Evaluation of Innovative Decentralized Sanitation Technologies in Ghana

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by

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Bachelor of Arts in Art and Mathematics
Luther College, 2013

Submitted to the Department of Civil and Environmental Engineering Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Civil and Environmental Engineering
at the
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ABSTRACT

It is estimated that 2.5 billion people lack access to improved sanitation, and 90% of wastewater in developing countries is discharged into the environment without any treatment. However, the construction of sewerage systems and centralized wastewater treatment plants is neither an affordable nor appropriate solution for many areas. Therefore, an emphasis has arisen on decentralized sanitation technologies that treat waste on-site and recover resources that can be used to generate economic gains. Using a case study method and an evaluation matrix, this thesis evaluates the efficacy and scalability of several such innovative sanitation technologies.

The decentralized technologies evaluated include the Clean Team Toilet, Microbial Fuel Cell Latrine, Biofil Toilet, Microflush Toilet, and the more traditional pour-flush toilet. Two semi-centralized technologies, the IMWI Fortifer pellets and Ashesi University's small-scale wastewater treatment system with anaerobic digestion, were studied as well. Case studies of these technologies were conducted in January 2014 in Ghana and involved surveys of users and interviews of service providers and their competition where possible. The evaluations were completed using this information and were guided by criteria on sanitation outcomes, business management, and technology categories.

We conclude that the Biofil Toilet is the current gold standard for decentralized sanitation, although it is costly. The locally sourced Microflush Toilet is recommended for middle- and low-income families and small aid projects, for it functions similarly to the Biofil Toilet but is approximately one-fifth the cost. For large projects in densely populated areas, the Clean Team Toilet is recommended if a reuse for waste and safe disposal of biocide can be established. Other technologies require further development before they can be recommended for implementation and use.

Thesis Supervisor: Susan Murcott
Title: Senior Lecturer of Civil and Environmental Engineering

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Table of Contents

List of Abbreviations

ASU – Arizona State University
BMGF – Bill and Melinda Gates Foundation
BOD – Biochemical Oxygen Demand
CEPT – Chemically Enhanced Primary Treatment
CLTS – Community-Led Total Sanitation
CTT – Clean Team Toilets
EcoSan – Ecological Sanitation
GDHS – Ghana Demographic Health Survey
GHS – Ghana Cedis
GMICS – Ghana Multiple Indicator Cluster Survey
GSAP – Global Sustainable Aid Project
I-WASH – Integrated Approach to Guinea Worm Eradication through Water Supply, Sanitation, and Hygiene
IWMI – International Water Management Institute
JMP – Joint Monitoring Project
KVIP – Kumasi Ventilated Improved Pit Latrine
MDG – Millennium Development Goal
MEng – Master of Engineering
MFBF – Microflush/Biofil
MFCL – Microbial Fuel Cell Latrine
MIT – Massachusetts Institute of Technology
NGO – Non-Governmental Organization
PHW – Pure Home Water
TSS – Total Suspended Solids
UN – United Nations
UNDP – United Nations Development Programme
USAID – United States Agency for International Development
US$ – United States Dollar
WaFo – Waste to Food Program
WASH – Water, Sanitation, and Hygiene
WEDC – Water, Engineering and Development Centre
WHO – World Health Organization
WSP – Water and Sanitation Program
WSUP – Water and Sanitation for the Urban Poor
WUZDA - Wuni Zaligu Development Association
WWTP – Wastewater Treatment Plant

1 Introduction

1.1 Purpose

Sanitation coverage is not only a means of improving human well-being, but also of ensuring human dignity. However, sanitation as high income nations know it, with flushing toilets, underground sewer systems, and wastewater treatment plants, is not feasible for a large proportion of the world's population that currently lacks improved sanitation. Additionally, even in areas with access to improved sanitation, waste is not always treated or disposed of in a sanitary manner. For example, untreated septage is typically discharged into the ocean at Korle Lagoon in Accra (Yaro 2014), and other plants, such as the one at the Burma Military Camp in Accra, are in disrepair and cannot be properly used (IWMI 2008). For such communities, the large-scale, capital- and energy-intensive centralized treatment systems of high-income nations do not make sense; they are too expensive, are not accessible to communities without sewer systems, and waste precious resources that could be recovered and used to generate income. At the other extreme, open pit latrines are not a suitable answer because, although they do not rely on a centralized grid, they do not hygienically separate waste from human contact, thereby facilitating the spread of diseases. With this grand challenge in mind, there has been a recent wave of innovative sanitation technologies that operate off the grid, recover waste in a useful form, and/or prevent water-related diseases.

The purpose of this thesis is to evaluate several of these innovative solutions in order to inform entrepreneurs, donors, and public health professionals in the sanitation sector, both in Ghana and around the world, as they look to identify technologies most applicable to their communities of interest. Through the guidance of Senior Lecturer Susan Murcott, interviews and inspections of a number of innovative sanitation facilities were conducted in order to evaluate their successes and failures in terms of business management, technology, and behaviors. The data obtained through these interviews and inspections is analyzed in the following chapters, and conclusions and recommendations are made in order to inform future projects.

1.2 Global Sanitation Overview

Today, lack of access to improved sanitation facilities is one of the world's greatest obstacles for development. Globally, 2.5 billion people lacked access to improved sanitation in

2011, and, of these people, 1.1 billion practiced open defecation (WHO/UNICEF JMP 2013) and 1.4 billion earned less than US$2 per day (Watkins 2006). However, if high-income countries' standard for sanitation, private access to a flush toilet with continuous water supply, were the benchmark for classification of "adequate" sanitation, this statistic would actually increase to 4 billion individuals without adequate sanitation (Watkins 2006).

This is significant because estimates show that a child dies every 21 seconds due to diarrhea, amounting to 1.5 million preventable deaths of children under age five each year (Johannson 2009). It also *contributes* to 18 million deaths per year and causes stunted growth in many more (WHO/UNICEF JMP 2010). Diarrhea can kill or stunt growth by causing acute or chronic dehydration. Acute dehydration results in hypotension, renal failure, and circulatory collapse, evolving into shock and organ failure, while chronic dehydration causes malabsorption of nutrients and malnutrition (Gill 2012). Diarrhea is often caused by ingestion of bacteria in human feces through the fecal-oral pathways, as is shown in the F-Diagram in Figure 1-1 (New Internationalist 2008). Interventions that provide improved sanitation can disrupt three of these four pathways, leaving only contamination of fingers as a likely path of transmission to a new host. This is addressed by sufficient water quantity and hand washing. Studies show that, as a result, improvements in sanitation coverage could eliminate 33% of deaths due to diarrhea (Johansson 2009) and 24-36% of diarrhea cases (Esrey 1985, Fewtrell and Colford 2004).

The importance of sanitation is well documented, but it often does not receive as much attention as other indicators of development that have more tangible and immediate benefits. In fact, in the year 2000, the world's leading development institutions and all countries agreed upon eight Millennium Development Goals (MDGs) in order to improve humans' quality of life and alleviate poverty. At that time, sanitation was not a part of these goals. However, after a great amount of lobbying by interest groups, Target 7C was expanded to include the goal of reducing by half the proportion of people without access to basic sanitation. Since this addendum in 2002, the proportion of the world with access to improved sanitation has increased from 49% to 64%. However, one billion more people must gain access to improved sanitation by 2015 in order to reach the goal, for which the world is not on track. Target 7C originally was created as a goal to reduce by half the proportion of people without access to improved sources of drinking water, and this was achieved in 2012. This is evidence supporting the argument that the problem of inadequate sanitation is not receiving the prioritization that it warrants (WaterAid 2007).

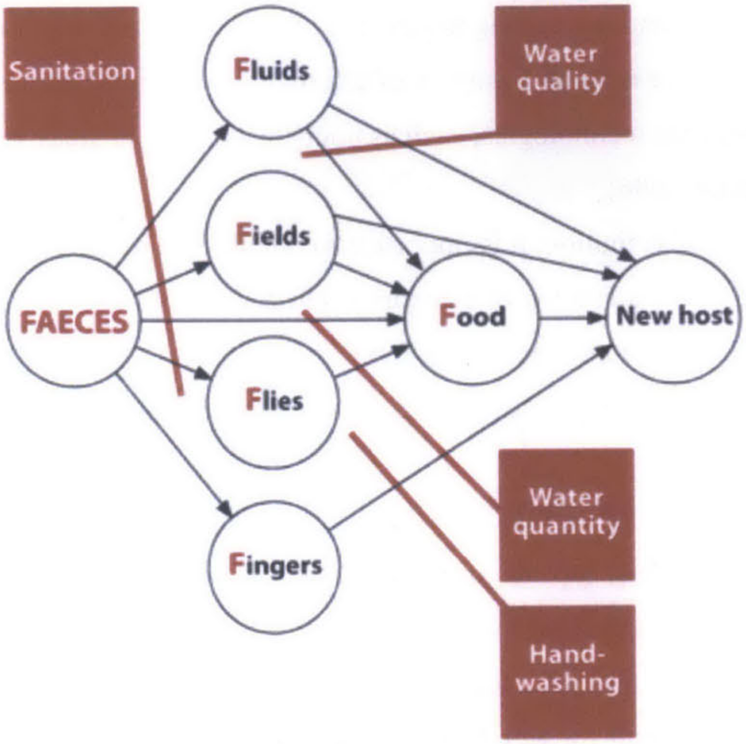


Figure 1-1 The F-Diagram shows common fecal-oral pathways for disease transmission (New Internationalist 2008)

Additionally, studies have shown that people tend to consider sanitation a lower priority than water. The United Nations Development Program cites six barriers to improvement of sanitation as reasons for sanitation's lag behind advances in drinking water. The first barrier is national policies. Because sanitation is an issue that affects many different aspects of life, it is often managed by several different government agencies, and this fragmentation creates problems in enforcement of policies. The second barrier, behavior, is problematic because sanitation is a shared effort; that is, in order for a community to reap the benefits of improved sanitation, the entire community must partake of improved sanitation in order to eliminate the potential for contact with human feces, whereas a single household can benefit from potable water. Third, because the benefits of an improved water source are more immediate and tangible than those of improved sanitation, perceptions of donor institutions and users are often biased toward investments in water rather than sanitation. Poverty is the fourth barrier, for 1.4 billion people of the 2.5 billion without improved sanitation earn less than US$2 per day. As a result, they cannot afford to make large investments in sanitation and lack collateral necessary to take out loans. Fifth, gender is a major obstacle for sanitation. Studies show that women place a higher value on sanitation and are willing to pay more to obtain it than men are. Finally, the sixth barrier is supply; there is an undersupply of affordable sanitation technologies and an oversupply of inappropriate technologies, such as pour-flush toilets in areas without reliable access to water (Watkins 2006).

