

THE ROLE OF SMALL-SCALE BIODIGESTERS IN THE ENERGY, HEALTH, AND  
CLIMATE CHANGE BASELINE IN MEXICO

HUMBOLDT STATE UNIVERSITY

BY

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## ABSTRACT

### THE ROLE OF SMALL-SCALE BIODIGESTERS IN THE ENERGY, HEALTH, AND CLIMATE CHANGE BASELINE IN MEXICO

Alexander Eaton

This thesis addresses aspects of the technical, economic, and social challenges to the implementation of small-scale biodigester systems at small pig farms in Mexico. I outline the development and testing of an improved biodigester design aimed at addressing weaknesses in traditional low-cost systems. The improved biodigester design has technical advantages over the traditional bag biodigester, including durability, repairability, and ease of installation. The life cycle cost over 15 years is estimated to be 40% less than the traditional low-cost system.

Among the benefits of biodigesters are renewable energy production, waste treatment, greenhouse gas emissions reduction, and human and environmental health improvements. Many of these benefits can be converted into monetary values using current markets and valuation techniques. Using these values I have estimated a cost/benefit relationship for the installation of biodigesters, expressed in terms of payback rates (years). A 10-meter biodigester for a small farm has a 2.8 year payback rate based only on energy services (displacing fuelwood); a 1.5 year payback including energy services and emissions reductions; and a 0.9 year payback when energy services, emissions reductions, and avoided health risks are considered.

Biodigesters may also have additional positive externalities such as improved environmental health and socioeconomic indicators. Given this wide range of benefits, distributed in many distinct areas, it is reasonable to consider a wide range of potential funders for a broad-scale biodigester deployment project.

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## CHAPTER ONE – INTRODUCTION

Small-scale anaerobic digesters, or biodigesters, can potentially play an important role in reducing greenhouse gas emissions and human and environmental health risks while also improving economic conditions for small farms in Mexico. Although the benefits of implementing small-scale biodigesters have been demonstrated for nearly thirty years, significant challenges to realizing these benefits on a broad scale remain (Pound et al. 1981, Botero and Preston 1987). In this research I attempt to identify and address aspects of the technical, economic, and social challenges to a broad scale implementation of small-scale biodigesters systems at pig farms in Mexico.

Biodigesters use anaerobic digestion (AD) to convert animal, human and other organic waste into a potent organic soil amendment that can support sustainable agriculture efforts. The byproduct of this process is a methane-rich biogas that can be used as a renewable energy source for cooking, heating, and electricity generation. In this work, these energy benefits delivered to the end user of the biodigester system will be considered the primary direct benefits. Additional direct benefits such as reduced odor and insect populations will also be considered.

Biodigesters also produce a number of other important benefits that may be realized by the end user and others in society such as reduced greenhouse gas emissions and improved local human and environmental health. These co-benefits,



or additional benefits that go beyond end user direct benefits, will be examined as positive externalities of biodigester installations. A positive externality is a benefit to other members of society generated as a side effect or consequence of a product or economic exchange. Because the other members of society do not pay for the benefit, society is unlikely to allocate the socially optimum quantity of the good or service (Hackett, 2006).

The use of biodigesters reduces greenhouse gas (GHG) emissions by displacing traditional fuels and capturing and destroying methane that would otherwise be emitted. The reduction of these emissions is then a positive externality of biodigesters realized by the global community (Dong, 2006; UNFCCC, 2009).

Additionally, if biodigester implementation efforts were focused on poor segments of the population, these benefits could contribute to a portion of the Millennium Development Goals (MDGs)—an initiative of the United Nations that sets numerical targets for improving socioeconomic, health, and environmental indicators for the world's poor (Gakidou et al., 2007).

The MDGs provide a useful framework to put co-benefits, or positive externalities, into context. Because the MDGs have been developed by the United Nations along with support from the international community, the history of funding projects within the MDG framework provides an indicator in which global motivation to realize similar benefits can be assessed.

My goal in this work is to present and support four key ideas:

1. Low cost plug-flow plastic biodigesters, and corresponding installation programs, need significant technical and programmatic improvements to be successful.
2. When cost benefit analysis of biodigester systems take into consideration the full range of benefits, including those associated with energy, health (including reduced indoor air pollution and organic waste contamination), and greenhouse gas emissions reduction, the payback rates can be very high.
3. If biodigester implementation efforts were focused on poor segments of the population, benefits derived from biodigesters could contribute to a portion of the Millennium Development Goals (MDGs).
4. A subsidized market approach supported by government and private groups motivated by the direct and co-benefits outlined above, would be an effective and justifiable way in which to promote the broad-scale development of small biodigester systems.

In addition, an import aspect of this work is the technical development process of the Mexico Biodigester Program. This includes the development of an improved small anaerobic digester system and background research into the history of biodigester development in Mexico.

Specifically, in Chapter Two of this document I outline a brief history of the development and use of low cost biodigesters along with the chemical and

mechanical function of a plug-flow digester. I also present background into greenhouse gas emission regulations, and how climate change policy has affected biodigester development. Finally, I present Mexico in the context of biodigester development, and give background on the country.

In Chapter Three I outline the technical improvements that I have made to the low cost plastic plug-flow biodigesters through the Mexico Biogas Program of the International Renewable Resources Institute, Mexico (IRRI). I present a detailed account of the design process, and the background of the IRRI Mexico Biogas Program.

In Chapter Four I consider the economic performance of the various designs of low cost digester systems and the economic benefits that can be derived from biodigesters. In this section I will discuss both the direct economic benefits that the end user receives for energy services and the indirect benefits of reduced greenhouse gas emissions, indoor air pollutants, local organic contamination, and environmental degradation. Chapter Four ends with a cost benefit analysis of biodigester interventions, comparing purely direct benefits with both direct and indirect benefits combined.

In Chapter Five I outline potential funding opportunities for biodigester systems, including an unsubsidized market approach, emerging carbon markets, and international funding aimed at alleviating the health burden of the rural poor. I present the challenges and the estimated scale of each opportunity relative to

Mexico. I conclude Chapter Five with an example of a multi-funder approach for subsidizing biodigester implementation in Mexico.

My conclusions are outlined in Chapter Six. I present a summary of the opportunities and challenges to widespread use of small-scale biodigesters in Mexico, and conclude that a program that could aggregate costs and benefits of many small systems could be economically feasible. Next steps and suggested future research are also proposed.

This work is the compilation of three years of research, design, and implementation surrounding biodigester technology. Aspects from field reports, project proposals, field data, and scholarly literature are included. The majority of the fieldwork is based in Mexico, and experience has been drawn from multiple biodigester installations throughout the country. However, small-scale biodigesters have been applied around the globe, particularly in Asia, and this work draws from a broad base of international research.

## CHAPTER TWO- PROJECT BACKGROUND

### Anaerobic Digestion and Humans

Anaerobic digestion (AD) is a chemical process similar to fermentation in which anaerobic bacteria breakdown complex organic materials. The term anaerobic refers to a chemical process not driven by free oxygen. The anaerobic bacteria used in this process are similar to those found in the digestive tracts of humans and most animals. In addition to digestive tracts, anaerobic digestion occurs naturally in swamps, marshes, ocean depths, and in deep layers of organic matter such as those found in tropical forest floors.

Humans have utilized anaerobic digestion for hundreds of years, and evidence exists that ancient Egyptians utilized biogas from sewer systems to provide lighting. In the 1930s small groups in India and elsewhere began to develop early versions of the biodigester systems that are in use around the world today. After World War II there was renewed interest in the technology for re-development efforts in Europe, as well as some small projects in the United States (NIIR, 1990).

Although there were small pockets of development, anaerobic digestion was not emphasized as a major energy source in industrialized nations for most of the 20<sup>th</sup> century. This was largely based on the widely available, low cost petroleum-based fuels and the proliferation of reliable electrical distribution systems (NIIR,

1990). However, during this same period, anthropogenic sources of methane from anaerobic digestion increased. These sources primarily include large landfill and agricultural sources (EPA, 2009).

In the developing world, however, the heavy reliance on biomass fuels for energy has made the development of alternative energy sources more appealing. By the 1970's, the energy crisis gave small-scale biodigester installation programs the boost they needed, and millions of biodigesters were installed in China and India (NIIR, 1990). Since then, developing nations have been the primary drivers in the development of small-scale anaerobic digestion technology. Notable development programs include China, Nepal, India, Vietnam, Colombia, Peru, Ecuador, Tanzania, and Costa Rica (An et al., 1996; Lansing, 2008).

Recent research and development effort in anaerobic digestion has been primarily in larger industrial-scale systems. In Europe and the United States, anaerobic digestion technology has been revisited as an option for managing large sources of organic waste such as agricultural or food waste. Large systems can effectively manage a wide variety of waste streams, while also producing significant amounts of energy in the form of biogas. Electricity generation, transportation, and heating systems have all been powered by large-scale biodigester systems, and opportunity in this sector continues to drive investment into large-scale biogas technology (RCM, 2006; EPA, 2009; UNFCCC, 2008).

## Development of Anaerobic Digestion Systems through Global Climate Change Policy

Beginning as early as the 1960s, scientists began to publicly warn that global climate change, specifically global warming, was an inevitable outcome of carbon dioxide emissions from burning fossil fuels (Lovins, 1977; UNFCCC, 2008). In 1992—after more than two decades of United Nations conferences on the environment and climate change—a United National Convention on Climate Change outlining the first international framework for reducing Greenhouse Gas (GHG) emissions was signed and ratified by 192 countries. In 1997 an international treaty designed to enforce the United Nations Framework Conventions on Climate Change (UNFCCC), was signed in Kyoto, Japan. Ratified by 182 nations, the Kyoto Protocol went into force in February of 2005 (UNFCCC, 2008).

### The Clean Development Mechanism

The Kyoto Protocol committed 37 industrialized countries (Annex B) to reduce their greenhouse gas emissions to an average of 5% below established 1990 levels. Under the agreement each nation is required to reduce national emissions, but it also established three market mechanisms to “offset” emissions in other ways. Of those, the Clean Development Mechanism (CDM) allows Annex I countries to receive certified emissions reduction credits (CERs) by investing in carbon reduction projects in countries that are not required to reduce emissions (UNFCCC, 2008).

Approximately 250 industrial biodigesters have been installed all over the world as “methane capture” projects funded by the CDM. Host countries include Brazil, Mexico, China, Indonesia, India, Chile, Armenia and the Philippines (UNFCCC, 2008). Methane gas is a potent greenhouse gas, with a greenhouse gas forcing potential 21 times that of carbon dioxide (EPA, 2009). The high forcing potential makes methane capture a relatively lucrative process in the context of the CDM framework. Methane capture projects have seen a recent rise in non-Annex I countries, with Brazil and Mexico leading the way with approximately 200 projects between the two countries (UNFCCC, 2009).

With nearly 30% of the global methane capture projects within the Clean Development Mechanism (UNFCCC, 2009), Mexico has proven itself as a willing partner in developing anaerobic digester projects. Participating in CDM projects has also proven to be good business for Mexico, with an estimated US \$40,000,000 of international investment towards infrastructure projects in the country since 2003 (UNFCCC, 2009).

### Anaerobic Digestion Fundamentals

Biodigesters treat organic waste and produce methane gas because of the natural process of anaerobic digestion. Anaerobic reactions are complex biochemical processes that involve multiple microbial populations to break down complex organic materials (Malina and Pohland, 1992; McCarty, 1964).



The AD process consists of two major stages, as shown in figure 1. In the first stage, waste conversion, complex organic compounds are converted into a variety of intermediate organic acids. In the second stage, waste stabilization, the organic acids are broken down in methane and carbon dioxide. Figure 2 shows a more involved version of this same process (Malina and Pohland, 1992; McCarty, 1964).

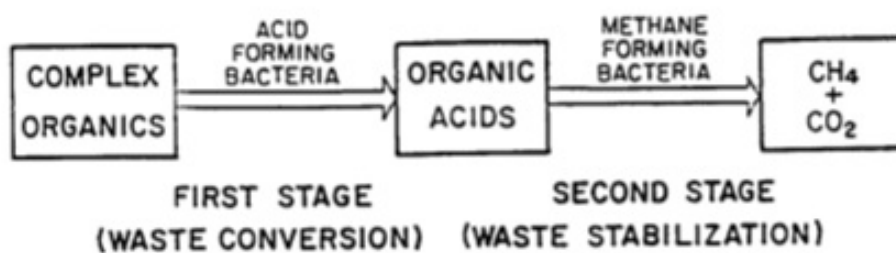


Figure 1. The anaerobic digestion process consists of two major stages, acidogenesis (waste conversion) and methanogenesis (waste stabilization) (Malina and Pohland, 1992).

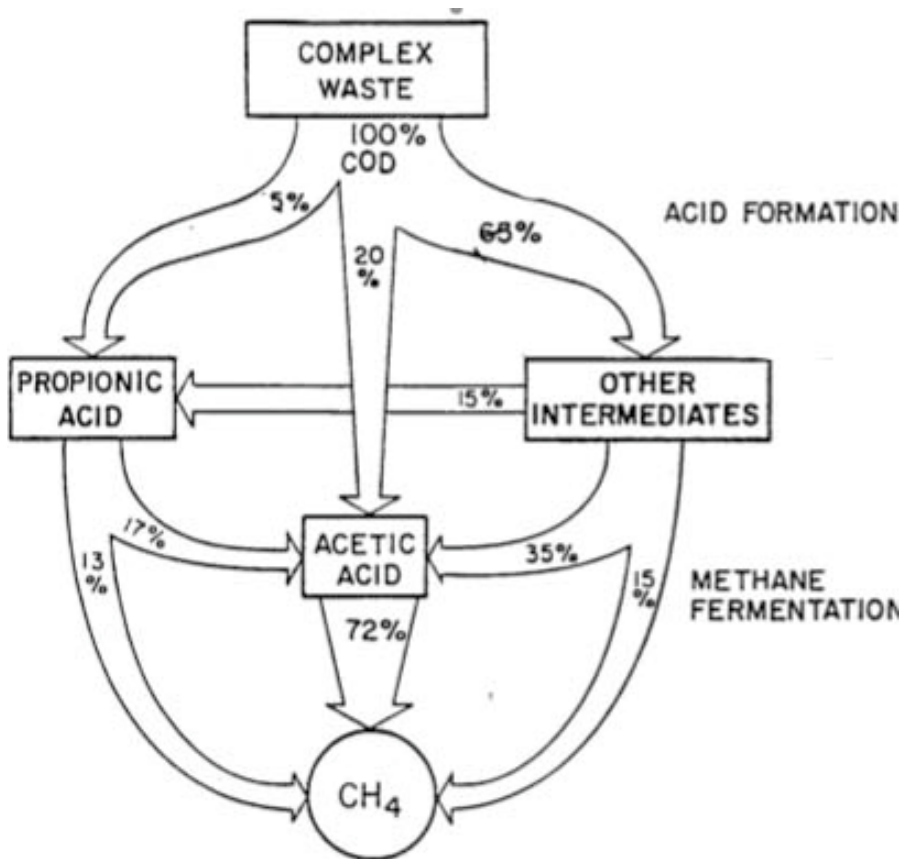


Figure 2. The anaerobic digestion pathway from organic waste to methane, showing the multiple conversion processes. COD stands for Chemical Oxygen Demand, a common measure for the organic material in a complex waste. (Malina and Pohland, 1992).

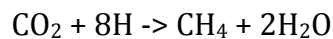
Table 1 shows a list of some of the intermediate organic acids that are broken down during the primary acidification.

Table 1. Some of the common volatile acid intermediates in the anaerobic digestion process (Malina and Pohland, 1992).

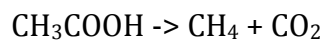
Acid	Chemical Formula
Formic Acid	HCOOH
Acetic Acid	CH <sub>3</sub> COOH
Propionic Acid	CH <sub>3</sub> CH <sub>2</sub> COOH
Butyric Acid	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOH
Valeric Acid	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> COOH
Isovaleric Acid	(CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub> COOH
Caproic Acid	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> COOH

The most common and well know methane formation pathways are the hydrogen-mediated reduction of carbon dioxide and the cleavage of acetic acid. Both of these reactions are shown in equations 1 and 2.

Equation 1



Equation 2:



The methanogenic bacteria that are responsible for the cleavage of acetic acid are about half as common as those that reduce carbon dioxide. Therefore, as

the products of equations 1 and 2 indicate, a common biogas composition is then approximately 65% methane, and 35% carbon dioxide (Malina and Pohland, 1992; McCarty, 1964).

Biogas generated in simple biodigesters will nearly always contain a number of other constituents such as water vapor and hydrogen sulfide. While these biogas components are found in low concentrations (e.g., hydrogen sulfide is often much less than 1% of the total composition), they can provide significant challenges for biogas end-use.

#### Biodigester Fundamentals

Biodigesters are compartments sealed from the outside air to promote the anaerobic digestion processes. Because organic waste is often added regularly to the system, the compartment is generally sealed with a water trap that allows a liquid slurry to enter the system while not allowing the outside air to contaminate the inside anaerobic environment (Preston, 2002; Lansing, 2007; Herrero, 2008; Pound et. al, 1981).

Basic biodigester systems are installed level, with the exit pipe of the biodigester determining the water level within the system. This is illustrated in Figure 3. This figure shows the system completely full, so that when a unit of material is added to the system, and equivalent amount of material is displaced through the exit pipe.

Given the “water level” dynamic of biodigesters, a general hydraulic retention time (HRT) can be calculated for each system. Given a total liquid volume of X liters, and an input of Y liters/day, the nominal, or design, HRT (in days) is then  $X/Y$ . For example, a digester system with a liquid volume of 3000 liters with a daily input of 100 liters has an average HRT of 30 days. Due to sedimentation and flow dynamics, all material in the biodigester does not maintain the same HRT, and material may exit the system earlier or later than the design HRT (An, 1997; Kounnavongsa, 2008).

During the residence time in the biodigester, the AD process described above breaks down the organic material and creates biogas. The biogas is captured within the biodigester, and extracted through a smaller access on the top of the digester, also shown in Figure 3. In many cases, the gas is produced in the digester at a pressure sufficient (often less than one inch of water column to six inches of water column pressure) for the gas to flow naturally through a simple hose to the gas end-use (Preston 2002, Lansing 2007; Herrero, 2008, Pound et. al., 1981).

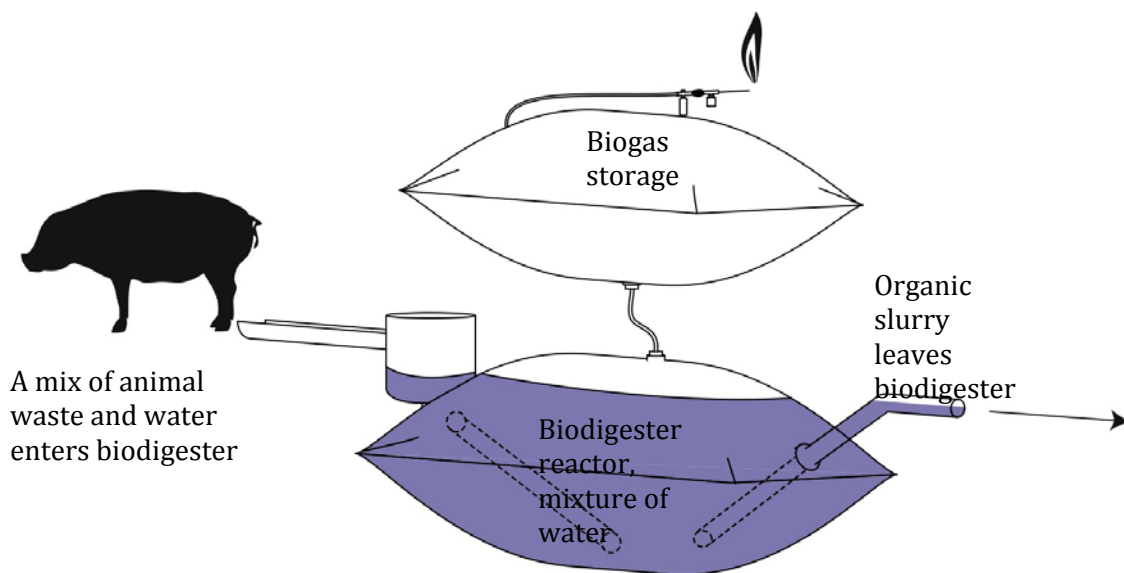


Figure 3. This shows the primary components of a simple biodigester, including the water level throughout the system, the water trap that does not allow for outside air to enter the system and the biogas storage.

### Small-Scale Biodigester Systems: A brief background

Small-scale biodigester systems generally come in three variations that have remained relatively unchanged for over 20 years: 1. the fixed dome digester; 2. the floating cover digester; 3. and the plug flow plastic digester (Preston 2002, Lansing 2007). There have been more than seven million of the fixed dome, or Chinese model, digesters constructed in the world, primarily in China. These systems are generally constructed from cement and require a high level of skill, time, and money to install. Fixed dome systems generally have low gas production rates and long waste hydraulic retention times. These systems are often plagued with gas leaks that are hard to pinpoint and repair (Lansing, 2007). Figure 4 and 5 show the dome biodigester design. These issues combined with low availability of spare parts and a heavy dependence on governmental subsidies have led to a major down turn in recent installations of these systems worldwide (Preston, 2002; Lansing, 2007; Herrero, 2008).

With an estimated 3 million systems, the floating cover, or Indian design, is the second most prevalent design. The floating cover design is very similar to the fix-dome design, except that the dome is “floating” on the gas pressure generated by the system.

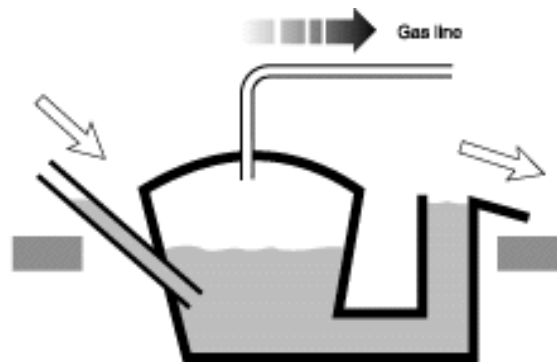


Figure 4. A graphic of the fixed dome biodigester that shows basic inlets, outlets, and function of the system (An et al., 1996)



Figure 5. A fixed dome biodigester under construction at the Mukuru BioCentre in Kenya. The high technical skill needed to construct these systems is apparent here (photo: Dyfed Aubrey).



This system maintains a consistent pressure as the gas volume changes. Because there are moving parts and a metal or fiberglass cap, floating cover digesters are even more expensive than fixed dome systems. The floating cover design is shown in Figures 6 and 7. With a high installation cost and skill level needed, these systems have primarily served relatively wealthy farmers and landowners, or have been heavily subsidized by government or international funds (Preston, 2002).

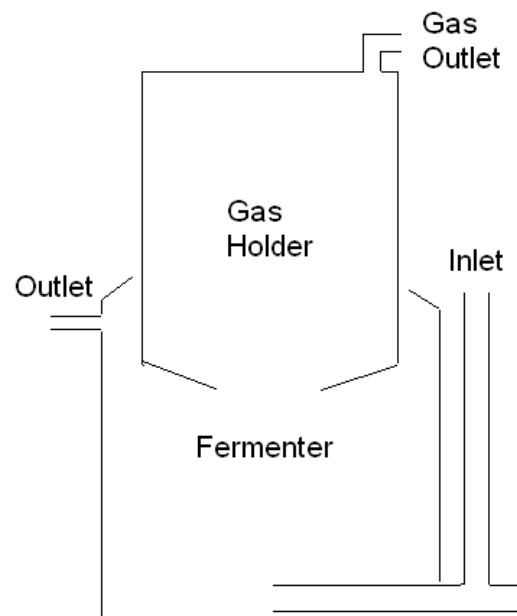


Figure 6. This diagram shows the basic function of the floating cover design. The gasholder is allowed to move up and down given changing volumes of biogas. The fermenter (or reactor) can be constructed from concrete similar to a fixed dome design (ARTI, 2008)



Figure 7. This floating cover digester is at a cattle ranch in Argentina. While most common in India, fixed dome designs are found all over the world (Proteger, 2005).

In response to the high cost and construction skill necessary for the installation of the fixed dome and floating cover designs, a low cost plastic plug flow digester was developed. Referred to as the “Taiwanese Design” or “tubular plastic design,” this continuous-flow flexible tube biodigester is based on the bag digester model described by Pound et al. (1981) and simplified by Preston and co-workers, first in Ethiopia and Colombia and later in Vietnam. An early diagram of the their bag digester is shown in Figure 8. Within three years, more than 800 polyethylene digesters were installed in Vietnam, mainly paid for by farmers (An et al., 1997). Currently there are over 20,000 of the low cost systems installed in Vietnam, and there is no longer a need for subsidies to purchase materials (Preston, 2002).

Design and development work on the flexible bag digester moved into Latin America in the mid 1990's with the help of early pioneers of the technology T.R. Preston and Raul Botero (Lansing, 2008). In Costa Rica, Botero joined *Escuela de Agricultura de la Región Tropical Húmeda* (EARTH) University in Costa Rica, where low cost biodigesters are designed and tested. His efforts at EARTH have led to the installation of over 1000 bag-style digesters in Costa Rica (Lansing, 2008).

In Colombia Preston worked closely with *Centro para la Investigación de sistemas sostenibles para la Producción Agropecuaria* (CIPAV), an organization that has disseminated 3000 polyethylene biodigesters across Colombia. Research and installation manuals that have come from CIPAV have been distributed widely. This material has influenced biodigester initiatives throughout Latin America (CIPAV, 2008).

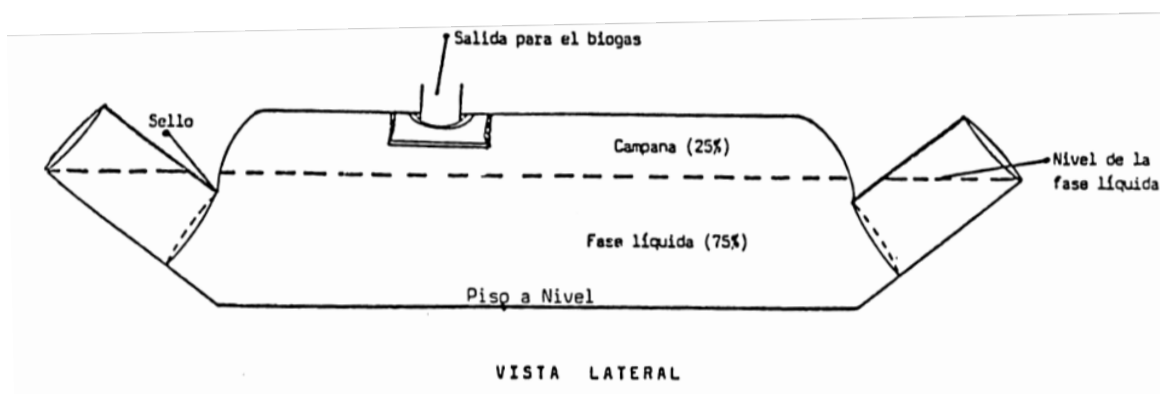


Figure 8. This diagram of an early version of the low-cost bag digester (also referred to as the Taiwanese Model) is from an early construction manual by Botero and Preston (1987).

## Large Scale Biodigester Development in Mexico

Biodigesters also include large industrial scale systems that are designed to treat waste from commercial operations, including large farms. Mexico has the second largest pig population in Latin America, and has been in a transition from smaller traditional farms to larger U.S. -type industrial operations (Franco, 2008).

The common practice for manure management at these large pig farms in Mexico is storage in open manure lagoons. These lagoons are anaerobic below the water level, and produce large amounts of methane that bubbles out of the surface of the lagoon. These methane emissions provide a baseline emissions level for large farms. Large biodigesters are considered a methane-abatement technology that can capture and destroy methane produced by the farm waste (UNFCCC, 2008; Franco, 2008).

The construction of large biodigesters in Mexico began in late 2003 and was driven by initial stages of the carbon trading under the Kyoto Protocol. One company, Agcert, focused on Mexico, and promoted a simple covered lagoon-style digester (Franco, 2008).

The Agcert design consists of a large lagoon lined with HDPE. The liner is anchored into the top of the banks of the lagoon with about two meters of excess liner left out of the anchor trenches. The lined lagoon is then filled with a mixture of water and waste, and a large HDPE cover is floated across the slurry. The cover is

welded to the excess liner material completely sealing the lagoon. Gas is captured under the cover, and removed with large electric gas blowers. The gas is metered, and then sent to a large flare that destroys the methane in accordance with regulations under the Kyoto Protocol (UNFCCC, 2008; Moser, 2008).

Waste flows in and out each day like the simple biodigester described in Chapter Two. Agcert contacted hundreds of large farms, promised free anaerobic digester systems, and made the farmers sign exclusivity contracts that only allowed them to deal with Agcert regarding any future digester work. The company built over 85 covered lagoon digesters in just over two years. More than 100 systems were built in Mexico during the same time period, as other companies (many born from ex-employees of Agcert) entered the business (Franco, 2008).

