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**EMERGING BIODIGESTER TECHNOLOGY IN HONDURAS:  
BIOPHYSICAL PROCESSES AND OPERATION**

**By**

**N. Stuart Green**

**B.S., Montana Tech of the University of Montana, 1999**

**Presented in partial fulfillment of the requirements**

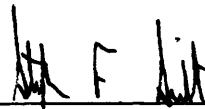
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**Master of Science**

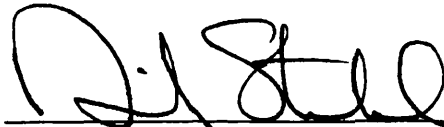
**The University of Montana**

**December 2005**

**Approved by:**



**Dr. Stephen F. Siebert, Chair**



**Dean, Graduate School**

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## ABSTRACT

Green, N. Stuart, M.S., December 2005

Resource Conservation

Emerging Biodigester Technology in Honduras: Biophysical Processes and Operation

Chair: Dr. Stephen F. Siebert

SFS

I studied biophysical and operational aspects of anaerobic biodigesters in rural Honduras in order to gather baseline information on the performance of biodigesters in the region. Biodigester technology has recently been introduced in Honduras and no region-specific information about their operation or performance exists. This study examines how biodigesters function in rural Honduran environments. The objectives of this study were to: 1. quantify biodigester processes, 2. describe biodigester operational practices, and 3. develop a typology of successful biodigester operation that also provides suggestions for improving biodigesters in the region.

Biodigester processes were in many ways comparable to projects in Asia, where most technical biodigester research has taken place. Operational practices varied among users, and inconsistent operator practices occasionally led to biodigester failure. No sites utilized biodigester effluent for practical applications, instead it was discharged. Common technical problems included flooding, sedimentation, animal damage, and poor water seals.

Results from my study suggest that biodigesters are performing well in Honduras. Rural farmers' attitudes towards the technology are generally positive and the majority of projects provided "enough" biogas, as determined by their operators. However, there are a number of ways in which biodigester design, technology extension, and operator practices might be refined. In particular, the technology could benefit by increasing safeguards against common types of failure, redesigning water seals to make them more robust, standardizing operator training, clearly defining extension goals, and focusing technology extension on interested, willing participants.

## ACKNOWLEDGEMENTS

It would be impossible to list all of the many scores of people who have collaborated with me on this project, but I would like to extend my heartfelt thanks to all. Thank you for all of the confidence, the encouragement, and assistance. But, for all the work that went into this project, this paper is only a reflection of greater work being done by others. Development workers, farmers, university gurus (even grad students), the foundation of this project rests on your achievements in the real world.

I spent two years in the Peace Corps where I learned how challenging it can be to work in a different country. As a graduate student, I learned how difficult it can be to design, plan, and orchestrate work from a country thousands of miles away, let alone execute it. I owe a special thanks to all of the staff at Sustainable Harvest International for graciously helping me realize this study. Having few resources of any kind, we somehow managed to make it all happen. *Hay que pensar en milagros*. Bruce, Flo, and all the staff in Maine, you're amazing, keep up the good work. I hope this is worth the wait! Yovany, Jon, Greg, and the entire staff of SHI Honduras, there are no better people to be at the helm of development. Thank you for watching out for me; your generosity knows no limits. I owe a great debt to the Zelaya family for opening their doors to a grinning, dusty foreigner with a banjo on his back and a crate full of science gear. You were never too concerned about the mysterious *experimentos* that kept me up until 3 AM, but you always made sure I had a full belly. Thanks also to Laura Brown, for putting together SHI's biodigester information manual. The manual is great and it's good to know that some of this research has already made it back into the field.

I must also thank the many people who helped me through this project without realizing what they were doing. My Peace Corps family, coworkers, collaborators; none of this would have happened without your guidance, friendship, and support. It was hard to fully appreciate my Honduran reality those first few months, and by the time I could, I was caught up in an amazing, heart-wrenching, rollercoaster. I'll never forget.

Big thanks go to everyone who helped with equipment on the trip. Don, Jeanne, and all the folks at SHI – Honduras, thanks for helping me gear up the mules.

Emily, Editor Supreme, Connoisseur Extraordinaire of fine malted beverages from around the world; thanks for helping me domesticate this paper. I'd be languishing forever in graduate school if not for your help. I owe you big-time.

To Dr. Stephen F. Siebert, Pillar of Patience, I owe a tremendous amount of thanks for being a trusted advisor and friend. You are more of an inspiration than you know, Steve; thanks for pointing this wayward engineer down a path well worth walking.

Finally, to my family, I love you all. Thank you for supporting me through the years of traveling, wandering, schooling, working, and adventuring that have taken me so far away.

Being home is the greatest reward.

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## **PREFACE**

At its heart, this paper is the result of 27 months that I spent as a US Peace Corps Volunteer in Honduras, where I worked alongside rural communities on natural resource conservation issues. I left for Honduras in May 2000, and returned to the United States in September 2002. Using my Peace Corps experience as a foundation, I returned to Honduras from August to October 2004 in cooperation with the College of Forestry and Conservation at the University of Montana and Sustainable Harvest International (SHI), a non-profit organization working throughout Central America. Over the course of two months, I conducted a review of SHI's biodigester projects in Honduras.

I chose to study biodigesters because they offer an opportunity to bridge the gap between several fields in which I am interested. My work as a Water and Sanitation Engineer in Honduras was surrounded by scores of disastrous, and sometimes brilliant, development projects that poured into the region following Hurricane Mitch in 1998. At the same time, I became aware of the intricate web of social and environmental forces underlying the small villages where I lived and worked. As my Peace Corps service drew to a close, I had a B.S. in Environmental Engineering, a burgeoning interest in natural resources, and a firm understanding that development work is much more than concrete and rebar; and so, I returned to the States to begin my Master's work. As I searched for a link between engineering, resource conservation, and sustainable development, my longtime obsession with alternative energy uncovered the biodigester.

After months of research and scores of email, I was able to coordinate a research project with the kindly folks of SHI Honduras, who had built up a small base of biodigester projects in the country. Somehow, I managed to fit my field laboratory into

my backpack, and off I went to investigate the life and times of biodigesters in Honduras. For the next two months, I tromped through the Honduran countryside to measure biodigester operation and to see what the operators themselves had to say about the technology. This paper is the result of those two months.

Biodigesters are uniquely qualified to address a variety of environmental problems, such as deforestation and pollution, and they empower people with a tool for pursuing energy independence. Despite the success of biodigesters in other parts of the world, comparatively little has been done with the technology in Central America; at present, little substantive information is available on biodigesters anywhere in the region. The study I conducted attempts to fill this information gap by providing scientific and observational data on biodigesters to a broader audience.

To help inform the reader and provide a context for my research, this paper begins with a brief introduction to biodigester technology, followed by several chapters detailing the actual study. It is my hope that this paper will serve as a useful source of information to further develop and refine biodigester technology and performance in Honduras and around the world.

N. Stuart Green

October 2005

## **CHAPTER 1—INTRODUCTION TO BIODIGESTER TECHNOLOGY**

*“It’s very easy to understand a biodigester. You see, it works just like a stomach...”  
Don Lelo, biodigester operator, La Arada, Santa Bárbara*

### **Role of the biodigester**

Human populations continue to expand across the landscape, natural resource consumption continues to increase, and scarce resources are divided ever more finely. According to the *State of the World’s Forests 2005* report issued by the United Nations’ (UN) Food and Agriculture Organization (FAO), deforestation and forest degradation are persistent global resource problems, particularly in the Tropics. In Central America, 1.2 percent of natural forest cover is lost annually (EarthTrends 2003).

Humans continually consume more energy resources and much of the world relies on wood energy. Only 5 percent of the Earth’s total primary energy supply is provided by wood energy but it is used widely, mostly in the form of fuelwood (FAO 2005). Fuelwood accounts for about 14 percent of the energy produced in G8 nations, but 69 percent of energy produced in the rest of the world (FAO 2005). These seemingly contrary statistics reflect the differences in energy development and availability between countries.

Consumption of fossil fuels also continues to increase. Between 1990 and 2000 annual per capita use of diesel and gasoline increased 1.75 percent to a current level of 174 liters per person (EarthTrends 2005). Adding to the demand for petroleum products is the over-reliance and mismanagement of agrochemicals. For example, the UN cites “evidence of continuing several serious deficiencies in critical areas of pesticide regulation, management and control in many countries, particularly in the African and Latin American regions” (FAO 1998) while world fertilizer inputs increased 5.2 percent

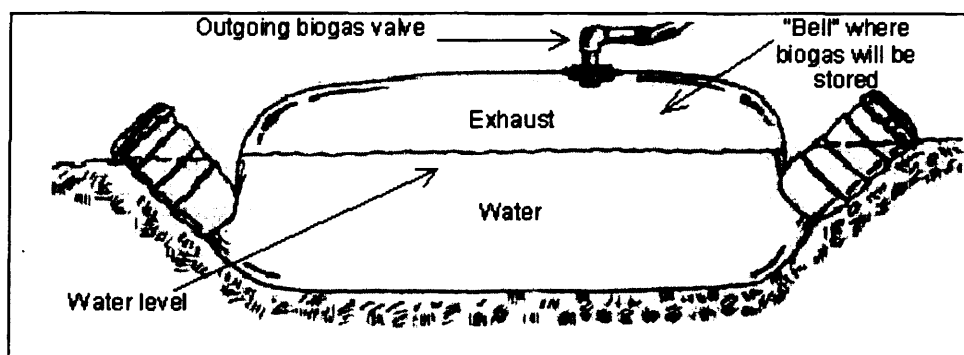
between 1996 and 2003 (FAO 2003). Now more than ever, applied research has the potential to develop more efficient technologies, take advantage of renewable resources, minimize waste, and optimize recycling of existing resources.

Many international development, government, and educational organizations address the natural resource and energy problems noted above. One means to that end is the *biodigester*, a technology that generates *biogas* (a combustible methane-based fuel) and nutrient-rich, organic effluent (a high-quality natural fertilizer) (Aguilar 2000). In addition to producing fuel and fertilizer, biodigesters can increase crop yields, decrease deforestation pressure, reduce wastes and pathogens, elimination of waste odors, and improved household health (An et al. 1997, 1997b; Luitweiler,, no date; Rodriguez and Preston 2000; Sophea and Preston 2000).

There are several different types of biodigesters. “Fixed dome” (Chinese) and “floating canopy” (Indian) models are common; although they are difficult to install, expensive, and replacement parts can be difficult to obtain (An et al. 1997b). In the 1970’s Taiwanese engineers began developing low-cost, flexible structure (polyethylene) biodigesters that were more accessible to low-income farmers than previous models (An et al. 1997b).

Low-cost polyethylene biodigesters employed by development organizations are relatively inexpensive, with material costs averaging between \$25 and \$100 dollars per unit, depending on material and extension costs (An et al. 1997; Bowles, SHI Country Dir., personal com.; Sophea and Preston 2000) Projects are easy to install, simple to operate, and have been shown to pay for themselves in less than six months time (An et al. 1997).

A typical SHI-type polyethylene biodigester consists of two main parts: the biodigester tank and a PVC gas line (See Figure 1). The tank is made of tubular polyethylene, partially entrenched and filled with liquid. Inlet and outlet tubes are attached to each end of the tank and oriented to create a water-sealed, anaerobic environment necessary for the production of biogas. The gas line carries biogas to a small stove where it is then combusted. In many countries, biodigester designs incorporate a second polyethylene tube placed at a mid-point in the gas line, which is used to store biogas (see Rodriguez and Preston,, no date); however, such a design is not being used in Honduras.



**Figure 1.** Schematic of anaerobic biodigester, a similar design is used by SHI. (Source: Aguilar 2000)

In their paper summarizing the installation and performance of low-cost biodigesters on small-scale farms, An et al. (1997b) describe the principal advantages of biodigester technology as:

- a reduction in workload, especially of women;
- a reduction in pressure on natural resources, such as fuelwood...;
- cheap energy production, resulting in cash savings;
- improving the farming system by recycling manure through biodigesters to produce gas for cooking and effluent for fertilizer...;
- making use of waste which would otherwise cause pollution...

### **Scope of biodigester implementation**

Biodigesters have been especially successful in Asia; in 1992, the FAO reported more than five million units in China alone. The proliferation of project in China is due to government efforts to develop and implement simple, appropriate biodigesters. The technology is bolstered using State biogas training extension programs, low-interest loans to farmers, and the direction of the State Science and Technology Commission and Chinese Academy of Sciences. In addition, there is a “collective support” structure of biogas service companies and local government investment. In addition, China has high potential for biogas and effluent utilization (FAO 1992). The technology is used by more than 25 million Chinese as a viable, low-cost means to meet local energy needs (FAO 1992).

Biodigesters are most common in China and India (both of which have well-developed, national biogas programs), but are also found in Vietnam, Cambodia, Laos, and Burma (An et al. 1997b, FAO 1992). In addition, successful projects have been undertaken in other parts of the world, including Colombia, Tanzania, the Philippines, Senegal, and many others (CIPAV 2005, Cortsen 1996, Taveros 2001, Youm 1999).

Extensive investigations have been conducted on biodigesters in Asia and South America. The Center for Research in Sustainable Systems of Agricultural Production

(CIPAV) and the University of Tropical Agriculture (UTA) are recognized for their biodigester research activities. These two research stations in particular play an important role in modern biodigester development, making up-to-date research available to a broad audience via internet publications. Several other groups are working with biodigesters in Asia, such as the Economic and Social Commission for Asia and the Pacific, the World Health Organization, and at least three different branches of the UN (FAO 1992)

The country-specific evaluations of biodigesters cited above suggest that biodigesters are sensitive to local environmental, social, and economic conditions. Consequently, biodigester research and development in one area, while valuable in a general sense, may not be directly applicable to biodigesters in other regions. Most available biodigester data stem from sites in Vietnam, Cambodia, and Colombia. While insightful, there exists a fundamental information gap regarding how biodigesters function in other geographic regions and physical environments that limits their development and use. Prior to this study I could find no technical information on biodigesters in Honduras. Some biodigester research has occurred in other Central American countries but the data are not public. Consequently, I crafted my research to provide insight into biophysical and operational processes of biodigesters in Honduras.

As noted above, biodigester technology has flourished in Asia. However, it has not experienced extensive or rapid development in Latin America. During the 1970s, polyethylene biodigester tubes offered a new alternative to more expensive Chinese and Indian models, resulting in significantly decreased implementation costs and increased availability to low-income farmers (An et al. 1997b). Sustainable Harvest International (SHI), a non-profit organization promoting sustainable development in Central America,



is now introducing polyethylene biodigesters in Honduras on a limited basis. In addition to SHI, other institutions working with biodigesters in Latin America include Earth University (Costa Rica), CIPAV (Colombia), and the Peace Corps (various countries).