In order to discuss sanitation, it is important to establish an understanding of the sanitation ladder, which is a hierarchy of categories into which different types of latrines fall. The two main categories are improved and unimproved sanitation. An improved sanitation facility is defined as "one that hygienically separates human excreta from human contact," is only used by one immediate family, and is accessible at all times. Unimproved sanitation describes any facility that is not improved, and this classification has three subcategories that were defined in 2008. The first subcategory is shared facilities, which are technically improved but are either public or regularly used by individuals outside of the owner's family. The lack of a sense of ownership commonly exhibited by shared facilities' users often leads to a less clean, poorly maintained environment, so such facilities are considered unimproved. The second subcategory is simply unimproved sanitation, which is used to describe any facility that does not hygienically separate human excreta from human contact. The final subcategory is open defecation. In 2011, 64% of the world's population was using improved sanitation facilities, 10% was using unimproved facilities, 11% was using shared facilities, 15% was practicing open defecation (WHO/UNICEF JMP 2013). Figure 1-2 shows the world's progress on the sanitation ladder from 1990 to 2011 by region. Figure 1-3 provides a list of different latrine types that are categorized as improved or unimproved, and Figure 1-4 is a visual representation of the sanitation ladder.

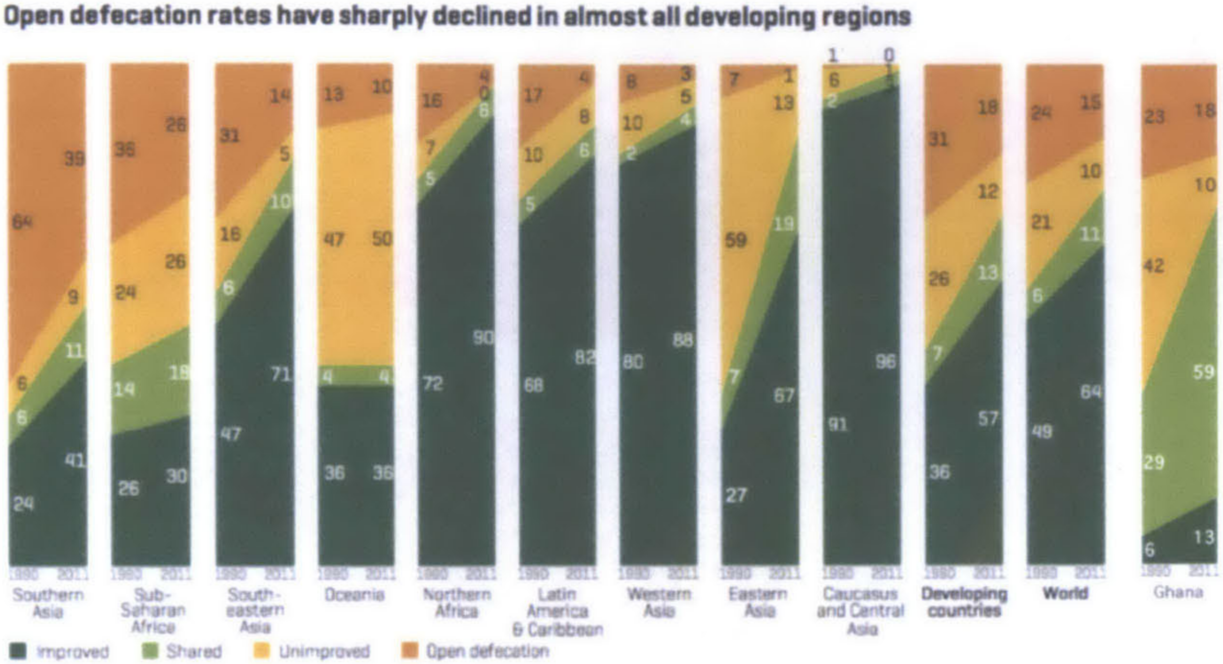
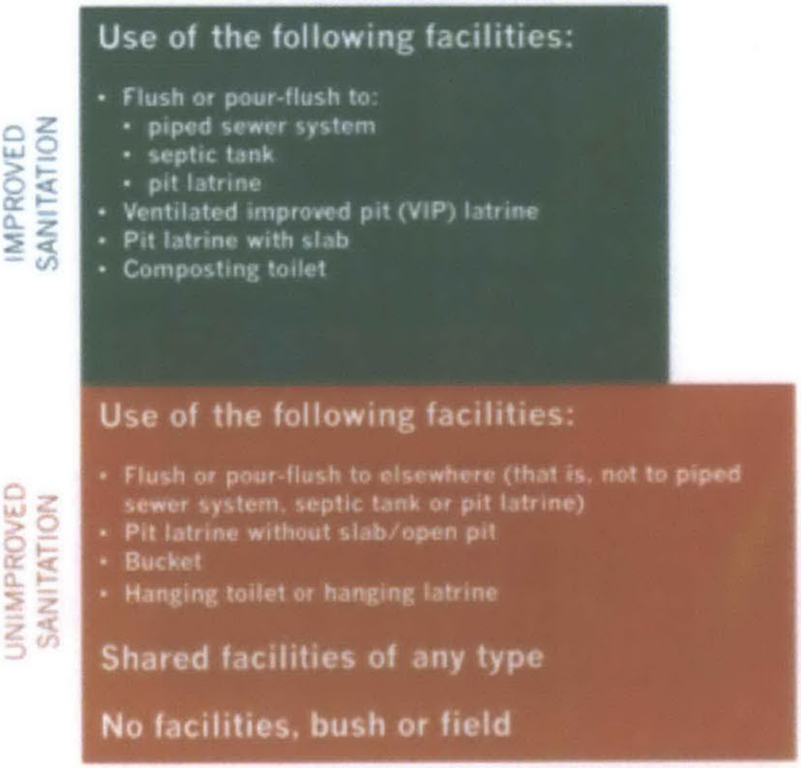


Figure 1-2 Sanitation coverage trends from 1990-2011 (WHO/UNICEF 2013)



Use of the following facilities:

- Flush or pour-flush to:
  - piped sewer system
  - septic tank
  - pit latrine
- Ventilated improved pit (VIP) latrine
- Pit latrine with slab
- Composting toilet

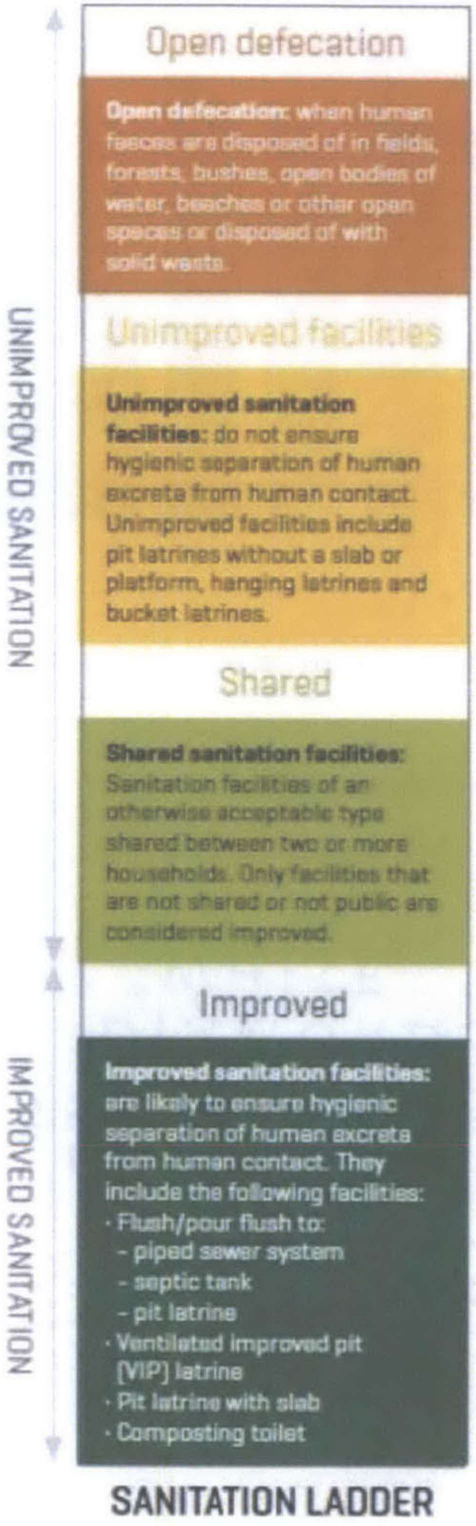
Use of the following facilities:

- Flush or pour-flush to elsewhere (that is, not to piped sewer system, septic tank or pit latrine)
- Pit latrine without slab/open pit
- Bucket
- Hanging toilet or hanging latrine

Shared facilities of any type

No facilities, bush or field

Figure 1-3 Types of sanitation and classifications (WHO/UNICEF JMP 2013)



Open defecation: when human faeces are disposed of in fields, forests, bushes, open bodies of water, beaches or other open spaces or disposed of with solid waste.

Unimproved sanitation facilities: do not ensure hygienic separation of human excreta from human contact. Unimproved facilities include pit latrines without a slab or platform, hanging latrines and bucket latrines.

Shared sanitation facilities: Sanitation facilities of an otherwise acceptable type shared between two or more households. Only facilities that are not shared or not public are considered improved.

Improved sanitation facilities: are likely to ensure hygienic separation of human excreta from human contact. They include the following facilities:
- Flush/pour flush to:
  - piped sewer system
  - septic tank
  - pit latrine
- Ventilated improved pit [VIP] latrine
- Pit latrine with slab
- Composting toilet

Figure 1-4 Sanitation Ladder (WHO/UNICEF JMP wssinfo.org 2013)

1.3 Sanitation in Ghana

This global sanitation data provides a background against which Ghanaian sanitation can be compared. Ghana, according to the United Nations Development Programme, is 135th out of 187 nations on the Human Development Index, thanks in part to a stable democratic government. This ranking is considerably ahead of Ghana's neighboring nations of Togo, Cote D'Ivoire, and Burkina Faso, which have rankings of 159, 168, and 183, respectively (UNDP 2013). Still, Ghana's rate of improved sanitation coverage is the sixth worst in the world at only 13%, as is shown in Figure 1-5 (WHO/UNICEF JMP 2013). This is, without a doubt, a great hindrance to Ghanaian development.