The design of the Agcert system and the business model had some major flaws that eventually led to Agcert completely abandoning its systems in Mexico and being largely discredited in the industry. Most importantly, the systems all seemed to function well for the first 12-18 months, but would slowly fill with solids because the digesters lacked an agitation system that would prevent solids from settling and then accumulating in the biodigester reaction chamber. Systems were all based on the same “cookie-cutter” design and therefore many systems had site-specific problems. Lack of experience on the part of some installers also led to large mistakes; one system was built without an exit (Moser, 2008).

As gas production fell, so did the profitability of the systems due to drop in certified emissions reductions. Agcert investors lost a lot of money, and the Mexican offices of Agcert were shut down leaving many farmers without a resource for maintenance or repairs. To date, the Mexican government has hired other firms, including RCM Digesters International LLC, to fix some of the Agcert systems (Moser, 2008).

The Introduction of the Bag Model to MexicoThe following section outlines biodigester projects that have been initiated in Mexico to promote the low-cost polyethylene digester. Particular focus is put on the people that have had the most contact with the IRRI-Mexico Biogas Program, including Callatana Nambo. This information below is based on extensive online research, interviews, field visits, and government and university contacts. The projects listed here may not be exhaustive of all low-cost biodigester efforts in Mexico.

#### Callatana Nambo<sup>1</sup>

In 1997 Callatana Nambo, a local farmer (Figure 9), was participating in field research in Erongaricuario, Michoacán for a government group promoting rural agriculture. Through this group she was invited to bring ten representatives from Erongaricuario to an afternoon presentation about biodigesters in Morelia, Michoacán. The presentation was short, and very unclear to the rural residents. There was no demonstration of the technology, and they felt let down.

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<sup>1</sup> The following information is from a January 2009 interview with Callatana Nambo, with some information filled in by over two years of working with her.

Ms. Nambo complained to a representative of the Governor of Michoacán, whose office had sponsored the event. “Invite us to a place to where the gas is being produced so we can learn about this technology,” she asked the representative. A week later she was given an invitation and plane ticket to attend a weeklong training in Colombia with CIPAV (Nambo, 2008).

Ten people from the region were asked to attend, but all were government employees or friends except Ms. Nambo. The course provided them an opportunity to build a polyethylene biodigester at a farm in Columbia, shown in Figure 10. Ms. Nambo was the only participant from the course that returned with the intention of installing biodigesters in Mexico.

When she returned she set out to build a system in Mexico. In the small community of Caricharo, Michoacán, she built her first digester at a small pig sty far from any houses. All of the neighbors called her “crazy,” but the system shortly began producing gas. Without any gas control hardware, her first attempt at producing a biogas flame resulted in a large flame shooting from the end of the open plastic hose. After eight days, a local resident took a knife to the system (Nambo, 2008).

She built the next system in her house to receive manure from three pigs she kept in her backyard. The system functioned from 1998 until 2005 when she replaced the plastic. During this time she promoted and demonstrated the technology, and began to build local community support. By 2005 she had a list of

25 families that were interested in receiving biodigesters. After a long application process, the state finally provided \$7000 Mexican Pesos (MN) per biodigester for Ms. Nambo to install the 25 systems.



Figure 9. Callatana Nambo, in her home in Erongaricuaró, Michoacán.





Figure 10. An early plastic biodigester installed by a course in Colombia attended by Ms. Nambo in 1997.

Once Ms. Nambo had installed 25 biodigesters through the program, the recipient families had a party for the funders. During the “thank you” event, Ms. Nambo was given additional funds for the installation of 25 more biodigesters. This time she was given only \$5000 MN per system (Nambo, 2008).

I first met Ms. Nambo when I started working for IRRI in 2006. She was still in the process of applying for the State funds to build the first 25 biodigesters. The president of IRRI-Mexico, Ilan Adler, who had worked in Erongariquaro and had heard of Ms. Nambo’s biodigester the year before, introduced us. She was still

unsure how to fund the installation of the systems, and we brainstormed a way in which IRRI-Mexico could support her efforts.

#### Other Biodigester Development Efforts

Another early biodigester program was organized through the University of Guanajuato. Through this program, university students with the help of a local engineer installed 64 small biodigesters in 1998. There was an informal evaluation done of the systems two years later that found that less than one third, about 20 systems, were still functioning. The main cause of failure was reportedly damage to the plastic, neglect, and an apparent lack of follow-up to get the systems functioning properly. The engineer who was interviewed believed that material strength was a key issue, but that also a lack of appropriate shelter to house and protect the systems played a large part in the material damage (Morales, 2008).

The University of Guanajuato learned about plug flow digesters through a combination of online resources and connections with engineers that constructed large commercial biodigesters. This is similar to the infusion of various other small biogas projects that have been initiated elsewhere in Mexico. During the late 1990's a handful of individual systems were built in Mexico, often motivated by online resources or visits to training centers in either Costa Rica or Colombia. This includes a demonstration system built at the Eco-Technology Center of *Las Cañadas Bosque de Nieblina* (Las Cañadas, 2008), three small systems built at a training

center in Teotejaucan near Mexico City, and potentially others through Universities and non-profit groups.

A friend of Ms. Nambo, Froylan Barrio, also attended a training course at CIPAV in Colombia and has reportedly built just over 30 small digester systems using funds from the state of Michoacán to help rural farmers. No follow-up data from those installations were available (Nambo, 2008).

#### Mexico as a Case Study for Biodigester Development

Mexico provides a good opportunity to examine a wide range of environmental, social and economic contexts for the development of biodigester installation projects. Mexico is also a non-Annex I country under the Kyoto Protocol, and therefore is eligible to be a host country for CDM funded projects. In fact, Mexico has 8% of the total global CDM projects (113 projects), and 30% of the total waste gas recovery projects (which include biodigesters). Of Mexico's 110 projects (5,037,242 tonnes of emissions reductions (ERs) as reported by the UNFCCC), over 90% consists of anaerobic digestion methane capture projects (UNFCCC, 2008).

A land of extremes, Mexico has a wide variety of terrain and climate types, with elevations ranging from sea level to nearly 6000 meters. Temperature and weather can range from freezing to 40 °C and rainfall ranges from 3000 mm to only 12 mm per year.

The socioeconomic makeup of Mexico is equally as varied. The annual per capita income is about US \$7000 (US 2005 dollars), and the average income is lower

in the rural segment of the population. Nearly 10% of the total population is under the national poverty line (with a bit under 2% under the global poverty line), yet Mexico is also home to the world's richest man. Mexico is ranked 53rd in the world of the 177 countries ranked by development indicators (WHO, 2008). With a very unequal distribution of wealth (GINI Score of 53, where 0=equal distribution of wealth and 100=perfectly unequal distribution of wealth), the top earning 20% of the Mexican population controls over 60% of the country's resources, while the bottom 20% of the population must split just 3.5%. The rural population is largely agrarian, and comprises 24% of the total 120 million people in the country, but agriculture only represents 4% of the total GDP of Mexico (Corbacho and Shwartz, 2002; WHO, 2008).

While Mexico is home to modern urban centers, it is still considered a developing nation. One in four households use fuel wood for either all or part of their energy for cooking (Masera, 2005). The remaining energy needs throughout the country are met largely with Liquid Petroleum (LP) gas and electricity at a large economic burden for much of the low-income rural population. Of the total rural population, only 48% have access to improved sanitation systems; 52% use unimproved latrines or defecate in the open. While 85% of the rural population has access to "improved" water sources, this does not include any water filtration or treatment, and piped water is only available in the homes of 73% of the population (WHO, 2008).

### CHAPTER THREE: LOW-COST BIODIGESTER TECHNICAL RELIABILITY AND THE DEVELOPMENT OF THE IRRI-MEXICO IMPROVED BIODIGESTER DESIGN

The Mexico Biogas Program is an initiative started by members of IRRI along with local community organizations from Michoacán and Chiapas. I am the founding director of the program, which has since been supported by the Mexican office of the Secretary of the Environment (SEMARNAT), the Federal Forestry Commission (CONOFOR), the Indigenous Community Development Office (CDI), the U.S. AID program, the U.S. EPA Methane to Markets Program, and numerous local state and governments. The program has specifically developed educational programs and technical research surrounding small-scale biodigesters in Mexico (IRRI, 2009).

With just over three years in operation, the Mexico Biogas Program has reached two key conclusions surrounding the implementation of small-scale biodigesters systems. First, over-all technical reliability of simple plastic-bag models was very low, and this was an important factor influencing the adoption rate of the technology. Second, there were non-technical programmatic elements to a biodigester installation program, particularly education and follow-up, which also influence the adoption and success of biodigester systems.

These conclusions are drawn from design work and educational programs conducted by IRRI-Mexico. We have found that a pre-fabricated High Density Polypropylene (HDPP) material provides for higher technical reliability in

biodigester reactors. We have also found that educational programs and scheduled follow-up sessions with biodigester users greatly increase use and help avoid non-technical failures of the systems.

In this chapter I outline the background of small-scale biodigester systems, with a focus on the tubular plastic-bag model. Included is a discussion of the basic chemical and mechanical function of small biodigesters. A brief history of the transition of the biodigester technology in Mexico and the beginnings of the Mexico Biogas Program are also presented. The early experience of the Mexico Biogas Program will highlight work with the plastic bag digester design, and how design improvements were developed, implemented, and tested. Finally, the new IRRI Biodigester design is presented and compared to the original plastic bag model.

#### The IRRI-Mexico Biogas Program

The IRRI-Mexico Biogas Program was developed initially to support the efforts of Ms. Nambo in Michoacán. The first project of the Mexico Biogas Program was a biodigester installation course in June of 2006. The course utilized the knowledge of Ms. Nambo and Mr. Barrio, both of whom had been trained in Columbia. The concept was that course proceeds and the efforts of course participants would enable the installation of biodigesters for local residents. The course participants installed a biodigesters in two of the original 25 homes that had been waiting for a biodigester.

From the publicity generated by the course, two more biodigester installations were scheduled through the CDI. Two biodigesters were installed in the *Distrito Federal*, on the outskirts of Mexico City.

Between January and April of 2007 I installed two small biodigesters along the Guatemalan boarder of Chiapas. In May we installed another system in Erongariquaro, Michoacán as part of the second Biodigester Installation Course.

#### Description of the Original Biodigesters Installed by the Biogas Program

All of these systems were a slightly modified version of the Taiwanese model that had been adopted from CIPAV in Columbia. The system utilized small concrete receiving basins that interfaced with a double layer of polyethylene plastic to form the reactor of the system. A small plastic reservoir was connected to the reactor to facilitate extra gas storage. The plastic is connected to the concrete tubes by wrapping multiple layers of car tire inner tube.

The inner tube is cut into a long (6-10 meters) strip about 6-10 cm wide. The cutting method (best with lots of hands!) is shown in Figure 11. The open end of the tubular plastic is wrapped around the concrete tubes, and then secured initially using a piece of tape (Figures 12 and 13). The long strip of tire inner tube is stretched and wrapped tightly around the plastic to secure it in place and create an air and watertight seal.



Figure 11. Tire inner tube is cut in long continuous strips to be used to secure the biodigester and reservoir to entrance and exit tubes. Many hands make this process easier and produce better material.





Figure 12. Above shows the Colombian digester model with concrete boxes and tubes for the effluent in and out of the biodigester. This site is in Michoacán.



Figure 13. The mouth of the tubular plastic is folded around entrance and exit tubes and secured initially with tape before it is wrapped with tire inner tube. This is a system in San Jose Zapotal, Chiapas.



Figure 14. An example of an early biogas digester of the IRRI Mexico Biogas Program. Concrete receiving basins and a large plastic gas reservoir are shown here. This system is in Michoacán.

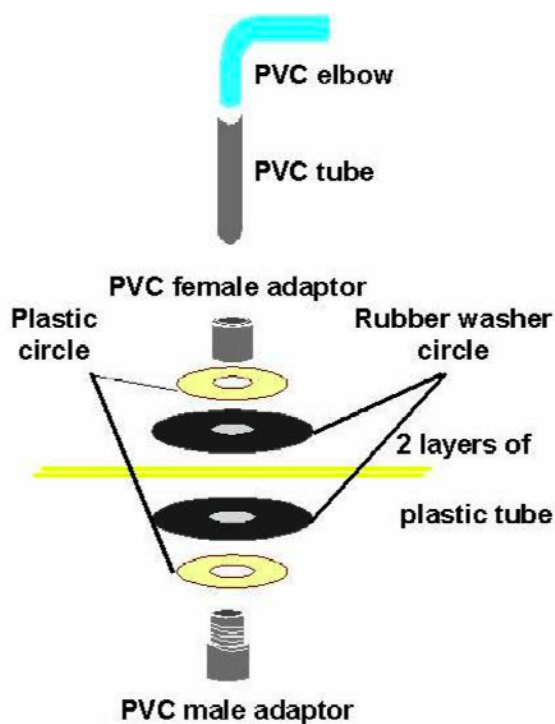


Figure 15. The gas exit is made in the biodigester by securing hard plastic disks on either side of the plastic material with 1 inch threaded PVC. Two disks made of tire inner tube ask as gaskets.

The gas leaves the biodigester reactor through a small exit, shown in Figures 14 and 15. Two small circular disks made of hard plastic (generally from motor oil jug material) act as a flange that seal the layers of the biodigester plastic between two small rubber disks made from the same tire inner tube material. A male and female threaded 1 inch PVC piece are connected from outside and inside the system and seal the entire system together to make and airtight gas exit.

The gas then runs through a small length of pipe to a gas reservoir, which is sealed in a similar manner. The gas exits the reservoir through a 1 inch plastic hose

and is run through a small gas management system (figure 16): a safety escape valve, a ball valve, and a sulfur filter. The sulfur filter uses either steel wool or iron shavings as a medium to extract the small amount of sulfur out of the biogas.<sup>2</sup>

From the gas management system the gas is run through 1-inch plastic hose to the point of end use. End use is generally a small star-shaped burner that is used for cooking or water heating (figure 17). The burner has a ball valve and generally reduces from 1-inch to  $\frac{3}{4}$  or  $\frac{1}{2}$ -inch hardware to increase gas pressure at the burner.

Each system has some small variation to accommodate the site conditions, but the general design is similar to those described by Preston, Botero, and others (Botero and Preston, 1987; Brown, 2005; CEDECAP, 2007; Botero, 2007).

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<sup>2</sup> Hydrogen sulfide ( $\text{H}_2\text{S}$ ) binds with the iron (III) oxide ( $\text{Fe}_2\text{O}_3$ ) and is removed from the gas in the following reaction:  $2 \text{Fe}_2\text{O}_3(\text{s}) + 6 \text{H}_2\text{S}(\text{g}) \rightarrow 2 \text{Fe}_2\text{S}_3(\text{s}) + 6 \text{H}_2\text{O}(\text{l})$  (Johnson et al., 2008).

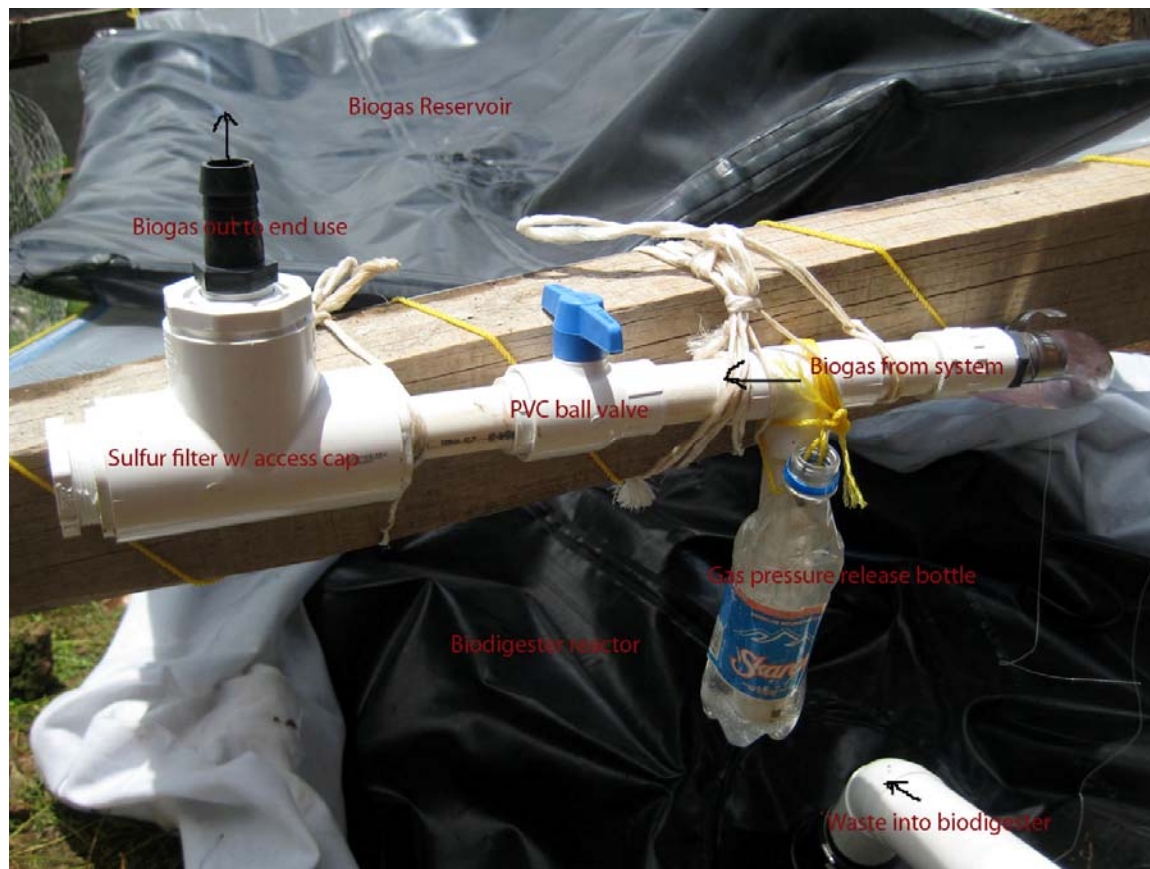


Figure 16. The gas management system of an IRRI Mexico biodigester, showing the gas pressure release, the PVC valve, and the sulfur filter. The biogas entrance and exit are labeled, as well as the biodigester reactor and reservoir.





Figure 17. A simple star burner burning biogas. It is difficult to photograph biogas flames as they are generally clear or light blue.

#### Early Experience of the IRRI-Mexico Biogas Program

Common failures of the Taiwanese digesters have been outlined by An, et al., in a study of plastic biodigesters in Vietnam, and supported by others (An et al., 1997b; Lansing, 2008). The most common failure is damage to the plastic due to humans, animals, sun, or falling objects. Of 35 farmers interviewed in 1996 in Vietnam the systems studied by An et al (1997a), 40% failed due to damage to the plastic.

The experience with the original digesters installed by IRRI Mexico supported these findings. Of the eight original systems installed, over half of them presented some concerns regarding reliability due to the fragile nature of the plastic. An outline of the original IRRI-Mexico systems and their current status is included in Table 2.

Table 2. Summary of performance for the original IRRI biodigesters

Install Date	Biodigester Project	Functioning as of March 2009	Comments
1998	Eronga 1	Y	This is Ms. Nambos original system. There have been multiple incidents of leaks in both the plastic and the hose interface. IRRI replaced plastic reservoir in June of 2006 for leaks.
June, 2006	Eronga 2	N	This is the biodigester built with the first IRRI biogas course. The system functioned for eight months until the family sold their pigs and a family member wanted to build his home where the biodigester was.
June 2006	Eronga 3	N	This was also built during the first IRRI course. This system initially had some issues with the width of the trench which were repaired by Ms. Nambo by adding sand bags along one side in order the relieve pressure on the plastic. The system functioned well until the family decided to add an additional dwelling in the back of the house that displaced the system.
March 2007	Eronga 4	Y	This was installed during the third IRRI biogas course. The system produced gas initially, but was punctured by nail in a board that was laid on the reactor to cover the effluent outflow. This leak was repaired using a combination of tape and a clamp, and by pushing the leak below the water line. Other gas leaks in the reservoir caused additional issues. The system was reportedly replaced by Ms. Nambo, but had additional issues with leaks.
May 2006	Tlaloc	Y	This is at a small commercial swine operation just outside Mexico City. A small leak caused during the installation prompted the first round of testing in repair methods. An additional large leak in the reactor and a small puncture in the reservoir were eventually resolved with many layers of tape.
May 2006	Topilejos	N	Large leaks occur during the construction of a roof over the system. Leaks were initially repaired with large wooden clamps. Follow-up repairs with tape initially fixed the system, put it was fatally torn from below by workers try to unclog the effluent inlet.
January 2007	Chiapas 1	Y	This system remained well protected, and functioned well. The family was collecting cow manure from the field to feed the system, and a family illness ended this practice. Gas production tapered and failed, but was restarted successfully almost a year later. Not puncturing this plastic was a constant point of stress on the long journey into the village, during installation, and currently.
April 2007	Chiapas 2	Y	This was installed during an Appropriate Technology Course at a local boarding house. An initial clog in the hose was removed and biogas began to flow immediately. The system was well protected and has only had small repairs, but damage is still a concern.



### Additional Mexican Biodigester Experience

In addition to the original plastic biodigesters installed by IRRI-Mexico, I evaluated the 50 systems installed by Ms. Nambo. All of these systems were constructed in a similar manner to those installed by IRRI-Mexico and described above. As shown in Table 2, through site visits and interviews we estimated that in August of 2008 approximately 30 of the original 50 systems were still working. This survey was conducted by Ms. Nambo and me, and simply included a visual inspection of the biodigester and a short interview with the users of the system. I was able to visit 16 sites, and the rest are reported from site visits by Ms Nambo. The mayor sources of failure were system damage, a decision to move the system, or the family no longer had animals to supply the digester with organic waste.

Table 3. Current status of 50 systems installed by Callatana Nambo in Michoacán

<b>Number of systems</b>	<b>System Failure Type</b>	<b>Percentage of total installed systems (50)</b>
30	Still functioning, at least part of the year	60%
16	Bag reactor damage, generally from human, animal, sun or unknown.	32%
2	Decision to move system—this essentially means the system was taken out so the space could be used for something else, and was not re-installed	4%
2	Family no longer maintained enough animals to keep the biodigester running, and the system then came into disrepair	4%

The only other small-scale plastic biodigester in Mexico that has been evaluated as part of this research was in San Jose Zapotal, Chiapas. A Christian non-profit group had installed this system behind a local home. The system never worked because the plastic ripped during the installation. There had obviously been a lot of effort put into the repair of the plastic bag, as it was covered with three different types of tape. It could not be repaired.

This experience introduced the concept of biodigester as a technology that does not work (figure 18). The community learned an important lesson about how “unreliable” biodigester technology is. Because of the community’s first interaction with the technology was negative, initiating a new biodigester project was challenging. Instead of introducing a new idea, I had to give a positive spin on a technology the community had a negative perception of. This is an important challenge given the wide spread availability of inexpensive, but unreliable, biodigester designs on the internet and with various local groups.



Figure 18. A failed biodigester in Chiapas pushes a negative stereotype of the technology for the local community.

#### Objective for Improved Biodigester Program

With nearly 30 years of focused research into low-cost biodigester design, some clear design objectives have emerged. While millions of these systems have been installed world wide, there is now a wide body of evidence that shows that low reliability, mostly in the form of un-repairable gas leaks, are the number one cause for failure (Preston, 2002; An et al., 1996; CEDECAP, 2009). Improving the reliability of the primary reactor materials was therefore the key design objective.

Other studies have support our experience that site conditions and the high level of technical skill and time required can affect adoption rates of biodigesters

(An et al. 1997b; CEDECAP, 2008; Lansing, 2009). Additional objectives were therefore to increase the variety of site conditions that can accommodate a biodigester, and to simplify the installation process.

#### Considerations for the Design of the Improved Biodigester System

In order to focus the design efforts of the improved digester system, I focused on the key issues from the academic literature and from our own experiences with the Mexico Biodigester Program. The central issues were the reliability of the low cost bag model and the local capacity surrounding the general concepts of the technology.

#### Reliability

An and colleagues (most notably Thomas Preston) had observed the fact that the fragile nature of the plastic biodigesters was the most significant weak point in the design. Further, they noted that most plastic would not be able to last more than two years if the system was not protected from the sun (An et al., 1997b).

Given that the literature review of plastic biodigesters supported our findings in Mexico, we developed three main design objectives for improving the technical reliability of the plastic biodigester. First, and most importantly, we wanted to improve the reliability of the systems by improving material durability and reparability. As an extension of this durability, including a way to protect the system from the main enemies—sun, people, falling objects, and animals—was also a priority.

Second, we wanted to reduce installation time and the skills needed to successfully install a biodigester. By making the installation easier, we hoped that we could promote a wider diffusion of the biodigesters because there would be less need for skilled technicians.

Third, we wanted to increase the variety of site conditions that the system could accommodate. This was to make the system more versatile, but also to reduce construction cost and effort. As part of our effort to achieve these objectives we sought to minimize excavation and cement use.

Our experience installing biodigesters with IRRI-Mexico has shown that low technical reliability lowers public confidence in the biodigesters technology and therefore overall reduces adoption rates. Particularly telling, a study in Peru demonstrated that there is a very low re-installation rate if the biodigester stops functioning correctly (CEDECAP, 2008). This is the case with both large plastic failures and small user-errors that could be easily avoided. Low reliability also greatly affects potential investors in biodigester technology as well. Funders from both government and the private sector have expressed concerns with funding systems that cannot provide strong user reliability (Franco, 2009). This reliability is, however, not completely technical, and operational management issue become important if systems are to be successful.

### Local Capacity and Other Considerations

It became clear that there was a need to provide more comprehensive follow-up in order to address concerns expressed by some end users, and to encourage the continued use of the system. This is supported by the work of An and colleagues in Vietnam. They note that for other agricultural techniques, extension field workers would be closely involved to build capacity and provide follow-up. Further, they state that many problems that lead to biodigester failure could be avoided with closer management from agricultural extension workers. They suggest a closer relationship between recipient households and the program managers and researchers involved with the installations (An, et al., 1997a).

This is supported by research by CEDECAP and *Soluciones Practicas* in Peru and Bolivia. Summarizing their experience with 300-350 biodigesters in the two countries they found that follow-up and proper infrastructure to support ongoing use and maintenance was needed for the successful integration of biodigesters (CEDECAP, 2008).

Sunderasan Srinivasan (2007) has promoted the idea that in India, microfinance institutions (MFIs) should not only facilitate the construction of small plants, but also provide ongoing incentives for continued use (Srinivansan, 2007). This is supported by work in Mexico with improved cook stoves. Research found that adoption rates were significantly higher when technicians conducted follow-up visits (Bailis et al., 2008).

In many cases researchers have found that digesters were moved after only one or two years. This suggests that there was not an appropriate amount of thought given to the future conditions of the biodigester site. Preston argues that current emphasis has been given to biodigesters as a low cost addition to a farm system, not as a central integrated component of a farm system. The system becomes a central component because it is waste receptor, produces organic soil amendment, and provides energy. Better promoting this central relationship a biodigester should have with the site my help end users choose a more long term site for the system (Preston, 2002).

Additionally, fluctuation in the number of animals that families owned over time was an unexpected, but rather common issue. When there are no animals supplying waste to the biodigester, gas production falls off within weeks or months (Lansing et al., 2008). When gas production is reduced, the biodigester often falls into disrepair from lack of maintenance.

Stephen Gudeman (2001), notes that in Latin America animals such as pigs can be used as a type of “bank account” where extra corn and food can be deposited. When times are tough, pigs can be sold at the market or eaten. It may be many months or even years before new piglets can be acquired. This would indicate that, in small backyard animal rearing operations in lower income households, the fluctuations of the animal population should be expected. The conclusion then is that a successful biodigester program would also need a mechanism that would

allow families to maintain animal populations, or else manage their biodigester system in a way that would allow large shifts in input material.

As a final consideration, there is a very limited capacity in Mexico to promote the development of small-scale biodigesters. There are currently no commercial models of small biodigesters available for sale in Mexico. Although there are a few isolated groups that are attempting to install small biodigesters, there appear to be only a few hundred systems in varying conditions throughout the country.

IRRI-Mexico is recognized as one of the leading biodigester installation organizations in Mexico, but IRRI currently has only five individuals that are qualified to lead biodigester installation courses or install systems. This is indicative of the nascent character of the small-scale biogas industry in Mexico.

#### Development of an Improved Biodigester Design

I began the design process with two designs that I had developed through work with the older systems, literature review, and interviews with Ms. Nambo and others who had experience with biodigesters. The key then was to find an appropriate material to build the biodigester reactor, and then to determine if my designs were practical for fabrication. One independent floating cover design was not practical because of fabrication limitations, and therefore I continued work on a full bag biodigester design. The design process is outlined below.



### Improved Biodigester Design

The key differences between the improved biodigester design and the standard low-cost bag model is the material and the fabrication and installation process. The improved biodigester system is pre-fabricated from High Density Polypropylene (HDPP, see Table 4). This is compared to the relatively fragile standard tubular plastic that is used in low cost biodigester models that is made from low-density polyethylene. This change was to increase durability and weather resistance of the improved biodigester, and also to use a material that is easier to work with. The HDPP can be shaped and welded in a way that the low-density polyethylene cannot.

In the fabrication process the biodigester is completely sealed except for specific liquid and gas outlets. The standard low-cost bag biodigesters are made from tubular plastic that is open on both ends and must be sealed during installation. Because the improved biodigester is pre-fabricated, all of the entrances and exits to the system can be made with threads or other gasket-sealed connections to adapt to PVC or other tubing. The tubular plastic must be cut on-site to allow for entrances or exits, and then sealed over PVC or other tubing by using tire inner tube or another homemade gasket system (as described in the previous chapter).