Faced with many of the same political, social, and environmental issues that challenge the rest of Central America, rural Hondurans are in a position to reap substantial benefits from biodigester technology. Central America, Honduras in particular, appears climatically and agriculturally well-suited for biodigester implementation and development.

## **CHAPTER 2—A STUDY OF EMERGING BIODIGESTER TECHNOLOGY IN HONDURAS: BIOPHYSICAL PROCESSES AND OPERATION**

*“It’s like magic. Nobody understands how it really works...but it does!”  
Don Soza, Biodigester Operator, La Habana, Yoro*

### **Introduction**

During the 27 months I spent as a Peace Corps Volunteer in Honduras (2000-2002), I traveled throughout the country working with rural communities on water and other natural resource conservation issues. During that time, I did not observe a single biodigester project. Moreover, I became aware of the complete lack of alternative energy sources, the only exception being a few micro-scale solar energy projects in remote areas. Nearly every Honduran family I interacted with, including many urban residents, relied on fuelwood to meet their energy needs. High fuel acquisition costs, global climate trends, and food and resource scarcity warrant investigation of alternative technologies in an attempt to reduce household energy costs and foster more efficient resource use. Biodigesters may provide an alternative to traditional fuelwood use.

Biodigester technology can be utilized as both an alternative energy source *and* an environmental conservation tool (Mungia, National Dir. SHI, personal com.). In the past few years, biodigesters have emerged in Honduras in this context. SHI’s biodigester installation program aims to offset the harvesting of fuel wood by providing rural families with alternative energy sources. Biodigesters use the process of anaerobic decomposition to produce biogas (a mixture of methane, carbon dioxide, and other gasses), which can be combusted for cooking and other uses. Polyethylene biodigesters are relatively simple to build and require little more than a steady supply of organic matter and water, meaning they are well suited for use in rural areas. Secondary benefits

of biodigesters are the production of high-quality organic fertilizer, improved household air quality, decreased reliance on external fuel sources, and waste treatment (An et al. 1997b, Rodriguez and Preston, no date, Sophea and Preston 2000).

SHI's biodigester projects are predominantly small, single-family units; however, at least two projects have included larger units associated with commercial pig farms. The majority of small-scale, single-family biodigesters utilize cow manure as the primary substrate used to produce biogas. SHI does not have any set criteria for selecting the families it works with (Hurst, SHI Program Director, personal com.); rather, the organization lends technical support to families and community groups upon invitation from rural collaborators (SHI 2005).

### **Description of research**

This study involved a two-month, engineering-based investigation of biodigester projects in Honduras, Central America. The overall intention of my investigation was to gather region-specific, baseline biodigester data.

When I began my research in August 2004 SHI had installed 11 biodigesters, each project unique but all based on the same design. The biodigester sites investigated in this project were concentrated in two geographic regions: the Departments of Santa Barbara and Yoro. Broadly speaking, my field research was divided into three time periods. During the first six weeks, I gathered biophysical process data from five biodigesters in Santa Barbara via an intensive monitoring (IM) scheme of scientific measurement and experimentation. During the seventh week, I conducted a regional inspection (RI) in Yoro and briefly visited 6 additional biodigester sites and took measurements similar to the IM

scheme. During the seventh and eighth weeks, I administered a questionnaire for biodigester operators, which was designed to document farmers' operational practices. I documented operation and management practices of 91 percent (10 out of 11) of known biodigester operators in Honduras. All biodigesters examined in this study were constructed by SHI extensionists and their *campesino* (rural farmer) collaborators.

### **Study objectives**

At present, baseline data for biodigesters in Central America is either unavailable or does not exist. Such data may be useful for refining and assessing biodigester technology and management throughout the region. With this in mind, the objectives of this study were to:

1. Quantify biodigester processes through scientific measurement and experimentation;
2. Describe biodigester operational practices by documenting:
  - a. daily operational practices,
  - b. common biodigester problems, and
  - c. technological adaptations;
3. Develop a typology of successful biodigester operation and provide suggestions for improving biodigesters in the region.

### **Background and environmental trends of Honduras**

#### *Background on Honduras*

Slightly larger than the state of Tennessee, Honduras is located in Central America and is bordered on the north by the Caribbean Sea and on the south by the Gulf of Fonseca (See Figure 2); to the west it is bordered by Guatemala and El Salvador and to the east by Nicaragua (Central Intelligence Agency, CIA 2004). The terrain is mountainous throughout 80 percent of the interior, with narrow lowland plains along the

coast. The climate is temperate in the mountains and subtropical in lowland areas (CIA 2004). Less than 10 percent of the land area is arable, with much of this land occupied by export agriculture and therefore unavailable to small farmers (Library of Congress, no date). Annual precipitation is evenly distributed along the northern (Caribbean) coast; however, as one moves inland or toward the Pacific lowlands, a pronounced dry season occurs from November to April (Library of Congress, no date).

In October 1998, Honduras was devastated by Hurricane Mitch, recognized by the US National Oceanic and Atmospheric Administration (NOAA, no date) as one of the most powerful and destructive hurricanes ever recorded making landfall in Central America and the Caribbean. According to the United States Geological Service (USGS 2001), as the storm reached its peak, it stalled directly over Honduras for two days, releasing more than 4 inches of rain per hour with sustained winds exceeding 180 miles per hour. In the aftermath, the already struggling country faced catastrophic flooding, landslides, and an estimated 10,000 deaths (CARE 2003). Another 1.4 million people were left homeless, 92 bridges were washed away, and approximately 70 percent of the country's crops were destroyed (USGS 2001). International aid was unprecedented and quick to respond, yet today, Honduras continues to suffer the aftereffects of Hurricane Mitch (Thompson and Fathi 2005). Many of my own Peace Corps projects were centered on hurricane reconstruction and I witnessed the destruction firsthand. When I returned to Honduras in 2004, the storm's effects were still evident.



Figure 2. Map of Honduras and location of study areas. (Modified from CIA 2005)

Honduras is one of the poorest countries in the Western Hemisphere, exhibits extremely unequal division of wealth between the rich and poor, and unemployment rates approaching 30 percent (CIA 2003). A traditionally agrarian country, 54 percent of the country's 6.9 million people live in rural areas (FAO 2005), mostly practicing subsistence

farming. My experience working with rural peoples, water systems, and biodigesters reminded me daily that Hondurans are intricately tied to the health and integrity of their landscape. Unfortunately, soil productivity is often low, environmental problems are commonplace, and more than half the population lives below the poverty line (CIA 2003; EarthTrends 2003b).

#### *Environmental trends in Honduras*

According to the Center for International Policy (CIP 2001) the “Most Pressing Environmental Issues” in Honduras are deforestation, land tenure, water contamination, erosion, illegal wildlife traffic, mining, air pollution, and soil contamination. Additionally, current literature agrees that these issues are major environmental trends, which are both far-reaching and complex (CIA 2004, CIP 2001, Honduras This Week 2001, Kraul 2005). Consequently, I will briefly discuss three issues with the most direct links to biodigester technology: deforestation, pollution, and declining agricultural productivity.

Deforestation is a problem throughout Honduras. Between 1990 and 2000, Honduras lost an average of 59,000 hectares per year, equivalent to about 1 percent average annual reduction in forest cover (FAO 2005). This loss is due to multiple forces, such as urban and agricultural expansion, cattle development policies, fuelwood harvesting, forest fires, diseases, and illegal logging (CIP 2004).

Fuelwood is a significant source of energy in Honduras, representing 54 percent of national energy consumption, and is used primarily by the residential sector (EarthTrends 2003c). Hydroelectric resources provide approximately 6 percent of national energy needs and fossil fuels constitute the remaining 40 percent (ibid). When one considers the difficult economic situation in Honduras and inadequate energy

infrastructure, it is not difficult see why fuelwood is the only viable energy source for households, especially rural ones. However, deforestation in Honduras is not being driven solely by fuelwood consumption; illegal timber harvesting, land clearing, and a growing population all exert pressure on Honduran forests (CIP 2004).

During my Peace Corps experience, I found that deforestation was a fact of life for my Honduran neighbors. I looked on as they ventured daily into the surrounding forests to gather the day's *leña* (fuelwood), the only energy source readily available to them. As if to punctuate deforestation issues in the small town where I lived, a sawmill sat on a hill about 100 yards behind my house; I awoke each morning to the whining sounds of timber being milled. Thinking this sawmill might form an interesting basis for a community forestry project, I began talking with town residents. Through these discussions, I learned that the mill was completely unregulated. The owner of the mill (who was also happened to be the Mayor's brother) also enjoyed full tax exemption and complete autonomy, with no apparent accountability for his, or the mill's, actions. In disbelief, I asked my friends and neighbors to explain the situation. My landlady summarized it most succinctly: "*This is how things work here. Every town has a mill like this one...*" (*Doña Rubia, resident of San Francisco, Choluteca, personal com.*).

In urban areas, deforestation pressures are exacerbated by the presence of large, resource-poor shanty towns that comprise the periphery of most Honduran cities. Shanty towns are typically unorganized, lack official government or organization, and consequently have little capacity for resource management. I routinely observed widespread deforestation by squatters in and around Honduran cities.



Deforestation is also a significant problem in sparsely inhabited areas. According to the Association for a More Just Society (AJS 2004), Honduran law does little to curb illegal cutting or to address reforestation issues. My own experiences in the Honduran countryside drove home the near complete lack of environmental enforcement. Despite these trends, a new *campesino*-based environmental movement has emerged in some parts of the country to confront unregulated, pro-corporate timber and mining policies and the corrupt officials that support them (Honduras This Week 2001, Kraul 2005). Nevertheless, deforestation persists and contributes to larger environmental problems, particularly compromised watershed integrity, declining soil fertility, erosion, drought, and habitat loss (FAO 2005).

Pollution and land degradation are enormous problems in Honduras and are beyond the scope of this paper; however, a few examples will illustrate Honduras' overall pollution situation. Lacking functional waste disposal infrastructure, household refuse is commonly burned in the street or indiscriminately dumped. Farmers are commonly exposed to petrochemicals and pesticides, which are distributed and used without licenses, training, or proper equipment. In 1993 the FAO reported:

“Forty-eight percent of developing countries said that pesticides were still being stored improperly and unsafely and that disposal of pesticides and containers, at both warehouse and farm level, and improper siting and control of wastes from formulating plants presented serious, persisting problems in 66 percent of developing countries, in all regions, but particularly so in Latin America.”

Pesticide management in Honduras continues to suffer these limitations. In addition, potable and wastewater treatment facilities are almost non-existent in rural areas. Inadequate access to waste disposal and treatment results in contaminated waterways and increased health risks. These are only a few pollution issues that I observed while living

and working in Honduras, but they demonstrate that pollution is a widespread problem that affects almost the entire population.

Land degradation is a complex problem in Honduras. Agricultural techniques are often unsustainable; subsistence farming commonly occurs on steep hillsides that are prone to erosion. In addition, many farmers rely on centuries' old agricultural burning practices to clear fields; a majority of *campesinos* believe this practice regenerate soil nutrients. Increases in population and land tenure inequities have forced many farmers to divide family plots among their children, which are then cultivated more intensely to make up for reduced size. As one farmer noted, "*Honduras used to be the bread basket for all of Central America. But now, we import much more than we produce*" (Don Lelo, farmer, personal com.).

There are many underlying forces that we might look at to help understand the current environmental state of Honduras. Geist and Lambin (2001) identify five main factors that underlie tropical deforestation: economic, policy (institutional), technological, cultural (socio-economic), and demographic. All of these factors are at work in Honduras on some level and, in a general sense, shape Honduras' environmental situation. Based on my experience, environmental problems in Honduras are affected most by economic, cultural, and demographic factors.

A full analysis of Honduras' environmental issues is beyond the scope of this paper. Key problems include severe economic and agricultural pressure on rural families, a poorly developed conservation infrastructure, unsustainable farming practices that do not reflect rapidly changing social conditions, and an unforgiving physical environment for many farmers.

### **CHAPTER 3—SITE AND METHODS**

*“Five of the biodigesters are located very close they say, about 10 kilometers. But it still takes all day to get there and back, even on a motorcycle...”*

*Excerpt from field journal*

#### **Site description**

A site, for the purpose of this study, refers to the immediate area where a biodigester is operated by a single person or family. All biodigester sites are located in poor, remote villages practicing subsistence farming; very little is produced for markets outside the villages. Sites have no gridded electricity or potable water (although some homemade aqueducts exist) and petroleum products are expensive and scarce. Consequently, fuel wood is used to satisfy virtually all local energy needs. Prevailing economic conditions in rural Honduras are typical of many areas in Central America where at least 45% of the population survives on less than \$2 per day (EarthTrends 2003b).

I conducted my research at 11 biodigester sites located in two geographic regions, the Department of Santa Barbara and the Department of Yoro. The town of Azacualpa, Santa Barbara, served as base of intensive monitoring operations because it is centrally located. Azacualpa sits at the bottom of the Azacualpa Valley and has a hot and dry climate, typical of low-lying regions in western Honduras (See Figure 2). The village of La Habana, Yoro, provided an opportunity to inspect an additional five sites and one defunct site. La Habana is characteristic of the Yoro region, which is temperate and mountainous. Heavy precipitation is common in all regions of Honduras; San Pedro Sula, Honduras, located near the study sites, receives 48” of precipitation annually

(Weatherbase, 2005). Maps of the biodigester study areas can be found in Appendix 1: Biodigester Study Areas.

The selection of biodigester sites for intensive monitoring and regional inspection was based on accessibility. Poor infrastructure, unpredictable weather, and personal safety issues make access to the research sites difficult; these factors, along with the need to regularly collect field data, led me to focus intensive monitoring efforts in Azacualpa. In the Azacualpa Valley there are five biodigesters, I monitored all five on a daily to weekly basis as determined by transportation and accessibility. The regional inspection, based in La Habana, was similarly constrained by limited transportation and poor road conditions. Seven biodigesters are located in or near La Habana, I inspected six of these sites, of which, five were functional and one defunct.

## **Methods**

Objective 1 sought to quantify biodigester biophysical processes and included two components: an intensive monitoring program and a regional inspection. Objective 2 involved gathering operational data through a questionnaire administered to biodigester operators. Objective 3 involved creating a typology of successful biodigester operation based on the field data collected and my experiences working and interacting with rural biodigester project participants.