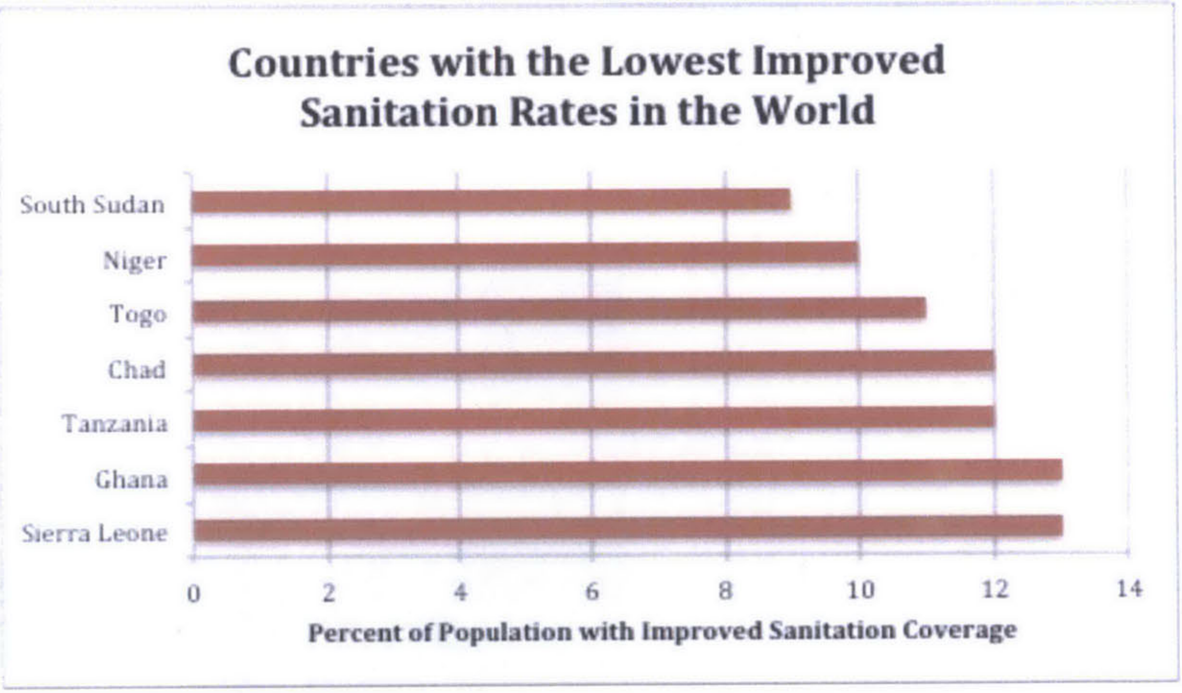
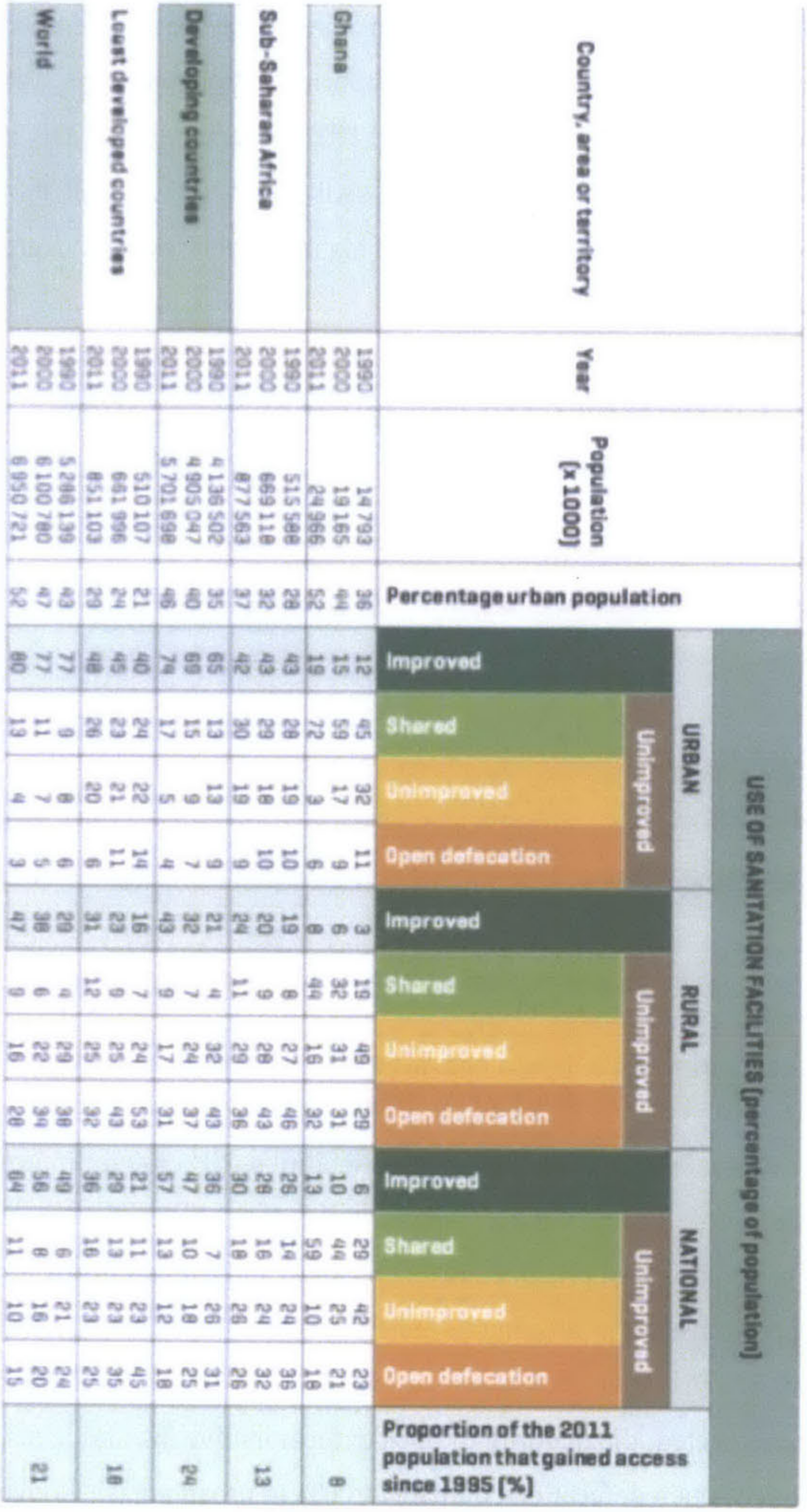


Figure 1-5 Countries with the lowest improved sanitation rates in the world (Data from UNICEF/WHO JMP 2013)

Nationally, 59% of Ghanaians use shared sanitation facilities, 10% use unimproved facilities, and 18% practice open defecation. Ghana is quite similar to other developing nations in proportions of the population that practice open defecation and use unimproved sanitation facilities, but it has a far greater proportion of individuals that use shared facilities and a far lower proportion with access to improved sanitation.

As might be expected, the majority of open defecators live in rural areas, where 32% of the population practices open defecation compared to 6% in urban areas. Conversely, 72% of urban Ghanaians use shared facilities compared to 44% of rural Ghanaians (WHO/UNICEF JMP 2013). The statistics for urban, rural, and national sanitation for Ghana and other relevant areas are displayed in Figure 1-6.



Country, area or territory	Year	Population (x 1000)	Percentage urban population	USE OF SANITATION FACILITIES (percentage of population)												Proportion of the 2011 population that gained access since 1995 [%]
				URBAN				RURAL				NATIONAL				
					Unimproved				Unimproved				Unimproved			
				Improved	Shared	Unimproved	Open defecation	Improved	Shared	Unimproved	Open defecation	Improved	Shared	Unimproved	Open defecation	
Ghana	1990	14 793	36	12	45	32	11	3	19	49	29	6	29	42	23	8
	2000	19 165	44	15	59	17	9	6	32	31	31	10	44	25	21	
	2011	24 966	52	19	72	3	6	8	44	16	32	13	59	10	18	
Sub-Saharan Africa	1990	515 588	28	43	28	19	10	19	8	27	46	26	14	24	36	13
	2000	669 118	32	43	29	18	10	20	9	28	43	28	16	24	32	
	2011	877 563	37	42	30	19	9	24	11	29	36	30	18	26	26	
Developing countries	1990	4 136 502	35	65	13	13	9	21	4	32	43	36	7	26	31	24
	2000	4 905 047	40	69	15	9	7	32	7	24	37	47	10	18	25	
	2011	5 701 698	46	74	17	5	4	43	9	17	31	57	13	12	18	
Least developed countries	1990	510 107	21	40	24	22	14	16	7	24	53	21	11	23	45	18
	2000	661 996	24	45	23	21	11	23	9	25	43	29	13	23	35	
	2011	851 103	29	48	26	20	6	31	12	25	32	36	16	23	25	
World	1990	5 286 139	43	77	9	8	6	29	4	29	38	49	6	21	24	21
	2000	6 100 780	47	77	11	7	5	38	6	22	34	56	8	16	20	
	2011	6 950 721	52	80	13	4	3	47	9	16	28	64	11	10	15	

Figure 1-6 Use of sanitation facilities in Ghana and relevant regions (Data from UNICEF/WHO JMP 2013)

The most noticeable differences between Ghana and other similar regions are Ghana's unusually low rate of improved sanitation and its unusually high rate of shared sanitation. Still, while these categories are useful for measuring progress made in the sanitation sector, it is important to remember that sanitation is not a black and white issue. That is, just because Ghana is struggling to expand its improved sanitation coverage does not mean that its sanitation experts have their priorities misaligned. For example, shared sanitation coverage rose from 29% in 1990 to 59% in 2011. This data implies that, rather than focusing on ensuring that each Ghanaian family has an unshared improved facility, a focus has been placed on the installation of public and shared facilities. While this does not increase the improved sanitation rate, it is likely a more efficient means of decreasing the open defecation and unimproved sanitation rates. In this way, it appears that Ghana is progressing along the sanitation ladder with a step-by-step approach in order to give a wider group of people access to some type of sanitation, albeit unimproved by United Nations definitions. Still, the rapid rise of shared facilities raises some questions, as will be addressed in the next section on the economic impacts of poor sanitation in Ghana.

1.3.1 Economic Impact of Poor Sanitation in Ghana

It is estimated that Ghana loses US$290 million per year due to poor sanitation. In 2012, when this study was conducted, this was equivalent to 1.6% of the nation's gross domestic product. The majority of this, US$215 million, is lost as a result of premature death. Each year, 19,000 Ghanaians die from diarrhea, and approximately 90% of these deaths are preventable with proper sanitation, water, and hygiene. An additional US$54 million is spent on health care for diseases attributed to poor sanitation. The remainder of the lost cost stems from productivity losses. Each person who practices open defecation spends approximately 2.5 total days per year seeking out private areas to defecate. This amounts to US$19 million lost per year, and this loss falls disproportionately on women. Another US$1.5 million is lost due to productivity time lost while ill from diarrhea that is preventable with proper sanitation. Not included in these numbers are the costs of funerals, cholera cases, water treatment, inhibited cognitive development, and decreased tourism. It is estimated that these costs are greater than US$12.6 million per year (Water and Sanitation Program 2012).

The economic losses due to poor sanitation have the greatest impacts on the poor, creating a cycle of poverty and poor sanitation. Because most sanitation advances require an investment, and the poorest Ghanaians lack the collateral necessary for loans, it is very difficult for the poorest Ghanaians to obtain improved sanitation facilities (Osumanu 2008). Also, the poorest 20% of Ghanaians are 22 times more likely to practice open defecation than the richest 20% and thereby are far more likely to have contact with human excreta and contract diseases (Water and Sanitation Program 2012). Figure 1-7 shows the cost per capita of unimproved sanitation as a percent of income by wealth quintile.