The difference in these two models is that error and variation can be minimized with the improved biodigester system because of the easy adaption of tubing for the gas and liquid entrances and exits of the system. The standard low-cost model requires more skill to seal to tubing, and ultimately the connections cannot be as secure. Even when a standard system is installed properly, the properties of the reactor material mean that it will be far less reliable than a system made of HDPP.

The improved system also comes with a sheet of geo-textile; a fabric-like material that is made from recycled plastic. This material is made available because vendors of HDPP also sell geo-textile as a liner for large jobs such as lined lagoons and water storage facilities. The geo-textile is installed below the biodigester to protect the system from sharp objects on the ground and from the future intrusion of animals and plants. The geo-textile is also useful to protect the biodigester during shipping and before installation.

With the geo-textile to protect it, the biodigester can be installed nearly anywhere. The strength of the HDPP material allows the improved biodigester system to fully support the weight of the liquid slurry inside of it. This means that only small (<40 cm) earthen banks are needed to support the digester. Small rock or wooden walls would also support the system.

The standard low-cost model requires a deep trench be dug or a large sturdy wall be built to support the biodigester because the weak tubular plastic cannot

support the weight of the liquid slurry inside. Although the improved biodigester can still be installed in a trench (this is often necessary to accommodate the grade of a particular site), it has the large advantage over the standard design of being able to be installed nearly anywhere.

Not having to dig a large trench drastically reduces installation time, as this is often over 50% of the total installation process, and definitely the most labor-intensive aspect. Installation time is also reduced because the connections of the improved system are pre-assembled, and require no additional assembly on-site. The standard biodigester system installation requires a laborious assembly process to secure all of the tubing connections.

The improved biodigester system went through a few small variations as outlined below. The biodigester is prefabricated from 0.75 mm HDPP. A diagram and photos of the system are included in Figures 19-25. The basic function of the biodigester is not different from the standard tubular plastic biodigester, as explained in Chapter Two. The digester uses HDPP four-inch wide sleeves that are welded to the bottom of the biodigester to connect the inlet and outlet pipes to the body. Four-inch PVC pipe is slid into the sleeve and the sleeve is secured around the pipe with gasketed four-inch hose clamps and a special HDPP reinforced tape. The gas exit is either a similar sleeve of two inches that is connected to two inch PVC, or a bulkhead fitting with a threaded adaptor.

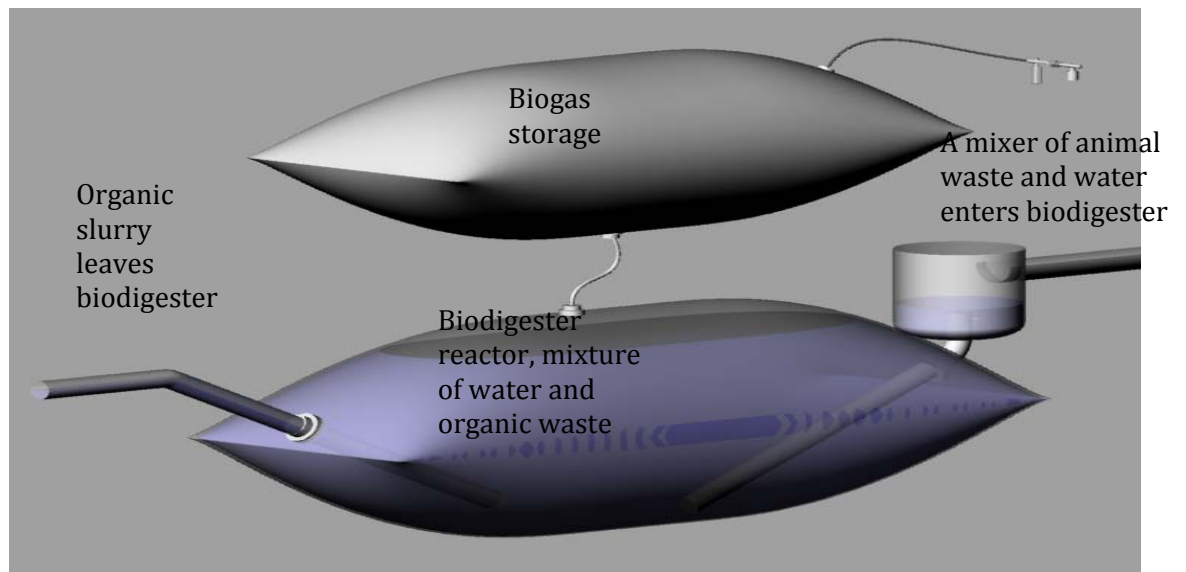


Figure 19. A model of the improved biodigester showing the water traps that prevent outside air from entering the system.



Figure 20. The author tests the durability of the improved biodigester system in Jalisco. Standing on top of the older tubular plastic biodigester design would not have been recommended, and would likely tear the systems. The improved system could be jumped and walked on easily.



Figure 21. Children examine an improved biodigester system in Guanajuato.





Figure 22. The exit and entrance connections for the biodigester can be seen on this system installed at a demonstration center in San Cristobal de Las Casas, Chiapas, Mexico. Also shown here is the ability of the improved biodigester to be installed without supporting walls or a deep trench as was needed with the standard low-cost biodigester design.



Figure 23. A recently (April 2009) built improved digester with the sleeves of the system that will connect to the PVC inlets and outlets visible. This digester is not installed and has just been unwrapped onsite for inspection before the installation at GIRA.



Figure 24. A closer look at the inlet and outlet design for liquids shows the double four-inch hose clamp sealing the PVC pipe to the biodigester body. This PVC tube continues into the biodigester about 40 cm.



## Design Process of the Improved Biodigester System

In September of 2007 we scheduled another biodigester installation course. The course was scheduled to take place in Mazamitla, Jalisco. A student of our second biogas course owned a small geomembrane fabrication business in Morelia, Michoacán, and we had discussed constructing a biodigester from his High Density Polyethylene (HDPE). He invited me to spend the day at his location to try and assemble a biodigester from the geomembrane. Our primary goal was to design a way in which the effluent inlet and outlet could be constructed without the use of the expensive hardware that was utilized for water tanks. By the end of construction we had some good ideas, but no biodigester. The technicians seemed discouraged, and there was no second invitation extended to me to finish the construction.

We found another supplier in Guadalajara who advertised geomembrane water tanks. They utilized a reinforced 0.75 mm HDPP and made flexible bags for water storage. The bags were similar size and shape to the flexible bag biodigesters we were currently building. The HDPP material was durable with over 80 lbs of tear resistance, and could be repaired with a heat gun or a special HDPP reinforced tape designed to adhere with the material.

We ordered a bag digester from the company, and because it was their first time making the system, they donated the material. The bag was fabricated at the

workshop in Guadalajara (Figure 25), with effluent entrances and exits made from 4-inch PVC connections. The gas exit was made from a 1-inch PVC connection.

The retail cost of the system was very high however because over US \$200 was used in just hardware and screws to create the perforations in the bag. This was more than we wanted to spend for the entire system. Large and heavy stainless steel bolts were used for securing the expensive PVC hardware.



Figure 25. Fabrication of an early improved biodigester. A heat gun and roller is used to seal the plastic. Heavy and expensive PVC tube adaptors can be seen for the inlet and outlets connections.

The system did not work ideally on the first installation attempt. The construction technique left large, heavy creases in the material where it was welded shut, making the bag less flexible than it could have been. The effluent entrance and exit were also placed poorly, down in the bottom corner of the bag instead of centered. Lining the system up in the trench meant that the system had to be twisted slightly (Figure 26).



Figure 26. The same digester shown in Figure 25 is shown here installed. This first attempt left the digester twisted because of the location of entrance and exit valves on the corners, while the site was designed for the entrance to be centered on the bag.



Figure 27. The same digester as in Figure 25 and 26 is shown here after it was untwisted, with the waste entrance and exit pipes at the site modified to accommodate the corner mounted exit and entrances of the biodigester.

Straightening the bag and adapting the site to the system by adding additional piping to the effluent inlet resolved this twist (Figure 27). There were also leaks in the heavy inlet and exit hardware, and some small leaks in the material. These were caused during the fabrication of the system. Both of these leaks were repaired with the specialty tape.

Attending the Mazamitla course and installation was a third supplier of geomembrane. He had attended the course as a way to understand what other markets may be open for his product in Mexico, since geomembrane was already being used to build large industrial-scale biodigesters for large farms. He invited me to his workshop in San Luis Potosi to build a biodigester.

The breakthrough in San Louis Potosi was twofold. First, a new material called Enviroliner™ from Layfield Geomembrane had just been released. Enviroliner is a new, more flexible HDPP that has a puncture resistance of over 60 lbs., making it very durable. The material is also very workable, and can be shaped and sealed using an extrusion welder, shown in figure 28. The material has a high resistance to the sun, and is guaranteed for 20 years of outdoor applications. Second, the company had also recently released a low cost HDPP adapter for pipe entrance and exits as shown in Figure 29. This resembled a brimmed hat with a wide square brim, and could be welded onto the fabricated bags.

Using this tube adaptor, 4-inch PVC could be inserted into the bag to allow the improved biodigester to function more closely to the original Taiwanese design. With some other improved fabrication techniques, including extrusion welding, we were also able to reduce the rigidity of the seams.

Table 4 gives selected material specifications for Layfield Environliner and a reinforced HDPP that we have since used to construct the improved biodigester models.



Figure 28. The HDPP extrusion welding gun can be seen here sealing the HDPP Eviroliner in San Luis Potosi, Mexico.



Figure 29. The first improved biodigester made from HDPP Enviroliner. In the foreground a new PVC adaptor sleeve can access port can be seen. This is a 10 m improved biodigester.

Table 4: Some selected properties of two brands of HDPP that have been used to construct small, improved biodigesters.

Property	Thickness	Tensile Strength	Elongation	Tear Resistance	UV Resistance %HPOIT* Retained
<b>Layfield Environliner 6030</b>	30 mil (0.75 mm)	115 ppi	800%	16 lbs	80% at 20,000 hours
<b>Raven Industries DURA-SKRIM J30BB</b>	30 mil (0.75 mm)	110 ppi	750%	97 lbs	Not listed

\*High Pressure Oxidative Induction Time is an industry measure of UV resistance

### Fabrication of the Improved Biodigester Design

The fabrication process starts with a sheet of the HDPP Enviroliner that is 3.8 m wide by the desired length of the biodigester. The sheet is doubled over on itself along its long edge, and a long plastic extrusion weld is made to make a tube that is open on both ends. This means that the biodigester tube has approximately a 3.6 m circumference (some material is lost in the overlap of the weld) and approximately a 1 m<sup>2</sup> surface area at the mouth of the tube. This implies that volume can be calculated as the length of the system (m) multiplied by one square meter as shown in equation 3.

Equation 3.

$$\text{Length of biodigester (m)} * \text{surface area of system cross section (1 m}^2\text{)} = \text{system volume (m}^3\text{)}$$

The gas exit valve is then installed and holes are cut for the effluent inlet and outlet. The ends are then sealed, and the corners are removed. Finally the tube adapters are welded on over the effluent holes. Alternatively, we have also begun fabricating the tube adapters to reduce costs by simply welding a small tube that is made to fit the desired PVC access onto the digester, as shown in Figure 23.

We constructed a 10 m<sup>3</sup> biodigester that was later installed in a small community outside of Mazamitla called *Coral Falso*, shown in Figure 19. Since then there have been small design variations surrounding the placement of the effluent



inlet and outlet, but the basic design has remained the same. To date, there have been ten improved biodigesters installed throughout Mexico, including in the states of Yucatan, Guanajuato, Michoacán, Jalisco, and Chiapas.

#### Results of the Improved Biodigester System

The results of the biodigester system are taken from a compilation of user interviews and direct observations of each system. I used biogas production and composition as an indicator to determine whether or not the improved biodigester design provides similar results as previous biodigester designs. Table 5 shows biogas carbon dioxide and methane concentrations measured in five different biodigester systems on different occasions between 2008 and 2009.

In Table 5, the carbon dioxide content was measured with a Bacharach Fryrite CO<sub>2</sub> Meter that measures carbon dioxide in water saturated gas between 0-60% concentrations (Bacharach, 2009). Within the biodigester industry it is assumed that methane makes up the balance of the gas composition that is not measured as carbon dioxide, with accuracy within +/-3% (Moser, 2008).

Table 5. Carbon dioxide measurements and methane concentration calculations for six improved biodigester systems in Mexico taken between 2008 and 2009.

Date	Location	Average CO <sub>2</sub> Composition (three tests)	Estimated CH <sub>4</sub> Composition (high estimate)	Low estimate
7/28/08	Mazamitla 1	28	72	69
7/28/08	Mazamitla 2	26	74	71
8/1/08	Los Baños	28	72	69
8/5/08	Mazamitla 1	26	74	71
8/5/08	Mazamitla 2	28	72	69
8/12/08	Eronga. 1	34	66	63
2/10/09	Eronga. 2	32	68	65
20/04/09	Buena Vista Pachan	30	70	67
22/04/09	Tziscoao	32	68	65
28/04/09	Eronga 1	32	68	65
	<b>Mean</b>	<b>30</b>	<b>70</b>	<b>67</b>

All measurements taken with Bacharach Fryrite CO<sub>2</sub> 0-60% Product number 10-5032

Gas measurements were taken by accessing the biogas in the system through either the pressure release bottle or by disconnecting the system on a part of the gas line. The Bacharach gas meter was first calibrated adjusting the calibration needle to the fluid level within the meter. The meter comes with a gas sampling hose that

can fit easily into the gas line of the biodigester. The open end of the gas line is kept under water (in either a small bucket or in the pressure escape bottle) in order to keep the system closed from the outside air. The gas sampling hose has a small hand pump that moves gas into the Bacharach gas meter. The pump is pumped 18 times to ensure that the system is completely filled with the gas sample. Once the meter is full, the sampling hose is disconnected. The meter is inverted twice, and then left at a 45-degree angle for 10 seconds to ensure all the fluid returns to the main chamber of the meter. The CO<sub>2</sub> composition of the gas (as a percentage) is indicated by the fluid level in the meter.

The carbon dioxide concentration was measured three times, the results were averaged, and the methane content was then calculated as follows:

Equation 5:

$$\text{Low Estimate: methane \%} = 100\% - \text{carbon dioxide \%} - 3\% \text{ other gas constituents}$$

Equation 4:

$$\text{High Estimate: methane \%} = 100\% - \text{carbon dioxide}$$

These results show that the biogas is within the gas composition range of established manure biodigesters, between 55-80% methane (Preston, 2002; An et al., 1996; Moser, 2008).

Initial observations indicate that the improved biodigester design functions reliably and delivers the benefits observed from previous biodigester programs.

These benefits include improved sanitary conditions and manure management, reduced odors and flies, improved fertilizer properties of the effluent, reduced GHG emissions, renewable energy generation, and reduced household expenditure to meet energy needs.

These benefits were realized without the weaknesses established by previous biodigesters projects. Notably, biodigester installation times were reduced significantly. On multiple occasions technicians were able to install the systems from start to finish in less than one full workday. This is compared to two to five days that have been established as the normal installation time (An et al., 1996; Lansing, 2008; CEDECAP, 2008; Herrero, 2008; Brown, 2005).

The reduced installation time was largely due to the fact that the improved design had structural integrity on its own, and does not require a full excavation or retaining wall to support the weight of the liquid slurry. The integrated PVC inlet and outlet tubes seemed to adapt to a wide variety of site conditions better than the tubular biodigester design that required that concrete inlet boxes (called *registros* or registers in Spanish) be constructed. Limited space, bedrock, or unusually shaped sites will still allow for biodigester installations without the need for concrete construction or the need to dig a deep trench.

Although a small amount of concrete was often used to fix inlet and outlet tubes in place, the concrete requirements were significantly less than in the earlier

design, and it is not necessary to wait for the concrete to dry to continue with the installation.

The most significant improvement was the durability and reparability of the material. This allowed for the material to be shipped and packed into remote locations without worry of a small perforation undermining the installation. There were many occasions when children would walk across the system or a falling object would land on the system without issue (something that would have been a major problem with the standard plastic material).

The new systems were not without issues. Many of the systems arrived from the workshop with small leaks, and many of the gas exits of the reactor and reservoir has leaks, apparently from not being secured tightly enough.

The main difference between these leaks and the leaks that were experienced in the original polyethylene was the ability to repair them easily. The specialty tape that is designed to make repairs in the HDPP made the difference, and the act of mending the small leaks before the installation was used to train the end users in case they would have to replace small leaks in the future.

Leaks, however, were not appreciated, and there were repeated meetings with the fabricator to ensure that the systems did not start with leaks. A leak seems to make the end users automatically skeptical of the system, and while they are easily fixed, there is a certain lack of confidence that can be observed.

## Conclusion

At the outset of the IRRI-Mexico Biogas Program there was only a small amount of research into small-scale plastic biodigesters. Although multiple installation manuals were downloaded from the Internet, there was nearly no research into the published literature. The observations that durability, installation time, and a better site adaptability were key design shortfalls of standard tubular plastic digesters were made independently by the IRRI-Mexico Program through experience. Later, these observations were supported by research into the published literature on similar biodigester projects.

Other organizations and individuals have also worked with similar design objectives for improved biodigesters (CEDECAP, 2008; Lansing, 2008), and there is some evidence that geomembrane was used to prefabricate small biodigesters in other occasions. For example, a webpage shows some photos of high-density polyethylene biodigesters in the Philippines (Baron, 2008). One such system was recently built in Peru from a PVC material (CEDECAP, 2009), and a similar system was recently installed at a testing center in Costa Rica with EARTH, but with another PVC substrate material (Lansing, 2008).

There are still many improvements that could be made on the design and the installation process. These include the incorporation of roof and protection systems that can also potentially improve the solar heat gain of the system, incorporation of

equipment to better utilize biogas, and the production of pressurization systems to make biogas a more versatile energy source.

Hopefully, future international cooperation will continue to push the progression of biodigester technology. For example, IRRI has worked with other groups to coordinate the first Latin American Small-Scale Biodigester conference in Cajamarca, Peru, including representatives from nine countries in Latin America working on biodigester systems. The conference was in May 2009, and more details on the conference are included in Appendix A.

Equally important is the ability of small-scale biodigester efforts to overcome the challenges associated with follow-up with biodigester recipients, maintenance of animal populations to keep the biodigester functioning properly, and incorporation the biodigester as the center of small agricultural systems.

## CHAPTER FOUR: FINANCIAL CONSIDERATIONS AND BENEFITS DERIVED FROM THE IMPROVED BIODIGESTER SYSTEM

Biodigesters are often seen as an energy source, with the direct benefits derived from the system calculated in terms of the energy content of the biogas produced for use. Some have argued that biodigesters must be incorporated as a central piece of rural farm systems so that a wider range of environmental, health, and sanitation benefits can be realized and properly valued. The “narrow scope” of energy benefits often considered in cost benefit analysis of biodigesters therefore does not reflect the true benefits biodigester provide to their users and society (Srinivasan, 2007; Botero, 2002).

In recent years, large-scale biodigesters have been able to receive up-front capital investment funding through inclusion in GHG emission reduction markets such as the Clean Development Mechanism of the Kyoto Protocol (UNFCCC, 2008). This same funding has not yet emerged as a viable source of investment for small-scale systems, and therefore benefits continue to be calculated within the “narrow scope” of energy services provided to the end user.

In this chapter I first compare the economic performance of the standard low-cost plastic digester with those of the improved HDPP IRRI-Mexico digester design. This comparison is presented in terms of the up-front capital investment and the life-cycle costs of the two systems.



I then present a framework with which to begin evaluating the direct benefits and co-benefits that can be derived from biodigesters, including reduced GHG emissions, improved indoor air quality, and improved sanitation and environmental services. I conclude this chapter with cost benefit calculations. In the first cost-benefit calculation I use only the direct benefits of biodigesters, and in the second I use all direct and co-benefits.

Through this initial evaluation of the benefits derived from small-scale biodigesters, I conclude that energy services are indeed too narrow a scope to determine the overall feasibility of installing biodigester systems.

#### Cost Comparison of the “low cost” Plastic Biodigesters and the Improved Biodigester System

Experiences from around the world have produced a range of installation costs of low cost bag-type biodigesters ranging from US \$5 to US \$200 (CEDECAP 2008; Lansing, 2008; An et al., 1996). These costs generally do not consider labor and materials obtained locally. The lowest cost systems also use the bare minimum materials. These low-cost designs place a lot of responsibility on the end users because of the minimalist approach to components.

The costs of the original biodigester systems installed by IRRI-Mexico are outlined in Table 6. These are higher than other reported programs (CEDECAP 2008; Lansing, 2008; An et al., 1996). This seems to be because of lower material

costs in Asia and other locations in Latin America where data from other studies were generated. We may have also used a higher quality plastic as there are much quality and price variations within the plastic that is sold as “greenhouse plastic.” In addition, the results in Table 6 include all material and labor costs for the installations. Finally, there was more PVC used in the original IRRRI system to provide safety release valves and on/off valves to control the flow of gas from multiple points.

Table 6. Example costs of the original tubular plastic biodigesters installed by the IRRI Mexico Biogas Program. This example is based on an eight meter long reactor with a two-meter long reservoir.

Tubular	Components	Amount	cost per unit (pesos)	Cost	Subtotal
Accessories	1" Female threaded Adaptor	2	\$5.20	\$10.40	
	1" Male threaded Adaptor	0	\$2.32	\$0.00	
	1" 90 Elbow	1	\$6.71	\$6.71	
	2" Tee	1	\$91.00	\$91.00	
	1.5" Threaded Cap	1	\$25.00	\$25.00	
	2-1.5" Reduction Bushing	1	\$42.00	\$42.00	
	2-1" Reduction Bushing	2	\$42.00	\$84.00	
	1" PVC Valve	1	\$50.00	\$50.00	
	1' Tee	1	\$7.86	\$7.86	
	1" threaded hose adaptor	2	\$5.00	\$10.00	
	1" polyethylene hose	2.3	\$3.00	\$6.90	
	1" PVC pipe	0.5	\$9.87	\$4.94	
	6" PVC Pipe	1.5	\$80.00	\$120.00	
Reactor	plastic reactor	26	\$70.00	\$1,820.00	
Reservoir	plastic reservoir	5.2	\$70.00	\$364.00	
					<b>\$2,184.00</b>
Stove	Burner	1	\$60.00	\$60.00	
	3/4" coupler	1	\$10.00	\$10.00	
	3/4" 18 cm threaded nipple	1	\$25.00	\$25.00	
	3/4" threaded stainless steel valve	1	\$40.00	\$40.00	
	3/4" flexible plastic hose	2	\$12.00	\$24.00	
	3/4"-1" hose to hose adaptor	1	\$8.00	\$8.00	
	3/4" threaded hose adaptor	1	\$5.00	\$5.00	
					<b>\$172.00</b>
Additional Material	Packing Tape	1	\$12.78	\$12.78	
	Teflon Tape	1	\$3.00	\$3.00	
	Steel Wool (non-stainless steel)				
	PVC Glue	1	\$28.81	\$28.81	
					<b>\$44.59</b>
			<b>Total Materials</b>	<b>\$2,859.40</b>	
			<b>Labor</b>	<b>\$2,500.00</b>	
			<b>Total System Costs</b>	<b>\$5,359.40</b>	
<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <b>Cost in US\$ (using 2009 average exchange rate of 13:1)</b> </div>		<b>\$412</b>			

Table 7. An example of the costs of an 8 m<sup>3</sup> improved biodigester for comparison with the tubular plastic model. As with the tubular plastic model, accessory structures and concrete work have not been considered.

Improved	Components	Amount	Unit Cost	Cost	Subtotal
Accessories	1" Female threaded Adaptor	2	\$5.20	\$10.40	
	1" Male threaded Adaptor	0	\$2.32	\$0.00	
	1" 90 Elbow	1	\$6.71	\$6.71	
	2" Tee	1	\$91.00	\$91.00	
	1.5" Threaded Cap	1	\$25.00	\$25.00	
	2-1.5" Reduction Bushing	1	\$42.00	\$42.00	
	2-1" Reduction Bushing	2	\$42.00	\$84.00	
	1" PVC Valve	1	\$50.00	\$50.00	
	1' Tee	1	\$7.86	\$7.86	
	1" threaded hose adaptor	2	\$5.00	\$10.00	
	1" polyethylene hose		\$3.00	\$6.90	
	1" PVC pipe		\$9.87	\$4.94	
	6" PVC Pipe		\$80.00	\$120.00	
					<b>\$458.81</b>
Reactor	Labor	2	\$100.00	\$200.00	
	Material	13.2	\$220.00	\$2,902.90	
Reservoir	Labor	1	\$100.00	\$100.00	
	Material	4.1	\$220.00	\$909.33	
					<b>\$4,112.23</b>
Stove	Burner				
	3/4" coupler	1	\$60.00	\$60.00	
	3/4" 18 cm threaded nipple	1	\$10.00	\$10.00	
	3/4" threaded stainless steel valve	1	\$25.00	\$25.00	
	3/4" flexible plastic hose	1	\$40.00	\$40.00	
	3/4"-1" hose to hose adaptor	2	\$12.00	\$24.00	
	3/4" threaded hose adaptor	1	\$8.00	\$8.00	
					<b>\$167.00</b>
Additional Material	Packing tape	1	\$12.78	\$12.78	
	Teflon tape	1	\$3.00	\$3.00	
	Steel wool			\$0.00	
	PVC glue	1	\$28.81	\$28.81	
					<b>\$44.59</b>
			<b>Total Materials</b>		<b>\$4,650.80</b>
			<b>Labor</b>		<b>\$1,500.00</b>
			<b>Total System Costs</b>		<b>\$6,150.80</b>
	<b>Cost in US\$ (using 2009 average exchange rate of 13:1)</b>	<b>\$473</b>			

As shown in Tables 6 and 7, the improved biodigester system has almost a 40% higher initial material cost. This is primarily due to the extra cost of the HDPP material for the reactor and the reservoir compared with the original type of plastic that was used. However, the installation cost of the improved system is an average of 40% less than that of the tubular plastic biodigester, making the total installed cost of the improved digester about a 13% more than the tubular plastic biodigester.

While it is hard to estimate the service life of the original type of plastic, estimates have been made from between three to 20 years (Lansing, 2008; An, 1996; Preston 2002). Our field experience shows that an average useful life of the original type of plastic is between 1-5 years, although one system in the home of Ms. Nambo just reached six years (Nambo, 2009).

The useful life of the improved system can be estimated as the life of the reactor material, which is guaranteed for 20 years in all outdoor applications, within the temperature range of -75 and 180 degrees Fahrenheit. Because there are not data directly related to the lifespan of the improved digesters aside from material data, more research is necessary to evaluate the ultimate life of the improved systems.

### Life Cycle Cost Assessment

In order to conduct a life cycle assessment (LCA) of two given alternatives, an estimated life span on the longest lasting (or most significant) component must be estimated (Sandia National Laboratories, 2002). Given the longer life of the HDPP

reactor, in order to compare the life cycle costs (LCC) of the two different biodigester designs, the costs of keeping the tubular plastic biodigester functioning as long as the estimated life span of the improved biodigester system must be considered. In this life cycle assessment (LCA), we will conservatively assume that the improved biodigester will last 15 years and that the tubular plastic reactor will last an average of five years. This means the cost of replacing the tubular plastic reactor at least twice must be included over the 15-year period of the LCA.

An LCA uses the present value of future costs or revenues in order to estimate the economic performance of two alternative systems that will provide similar services. An LCA is not necessarily an accurate estimate of the actual costs or benefits of the two systems during this time period. Rather, it is a means by which the two alternatives can be compared using similar assumptions (Sandia National Laboratories, 2002). Using a methodology presented by the Sandia National Laboratories (2002), this LCA will use the following equation:

Equation 6.

$$LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw}$$

where:

C = capital cost (initial capital expenditures, system design, & installation)

M = sum of annual maintenance costs

E = sum of annual energy costs (e.g. fuel)

R = sum of all anticipated equipment repair and replacement costs

S = salvage value of system equipment at the end of the life cycle period

pw = the "pw" subscript indicates the present worth of each factor

In this case it is assumed that the energy value that is produced from each biodigester will be the same (although the better reliability of the improved biodigester system means that it would likely provide more energy overall). Because the value given to that energy will vary greatly based on the energy source that is being replaced, a value of zero has been given. It is also assumed that there is no salvage value of either system. The systems have also been given the same annual maintenance costs based on changing the sulfur filter medium. An average discount rate of 10% has been assumed for both systems over the 15-year period of the LCA. Additional details on the assumptions used for the LCA are included in Table 8.

