.un.org/unsd/mi/pdf/mdg%20book.pdf.

United Nations Framework Convention on Climate Change (UNFCCC). (2009). Clean Development Mechanism. Retrieved January 10, 2013 from: http://cdm.unfccc.int/index.html.

UNDP (2010) Human Development Report 2010. 20th Anniversary Edition. United Nations Development Programme, New York. Available at http://hdr.undp.org/en/media/HDR_2010_EN_Complete_reprint.pdf.

UNESCO (2006) Capacity building for ecological sanitation. The International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organisation, Paris, France and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany. Available at http://unesdoc.unesco.org/images/0014/001463/146337e.pdf

UNF. (2013). Global Alliance for Clean Cook stoves. Retrieved March 23, 2013 from United Nations Foundations; http://community.cleancookstoves.org/home

U.S. Department of Energy. (2009). Community greening: How to develop a strategic energy plan. National Renewable Energy Laboratory (NREL).

Van Buren, A., McMichael, J., Cáceres, R., & Cáceres, A. (1984). Composting Latrines in Guatemala. Ambio, 13:4, 274-277.

Vinoth, K., & Kasturi Bai, R. (2008). Solar greenhouse assisted biogas plant in hilly region – A field study. Solar Energy 82, 911–917.

Viquez, A. J. (2009). Case Study: Technical and economic feasibility of electricity generation with biogas in Costa Rica. Retrieved August 12, 2012 from Dos Pinos
Vinoth, K. K. & Kasturi Bai, R. (2005). Plastic biodigesters – a systematic study. Energy for Sustainable Development 9(4), 40-49.

Walekhwa, P.N., Mugisha J., & L. Drake. (2009). Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. Energy Policy 37, 2754-

2762. (112) http://caes.mak.ac.ug/research/research-publications/128-publications-for-2009/688-biogas-energy-from-family-sized-digesters-in-uganda-critical-factors-and-policy-implications.html.

Weiland, P. (2010). Biogas production: current state and perspectives. Appl Microbiol Biotechnol 85, 849–860.

Weinberg, P. J. (2002). Capra cylindricornis. Mammalian species, 695, 1-9.

Werner, C., Bracken, P., Mang, H.P., & Klingel, F. (2004). Ecological sanitation – principles and technologies. Key-activities, services and current pilot projects of the international ecosan programme of GTZ., Proceedings of the 2nd International Symposium on ecological sanitation"ecosan - closing the loop", incorporating the 1st IWA specialist group conference on Sustainable Sanitation, Luebeck, Germany.

Widodo, T. W., Asari, A., N. A., & R.E. (2009). Design and development of biogas reactor for farmer group scale. Indonesidan Journal of Agriculture, 2(2): 121 -128.

World Business Council for Sustainable Development (WBCSD). (2004). Facts and trends to 2050. Energy and climate change.

World Health Organization (WHO). (2009). The energy access situation in developing countries. Retrieved January 26, 2013 from: United Nations Development Programme
(UNDP): http://www.who.int/indoorair/publications/energyaccesssituation/en/

World weather online. (2012). http://www.worldweatheronline.com/Qiubei-weather-averages/Yunnan/CN.aspx.

WWF. (2012). The Ecological Footprint Atlas. Retrieved January 9, 2013 from China Ecological Footprint, 2012: http://www.footprintnetwork.org/images/article_uploads/China_Ecological_Footprint_2012.pdf.

Xavier, S. & Nand, K. (1990). A Preliminary Study on Biogas production from cow dung using Fixed-Bed Digesters. Biological Wastes 34, 161-165.

Yinan, Z. (2005). Livestock waste management in East Asia. Environmental Impact Assessment, Guangdong. Project Preparation under the PDF-B Grant. Department of Environmental Science, Zhongshan University.

Ying, L., Daming, H., Buchanan, S., & Jiang, L. (2009). Ecological Footprint Dynamics of Yunnan, China J. Mt. Sci. 6, 286–292.

Yu, H. W., Samani, Z., Hanson, A., Smith, G. (2002). Energy recovery from grass using two-phase anaerobic digestion.Waste management 22, 1-5.

Zelelke, A. (2008). Application of Renewable Energy in Fuelling Sustainable Development in Africa. Evans Mensah Hervie (Ed), A new approach for wider dissemination of biogas in Ethiopia (pg. 42). University of Flensburg, Germany, Sustainable Energy Systems and Management (SESAM):Deutscher Akademischer Austauschdienst

Zeng X, Ma Y, Ma L. (2007). Utilization of straw in biomass energy in China. Renewable and Sustainable Energy Reviews; 11:976–87.