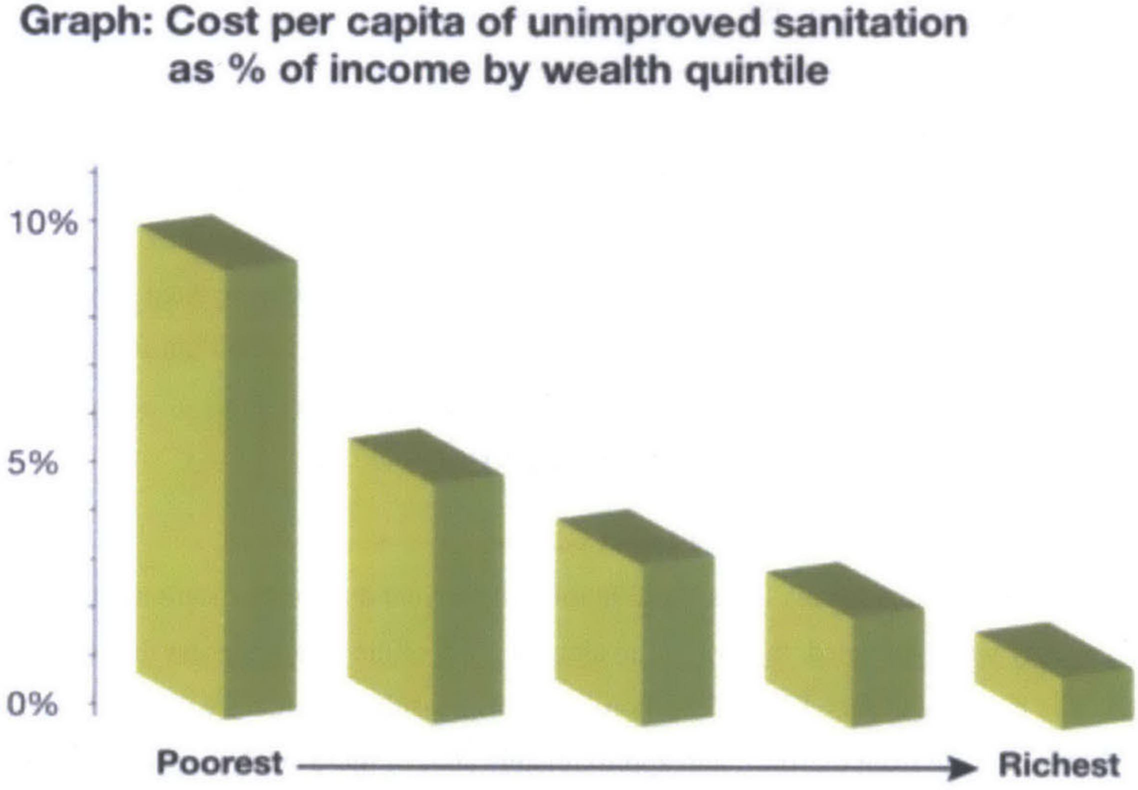


Figure 1-7 Cost per capita of unimproved sanitation as a % of income by wealth quintile in Ghana (WSP 2012)

Finally, as mentioned in the previous section, although shared facilities do separate excreta from human contact and so have one of the important characteristics of improved sanitation, they are not necessarily considered improved by UN definitions because of lack of cleanliness, which is a common problem. The results of a WSP study are shown in Figure 1-8 and indicate that open defecation has the greatest cost per user at US$17 per person per year due to lost access time. However, shared facilities actually have the greatest costs due to mortalities and healthcare, which signifies that they actually may be less sanitary than even open defecation due to their many users. Given Ghana's recent rise in shared facility usage, this is alarming and may be a point for consideration in future planning (Water and Sanitation Program 2012).

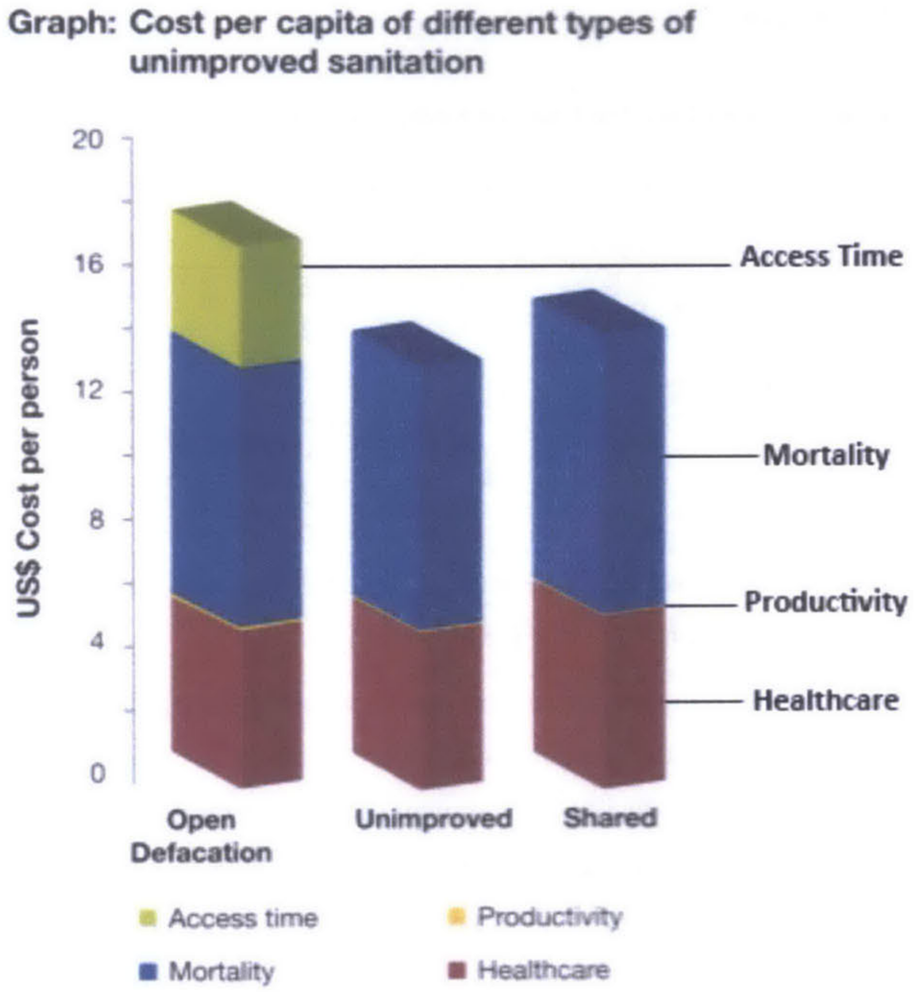


Figure 1-8 Cost per capita of different types of unimproved sanitation (WSP 2012)

1.3.2 Urban Sanitation in Ghana

The majority of the sanitation innovations that are reviewed within this thesis are urban projects that are located within Accra, Kumasi, and Tamale, the three largest cities in Ghana. The populations of these cities are 1,848,614, 2,035,064, and 371,351, respectively (Ghana Statistical Service 2010). The most recent available statistics for access to toilet facilities within these regions are listed in Table 1-1. These statistics can be compared to the JMP statistics, which estimate the national open defecation rate to be 18%, the rural population's open defecation rate to be 32%, and the urban population's open defecation rate to be 6% (WHO/UNICEF 2013). This information may also be used to identify suitable markets towards development of a model for successful sanitation in a given city such as Tamale, where the open defecation rate is 30.7 percent.

Table 1-1 Types of toilets found in Ghanaian cities (Data from Ghana Statistical Survey 2005)

Type of Toilet Facility	Accra	Kumasi	Tamale	Urban Ghana
Flush toilet	30.5	35.7	6.1	20.6
Covered Pit-Latrine	7.7	15.5	1.7	13.9
VIP/KVIP	48.7	38	51.8	46.6
Bucket/pan	10.3	2.6	9.4	4.6
Uncovered pit latrine	0.9	0.8	0.5	4.1
Bush	2.1	7.3	30.7	9.6
Others	0.1	0.1	0.5	0.6
Total	100	100	100	100

1.3.3 Privatization of Public Sanitation Facilities in Ghana

Before the early 1990s, sanitation in Ghana was dominated by the public sector, and the government was held responsible for the poor condition of sanitation services. Urban overcrowding of the mid-1980s strained the government's sanitation resources, and the Government of Ghana faced severe budget problems in the early 1990s. As a result, the government allowed municipal and metropolitan assemblies to privatize water and sanitation in order to relieve these burdens. Many did pursue this option in the 1990s in order to take advantage of the lowered prices and new technologies that were expected to result from private sector competition. For example, Tamale allowed privatization of sanitation and water services in 1996, and now all 146 public toilets in the city are privately owned (Osumanu 2008).

However, for many reasons, this privatized system has not provided the benefits that were anticipated. First, within this privatized system, the government was supposed to maintain a regulatory role. However, this regulation is very ineffective because government responsibilities with respect to sanitation are fragmented across a number of government institutions, and enforcement has been lacking. Second, private investors were far keener to enter into the water sector than the sanitation sector because sanitation has a lower level of cost recovery and profit than the water sector (Osumanu 2008). Also, work with sanitation is stigmatized with a sense of disgust due to the handling of human waste. In the end, privatization of sanitation in Ghana has been problematic because it began out of desperation rather than out of opportunity. Third, when the privatization of public toilets took place, there was not a bidding process for the contracts, but instead contracts were awarded to supporters of political leaders. Fourth, privatization intrinsically assumes that users of public toilets are customers rather than partners in development (Osumanu 2008). Additionally, evidence indicates that a planning window of 10-15 years is necessary for sanitation projects, but entrepreneurs and NGOs actually use an average planning window of 2-3 years (Watkins 2006). Finally, the public toilet fees did not decrease with privatization as was expected. Rather, the prices for toilet usage increased because service providers had to bribe officials to connect to water networks, have to pay high tariffs to water companies, and often do not possess enough collateral to access loans for new infrastructure (Osumanu 2008).

Still, privatization of sanitation can work. In fact, Cote d'Ivoire, Guinea, and Senegal have successfully achieved it (Osumanu 2008). In order for privatized sanitation to work more effectively in Ghana, the Ministry of Local Government, Rural Development, and Environment must establish a better system of regulation, and sanitation must rise on the top of the political agenda (Osumanu 2008). Also, private investors must attempt to better understand what people value about improved sanitation within the context of local cultures in Ghana and why they value it (Watkins 2006). As will be shown in the case studies in chapters 3-6, it appears that people value convenience/proximity to home most and odor repression/cleanliness second. Cost and type of toilet are lesser concerns in urban settings and greater concerns in rural settings where adoption of toilet use is a concern. Toilet planning and management should reflect these values.