In order to calculate the present worth of the inputs in this LCA, the discount (or interest) rate is used to estimate how much money must be put aside today so that you would have the given amount of money in the future. For a single sum of money, such as the cost of replacing equipment in the future, the following equation is used:

Equation 7.

$$P = F/(1+I)^N$$

where:

P = the single present worth of a future sum of money

F = the estimated future sum of money

N = year at a given discount rate

I = discount (or interest) rate

In order to estimate the total sum of annual costs (or revenues) for a given project, the same discount rate is used to estimate the total money that you would need today in order to have a sufficient amount of money to cover the annual costs. In this LCA, the equation would apply for annual maintenance costs of operating the biodigester, as follows:

Equation 8:

$$P = A * [1 - (1 + I)^{-N}] / I$$

where:

P = the uniform present worth of an annual sum of money

A = the annual sum of money (maintenance costs)

N = year at a given discount rate

I = discount (or interest) rate



Table 8. Assumptions used to conduct the LCA of the tubular plastic biodigester and the improved biodigester system. All costs are in Mexican Pesos (MN), include installation costs, and assume a 10% discount rate.

Part name	Plastic Reactor	Plastic Reservoir	Misc. PVC/Hoses	Annual Maintenance
<i>Tubular plastic biodigester</i>				
<b>Cost (MN)</b>	\$4,320.00	\$864.00	\$1,000.00	\$50.00
<b>Replace every X years</b>	5	5	8	1
<b>Adjusted value (MN)</b>	\$4,750.73	\$1,609.43	\$466.51	\$380.30
<i>Improved Biodigester</i>				
<b>Cost (MN)</b>			\$1,000.00	\$50.00
<b>Replace every X years</b>			8	1
<b>Adjusted value (MN)</b>			\$466.51	\$380.30

Table 9. The LCA of the tubular plastic biodigester and the improved biodigester system. This table uses assumption from Table 8, and assumes a 10% discount rate. The improved system is over 40% less expensive of the 15-year time period assessed.

	Capital Cost (C)	Sum of annual Maintenance (M)	Sum of Annual Energy (E)	Sum of all equipment replacement (R)	Salvage value (S)	Total LCC
<b>Tubular Plastic Biodigester</b>	\$5,411	\$380	\$0.00	\$5,684	\$0.00	<b>\$11,475</b>
<b>Improved Biodigester System</b>	\$6,022	\$380	\$0.00	\$466	\$0.00	<b>\$6,869</b>

Using the assumptions outlined in Table 8, and the LCA equations outlined above, Table 9 shows the LCA of the tubular plastic biodigester and the improved biodigester system. The improved system is more than 40% less expensive over its 15 year estimated life span, providing the same services as the tubular plastic biodigester.

#### Benefits Derived From Biodigesters

When the primary benefits of biodigesters are described, the focus is generally on the clean, renewable energy that is provided for the recipient household. Less commonly, the benefits from the improved fertilizer from the system are described as well. Srinivasan (2007) has argued, however, that there is a surplus of benefits received from broad-scale implementation of biodigester systems that extend well beyond the “narrow scope” of clean energy for the recipient family.

This section will more completely describe the benefits received from biodigesters systems and present a framework for quantifying those benefits. For the sake of this research, energy and additional co-benefits that potentially could lead to the funding of biodigester implementation projects will be the primary focus.

Specifically, the following sections show that the reduction of household GHG emissions from the use of biodigesters can be a significant benefit. Additionally, the human and environmental benefits that contribute to the MDGs can be improved when biodigesters are used for both supplying energy and processing waste.

## The Potential Role of Biodigesters in the Energy and Sanitation Baseline

Biodigesters can be installed as an intervention to reduce greenhouse gas emissions, improve indoor air quality, reduce water contamination, and avoid environmental degradation. The degree to which each system brings about change in a particular household will vary greatly between individual households so it is common to calculate these changes at a population level. The following provides an estimate of the improvements that could be made given a broad scale implementation of small biodigesters.

### Greenhouse Gas Emissions

The baseline GHG emissions for households in the developing world that might be reduced by the implementation of biodigester projects come from two primary sources. First, combustion of biomass produces carbon dioxide and other GHGs at a rate of approximately 150-300 g of CO<sub>2</sub>e<sup>3</sup> per MJ of energy delivered (Kammen, 2003). The net GHG production rates vary greatly among households and energy systems, and have been estimated to be between 5 and 10 tonnes of CO<sub>2</sub>e per household per year for households in rural Mexico (Berrueta et al., 2007).

Second, organic waste, particularly human and animal waste, can produce methane during anaerobic decomposition. In Mexico, Franco (2007) has shown a common source of these emissions are small hog farms when waste is stored in

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<sup>3</sup> CO<sub>2</sub>e is the common abbreviation used to mean carbon dioxide equivalent.

lagoons. For example a small hog farm with 10 producing females would produce an estimated 8-10 tonnes of CO<sub>2</sub>e per year.

Biodigesters can reduce GHG emission by capturing methane emissions from organic waste and destroying the methane through combustion. Figure 30 shows the potential methane production from different organic wastes. To convert a known mass of methane to the universal CO<sub>2</sub> equivalent (tonnes CO<sub>2</sub>e) global warming potential, multiply the methane mass by 21 (UNFCCC, 2008).

Using the higher heating value (HHV), the captured biogas provides an energy source at a rate of approximately 0.023 MJ/liter when the average methane content is 60%.<sup>4</sup> This energy can therefore displace some portion of biomass or petroleum based fuels and the associated emissions. As shown in Figure 31, biogas has the lowest global warming potential per energy unit delivered to the cooking pot of the most common fuels available for cooking and household energy shown on this chart (Smith et al., 2005).

During cooking, the displacement of biomass fuels reduces GHG emissions at a rate between 83 and 375 g CO<sub>2</sub>e/MJ<sup>5</sup> delivered to the pot. Replacing LP gas with biogas also reduces 35 g CO<sub>2</sub>e of GHG emissions for every MJ delivered to the end user (Smith, et al., 2005).

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<sup>4</sup> Methane has an energy content of 0.038 MJ/L (Oak Ridge National Laboratory, 2009). Biogas that is 60% methane therefore has methane content equal to: Methane Content Biogas = 0.038 MJ/l \* 0.60 = 0.023 MJ/l

<sup>5</sup> The large range here is because "biomass" can refer from everything from dung to dried fuelwood and can be burned in different open fire or stove scenarios with varying efficiencies (Smith, et al., 2005).

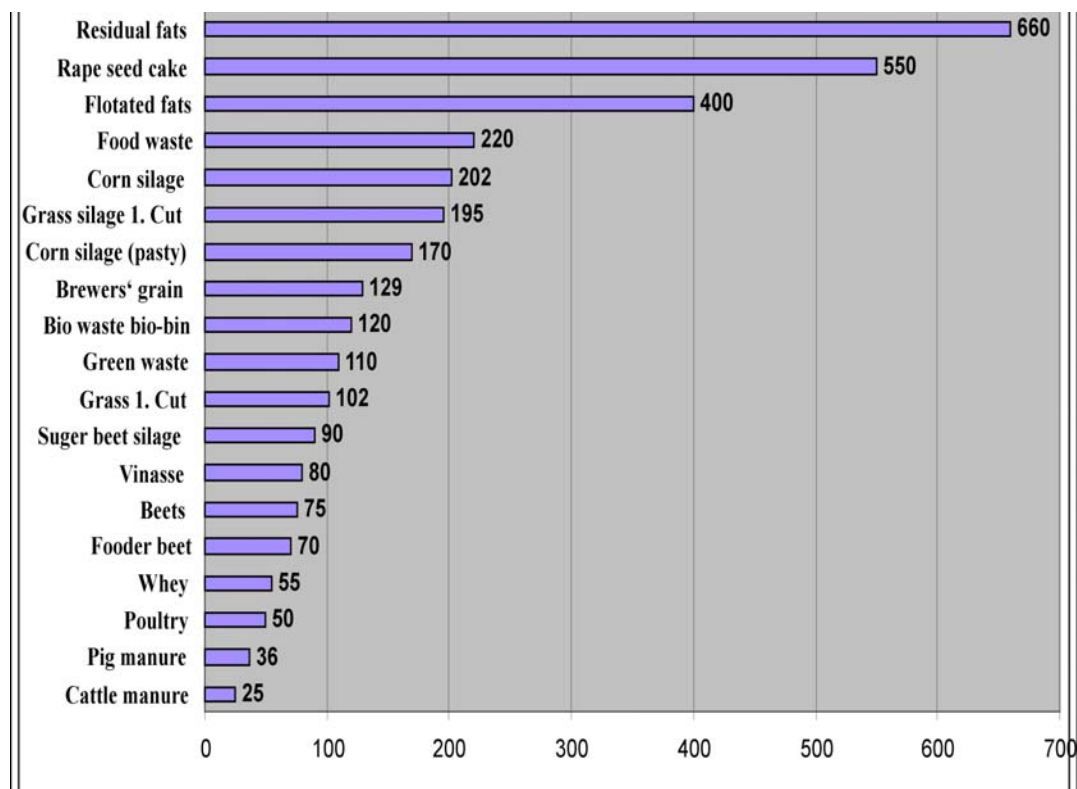


Figure 30. Gas yields of various organic materials in m<sup>3</sup> of gas per dry ton of material (M-Con Bio, 2009)

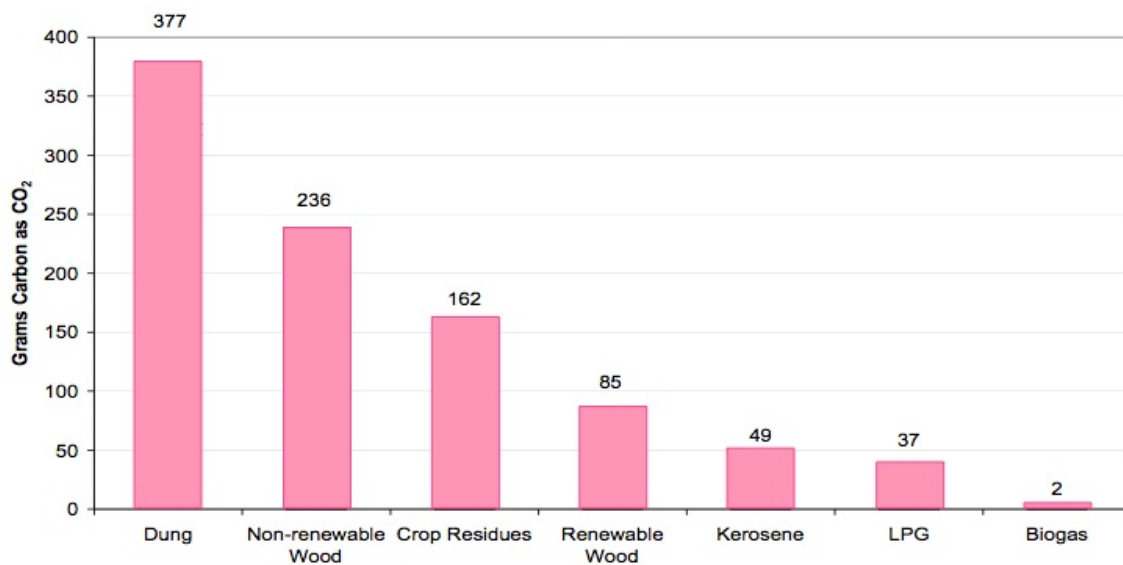


Figure 31. Global warming commitments from a MJ of energy delivered by different household fuels with typical stoves in India: Kyoto GHGs only (Smith, et al., 2005).

Biogas electricity generation that is used as an alternative to the Mexican grid-mix displaces GHG emissions at a rate of 0.6 tonnes CO<sub>2</sub>e / kWh of electricity delivered (Lokey, 2008). The Mexican grid mix is comprised of 81% fossil fuels, and these contribute to the relatively high carbon intensity of the electricity.

Large hydro makes up 11% of the reportedly “low carbon” electricity. Hydropower is commonly considered to have low carbon emissions, but because of the large reservoirs necessary to make large hydro stations, large hydropower may have some uncalculated GHG emissions associated with it<sup>6</sup> (Lokey, 2008).

#### Indoor Air Pollution

In low-income developing countries many households use biomass fuels in simple stoves with poor combustion characteristics (Kammen et al., 2003). Macht et al. (2007) estimate that 2.4 billion people rely on biomass fuels worldwide, and that over half of household energy is from biomass in developing nations. This may be as high as 10% of all human energy demand worldwide (Smith, 2006).

In Mexico, one in four households use fuel wood for either all or part of their energy for cooking (Masera, 2005). Some common cooking systems are shown in Figures 32 and 33. The combustion of biomass produces small particulates and gas constituents that have been shown to be harmful to human health. Biomass combustion for cooking and heating exposes women and children to particulate

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<sup>6</sup> Large hydro dams in tropical areas can release carbon dioxide and methane as biomass breaks down in the depths of the lakes, but there is a wide range of emissions estimates from negligible to higher than fossil fuel emissions rates (Fearside, 1997; WCD, 2000; Gaffin, 2000).

levels that are ten times the World Health Organization's (WHO) guidelines (Masera, 2005; Smith, 2000). Specific cooking patterns in Mexico result in exposure of women and children to particulates for an average of two to four hours per day and more when additional commercial activities, such as tortilla making, are conducted around a fire (Masera, 2005).



Figure 32. This image was taken of a common cooking system in Chiapas. The smoke from woodfuel (shown on the left, and apparent from the blackened pots on the right) can cause many health concerns for women and children due to prolonged exposure.





Figure 33. This is another common cooking system in Mexico, seen here in Yucatan. This stove is used to cook for over 40 children in a children's shelter, but is common or "high end" for what is commonly used in the area

Exposure to poor indoor air quality from biomass fuels is linked to acute lower respiratory infection (ALRI) causing pneumonia in children under 5 years old. ALRI is the number one killer of children worldwide and is the disease responsible for the most lost years of life on earth (Smith, 2006). Together with Chronic Obstructive Pulmonary Disorder (COPD) in women with prolonged exposure from cooking on unvented fires, biomass fires may be responsible for up to 2.4 million lost lives each year. With over 38.5 million Disability Adjusted Life Years (DALYs) attributed to cooking with open fires, cooking with biomass accounts for 3.5% of the global disease burden (Smith, 2006).

While replacing biomass with LPG and electricity is an available alternative for a large part of the rural population, the initial investment in the equipment is often prohibitive for low-income rural residents. The cost per unit of energy of LPG and electricity is also very high compared to biomass fuel that can be either inexpensively purchased or collected by the end user (Smith et al., 2005). For this reason, even if households make the initial investment in LPG or electrical equipment, biomass fuel is rarely completely eliminated. Rather, households tend to maintain the use of biomass to hedge against increasing energy costs and because of traditional attachments<sup>7</sup> (Bailis et al., 2008).

Much of the research on indoor air pollution is linked to efforts to introduce efficient, vented cooking stoves, LPG stoves, solar cookers or other biomass fuel alternatives in developing countries. As shown in Figure 34, Smith et al. (2005) compared cooking alternatives to LPG with respect to indicator indoor air pollutant emissions. They show that biogas produced less carbon monoxide and hydrocarbons and only slightly more particulate matter than LPG, but still 10 times less than biomass fuel combustion.

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<sup>7</sup> Traditional attachments include the flavor the wood smoke gives to some foods and the culture of having a fire in the home.

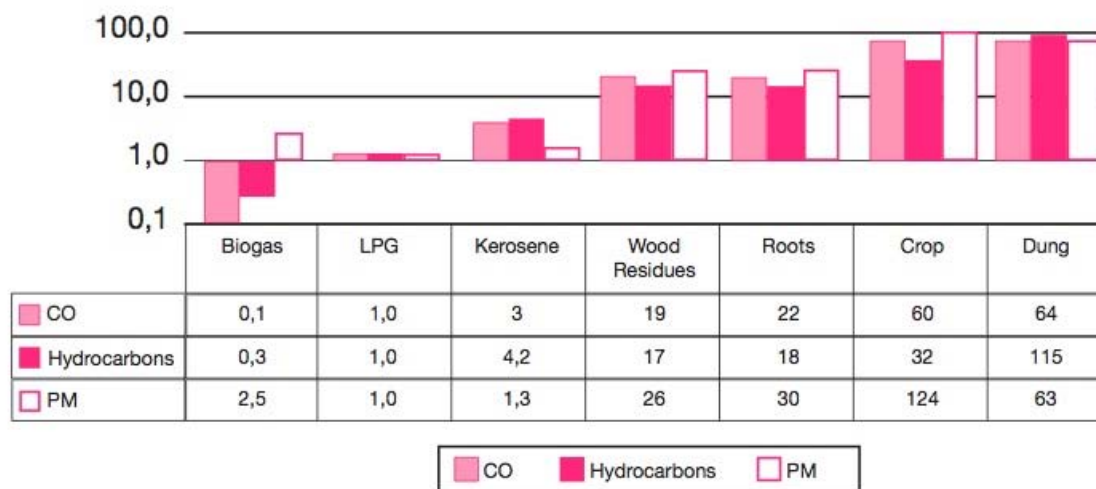


Figure 34. Health-damaging pollutants per unit energy delivered: ratio of emissions to LPG (Smith et al., 2005). The values are shown as grams per mega joule of energy delivered to the cooking pot (g/MJ-d).

#### Water Quality and Sanitation

Of Mexico's rural population, only 48% have access to improved sanitation systems and 52% use unimproved latrines or defecate in the open. Additionally, a large portion of the rural populations participates in some form of animal husbandry in Mexico. There is essentially no control of animal waste aside from open lagoons, land application, or occasional composting (Franco, 2008).

This untreated human and animal waste contains high concentrations of viruses and bacteria, which can cause infection and disease when humans are in direct contact, or when water supplies are contaminated. Untreated waste also attracts insects that can act as mechanical vectors in pathogen transmission.

Diarrheal disease accounts for 17% of the deaths of children under 5 years old in

developing countries worldwide, for a total of 1.8 million total deaths per year.

Almost 94% of cases can be attributed to environmental contamination, including lack of sanitation and safe drinking water. In addition to the deaths, many more people are taken ill from enteric disease each year, and the disease has a large DALY toll on the developing world each year (WHO, 2008). In Mexico, approximately 28% of children under one year old have intestinal infections (PAHO, 2008).

Biodigesters provide an alternative waste treatment system to latrines, open manure storage (figures 35 and 36), or open defecation that eliminates more than 95% of pathogens of treated waste. RCM Digesters (2007) have shown pathogen reduction values consistently in the range of 90% and An et al. (1996) has demonstrated 99.9% bacteria reductions (Table 10).



Figure 35. A small family pigpen in Guanajuato, Mexico before a biodigester installation. Waste contamination in the family living area is apparent in the foreground.





Figure 36. The same site as in figure 35 is shown here after the biodigester installation. Waste is contained and transported to the biodigester through collection canals.

Table 10. Data from An et al. (1996) shows the reduction of select pathogens in swine manure through treatment in biodigesters in Vietnam (loading means raw manure, and effluent refers to material leaving the biodigester).

	MEAN	RANGE
E. coli of loading (10 <sup>3</sup> cell/ml)	52,890	11,000 - 150,000
E. coli of effluent (10 <sup>3</sup> cell/ml)	75	2 - 450
Coliforms of loading (10 <sup>3</sup> cell/ml)	266,780	11,000 - 480,000
Coliforms of slurry (10 <sup>3</sup> cell/ml)	236	7 - 250

Statistical analysis reported by RCM (2007) suggests that temperature appears to be a reliable indicator for predicting the reduction of indicator pathogenic organisms in pig manure. In swine manure, indicator organisms are *Escherichia coli*, the pathogens *Salmonella typhimurium*, *Staphylococcus aureus*, and *Yersinia enterocolitica*, and the enterovirus group of viruses. The reductions of pathogen densities were found to be exponential as temperature and time increased (RCM, 2007). RCM (2007) suggests that mesophilic (15-40 degrees Celsius) anaerobic digesters may offer the greatest potential for reducing pathogens in swine wastes when longer HRTs are used as compared to other anaerobic temperature regimes or other current waste treatment practices such as open lagoon and aerobic treatment (RCM, 2007).

In Mexico, the pathogens in pig manure that have been identified as zoonotic<sup>8</sup> (passed between animals and humans) are the pathogen *Salmonella* and the fungi *Candida*, with *Salmonella* being the most concern from a human health perspective (Pell, 1997). *Cryptosporidium parvum* and *G. Lamblia* may be present in pig manure in very small concentrations, and may be infectious to humans (Pell, 1997). Significant reduction of *Cryptosporidium parvum* has not been shown in biodigesters, but effluent concentrations have been reduced, likely from sedimentation inside the biodigester (RCM, 2007).

Jones (1999) has confirmed the ability of these pathogens, if untreated, to persist in the local environment as a local health threat. Jones shows that *E. coli* O157, which is present in barnyard feces such as pig and cow manure, can persist over 100 days in soil, over three weeks on plant matter (such as vegetables and other garden plants), up to 90 days in rivers, and over 300 days in bottled water (Jones, 1999). This means that animal and human waste management can have significant impacts on human health when humans and manure are in close contact, when green manure is used as a soil amendment, or when manure can contaminate local water supplies.

Biodigesters also provide a more effective waste containment and management system as compared to open storage. Therefore, water contamination and other infection pathways are reduced from the household and local watershed.

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<sup>8</sup> The virus responsible for foot-and-mouth disease (aphthovirus of the family Picornaviridea) is considered a zoonotic organism, but it has not been reported in Mexico.



Although the degree to which biodigester installation can be linked directly to reduced cases of enteric disease remains unclear, there is a large body of evidence that confirms that biodigesters do eliminate many of the risk factors for enteric and other waterborne diseases (Lansing, 2008; An, 2002; Winrock, 2005; An et al., 1996; RCM, 2007).

### Environmental Degradation

The energy and sanitation systems of rural Mexico affect the surrounding local environment by contributing to deforestation and organic contamination of watersheds. Some believe that demand for subsistence fuel wood may be the leading cause of deforestation worldwide (Macht, et al., 2007), although many other studies have shown that fuelwood collection is likely not the leading cause of deforestation (Arnold, 2003; Leach and Mearns, 1988; Masera, 2005). A recent study has shown that fuel wood collection has contributed to a critical state of forests in a number of rural areas in Mexico where there is an unsustainable harvest of fuelwood. This shows that the forest wood fuel harvests in some areas are indeed exceeding the carrying capacity of the forests (Bailis et al., 2008).

Deforestation both reduces the forest ecosystem and increases the impacts of erosion and sedimentation in the local watershed. The decreased forest cover increases the rate in which the nutrient-rich topsoil is flushed out of the area (Macht et al., 2007).

Biodigesters help alleviate both the demand for fuel wood, and therefore help reduce the amount of fuel wood that must be collected from the forest. With an energy content of approximately 15 MJ/kg HHV (Harte, 1988), wood could be potentially displaced at a rate of 1.5 kg / m<sup>3</sup> of biogas delivered.

The contribution of organic loading within a watershed from human and animal manure greatly affects the function of the entire watershed. Once this waste enters the watershed it causes imbalances in the natural organic material levels. This can lead to algae blooms, toxification, and eutrophication (RADDP, 2008).

The negative affects of organic pollution, chemical fertilizers, and erosion in a watershed are more difficult to calculate, as they depend on a complex group of factors specific to each watershed. In the Lake Patzcuaro Region of Michoacán, the group *Recuperacion de la Cuenca del Lago de Patzcuaro* (2008), the national state governments, and other NGOs have done a lot of work to analyze the “killing” (essentially eutrophication and chemical contamination) of Lake Patzcuaro through the introduction of a heavy organic load from the surrounding agricultural and urban runoff. Over 70% of the human waste and nearly 100% of the animal waste enters the lake untreated (RADDP, 2008).

In the case of the Lake Patzcuaro region, the build-out of biodigesters in the watershed may be able to improve the water quality of the lake by reducing deforestation and thus erosion, reducing the animal and human waste, and providing an alternative to chemical fertilizers. But, as with all of the benefits of

biodigester systems, a cost benefit analysis must be conducted before biodigesters will be seen as a viable intervention.

### Cost Benefit Analysis of Biodigester Interventions

Hackett (2006) and others (e.g., Hutton, 2001) have shown that an intervention can be compared to a baseline scenario using a number of different cost benefit analysis (CBA) techniques. In order to calculate a CBA researchers must determine: 1. the boundaries to the costs and benefits that are included; 2. the way in which the time value of money (or discount rate) is accounted for, and; 3. how human life and human and environmental health are valued.

#### Direct Costs and Benefits

From work by Winrock (2005) and Lansing (2008), direct economic costs of biodigesters include the capital costs of fabrication and installation and any yearly operating, maintenance, and monitoring costs. Direct economic benefits of biodigesters are generally measured in the amount of energy units provided or the avoided costs of the energy displaced by the biodigester.

Because the biogas that is produced by biodigesters can displace biomass fuels, LPG, or electricity, the value of the energy that is generated is calculated based on the energy source that is being displaced. Most communities have a standard value for the energy that is commonly used, most easily for the commercial value of electricity or LPG. Even in the case of fuel wood use there is generally an accepted local market value of a bundle wood based on the time it takes to collect that

quantity of wood, adjusted for the local demand. Most people also have a value of their own time, so can also roughly calculate the “cost” of the time it takes for them to collect wood for the household.

Simple payback period (in years) for a biodigester would then be equal to the total cost of the biodigester system (C) divided by the annual value of energy benefits (E) provided by the system, as follows:

$$\text{Simple Payback} = C/E$$

In order to get a better idea of how the energy benefits of a biodigester interact with the economics of the end user, a present value sum must be calculated for the energy benefits over the life of the system using the discount rate that is used by the end user to make other similar decisions. Figure 37 is an example of the diverse energy use options. In addition, energy prices can fluctuate differently than the normal discount rate used for other items (Sandia National Laboratories, 2002). The following equation calculates the present worth of annual sums of money (such as energy benefits) that have a discount rate different than the standard rate for other items:

Equation 9:

$$P = A\{(1+E)/(I-E) * [1 - [(1+E)/(1+I)]^N]\}$$

where:

P = the uniform present worth of an annual sum of money

A = the annual sum of money (energy benefits)

N = year at a given discount rate

I = discount (or interest) rate

E = discount rate (relative to I) of energy benefits

Therefore, to get a payback based on the present value of the energy benefits that will be receive in the future that reflects the value of money of possible end users, the equation above is combined with that of the simple payback, as follows:

Equation 10:

$$\text{Present value payback rate} = C / A\{(1+E)/(I-E) * [1 - [(1+E)/(1+I)]^N]\}$$

where:

C = the total cost of the biodigester

A = the annual sum of money (energy benefits)

N = year at a given discount rate

I = discount (or interest) rate

E = discount rate (relative to I) of energy benefits

These calculations vary greatly for each system based on a wide variety of baseline energy costs, total gas production of each system, and additional direct and installation costs of biodigesters in different sites. An example of these variations is

presented as a series of life cycle costs in Tables 11 and 12. Figure 37 shows the variation in life cycle costs based on the amount of traditional fuel that is displaced.



Figure 37. LPG tank and bundles of fuel wood in Yucatan shown the diverse sources of energy the families in Mexico use to meet their primary energy needs. Hard to identify in the photo are electrical cords that also provide energy to this site.

These data come from three different installations of biodigester systems in Mexico where the biogas is used to replace different energy baselines. This LCA does not attribute any capital costs or maintenance costs to existing systems such as woodstoves, electric boilers, and LPG stoves in order to be conservative in regards to the effect of biodigesters on each energy baseline. In all scenarios, a uniform 10% discount rate is used and there was no energy escalation rate applied above the

normal discount rate is used. Conducting sensitivity analysis surrounding the different escalation rates of fuels in Mexico could provide a more detailed look at the LCA of biodigesters in relation to other fuels.

It is important to note that energy benefits are not attributed to the biodigester systems, rather energy costs are attributed to the baseline system in order to avoid double counting. Even so, biodigesters have a lower lifecycle cost than each of the common energy alternatives in Mexico in these examples. While these are only three examples, I believe each of these sites was representative of the type of energy consumption I have seen in each region. Moreover, biodigesters were significantly less expensive than each alternative, nearly 35% less expensive than the closest second alternative. It is also important to note that ideally technologies such as improved cookstoves like the *Patsari*<sup>9</sup> and LPG stoves would be used along with biodigesters, rather than being seen as distinct alternatives.

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<sup>9</sup> *Patsari* means “to take care” in the indigenous language Perpecha, and refers to the improved cook stove developed by GIRA in central Mexico (GIRA, 2009).

Table 11. The LCC of biodigester designs vs. wood fuel use as reported by Massera et al., (2001) in Michoacán. The biodigesters, in this scenario, are replacing 50% of the fuel wood use, and therefore energy costs of the remaining 50% of the fuel wood use are included in the energy costs of the biodigester systems.

Technology Used	Improved Biodigester System (replacing 50% of fuelwood use)	Tubular Plastic Biodigester	Open wood fuel use, Michoacán	Improved Biodigester System (replacing 50% of fuelwood use from Patsari)	Patsari <sup>10</sup> Improved Cook stove, Michoacán
Initial material cost	\$4,650	\$2,859	\$0	\$4,650	\$715
Total Installation Costs	\$1,500	\$2,500	\$0	\$1,500	\$1,235
Annual Energy Costs	\$2,235	\$2,235	\$4,470	\$1,341	\$2,682
PW Total Energy Costs	\$17,000	\$17,000	\$33,999	\$10,200	\$20,400
Annual Maintenance Costs	\$50	\$50	\$0	\$50	\$50
PW Total Maintenance Costs	\$380	\$380	\$0	\$380	\$380
PW Total Replacement Parts	\$467	\$5,684	\$0	\$467	\$0
<b>Total Lifecycle Costs</b>	<b>\$23,996</b>	<b>\$28,473</b>	<b>\$33,999</b>	<b>\$17,197</b>	<b>\$22,730</b>

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<sup>10</sup> The Patsari improved cookstove has been shown to use 60-70% less woodfuel to deliver the same energy services to a household (Masera, 2005).