### *Quantification of biophysical processes: intensive monitoring*

I selected a small number of biodigester sites for the intensive monitoring program which made it possible to collect the daily to weekly environmental data necessary for a quantitative biodigester process assessment. Biodigester processes were

monitored primarily via the measurement of system inputs and outputs. Intensive monitoring occurred at five biodigester sites in the Azacualpa Valley between August and October of 2004.

To properly assess biodigester processes, a great deal must be known about the system, its operations, and ambient conditions. However, a complete accounting of biodigester processes is difficult in remote field conditions. Consequently, the variables chosen for intensive monitoring were selected based on ease of measurement and ability to contribute to biodigester process analysis. Variables chosen for intensive monitoring are listed in Table 1.

**Table 1. Variables selected for intensive monitoring of five biodigesters in Santa Barbara, Honduras**

Measurement type	Variable	Unit
Field measurement	Substrate type	--
	Substrate weight	Kg / day
	Water weight	Kg / day
	Slurry pH	--
	Slurry temperature	° C
	Effluent pH	--
	Effluent temperature	° C
Lab measurement	Dry matter (DM)	% wt
	Biochemical Oxygen Demand (BOD4)	mg DO/ L sample

During a typical site visit, I recorded each of the field measurements listed in Table 1. When necessary, samples were taken for lab measurements and were analyzed upon returning to Azacualpa. I recorded substrate type and weight prior to charging the biodigester. When it was impractical to weigh the entire substrate input (as with commercial pig farms), a single composite sample of manure inputs from 6-10 pens was weighed and averaged; mean manure input was then multiplied by the total number of pig

pens. I recorded water loading directly or estimated it by multiplying wash time by hose flow rate. Measurements of substrate and water weights were made with a My Weigh, MHS-50 hanging scale. Water pH, slurry pH, and effluent pH were measured using a PocketTestr2 digital pH pen. Slurry and effluent temperature were measured using a Fisherbrand Traceable digital thermometer. Daily measurements were recorded on a Daily Data Sheet, a copy of which can be found in Appendix 2: Field Research Documents.

The following intensive monitoring activities were conducted approximately once a week as determined by site accessibility and weather conditions. I calculated substrate Dry Matter (DM, % wt) by weighing a fresh manure sample and then drying to constant weight in a solar oven. The proportion of dry weight to initial weight yielded the percent dry matter of the sample. For this process, I used a J Scale JS-120 digital scale and a homemade box-type solar oven constructed from cardboard and aluminum foil. A complete description of the field procedure for determining DM is detailed in Appendix 3: Laboratory Procedures.

To ascertain biodigester capacity for wastewater processing, I used an improvised dissolved oxygen laboratory to estimate four-day Biochemical Oxygen Demand (BOD<sub>4</sub>) of single point samples taken from biodigester influent and effluent. The lab consisted of a YSI Model-55 digital DO Meter, 1-liter plastic bottles, and purified water for sample dilution. Field conditions did not allow the use of a BOD incubator. Consequently, I opted to use an insulating cooler to prevent bottle temperature fluctuation during the incubation period. A four day incubation period was selected to compensate for high ambient temperatures (Garbely et al. 2002); mean daily temperature in Azacualpa was

approximately 25 °C. The complete field procedure for the approximation of BOD4 is detailed in Appendix 3. All field equipment was calibrated as specified in accompanying manuals and literature.

*Quantification of biodigester processes: regional inspection*

I conducted a regional inspection (RI) of six biodigesters, five functional and one defunct. Only one functional SHI biodigester was overlooked by the inspection (due to poor site access). Transportation and accessibility issues were the primary factors influencing the total number of sites visited and order of visitation.

Biophysical measurements taken as part of the inspection included all of the “field measurements” listed in Table 1; lab measurements were not performed as part of the regional inspection. Information was also gathered on design parameters, biophysical processes, and operations. The data collected by the RI helps to create a “snapshot” of biophysical processes, which can be contrasted with intensively monitored site data to determine the degree of similarity between the systems. Data from the regional inspection were recorded on Daily Data Sheets in the same manner as Intensive Monitoring.

*Description of operational practices: questionnaire for biodigester operators*

I designed a questionnaire to gather data on biodigester operational practices and performance. The questionnaire was administered in an informal and conversational manner at the 11 sites where I conducted IM and RI activities. Respondents included the biodigester operator and biogas users, typically a married couple. Using the questionnaire, I documented operation and management practices of 91 percent (10 out of 11) of known biodigester operators in Honduras. All operators were participants in SHI’s biodigester program, but otherwise had no affiliation with one another.

### *Methodological constraints*

My study set out to quantify biogas production, but this proved very difficult given the single-tube biodigester design and remote study sites. Attempts to determine gas production using water displacement failed due to low gas pressure in the biogas line and gas storage area. In addition, attempts to measure biogas production based on biodigester tube inflation time were derailed by low gas pressure, time constraints, and inconsistent tube geometry. In Table 8, I present estimates of daily stove use (i.e. biogas consumption) as a surrogate for gas production.

My study was also limited by other factors, such as the small number of biodigesters in Honduras (N=11). Other factors restricting the scope of my study included limited transportation, unpredictable and severe weather, time constraints, lack of electricity and scientific equipment, and operator unavailability during harvest season.



## CHAPTER 4—RESULTS

*“That gringo, he is so skinny. He stays up all night doing experimentos...”*  
*Doña Carlota, Azacualpa*

Biodigesters are relatively simple, but the factors that influence biodigester behavior are complex. The following data represent diverse biological processes at work, as well as various operation and management practices. Results are organized by topic and presented in summary form, with special focus on the most “functional” biodigesters. For this study, a functional unit was defined as producing “enough” biogas, as determined by operator families from the questionnaire.

### **Quantification of biophysical processes**

Eleven biodigester sites were visited during the study, representing nearly all (91 percent) of SHI’s functional biodigesters (see Table 2). When my research began, ten sites were functional and one defunct. At the study’s end, two functional digesters had ceased working and become defunct, which offered some insight in to the causes of biodigester failure. Only one SHI biodigester was overlooked by my study, which was inaccessible due to its remote location and poor accessibility.

A typical SHI biodigester is situated in an earthen trench approximately 0.7 m deep by 0.7 m wide (see Appendix 4. SHI Biodigester Construction Manual). Two five-gallon buckets are attached, one each for the inlet and outlet. The polyethylene tank is then half-filled with water, the biogas line attached, and the unit is charged with a large, initial slurry load. Approximately 1-2 months are required until the initial charge begins producing biogas.

**Table 2. Location of biodigester sites studied in rural Honduras**  
 (\* intensive monitoring site) (\*\* biodigester studied was recently constructed)  
 (> change in status during study)

Department	Municipality	Site (Village)	Manure Substrate	Biogas Production
Santa Barbara	Quimistan	Rio Blanco	Pig	Enough
Santa Barbara	Quimistan	Las Columenas	Pig	Enough
Santa Barbara	Azacualpa	Tereritos*	Pig	Enough > none
Yoro	Yoro	El Calichal	Cow	Some > none
Yoro	Yoro	Las Cuchillas	Cow	Little**
Yoro	Yoro	Mataderos	Cow	Enough
Yoro	Yoro	La Havana	Cow	Enough
Santa Barbara	Azacualpa	*Las Dantas	Cow	Little**
Santa Barbara	Azacualpa	*La Arada	Cow	Enough
Santa Barbara	Nueva Frontera	*El Oro	Cow	Enough > none
Santa Barbara	Nueva Frontera	*Piladeros	Cow	Enough

All of the biodigesters I studied were single-tube construction, similar to the type described in Aguilar's comprehensive manual *How to install a polyethylene biogas plant* (2000). This design integrates gas production and storage into a single polyethylene tube so that no separate gas reservoir is needed. In contrast, double-tube designs utilize two polyethylene tubes, one for generating biogas and one for biogas storage (An et al. 1997, b, Rodriguez and Preston, no date).

Average biodigester design parameters are listed in Table 3. The relationship between liquid volume and total volume is important, especially for single tube biodigesters, and affects water seal formation, biogas storage potential, and tank pressure. On average, biodigester tanks were about half-full (48 percent) of liquid; because SHI biodigesters do not utilize a separate gas reservoir, the remaining volume (52 percent) was used for biogas storage. Mean biodigester tank volume was 3.0 cubic meters and mean liquid volume was 1.7 cubic meters, assuming biodigester tanks are cylindrical.

**Table 3. Design parameters from 11 biodigesters in rural Honduras  
(\* Does not include NGO costs, \$1 = L.18)**

<b>Parameter</b>	<b>Mean</b>	<b>Range</b>
Biodigester length (m)	8.32	5.3 - 15.6
Biodigester width (m)	0.73	0.61 - 0.84
Distance to kitchen (m)	14	5 - 20
Total volume (m <sup>3</sup> )	3.0	2.2 - 6.5
Liquid volume (% total volume, est.)	48%	35% - 60%
Project cost, total (L., US\$)	L.1350, \$75 (est.)	n/a
Project cost, family (L., US\$)*	L.222, \$12	L.0 - 700, \$0 - 39
Family labor to build (man hours)	23	7 - 36

Summary biophysical data collected during intensive monitoring and the regional inspection are listed in Table 4. This data provides a foundation for understanding basic biodigester processes in Honduras and allows us to make a number of interesting inferences that show biophysical process are, in part, affected by operator practices and biodigester design. I have separated the data into three columns; the first two columns illustrate mean values for cow and pig manure-based systems respectively, while the third lists biophysical process means for the entire sample population; this separation is necessary for observing the differences intrinsic to each system type.

Slurry composition (substrate weight plus water weight) was highly variable, depending entirely on individual operator charging practices. Dry matter, total water load, loading rates, and residence time are all functions of substrate weight and water weight. Consequently, all were influenced by variation in operator practices. There were several important design differences between pig- and cow-based systems; the most notable of these differences was variation in total mean water loading.

**Table 4. Biodigester process means for 11 biodigesters in rural Honduras  
(n = number of sites, DM = dry matter)**

Primary substrate	Cow manure (n=8)		Pig manure (n=3)		All sites (n=11)	
	Mean	Range	Mean	Range	Mean	Range
Substrate weight (kg / day)	4.0	0.6 - 7.7	87.3	--	17.8	0.6 - 87.3
Water weight (kg / day)	14.8	6.4 - 40.0	1434.8	364.5 - 2964.0	547	6.4 - 2964.0
Slurry pH ( )	7.3	6.7 - 7.6	7.8	7.5 - 8.0	7.5	6.7 - 8.0
Slurry temp (°C)	27.2	23.8 - 30.8	28.4	25.6 - 33.3	27.6	23.8 - 33.3
Effluent pH ( )	6.7	6.5 - 7.1	6.8	6.3 - 7.1	6.8	6.3 - 7.1
Effluent temp (°C)	25.3	22.3 - 29.5	27.4	25.1 - 29.9	26.0	22.3 - 29.9
Water pH ( )	7.9	7.6 - 8.4	8.4	--	7.9	7.6 - 8.4
Substrate DM load (kg / day)	0.9	0.1 - 1.7	19.2	--	3.9	0.1 - 19.2
Total water load (kg / day)	17.9	8.5 - 40.5	1043.9	--	188.9	8.5 - 1043.9
Slurry DM (% wt)	7%	0% - 13%	2%	--	6.1%	0% - 13%
Liquid volume (approximate m <sup>3</sup> )	1.4	0.9 - 1.9	2.2	1.2 - 3.3	1.63	0.9 - 3.3
Loading rate (kg DM / m <sup>3</sup> liquid day)	0.9	0.1 - 1.8	--	--	0.9	0.1 - 1.8
Residence time (days)	101	47 - 182	--	--	101	47 - 182

One fundamental design difference between cow- and pig-based units that merits examination is the manner in which charging occurs. Cow-based units are charged using 1 or 2 hand-mixed, five gallon buckets. In contrast, pig-operated units were charged using a hose and a network of channels, which route slurry directly to the biodigester during the daily washing of pig pens. On a daily basis *hose-and-channel* systems use up to 60 times as much total water load with up to 10 times longer operation times compared to bucket-based systems; but, they provided a convenient and effective means of cleaning pigpens while simultaneously charging the biodigester.

The data from Table 4 indicate that biophysical processes in Honduras are similar to those reported by other researchers (An et al. 1997, Sophea and Preston 2000). Nonetheless, residence times in Honduras are about 3-4 times higher than values reported for Asian biodigesters (Thy et al. 2003). This is likely due to the small daily charging volume used. Honduran biodigesters averaged 4 kg substrate per day while An et al. (1997b) report 16 kg substrate per day.

During intensive monitoring of biophysical processes, I conducted two types of laboratory measurements, an analysis of Dry Matter (DM) and an estimation of 4-day biochemical oxygen demand (BOD<sub>4</sub>). Results from DM analysis are presented in Table 5 and reveal that both cow and pig manure both contained 22 percent DM by weight. Results from BOD<sub>4</sub> reduction analysis are presented in Table 6. Due to limited control during oxygen testing (such as no BOD incubator), BOD<sub>4</sub> results should be considered estimates. Nonetheless, the process of biodigestion significantly reduced the high levels of BOD associated with raw animal waste.

**Table 5. Average substrate dry matter from 9 manure samples taken from biodigesters in Honduras (DM = dry matter, % wt) (n= number of manure samples)**

	Mean	Range
Cow manure DM (n=8)	22.0%	15.4 - 29.9%
Pig manure DM (n=3)	22.0%	17.7 - 24.6%

**Table 6. Approximate 4-day Biochemical Oxygen Demand (BOD4) of biodigester influent and effluent (n = number of samples, \* = adjusted for BOD observed in blanks)**

Sample type	BOD4 (mg/l)		
	Cow manure (n=4)	Pig manure (n=4)	All sites (n=8)
Influent	1218	1740	1479
Effluent	661	356	509
Blank	--	--	208
<b>Average BOD4 reduction achieved via biodigestion (%)*</b>			
	55%	90%	76%

### Questionnaire for biodigester operators

In this section, I present the results from my questionnaire for biodigester operators. Summary data are presented in the following sections and a sample questionnaire can be found in Appendix 2.

The questionnaire documents multiple aspects of biodigester operation and processes; specifically, it investigates the following:

- project costs
- impact of biodigesters on family fuel needs;
- farmers' opinions of biodigesters;
- operational practices;
- biodigester performance;
- technical problems, and
- technological modifications.