1.4 Privatized Sanitation Innovations in Ghana

Despite its challenges in the sanitation sector, Ghana is a peaceful nation with a vibrant democracy, and, if it can overcome these challenges, it is plausibly on the verge of rapid progress. Because of this, there has been a recent wave of projects and innovations addressing these water, sanitation and hygiene (WASH) challenges in Ghana. In 2013, Master of City Planning graduate students from the MIT Department of Urban Studies and Planning, together with two fellows (Fulbright/Humphrey-MIT and Loeb-Harvard), under the supervision of MIT Senior Lecturer Susan Murcott, did a field survey during January that included visiting and evaluating several innovative sanitation projects in Ghana. Most of these projects are part of the

Bill & Melinda Gates Foundation's Water, Sanitation & Hygiene program, which emphasizes the development of technical solutions that can lead to radical and sustainable improvements in sanitation in the developing world. The MIT Urban Studies and Planning team found that these projects were facing serious challenges in terms of management, application of technologies, and cultural obstacles. However, it was expected that these challenges could be overcome with better use of participatory planning and design and with greater attention to sanitary/environmental engineering fundamentals. These projects are summarized in the following sections, and their locations are highlighted in the map in Figure 1-9.

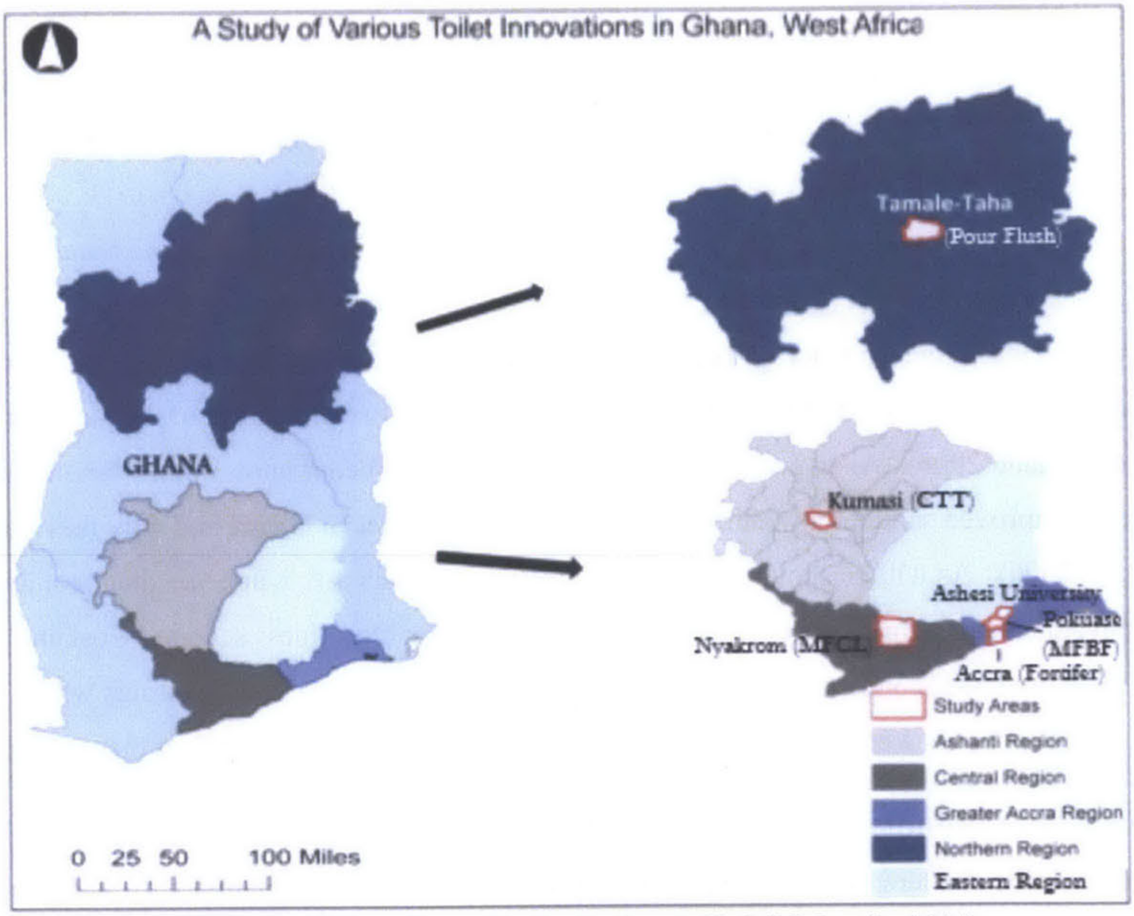


Figure 1-9 Locations of technologies studied (Mubambe 2014)

1.4.1 Clean Team Toilets

The Clean Team Toilets project is based in Kumasi, Ghana and provides pre-fabricated urine-diverting portable toilets to homes on a subscription fee basis. Upon delivery, these plastic toilets are filled with biocide and chemicals that reduce odor. Solid waste is deposited into this chemical-filled basin, while urine is diverted outside the home or into a plastic container with the use of a urine-diverting toilet seat. A "Clean Team" regularly seals and collects the buckets of waste from homes, replaces them with new clean buckets, and empties the used ones at a central collection point (Tanner 2013). This process is depicted in Figure 1-10.

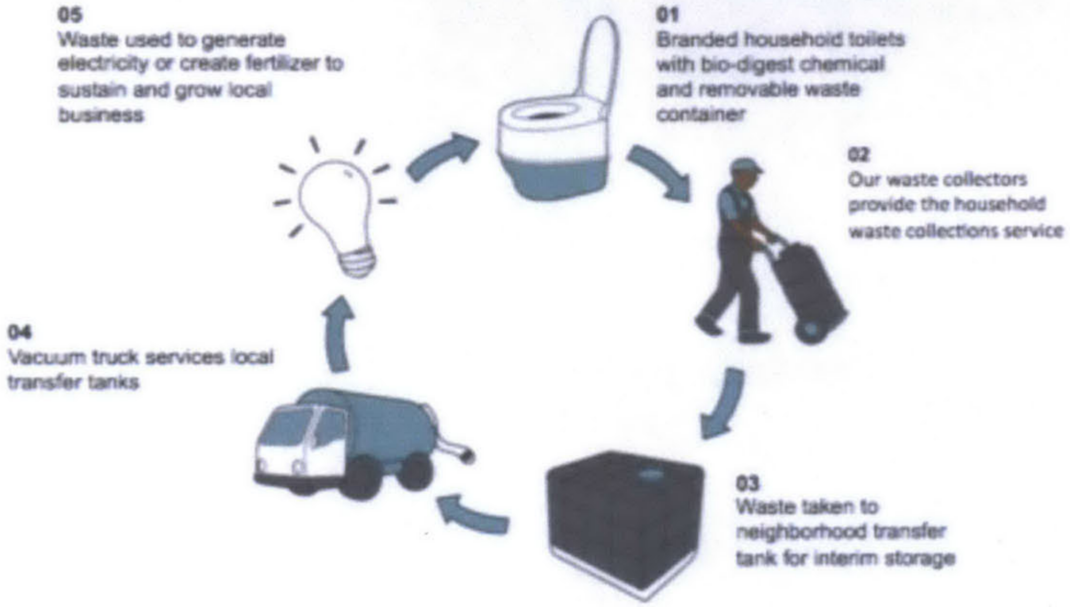


Figure 1-10 Clean Team Toilet operation process (CTT 2014)

1.4.2 Microbial Fuel Cell Latrine

The Microbial Fuel Cell Latrine, located in the small town of Nyakrom outside of Accra, composts waste to be used as a soil additive just as the Microflush/Biofil Toilets, described next, do. However, it is unique in that it uses this waste to produce electricity while it is drying. The pit acts as a fuel cell, using the organic matter as the fuel and the nitrates (which are created by bacteria that consume the waste) as the oxidant. The organic matter is oxidized at an anode, while the ammonium from the urine is denitrified into nitrates, which are reduced at a cathode. This process produces electricity to power the facility's light at night, making it safer to use. The Microbial Fuel Cell Latrine, shown in Figure 1-11, was developed by the University of Massachusetts-Amherst and Arizona State University (Tanner 2013).

Figure 1-11 Rear side of the Microbial Fuel Cell Latrine, showing electricity-generating technology

1.4.3 Microflush/Biofil Toilet

The Microflush/Biofil Toilet design, shown in Figure 1-12, was developed by Kweku Anno and Stephen Mecca of Providence College and was been piloted in Pokuase, a suburb of Accra, Ghana. Since its development, the pair has separated, and now Anno's Biofilcom company in Djorwulu, Greater Accra produces a different variation of the design called the Biofil Toilet, and Mecca's Global Sustainable Aid Project (GSAP) produces a variation called the Microflush Toilet in Pokuase, Greater Accra. The original toilet design reuses greywater that has been used for hand washing, which is then used to flush the toilets. The Biofil toilets have maintained this feature, but the Microflush Toilets have eliminated it in order to reduce costs. After flushing, the waste is sealed away from human contact by a valve, and it composts, with the assistance of vermiculture, for two years in a pit before it is removed for use as fertilizer. The system promotes hand washing by requiring water to run through the sink in order to flush the toilet.

Figure 1-12 Inside of the public Microflush Biofil facility, where the sink connects to the toilet to provide grey water for microflush

1.4.4 Taha Islamic Kindergarten Pour-Flush Toilet Block

Pure Home Water and the MIT Public Service Center donated a sanitation block, shown in Figure 1-13, to the Taha School 5 kilometers east of Tamale, Ghana in June 2013. It was designed and constructed by MIT Master of Architecture student John Maher with collaboration from Pure Home Water and the skills and labor of 4-10 men from Taha over a period of 30 days. This toilet block contains six pour-flush toilets that drain into a septic tank. In the original configuration, three of the seats were for use by males, and three were for use by females. However, the case study in the sixth chapter of this thesis revealed problems with adoption of the toilets due to this configuration. As a result, after January 2014, the configuration was modified such that there is now a “school side” and a “community side” to the toilet block, with each side further divided by gender.

Figure 1-13 Taha pour-flush school block

1.4.5 Ashesi University's Small-Scale Wastewater Treatment System and Anaerobic Digester

Ashesi University, located in Berekuso, Ghana in the Northern outskirts of Accra, constructed a small-scale, on-site wastewater treatment system in order to prevent their untreated wastewater from running downhill into the pineapple fields and water supply of the village of Berekuso. This wastewater treatment system features an 80 m^3 anaerobic waste digester, primary and secondary clarification tanks, an aeration tank, and two chlorination tanks. The recovered biogas is used to power cooking stoves in the kitchens of the Ashesi canteen, and the treated water is used as irrigation water for the campus gardens (Figure 1-14).

Figure 1-14 Ashesi University's methane collection system, attached to their anaerobic digester

1.4.6 IWMI's Fortifer Pellets for Agriculture

The Recovery of Organic Matter and Nutrients from Fecal Sludge for Food Production in Ghana project, or Waste to Food (WaFo), is a project that converts excreta into sanitized fertilizer pellets (Figure 1-15). Funded by the International Water Management Institute and the Bill and Melinda Gates Foundation, this project has focused on the optimization of the pellets' composition, but it is now beginning its commercialization stage in Tema, Greater Accra. This technology prevents waste from entering the environment by removing it through drying and composting processes. It also incentivizes this process by reclaiming valuable nutrients that can be used to generate a profit.