Appendix A – Photos from the Jiudai Yakou village

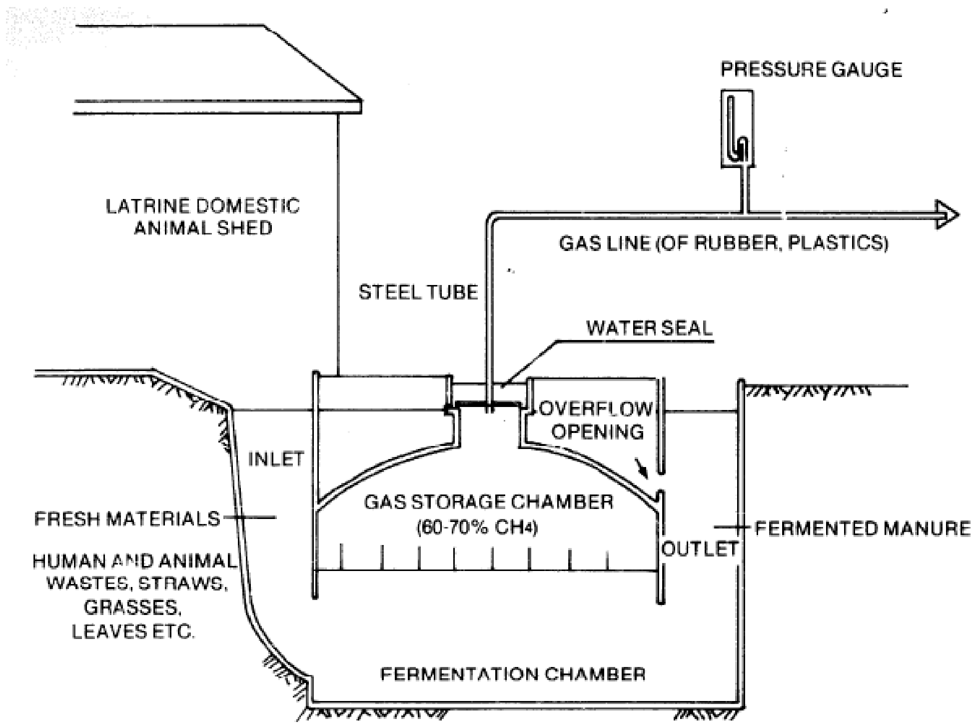
Current latrine at the Chinese village ***Current pigsties conditions***

Jiudai Yakou village's electricity transmission lines

Jiudai Yakou village's corn crops

The sewing group at the Jiudai Yakou village

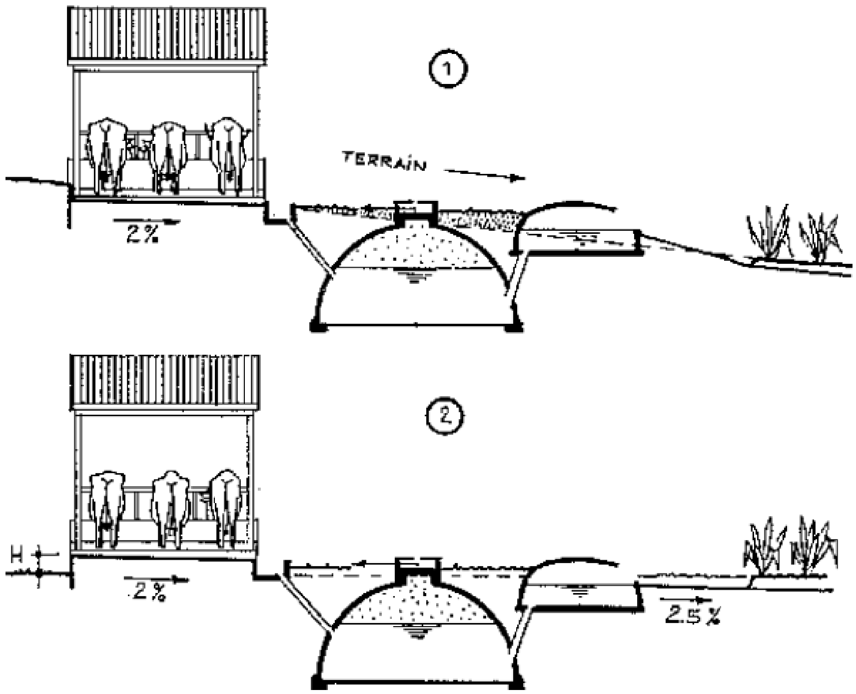
Appendix B – Fixed Dome Biodigester's designs and specifications



Chinese Fixed Dome Biodigester (Barnett, 1978)