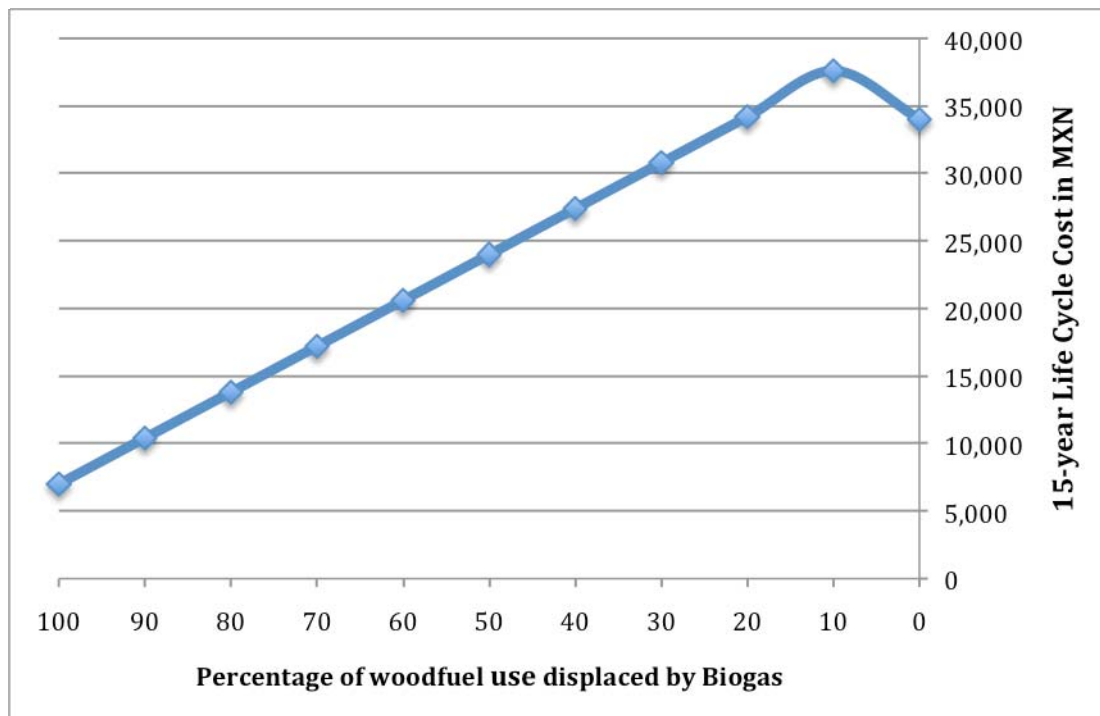


Figure 38. As biogas replaces woodfuel, the 15-year life cycle costs are reduced because the reduced energy costs of woodfuel. In this graph, 100% represents only the LCC of the biodigester and 0% is simply the LCC of the woodfuel. 10% on this graph represents the LCC of the biodigester plus the LCC 90% of the standard fuel wood use; 90% represents the LCC of the biodigester plus 10% of LCC of standard wood fuel use. Wood fuel use data is from Massera (2005).

Table 12: Life cycle assessment of improved biodigester systems relative to examples of two major energy alternatives that are common throughout Mexico. In these scenarios the biodigesters are intended to replace 100% of the energy alternative, therefore no energy costs are included for the biodigesters. No material or installation costs are included for the electricity or LPG in this scenario because they are considered the baseline technology. Data is based on interviews, observations, and data collection from biodigester systems in Mexico.

<b>Technology Used</b>	<b>Improved Biodigester System</b>	<b>Tubular Plastic Biodigester</b>	<b>Electric Hot Water Heating in Mazamitla, Jalisco</b>	<b>LPG in Tzisco, Chiapas</b>
<b>Initial material cost</b>	\$4,522	\$2,911	\$0	\$0
<b>Total Installation Costs</b>	\$1,500	\$2,500	\$0	\$0
<b>Annual Energy Costs</b>	\$0	\$0	\$1,980	\$1,980
<b>PW Total Energy Costs</b>	\$0	\$0	\$18,268	\$16,607
<b>Annual Maintenance Costs</b>	\$50	\$50	\$0	\$0
<b>PW Total Maintenance Costs</b>	\$380	\$380	\$0	\$0
<b>PW Total Replacement Parts</b>	\$467	\$5,684	\$0	\$0
<b>Total Lifecycle Costs</b>	<b>\$6,402</b>	<b>\$11,475</b>	<b>\$18,268</b>	<b>\$16,607</b>

### Evaluating Additional Costs and Benefits<sup>11</sup>

The calculation of LCC of energy benefits is rather straightforward, as shown above. More problematic is how the additional health and environmental can be incorporated into a CBA for biodigester interventions? Human health concerns, including loss of life and disability adjusted life years (DALYs),<sup>12</sup> are clearly a large part of the external costs associated with the baseline scenarios in developing countries. This is most clearly shown by the fact that biomass fuel use and limited access to sanitation and clean water services may be equivalent to nearly 10% of the global burden of health (Smith, 2006; WHO, 2007). However, Hackett (2006), Hutton (2001) and others have described the uncertainty and variability in associating a value with DALYs or loss of human life.

Most recent interventions into sanitation and water quality evaluate projects by calculating a cost per reduced DALY. For example, a recent WHO report by Hutton (2001) estimated that \$150 USD/reduced DALY was the high end of investments that had a positive payback when loss of productivity, health costs, and opportunity costs were considered. Given high pathogen reduction in biodigesters, the degree to which this reduces the overall water contamination risk factor for a

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<sup>11</sup> This section does not specifically address high monitoring costs associated with GHG accounting under the CDM, present value of benefits in the future, and a number of other details in the calculation of returns in order to convey the basic concepts of biodigester evaluation simply and clearly.

<sup>12</sup> DALY stands for Disability Adjusted Life Year, which means and the aggregation of time spent with some sort of disability or sickness that impairs normal work or activities within a population for a total of one year (E.G. 365 people in a given population sick for one day each or one person sick for one year are both equal to one DALY).

given community would give an estimated amount of reduced DALYs from sanitation (RDs) per biodigester installation.

Using a wide survey of existing studies, Smith et al. (2005) estimated that the odds ratio<sup>13</sup> for COPD for women due to prolonged use of biomass was 3.2, 95% CI 2.3–4.8; ALRI in children younger than 5 years old has an odds ratio of 2.3, CI 95% 1.9–2.7 with household biomass use. These were compared to control groups that used household fuels other than biomass, such as LPG or electricity, for cooking and heating. With established odds-ratios for biomass fuel, if biogas were to displace 100% of biomass use in a household then the risk of COPD for women would be reduced by a factor of three and the risk of ALRI in children under five years old would be reduced by a factor of two.

These risk factors and overall burden of health must be converted to a specific context in order to convert the values into actual DALYs or loss of life avoided. A value would then need to be given to a life and to a DALY. Those values would also change based on the age of the person affected by the illness (Smith, 2001). The estimated value of the DALY could then be multiplied by the estimated number of reduced DALYs from indoor air pollution and water contamination per biodigester installation. This is the health value of biodigesters estimated in

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<sup>13</sup> An odds ratio is often used in epidemiology to characterize the effect a particular risk factor (i.e. exposure to poor indoor air quality) has on the prevalence of a particular condition. The ratio is made between two dichotomous groups, one exposed to the risk factor and the other a control. An odds ratio of one signifies no relationship between the risk factor and the condition; odds ratios above one signifies increased risk of the condition, and below one signifies decreased risk of the condition.

economic terms (HB). Comparing the value of health benefits from the biodigester to the total cost of the biodigester system (C) produces a simple payback of the biodigester from reduced health risks in the following manner:

Equation 11:

$$\text{Simple Payback from Reduced Health Risks} = C / \text{HB}$$

This relationship can also be converted into present value using present value calculations. According to Hutton (2001), these would be significantly different values based on the age of the person receiving the health benefits because of the long term potential of younger person to convert health benefits into positive economic benefits. Because health benefits are likely to be equally important into the future, an equation that provides a uniform value of these benefits into the future is used, as follows:

Equation 12:

$$\text{Present Value Payback from Annual Health Benefits} = C/A*[1-(1+I)^{-N}]/I$$

where:

C = Total cost of improved biodigester system

A = the annual value of avoided health risks

N = year at a given discount rate

I = discount (or interest) rate

A similar method is then used to estimate the value of the GHG emission reductions from each system. By combining baseline work from Bailis et al., (2004) and Kammen et al. (2004), GHG emissions reductions (ER) could be estimated. Again, using total biodigester costs (C), you can estimate a simple payback based on Emissions Reduction Benefits realized by installing biodigesters in the following manner:

Equation 13:

$$\text{Simple Payback from Emissions Reduction Benefits} = C/ER.$$

Converting these future benefits into present value is done using the equations previously used to evaluate energy benefits. This could include an escalating rate for the price of emissions reductions if they vary at a rate that differs from the standard discount rates in the following manner:

Equation 14:

$$\text{Present value payback rate of Emissions Reductions} = C / A \left\{ \frac{1+E}{1+I} \right\}^N \left[ 1 - \left( \frac{1+E}{1+I} \right)^N \right]$$

where:

C = the total cost of the biodigester

A = the annual sum of money (emissions reduction benefits)

N = year at a given discount rate

I = discount (or interest) rate

E = discount rate (relative to I) of emissions reduction benefits

Given these relationships, there are then a few different ways that biodigester benefits can then be framed. Comparing the total reduced DALYs with ERs, would give reduced DALYs per ER generated from a biodigester project, as follows:

Equation 15:

$$\text{Reduced DALY per Emissions Reduction} = \frac{\text{Total avoided DALYs}}{\text{Total Emissions Reduction}}$$

This could be promoted as a “premium” ER with a higher market price. Conversely, reduced DALYs could be promoted as having a given amount of ERs generated by the biodigester health intervention. The renewable energy units

generated by the biodigester could also be associated with a given amount of DALYs and ERs by inverting the relationship shown above.

A model for conducting a total present value payback for a given biodigester installation would then divide the total cost of an improved biodigester (C) by the sum the present value of energy benefits, emission reduction benefits, and health benefits. A present value payback is then:

Equation 16:

$$\text{Total Present Value Payback from a biodigester} = C / (EB + ER + HB)$$

where:

C = Total Improved Biodigester Cost

EB = Present value of total energy benefits

ER = Present value of emissions reduction benefits

HB = Present Value of all Health Benefits

With a variety of different costs and benefits for biodigesters globally, there will likely be a wide range of simple paybacks. Some estimated payback times have been calculated below in Table 13 using input data from my Mexico research. These models show that biodigesters can reasonably have rates of return from 1-2 years without considering health benefits, and under a year if conservative health benefits are attributed to the biodigesters. Given a large sensitivity to price per ER and the value given to each DALY, further analysis is needed given specific installation contexts of biodigesters.



Table 13. An example cost-benefit analysis uses varying health benefits for a 10-meter household biodigester installation treating backyard animal waste to estimate simple payback rates. Assumptions for energy and emission reduction benefits are taken from LCC work earlier in this chapter.

	No health Benefits considered	Health Benefits = \$1500 / DALY @ 1 DALY per year	Health Benefits = \$1500 / DALY @ 2 reduced DALYs per year
<b>Total Cost of Biodigester (US\$)</b>	\$6,150	\$6,150	\$6,150
<b>Energy Benefit per year (displacing 50% of fuel wood)</b>	\$2,235	\$2,235	\$2,235
<b>Emissions Reduction (ER) per year (10 ERs per year @ \$15 US/ ER)</b>	\$1,950	\$1,950	\$1,950
<b>Value of Health Benefits per year</b>	\$0	\$1,500	\$3,000
<b>Total Benefits per Year</b>	\$4,185	\$5,685	\$7,185
<b>Simple Rate of Return (years)</b>	1.5	1.1	0.9

### Conclusion

CBAs of biodigester installations that only consider the energy benefits generated from biogas production fail to consider significant benefits that may come from improved indoor air quality, improved sanitation services, and the reduction of GHG. When a CBA includes these externalities of the current sanitation and energy

infrastructure in the developing world, biodigesters can have simple payback rates below one year in some cases.

There is large variation, however, between the costs and benefits generated by biodigester systems around the world, and specific data for each project would be needed to estimate a payback rate for a given region. There are also potentially large sources of uncertainty when determining the benefits that are actually generated from each installation, as most DALYs are calculated by mean risk within a population.

Proposals for biodigester installations must consider how the benefits are distributed or how they fit into environmental or health goals of government or non-governmental organizations. The feasibility of verifying and commoditizing ERs relative to ER markets and other drivers of ER reduction projects must also be considered. Finally, the degree that end-user market forces will contribute to biodigester installations will depend on the current discount rate, the degree to which credit is available, and the perspective end-users' perceived benefits from biodigesters.

## CHAPTER FIVE: EXTERNAL FUNDING, POTENTIAL AND CHALLENGES

Given the wide range of benefits that can be derived from biodigester systems and the potentially high rate of return that can be realized through investment in biodigesters, why then does initial investment in small-scale biodigesters remain one of the primary barriers to implementation? In this chapter I outline a number of potential funding sources, and conclude that the primary issue is not availability of funds, but rather a coordinated effort to properly identify benefits of biodigester systems.

This section will explore the possibilities for funding the broad-scale implementation of biodigesters in Mexico. Possible funding mechanisms and the challenges associated with each will be examined. These funding mechanisms will include unsubsidized market funding in which systems are purchased in full by end users, carbon funding in which systems are installed as carbon abatement projects, and health and sustainability funding in which biodigesters are installed to meet MDGs. This chapter concludes with a proposed model for combining funding efforts in-order to promote the broad-scale implementation of biodigester systems in Mexico.

### Positive Externalities as Economic Considerations

It is useful to understand how positive externalities affect the allocation of goods and services in society. In the case of biodigesters in Mexico, there are benefits that are being received by members of society that did not pay for them. These include GHG emissions reductions, and reduced contamination of local watersheds.

In Figure 38, the supply and demand chart shows that there is a marginal external benefit of over \$450 that is not paid for (difference between the slope of the Social Benefits demand line and the private demand line), or over 30% of the true social value. This leads to an under-allocation of over 30% of the good or service because the true value is not reflected in the price. The data in this graph are only to illustrate the dynamics of positive externalities, and to graphically show why alternative funding scenarios beyond simple market funding are considered in this chapter.

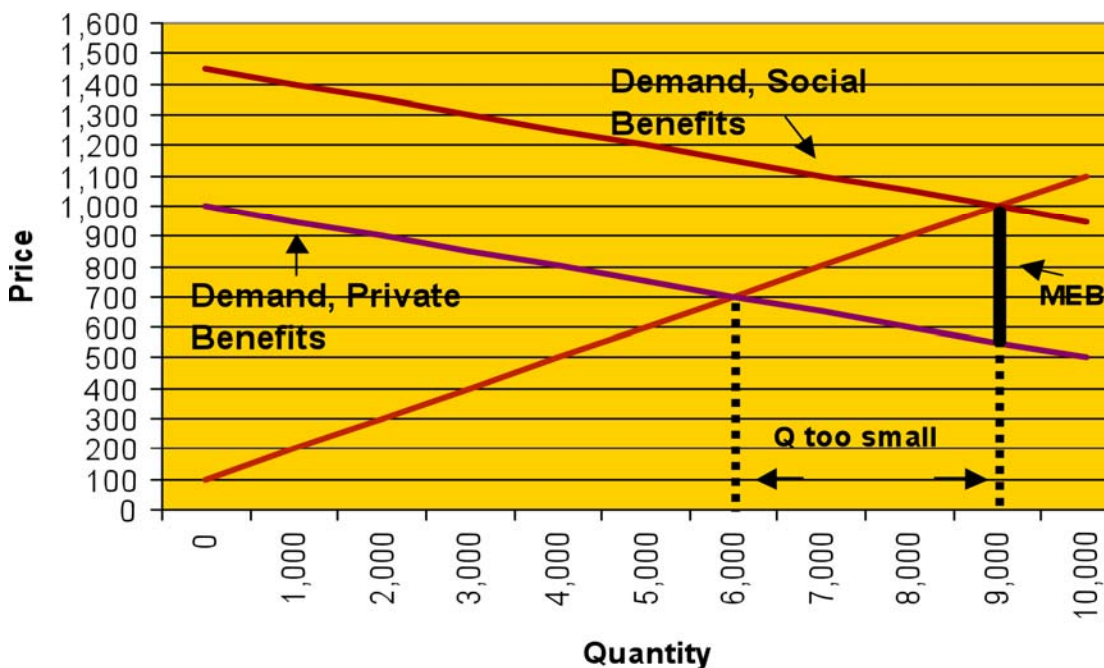


Figure 39. An example supply and demand curve used to illustrate positive externality and how society will under-allocate resources when full price is not paid for all of the benefits realized by a good or service. MEB stands for Marginal External Benefit, in this case the GHG emissions reductions and health benefits that are not paid for. Graphic from Hackett (2006).

#### Unsubsidized Market Funding

There is a substantial global social movement towards allocating goods and services for marginalized populations through the use of market mechanisms. This can be seen in the development of businesses that provide goods and services for the world's poor, as well as a general shift even in state supported projects and the

donor community for social entrepreneurship to provide health interventions (Bailis et al. 2008). In the context of renewable energy and consumer goods there can be some benefits to this approach because an investment from the end users means that they become further vested in the success of the system (ESMAP, 2000; Dees, 1998; Nambo, 2008).

Market funding simply implies that there is a demand for biodigesters from families and communities that have an organic waste stream that can be treated by a biodigester and have a desire to generate a source of renewable energy, improved waste treatment, and reduced odors and insects. In the simplest model, individuals, groups, or businesses that had a use for biodigesters would pay the full price for the system up-front.

Another market model includes purchasing the system using credit, in the form of a small loan or deferred payment from the supplier of the systems. These types of small loans are often referred to as microcredit. In this case, the end user is still responsible for the entire cost of the biodigester plus the cost of the credit. There are currently many forms of microcredit in the world with monthly interest rates that range from 5-30% per month (Mix Market, 2009).

The Mix Market, a web-based microfinance information platform, lists 47 microfinance institutions (MFIs), from banks to non-profit organizations. Of these 47, there are 11 organizations that received a “Five Diamond” rating for information disclosure, service to customers, and economic performance. The distribution of

these organizations shows that MFI service is available in nearly all parts of Mexico (Mix Market, 2009).

Additionally, there are many small MFIs that are not registered that provide specific services. For example, the non-profit MFI *EduPaz* (Education for Peace) is a group located in Comitán, Chiapas which provides micro-credit for farmers and small start-up businesses for just under 5% monthly interest rate on short term loans (EduPaz, 2008).

Microcredit loans can come with a range of constraints. Those can include checking the credit rating of the loan recipient, requiring that more than one party guarantee the loan, and requiring the money be used for purchases that can be shown to generate some income. Some international programs have provided microcredit for the installation of small biodigesters in India, Nepal, and Vietnam (An et al., 1997b).

In Mexico, there has been initial discussion with EduPaz, which has stated that they are willing to provide funding for small biodigesters. EduPaz seems interested in better understanding how the biodigester may be able to provide the end users with a way to repay the loan. This “payback” period is defined as the amount of time the system requires to generate a value to the end user equal to the initial price paid for the system (plus the debt service on the loan).

### Market Value of Biodigesters

In order for market forces to promote the broad-scale implementation of biodigesters, the cost of the systems must be equal or below the market value of the services they provide. Many of the benefits provided have benefits that vary greatly in value between users. Also, because the value of the benefits provided by biodigesters are distributed over the lifetime of the system, the present value of money, or discount rate, for a given prospective purchaser must be considered.

The market value for biodigesters will often be tied to the perceived benefits to the end user, which were described in Chapter Four as energy benefits—energy supplied as biogas that can displace other fuels like biomass, LPG, or electricity. Additionally, many of the direct benefits provided by biodigesters that may be factored into the market price vary greatly in value between users. For example, in Mexico biodigesters have been shown to provide benefits such as a reduction of odor and flies. While for many households this reduction cannot necessarily be converted into a cash value, for others it means the difference between raising pigs or not (or the number of pigs they can raise), which has a direct economic benefit to the household. The calculation of these benefits may be different for different end users.

The same is true for human and environmental health benefits. Here, the benefits would be the reduction of climate change forcing potential or the reduced



risk factors for enteric or respiratory disease. While the benefits may be apparent, the present value put on those future benefits (or avoided risks) by a given family can vary greatly.

Once the value of the energy that can be displaced by the biodigester is calculated, the simple calculation from Equation 6 in Chapter Four provides a payback period or rate of return for the investment in the biodigester. End users can use this payback period or rate of return to calculate whether or not they wish to purchase the system.

### Challenges of Market Funding

In the following section some challenges to unsubsidized market funding for biodigester systems are outlined. Those include initial funding or the “first-cost” barrier, limited access to capital, and the high discount rates of the rural poor. Additional arguments against unsubsidized market funding from other similar development efforts are also examined.

#### Initial Funding

Small-scale biodigesters frequently have an initial costs ranging from US \$5-1500. There is generally a tradeoff between low cost and high quality materials. The more expensive systems tend to be fixed dome or floating cover digesters that often have a longer useful lifespan relative to the very low cost Taiwanese-model plastic digester.

Although the cost benefit analysis in Chapter Four has demonstrated that price of a biodigester is relatively low for the benefits that the system may be able to provide for a household or small business, the availability of cash or credit to pay the initial cost of the system is still very limited for the average low-income rural family in Mexico. The cost of an improved biodigester averages US \$600, which is nearly 10% of the annual per capita income of Mexico, and a much high proportion of the annual income for poor rural residents (WHO, 2008).

A recent survey of 30 prospective biodigester recipients in Michoacán showed that willingness to pay was a maximum of US \$50-100, when average installation costs per biodigester have been US \$600. These same survey participants also expressed that they would not want to go into debt to install a biodigester, by receiving a small loan for example (Nambo, 2008).

#### Present Value and Access to Capital

Although the cost benefit analysis in Chapter Four has demonstrated that biodigesters may have relatively short payback periods (as low as 0.9 years, as shown in the previous chapter) when health benefits, energy production, and carbon emissions are considered, there are still some significant challenges to market funding. Among other factors, high discount rates and low access to cash and/or credit of rural families are possibly the most difficult to overcome.

Economic research has shown that the rural poor can have annual discount rates as high as 40%, with rates of 10-15% being very common. This means that

even rapid payback rates for an investment are not appealing. These high discount rates are often closely linked with a family's ability to meet their basic needs, and therefore their ability to make investments for the long-term is limited (Markandya and Pearce, 1991).

There is a significant amount of behavioral research surrounding health decisions that show that most people have a high discount rate relative to health concerns. The conclusion essentially is that conveniences (or pleasures) today are valued higher than the risk of negative health affects in the future (Fuchs, 1980; Gafni and Torrance, 1984). This is also true with environmental benefits, particularly those that have large time-scales and higher levels of uncertainty. A recent study by Hepburn et al. (2006) shows that across many social contexts the threat of climate change or even long-term local contamination is heavily discounted because of the long timescale and levels of uncertainty.

The availability of cash is related to this high discount rate. In order to meet basic needs, cash is often spent rapidly when it is available (Markandya and Pearce, 1991). The availability of credit is also limited for the rural poor. This limitation can either be because of limited credit infrastructure, a limited ability for the poor to qualify for credit, or an aversion to borrowing money because of high interest rates or fear of repayment.

### Additional Arguments Against an Unsubsidized Market Approach

Srinivasan (2007) has used the development of biodigesters in India as his case study for the argument that funding sources should be as varied as the distribution of benefits from biodigesters. Because the family (or any given end user) is too narrow a scope by which one should evaluate the benefits of biodigesters, he argues, the overall recipients of the full gamut of benefits should also help fund the systems.

The continuation of his argument is that a pure market mechanism puts far too much burden on the end user of the system to provide the additional benefits to society as a whole. The positive externalities of biodigesters that go unaccounted for would therefore cause a distortion in the market (Srinivasan, 2007). This distortion in the market caused by the positive externalities will then result in less than the socially optimal equilibrium quality of biodigesters distributed by the market (Hackett, 2006).

Additionally, the current state of biodigester technology works against some of the basic principles necessary for a market to function efficiently. As outlined in Chapter Two, the current capacity surrounding small-scale biodigesters is very underdeveloped. In order for a market to allocate resources correctly, participants must have access to the goods and services, and have full access to information about the goods and services available (Hackett, 2006).

Bailis, Masera, Berueta, and Cowan (2008) examined a trend of donors to push for a more “market based” approaches for the dissemination of efficient woodstoves. The stoves provide many of the same health and environmental benefits of biodigesters by reducing indoor air pollution, deforestation, and greenhouse gas emissions. Donors appeared to be following the logic that organizations that provide stove dissemination should “shed donor dependence” and institute a more commercialized model of promoting efficient stove use. This trend seems to run parallel with a global shift towards promoting market mechanisms as an effective way to provide goods and services to underserved, poor populations. These same populations have also been seen as a large “untapped market”, with companies looking to promote their goods to the “bottom of the pyramid” (Hammond and Prahalad, 2002; Bailis et al., 2008).

Bailis et al. argue that a market-based approach has some serious drawbacks and “creates a fundamental tension between neo-liberal discourse and global health” when the goal is providing health, energy, and environmental benefits for the poor. This is a result of an inability of poor populations to make large initial capital investments. Interventions that involve health, energy, and sanitation often include a particularly large marketing burden to promote the fundamental behavioral changes needed for adopting systems related to basic needs. Finally, the continued burden of research, development and monitoring needed to ensure the

long-term success of household energy interventions must also be funded (Bailis et al. 2008).

An argument made by Emmanuela Gakidou et al. (2007) considering global health interventions supports the research of Bailis et al. in Mexico. Gakidou et al. argue that in order to attain the global health and sustainability goals set by the MDGs, the most effective (most impact for least amount of investment) expenditure of resources would focus on providing health interventions to the poorest 10% of the world's population. This is in direct contrast with market models that argue for "trickle down" diffusion through market mechanisms that tend to disproportionately support the less poor of the world's poor population (Gakidou et al., 2007).

These arguments work against the idea that broad-scale implementation of biodigesters as a health and renewable energy intervention for poor rural populations is likely through an unsubsidized market approach alone.

#### External Funding Opportunities for Biodigesters

With the multiple benefits that may be realized through biodigester installations, it would seem that these systems would be considered a viable recipient for funding from the billions of dollars that are spent each year to achieve similar benefits. For example, official international development assistance pledged by the primary donors to the MDGs was \$80 billion in 2004 to \$130 billion in 2010 (US 2004 dollars) to reach water, sanitation, and sustainable development goals

outlined the Millennium Development Goals. Over \$100 billion (US 2004 Dollars) has been given each year since 2005 towards the MDGs (United Nations, 2009). CDM projects will generate an estimated \$15 billion in investment between 2005 and 2012 globally, and CDM offset projects in Mexico generate approximately \$130 million (US 2008 Dollars) of revenue from carbon markets each year (UNFCCC, 2009). This shows that there is a significant amount of funding available for projects that have similar end-results as small-scale biodigester projects, and that Mexico could be a recipient of these funds.

#### Funding Biodigesters from Carbon Markets

When the Kyoto Protocol went into force in 2005, it represented nearly a 40-year effort to raise international awareness about global warming and over 10 years of intense international negotiations and planning to develop the framework, oversight, and political backing to support the orchestrated reduction of GHG emissions (UNFCCC, 2008). One of the key results of the Kyoto Protocol has been the development and refinement of an international trade in carbon offsets, or emissions reduction credits (ERs). This “Carbon Market” is driven by both legal binding commitments by countries to reduce GHG emissions and by entities that “voluntarily” purchase carbon offsets.

### Carbon Markets

The tenets of a successful carbon market have been shown to be: 1. long-term GHG emission reductions (ERs) that are additional,<sup>14</sup> verifiable, and based on sound scientific and technical analysis; 2. data management system that is transparent and can register, sell, and retire ERs to avoid “double counting” and ensure only verifiable ERs are sold; 3. a scarce quantity of carbon, meaning a just allocation of credits that reflect a true effort to reduce overall global emissions (VCS, 2008).

Carbon market prices ideally reflect the cost of completing projects and implementing technical modifications that reduce carbon emissions. However, other factors control carbon prices as well, including consumer demand and confidence in specific types of ERs (PC, 2008).

### Compliance Markets

Compliance carbon markets are based on legally binding GHG emissions reductions agreed to by, or forced upon, a geographic region or industry. The 37 countries with legal obligations to reduce GHG emissions under the Kyoto Protocol have ratified laws that commit their industries to reduce GHG emissions according to the international treaty. This has created consumers of carbon credits because

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<sup>14</sup> The term additional refers to the carbon market principle of “additionality”, which is intended to ensure that only emissions that are reduced *in addition* to what would have been reduced *without* emission reductions efforts can be commercialized and sold.



these nations must either reduce their own GHG or purchase ERs that have been certified by the Executive Board of the Intergovernmental Panel on Climate Change (IPCC).