Figure 1-15 Two researchers produce fertilizer pellets from composted fecal sludge

2 Methods

2.1 Triangulation: A Solution to Biased Responses on the Sensitive Topic of Sanitation

An individual's access to sanitation is closely tied to his/her senses of privacy and dignity, and sanitation coverage is therefore a very sensitive topic. Because of this, obtaining accurate information regarding sanitation coverage and behaviors related to sanitation is quite difficult. In surveys and interviews, it is easy for participants to give inaccurate "courtesy" responses in order to please the interviewer or save themselves from feelings of shame, especially if they practice open defecation (Hernandez 2010). As an example, during interviews for this thesis in the Taha village outside of Tamale, Ghana, a series of questions were asked in order to determine whether or not a pour-flush toilet facility was being used. Households near the toilet were interviewed and asked, "Do you use the pour-flush toilet located by the Taha pre-school? If so, how often?" Of the seven homes nearest to the toilet, six households claimed that their family members use the facility at least twice per day. In order to check the validity of the responses, the author returned to Taha the next day to observe and count the number of individuals who used the toilet from 6:00 – 9:30 AM, for the early morning is peak time for public toilet use in Ghanaian culture, according to interviewees. Only one individual, who was visiting from another city, used the toilet during this time, suggesting that the interview responses were biased due to the sensitive topic of sanitation.

This revealed the need for triangulation of data. Triangulation is the use of multiple study methods and/or data sources in order to cross-verify collected data. This provides a picture more representative of reality, demonstrates the level of uncertainty in collected data, and reveals qualitative information on the reasoning and decisions of interviewees. This qualitative information is essential for evaluations of sanitation facilities, for it reveals the inconsistencies between the beliefs, practices, and desires of latrine users and those of the latrine's management personnel. This qualitative information also informs decision-makers on how to best solve problems of sanitation. After all, especially in the sanitation sector, challenges are more cultural and behavioral than technical. Therefore, the best engineering solutions cannot be reached without thorough examination of cultural and behavioral issues.

2.2 The Case Study Method

While triangulated information does provide a more robust, accurate picture of reality, it can be difficult to analyze because it comes in many different forms, both qualitative and quantitative. For this reason, a flexible study method must be used when triangulation is necessary. The case study method provides this flexibility, allows for contextual analysis, and also facilitates the evaluations of several different technologies, some of which are prototypes. For these reasons, it is the method used to evaluate the innovative sanitation technologies examined in the following chapters.

A case study is "a story about how something exists within a real world context that is created by carefully examining an instance" (CAPAM 2010). A field case study is a type of case study in which original research is done within the context being studied (CAPAM 2010). For this thesis, a field case study of each of the sanitation innovations listed in the previous chapter was carried out in order to obtain generalizable conclusions on each technology. These conclusions were then put into an evaluation matrix in order to score the technologies on a numeric scale.

Each chapter on decentralized sanitation technologies begins with a technological overview of the toilet under consideration. This is followed by the case study, which is presented in four sections. The first section, Context, describes the area and culture in which each technology was implemented and studied. The second, Strategy, describes how the technology was implemented and the reasoning behind the decisions of those who implemented it. In the third section, Outcomes, the results of user surveys and other data are presented and analyzed. Finally, in the Discussion Points section, the facility is evaluated and recommendations are made for future implementations of the technology.

The two chapters on centralized sanitation projects, the Fortifer project and Ashesi's wastewater treatment system and digester, are structured in a slightly different manner, for they seek to present solutions to specific target problems. For this reason, these chapters begin with the Context section, in which the target issues in question are explained. Then, a Strategy section follows. This section contains both the technical and business strategies used to address the target problems. An Outcomes section presents any results from the implementation of the technology, although surveys were not applicable for the centralized technologies. Lastly, recommendations are made for future implementation and further development of the technology in the Discussion Points section.

2.3 Determining and Defining Indicators for Successful Sanitation

The first step in a case study is "determining and defining research questions" (Soy 1997). Through an intensive literature review and collaboration with MIT Senior Lecturer Susan Murcott and Alyse Schrecongost of the BMGF, research questions and topics were defined in the form of a list of indicators for successful sanitation. A literature review of existing sets of indicators for successful sanitation revealed that indicators are typically organized within a system of categories including sanitation outcomes, business/financial management, and technology. These general categories were adopted and then further refined by defining a list of indicators adapted from the USAID Access and Behavioral Outcome Indicators (2010), the ENVISION Sustainability Rating System (*Envision*... 2013), recommendations from WEDC Well Fact Sheets (Loughborough University 2014), the Ghanaian Demographic Health Survey's Ghanaian Multiple Indicator Cluster Survey (2011), Amparo Flores's Ph.D. thesis *Towards Sustainable Sanitation*: Evaluating Sustainability of Resource-Oriented Sanitation (Flores 2010), and the USAID/Rotary WASH Sustainability Index Tool (USAID/Rotary 2013). The indicators were then reviewed by scholars in the sanitation field. The final set of indicators used for this project is displayed in Appendix A.

2.4 Data Collection Methods

The second step in a case study is to "select the cases and determine data gathering and analysis techniques" (Soy 1997). The six cases to be studied were listed in sections 1.4.1 to 1.4.6. The data gathering techniques have been varied in order to maximize the benefits of triangulation. In this study, data has been triangulated using participant counting/observation, user surveys, inspections, and interviews of latrine managers and government officials where applicable and feasible. Each of these data collection methods is further explained below.

2.4.1 Participant Counting/Observation

For public and shared toilets, participant counting/observation is a useful tool for estimating the number of users of a given facility. In order to conduct participant counting, the author and Mubambe positioned themselves in a conspicuous location outside each sanitation facility in the sample set and counted the number of users over a given period of time. Also recorded were each user's gender and whether he/she was a child or an adult. These studies were originally conducted between 1:00-1:30 PM. However, through interviews, it became apparent that it is the cultural norm to use public toilets in the morning, with a high number of users arriving around 6:00-8:00 AM. Therefore, observation/counting sessions were also conducted beginning at 6:00 AM and ending at 8:00 AM or later, where noted. Inspections of the toilet facilities' conditions, both in hygienic and technical senses, were conducted as well.

2.4.2 User Interviews

In addition to counting users and recording their gender and age groups, user interviews were conducted. The interview questions, displayed in Appendix B, are based on the indicators for successful sanitation that were identified in the evaluation criteria (Appendix A). In order to further overcome the temptation of research participants to give false answers on this sensitive topic, a method adapted from the Bayesian Truth Serum was used to further triangulate responses (Prelec 2004). In this method, direct questions about the respondent's behavior were followed by questions about his/her neighbors' behaviors. For example, question 2A asks how often the respondent uses the toilet facility under evaluation. This response, and the response of other users, can be compared with the response to 2B, which asks how often the respondent's neighbors use the facility. If the vast majority of respondents claim to use the toilet daily but also claim that their neighbors never use it, a level of uncertainty in the data can be inferred.

Because the total number of daily users was not possible to predict or measure during my limited time at each study location, it was not possible to determine a statistically relevant sample size. Rather, as many user surveys as possible were conducted, and responses that were given by a considerable majority were used in the case study write-ups in subsequent chapters. Sample sizes were 17 for the Microbial Fuel Cell Latrine, 15 for the Microflush/Biofil Toilets, and 7 for the Taha Islamic Kindergarten Pour-Flush Facility. User interviews were not feasible for the Clean Team Toilet case study because the toilets were in homes, so it was difficult to determine which houses subscribed to the service and which did not. User interviews were not applicable for the centralized technologies.

2.4.3 Interviews of Service Providers and Government Officials

The final piece of the triangulation was interviews with latrine/sanitation business managers and government officials, where applicable. The interview questions are displayed in

Appendix C, although not all questions were applicable to each sanitation technology evaluated, nor did every respondent have an answer to every question. These interviews focused on the feasibility, maintenance, and success of each technology as well as the business management strategies and financial aspects of the projects. The final section on sanitation outcomes is used to validate responses from users.

3 Clean Team Toilets

3.1 Technological Overview

Clean Team Toilets (CTT) is a subscription-based sanitation service managed by partners from the corporation Unilever, the design firm IDEO.org, and the NGO WSUP (Water and Sanitation for the Urban Poor). CTT loans a portable plastic toilet to each of its subscribers. Inside each toilet is a plastic bucket that fills with waste until it is collected by a member of the Clean Team, who replaces the full bucket with a new one. The waste is then taken to a central location where the buckets are cleaned and the waste is deposited into a holding tank. This process is depicted in Figure 3-1 below (CTT 2014).

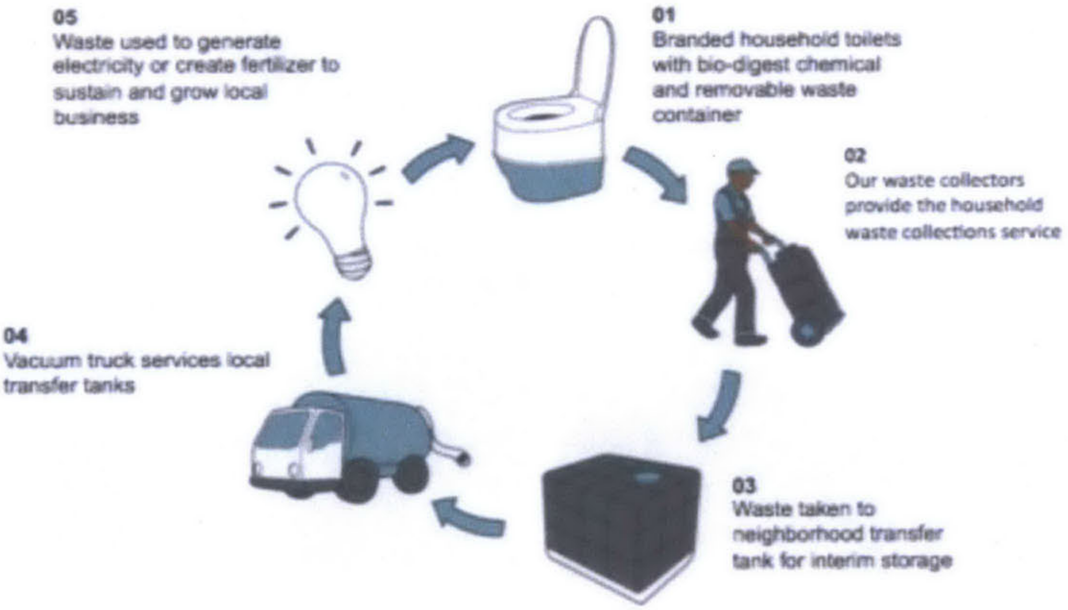


Figure 3-1 CTT's operation model (CTT 2014)

3.1.1 Toilet Unit

The Clean Team Toilet, shown in Figure 3-2, is a portable, molded plastic toilet that features a removable top and urine diversion. Removal of the top of the toilet reveals the bucket hidden within. The CTT buckets were originally white, but they have since been changed to black in order to better mask the sight of waste. Each bucket has a sealable lid that is screwed on before the waste is transported. In order to slow the accumulation of waste and allow for less frequent collection, each toilet features a urine-diverting seat (Figure 3-2). Because of this, instead of filling the bucket with liquid waste, the urine exits the toilet through a hose. In the past this urine was discharged outside into the open sewer gutters or into the ground. However, Clean Team has begun to collect the urine in containers in order that they might sell it for use as a fertilizer in the future (Yeboah 2014). Urine does hold potential as a marketable fertilizer and is examined further in Chapter 8.