	Digester		Expansion	chamber
R m	avg. VD m³	max VG m³	r m	VG m³
1,50	5,10	2,50	0,90	1,05
1,80	5,30	3,00	1,00	1,31
1,70	8,00	3,00	1,10	1,61
1,80	10,00	3,50	1,20	1,93
1,90	12,00	3,50	1,30	2,29
2.00	14.00	4,00	1,40	2.66
2.10	17,00	4,00	1,50	3,07
2,20	19,00	4,50	(1.60)	(3.51)
2.30	22.00	4,50	(1.70)	(3.97)
2,40	25,00	5,00	(1.80)	(4.46)
2.50	29,00	5,00	(1.90)	(4.98)
2,60	32,00	5,50	(2.00)	(5.53)
2,70	37,00	6,00		
2.80	41,00	6,00	For VD >3.00 m³ it is advisable to construct several chambers or expansion channels instead of spherical chambors	
2,90	46,00	6,00		
3,00	51,50	6,50		
3,10	57,00	7,00		
3,20	63,00	7,00		
3,30	69,00	7,50		
3,40	76,00	7,50		
3,50	83,00	8,00		

Dimensions of Fixed Dome Biodigesters (Sasse et al., 1991)



Position of biodigester to stable floor

1) Horizontal ground, 2) Lift the floor of the stable

(Sasse et al., 1991)

Appendix C - Net Present Value calculations

FIXED DOME BIODIGESTER (FDB) (Minimum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash inflow and outflow	6%
0				1400		(1400)	
1	5491.9	3172.86	1371		600	9435.76	8,901.7
2	5491.9	3172.86	1371		600	9435.76	8,397.8
3	5491.9	3172.86	1371		600	9435.76	7,922.5
4	5491.9	3172.86	1371		600	9435.76	7,474.01
5	5491.9	3172.86	1371		600	9435.76	7,051
6	5491.9	3172.86	1371		600	9435.76	6,651.8
7	5491.9	3172.86	1371		600	9435.76	6,275.3
8	5491.9	3172.86	1371		600	9435.76	5,920
9	5491.9	3172.86	1371		600	9435.76	5,585
10	5491.9	3172.86	1371		600	9435.76	5,268.9
11	5491.9	3172.86	1371		600	9435.76	4,970.6
12	5491.9	3172.86	1371		600	9,435.76	4689.3
13	5491.9	3172.86	1371		600	9,435.76	4,423.9
14	5491.9	3172.86	1371		600	9,435.76	4,173.5
15	5491.9	3172.86	1371		600	9,435.76	3,937.2
16	5491.9	3172.86	1371		600	9,435.76	3,714.4
17	5491.9	3172.86	1371		600	9,435.76	3,504
18	5491.9	3172.86	1371		600	9,435.76	3,305.8
19	5491.9	3172.86	1371		600	9,435.76	3,118.6
20	5491.9	3172.86	1371		600	9,435.76	2,942.1
							108,227.4
							106,827.4

Since the FDB has a useful life of ten years, the NPV is calculated as follow: $9,435.76 x 7.360 (factor for an annuity of 6% for 10 years) - $1400 = $68,048 and the NPV for six years is as follow: $9,435 x 4.917 (-1400) = $44995.63.

FIXED DOME BIODIGESTER (FDB) (Maximum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash inflow or outflow	6%
0				(3500)		(3500)	
1	5491.9	3172.86			1500	8535.8	8,052.6
2	5491.9	3172.86			1500	8535.8	7,596.8
3	5491.9	3172.86			1500	8535.8	7,166.8
4	5491.9	3172.86			1500	8535.8	6,761.1
5	5491.9	3172.86			1500	8535.8	6,378.4
6	5491.9	3172.86			1500	8535.8	6,017.4
7	5491.9	3172.86			1500	8535.8	5,676.8
8	5491.9	3172.86			1500	8535.8	5,355.4
9	5491.9	3172.86			1500	8535.8	5,052.3
10	5491.9	3172.86			1500	8535.8	4,766.3
11	5491.9	3172.86			1500	8535.8	4,496.5
12	5491.9	3172.86			1500	8535.8	4,242
13	5491.9	3172.86			1500	8535.8	4,001.9
14	5491.9	3172.86			1500	8535.8	3,775.4
15	5491.9	3172.86			1500	8535.8	3,561.7
16	5491.9	3172.86			1500	8535.8	3,360
17	5491.9	3172.86			1500	8535.8	3,169.9
18	5491.9	3172.86			1500	8535.8	2,990.5
19	5491.9	3172.86	1371		1500	8535.8	2,821.2
20	5491.9	3172.86	1371		1500	8535.8	2,661.5
							97,904.5
							94,404.5

Since the FDB has a useful life of ten years, the NPV is calculated as follow: $8,535.8 x 7.360 (factor for an annuity of 6% for 10 years) - $3500 = $59,323.49 and the NPV for six years is as follow: $8,535.8 x 4.917 (-3,500) = $38,470.529.