Material costs for an average single-family biodigester total approximately \$40 to construct a 3.0 cubic meter biodigester; SHI contributes about \$25, with the remaining \$15 paid by the family. Interviews with biodigester operators report similar figures. During my study, families spent an average of US \$12 on materials, mainly for the PVC gas line and accessories. The cost of a biogas stove is \$10-\$20 depending on the design used, although a simple stove can be constructed with bricks and a few inches of steel pipe. Polyethylene costs for a family-sized unit are approximately \$15-\$25. Labor costs for a single-family biodigester average \$35. The family contributes about \$15 in labor and SHI contributes \$20 in extensionist labor (Bowles, SHI Country Dir., personal com.).

**Table 7. Approximate project costs for a single-family biodigester (3.0 cubic meter volume)**

<b>Item</b>	<b>Approximate Cost (USD)</b>
PVC pipeline, valves, and accessories	\$15
Polyethylene plastic and stove	\$25
Extensionist labor	\$20
Family labor (in kind donation)	\$15

The combined materials and labor costs average \$75 for each family-sized biodigester, or \$25 per cubic meter of tank volume. Total project costs are likely higher than \$75 when all extensionist activities are taken into account. SHI is a progressive organization extensionists receive generous salaries, benefits, training, and motorcycle transportation. Altogether, SHI spends about \$70 a day to keep an extensionist in the field (Reed, SHI Executive Dir., personal com.). Biodigester extension is significantly more expensive by this accounting. However, SHI extensionists work on many different

projects and usually spend only some of their time working with biodigesters; consequently, \$75 is assumed to be the total cost of a single-family biodigester.

In Honduras, polyethylene plastic is the single largest material expense and has to be special-ordered in 1000 pound rolls at a cost of \$1 per pound (Bowles, SHI Country Dir., personal com.). High manufacturing costs and lack of availability mean that polyethylene plastic is not easily accessible to *campesinos* and can only be obtained with the help of SHI.

Table 8 summarizes the impact of biodigesters on fuel needs and Table 9 looks at fuel use, acquisition, and production at biodigester sites. Importantly, all families continued to rely on fuelwood after biodigesters were introduced, even those with highly functional units. However, fuelwood consumption after biodigester implementation decreased by an average of 54 percent. (See Table 8.)

All respondents gathered, rather than purchased, their fuel wood; consequently, biodigesters provided no direct economic savings from fuelwood. However, one farmer completely offset his propane fuel needs with biogas, resulting in a savings of approximately \$20 per month (Don Lelo, biodigester owner, personal com.). This savings is equivalent to about ten days pay in rural Honduras.

**Table 8. Impact of biodigesters on family fuel needs at sites with before / after data**

	Mean	Range	n
Total fuelwood gathering time, before biodigester (hrs / wk)	4.2	0.8 - 18.7	6
Total fuelwood gathering time, after biodigester (hrs / wk)	2.4	0.3 - 8.8	6
Time saved from gathering fuelwood (hrs / wk)	1.8	0.0 - 8.8	6
Wood fuel decrease after biodigester (%)	54%	0% - 83%	7
Daily biogas stove use (hrs)	4	0 - 10	11



**Table 9: Family fuel use, acquisition, and production at biodigester sites**  
**(n = number of families, LPG = liquefied propane gas)**

	Before biodigester	After biodigester
<b>Daily fuel source(s)</b>	<b>N</b>	<b>N</b>
Wood	11	11
Biogas	0	8
LPG	1	0
<b>Women and children responsible for wood fuel acquisition?</b>		
Yes	0	0
No	9	9
Sometimes	2	2
<b>Gas produced for family needs?</b>		
Enough	--	6
Little	--	2
None	--	3

Questionnaire results suggest little change, in gender-based division of labor after biodigester implementation. Women and children were responsible for fuelwood collection at only 2 of 11 sites (18%), a number that did not change after the introduction of biodigesters. At study sites fuelwood was almost exclusively gathered by males. Nevertheless, women benefit from the clean-burning biogas stoves, which improve kitchen air quality and increase fuel efficiency. Additional research is needed to determine detailed effects of biodigesters on different family members and overall household benefits.

At the time of my study, only 6 of 11 (55 percent) of units were classified as producing “enough” biogas for family needs; however, all units achieved some measure of biogas production during their project life. Two units (18 percent) produced “little” amounts of biogas, both of which were new projects and not yet fully operational (See Table 9). Three units (27 percent) produced “none”; the units were previously functional

but had declined in gas production or failed due to technical problems. The most common causes of biodigester failure are discussed later in this chapter.

Farmers' attitudes toward the technology were generally favorable; 10 out of 11 families (91 percent) had positive opinions of biodigesters (see Table 10). In spite of these positive attitudes, I observed very little technology diffusion between *campesino* farmers; biodigester projects were generally initiated by extensionists. However, it may be too early to detect biodigester diffusion among rural farmers because the technology has only been in use for three years. Only one farmer (Tereritos site) had a negative opinion of his biodigester, which arose from a conflict of interest between the operator (project owner) and biogas user (caretaker). The project was eventually abandoned. Operators at the rest of my study sites reported a positive experience using biogas, even where the unit failed.

Nearly all biodigesters (91 percent) were implemented as demonstration projects, and SHI paid more than 50 percent of total project costs. However, at least one private individual acted on his own to obtain technical advice from SHI, resulting in the incorporation of a large biodigester into his commercial pig farm. During the course of this study, project expenses were predominantly paid by the non-profit; farmers generally contributed labor and limited building materials.

**Table 10. Eleven families' opinions of biodigesters and participation in extension programs (n = number of families)**

<b>General opinion of Biodigester</b>	<b>N</b>
Positive	10
Negative	1
<b>Motivation for construction</b>	
New SHI demonstration project	10
Save wood	4
Visited demonstration project	3
Take advantage of manure	1
<b>First information from</b>	
Extensionist	8
Visiting demonstration farm	3
<b>Project costs</b>	
SHI paid totally	5
SHI paid more than 50%	10
Farmer paid totally	1

#### **Operation and performance details**

General biodigester operational practices are listed in Table 11, below.

**Table 11. Operational practices at eleven biodigesters in rural Honduras (n = number of operators, \* based on 10 responses)**

<b>Number of farmers...</b>	<b>N</b>
Using cow manure	8
Using pig manure	3
Using fruit waste	2
Using agricultural waste	2
Using food scraps	2
Using viscera	2
Using effluent for "nothing"	9*
Indicating substrate is abundant	11
Indicating that water is abundant	10
Using chlorinated water	2

All farmers used manure as their primary substrate: 73 percent used cow manure and 27 percent used pig manure. Most operators also reported using secondary substrates,

such as fruit and agricultural waste, food scraps, and viscera from slaughtered animals (primarily chickens). Unfortunately, I was unable to observe the use of secondary substrates and therefore could not document their quantities and effects on biodigester performance. However, farmers reported that secondary substrates, coffee millings and grey water in particular, had a positive effect on gas production.

Biodigester effluent was not utilized at any of the sites. Nine out of ten operators (90 percent) indicated that effluent was used for “nothing.” One site (Las Columnas) collected effluent in an oxidation pond where it was stored temporarily and then discharged into a drainage ditch.

General management data for biodigesters studied are listed below, in Table 12.

**Table 12. Operation and performance data from 11 biodigesters in rural Honduras**

	<b>Mean</b>	<b>Range</b>
Slurry mix ratio (% volume manure)	38%	5% - 50%
Charging frequency (charges / day)	1.4	0.1 - 4
Daily operation time, family (min)	19	4.7 - 90
Daily operation time, commercial (min)	255	52 - 300
Average days to first gas production	37	18 - 70
Maintenance costs to date L.0.00	L. 0.00	--

Operator training was generally informal, occurring over several days during biodigester construction. I observed extensionists training *campesino* operators to use a slurry mix ratio of 50 percent manure: 50 percent water. My study recorded a mean slurry mix ratio of 38 percent manure by volume, ranging from 5-50 percent due to differences in operational practices. More than one operator spoke of using pure manure to charge his biodigester although this 100 percent mixing ratio was not captured at the time I

administered the questionnaire (discussed below). Operators commonly deviated from extensionists recommendations of a 50:50 slurry.

While in the field, I noticed that the most functional biodigesters often had very low mixing ratios (i.e. “watered-down” slurries). Responses from the questionnaires suggest a relationship between low mixing ratios and biodigester functionality (all biodigesters that produce “enough” biogas according to the operator). Out of eleven biodigesters surveyed, the six lowest mixing ratios were also the six most functional biodigesters (see Table 2). Each of these functional biodigesters incorporates one of three means of diluting the slurry mixing ratio:

1. the biodigester has a hose-and-channel loading system, which can deliver 25 times as much water as a hand-mixed system (discussed below);
2. biodigester operators adopted lower mixing ratios based on personal experience;
3. operators add secondary loads of water or grey water in addition to the regular slurry load.

Two of the six most functional biodigesters fall into each of the three categories above. The remaining five less-functional biodigesters did not incorporate any of these actions.

Mixing ratios at pig-based units were especially low where *hose-and-channel* charging systems were used. A hose-and-channel system allows farmers, with the aid of a garden hose, to wash excrement from penned animals directly to the biodigester inlet via cement, brick, or metal channels in the ground. Hoses used for washing manure into a biodigester provide little control over total mixing ratio and are difficult to measure precisely. Consequently, hose-and-channel systems use substantially more water per kilogram of substrate and necessitate dramatically lower mixing ratios. This system works well with pigs, but is not being used with cows because the latter require a large forage area and, in Honduras, are not generally penned. Cow-based slurries are mixed by

hand in 5 gallon batches, making it easy for the operator to control the overall mixing ratio.

While low mixing ratios appeared to generally increase performance, I documented two cases where high mixing ratios negatively impacted biodigester performance. The biodigester at El Oro functioned well for several months, but biogas production began to decline thereafter. After several weeks of informal conversations, operators admitted to charging their biodigester with pure manure (a 100 percent mixing ratio). Manure build up eventually caused a change in anaerobic digestion processes that resulted in production of non-combustible gasses and tank sedimentation. A similar sedimentation event occurred at another site (Las Dantas), but the problem was corrected by flushing the biodigester tank with additional water.

Operators use a variety of charging intervals without apparent ill-effects. Mean charging frequency among all biodigester operators is 1.4 charges per day. Operators of pig-based systems charged their biodigesters most frequently, averaging 3 charges daily. Operators of cow-based units charged less frequently, averaging 0.7 charges daily. Biodigesters were charged as often as three times a day (all hose-and-channel sites) or as infrequently as every two weeks (La Habana site). Charging frequency did not appear to affect biodigester performance, perhaps because anaerobic decomposition occurs over a much longer period, optimally between 10 and 30 days (Thy et al. 2003) depending on substrate, climate, and type of biodigester. It is worth noting that less-frequent charges were proportionately larger than daily charges, such that the total charged delivered did not change. For example, a two week charging interval used approximately the same volume of slurry as 14 daily charges.

Smaller, family-sized biodigesters appear to offer a larger net benefit to families because they provide enough biogas to meet family needs without long operating times associated with commercial units. Family-sized units require about 19 minutes each day to operate and still provide “enough” biogas according to farmers. Large, commercial biodigesters offer nearly inexhaustible biogas supplies for operator families, but require much more management time. The commercial units I studied averaged about 4 hours of daily operation and maintenance.

### **Technical problems experienced**

Technical problems experienced by biodigester operators are listed in Table 13. Flooding, sedimentation, and animal damage were the most frequently reported problem. Flooding occurs when rainwater is inadvertently routed into the biodigester tank or when runoff fills the biodigester trench. Hose-and-channel systems were at greater risk of flooding because the channels route unwanted runoff from the pen area directly into the biodigester inlet. Runoff routing was less of a problem where pens and channels were protected from rain. Barriers such as roofs, earthen mounds, and trenches were effective means of reducing trench flooding and unwanted runoff routing.

Among the units I studied, 75 percent of sedimentation problems were the result of sediment deposited by the overland flow of precipitation. In at least one case, sedimentation was the result of improper operator practices; the operator at El Oro repeatedly charged his biodigester with pure manure (a 100 percent mixing ratio). This practice led to a build-up of solids in the biodigester, production of an inflammable gas, and eventually, tank solidification.

**Table 13. Technical biodigester problems reported by biodigester operators in rural Honduras (\* = researcher observation)**

<b>Problem</b>	<b>Number of sites</b>
Flooding / sedimentation	4
Animal damage	3
Lack of biogas	2
UV damage	1
Cracked biogas pipeline	1
Escape valve not functional	1, 8*
Poor water seal / low gas pressure	8*

Animal damage was the second most frequently reported technical problem.

Animals caused the failure of three separate projects, all of which were eventually repaired or replaced with the help of SHI extensionists. Failure generally occurred when livestock stepped on the biodigester tank, or when animals pierced the polyethylene while foraging for food scraps near the inlet. Even small animals can damage biodigesters; the operator at Mataderos reported that a small kitten climbed onto and punctured his biodigester tank.

Animals are not well-controlled in Honduras and can easily damage biodigesters if they are not protected properly. Operators that constructed adequate fencing around biodigesters did not experience animal damage. Nearly a year after my fieldwork, SHI staff in Honduras reported that animal damage is the single largest cause of biodigester failure (Bowles, SHI Country Dir., personal com. 2005).

Polyethylene disintegration is a potentially serious, though uncommon problem in Honduras. Ultraviolet (UV) radiation damages polyethylene plastic unless it is properly protected (An et al. 1997b). This protection takes two main forms: 1. a UV protectant applied during plastic manufacture, and 2. a roof over the biodigester tank. Only one biodigester (El Calichal site) experienced tank failure due to excessive UV exposure; and,



several factors contributed to its failure. The biodigester was located in the high-altitude tropics, had no roof, and according to extensionists had no UV protectant. After functioning well for two years, the exposed polyethylene tube became brittle, lost structural integrity, and ruptured in several places.

Nine out of ten biodigesters (90 percent) have chronic problems with poor water seals and non-functional safety valves. This type of problem reduces biodigester performance, but does not necessarily threaten project integrity. Water seals at all study sites were small compared to design specifications, which call for water seal depth of at least 3-4 inches (Aguilar 2000). At study sites, inlet and outlet tubes were submerged only 1-2 inches below water line, lowering the effective pressure at which biogas could be stored. At sites with poor water seals low biogas pressure is a chronic problem.

### **Modified biodigester designs**

Biodigesters are constructed using one basic design, but it is not uncommon for operators to modify and adapt the design slightly. Table 14 lists the most significant design modifications observed in the field, along with *campesino* suggestions for improving the technology.