Figure 3-2 The Clean Team Toilet, featuring urine diversion through the front of the toilet and a hose

The Clean Team Toilets are currently manufactured in China, but CTT has molds in Ghana and is searching for a manufacturer in Kumasi or Accra. The toilets cost approximately GHS200 (US$91)* each, plus import duties and shipping costs. Currently the importation of toilets is handled by Unilever, a sponsor of the program (Aruna 2014).

Within each bucket is a biocide called One Shot Cherry (Chemical 4) that disinfects deposited waste, thereby limiting risk of pathogen transmission between users. Each bucket is filled with 75mL of One Shot Cherry (Chemical 4) and 5 L of water (Gyamfi 2014). The main ingredient of One Shot Cherry (Chemical 4) is pentane-1,5, also known as glutaraldehyde, which

*US$1 = GHS 2.20 (Jan. 2014)

is an effective sterilizing agent. However, glutaraldehyde has a fairly strong odor, and inhalation of glutaraldehyde vapors can induce throat and lung irritation, asthma episodes, breathing difficulty, sneezing, and wheezing (CDC 2012). Because glutaraldehyde is a rather high concentration of the biocide, 5-10%, CTT denies service to customers who lack a well-ventilated room in which the toilet may be placed (Yeboah 2014). A secondary biocide, Bronopol, or 2-Brono-2-Nitropropane-1,3-Diol, is also in the CTT biocide, but this substance is less concentrated, at <5%. Its MSDS also contains warnings that it may be irritating if inhaled (Spectrum 2008).

Additionally, problems with reuse of waste for fertilizer and electricity production are complicated because One Shot Cherry (Chemical 4) is such a large fraction of the final sludge's volume. At the time of publication, alternative biocide options were being researched by CTT in collaboration with Cranfield University (Aruna 2014). The MSDS for One Shot Cherry (Chemical 4) can be found in Appendix D.

3.1.2 Collection Process

Depending upon family size and ability to pay, subscribers' toilet buckets are collected by Clean Team workers two to four times per week. The Clean Team travels with push carts or tuk-tuks, which are small three-wheeled motorized carts, from house to house, collecting used buckets and leaving new ones in each subscriber's toilet. As they collect the buckets, they bring them to curbside "transfer stations," where they accumulate before being taken to the larger central processing point (Yeboah 2014).

At the central processing point, used buckets are emptied into a large Poly-tank and then are washed with water and disinfectant by a worker garbed in protective clothing. In order to avoid problems with intermittent piped water supply, CTT contracts tanker trucks to regularly fill their Poly-tanks with water. The central collection point uses approximately 8000 liters of water per week in order to serve 500 toilets, or roughly 16 liters of water to service each toilet each week. According to members of the Clean Team, approximately one liter of water is used per bucket wash, and each bucket is refilled with a five-liter solution of biocide and water before being returned to circulation (Yeboah 2014). The turnaround on bucket cleaning and refilling is quick; there are three buckets for every two toilets in service, and about 40 percent of the buckets are collected on any given day (Aruna 2014). The collection process is shown in Figures 3-3 to 3-5.

Figure 3-3 A Clean Team waste collector exchanges a used bucket for a new one at a subscriber's home. This particular toilet is an older model.

Figure 3-4 Waste collectors gather used buckets at a curbside transfer location before taking them to the central processing location

Figure 3-5 The central processing location. Here, buckets are emptied into polytanks for holding until a vacuum truck transports the sludge to Dompoase. Clean Team members disinfect the buckets before recirculation.

3.2 Case Study

3.2.1 Context

CTT began pilot operations in 2010 in Kumasi, Ghana, which is shown in Figure 3-6 below. Although since 2011 CTT has operated as a business, it is not yet generating a profit and therefore relies on funding from the Stone Family Foundation and the UK Department for International Development (Yeboah 2014). Because of WSUP's involvement, the focus of CTT is on the urban poor. However, their clients are primarily traders and businessmen/women who are not monetarily poor but rather are poor in the sense that they lack sanitation (Aruna 2014).

CTT currently operates in nine main services areas in the Northwest quartile Metropolitan Kumasi, as is shown in Figure 3-7. These are Ashtown, Manhyia, Alabar, Akwatialine, Sabon Zongo, Asywasi, Aboaso (Two sites), Dichemso Bramposo. The project began in Ashtown, where, due to a history of use of unimproved bucket toilets, many of the houses had existing specified toilet rooms. After finding success there, the business expanded to other areas (Aruna 2014).

Before CTT existed, most of the service areas depended upon public toilets, bucket toilets, or flying toilets (Yeboah 2014). Bucket and flying toilets are forms of sanitation in which the user defecates into a container, which is typically a bucket or bag, and disposes of it in this streets or environment. While the public toilets provided better consolidation of waste, many of

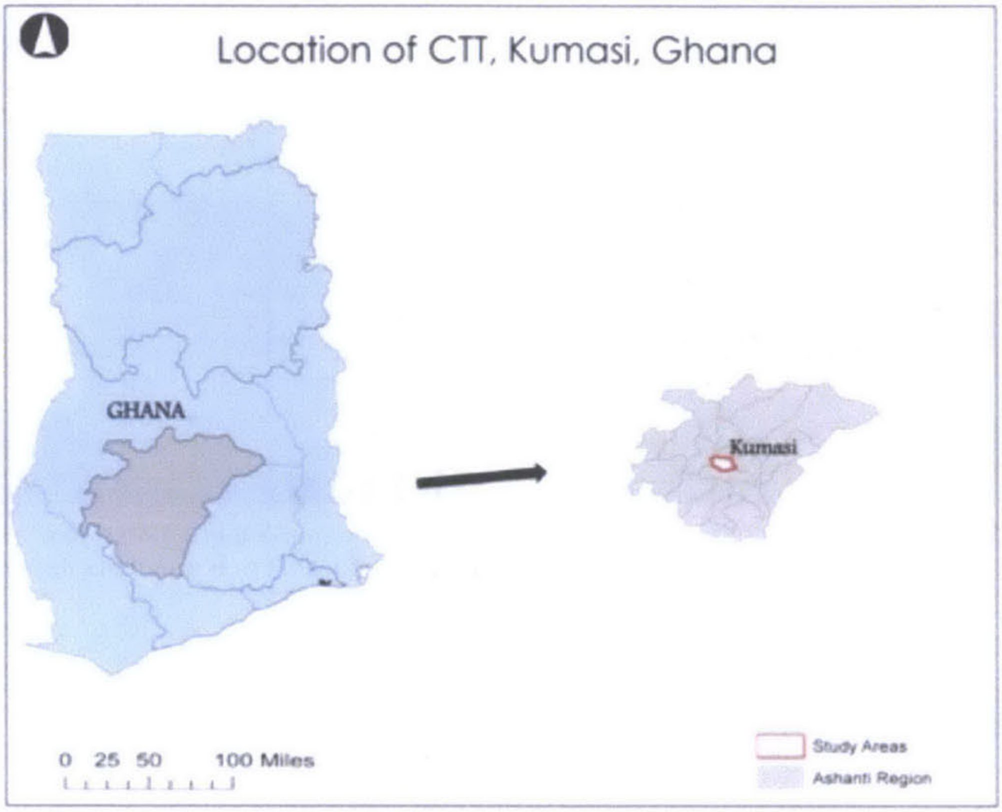


Figure 3-6 Location of CTT, Kumasi, Ghana (Credit: Knutson and Mubambe 2014)

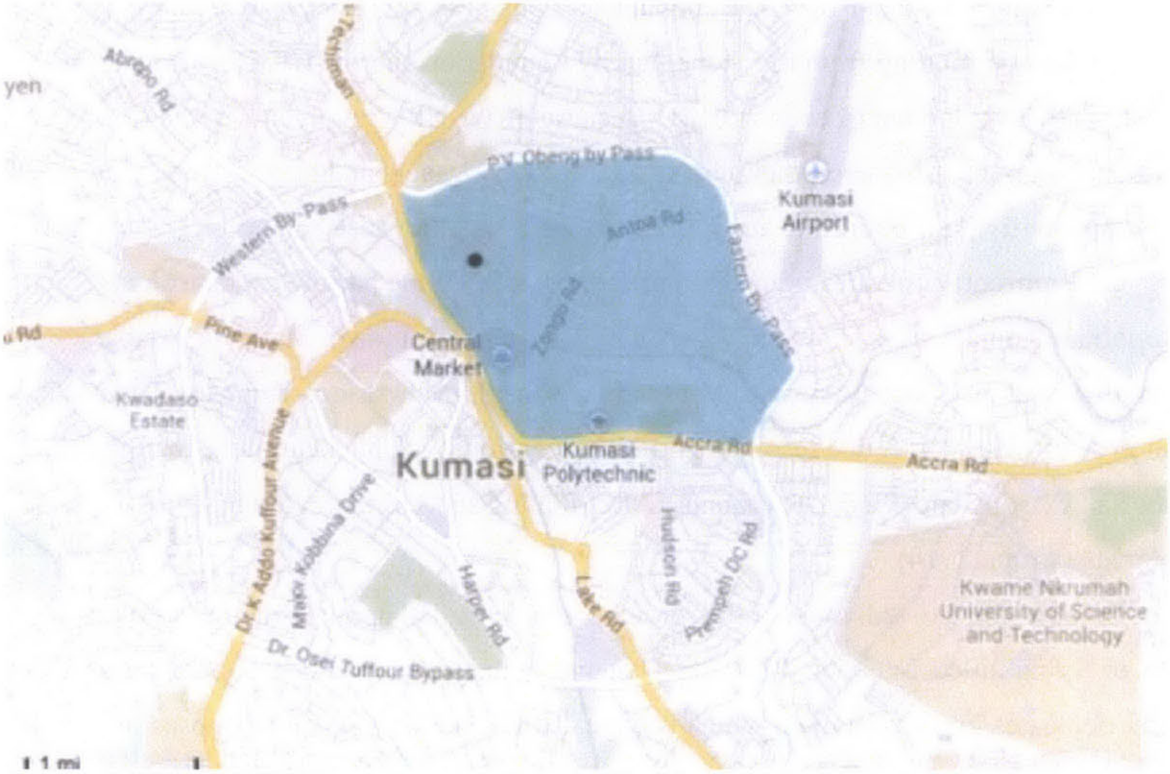


Figure 3-7 Map of CTT's service area, in teal. The black dot is the central collection point in Ashtown

them are poorly maintained, unsanitary, and sparsely located. Figure 3-8 shows the conditions of eight of the public toilets in CTT's service area. Homes that are far from the clusters of public toilets benefit most from CTT subscriptions, for they save both the greatest amount of time and money by not having to travel to defecate.