FLOATING DRUM BIODIGESTER (FLDB) (Minimum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash flow	6%
0				1750		(1750)	8,760.2
1	5491.9	3172.86	1371		750	9285.76	8,264.3
2	5491.9	3172.86	1371		750	9285.76	7,796.5
3	5491.9	3172.86	1371		750	9285.76	7,355.2
4	5491.9	3172.86	1371		750	9285.76	6,938.9
5	5491.9	3172.86	1371		750	9285.76	6,546.1
6	5491.9	3172.86	1371		750	9285.76	6,175.6
7	5491.9	3172.86	1371		750	9285.76	5,826
8	5491.9	3172.86	1371		750	9285.76	5,496.3
9	5491.9	3172.86	1371		750	9285.76	5,185.2
10	5491.9	3172.86	1371		750	9285.76	4,891.6
11	5491.9	3172.86	1371		750	9285.76	4,614.7
12	5491.9	3172.86	1371		750	9285.76	4,353.5
13	5491.9	3172.86	1371		750	9285.76	4,107.1
14	5491.9	3172.86	1371		750	9285.76	3,874.6
15	5491.9	3172.86	1371		750	9285.76	90,185.6
							88,435.6

Since the FLDB has a useful life of ten years, the NPV is calculated as follow: $9,285.76 x 7.360 (factor for an annuity of 6% for 10 years) - $1,750 = $ 66,594 and the NPV for six years is as follow: $9,285.76 x 4.917 (-1,750) = $ 43,911.094.

FLOATING DRUM BIODIGESTER (FLDB) (Maximum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash flow	NPV
0				4200		4200	6%
1	5491.9	3172.86	1371		1800	8235.76	7,769.6
2	5491.9	3172.86	1371		1800	8235.76	7,329.8
3	5491.9	3172.86	1371		1800	8235.76	6,914.9
4	5491.9	3172.86	1371		1800	8235.76	6,523.5
5	5491.9	3172.86	1371		1800	8235.76	6,154.2
6	5491.9	3172.86	1371		1800	8235.76	5,805.9
7	5491.9	3172.86	1371		1800	8235.76	5,477.3
8	5491.9	3172.86	1371		1800	8235.76	5,167.2
9	5491.9	3172.86	1371		1800	8235.76	4,874.7
10	5491.9	3172.86	1371		1800	8235.76	4,598.8
11	5491.9	3172.86	1371		1800	8235.76	4,338.5
12	5491.9	3172.86	1371		1800	8235.76	4,092.9
13	5491.9	3172.86	1371		1800	8235.76	3,861.3
14	5491.9	3172.86	1371		1800	8235.76	3,642.7
15	5491.9	3172.86	1371		1800	8235.76	3,436.5
							79,987.8
							75,787.8

Since the FLDB has a useful life of ten years, the NPV is calculated as follow: $8,235.76 x 7.360 (factor for an annuity of 6% for 10 years) - $4,200 = $ 56415.91 and the NPV for six years is as follow: $8,235.76 x 4.917 (-4,200) = $ 36,297.9

.

TUBULAR POLYETHYLENE BIODIGESTER (TPB) (Minimum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash flow	NPV
0				245		245	6%
1	366.127	211.524	91.4		105	564.051	532.1
2	366.127	211.524	91.4		105	564.051	502
3	366.127	211.524	91.4		105	564.051	473.6
4	366.127	211.524	91.4		105	564.051	446.8
5	366.127	211.524	91.4		105	564.051	421.5
6	366.127	211.524	91.4		105	564.051	3,97.6
							2,773.6

TUBULAR POLYETHYLENE BIODIGESTER (TPB) (Maximum capital cost)							
Year	Energy savings	Fertilizer	CO_2 Credit revenue	Capital cost	O&M costs	Net Cash flow	NPV
0				350		350	6%
1	366.127	211.524	91.4		150	519.051	489.7
2	366.127	211.524	91.4		150	519.051	461.9
3	366.127	211.524	91.4		150	519.051	435.8
4	366.127	211.524	91.4		150	519.051	411.1
5	366.127	211.524	91.4		150	519.051	387.9
6	366.127	211.524	91.4		150	519.051	365.9
							2,552.3
							2,202.3