One important modification to projects was the use of different materials to provide cover for the biodigester tank. Two projects incorporated dark-colored plastic sunshades to protect their biodigester tubes. In both cases, the plastic was supported by wooden stakes, creating a “tent” over the biodigester tube. I observed other types of cover as well, including natural shade (vegetation), tin sheeting, and bamboo stalks. Each type

of cover has specific advantages: plastic is easy to remove, natural shade is inexpensive, and tin is durable.

**Table 14. Suggestions and modifications to improve biodigesters in Honduras**

<i>Campesinos</i> suggestions for improving biodigester projects	Number of sites
Develop lighting fixtures that use biogas	2
Install biodigester above ground level to prevent flooding	1
<b><i>Campesino</i> modifications to biodigester design</b>	
Toad exclusion cap on inlet pipe	1
Safety valve mounted on inverted U of PVC above biodigester gas outlet	1
Trench backfilled with sand to prevent puncture and tube deformation	1
Blue plastic used for sun protection / heat trapping	2
Inlet and outlet made from 4"-6" PVC	3
Inlet pipe runoff diversion elbow	1
Slurry mixed with household grey water	1
Natural vegetation used to shade digester	3

PVC inlet and outlet tubes allow for larger, more adjustable water seals, but are not affordable to all operators. The basic biodigester design utilizes a pair of five gallon buckets for inlet and outlet pipes; however, three operators opted to substitute 4-6" diameter PVC. All PVC lengths were scrap material scavenged from local construction projects and were approximately 1 yard in length.

Biodigesters in Honduras exhibit a wide range of biophysical processes and operate under a variety of environmental conditions. The processes documented during my study were generally within the ranges reported in biodigester literature. However, the data illustrate the great deal of variability in constructing and operating biodigesters in the Honduran countryside.

## CHAPTER 5—DISCUSSION

### **Biophysical process insights**

Biodigesters in Honduras appear to be operating successfully in diverse biophysical and management environments, suggesting that the technology is adaptable to a variety of environmental conditions and operational procedures. With this general functionality in mind, a number of inferences can be made.

#### *Biodigester performance*

The four most productive biodigesters use lower mixing ratios than are recommended during operator training. Slurries with as little as 0.3% percent DM (by weight, La Habana site) are capable of generating enough biogas for a small family, though operators are trained to use 50 percent manure slurries (by volume, approximately 11% DM by weight). Lower mixing ratios also help prevent sedimentation within biodigester tanks by maintaining a fluid environment and presumably creating a more favorable environment for anaerobic flora and natural decomposition processes.

Biodigester performance does not diminish as total substrate decreases. Measurements of slurry DM (% weight) were lower than average at 75 percent of the most productive biodigesters, illustrating that slurry thinning may be linked to improved biodigester performance. Both slurry mixing ratios (obtained through interviews and observation) and DM data (measured experimentally) suggest that watered-down slurries perform better than, or as well as, biodigesters using mixing ratios of 50 percent and higher.

The use of secondary substrates may improve biogas production. Although I did not observe this directly in the field, all farmers reported occasionally charging their biodigesters with a variety of secondary substrates. However, manure remained the primary substrate in all biodigesters. Field observations suggest that daily addition of food scraps or grey water may be linked to increases in biogas production.

Two different mechanisms might explain how secondary substrates increase biogas production. 1. Secondary substrates are not mixed into the manure slurry; instead, secondary charging usually occurs later in the day (after meal times in the case of food scraps). Additional charging augments tank mixing and could increase decomposition efficiency. 2. Secondary substrates may provide anaerobic flora with micronutrients that are not present in manure slurries and create a more favorable environment for bacterial growth. Unfortunately, I found nothing in the literature that specifically addresses the effects of secondary substrates on anaerobic decomposition processes and future research is needed to investigate these relationships.

#### *Analysis of BOD reduction*

Preliminary field data suggest that biodigesters in Honduras are very effective in reducing slurry BOD, especially in pig manure-based systems. Reductions in slurry BOD can lead to improved local water quality because biodigester effluent is less harmful than untreated excreta (An et al. 1997b, Rodriguez and Preston,, no date). Furthermore, treated slurry is less attractive to rodents, insects, and scavengers than unprocessed waste and reduces the spread of disease (Green Box Systems Group,, no date).

Family-sized biodigesters are unlikely to improve local water quality except on a very small scale due to their small processing capacity. However, field measurements

indicate that family-sized biodigesters could accommodate nearly three times as much slurry (up to 14 gallons of slurry per day) and still achieve a 34-day residence time. Biodigester literature suggests that a 10 to 20 day residence time is sufficient for complete anaerobic decomposition in a functional biodigester (Thy 2003). Additional improvements in water quality might be gained by using biodigesters to treat waste from household latrines, but I observed some cultural resistance to this idea. Since I concluded my study, at least one biodigester has been constructed by Peace Corps Honduras that relies exclusively on human excreta (Bowles, SHI Country Dir., personal com.). The utility of biodigesters for processing human waste has been well documented (An et al. 1997b).

Biodigesters used on commercial farms have the potential to significantly improve local waterways because they process large quantities of waste that would otherwise be discharged directly into local surface waters. Such was the case in Las Columenas, where, according to the operator, a local waterway was “reborn” after biodigester implementation (Don Bonilla, operator, personal com.). However, improvements to water quality are likely to be limited unless biodigester use becomes more widespread.

#### *Energy availability and use*

Biodigesters are unlikely to completely replace traditional fuelwood consumption by rural Honduran families. Only one household (La Habana) came close to replacing its fuelwood use with biogas; all other households, including those with biodigester that produced “enough” biogas, continued to rely upon fuelwood to some degree. I identified

four factors in La Habana which probably explains why biogas completely replaced traditional fuelwood use:

1. the biodigester is highly functional;
2. the family is motivated and enjoys using the biogas stove;
3. the biodigester requires little labor input (4.7 minutes per day);
4. the slurry mixing ratio is low (0.3%).

While biodigester functionality and operator motivation are crucial for a successful biodigester, low labor input is probably most important. Projects with low daily operation times provide greater net benefits to project owners. The operator at La Habana was able to achieve exceptionally low daily operation times by delivering a single, large charge once every 15 days (20 liters cow manure mixed with 40 liters of water); in addition, approximately 3 kg of food scraps were added daily, along with 20 liters of water. This charging scheme resulted in low average operating times, reduced slurry mixing ratios, and the addition of secondary substrates. The fourth point above, low slurry mixing ratio, is linked to increased biogas production among study sites. La Habana utilized the lowest slurry mixing ratio of all sites. These four points combine to make La Habana a unique study site. While the data from this site are compelling additional research is needed to determine how the above mentioned factors interact and affect biodigester functionality.

Overall, biodigesters resulted in a 54 percent decrease in mean household fuelwood consumption. Women preferred using biogas stoves for fast-cooking foods (such as coffee, eggs, and warming *tortillas*), but favored traditional fuelwood for slow-cooking foods (such as soups and beans). Fuel preferences are based in part on the fact that biogas stoves light instantly, but can only burn for a few hours before the biogas supply is depleted. Traditional wood-fired *fogones* (stoves) can be used to cook for longer

periods, but take time to fire. Families indicated that biogas stoves had no appreciable effect on food flavor; many women warmed tortillas directly on the biogas flame. Thus, families are likely to continue burning fuelwood unless biodigesters are able to produce and store larger quantities of biogas, accommodating more extended and diverse uses. Nonetheless, biodigesters have significantly reduced fuelwood consumption among operator families.

### **Biodigester operation and management insights**

Fertilizer effluent has great potential value in Honduras, where agriculture is an economic mainstay and unsustainable farming practices are common (Library of Congress,, no date). Biodigester effluent has been shown to have a positive effect on the yield of many crop species (An et al. 1997, Sophea and Preston 2000, Venning 2001). In addition, effluent may provide an inexpensive alternative to agrochemicals and help retain site nutrients. Interactions between fertilizer effluent and soil chemistry have not been examined in sufficient detail; however, the FAO (1992) reports that up to 90 percent of slurry Nitrogen, Phosphorus, and Potassium are retained in the effluent. Future research might examine relationships between effluent, soil type and structure, cation exchange capacity, and water retention. The results of such research could be presented as a soil amendment handbook for different soil types, biodigester substrates, and crop species. Such a document would elucidate the role of effluent in sustainable agriculture and could encourage wider adoption of biodigester technology.

Although petrochemicals and agricultural intensification are sometimes perceived as “the only way, the best way to increase crop yield” (Don Moncho, farmer, personal

com.), biodigesters offer similar benefits while reducing resource dependence and providing more economically sustainable productivity (i.e. lowered operation costs compared to agrochemicals, Hurst, SHI Country Dir., personal com.). Biodigester effluent is essentially free to operators because it is a natural byproduct of the biodigestion process. Furthermore, it is organic, non-toxic, requires no special equipment, and is easy to apply.

Despite the potential benefits, operator families do not utilize effluent at all; instead, it is discharged. Two factors are likely responsible for the lack of effluent use among operators. First, operator training focuses predominately on generating biogas fuel, providing little information on the value of effluent as a fertilizer. Second, there may be cultural resistance to effluent use because it is a non-traditional farming method and has not been demonstrated as an effective fertilizing agent. In addition, farmers may be reluctant to apply manure-based fertilizers to staple food crops. At present, effluent at all sites is discharged un-utilized into a drainage ditch. More research, extension, and demonstration are warranted to explore how fertilizer effluent might be adapted for use in Honduran agriculture.

#### *Daily operational practices and training*

Proper training is critical for operation and maintenance of biodigesters in Honduras (discussed further in Chapter 6). Participant families are taught how to operate biodigesters by extensionists, but operator practices often diverge from recommended practices, especially slurry mixing and charging frequencies. These inconsistent operating practices occasionally lead to biodigester failure. One such failure (El Oro site) was due to excessive substrate loading and subsequent sedimentation of the biodigester tube.



During installation of the unit, extensionists trained the family to charge the biodigester with standard influent slurry (50 percent manure, 50 percent water). Despite the training, the family began charging the biodigester with pure manure under the assumption that it would increase biogas production. Biogas production was initially high and continued after sedimentation; however, the sediment-filled tank produced gas that was no longer combustible. The anomalous gas did not exhibit the pungent odor typical of biogas, indicating a fundamental change in tank microbiology after sedimentation. Despite efforts to “flush” the sediment and affected bacteriological flora from the tank, production of non-combustible gasses continued until the project was abandoned. A consistent, more thorough approach to biodigester training may help to reduce project failure due to improper operation. The situation in El Oro demonstrates that there may be value in urging operators to use a lower slurry mixing ratio and making sure that training emphasizes the importance of maintaining a fluid environment within the biodigester tank.

Long term biodigester success appears to be more likely when project owner, operator, and biogas beneficiaries reside in the same household. In most cases, biodigester owners are also the operators and primary biogas consumers. At one site (Tereritos site) there was a division in management responsibility that led to biodigester neglect and eventual project failure. The owner of this commercial pig farm was not the primary biogas consumer and felt little incentive to maintain the biodigester. The owner benefited from the hose-and-channel aspect of the biodigester, as he could easily clean the pig pens, but lived off-site and had no use for the biogas. Conversely, the biogas consumer (the farm caretaker) was interested in using biogas but was unwilling to

perform additional work washing the pig pens as he did not benefit financially from the pig farm. This illustrates the value of sharing project responsibilities and benefits, so as to increase project ownership, satisfaction, and sustainability.

There may be other methods of increasing project ownership beyond ensuring a direct link between the system operator and biogas consumer. Such methods could focus on building strong collaborative efforts, similar to community forestry or coffee cooperatives. In areas with poorly developed access to energy resources, like Honduras, there may be an opportunity for cooperative development of local energy resources (Brown, natural resource specialist, personal com.). Community energy development may help alleviate common biodigester problems, such as failure to maintain projects due to poor training, inattentiveness, or perceived lack of benefit (Brown, natural resource specialist, personal com.). Future research should investigate the potential for community scale energy development and possible avenues for its implementation.

As mentioned in the previous section, low slurry mixing ratios appear to increase biodigester performance and decrease the risk of tank sedimentation. Operators were trained to mix slurries according to SHI guidelines, but farmers often deviated from these guidelines. During my study, operators offered no definitive explanation as to why they adopted different mixing ratios. The operator in Piladeros, Don Manuel, summarizes the response of many operators: "...this is just the way I do it, it seems to work." Variation in slurry mixing ratios has a distinct impact on biogas production rates; yet, most of the operators I interviewed were not aware of the relationship.

Variation in charging frequency does not appear to have a direct effect on biogas production. However, some charging schemes alter the slurry mixing ratio, which may

affect biogas production. Operators are trained to charge their biodigesters once daily, but I observed frequencies ranging from multiple-daily to bi-weekly charges. These time differences are likely unimportant given that the lowest charging frequencies are only a fraction of the mean residence time (101 days). Current practice advocates daily charging; however, a large, bi-weekly charge might provide more significant tank mixing than a small, daily charge. Under such a system, daily operation time might be reduced while offering an opportunity to increase performance. More research is needed to determine the exact effects of different charging frequencies on biogas production.

#### *Implications for the family*

Biodigesters provide opportunities to improve the wellbeing of all household members. Women can benefit through increased ease of cooking and improved indoor air quality. In the questionnaire, *campesino* women responded that they enjoyed using the biogas stove and that differences in household air quality were apparent. Traditional *fogones* often burn inefficiently and are smoky, leading to poor indoor air quality and a buildup of creosote on kitchen ceilings and walls. In contrast, biogas stoves burned cleanly. Men and children also benefited from improved air quality and spent less time gathering fuelwood.

#### *Biodigester costs and extension*

Polyethylene biodigester project costs in Honduras were similar to other Latin American Countries, but were higher than costs reported in Asian countries. Total costs in Honduras (\$25 per m<sup>3</sup>) were slightly less than those reported for Colombian units (\$30 per m<sup>3</sup>, An et al. 1997b); but as I mentioned above, Honduran extension costs may not be fully accounted for. Material costs in Honduras are about 50 percent higher compared to

Cambodian biodigesters (Sopheha and Preston 2000). It is difficult to compare materials costs between countries because of the diversity of designs in use, import taxes, and transportation costs. For example, the cost in Cambodia is approximately \$28 for materials, but that also includes the construction of an attached latrine.