Certified Emissions Reductions (CERs) under the CDM are currently traded under the European Trading Scheme (ETS), the world's largest carbon market, and other markets under the Kyoto protocol, including Japan. The ETS only accepts CERs that have originated<sup>15</sup> according to the methodologies and regulations of the Kyoto Protocol, managed by the United Nation's Intergovernmental Panel on Climate Change (UNFCCC, 2008).

The Regional Greenhouse Gas Initiative (RGGI) that includes the electrical generation industry in 10 Northeastern U.S. states and recent California laws will also create a new, distinct compliance market (PC, 2008). Because these are not included under national or international regulation, these markets currently retain some features of voluntary markets.

#### The Clean Development Mechanism

The Kyoto Protocol committed 37 industrialized countries (Annex B) to reduce their greenhouse gas emissions to an average of 5% below established 1990 levels. Under the agreement each nation is required to reduce national emissions, but it also established three market mechanisms to "offset" emissions in other ways. Of those, the Clean Development Mechanism (CDM) allows businesses from carbon

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<sup>15</sup> Originated is a carbon industry term to describe the process by which an emissions reduction project reduces emissions, and then has those reductions certified and commercialized.

intensive industries within Annex I countries to receive certified emissions reduction credits (CERs) by investing in carbon reduction projects in countries that are not required to reduce emissions (UNFCCC, 2008).

Industrial biodigesters have been installed in 16 countries as “methane capture” projects funded by the CDM. With nearly 30% of the global methane capture projects within the Clean Development Mechanism (UNFCCC, 2009), Mexico has proven itself as a willing partner in developing anaerobic digester projects. Participating in CDM projects has also proven to be good business for Mexico, with an estimated US \$40,000,000 of international investment towards infrastructure projects in the country since 2003 (UNFCCC, 2009).

The CDM was developed both to allow Non-Annex I countries to meet their emissions reduction requirements and to assist developing countries in achieving sustainable development goals. Because methane has 21 times the global warming forcing potential of carbon dioxide and only a 7-20 year retention time in the atmosphere (as compared to an average 100 year retention time for carbon dioxide), it is considered one of the highest priorities for making near-term gains in reducing the atmospheric concentration of GHGs. Anthropogenic methane emissions represent 15% of the total annual anthropogenic GHG emissions on a CO<sub>2</sub> equivalence (EPA, 2008; UNFCCC, 2008).

The majority of anaerobic digestion methane capture projects in the agricultural sector have fallen under the small-scale methodology *AMS III-D*:

*Methane Recovery*. When those projects also contained an energy generation component such as a biogas powered electrical generator or Combined Heat and Power (CHP) system, the *AMS I-A: Electrical Generation by the End User* or the *AMS I-C: Thermal Energy Generation by the End User* methodologies are used and the multiple parts of the project are bundled together and submitted as one CDM project. Currently there is another methodology, *AMS III-R: Methane Recovery in Agricultural Systems at a Household or Small Farm Level*, that deals with the application of small household digesters. There has been only one project that has applied for approval using this methodology (UNFCCC, 2008).

#### CDM Policies

The CDM is divided into two major methodologies, large and small-scale projects, delineated by the number of CERs generated by the project. Small-scale projects are those that represent less than 60 kt of CO<sub>2</sub>e per year or have energy generation capacity of less than 15 MW of electricity or 45 MW of thermal energy (UNFCCC, 2008).

Projects are officially initiated with a Project Idea Note (PIN), a short document that outlines the official CDM methodology being used, a narrative of the project, the project participants, and the anticipated ERs to be produced. The PIN is used to present the project early to regulators and investors to receive early comments and concerns. Project Development Document (PDD) then outlines the material from the PIN in far greater detail, and includes the baseline conditions and

specific plans for monitoring and verification. The PDD must be approved by the host country's Designated Operational Entity (DOE) and then registered by the CDM Executive Board (Sterk, 2006).

Not until this point can project implementation begin. Once the project and all necessary monitoring equipment are installed, another Designated National Authority (DNA) must then verify the project. Once this verification is received, the CDM Executive Board can release the CERs for sale. This process can take two years or more (Sterk, 2006; Lokely, 2008). Project monitoring and verification must continue under the approved PDD for renewable periods of seven or ten years (UNFCCC, 2008).

### The Gold Standard

Widely considered a success, the Gold Standard methodologies have attempted to tackle many of the harder questions concerning environmental, health and sustainable development goals. The Gold Standard enhances CDM methodologies by evaluating carbon projects based on sustainable development attributes, and rewards participants with a higher market value of the CERs issued (Sterk, 2006; GS, 2008).

### Voluntary Markets

While the CDM is the most well established funding mechanism, there are other international programs that leverage funds from industrialized countries to support GHG emissions reduction projects. There has also been serious consideration of similar mechanisms in proposed U.S. emission regulations (Capor, 2008).

Alternatively, there are currently many voluntary carbon markets worldwide that are driven by entities—individuals, companies, or states—that want to off-set carbon emissions, but are not required to by law. In some cases these ERs have the qualifications to be certified as CERs, but the transaction cost and certification requirements make the process prohibitive. The Voluntary Carbon Standard (VCS) is an important emerging institution for the global voluntary market. The VCS was established as an attempt to consolidate multiple voluntary markets and combine solid methodologies and verifiable reductions with flexibility and streamlined administrative overhead (VCS, 2008). These qualities allow investment in small-scale renewable energy projects through voluntary markets, although these markets are significantly smaller than the current compliance markets.

#### Anaerobic Digestion Projects and the Carbon Market

Anaerobic digestion projects have been primarily conducted under the CDM Small Scale Methodology AMS III-D: *Methane Recovery* and AMS I-A: *Renewable*

*Energy* that cover both the capture and destruction of methane and the production of renewable energy with the resulting methane. These projects are classified under “small-scale” methodologies in the CDM framework, but the smallest of these generates over 1200 ERs per year, and the average is closer to 10,000 ERs per year (UNFCCC, 2009).

In this work, I use the term “small-scale biodigesters” to refer to systems that would have ER production capacity of between 3 and 1000 CERs per year, given that the Mexican biodigesters we are working with would produce 5-100 CERs per year. This would include the use of CDM methodology AMS III-R (version 1) - *Methane recovery in agricultural activities at household/small farm level*, as well as AMS I-C (version 12) - *Thermal energy for the user with or without electricity*.

There is currently only one project of this type seeking registration with the CDM Executive Board. That project is in China, and proposes to build 33,000 household biodigesters for treating pig and human waste and to provide thermal energy to displace coal, the common household energy in the region. The proposal claims the project would produce over 54,000 ERs per year. This project is not yet approved (UNFCCC, 2009).

#### Voluntary Carbon Market Potential for Anaerobic Digestion

In addition to the CDM project being proposed, the carbon benefits of other small-scale projects have been touted, and there have been a few examples of the voluntary market ER sales supporting the development of biodigesters. There have

been mixed reviews of these projects, however, based on apparent lack of consistency in the methodology used to develop some of these projects (Sterk, 2006).

The recent move in the voluntary market towards a higher level of standardization (VCS, 2008) suggests that future efforts would do well to adopt accepted methane capture and renewable energy methodology, such as the CDM or the CDM Gold Standard. The CDM Gold Standard is particularly interesting because the extra emphasis on “high quality” offsets (based on the higher levels of community involvement in project development and additional sustainability indicators) have been able to obtain a higher market price. Because of the inherent work with the community that would be necessary with the broad-scale deployment of biodigesters, the methodologies of the CDM Gold Standard may be easier to maintain.

#### Carbon Market Value of Biodigesters

In the Chinese example that is using the CDM methodology AMS III.R (version 1), to calculate the methane destruction, the average reduction must be less than or equal to five ERs per year per installation. According to the Project Design Document (PDD) for the Chinese project, the ER per household for the reduction of coal in household energy use (under AMS I-C) is between 2 and 5 ERs per year. This equals an average of about 7 ERs per household per year from methane capture and the displacement of coal use.

The Chinese project is registered for a period of 10 years. Assuming the recent rate of US \$15 / ER/yr with the ETS, this could provide an equivalent of US \$105 per system per year. The present value of \$105 per year over the 10-year period (using a 5% discount rate for the investment) is approximately \$811 of total revenue from the carbon market per system (here assuming a stable US \$15 / ER).

In the Chinese case the digesters average approximately \$550 per system for the construction. This means, according to the calculations in Chapter Four, the simple payback period for the systems with carbon funds is 5.23 years. This calculation is only used for reference as we are disregarding project maintenance and monitoring costs.

#### Potential Carbon Market for Small-Scale Systems in Mexico

There are an estimated 18-20 million domestic pigs in Mexico (Franco, 2006). Of this population, 40-50% of them are raised on small, low-tech farms and in backyard household farms (SAGARPA, 2003; Losada et al., 1995). This means that there are potentially over two million tCO<sub>2</sub>e/year worth of methane capture ERs in this sector<sup>16</sup>.

The National Bureau of Statistics (INEGI) in Mexico conducted the first agricultural census in 20 years in 2007. One of the objectives of the survey was to classify the number of households that had animals, along with the type and

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<sup>16</sup> 50% of 20 million pigs equals 10 million pigs that are possibly in small to medium farms in Mexico. 10 million pigs multiplied by 0.2 tCO<sub>2</sub>e per year equals two million tCO<sub>2</sub>e/year.



quantity of animal. These data were scheduled to be available by July of 2008, but as of July 2009 have yet to be released (INEGI, 2009).

The information from the 2007 Agricultural Census will provide very useful data for determining the number of animals being raised by households and the density of those animals in particular regions. This information will be important for determining the total potential for small biodigester implementation in Mexico and the areas in which it would be most productive to initiate projects. With data of animal numbers, and additional information from field studies, the baseline methane emissions from these small farms can be estimated.

There have been a number of studies that examine the current use of household energy in Mexico. For example, the Interdisciplinary Group for Research of Rural and Appropriate Technology (*GIRA*, acronym in Spanish) has been working on the diffusion adoption of efficient woodstoves for nearly 20 years. Building on their comprehensive research into GHG emissions from wood fuel use in Mexico, baseline GHG emissions per household can be estimated as well.

From GIRA data (2009), a rural Mexican household that utilizes wood fuel for a significant amount of their energy produces an average of about 5 tCO<sub>2</sub>e per year from the combustion of the wood, or about 1 tCO<sub>2</sub>e per year per person. Utilizing a general a rule of thumb (RCM, 2008) for enteric methane emissions from pig waste of about 0.2 tCO<sub>2</sub>e per year per pig, the emissions for a theoretical small family farm that utilizes wood fuel for a part of their energy needs can be calculated.

Say this farm was to maintain a population of eight pigs and five people with an average of five tCO<sub>2</sub>e per year from their wood fuel use. A likely project assumption is the reduction of wood fuel by half, and capture of 100% of the enteric methane emissions from the pig waste with a biodigester system. This would mean that we would produce 6.5 ERs per year with the installation of this system. Assuming the US \$15 / ER, the revenue from this system would be US \$97.50 per year, with a present value of \$753.00 considering the 10-year lifetime of the system and a 5% discount rate. This example is outlined in Tables 14 and 15.

The extension of this example would be to assume that you could find 1500 farms that had a similar average of the household above. If these 1500 farms were bundled into a single CDM offset project, they could generate about 10,000 ERs per year and 100,000 ERs over the 10-year lifetime of the project.

Table 14. An example calculation of GHG emissions reduction from a Mexican household.

<b>GHG Source in Household</b>	<b>Population</b>	<b>Emissions (tCO<sub>2</sub>e per year)</b>	<b>Total tCO<sub>2</sub>e per year</b>	<b>Reduction from biodigester</b>	<b>Reduction tCO<sub>2</sub>e per year</b>
Biomass Fuel Use	5 people	1 tCO <sub>2</sub> e per year/person	5 tCO <sub>2</sub> e per year	50%	2.5 tCO <sub>2</sub> e per year
Enteric Methane Emissions from Pigs	20 pigs	0.2 tCO <sub>2</sub> e per year per pig	4 tCO <sub>2</sub> e per year	100%	4 tCO <sub>2</sub> e per year
		<b>Total:</b>	9 tCO <sub>2</sub> e per year		6.5 tCO <sub>2</sub> e per year

Table 15. An example calculation of the carbon market revenue from this installation at a Mexican household.

<b>Emissions Reduction tCO<sub>2</sub>e per year</b>	<b>Price per ER (\$/tCO<sub>2</sub>e per year)</b>	<b>Total revenue per year (present US dollars)</b>	<b>Present Value of Revenue for 10-year project life (present US dollars)</b>
6.5	15	\$97.50	\$752.80

#### Challenges with Carbon Market Funding for Small Biodigesters

Given these tenets of the carbon market described earlier, some specific challenges to this theoretical project emerge. The first and most obvious root of these challenges is the number of individual systems, and therefore individual households, that must be included under the project. Just maintaining some form of contact with 1500 households over the course of the year implies that over 5-6 of the households must be contacted each business day of the year.

This implies significant cost and effort if it is the responsibility of the project developer to visit or monitor each system to confirm that the ERs being claimed each year are verifiable. This challenge grows significantly as the geographic density of the systems decreases.

The inherent challenges to small-scale biodigester development described in Chapter I all reemerge in this context. There are many reasons why a system may not last the entire 10-year project period. Given that projects are approved on this

long timescale, the fact that some percentage of the systems will not last the entire period signifies financial risk for project developers.

Finally, the biogas composition and flow meters that are currently commercially available come at a high cost (e.g., Valley Gas Solutions, 2009). These systems are designed for large anaerobic digestion systems, a context in which the relatively high cost (US\$5000) of the sensors is only a small part of the overall project cost. For small systems, there are currently no low-cost commercially available monitoring systems. The biogas monitoring systems that have been installed in field labs that monitor small biodigesters generally have low reliability and durability, and function because of the diligent monitoring of field technicians (Lansing, 2008).

A group of engineering students from Humboldt State University spent a semester examining the challenges of monitoring biogas production from small biodigesters. They made useful recommendations regarding some strategies that may work and identifying a few ideas that will not work as well. Based on their recommendations, there is a lot of room for continued research into the development of monitoring systems that could accurately verify the reduction of GHG emissions from the installation of biodigesters.

Of the lessons learned, one of the most important is that the solution may not be high-tech, or even technology based, but rather would integrate survey methods with rather simple indicators. Some of the monitoring methods may also be

developed in conjunction with improvements to the system that would improve their performance for the end users. An example of this would be a simple pressurization of systems that would allow better gas delivery to the end user and also open the door for lower cost metering systems (Johnson et al., 2008).

Given the advances in the Chinese project under CDM Small Scale Methodology AMS III-R and II-C, and the current price of ERs that originate from CDM projects, it appears that carbon markets could be a viable and important source of funding for the deployment of biodigesters in Mexico. To facilitate this, the data from the 2007 Agricultural Census would be extremely helpful. Additionally, some advances in the development of monitoring methodology and equipment would greatly improve the viability of a small-scale biodigester deployment and monitoring.

#### Health Intervention Funding of Biodigesters

As shown in Chapter II, biodigesters can have a positive impact on human health. This impact is primarily from reducing exposure to indoor air contaminants and reducing exposure to contaminants from animal and human waste in the local environment and water supply.

A large study that evaluated the effectiveness of programs aimed at meeting the MDGs found that effective interventions that address clean water and sanitation and clean household fuels would reduce child mortality rates by 14-31% in Latin

America. These benefits would reduce the regional gaps in achieving the MDGs by 30-48% (Gakidou et al., 2007).

Because biodigester interventions have direct benefits related to both indoor air quality and water quality and sanitation, they are a logical intervention to be funded in order to meet MDGs. Official international development assistance of \$80 billion in 2004 to \$130 billion in 2010 (US 2004 dollars) was pledged to reach water, sanitation, and sustainable development goals outlined the Millennium Development Goals (MDGs). Over \$100 billion (US 2004 Dollars) has been committed each year since 2005 towards the MDGs (United Nations, 2008).

Additionally, the US EPA has pledged millions towards improving indoor air quality in rural households internationally, an amount that compliments other non-profit organizations working on similar projects related to air and water quality (Hedon, 2009). Given this large funding potential, it seems reasonable to assume that biodigesters could be supported through these funding streams.

#### Challenges to Health Intervention Funding

Of the primary challenges related to funding biodigesters through health intervention funds, the most significant is proving a direct causal relationship between the intervention and improved health. Most epidemiological studies are based on population groups in order to provide an overall reduced risk factor (Hutton, 2001).

Guy Hutton describes water and sanitation interventions as providing “an interesting but challenging application of economic principles to resource allocation issues.” By this he means that most economic models used to evaluate return on health investments are based on providing direct health services (such as doctor visits and immunization), and do not evaluate environmental intervention designed to reduce risk factors (Hutton, 2001).

Specifically, Hutton (2001) describes environmental interventions as problematic for conventional economic health models because they provide large non-health benefits such as time savings and improved economic performance of a household and they produce a wide range of results between different households, making generalization difficult.

The main result of these issues, according to Hutton (2000), is that appropriate methods to evaluate interventions such as biodigesters from a health perspective are grossly underdeveloped relative to their ability to make positive health improvements. While there is a large body of evidence relating pathogen reduction and improved indoor air quality to biodigesters, linking biodigesters directly to health indicators is far more challenging, given under-developed methodologies for such studies.

#### Environmental Services and Funding for Biodigesters

Using the case of Lake Patzquaro in Mexico, environmental causes such as lake health, deforestation, local water and soil contamination, and species habitat

can generate large amount of international and local funding. Biodigesters, because of the reduced use of fuel wood and reduced organic contamination (as shown in Chapter Two), could be seen as an effective intervention to help tackle these issues.

Additionally, the large organic food movement in Mexico and around the world has created a large push for organic fertilizer. Effluent from biodigesters is an organic fertilizer, and in some locations there is large demand for it. Private funds to push the development of this resource are commonly coming from large agricultural systems. In Mexico, avocado farmers have been a driving force of this market (Diaz, 2008).

Environmental funding for biodigesters can also come from government groups that have a goal of improving the performance of local farm systems. For example, SAGARPA has a multi-million dollar program to provide advanced technology for farmers that improve overall sustainability and profitability of small farms.

#### Challenges to Environmental Services Funding for Biodigesters

The primary challenges of environmental services for biodigester are similar to those of health funding because the benefits are often hard to demonstrate. Additionally, they are often very locally driven. For example, while Lake Patzquaro has received a lot attention and funding to improve the condition of the lake, many other lakes in the region have the same problem, but receive almost no assistance. Here, the bottom line to determine the viability of environmental services funding



for biodigester depends on the local conditions, including local fertilizer markets and the environmental priorities of the local government agencies.

#### A Broad Scale Project Proposal for Small-Scale Biodigesters in Mexico

A biodigester project proposal that was modeled after the Chinese project that is using the AMS III-R and AMS II-C methodologies to evaluate the reduction of GHG emissions could be implemented in Mexico. Although the project would be framed as an emissions reduction project, additional goals would be the development of a local biodigester market—and infrastructure—and to realize the health and environmental benefits from biodigester systems.

Using the example household from Chapter II, the project would need to include approximately 1500 households in order to reach the 10,000 ERs/year threshold that generally makes projects appealing for private investors (Olian, 2008).

This project would have all the additional burdens that were described by Bailis et al. (2008), including marketing and education programs, careful follow-up and monitoring, and a closely linked research and development program that would allow for user feedback to influence future technical and programmatic elements. Given these burdens, other financial partners would need to be included in order to make the project viable. This would include health intervention funds such as those allocated to meet the MDGs and local Mexican initiatives, private and government

funds for increasing organic fertilizer and reducing environmental degradation, and government programs aimed at improving agrarian and economic sustainability.

### Project Steps

The initial stage of this project would include the identification of regions and sub-regions that have high densities of the appropriate demographic for this type of project. This demographic includes households and small farms that have animals such as pigs and cows contained in appropriate housing for adoption of a biodigester (e.g., not free roaming in a pasture).

Once these zones were identified, an intensive education and public awareness campaign would provide information and small workshops about biodigesters that would include the installation of pilot projects for demonstration purposes. The goal of this campaign would be the development of a list of at least 1500 households that are interested in installing a biodigester in their home or small farm.

With a list of prospective recipients, a concerted installation program would begin that would utilize local biodigester businesses established to accommodate this work. An order for this many biodigesters would allow for economies of scale in materials and labor.

Once the systems were installed, a monitoring and follow-up regime would be established that included the same biodigester installation and monitoring businesses. These businesses would be responsible to monitor systems, provide

maintenance, continue the promotion and installation of new systems, and provide technical and programmatic suggestion for program managers.

#### Proposed Funding Model

An integrated funding model for a large project of small-scale biodigesters would need to leverage carbon funding, health funding, funding from end-users (market funds) and additional funds such as those for environmental services. Because the project is far less viable if one of the pieces is missing, each funding entity would be able to claim the benefits of project in whole. For example, the carbon investors would be commercializing the GHG emissions reduction but could also claim that the ERs had additional health benefits. The funding for health interventions would be able to claim the human health benefits along with the fact that the project reduced GHG emissions (even though they would not be commercializing those benefits).

Based on a discussion with a carbon broker, most businesses that develop carbon projects want to see payback periods on their investments of no more than five years (Olian, 2008). Given this payback period, and a proposed quantity of ERs possible from the project, the total potential investment from the carbon funds can be back calculated. In our case, 10,000 ERs per year at an estimated \$15 US per ER per year for five years is \$750,000 in maximum investment for the project. If this were spread over 1500 systems, the total investment per system would be \$500 US.

Given this carbon investment possibility, we have a funding deficit of nearly \$1000 US per system based on estimated costs of biodigester system installation, follow-up and maintenance. If we were to establish an end-user price of \$500 US, and provide MFI funding in order to pay this up-front cost, the end user payback would be between 6 months to two years.

This leaves a remaining deficit of \$500 USD. Given an average family size of five, the per capita investment is \$100 US per system. For health services funds to cover this cost falls well within the current state of improvement relative sanitation services. The range is \$60-160 US (US\$ year 2000) per capita for providing open pit latrines and sewer connections respectively. These interventions have been shown to payback \$15-28 for every one dollar invested in recovered productivity, reduced health services needed, and household economic status (Hutton and Haller, 2004).

Table 16. An example funding distribution for the promotion of a biodigester installation project to include 1500 household biodigester systems. Additional funds could be received to support the program, including funds for environmental services, economic development and agricultural stimulus.

<b>Funding Source</b>	<b>Amount Provided/system</b>	<b>Project Total</b>	<b>Funding Motivation</b>
Carbon Funds	\$500	\$750,000	10,000 ERs / year @ \$15/ ER (10-year project life)
End User Funds (provided in part by MFI funding)	\$500	\$750,000	Energy services, improved waste management, reduced odor and flies, opportunity to increase animal numbers
Health Funds	\$500	\$750,000	Reducing Health Risks for 7,500 people
<b>Total</b>	<b>\$1,500</b>	<b>\$2,250,000</b>	

Given these levels of cooperative investments, the initial installment costs and follow-up for the systems could be covered. Additional funding, however, would be extremely useful in order to provide education, marketing, research, and business development for the biodigester businesses. This funding could ideally be funded by government entities as the goals fit within economic, agricultural, and social goals that many agencies in Mexico currently have (SAGARPA, 2009; SEMARNAT, 2009; SEDESOL, 2009; CDI, 2009).

## CHAPTER SIX - DISCUSSION AND CONCLUSION

In this chapter I present some discussion about the state of the carbon market and other enabling factors that will likely help progress the work outlined here. I also make suggestions for future research that have come out of my work in Mexico and through work with the *Red de Biodigestores de Latin America y el Caribe* formed in May of 2009 in Cajamarca, Peru. I conclude with a summary of the results of my work in Mexico on the development of the improved biodigester system and the economic analysis presented in the previous chapters.

### Critiques of the CDM

Now functioning in some form for over three years, the CDM has generated almost 3 billion tonnes of CO<sub>2</sub>e emissions reductions, close to 1300 projects (UNFCCC, 2008), and a fair share of criticism. While the process has been able to evolve in reaction to early criticism, some argue that there are organizational flaws. Many say that the program has not promoted enough emissions reduction projects nor has it promoted sustainable development (Sterk, 2006; Lokely, 2008; Capor, 2008; Brown, 2003).

The lengthy CDM process has widely been criticized as a major limiting factor to project development. This is partly because baselines and methodologies must be developed individually for each project and high rejection rates and low capacity at the local DOEs that creates approval bottlenecks. The process is also costly, with

high registration fees with the DNA, DOE, and the CDM Executive Board that are tens of thousands of dollars, often between 5-10% of project costs. These costs are all incurred at the front end of a project, when there is no guarantee of approval and before any revenue can be generated. Even with the new small-scale methodologies, it has estimated that for a project to be economically viable it must generate at least 8,000 CERs per year (Sterk, 2006). The combined effect of slow turn-around, high cost, and uncertainty can discourage investment (Capor, 2008; Lokey, 2008; Fisher, 2008).

The criticisms from the development sector are directed at the fact that benefits are evaluated solely from a climate perspective. Projects that also meet other development goals (such as economic development or the preservation of biodiversity) are not sufficiently rewarded over those that don't. This criticism is not aimed at the CDM exclusively, as there is a need to better combine funds dedicated for development, such as the Millennium Development Goals, with GHG abatement efforts to make projects with high additional benefits, such as environmental and human health benefits, appealing investments for carbon funding (Gold Standard, 2008; Srivastava, 2006; Brown, 2003).

An additional challenge of the CDM is its interaction with host countries. For example, assessment of projects' environmental, health, or social impacts is at the discretion of the local DNA, without a formal method of informing host countries about appropriate standards (Sterk, 2006). Conflicting energy and environmental

laws can limit the feasibility of renewable energy projects in developing countries through the CDM. For example, in Mexico it is challenging to gain interconnection agreements with the local electrical grid for renewable energy producers, limiting the investment potential in renewable energy development. International harmonization efforts of national policies are not addressed by the CDM (Lokey, 2008). Some also argue that the CDM creates perverse incentives for countries to neglect environmental policies (Sterk, 2006). Because of additionality requirements, if a country promotes better environmental standards it may be less likely to receive investment in emissions reduction projects (Dutsche, 2003).

The scale of the CDM transaction and monitoring costs prevent sustainable benefits from technologies that could be applied at household levels, where many development interventions have been shown as most effective. While the CDM seems to promote projects that are large, it is also criticized as being too small in scope. The focus on isolated individual projects, some argue, is inherently incapable of making large transformational effects towards sustainable development (World Bank, 2004; Sterk, 2006).

#### Reforming the CDM

Suggestions that would make the CDM more effective at both producing large quantities of CERs and having the flexibility to promote additional community development goals have abounded. A consolidation of these suggestions includes: streamlining of the project approval process; providing new flexible methodologies



and tools for monitoring; developing simple, conservative additionality benchmarks; and, shifting focus from individual projects to broader sectoral scopes.

Sectoral approaches have gained significant support, and are considered appropriate to ameliorate the current CDM model. While still broadly defined, sectoral approaches are promoted to encourage sector-wide transformation (as opposed to single projects), promote aggregation of dispersed activities, and allow a more consistent average price per ER to be calculated across a variety of projects with varying abatement costs. Sectoral projects could include policy interventions funded in part with host countries or larger scale “bundling” of similar or geographically associated projects (Sterk, 2006; Capor, 2008).

The estimated benefits of this approach include reduced transaction costs and time, removing one of the most significant barriers in the CDM (Fisher, 2008). The ability to aggregate a number of small projects promotes small-scale renewable energy development, which can produce more sustainable development benefits. Allowing governments to participate in sectoral-wide projects removes perverse incentives for weak environmental laws, as host countries would be rewarded by effective emissions reduction action (World Bank, 2008; Sterk, 2006). By building capacity within host countries surrounding specific technologies, a sectoral approach also makes future transition to emissions commitments for these countries easier (Brown, 2006).

### Technology and Methodologies to Demonstrate System Potential and Benefits

Because biodigesters have been shown to have human and environmental health benefits and greenhouse gas abatement potential, funding to support the Millennium Development Goals, the Greenhouse Gas abatement goals, and a number of Mexican and international environmental and health initiatives are well positioned to potentially support the development of small-scale biodigesters. However, the opportunity to receive this support has not been realized because of missing data, technology, and methodologies that are needed to design a program that would allow potential program funders to clearly calculate the potential benefits.

In the environmental and human health sectors, there is a lack of data relating biodigester installation with direct human and environmental impacts on a broader scale. While biodigester performance data support the human and environmental health benefits that can be realized, these benefits vary between households, and it is difficult to estimate the effects that biodigesters would have if implemented on a broad scale for three key reasons.

First, a lack of information about the number and scale of small commercial and backyard pig farms has created uncertainty among potential carbon market investors about the scope of the opportunity. Second, issues related to initial cost, technical reliability, and the local capacity to manage the systems have limited their

use to a relatively modest number of farms. Third, sales of carbon credits from small biodigesters are hampered by the relatively high cost of monitoring and verifying the associated GHG emissions reductions.

### Suggestions for Further Research

In May of 2009, the first Latin American Biodigester Summit was held in Cajamarca, Peru. I helped conceive the summit with members from NGOs in nine Latin American countries. One of the objectives of the summit was to present the research and development that has been conducted by each group, and to develop a comprehensive list of suggestions for future research. This list is intended to help guide future research in the theme, and to avoid unnecessarily duplicating research that has already been conducted. The conclusions of the summit are included as Appendix A.