Biodigester costs in Honduras were financed predominantly by SHI, which covered at least 75% of real project costs (Bowles, SHI Country Dir., personal com.). At present, it is not known whether farmers are capable or sufficiently motivated to pay for the technology on their own. Most families (90%) had a positive opinion of their biodigesters, but it is unclear to what extent *campesinos'* opinions influence technology transfer because nearly all biodigesters (91%) were initiated as SHI demonstration projects. Time and follow-up research is necessary to determine if and how the technology might spread among farmers. Biodigester technology has only recently been introduced to Honduras, making the role of extension and demonstration extremely important in technology transfer. Given the success of biodigesters in other developing countries (An et al. 1997b), the technology could be expected to spread among rural farmers in Honduras as well.

The dissemination of biodigester technology on a larger scale will require more extensive programming and support, as well as increased availability of materials. At present, polyethylene plastic must be purchased in rolls of at least 1000 pounds at a cost of \$1 per pound in Honduras. SHI buys the plastic in bulk and distributes it to participant families. Given the high cost and production requirements, polyethylene is beyond the economic reach of *campesinos* without the help of a third party. Consequently, the high

cost of plastic may be the single greatest obstacle to long-term technology diffusion among farmers.

Motivations for biodigester construction include reduced fuelwood costs, environmental benefits, and economic incentives. When asked about their reasons for building a biodigester, families said: to save trees, take advantage of free fuel generated from animal waste, and improve cooking efficiency. A nearly identical rationale was presented by extensionists, suggesting that extension plays an important role in convincing project participants to try out the new, largely undemonstrated technology. No families mentioned free fertilizer as a reason to build biodigesters, although it has the potential to be an integral part of *campesino* farming systems.

Most operators were satisfied with their biodigester projects, although it was not clear if participants would have been willing to implement the technology without SHI's support and initiative. It is important to note, though, that the *campesinos* I worked with had only recently been introduced to biodigesters and were becoming more comfortable with the technology with every passing month.

### **Technical insights**

#### *Common problems*

Among the biodigesters I studied, flooding, sedimentation, and damage to the polyethylene tube were the most common technical problems. Flooding and sedimentation are linked, with precipitation often resulting in sediment build-up. Flooding was also responsible for occasional trench failure and washout of anaerobic flora. At sites with hose-and-channel systems, flood events are magnified because the

channels route unwanted rainwater to the biodigester. Although sedimentation is often the result of runoff, it is also caused by poor operational practices. Use of manure-heavy slurry at two sites (El Oro and Las Dantas) led to a gradual buildup and solidification of substrate within the biodigester tube.

The operator at Las Columenas prevented flooding-sedimentation problems by incorporating a flexible joint between the end of the channel system and the biodigester inlet. During precipitation events, the joint can be repositioned away from the biodigester to divert runoff into a drainage ditch. Other ways to prevent flooding-sedimentation include roofing above the biodigester trench, runoff barriers, and diversions.

Due to the prevalence of livestock in rural Honduran communities, animals pose an ever-present threat to biodigesters, but potential damage can be easily prevented. At least 25 percent of my study sites experienced animal damage severe enough to stop biogas production. However, animal damage only occurred where biodigesters were not fenced. Properly fenced biodigesters experienced no animal problems. Fences or other barriers are critical to protecting biodigesters, especially the polyethylene bag, and are simple and inexpensive to construct.

Only one site (El Calichal) experienced technical problems due to ultraviolet (UV) radiation. The biodigester at this particular site was the first unit constructed by SHI in Honduras, and according to extensionists the polyethylene was not treated with UV-protective coating. Given the high insolation and lack of protective cover, it is not surprising that the unit failed. According to extensionists who helped construct subsequent biodigesters, all other units were incorporated UV-resistant plastic and some included were sheltered by vegetation or roofing material.

### *Water seals*

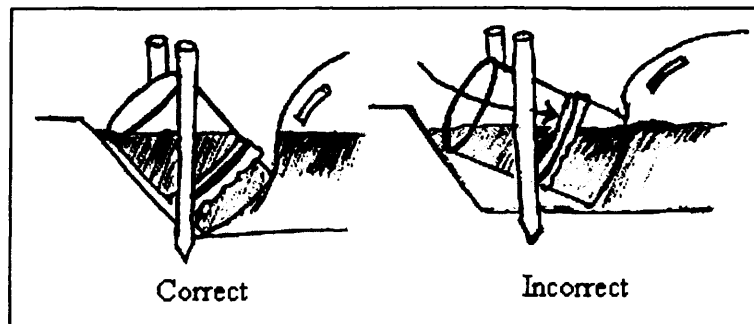
Poor water seal formation is the primary cause of low biogas pressure and resulted in undesirable biogas venting at inlet and outlet pipes. Water seals serve a variety of functions within the biodigester. Foremost, they form air-tight seals at the inlet and exit which maintain an anaerobic environment and prevent the entry of outside air. Second, water seals regulate the biogas pressure within the tank. When biogas is generated, it accumulates inside the polyethylene tube. If it is not drawn off for combustion, pressure begins to increase. When gas pressure exceeds the water seal pressure, the biogas escapes. Thus, small water seals result in low gas pressure and potentially undesirable gas leaks.

Low biogas pressure was a persistent problem at nine biodigester sites (82 percent); at eight sites (73 percent) poor water seals resulted in low gas pressure. Pressure is low enough that safety-valves do not function at any of these sites. At eight sites, I observed low biogas pressure caused by poorly formed water seals that allowed biogas to escape from the tank.

Inadequate water seals are capable of establishing an anaerobic environment but not for pressurizing the polyethylene tank. Seals of Honduran biodigesters averaged only about 2" in height, which is only a fraction the height called for by other single-tube designs (Aguilar 2000). The small seals tend to leak biogas at the inlet and outlet pipes and cannot sustain even low biogas pressure. Poor water seals do not cause direct biodigester failure, but do prevent units from reaching optimum functionality.

Water seals were particularly weak at sites utilizing five-gallon buckets for inlet and outlet pipes. Although cheap and readily available, the pipe formed by five-gallon

buckets is wide and difficult to position, especially when the biodigester is only half-filled with liquid. In such cases, pipes must be carefully anchored to the ground to ensure that a proper water seal has formed (see Figure 3. Water seal formation). Narrow pipes, such as PVC, create much more effective and adjustable water seals but are less available and more expensive.



**Figure 3.** Formation of a correct water seal. (Source: Brown 2005)

Non-functional safety valves are a visible side effect of low biogas pressure. Inlet and outlet water seals are much smaller than safety valve water seals, which are commonly filled with 4-6" of water. Weak seals at inlet and outlet pipes allow biogas venting well before the safety valve served its purpose; therefore, it is no surprise that most safety valves did not function. Essentially, escape valves are designed to regulate a biogas pressure that can never be achieved.

#### *Alternate design considerations*

Alternate biodigester designs should be evaluated for use in Honduras, especially those with the potential to solve common problems. For example, double-tube biodigesters make use of a dedicated gas storage tube that can be pressurized using an elastic strap or weighted string (Rodriguez and Preston, no date). This configuration



provides an effective remedy for the chronically low biogas pressures I observed at most sites. During my study, I noted that increased biogas pressure made for more reliable and more useful biodigesters. Consequently, research should be conducted on biodigester modifications with the potential to increase biogas pressure. Unfortunately, the biodigester design currently being implemented in Honduras integrates gas production and storage in a single polyethylene tube and offers no opportunity to control biogas pressure.

Alternate designs offer other advantages as well. Single-tube biodigesters are only half-filled with liquid, which provides space for biogas storage, but little liquid depth to form and maintain water seals. Secure water seals are critical for maintaining an anaerobic environment within the biodigester tank. The design used in Honduras calls for two 5-gallon buckets, one each for the inlet and outlet pipes. However, inlet and outlet pipes constructed from single buckets are short and wide, making them difficult to reposition and anchor. In contrast, double-tube systems rely on a completely-filled polyethylene tube, which provides ample liquid depth for water seal formation. When the biodigester tube is completely filled with liquid it is much easier to use five-gallon buckets as inlet and outlet pipes.

There are advantages to the single-tube design currently in use. For example, it has lower material costs than double-tube designs, it is easier to install, and it is potentially safer because biogas is usually stored outside, rather than in the home. However, the single-tube must balance the volumetric need for slurry *and* gas storage. While it is possible to accommodate both slurry and biogas storage in a single tank, these systems are vulnerable to the problems discussed above.

Based on my observations in the field, double-tube biodigesters may reduce common problems while simultaneously increasing biogas production and storage. Improved water seals minimize gas leaks at inlet and outlet pipes, increasing both net production and gas line pressure. A separate biogas reservoir increases storage capacity and allows operators to control biogas pressure (Rodriguez and Preston and Preston, no date) and can improve functionality.

All biodigesters utilize the same basic principles of anaerobic decomposition, but fundamental differences exist between pig- and cow-based biodigesters. The most important difference is the way in which charging occurs. Hose-and-channel systems are used in conjunction with penned animals, generally pigs, where the manure collects in one place and is easily washed into the channel network. Hose-and-channel systems are inappropriate for cows and other large animals that are not commonly penned in Honduras. Manure from free-ranging animals is dispersed and must be delivered to the biodigester by hand.

Another important difference is that hose-and-channel systems require substantially more water. More precisely, hose-and-channel systems in my study consumed an average of 16.4 kg water per pound of substrate, while hand-mixed systems average 3.7 kg of water per pound of substrate. As might be expected, this difference in water loading affects other process variables, including substrate DM load, total water load, slurry DM, loading rate, and slurry residence time.

Many operators felt that hose-and-channel systems are advantageous because they combine biodigester charging and pigpen cleaning into one relatively clean and easy daily chore. Using a hose, manure is washed from the pens and is carried by channels

directly to the biodigester. Although many operators were enthusiastic about hose-and-channel delivery systems, I observed several disadvantages. Exposed channels often routed surface runoff to the biodigester, disrupting biodigestion processes by flushing the tank with water and depositing sediment. Hose-and-channel systems also took longer to operate and provided no control over slurry mixing ratios. In contrast, hand-delivered systems had smaller labor requirements and did not utilize channels. In addition, hand-delivered systems had reduced water demand, lower project cost, and avoided the problems associated with runoff routing. Hose and channel systems may also be unfit for use in arid regions of Honduras, but this was not an issue at any of my study sites.

### **Biodigester modifications**

All biodigesters in Honduras exhibit a high degree of similarity because they are based on the same design and were constructed by one organization. Nevertheless, many operators modified the basic design. The more significant modifications included:

- a moveable joint on the inlet pipe to prevent runoff routing,
- protective tank cover using dark plastic tarps,
- inlet and outlet pipes with improved water seal control, and
- a biogas lighting system.

Due to problems associated with channeling surface runoff (and subsequent biodigester flooding) through hose-and-gutter systems, one farmer adapted a PVC elbow joint that could be repositioned. In the event of heavy precipitation, gutters would still intercept and carry surface runoff, but the flow could easily be directed away from the biodigester inlet and into a drainage ditch.

Modifications were commonly made to the materials used to cover the biodigester tube. Coverage protects the polyethylene and can take many forms including vegetative cover, tin sheeting, ceramic roofing tiles, and plastic tarps. Each type of coverage is unique in the way it intercepts precipitation, protects against puncture and UV exposure, and influences tank temperature. One farmer noted that covering the biodigester with blue plastic increased gas production; it is probable that dark plastic tarps result in improved heat trapping (i.e. radiation absorption) and protection of the polyethylene tube. Plastic tarps had the added advantage of being easily removed for inspection and periodic maintenance.

Like most bacterial processes, anaerobic decomposition is regulated in part by temperature. Consequently, different cover types might be used to optimize biodigester temperatures. Mean effluent temperatures observed in this study were only 26° C, but optimal biodigestion temperatures fall between 30-40° C (Green Box Systems Group, no date). Dark plastic tarps may be an inexpensive way to boost daytime heat absorption and biodigester productivity, while also providing UV and physical protection.

Several operators adapted PVC remnants for use as inlet and outlet pipes. The pipes are useful for establishing quality water seals given the low liquid level of the single-tube design. In turn, seal improvements allow for increased gas storage pressures without sacrificing biogas storage space.

Finally, the operator at the Las Columenas site adapted a lighting fixture for use with his commercial-sized biodigester. Using an old Coleman lantern retrofitted with a biogas feed and a new mantle, he can take advantage of his large biogas supply and illuminate a room in his house. Although only two operators suggested using biogas for

illumination, there could be significant interest in biogas lighting as all sites are in rural areas without electricity.

About half of Honduran biodigester operators have departed from basic construction, operation, and maintenance procedures even though the technology was only recently introduced. This departure could be the result of willingness to incorporate new technology, variability in operator and extensionist training, or age-old *campesino* ingenuity. Regardless of the specific reasons, Honduran operators have begun fine-tuning and experimenting with the technology, and will likely improve and adapt biodigesters to local household and environmental conditions. The cumulative modifications, experiences, and data gathered during this study will hopefully inform future biodigester design and operation, and thereby improve the technology's performance.

## **CHAPTER 6—TYPOLOGY AND CONCLUSIONS**

### **Typology of highly functional biodigesters in Honduras**

Based on the experiences and observations gathered during the course of this study, I offer the following suggestions to improve and expand biodigester technology in Honduras. The following recommendations may be useful to operators, extensionists, and non-profit project planners. In addition, I offer suggestions for future research that might provide further insight for improving the technology in the region.

Foremost, operators need to be explicitly trained in standard biodigester operating practices and the proper utilization of biogas and effluent products. In addition, training should educate operators in the prevention and repair of common technical problems, particularly sedimentation and animal damage. New training programs should emphasize lower (thinner) slurry mixing ratios, perhaps using 25 percent manure by volume with 50 percent water being an absolute maximum. Further experimentation is needed to determine ideal mixing ratios. To help ensure mixing consistency, mixing buckets could be distributed that are clearly painted with a “fill line” that graphically displays the proper amounts of manure and water to add.

General operation and maintenance procedures should be compiled in a non-technical field guide for operators. A sound, easy to follow guide is critical and may aid rural farmers who are just becoming familiar with the technology and may not intuitively grasp biodigester processes.

Projects should strive to produce biogas efficiently. Inlet and outlet pipes should be easily adjustable and able to create water seals at least 6” deep; this could be

accomplished using longer inlet and outlet pipes made of PVC or nested 5-gallon buckets. Well developed seals prevent biogas leakage and allow higher internal biogas pressures. Current single-tube biodigesters should be filled at least halfway, but no more than two-thirds full of liquid to leave sufficient room for biogas storage. Future biodigester projects should examine the potential of double-tube designs, which offer improved control over biogas pressure, potentially smaller tank digestion tanks, and incorporate a separate polyethylene biogas reservoir.

To avoid adverse effects from heavy precipitation, hose-and-gutter systems should include a moveable joint so that runoff and sediment can be channeled away from the inlet pipe. Furthermore, biodigesters should not be situated in low-lying areas that are prone to flooding and should incorporate runoff diversion channels where appropriate.

Biodigesters should be designed with a residence time sufficient for BOD reduction and complete anaerobic decomposition: a slurry residence time of 30 days should provide adequate digestion and water processing (Thy et al. 2003). The ideal biodigester would also incorporate human waste as a means of increasing production and minimizing pollution. The destruction of waste-born pathogens is desirable from a sanitation perspective, but would add latrine construction costs. But, there may be cultural resistance to the idea and there is inherent risk in using biodigesters to treat human waste.

Biodigester projects should incorporate clearly defined project goals and be implemented at appropriate scales. Small hand-charged units are best suited to reduce family fuelwood needs and improve household quality of living. Hand-charged units consume less water, require less labor, have faster payback times, and greater net benefits

to families than larger units. Larger units should be implemented when greater need for biogas or waste processing exists. Extensionist goals for each project should be clearly articulated: is the goal a reduction in deforestation pressure, waste management, energy production, or something else? Project scale is important and should be determined with the overall goals in mind.

### **Conclusions**

There is clear and demonstrated need for inexpensive, reliable, non-wood energy sources throughout Honduras and many other areas of Central America. Biodigester technology appears to function well in diverse environmental conditions in Honduras. More focused biodigester programs could lead to reduced fuelwood use, improved waste management, and provide a valuable source of energy and soil amendments. Selecting beneficiary families who are interested, willing, and have clear energy needs can help ensure useful, well-maintained projects by increasing project ownership. Biodigester life may be increased by more thorough training of project operators and addressing the most common technical problems, particularly protection of biodigester tube from animals and exposure to the elements. Biodigester functionality may be improved by narrowing inlet and outlet pipes to create more robust water seals and increasing the volume of daily charge such that tank residence time is between 20 and 30 days. Potential benefits of increased biodigester use include application of effluent as a fertilizer to sustain or increase crop yields and thereby reduce land expansion and deforestation pressures.

This study provides an initial look at the emergence of biodigester use in Honduras. The technology appears promising: biodigesters have the potential to



positively impact the lives and environments of many Central Americans. At present, SHI is responsible for the implementation of most biodigester projects, but given the success of biodigesters in other rural areas of the world, there is an opportunity for the technology to diffuse among rural Honduran farmers.

Future research is needed to refine the technology and to ensure that it is appropriate to local social and environmental conditions. Research should explore changes to operator training programs, the utility of fertilizer in Honduran agricultural systems, and the potential for community energy development. Future investigations should also explore different types of plastic covers, charging frequencies, substrates, and optimal mixing ratios under different conditions. As biodigester technology spreads, it will be increasingly important to assess farmers' ability to fund projects, availability of replacement parts, and the lessons of past projects. Biodigester projects should seek to reduce costs, especially the two most expensive items: polyethylene plastic and extension. Investigations are also warranted to research alternate biodigester designs, particularly those that incorporate separate gas reservoirs, optimal biogas production temperatures, *campesino* willingness to adopt and pay for the technology, and ongoing local adaptations of the technology.

## **POSTSCRIPT**

After returning from my field season in the fall of 2004 another graduate student, Laura Brown, began working in Honduras with SHI. I had the opportunity to connect with Laura, who was preparing various educational materials for the organization. Together we were able to prepare a short biodigester manual for distribution to *campesino* farmers. Many of the recommendations presented in this paper were incorporated into the manual. The manual is the first biodigester publication compiled for use by SHI extensionists and rural farmers in Honduras. It is also the first publication that documents and standardizes biodigester training, many thanks to Laura for all her work compiling the information and putting the manual together. A copy of the manual can be found in Appendix 4: Biodigester Manual.

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## Appendix 2: Field Research Documents

### Daily Data Sheet

Biodigester environmental data sheet

Biodigester name:

Family name:

Daily data

Weekly data

Date:		Date:	
<i>Slurry influent</i>		Substrate wet weight:	(g)
Substrate type:	( )	Substrate dry weight:	(g)
Substrate weight:	(Kg)	Substrate Dry Matter:	(%)
Water weight:	(Kg)	Influent BOD:	(mg/l)
Slurry pH:	( )	Effluent BOD:	(mg/l)
Slurry temp:	(deg C)		
<i>Fertilizer effluent</i>			
Effluent pH:	( )		
Effluent temp:	(deg C)		
<i>Biogas production</i>			
Time:	Height of displacement chamber:		
	(hour:minute)	(cm)	
	(hour:minute)	(cm)	
	(hour:minute)	(cm)	
	(hour:minute)	(cm)	

## Questionnaire for Biodigester Operators

### 1. Location and general information

Department:

Municipality:

Village:

Date:

Family name:

Operator interviewed:

### 2. Operation

Substrate used: (pig, cow, coffee, other)

Use of effluent: (ponds, fertilizer, nothing)

Daily operation time: (hours, minutes)

Substrate availability (circle one):    Abundant    Seasonally abundant  
Sufficient    Scarce

Water availability (circle one):    Abundant    Seasonally abundant  
Sufficient    Scarce

Training received in biodigester operation: (date, description)

### 3. Biodigester performance

Days to first gas production: (days)

Technical problems experienced (in interviewee's own words):  
(e.g. puncture, explosion, water availability)

Maintenance costs: (to date)

## Biodigester design parameters, processes, topics warranting further study

### 1. Location and general information

Department:

Municipality:

Village:

Village population:

Number of biodigesters in community:

Date:

Family name:

Interviewees present:

2. **Biodigester design parameters**

**Dimensions**

Biodigester length: (m)  
Biodigester width: (m)  
Height to liquid: (m)  
Reservoir length: (m)  
Reservoir width: (m)  
Distance to kitchen: (m)  
Material type (circle one): Polyethylene Other

Approximate date of construction:

General configuration and written description of biodigester:

3. **Biodigester process data (instantaneous measurement)**

Substrate type: ( )  
Substrate weight: (Kg)  
Water weight: (Kg)  
Slurry pH: ( )  
Slurry temperature: (deg C)  
Effluent pH: ( )  
Effluent temperature: (deg C)  
Gas production: (l/min)  
Time to fill gas reservoir: (hours)

4. **Family information and economic data**

Name of household head (circle gender): (male, female)

Name of biodigester operator (circle gender): (male, female)

**Demographic information**

Age	Male	Female
0-4	—	—
5-14	—	—
15-49	—	—
50+	—	—

Self-defined economic class: Low Middle High

Group-defined economic class: Low Middle High

Primary income (>80%, circle one): Agricultural Commercial Other

Livestock			
Type	Number	Age	Manure in biodigester (Y/N)
Pigs	—		—
Cows	—		—
Donkeys	—		—
Chickens	—		—
Other	—		—

Family land holding  
 Size:  
 Land use (type, % of holding):

5. Energy needs

Fuel type used  
 Before biodigester:  
 After biodigester:

Fuel source  
 Purchased: Price:  
 Gathered: Time invested:  
 Other:

Family member(s) responsible for fuel acquisition: (male, female)

Cooking time (hours for three main meals):

Gas produced for main meals (circle one): Enough gas Little gas  
 No gas

6. Biodigester construction and extension

Cost of biodigester materials: (Dollars or Lempiras)

Funding source (circle one): Private funds Loan NGO Other

Labor required for biodigester construction: (people, hours)

First information from (circle one): Relatives Friends NGO  
 Media Other

Motivation for constructing biodigester (in interviewee's own words):

Overall cost savings of biodigester (interviewee's own words):

General opinion of biodigester (in interviewee's own words):

## **Appendix 3: Laboratory Procedures**

### **Procedure for Dry Matter (DM) Measurement**

**NOTE:** This experimental procedure was used to determine the percent dry matter of biodigester substrates (manure). Manure composite grab samples were collected at biodigester sites using sealed plastic vials and weighed within a few hours of collection. A solar oven was used to dry samples due to its portability and lack of a forced draught oven.

#### **Procedure for determining Dry Matter (DM, % weight)**

##### **Equipment and supplies**

- J Scale JS-120 digital scale
- 50 ml clear plastic sampling vials.
- Solar oven, box type

##### **Preparation**

1. Wash, dry, and number sampling vials.
2. Using the digital scale, record the tare weight of each vial.

##### **Sample weighing**

3. Record sample type, sample origin, vial number, time, and date.
4. Zero the scale using the tare weight of the empty vial.
5. Place sample on scale and record weight.

##### **Sample drying**

6. Place sample in solar oven and leave sample to dry, using the scale to monitor sample weight.
7. When sample has dried to constant weight, repeat steps 4-5.

##### **Determination of DM**

8. Using the initial and final sample weights, calculate DM using the following formula:  $DM (\% \text{ weight}) = DM \text{ final} / DM \text{ initial}$   
<Procedure for Determining BOD4>



## **Procedure for Determining 4 Day Biochemical Oxygen Demand (BOD<sub>4</sub>)**

**NOTE:** The following experimental procedure was adapted from traditional (Standard Methods) and alternative (Garbely 2002) BOD measurement techniques to better accommodate field constraints. Specific obstacles to traditional BOD testing included intermittent electricity, difficulty of transporting glassware over poor roads, and lack of chemical stores. Because this procedure lacks the rigorous laboratory controls typically associated with BOD testing, results from this procedure are not directly comparable to standardized BOD results; however, the results are useful for determining the relative difference in BOD of biodigester samples. Single grab samples of effluent were used for dilution.

### **Equipment and supplies:**

- (18) BOD bottles (two sets of nine). Bottles used were opaque white 1 L HDPE plastic with approximately 1-inch mouths
- YSI Model 55 Dissolved Oxygen meter
- 3 ml disposable plastic pipettes
- Graduated plastic cylinders, various volumes
- Aguazul brand purified water
- Magia Blanca brand chlorine bleach
- Rubbermaid cooler, 54 Quart capacity

### **Bottle preparation and sterilization:**

1. Fill BOD bottle with approximately 100 ml of chlorine solution (10 ml chlorine bleach to 1 L purified water).
2. Affix cap and shake 30 seconds.
3. Pour out contents of bottle.
4. Repeat steps 1-3, then place bottle upside-down on a clean cloth to dry.
5. Replace cap when dry.
6. Repeat steps 1-5 for each bottle to be sterilized.

### **Sample dilution and incubation:**

7. Mix biodigester samples well taking care not to introduce air bubbles.
8. Fill BOD bottle with 1 L purified dilution water.
9. Using a plastic pipette, add 3 ml of biodigester influent sample OR biodigester effluent sample OR purified water.
10. Use a digital oxygen (DO) meter to record DO of the dilution water and sample.
11. Record bottle number, sample type, and initial DO.
12. Squeeze BOD bottle until water level rises to the mouth of the bottle and affix cap. (This action eliminates the airspace within the bottle that would otherwise skew the DO readings.)
13. Place BOD bottle in insulated cooler.
14. Repeat steps 7-13 until (9) bottles have been filled: (3) with influent samples, (3) with effluent samples, and (3) with purified water blanks.

**BOD4 determination:**

15. After exactly four days, remove BOD bottles from cooler.
16. For each bottle, remove cap and use DO meter to record the DO of the diluted sample.
17. The initial and final DO readings can be used to calculate the approximate BOD4 using the following equation:

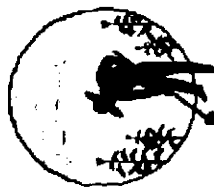
$$(\text{BOD final} - \text{BOD initial}) / (\text{sample size ml} / 1000 \text{ ml})$$

BOD of dilution water was corrected for by subtracting mean BOD4 of blanks from mean BOD4 of diluted effluent samples.

## Appendix 4: Biodigester Construction Manual

(Document is also available from [www.sustainableharvest.org](http://www.sustainableharvest.org))

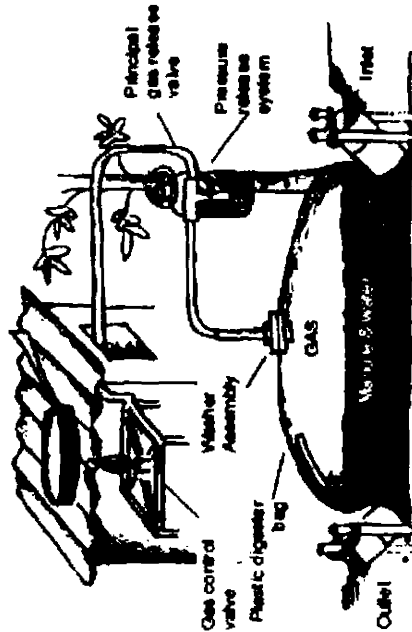
### Gas Bio-digester Information and Construction Manual For Rural Families



Fundación Cosecha Sostenible Honduras  
FUCOSOH  
Oficina de la Coordinación Nacional

#### Table of Contents

- I. What is a bio-digester?
- II. Considerations before building a bio-digester
- III. Materials and instructions for installing a family sized bio-digester
- IV. Operating and maintaining a bio-digester
- V. Common questions & problems



Written and compiled by Laura Brown, November 2004. This report is based on information gathered by Bruce Maerum, Stuart Green, and the agricultural extensionists employed by FUCOSOH. FUCOSOH has provided technical and financial support for the construction of 25 bio-digesters in rural Honduras.

## I. What is a bio-digester?

For many years rural families around the world have used bio-digesters to convert readily accessible animal or plant waste into gas fuel. Bio-digesters use a process of oxygen free decomposition in which bacteria in the animal or plant waste produce a mixture of methane, carbon dioxide, and other gases that are stored inside. Bio-digesters are relatively simple to build and operate, and require little more than a steady supply of organic matter and water.

Bio-digesters provide benefits to families and communities by:

- Reducing the amount of wood fuel used by the household
- Preserving forests that naturally clean the water and air and provide habitats for thousands of species of unique plants and animals
- Producing high-quality organic fertilizer as a by-product
- Improving household air quality by reducing reliance on smoky wood burning stoves
- Providing a method for treating raw waste and reducing the flow of raw waste into clean streams and rivers

## II. Considerations before building a bio-digester

### Fuel needs

A family sized bio-digester will provide about 4 hours of fuel per day. Most families will still use some wood fuel for daily cooking or lighting needs.

### Space

Bio-digesters require about 10 square meters of open space in a location below the ground level of the household.

### Cost

At the time of publication the cost of parts (not including the plastic bag or sleeve) for a family sized bio-digester was about \$10 (in Honduras). At this time FUCODECO is able to provide support for plastic and technical support for most bio-digesters. Ask your local artisan/worker for more information about the cost of a bio-digester for your family.