I presented the work in this document at the summit, as well as what I believed future research objectives should be. My work and suggestions are included in the proceedings of the summit, and below I summarize the future research that has been suggested by the group as a whole. Suggestions for future research were broken up into five central themes: technological, environmental, economic, social, and health related.

Technological suggestions for future research include development of equipment to monitor and measure outputs from biodigesters, the continued development and experimentation with new materials with which to construct

biodigesters, and improved low-cost gas delivery systems and end-use equipment.

Work was also suggested in the integration of all the technical aspects of a biodigester so that it may be effectively incorporated as the epicenter of small agricultural systems.

Environmental suggestions include research into the use of biodigester effluent as a fertilizer and the associated risks. Also included is research into the emissions of biogas used indoors, and how effective low-cost filters are at reducing hydrogen sulfide. Research into greenhouse gas emissions from small farms and better calculations of the associated reductions from biodigesters was also suggested.

Economic research was suggested in the valuation of biodigester products such as biogas and fertilizer, reducing costs of biodigester installations, and the reduction of first-cost barriers through financing mechanisms. In addition, there were questions about how to manage external economic factors that can affect the use of biodigesters such as variations in animal populations that provide biodigester feedstock. Further development of a multi-funder approach to broad-scale biodigester installation was also suggested.

Areas for future social research include the developing education and capacity building programs, marketing and diffusion of technology, and working with cultural barriers to biodigester installations. Another suggestion is developing a standardized manner in which biodigesters could be evaluated so that researchers

from a broad range of contexts may share information more effectively. Also included was the development of an organization to facilitate the exchange of research findings and design improvements that would benefit a wide network of biodigester promoters. The *Red de Biodigestores de Latin America y el Caribe* (the Latin America and Caribbean Biodigester Network) was created based on this suggestion to promote and share biodigester research and development.

The key health research suggestions are focused on developing a better understanding of health benefits that can be derived from biodigester installations in varying contexts. This could include direct health observations that attempted to evaluate the risk of exposure to end-users before and after a biodigester installation. An additional health theme is evaluating the additional risk of pathogen exposure if human waste is treated in biodigesters. Further suggestions can be found in the summit proceedings in Appendix A.

### Conclusion

Small-scale biodigesters can potentially play an important role in reducing greenhouse gas emissions and human and environmental health risks while also improving economic conditions for small farms in Mexico. But with a myriad of environmental, social, and economic benefits, there are very few resources allocated to deploying biodigesters in Mexico.

The IRRI-Mexico Biogas Program was developed to better understand barriers to the development of low-cost biodigester systems, and to work on

solutions to those barriers. One inhibiting factor to biodigester deployment is the poor reliability of the current low-cost biodigester technology. This weakness led to the development of the improved biodigester system.

The improved biodigester system is a HDPP pre-fabricated bag that functions very similar to a standard low-cost bag biodigester. The system is assembled using extrusion welders specially designed to work with HDPP. The key differences between the traditional and improved systems are material strength, durability, and repairability. The material has a 20-year guarantee against the weather and sun. The system comes with prefabricated connections that allows for easier installation and less likelihood of installation errors. In addition, the system is strong enough to support the weight of the liquid slurry inside and therefore may be installed without digging the large trench that is necessary for standard bag biodigester models. This also helps reduce installation time and the associated manual labor costs.

The performance of the improved system in installations to-date has been excellent, with gas production rates, gas composition, and associated benefits as good or better than with the traditional low-cost bag biodigester. The success rate, however, has been 100% as compared to only a 60% success rate with the traditional bag model due to common reactor ruptures and leaks from low material strength. And while some improved systems have had small leaks, they have been easily repaired with a specialized tape that can provide a long lasting fix.

The strongest argument for the traditional bag biodigester as compared to other small-scale biodigester designs is the low cost. Although the traditional bag biodigester has a low initial investment cost, I have shown that the life-cycle cost of the improved biodigester is 40% lower because of the high reliability and long life. In addition, recent work with different HDPP materials and brands have shown that reactor cost may be able to be reduced as much as 50%.

I have also compared the life-cycle costs of the improved biodigester system against the life cycle costs of current energy technologies being utilized in Mexico. The improved biodigester has a far lower cost over its useful life than current fuelwood stoves, LPG gas stoves, and electric water heaters, and can provide the same energy services provided by these other technologies.

Further, there are health risks associated with the use of fuelwood in traditional woodstoves in Mexico for cooking and heating. Additional health risks are associated with the lack of treatment of animal and human waste in backyard farms. Biodigesters could be installed as a health intervention to reduce those health risks to families in Mexico. The deployment of biodigesters as a health intervention would directly support the Millennium Development Goals, and do so in a way economically competitive with past energy, water and sanitation interventions. I have suggested, based on evaluations of efforts to meet the MDGs, that focusing on the rural poor in programs to install biodigesters would be an efficient deployment strategy.

Biodigesters are also an effective carbon-abatement technology that can reduce the greenhouse gas emissions from rural farms. By capturing methane emissions from current open waste storage and reducing the amount of fuelwood and fossil fuel used to meet household energy needs, biodigesters can reduce GHG emissions. If commercialized, those GHG reductions could be sold as Emissions Reduction Credits and the proceeds could help subsidize the deployment of biodigesters in Mexico.

Additional environmental and social benefits can be realized from the installation of biodigester systems. Environmental benefits include reduced organic and pathogen contamination in local watersheds and reduced demand on local forest for fuelwood. Social benefits include educational opportunities surrounding community development and efficient resource use and opportunities for the formation of small businesses to install and maintain biodigesters. Reduced health burden and improved economic performance of small farms can also have positive social benefits to the larger community. These types of benefits may also be able to attract funding to biodigester installation efforts such as those coordinated through government and international groups promoting environmental or social goals.

I believe there will be a market demand for biodigesters because they provide energy and sanitation services which are competitive with current alternatives. They provide additional benefits to the end user such as odor and insect reduction, reduced household health risks, and the ability to increase the



amount of animals on a small farm. The key challenge to meeting this demand is providing financial mechanisms, such as micro-credit programs, that can help facilitate the initial investment in the technology.

Pairing micro-credit programs with subsidies from emissions reduction and health funding could nearly eliminate the “first-cost” barrier that exists for much of the rural poor population in Mexico. I have shown that, because of the benefits from biodigesters, the systems have a range of payback periods from 0.9 to 1.5 years given current installation costs and depending how health benefits are valued. Recent work with new materials may be able to even further reduce installation costs and therefore reduce payback periods. Larger biodigesters installation projects would also bring additional savings from economies of scale.

Moving forward, there is much important research and development that must still be done to advance the use of biodigesters in Mexico and throughout Latin America and the developing world. Key to the success of future biodigester efforts will be programs such as the Mexico Biogas Program and larger initiatives such the Latin American and Caribbean Biodigester Network. It will be important for future efforts to share and receive advancements from around the world so that the deployment of biodigesters can continue to progress.

## REFERENCES

- Alessandro, S. 2008. *Estudio de factabilidad de implementacion de biodigestores rurales en la zonaandina de Cajamarca* (Perú). Cajamarca: SolucionesPracticas.
- Alvarez R, Villca S, Lidén G. 2006. "Biogas production from llama manure at high altitude." *Biomass and Bioenergy* Vol.30: 66-75.
- An BX, Preston TR, Dolberg F, Rodríguez LJ, Sarwatt SV. 1996. Installation and performance of low-cost polyethylene tube biodigesters on small-scale farms. Available from: <http://www.fao.org/ag/AGa/AGAP/FRG/FEEDback/War/W5256t/W5256t06.htm>
- An BX, Preston TR, Dolberg F. 1997a. The Role of Low-cost Plastic Tube Biodigesters in Integrated Farming Systems in Vietnam: Sustainable Livestock Production on Local Feed Resources, p. 155, Ho Chi Min City, Vietnam: University of Agriculture.
- An BX, Preston TR, Dolberg F. 1997b. The Introduction of Low Cost polyethylene tube biodigesters on small-scale farms in Vietnam. *Livestock Research for Rural Development*. University of Agriculture, Ho Chi Min City, Vietnam.
- An BX. 2002. Biogas technology in developing countries: Vietnam case study. Vietnam. Available from: <http://www.mekarn.org/procbiod/an.htm>
- Arnold M, Köhlin G, Persson R. 2006. Woodfuels, livelihoods, and policy interventions: Changing perspectives. *World Development* Vol.34, No.3: 596-611.
- Arnold M. 2003. *Fuelwood Revisited: What Has Changed in the Last Decade?* Bogor, Indonesia: CIFOR.
- [ARTI] Appropriate Rural Technology Institute. (no date) cited 2008. ARTI Biogas Plant: A compact digester for producing biogas from food waste. (Website) Available from: <http://www.arti-india.org/content/view/45/52/>.
- [ASAE] American Society of Agricultural Engineers Standards. 2005. D384.2: Manure Production and Characteristics. St. Joseph, MI: ASAE.
- Bacharach, 2009. (internet) Information available at: <http://www.bacharach-inc.com/fyrite-gas-analyzers.htm>.

- Baron G. (no date) Cited 2008. A Small Scale Biogas Digester Designed and Built in the Phillipeans. (webpage) Available from:  
<http://www.habmigern2003.info/biogas/Baron-digester/Baron-digester.htm>
- Bailis R, Pennise D, Ezzati M, Kammen D, Kituyi E. 2004. Impacts of greenhouse gas and particulate emissions from woodfuel production and end-use in Sub-Sahara Africa. Berkeley, CA: Renewable and Appropriate Energy Laboratory
- Balis R, Cowan A, Berueta V, Masera O. 2008. Arresting the killer in the kitchen: The promises and pitfalls of commercializing improved cookstoves. (Not yet published).
- Botero R. 2007. Generación de energía eléctrica a partir de biogas. EARTH University. Available from: <http://www.earth.ac.cr/biblioteca.php>.
- Botero R. 2006. Manejo productivo de excretas en sistemas ganaderos tropicales. EARTH University. Available from: <http://www.earth.ac.cr/biblioteca.php>
- Botero R, Preston TR. 1987. *Biodigestores de Bajo Costo para la Producción de Combustible y Fertilizante a Partir de Excretas: Manual para su Instalación, Operación, y Utilización*. Costa Rica: EARTH University.
- Brown K, Corbera E. 2003. Exploring equity and sustainable development in the new carbon economy. *Climate Policy* 3S1, S41-S56.
- Brown LE. 2005. Gas bio-digester information and construction manual for rural families. Sustainable Harvest International.
- Berrueta V, Rufus E, and Masera O. 2007. Energy performance of wood-burning cookstoves in Michoacan, Mexico. *Renewable Energy*. Available from:  
[http://www.gira.org.mx/index.php?option=com\\_content&task=view&id=87&Itemid=111](http://www.gira.org.mx/index.php?option=com_content&task=view&id=87&Itemid=111)
- Capor K, Ambrosi P. 2008. State and trends of the Carbon Market 2008. The World Bank.
- [CDI] *Comisión Nacional de Desarrollo de los pueblos Indígenas*. 2008. Available from: [www.CDI.gob.mx](http://www.CDI.gob.mx).
- [CEDECAP] *Centro de Demostración y Capacitación en Tecnología Apropriada*. 2008. *Proyecto Piloto Biodigestores Familiares*. (Presentation), Cajamarca, Peru.

- Children's Mercy, 2009. (Webpage) Available at: <http://www.childrens-mercy.org/stats/definitions/or.htm>
- Chsanakya HN, Rajabapaiah P, Modak JM. 2004. Evolving biomass-based biogas plants: The ASTRA experience. *Current Science* Vol. 87, No. 7.
- Chau LH. 1998. Biodigester effluent versus manure, from pigs or cattle, as fertilizer for duckweed. *Livestock Research for Rural Development*, Vol. 10, No.3.
- Chen TH, Shuy WH. 1996. Performance of four types of anaerobic reactors in treating very dilute dairy wastewater. *Biomass and Bioenergy*, Vol. 11, no. 5: 431-40.
- [CIPAV] *Centro para la Investigación de sistemas sostenibles para la Producción Agropecuaria*. 2008. (Website) Available from: <http://www.cipav.org.co/>
- Corbacho A, Shwartz G. 2002. Income Distribution and Social Expenditure Policies in Mexico: What Can we Learn from the Data? *Lateinamerika Analysen* 1, S. 5-64. Hamburg: IIK.
- Cortsen L, Lassen M, Nielsen HK. 1996. Evaluation of Small Scale Biogas Digesters in Turiani, Nronga, and Amani, Tanzania. Denmark: University of Aarhus
- Dees JG. 1998. The Meaning of "Social Entrepreneurship." Available from: <http://www.caseatduke.org/>.
- Diaz, M. 2008. Personal Communication. Guadalajara, Mexico.
- Dong H, Mangina J, McAllister T. 2006. Chapter 10: Emissions from Livestock and Manure Management. IPCC Guidelines for National Greenhouse Gas Inventories. IPCC.
- Dutsche M, Michaelowa A. 2003. Development Aid and the CDM- How to interpret "Financial Additionality." Hamburg Institute of International Economics.
- Enkvist PA, Naucclér T, Rosander J. 2007. A cost curve for greenhouse gas reduction. *The McKinsey Quarterly* Number 1.
- [EPA] Environmental Protection Agency. 2009. (Internet) Climate Change and Greenhouse Gas Emissions Inventory, available at: <http://www.epa.gov/climatechange/emissions/index.html>
- [ESMAP]. 2000. Energy Services for the World's Poor. Washington DC: The World Bank.

- Fearnside PM. 1997. Greenhouse-Gas Emissions from Amazonian Hydroelectric Reservoirs: The Example of Brazil's Tucuruí Dam As Compared to Fossil Fuel Alternatives, *Environmental Conservation*, v. 24(1), p. 64-75.
- Fisher C, Newell R. 2008. Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management* 55: 142-162.
- Franco M. 2006. Methane to Markets: Mexico Program Overview. (Presentation) PA Consulting Group. Presented in Mexico City, Mexico.
- Franco M. 2008. *Taller Sobre Captura y Aprovechamiento de Metan Proveniente de Residuos Agropecuarios*. (Presentation) Morelia, Mexico: Methane to Markets Program.
- Fuchs, VR. 1980. Time Preference and Health: An Exploratory Study. Stanford University.
- Gaffin SR. 2000, Comparing CH<sub>4</sub> Emissions from Hydropower to CO<sub>2</sub> from Fossil Fuel Plants, Submitted to The World Commission on Dams, available from: [www.edf.org/documents/723\\_reservoirgases.pdf](http://www.edf.org/documents/723_reservoirgases.pdf)
- Gafni A, Torrance GW. 1984. Risk Attitude and Time Preference and Health. *Management Science* Vol. 3 no. 4.
- Gakidou E, Oza S, Fuertes C, Li A, Lee D, Sousa A, Hogan M, Hoorn S, Ezzati, M. 2007. Improving child survival through environmental and nutritional interventions: the importance of targeting interventions toward the poor. *JAMA* 298 (16): 1876-87.
- [GIRA] *Grupo Interdisciplinario de Tecnología Rural y Apropiada*. 2009. (website) Available from : [www.gira.org.mx](http://www.gira.org.mx).
- (GS) The Gold Standard, (Webpage) (no date), retrieved 2008. Available at: <http://www.cdmgoldstandard.org/>.
- Green S. 1999. Emerging Biodigester Technology in Honduras: Biophysical Processes and Operation. (Thesis). University of Montana.
- Gudeman S. 2001. *Anthropology of Economy*. New York: Blackwell Publishing.
- Hackett S. 2006. *Environmental and Natural Resource Economics*. New York: M.E. Sharpe, Inc.

- Hammond A, Prahalad CK. 2002. Serving the World's Poor Profitably. Harvard Business Review.
- Harte J. 1988. Consider a Spherical Cow. Sausalito, California: University Science Books.
- HEDON. 2009. Press Release: US Increased Efficient Woodfuel Funding. Available from: [www.hedon.info](http://www.hedon.info)
- Hepburn C, Phoebe K, Panopoulou E, Pantelidis E. 2006. Social discounting under uncertainty: A cross-country comparison. Journal of Environmental Economics and Management. doi:10.1016/j.jeem.2008.04.004.
- Herrero JM. 2008. *Biodigestores familiares: Guía de diseño y manual de instalación*. GTZ-Energía. Bolivia.
- Hutton G, Haller L. 2004. Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level. World Health Organization Press.
- Hutton G. 2001. Economic evaluation and priority setting in water and sanitation interventions. Water Quality: Guidelines, Standards, and Health. World Health Organization. London, UK: IWA Publishing.
- [INEGI] Instituto Nacional de Estadística y Geografía. 2008. Available from: [www.inegi.org.mx](http://www.inegi.org.mx).
- [IRRI] International Renewable Resources Institute. 2009. Mexico Biogas Program. (Website) Available from: [www.irrimexico.org](http://www.irrimexico.org).
- Johnson A, Jones E, Millet N, Taylor J. 2008. Patzcuaro Biogas Metering Project. (Report) Humboldt State University.
- Jones DL. 1999. Potential health risks associated with the persistence of Escherichia coli O157 in agricultural environments. Soil Use and Management. 15: 76-83.
- Kammen D, Pacca S. Assessing the Cost of Electricity. Annual Review Environmental Resources 29:301, University of California, Berkeley, 2004.
- Kartha S, Leach G. 2001. Using modern bioenergy to reduce rural poverty. Stockholm Environment Institute.

- Lansing S. 2008. Performance and optimization of low-cost digesters for energy production and treatment of livestock wastewater. [dissertation] Ohio State University.
- Lansing S, Botero R, Viquez J, Martin J. 2008. Quantifying electricity generation and waste transformation in a low-cost, plug-flow anaerobic digestion system. *Ecological Engineering* 34: 332-48.
- Lansing S, Botero R, Martin J. 2007. Small-scale digesters in Costa Rica. BioCycle International.
- Lansing S, Botero R, Martin J. 2007. Waste treatment and biogas quality in small-scale agricultural systems. *Biosource Technology* 99.
- Las Candas, (no date) Retrieved 2008. (Website) Available from: <http://www.bosquedeniebla.com.mx/pub.htm>
- Leach G, Mearns, R. 1988. *Beyond the Woodfuel Crises: People, Land, and Trees in Africa*. London: Earthscan.
- Lokey E. 2008. Barriers to clean development mechanism renewable energy projects in Mexico. *Renewable Energy*, doi: 10.1016/j.renene.2008.06.004.
- Losada H, Neale M, Vieyra J, Soriano R, River J, Cort's J, Grande D. 1995. The potential of traditional systems of pig production in the temperate region of Xochimilco. *Livestock Research for Rural Development*. Vol. 7, No. 1.
- Lovins A. 1977. *Energy Strategy: The Road not Taken? Not Man Apart*, Volume 6.
- Kounnavongsa B. 2008. Effect of mixing on gas production in plug flow tubular plastic biodigesters. Available from: <http://mekarn.org/msc2008-10/miniproject/minpro/boun.htm>
- Macht C, Axinn WG, Ghimire D. 2007. Household energy consumption: community context and the fuelwood transition. (Report) University of Michigan Population Studies Center.
- Malina JF, Pohland FG. 1992. *Design of Anaerobic Processes for the Treatment of Industrial and Municipal Waste*. New York: CRC Press.
- Markandya and Pearce. 1991. Development the environment and the social rate of discount. *World Bank Research Observer* Vol. 6 no. 2.

- Masera O. 2005. From Cookstoves to Cooking Systems: The Integrated Program on Sustainable Household Energy Use in Mexico. *Energy for Sustainable Development* 9, no. 1: 25-36.
- Masters, Gilbert M. 2004. *Renewable and Efficient Power Systems*. Indianapolis, IN: John Wiley and Sons, Inc.
- McCarty PL. 1964. Anaerobic waste treatment fundamentals III. *Public Works*, 95, 91-94.
- M-Con Bio, 2009. Available from:  
[www.epa.gov/epawaste/rcc/resources/meetings/rcc/peck.pdf](http://www.epa.gov/epawaste/rcc/resources/meetings/rcc/peck.pdf)
- Mix Market. 2009. About Mix Market. (website) Available from:  
[http://www.mixmarket.org/en/about\\_mix\\_market.asp](http://www.mixmarket.org/en/about_mix_market.asp)
- Morales S. 2008. (Personal Communication) University of Guantajuato, Mexico.
- Moser, Mark. 2008. (Personal communication) RCM Digesters International LLC.
- Nambo C. 2008. (Interview and Personal Communication) Erongariquaro, Mexico.
- [NIIR] National Institute of Industrial Research. 1990. *Handbook on Bio Gas and It's Applications*. Deli, India: AJ Kr. Gupa.
- Nordhaus WD. 2005. *Life after Kyoto: Alternative approaches to global warming policies*. Yale University.
- Olian, G. 2008. Personal Communication (Cleaner Climate) Sydney, Australia.
- [PAHO] Pan American Health Organization. updated 2008. *Mexico Health Profile*. (website) Available from: <http://www.mex.ops-oms.org/>
- [PC] Point Carbon. (no date) cited 2008. Available from: [www.pointcarbon.com](http://www.pointcarbon.com)
- Pell A. 1997. Manure and Microbes: Public and Animal Health Problem? *Journal of Dairy Science* 80: 2673-81.
- Pound B, Bordas F, Preston TR. 1981. Characteristics of production and function of a 15 cubic meter Red-Mud PVC biogas digester. *Tropical Animal Production*, Vol. 6: 146-153.



- Preston TR, Rodríguez L. 2002. Low-cost biodigesters as the epicenter of ecological farming systems. Proceedings Biodigester Workshop, University of Tropical Agriculture Foundation, Cambodia. Available from: <http://www.mekarn.org/procbiod/pres.htm>
- Proteger. 2005. *El Camino de la Biodigestion*. Available from: <http://www.proteger.org.ar/tecnologia>
- Quadir SA, Mathur SS, Kandpal TC. 1995. Barriers to Dissemination of Renewable Energy Technologies for Cooking. Deli, India: Centre for Energy Studies, India Institute of Technology.
- [RADDP] *Recuperación Ambiental de la Cuenca del Lago Patzcuaro*. (no date) Cited 2008. Available from: <http://www.recuperapatzcuaro.info/cuenca.htm>
- [RCM] Resource Conservation Management, 2007. Swine waste generation, collection, storage and treatment options. (report) RCM internal report, Berkeley, CA.
- Rodriguez L, Preston TR. 1997. Biodigester Installation Manual. United Nations Food and Agricultural Organization, available from: <http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/Recycle/biodig/manual.htm>
- [SAGARPA] *Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación*. 2008. Available from: [www.sagarpa.gob.mx](http://www.sagarpa.gob.mx).
- Sandia National Laboratories. 2002. Life-Cycle Costing. (webpage) Available from: <http://photovoltaics.sandia.gov/docs/LCcost.htm>
- [SEDESOL] *Secretaria de Desarrollo Social*. 2008. Available from: [www.sedesol.gob.mx](http://www.sedesol.gob.mx).
- [SEMARNAT] *Secretaria de la Media Ambiente*. 2008. Available from: [www.SEMARNAT.gob.mx](http://www.SEMARNAT.gob.mx).
- Smith KR, Rogers J, Cowlin S. 2005. Households and Ill-Health in Developing Countries: What improvements can be brought by LP Gas? Paris, France: World LP Gas Association.
- Smith KR. 2006. Health Impacts of fuelwood use in developing countries. *Unaxylasa* 224, Vol. 57.
- (SNV) Netherlands Development Organization. 2009. International Workshop on Financing of Domestic Biogas Plants. (Proceedings) Amsterdam: SNV.

- Srinivasan S. 2007. Positive externalities of domestic biogas initiatives: Implications for financing. *Renewable and Sustainable Energy Review* 12: 1476-84.
- Srivastava L. 2006. Climate protection for sustainable development or sustainable development for climate protection? A case study from India. *Global Environmental Change* 16: 120-22.
- Sterk W, Wittneben BB. 2006. Enhancing the clean development mechanism through sectoral approaches: definitions, applications, and ways forward. *International Environmental Agreements* 6:271-287.
- United Nations. 2009. Millennium Development Goals. (website) Available from: <http://www.un.org/millenniumgoals/>
- [UNFCCC] United Nations Framework Convention on Climate Change. cited 2008. Clean Development Mechanism. (Website) Available from: <http://cdm.unfccc.int/index.html>.
- [UNFCCC] United Nations Framework Convention on Climate Change. updated 2009. Clean Development Mechanism. (Website) Available from: <http://cdm.unfccc.int/index.html>.
- Valley Air Solutions. 2008. Products. (webpage) Available from: [www.valleyairsolutions.com](http://www.valleyairsolutions.com).
- Viquez J, Lansing S, Martínez H. 2008. Evaluating digester design for electricity generation. BioCycle International.
- [VCS] Voluntary Carbon Standard. 2008. (Website) Available from: [www.v-c-s.org](http://www.v-c-s.org).
- [WCD] World Commission on Dams. 2000. (Press Release) Does Hydro Power Reduce Carbon Emissions? Available from: [http://www.dams.org/news\\_events/press357.htm](http://www.dams.org/news_events/press357.htm)
- [WHOSIS] World Health Organization Statistical Information System. 2008. Available from: <http://www.who.int/en/>
- Winrock International. 2005. Financing Biogas through Microfinance in Nepal. (Report) Nepal: Biogas Support Programme.
- World Bank. 2008. Expert workshop on CDM methodologies and technical issues associated with power generation and power saving activities. (Report) Prepared by QualityTonnes for the World Bank Carbon Finance Unit.

World Bank. 2008. State and Trends of the Carbon Market Report. Available at:  
<http://web.worldbank.org/>.

World Bank. 2004. (Report) State of Development. Available from: [www.world  
Bank.org](http://www.worldbank.org).

## APPENDIX A

*Taller de Intercambio de Experiencias de Biodigestores en America Latina*

# Taller de Intercambio de Experiencias de Biodigestores en América Latina

## Resumen de Conclusiones

Cajamarca, Perú  
del 18 al 22 de mayo de 2009

Lugar: Centro de Demostración y Capacitación en Tecnologías Apropriadas  
CEDECAP



Con la participación de:



Organizan:



Green Empowement



Apoyan:





## Taller de Intercambio de Experiencias de Biodigestores en América Latina-- Resumen de Conclusiones

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El Taller es organizado por Green Empowerment y el Centro de Demostración y Capacitación de Tecnologías Apropriadas de Soluciones Practicas-ITDG. El Taller es financiado por WISION of Sustainability, una iniciativa de *Wuppertal Institute of Sustainability for Climate, Energy and Environment*, con el apoyo de la organización Sueca, ProEvolution para fomentar proyectos prácticos de energía sostenible.

## Objetivo

El proyecto “**Innovaciones de Biodigestores en América Latina**” es diseñado para aumentar la cantidad de proyectos de biodigestores exitosos e innovadores en América Latina a través de la mejora de la calidad de metodologías y materiales utilizados. Para lograr esto, el proyecto incluye:

- 1) Síntesis de experiencias con biodigestores
- 2) Compartir Innovaciones: Taller de Intercambio de Experiencias de Biodigestores en América Latina
- 3) Instalaciones de biodigestores en cinco países
- 4) Evaluación
- 5) Distribución de Lecciones Aprendidas

Este informe presenta las conclusiones del Taller de Intercambio de Experiencias de Biodigestores en América Latina, lo cual formó un paso crítico en lograr este objetivo.

## Síntesis de Exposiciones

El Taller de Intercambio de Experiencias de Biodigestores en América Latina logro convocar a 33 representantes de ONGs, universidades, pequeños negocios, fabricantes y usuarios de biodigestores de 10 países. Los expositores compartieron experiencias de biodigestores de diversos tamaños, materiales, y diversos modelos de gestión.



Los productos producida también esta utilizado para un rango de beneficios. Por ejemplo, en Costa Rica el uso primario es reducción de contaminación ambiental, mientras en Perú, Bolivia, Nicaragua y México, los usos primarios son abono orgánico, cocinas y alumbrado. En Colombia también se han implementado biodigestores para refrigeración y calentamiento de agua. En Las Filipinas se usa el biol para alimentación de peces y cerdos. Según los beneficios deseados, se varía los diseños de los biodigestores.

El rango de los tamaños de los sistemas varía entre 1m<sup>3</sup> a 10m<sup>3</sup> y en su construcción se utilizan diferentes materiales (polietelino, alto densidad polipropileno, textil de PVC,



y ferrocemento) y utilizan diversos materiales primas de vacas, cerdos, cuyes y desechos humanos. Hay evidencias que demuestra que los biodigestores, permite mejorar la calidad de vida y promueve pequeños negocios, pero queda en evidencia que aun hay la necesidad de investigar: materiales, costos, resistencia, usos, etc. En el campo de los materiales debe conocerse las bondades, limitaciones y costos de los diferentes materiales para adoptarlo en la difusión de la tecnología.

Los expositores compartieron nuevas innovaciones tecnológicos, por ejemplo el uso de biodigestores de forma trapezoidal, el manejo de inundaciones, retirar el lodo, etc. Así como investigaciones de los niveles energéticos del estiércol de cabra, cuyes, gallinas, etc., el tipo y forma del estiércol debe tener un manejo previo para alcanzar, y el ratio de combinación entre agua y estiércol para optimizar la producción de energía.