### Maintenance

Bio-digesters must be refilled and checked for proper functioning daily and may require some annual maintenance. The cost of replacement of most parts

is minimal but polyethylene plastic tubes can be expensive. If maintained properly the plastic end parts of your bio-digester will last for up to 7 years.

### Materials

Bio-digesters work best when fueled with pig manure, but cow manure, goat manure (not the milk), human waste, chicken droppings, and any other clean, organic and pebble free, biodegradable material can also be used. Digesters require about 1-2 shovels of clean, chemical and contaminant free manure every day. If you have more than 10 pigs, you may want to consider constructing a larger digester system to allow manure and water from the pens to flow directly into your bio-digester. The water used to fill the digester must also be at a moderate pH level and free of chemicals. Consult your artisan/worker if you are unsure about the water quality or materials you plan to use in the digester.

### Time

It will take about 2 days to complete installation of your bio-digester. Plan one day to dig the trench and another to assemble the materials.

## III. Instructions for installing a non-industrial family sized bio-digester

### Materials



NOTE: We recommend that you read the entire instruction manual carefully before purchasing materials as some sizes and dimensions may vary based on the location of the digester and your family's needs. The list does not include materials necessary for the installation of your stove. See "Constructing the gas line" in the section for more information on stove installation.

- 2 clear plastic tubes (Use #6 or #8 thick clear polyethylene plastic. This type of plastic is common and is usually available as a tube at least 4 feet long with the two long ends sealed to each other.) A tube 4

feet in diameter and 25 feet in length will supply a family with 4 hours of gas per day.

- 2 5-gallon pails with the bottoms cut out
- 2-3 used rubber tire inner tubes cut into 3-4 foot long, 2' long
- 1 1/2" male adaptor threaded to compression joint PVC
- 1 1/2" female adaptor threaded to compression joint PVC
- 2 large aluminum washers to fit male threaded PVC adaptor (These can be fabricated from used metal if necessary)
- 2 rubber washers, (1-2 cm larger than aluminum washers)
- 1 1/2" PVC T
- 1 piece of steel wool or fine mesh steel window screening
- 1 1/2" PVC pipe (about 3-4 feet, this will vary depending on the location of your digester)
- 1 1/4" flexible tubing (length will depend on distance to water source and to gas use site)
- 1 1 or 2 liter soda bottle
- 4 sturdy wooden stakes
- 1 small tube of PVC cement
- 1 piece of rope 5-10 feet longer than the digester

- 2 pieces of rope 6-10 feet each

You will also need a hacksaw, scissors, a machete or large knife, a hand or foot pump (if available) and shovels for digging the trench. A wrench will be helpful for tightening the washer assembly.

#### Choosing and preparing the site for your bio-digester

In order to protect your bio-digester from animal and weather damage it must be located in a smooth (flat-bottomed and flat walled) trench. Locate a site that is free of large trees, stumps, and free of any chemical contaminants (pesticides, fertilizers, herbicides etc.). The site should be no more than 60 feet (20 meters) from the house. Because gas rises, the site



Above: Bio-digester trench

must also be below the ground level of your house. Begin preparing the bio-digester site by clearing it of all bushes, roots, and trees.

Dig the trench to the following dimensions:

- Width: diameter of the plastic tube
- Length: about 2-4 feet shorter than the length of the plastic
- Depth: diameter of the plastic tube

In mountainous areas it may be necessary to dig a terrace and create walls with rocks and mud. Make the bottom of the trench as level as possible. Run your hands over the entire surface of the trench. Clear all roots or rocks as they may puncture the bio-digester bag.

#### Preparing Materials

- 1 Find an open flat area (a sports field works well) and lay out the plastic tubes end to end. Remove your shoes and carefully crawl through one of the bio-digester bags holding the end of the other. Be very careful not to puncture the bags. Once the bag is the side d completely through, remove any folds or wrinkles.



Above: Threading bio-digester bags. Be careful not to tear the bags.

- 2 Now is a good time to cut the hole for the washer assembly. Holding both corners and both bags, fold the plastic in half lengthwise about 6 feet from one end. Cut a hole as shown below that will allow the 1/2" PVC adaptor to fit through both bags on one sealed side of the plastic.





- 4 Attach the long solid PVC pipe to the weather assembly with cement. **NOTE:** Unless otherwise indicated, all PVC materials in the bio-digester should be cleaned sand paper or a file to ensure a proper cement seal.

#### Installing Inlet and Outlet Buckets

- 5 Lay your bio-digester carefully in the trench being sure that the gas outlet is centered. Cut out the bottoms of the 5-gallon buckets and sand or file the edges to remove any sharp areas that may damage the plastic. Slide one side of the bio-digester bag through the bottom of one of the 5-gallon buckets leaving about 1 1/2" of plastic coming out the top of the pit. Carefully fold the ends of the bag over 2-3 times and tie off each end with strips of rubber.

- 6 Push the bucket into the trench so it sits at about a 45-degree angle. At this time it may be necessary to dig ramps at the entrance or exit of the digester to accommodate the angle of the buckets. You may also consider digging a trench that will allow for easy accessibility to the entrance bucket. Repeat on the other end of the bag.

- 7 To secure the buckets pound stakes on each side of the inlet between the pits and the bag. Stakes should be placed a distance slightly smaller than the diameter of the bucket so the bucket will fit very snugly between them. Be very careful not to puncture the bag.

#### Positioning and Filling the Digester

- 8 Before filling your digester you must ensure that it sits snugly in the trench without lid or ventholes. Any leaks or ventholes that remain when the bag is filled with water may choke and form holes. This may be accomplished in several ways:

- If a diesel motor is available the digester may be filled with exhaust. Attach one side of a flexible hose

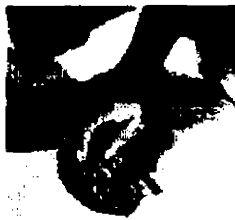


Above: Bio-digester bag is being filled between two feet while filling with water.

If you will need to transport the bags to a different location, fold and secure them so the elements or the head of a motor will not damage them.

#### Assembling the Gas Outlet

- 3 Place one washer and one gasket on the male adaptor (as shown below) and thread through the inner side of the plastic bag. Push the male adaptor through the hole. Assemble the remaining washer and gasket on the outside of the bag. Apply PVC cement to the male adaptor and secure the female adaptor firmly. Tighten with a wrench if available.



Above: Matching the washer assembly in the digester bag.



(do not glue) to the PVC pipe extending from the washer assembly and the other to the exhaust source. Fill just until the bag is smooth.

If a diesel motor is not available thread a long piece of rope through the digester bag and secure ends to nearby trees. The bottom of the bag should sit on the floor of the trench and the top should be raised slightly. Fill the bag with water as described below.

Fill the bag with air using a small hand or foot pump.

- 9. Attach one end of flexible plastic tube (do not glue) to the PVC pipe from the washer assembly and the other to a spigot. Fill the digester to 80%-75% capacity with water.

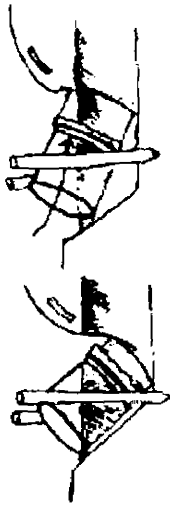
**NOTE:** Water used to fill the digester must be clean and have neutral pH (not too acidic or basic). Ask your veterinarian if your water source is suitable for filling the digester.

Below: Threading bags through the plastic bucket inlet tube. Only one bucket was used in this mode.



#### Completing Inlet and Outlet Tubes

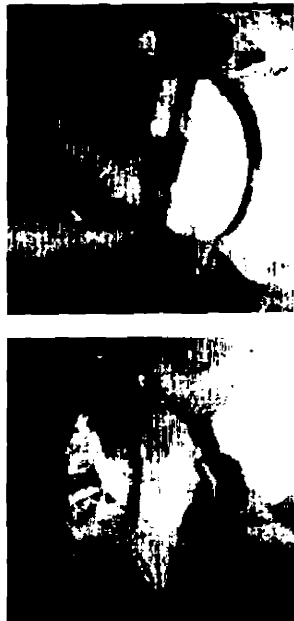
- 10. Untie the ends of the digester bag and fold the remaining plastic over the top of the bucket. Reach your hand through to smooth the plastic along the inside of the bucket. Slide another plastic bucket bottom and first inside the first bucket through the plastic tube. The plastic should be sandwiched between the two buckets. Wrap rubber ties around the bucket to secure the extra plastic.



CORRECT

INCORRECT

Below: Placing and securing inlet and outlet buckets. The bottom of the bucket should be submerged at least 6 inches below the water level.



- 11. If necessary reposition the angle of the inlet and outlet tubes so the bottoms are well below water level and fluid can easily flow out of the digester. Tie a long piece of rope between the two vertical stakes to hold the tubes firmly in place.

**VERY IMPORTANT:** Bio-digesters rely on water seals to maintain an oxygen free environment. If oxygen is allowed to enter the buckets that produce gas in the digester will die. To ensure a good seal inlet and outlet tubes must be secured to the bottoms at AT LEAST 6 INCHES below water level.

#### Assembling the Pressure Release Valve

- 12. Begin assembling the gas valve by rolling the sheet screen or sheet wood into a 1/2" tube. Push the tube into the PVC 'T' as shown.

Below: Completed valve assembly.



13. Assemble PVC pipes and valve as shown. VERY IMPORTANT: Leave one side of the PVC "T" unglued to allow steel wool to be replaced every 6-7 months.

14. The flexible plastic gas outlet tube may now be attached to the lead to-digester. The length of the tube will vary depending on the distance between the digester and the tree or other where the pressure release valve will be located. Soften one side of the flexible plastic tube with a flame or boiling water. Coat with cement and push the PVC gas outlet tube firmly into the flexible plastic (3-4 inches). Wipe lightly with a rubber toe. Attach the other end of the flexible tube to the valve assembly using the same procedure.



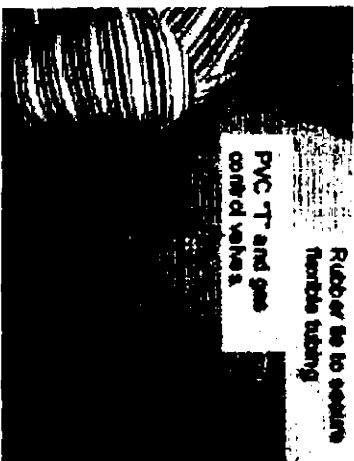
Above: Pressure release valve secured to a tree

Completing the gas line

16. Run a piece of flexible plastic tubing from the pressure release valve to the location where the gas will be used (the distance will vary). Secure the gas line to the valve assembly as in step 14.

17. If your gas line will be attached to a gas store, create a secure PVC assembly as shown in the picture below. The gas control valves located on your above should be closed securely. Connect the gas line to the PVC assembly on the above using the method described in step 14.

Right  
Attaching the  
spine to the  
plastic gas  
tube



Changing and preparing the digester for use

18. Be sure the gas valve is closed before changing. The digester should be rinsed by charged with about 20 buckets of manure and water mixture for the last day only. IMPORTANT: A few the feed change, your digester will require only TWO BUCKETS of change each day. Use any of the following mixtures:

- 1 shovel of cow Gornado manure. 1 bucket of water.
- 1/2 shovel of pig manure. 1 bucket of water.
- 1-2 lbs barium, coffee, or other binding capable plant waste. 1 bucket of water. IMPORTANT: Never use sharp or very hard materials such as bone or wood.



#### IV. Operating and maintaining your bio-digester

Bio-digesters take 50-70 days to begin producing gas regularly. If maintained properly your bio-digester will last for about 7 years. Polyethylene plastic degrades in the sun. If your digester is located in a sunny area constructing a simple roof made of plastic, bamboo, or leaves may increase the life of your digester by several years. A solid plastic cover functions well because it will trap the sun's heat and could improve gas production in your digester. Construct a fence around your digester if there is any chance of damage by animals.

Daily maintenance: Charge your bio-digester with two buckets of manure or plant wastes and water mixed to the ratios above. Check the inlet and outlet buckets to ensure that the level of water in the bag is adequate. Check the pressure release valve to ensure that the bottle is filled with water up to the small water hole. If the water in the pressure release valve is bubbling then the digester is functioning properly. Check inlet and outlet buckets to be sure no air is entering. Check for damage to the digester bag. Clean off any mud, slabs, or foreign material on the bag.

Periodic maintenance: The steel wood inside the PVC T assembly must be replaced every 7 months. Check gas lines for cracks and leakage.

The discharge from your digester is a clean organic fertilizer. Do not divert this discharge directly into lakes or streams. Consult your extensionist for more information about best uses for this fertilizer.

Contact your extensionist if you note any problems with your bio-digester.



Let initially charge your bio-digester with up to 20 buckets of manure mixed with water. After this the digester requires only 2 buckets of charge each day.

#### V. Common Questions and Problems

The bio-digester does not seem to be producing any gas.

Bio-digesters take 50-70 days to begin producing gas regularly. If your bio-digester is new, vent and continue charging with 2 buckets of manure and water mixture each day.

Gas production may drop or cease for many reasons including the entrance of air into the bag, changes in temperature, water pH, and contamination in the wastes used to charge the digester. Check to be sure that no air is entering the bio-digester from the inlet or outlet tubes. Next check the digester for any bag damage from foreign objects or animals that may allow gas to enter. If necessary increase the water level inside the bag.

Some producers have noted a drop in bio-digester gas production in winter months and during long periods of rain.

Soil around the bio-digester is washing onto and compressing the bag.

When soil or mud fall on the bio-digester they can deflate the bag, seal off the inlet, destroy the trench, and cause sedimentation to occur inside the bag. To avoid this problem construct a barrier to keep mud, rain, and soil out.

Many producers have constructed simple fences or barriers to prevent erosion from damaging the bio-digester bag. These may be constructed from wooden slats and bits of wood. Any mud that washes onto the bag must be cleaned off daily.

There appears to be gas in the bag, but there is no gas coming out of the stove/ramp outlet.

Check to be sure the gas valve is open. Occasionally pipes crack causing a leak in the gas line. Regularly inspect your gas lines for damage. Seal any damaged lines securely with glue and rubber feet.

Animals are damaging the digester bag.

Animals can quickly cause permanent damage to your bio-digesters. Be sure that your bio-digester is well protected from animals.

Do I have to use the same type of waste in my digester every day?

No. Bio-digesters work best with pig waste but you can use any clean, biodegradable material mixed with plenty of water.

Sedimentation is occurring inside the bio-digester. Is this OK?

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