Cada expositor también compartió su modelo de gestión que incluye pequeños negocios, alianzas con universidades, capacitación de técnicos certificados y programas de micro crédito. Hay consensos sobre la importancia de sostenibilidad, la selección adecuada, la capacitación, la organización de los usuarios. La formalización de programas de capacitación de promotores certificados en el manejo de biodigestores en Bolivia fue un modelo ejemplar.

La mayoría de los expositores están de acuerdo en que se debería financiar los biodigestores con una mezcla de subsidios y aporte de los usuarios, pero hay debate sobre si los subsidios deberían ayudar en la inversión inicial (materiales) o en operación y mantenimiento. También hubo discusión sobre quien(es) deberían asumir el subsidio y cuales serian los mecanismo de aplicación del mismo para no generar dependencia. Los mecanismos para las microfinanzas, es una estrategia interesante que algunas ONGs están explorando.

De igual manera, los expositores compartieron sus ideas sobre las condiciones sociales, políticas y económicas mas pertinentes para extender la tecnología y como podemos trabajar juntos para coordinar investigación y colaborar en la masificación de la tecnología.

Esta última tarea a significado que los participantes, a iniciativa de los organizadores, apoyen la formación de una red a nivel de Latinoamérica a fin de ir promoviendo espacios de intercambio que aseguren un flujo de información de las experiencias que se viene ejecutando por las instituciones participantes.

El CD tiene las presentaciones completas de los siguientes expositores:





## Green Empowerment



- Jason Selwitz, Green Empowerment (EEUU)
- Raúl Botero, Earth University (Costa Rica)
- Alex Eaton, IRRI (México)
- Gabriel Paco y Carlos Cuevas, GTZ (Bolivia)
- Mauricio Gnecco, APROTEC (Colombia)
- Davide Poggio, Universidad Politécnica de Cataluña (España) con colaboración de Instituto para una Alternativa Agraria (Perú)
- Rafael Escobar y Manolo Soria, Soluciones Practicas (Perú) y Marianna Garfi (UPC)
- Juan Morocho, Yanacancha (Perú)
- Patricia Rivadeneira y Diana Rojas, CARE (Ecuador)
- Genaro Carrión Ballena, Universidad de Cajamarca (Perú)
- Sonia Hilares, Centro de Promoción de la Mujer (Perú)
- Edmundo Rodríguez, CIDELSA (Perú)
- Auke Idzenga, Alternative Indigenous Development Foundation (Filipinas)
- Jaime Muñoz, Asofenix (Nicaragua)





## Instalaciones de Biodigestores

Durante dos días, instalamos dos modelos de biodigestores (uno de PVC de Soluciones Prácticas y la otra de alto densidad polipropileno de IRRI) para compartir y discutir detalles de diseños e criterios de instalación. Estas instalaciones, en el Instituto Nacional de Investigación Agraria, servirán como una planta piloto para investigación continua.









## Conclusiones de las Mesas Redondas

Dividimos en cuatro grupos para discutir Selección de Familias, Tecnología, Modelos de Gestión e Investigación Aplicada. Llegamos a las siguientes conclusiones:

### *Selección de Familias*

Las comunidades seleccionadas para un programa de biodigestores deberían cumplir con los criterios siguientes:

1. Dificultad en recolección de leña y otras formas de cocinar (LPG, electricidad). Por ejemplo, deberíamos enfocarnos en áreas con problemas de deforestación.
2. Número de animales adecuado, concentrados cerca de la casa.
3. Los biodigestores pueden ayudar a diferentes niveles económicos de las familias.
  - Productores medianos que pueden pagar el costo total
  - Productores pequeños que pueden pagar un % o ser objeto de micro-crédito
  - Familias pobres - con un programa de crianza de cerdos u otras especies menores.
4. Entusiasmo de participación de la familia o un miembro (mujeres y hombres) en encargarse de todas las tareas (mano de obra, cargar, mantenimiento, uso de biogás)
5. Tener suficiente agua sin cloro cerca de la instalación del biodigestor.
6. Tener un cultivo cerca del biodigestor para usar el biol.
7. Que la familia sea dueña de su parcela o tengan estabilidad habitacional
8. Seleccionar adecuadamente el sitio para construir el biodigestor
  - Tierra firme
  - Orientación solar
  - Cerca a la cocina
  - Cerca a concentración de animales
  - Zona que no tenga riesgo de inundaciones
9. Diseño de biodigestor debe estar de acuerdo demanda y tipo de uso de la familia.

El proceso de selección de una comunidad, y posteriormente, las familias:

1. Primero, hay tres formas para seleccionar la comunidad.
  - Implementar biodigestores donde la organización está desarrollando otros proyectos
  - Solicitud de comunidades al ONG ejecutor.



- Recomendaciones de otras organizaciones, instituciones y gobiernos locales.
2. Después, hay que conocer a los miembros de la comunidad (reuniones, entrevistas, información de líderes viejos, asambleas, reportes institucionales.)
  3. Finalmente, para seleccionar familias dentro de la comunidad, tomar en cuenta
    - Interés propio de las familias en los biodigestores.
    - Interés en el desarrollo de su comunidad, para ayudar a replicar el proyecto.
    - La parte política, religiosa y divisiones internas (i.e. si hay 2 partidos políticos, seleccionar beneficiarios de los dos partidos para evitar división y conflictos sociales )
    - Consideraciones económicas. Si es proyecto con subsidio enfocar en familias pobres-pero si tienen que pagar o hacer mantenimiento tomar en cuenta capacidad de pago.

Para la difusión de la tecnología, se ha definido los siguientes métodos:

1. Medios radiales que llegan a las comunidades. De personas que ya tienen biodigestores.
2. Programas gratis de la televisión
3. Aprovechar actividades de otras organizaciones
  - ONGs
  - Iglesias
  - Programas de salud
  - Cooperativas agrícolas
  - Programas estatales
4. Gobiernos municipales o regionales (“Comité de Desarrollo Municipal”/ “Mesa de Concertaciones”)
5. Centros técnicos o productivos (Por ejemplo, INIA o CEFOP en Perú)
6. Universidades agrícolas

### **Tecnología**

El diseño exacto y selección de materiales depende del contexto local. Si campesinos tienen que financiar todo el proyecto y no hay capital, seguimos trabajando con biodigestores de poca durabilidad de bajo





costo inicial (polietileno). Sin embargo, si hay otras fuentes de financiamiento, créditos, etc., entonces seleccionamos materiales más durables para los biodigestores (alto densidad polipropileno o PVC).

Hay consensos sobre la elección del biodigestor tipo tubular de plástico respecto a otros biodigestores en concreto, en particular el tipo Taiwán, por los siguientes aspectos:

- Es más fácil detectar eventuales fugas de gas
- No hay riesgo con sismos
- Es mas fácil de instalar
- Es mas fácil el transporte de materiales para la instalación en comunidades aisladas
- Es posible poner aislamiento para climas fríos
- Beneficios técnicos del flujo horizontal: mayor eficiencia biológica y menores “cortos circuitos”.
- Menores costos de inversión iniciales

Por otro lado el digestor tipo Taiwán permite una mayor vida útil y una mayor presión de suministro del gas (aunque no constante).

Es posible analizar parte por parte al biodigestor tubular. Por ello se empezó con el tema de la entrada. Se concluyó que la poza de cemento en la entrada es una buena solución para los modelos familiares porque:

- Ayuda a preparar la mezcla
- En casi todas las comunidades hay cultura de uso del cemento, aunque también se puede hacer con barro mejorado o con greda
- Se le puede añadir un filtro, para evitar la entrada de sólidos mayores de un cierto tamaño (en particular paja y materiales fibrosos)

Respecto a las tuberías de entrada y salida, no se ha llegado a una conclusión respecto a la importancia o menos de dotar el digestor con una salida para los lodos sedimentados: falta una demostración práctica de la eficacia de la tubería de purga en la remoción de los sólidos sedimentados. Lo mismo puede afirmarse para la decisión de poner la tubería de entrada a la altura de un 1/3 de la fase líquida para poder aumentar la agitación en el momento de la alimentación. En el caso de ausencia de tubería de purga, se ha propuesto de “masajear” el biodigestor para provocar la flotación de los sólidos sedimentados y efectuar en ese momento la alimentación del biodigestor y la consecuente descarga.

Posteriormente se habló de los materiales del reactor.





Se sacan las siguientes conclusiones sobre el polietileno.

- El polietileno ordinario presenta una escasa resistencia a la radiación solar, degradándose rápidamente (menos de un año si expuesto directamente al sol). Resultados mejores se obtienen usando polietileno para invernaderos, que contiene aditivos para disminuir la velocidad de degradación: puede considerarse un mínimo de tres años garantizados. En ambos casos se puede mejorar grandemente la duración del plástico (al menos del doble de duración) si disponemos el digestor a la sombra o bajo una cobertura que filtre la radiación UV.
- El polietileno no permite operaciones de soldadura o pegado, obligando así a las operaciones de amarre de los tubos carga y descarga mediante ligas de neumáticos. Es una manipulación que puede llevar a errores de instalación: rupturas en el plástico, deformación de las tuberías de carga y descarga por exceso de tensión de las ligas de neumáticos, etc.
- Es un material frágil, por lo que existen riesgos en su transporte e instalación.
- No es sencillo parchar eventuales huecos en el material

Se considera que el uso de polietileno para biodigestores tubulares ha cumplido una misión de vanguardia, frente a modelos rígidos en concreto y ladrillos; pero los inconvenientes que presenta causan un alto número de rupturas y abandono de los sistemas, disminuyendo su vida media útil y así disminuyendo la rentabilidad de la inversión económica. Por esta razón se propone como alternativa para futuros proyectos de diseminación a gran escala, el uso de materiales de alta densidad polipropileno y el PVC:

- presentan una mayor robustez y menor fragilidad en las operaciones de transporte e instalación;
- es posible centralizar ciertas fases de la producción (disposición de los tubos de carga y descarga, salida de gas), mejorando el control de calidad y facilitando las sucesivas operaciones de instalación;
- presentan una mayor vida útil y posiblemente una mayor rentabilidad económica respecto a los modelos en polietileno, a pesar de un mayor costo inicial.

El uso de materiales más durables (como alto densidad polipropileno), la centralización de ciertas fases en la producción del biodigestor, la posibilidad de reparar rupturas en el digestor, deberían permitir mantener altos valores de funcionamiento de la tecnología a lo largo de los años: se debería puntar a valores del 95% de digestores funcionando a 5



años de la instalación. En el caso del polietileno es posible alcanzar buenos resultados si se hace hincapié sobre la apropiación social de la tecnología, red de capacitadores y seguimiento (caso de Bolivia GTZ).

Un dato importante que deberíamos plantearnos en fase de diseño, es el tiempo de vida útil deseado para el digestor. En algunos países como Colombia, ciertos fenómenos migratorios hacia las zonas urbanas o hacia otras zonas productivas pueden limitar la importancia de diseñar un digestor con una alta vida útil. Se ha concluido que al menos 10 años de vida útil representan la meta de diseño, y que en caso de migración de todas maneras queda la posibilidad de vaciar, empacar y transportar el biodigestor.

El polipropileno que se ha presentado durante los días del encuentro, tiene garantizada una vida útil de 20 años, incluso con exposición directa del material a la radiación solar. Para el caso del PVC, se ha estimado una vida útil de 10 años aproximadamente, pero asegurando una adecuada protección de la radiación solar directa (sea con sombra, sea bajo un invernadero que filtre la radiación UV). En ambos casos falta verificar la durabilidad de las zonas que han sido selladas.

Para facilitar en el futuro la identificación y selección de nuevos materiales será importante elaborar una serie de estándares requeridos: propiedades mecánicas y físicas, resistencia al sol, características para su manipulación (sellado, pegado).

En general, la adopción de digestores prefabricados abre el debate respecto al nivel de centralización y globalización de la fase de producción. Hay que definir si existen las posibilidades técnicas y económicas de llevar la producción a un nivel intermedio de centralización (talleres regionales/provinciales); por otro lado se podría favorecer una centralización y estandarización “extrema” de la fabricación, incluso en países extranjeros asiáticos (en este caso podrían haber problemas de gastos aduaneros). De todas maneras, considerando la importancia de las acciones que estamos impulsando en la promoción de los biodigestores y en la abertura del mercado, es importante trabajar modelos de colaboración con las empresas privadas; por ejemplo se podrán elaborar servicios post-venta, planes de responsabilidad corporativas, fondos sociales etc.

Respecto al uso y valorización de los productos de la biodigestión (biol y biogás), existen todavía algunos puntos pendientes. Respecto al biol, se habló de la necesidad de definir más exactamente cuales son sus beneficios y las posibilidades de aplicación y tratamiento (secado), para poder así abrir un mercado. También es importante definir y reducir el riesgo de la aplicación del biol a causa de los patógenos presentes.





Respecto al uso del biogás también existen varios puntos que necesitan de ulterior trabajo:

- Evaluar la eficiencia de la combustión de gas. La eficiencia está relacionada también a la emisión de compuestos nocivos para la salud humana en caso de combustión incompleta. Algunos casos de malestar por parte de los usuarios que se han registrado en la región del Cusco podrían ser conectados con este hecho. ¿Podemos aumentar la combustión de gas mejorando la presión de gas en el reservorio o añadiendo soplador?
- Evaluar la posibilidad de la presurización. Se comentaron las tecnologías típicas: embolo-pistón, soplador, con peso sobre el reservorio. Alex comentó que existen también otras posibilidades de diseño. La presurización puede volverse necesaria en el caso de querer trabajar con aire primaria en la combustión.
- Evaluar la filtración del H<sub>2</sub>S. Lo más sencillo es con virutas/lana de fiero. Hay que evaluar la necesidad de oxidarlo previamente. Otra opción es el uso de filtros de tierra (ricos en Fe) como comentó Raúl Botero.
- Evaluar los patógenos en el biol para uso en verduras y productos de consumo.

### **Modelos de Gestión**

#### **Mecanismos de financiamiento**

- Privados:
  - Entidades financieras ligadas a actividad agropecuaria.
  - Empresas interés de realizar actividades de responsabilidad social (ej. Nestle, Gloria).
  - Ventanas de financiamiento externo, fondos privados mediante ONG's, Fundaciones, otros.
- Estatales:
  - Incorporación de la tecnología en programas de gobierno (Juntos, Sierra exportadora, etc.).
  - Programas de gestión ambiental (regionales, locales).
  - Incorporación en los presupuestos participativos.

#### **Sostenibilidad de los sistemas**

- Transferencia de conocimientos.
- Formación/capacitación de promotores.





- Fortalecimiento de capacidades locales (familia, líderes, autoridades, entre otros).
- Inducción al uso y aprovechamiento de productos del biodigestor.

### Roles institucionales

- Van de acuerdo a los intereses o necesidades o naturaleza:
- ONG's: capacitación, implementación, financiamiento, etc.
- Gob. Locales: políticas de difusión, incentivos, PIGARS, otras.
- Empresas: calidad del producto, cantidad, responsabilidad social?.
- Entidades financieras: créditos, otras.
- Instituciones académicas: investigación y desarrollo.

### Rentabilidad:

- Venta de biol,
- Uso en cultivos (producción, calidad, otras).
- Es necesario:
- Educar en el uso y comercialización
- Las instituciones de promoción: identificar mercados.
- No es posible comercializar el biogás, pero si usarlo para actividades productivas.

## *Investigación Aplicada*

Hay muchas instituciones que se dedican a la investigación sobre biodigestores. Hay que dinamizar el papel de las universidades y hay que aumentar la coordinación. La investigación debería tener en cuenta los objetivos finales de los beneficiarios y solucionar problemas prácticos. No hace falta desarrollar tecnologías o soluciones que no den beneficios a los beneficiarios. La investigación debería desarrollar estudios según los objetivos establecidos. Se propone la creación de una Red: Red BioLAC (Red de promoción de biodigestores en Latino América y Caribe).

La Red sobre biodigestores debería tener los siguientes objetivos: crear una biblioteca virtual con artículos, links de las instituciones que trabajan en biodigestión anaerobia, discusiones, promover eventos, desarrollar proyectos, buscar financiamientos, actualizar bases de datos, compartir y colaborar en





investigaciones, y desarrollar un plan de estudios para la certificación de técnicos.

Se concluyo que hay que investigar los siguientes temas:

**1. Investigar diversos materiales y diseño. Destino final de Materiales (posibilidad de reciclaje del material utilizado).**

Es importante probar materiales diferentes, para que la tecnología se vuelva más sostenible. Actualmente en Europa no se utiliza material en PVC, porque emite cloro. Sería interesante investigar materiales menos impactantes del plástico (como piel de oveja) y que se puedan reciclar. Sería también interesante estudiar el material utilizado junto con diferentes diseños, para aumentar la eficiencia de los biodigestores y disminuir el tamaño y entonces el material utilizado.

**2. Combinación de materiales de biodigestores**

Es importante investigar biodigestores hecho por una parte fija (zanja) y una parte de diferentes materiales (cúpula) para ahorrar plástico y facilitar obras de manutención.

**3. Agitación, rotura de nata y mayor superficie de colonización de bacterias**

Es importante desarrollar estudios sobre sistemas o soluciones para agitar y romper la nata, o para aumentar las superficies adonde se puedan alojar las colonias bacterias (Ej.: Uso de botellas de plástico flotantes adentro de los biodigestores).

**4. Formas de las zanjas**

La forma cilíndrica es la que permite de aprovechar toda la superficie de la bolsa, pero es difícil de realizar en el campo. Lo mismo para la forma octagonal que además tiene problemas de derrumbes de paredes. La forma tiene que ser elegida según el tipo de suelo. Actualmente se utiliza la forma trapezoidal, porque es fácil de construir y evita los derrumbes de las paredes. Este tipo de forma reduce la capacidad de la bolsa del 14 %, así que se necesita estudiar otro tipo de forma (Ej.: triangulo con la base de un cilindro).

**5. Ubicación de la salida y de la entrada del efluente**

**6. Materiales aislantes**

Hay que investigar otros tipos de materiales aislantes, resistentes por ejemplo a la lluvia y a la humedad (Ej.: hojas de eucaliptos, hojas de pino)

**7. Pendiente, tipo de techo, orientación y ubicación de los biodigestores**



Hay opiniones diferentes sobre al grado de inclinación o pendiente óptima de la zanja (de 1% a 4%). La orientación de los biodigestores depende mayormente de la topografía. La zanja tiene que seguir la topografía del lugar.

Para investigar los temas y sacar datos significativos, se establezco las siguientes pautas:

**1. Todas las mediciones comparables (Estandarización)**

Es importante desarrollar las mediciones utilizando las mismas pruebas y el mismo protocolo para que los resultados sean comparables en todos los países.

**2. Clasificación de sitios.**

Para comparar los resultados de la investigación en todos los países deberíamos hacer una clasificación ecológica, especificando en cuales condiciones trabajan nuestros biodigestores. La clasificación incluye la identificación de las zonas de trabajo y la descripción detallada de las condiciones climáticas y meteorologicas del lugar. Tenemos que definir diversos pisos térmicos para comparar el comportamiento del biodigestor en diferentes alturas:

- 0-1500 msmm
- 1500-2800 msmm
- 2800-3500 msmm
- >3500 msmm

**3. Caracterizar calidad de agua y de la materia orgánica en alimentación (composición y materia seca).**

La eficiencia de los biodigestores depende de la calidad del agua. Por eso es importante investigar la calidad del agua en la mezclas de alimentación.

**4. Documentar temperatura en la fase liquida**

**5. Documentar el potencial de generación de metano**

Lo que interesa, cuando se utilizan biodigestores con el objetivo de producir biogás, es el potencial de generación de Metano. Hay que investigar la variación de porcentaje de metano en biogás según por ejemplo el material en entrada (Ej.: utilizar residuos orgánicos).

**6. Tiempo de retención de la materia orgánica en el biodigestor.**

**7. Composición y caracterización de efluentes**



Es importante caracterizar el biol, según también las diferentes mezclas en alimentación y calcular por ejemplo la relación de elementos para obtener mayor cantidad de biogás y biol de mejor calidad.

## **Variables para La Evaluación de Proyectos de Biodigestores**

Desarrollamos las siguientes variables/indicadores para la evaluación del impacto de biodigestores en el bienestar familiar.

### **Técnicas**

- Producción de Biogás y su eficiencia
- Materiales
- Aplicaciones del Biogás
- Producción de biogás suficiente
- Durabilidad
- Posibilidad de diferentes usos del biogás
- Posibilidad de acuicultura
- Aprovechamiento de todos los productos derivados de la tecnología
- Calidad y cantidad de energía que están usando
- Eficiencia
- Evaluación del estado físico del biodigestor

### **Ambientales**

- Impactos en la atmósfera (manejo excretas y combustión)
- Impactos en el agua y los suelos (Reducción de efluentes dañinos al medio ambiente)
- Aprovechamiento de los productos de la tecnología
- Reducción de Desechos sólidos y reciclaje
- Materias primas empleadas para producir la energía
- Reducción en la deforestación

### **Económicas**

- Generación de energía limpia
- Incremento en la productividad (aumento en la cantidad de ganado)
- Posibilidad de producción orgánica
- Posibilidad de venta del Biol.
- Reducción en Gastos energéticos/Fertilizantes



- Voluntad de pago

#### **Sociales**

- Bienestar de la población (Control de insectos y males olores, menor tiempo en Recolección de leña, mayor productividad)
- Menor tiempo de recolección de leña y usos de tiempo disponible
- Facilidad de gestión
- Capacitación
- Desarrollo Rural
- Sanidad Comunitaria y Familiar
- Reducción de la migración hacia las ciudades
- Autoabastecimiento de alimentos y energía
- Mejoramiento en la nutrición familiar
- Sentimiento comunitario y participativo
- Perspectiva de la tecnología
- Status de la familia

#### **Salud**

- Tasa de enfermedades respiratorias (ira)
- Tasa de mortalidad
- Infecciones oculares
- Enfermedades diarreicas agudas (EDA)
- Salud Familiar (Limpieza de la casa)

## **Formación de Red de Biodigestores para Latinoamérica y el Caribe (Red BioLAC)**

En el marco del Taller de Intercambio de Experiencias de Biodigestores en América Latina, desarrollado entre el 18 y 22 de Mayo 2009, hemos creído por conveniente dar un acuerdo para formar la RED DE BIODIGESTORES PARA LATINOAMERICA Y EL CARIBE - RedBIOLAC, cuyos objetivos es promocionar a la tecnología de los biodigestores como alternativa para el desarrollo rural.

Para impulsar dicha red se acuerda que el CEDECAP sea, inicialmente, el ente formal que promueva la interacción de los distintos participantes. Esta RED contara con el apoyo de Green Empowerment (GE) e Ingeniería Sin Fronteras (ISF), con la participación de Raúl Botero de EARTH University (Costa Rica), Alexander Eaton del International Renewable



Resources Institute (México), Mauricio J. Gnecco de APROTEC (Colombia) y Jaime E. Muñoz de Asofenix (Nicaragua).

Firmamos un acta de acuerdo de formar dicha red y proponemos la siguiente misión, visión, y primero actividades.

### **Misión**

Promover la investigación aplicada y la difusión de la biodigestión anaeróbica como una herramienta para mejorar el bienestar de la población de América Latina y el Caribe.

### **Visión**

Ser una organización que apoya en una manera genuina la conservación ambiental y el bienestar socioeconómico en el medio rural.

### **Primeras Actividades Propuestas**

#### **1. *Evaluación de recursos, capacidad y potencia de biodigestores de pequeña y mediana escala en cada país de Red BioLAC (Mayo-Junio, 2009)***

Empezar a recopilar información sobre el Estado de Biodigestores en Latino América, evaluaremos la información que tenemos disponible, identificaremos las áreas donde falta información, y generaremos los siguientes pasos para conseguir esta información.

#### **2. *Escribir una lista de metas para Red BioLAC, su país, y Latino América***

Desarrollar una visión colectiva de metas del corto, mediano y largo plazo para la Red en términos de número de sistemas, avances de tecnología, coordinación, etc.

#### **3. *Coordinación de una junta de los actores principales de la Red BioLAC (Julio-Septiembre, 2009)***

Con ayuda de Green Empowerment y otros grupos, coordinaremos una junta de los actores principales para generar metas, acciones, reglas, y líderes para la RED BioLAC. Específicamente vamos a ver que tipos de propuestas podemos escribir juntos para apoyar las metas del grupo y las metas de la masificación de la capacidad de la tecnología en la región. Esperamos reunir en Noviembre 2009 para coordinar las acciones siguientes.





## Compromisos y Perspectivas

**PERU** – Soluciones Practicas (ITDG) en colaboración con Universidad Politécnica de Cataluña y Instituto Nacional de Investigación Agraria están empezando una planta piloto de biodigestores para la investigación de la tecnología, incluyendo materiales (geomembrana PVC y polipropolína), dimensionamiento, producción de gas y usos de biol. La metodología será definida según los criterios desarrollados durante el taller. El Instituto de Alternativas Agrarias también instalara 100 biodigestores con línea base y evaluación que añadirá a la investigación. ITDG instalara 10 biodigestores en el marco del proyecto WISIONS, continuara comparando los materiales y desarrollar el modelo de gestión y capacitación. Y también, ITDG quiere empezar el desarrollo de un plan de estudios para la certificación de técnicos de biodigestores – se esta esbozando la propuesta para tener un piloto con CEFOP y trabajar desarrollando un plan de estudios con otros miembros de Red BioLAC. Los representantes de Centro de Formacion Professional (CEFOP) va a instalar un biodigestor en el centro para que los jóvenes del CEFOP Cajamarca pueden participar como promotores de la difusión de la tecnología de los biodigestores y capacitado al mismo para que pueden replicar en sus futuras zonas de trabajo. El Centro de Demostración y Capacitación de Tecnologías Apropriadas (CEDECAP) encabezara Red BioLAC e impulsara el Foro de Biodigestores a [www.cedecap.org.pe/foros](http://www.cedecap.org.pe/foros). CIDELSA va a investigar sobre materiales geomembranas (PVC) con mayor duración, mejor el modelo tubular/piramidal con tapas y 3 salidas y otros cambios al diseño.

**NICARAGUA** - Asofenix instalara 3 tipos de biodigestores en la misma comunidad para comparar rendimiento y durabilidad: el modelo alto densidad polipropolino de IRRI-México, un modelo horizontal de ferrocemento con modificaciones aprendido durante el taller (tamaño y forma), y un modelo que combina una base horizontal de ferrocemento para durabilidad y una tapa de plástico para mantenimiento fácil.

**COSTA RICA** - EARTH University compartirá su metodología de investigación para ayudar en la estandarización de metodología y parámetros. Dentro del marco del proyecto WISIONS, se instalara y evaluara 10 biodigestores, enfocando en la capacitación de técnicos locales del campo para instalar y mantener los biodigestores, siguiendo el modelo de GTZ-Bolivia. Uno de los biodigestores instalados será de alto densidad polipropolino de IRRI-México para comparar diseños. También se enseñara los estudiantes sobre nuevas formas de aplicación de la tecnología motivando para diseñar y hacer investigación en otros temas de la misma biodigestion anaerobia.





**COLOMBIA** - Aprotéc instalara 2 biodigestores en una cooperativa de stevia (vaca y cerdos), un biodigestor para tratamiento de aguas negras y lanzara un anuncio público para diseminar la tecnología y buscar usuarios interesados en colaborar en investigación. Se enfocara en análisis social en la aceptación de biodigestores.

**BOLIVIA** - Seguirá mejorando quemadores, reservorios y diseños a diferentes alturas. También le interesa probar los nuevos modelos mostrados durante el taller, como el tipo de alto densidad polipropileno (IRRI-México).

**ECUADOR** - CARE Ecuador incentivara a agricultores y ganaderos con la implementación de esta tecnología para el fácil aprovechamiento de todos sus subproductos. Registrara datos para añadir a una base de datos de biodigestores en América Latina. Ayudara con el análisis de nuevas alternativas para el correcto funcionamiento de un biodigestor según la temperatura y la geografía de cada lugar y mejoras de las técnicas de uso de materias amigables al medio ambiente.

**MEXICO** - Instalará 10 sistemas, con capacitación y seguimiento, dentro del marco del proyecto WISIONS. Evaluara indicadores, metodología de investigación, y definición de los beneficios de biodigestores en términos económicos de ciclo de vida. Ayudara en formar Red BioLAC y desarrollar el concepto de un gran plan de biodigestores en América Latina.

**EEUU** - Green Empowerment gestionara el proyecto WISIONS con colaboración de los socios en México, Nicaragua, Perú, Colombia y Costa Rica. Desarrollara una metodología de línea base y evaluación para comparar datos. Ayudara a impulsar el Foro de Biodigestores y RedBioLAC. También coordinara con University of Michigan en investigaciones en modelos económicos y aportes de negocios en biodigestion.

**ESPAÑA** - Ingeniería Sin Fronteras (ISF) de Aragón ha solicitado un financiamiento para un proyecto de masificación de biodigestores en Perú. Además se ha firmado un convenio con otras dos instituciones, VSF (veterinarios sin fronteras) y CERAI (centro de estudios rurales de agricultura internacional) para promover la concienciación en el norte y realizar investigaciones en la facultad de veterinaria de Zaragoza. También ISF Cataluña y Universidad Politecnica de Cataluña son socios claves en la implementación de los biodigestores con ITDG en Cajamarca y la planta piloto de biodigestores en INIA.



## Lista de Participantes

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