Kumasi does have a sewer system with three wastewater treatment plants, but these plants can only handle wastewater from approximately one thousand homes (CTT 2014). Because Kumasi has a population of 2,035,065, nearly all the wastewater in the city remains untreated (Ghana Statistical Service 2010). This poses a problem for CTT as it attempts to dispose of its waste as well.

Figure 3-8 A look in on the condition of public sanitation in CTT's service area in Kumasi

3.2.2 Strategy

3.2.2.1 Revenue and Marketing

The strategy of CTT is to scale through return-seeking capital. Its subscription service provides a steady, sustainable flow of revenue, allowing for continued growth and confidence in management. As a subscription service, the Clean Team offers three options for regular collection of waste to its customers based on their ability to pay and their family size. As is shown in Table 3-1, smaller families or groups of users require less frequent collection than larger families, and the monthly subscription fee is accordingly lower. The collection frequencies listed in the figure are minimums; that is, a family of seven could opt to pay for either three or four collections per week, but it would not be allowed to subscribe for the twice per week collection option. An additional restriction is that the option for two collections per week is only available for homes that will place the toilet in a non-enclosed space. This is done in order to prevent irritations resulting from the glutaraldehyde (Yeboah 2014).

Table 2 Price and collection frequency intended for different family sizes

Family Size	Collections per week	Monthly Price (GHS/US$)	Original Price (GHS/US$)
0-5	2	25 / 11.36	15 / 6.82
5-10	3	35 / 15.90	20 / 9.09
10-15	4	45 / 20.45	N/A
	Everyday	No longer available	25 / 11.36

These subscription plans may initially seem expensive, but they actually represent savings for all households with more than three residents. Based on the survey of public toilets in the CTT service area, the average fee for public toilet use is GHS 0.22 (US$0.10)* per use. If each household member uses the toilet just once per day, this equals GHS 6.60 (US$3.00) per month per person. Figure 3-9 represents the costs of CTT and public toilets in Kumasi in terms of number of users. As expected, the greater the household population, the greater the savings provided by CTT.

IDEO.org has handled the branding of the product, but CTT does not currently have an aggressive advertising campaign because the demand for their product far exceeds their ability to supply toilets, as will be explained in the next section. For this reason, they do not air television, radio, or billboard ads. Rather, customer referrals, word of mouth, and door-to-door recruitment have proven to be sufficient strategies for expansion of their subscriber base (Aruna 2014).

A key component of CTT's marketing strategy is to maintain a desirable image despite the fact that waste handling is a business typically looked down upon in Ghana. Most of CTT's 26 employees work in the field; ten waste collectors, five sales/service associates, and three recruiters all travel in Kumasi, visiting subscribers and servicing toilets. In order to ensure their safety and protect their reputation, CTT pays their waste collectors competitive wages and has a

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*US$1 = GHS 2.20 (Jan. 2014)

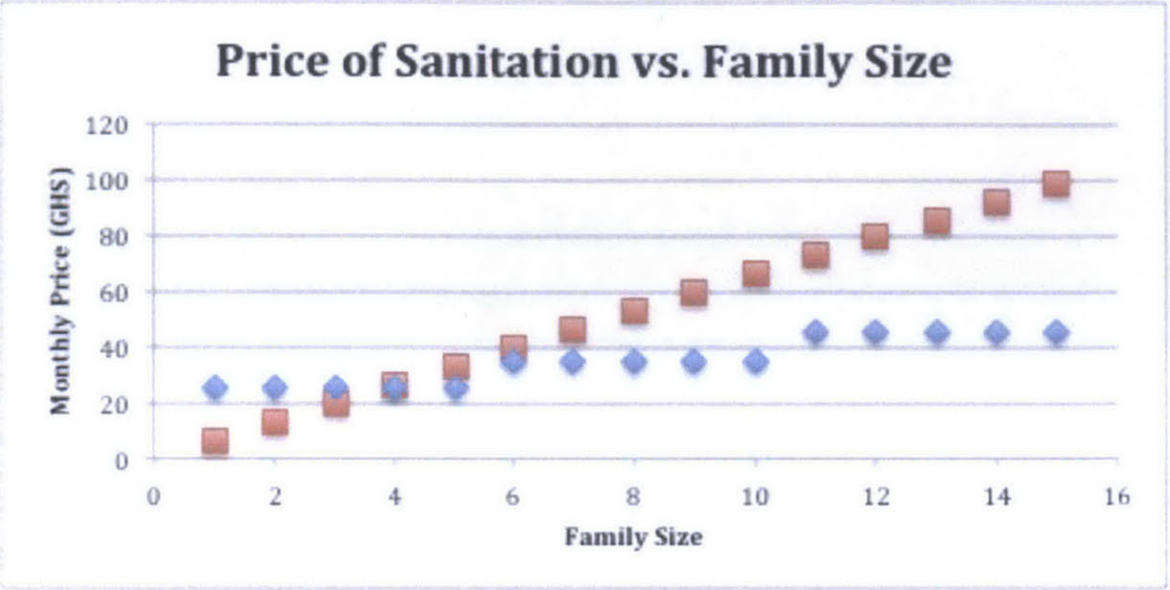


Figure 3-9 Price of Sanitation vs. Family Size. The blue data represent the CTT's price as a function of family size, while the red data represent the price of public sanitation in CTT's service area

strict, incentivized safety policy. Regular health checkups are arranged for all waste collectors, but there have never been diseases amongst the clean team. This could be attributed to the fact that CTT awards those who wear all safety gear and personal protection on a monthly basis, and those who do not are dismissed. In their efforts to further ensure the safety of their employees, CTT is creating machine/automated bucket cleaning for new central collection locations (Aruna 2014).

3.2.2.2 Plans for Growth

Currently, collected waste is transported to the Dompoase Metropolitan Waste Treatment Facility, where it undergoes natural treatment in man-made waste stabilization ponds (WSPs), as is shown in Figure 3-10. In this system, waste cascades through a series of artificial ponds, traveling from anaerobic to aerobic conditions. The first pond, called the anaerobic pond, acts as a simple settling tank, except that anaerobic conditions allow for degradation of organic waste by microbes (Manangi 2013). This step reduces the BOD, an indicator of organic matter, by 60-70% (Murcott 2014). The second pond is the facultative pond, in which algae and bacteria further degrade organic waste, reducing BOD by about 20% (Murcott 2014). The final pond, or maturation pond, is typically only around 1-1.5m deep, allowing sunlight to infiltrate to the

Figure 3-10 The waste stabilization ponds at Dompoase in Kumasi (Tanner 2013)

bottom of the pond. Here, aerobic processes reduce BOD by approximately 15%, nitrogen by 50%, and phosphorus by 80% (Murcott 2014). The wastewater is held within these ponds for a long residence period before being discharged a river. The treatment thereby results in a BOD reduction of just 70-80%, but it is a better alternative than direct discharge into rivers (Yeboah 2014).

In an effort to treat CTT's waste to a higher standard and to make CTT more self-sustaining, a partnership was formed between CTT and Waste Enterprisers to recover resources from the sludge with which a profit could be generated. The initial project was led by Bob Armantrout and was a combined effort of Columbia University, Waste Enterprises, the Kumasi Metropolitan Assembly, and the local Kwame Nkruma University of Science and Technology (KNUST). This project sought to generate biodiesel from collected sludge, but it did not continue after its pilot phase (Yeboah 2014, Tanner 2013).

Although this project did not prove to be feasible, CTT began a new experiment in February 2014 with Cranfield University to develop a new biocide that better controls odors, is more environmentally friendly and safe, and that does not impede recovery of resources from waste. Additionally, CTT is researching a dry system in which charcoal is used to cover waste instead of chemicals and the sludge is used to make cement. This project, if it proves feasible, will be piloted in Mumbasa in the near future (Aruna 2014).

Additionally, CTT has recently upgraded their toilet design to a simpler model, and they are in the process of decommissioning old toilets. After toilets are decommissioned, they are collected to be crushed and then sold to a plastic recycling company. Although crushing the toilets may seem wasteful, it is standard practice in order to prevent the toilets from being reused without proper waste collection. If this were to occur, the waste would likely be dumped into the environment, and biocide would not be used in the tank, resulting in unsanitary conditions both within the toilet and at the point of dumping (Aruna 2014).

3.2.3 Outcome

3.2.3.1 Results and Outlook

Clean Team Toilets began their pilot operations in 2010 with a group of 20 subscribers. After growing to 100 users, CTT opened as a business in April 2011. Since that time, they have experienced success and rapid growth, and, as of January 2014, the Clean Team served 3500 individuals through 500 toilet subscriptions, which is their maximum operating capacity. The Clean Team collected 180 metric tonnes of sludge over the course of 2013, which means each subscribing household generated over 360 kilograms of sludge over the course of the year (Aruna 2014).

Although CTT is currently operating at capacity, it has ambitious plans for expansion. According to the CTT operations manager, Abigail Aruna, the demand for CTTs is growing rapidly. In fact, approximately 120 of the 500 total subscriptions were added in December 2013, the month preceding this case study. Therefore, CTT must rapidly increase its supply in order to match the rising demand. To achieve this, CTT has set a target to achieve 7000 toilet subscriptions by the end of 2014. At the time of the case study, 2000 toilets were ready to deploy to new subscribers, but CTT lacked the ability to collect and process the waste from more subscribers. At that time, CTT had only one central waste-collection site in Ashtown and a "micro-site" cage where a very small number of buckets are treated. However, expansion of the Ashtown central site's capacity to more than 500 toilets was not possible because of size constraints and complaints from nearby residents regarding the smell. As a solution, CTT is planning the construction of four additional central collection sites by 2015 in order to increase the capacity to 10,000 toilets. These sites will feature automated machine cleaning of buckets in order to minimize health hazards of employees. The first of these sites, near the Dompaose Metropolitan Waste Treatment Facility, was to be completed in March. This plant is designed to increase the collection capacity by 2,000 toilets, and CTT is confident that the demand exists to meet this additional supply (Aruna 2014). In fact, CTT believes that the demand is great enough that 10,000 subscriptions may be in place by early 2015, assuming that the four central collection points are constructed on time. Once the CTT model has been proved by reaching the target of 10,000 subscriptions in Kumasi, CTT will look to expand to Accra and other African countries (Aruna 2014).

3.2.3.2 Collection, Response to Price Increase, and High Delinquency Rates

Although nearly every home observed was able to afford electricity and cable, CTT's payment collectors reported problems with high delinquency rates. CTT has a policy of allowing a one week grace period for late payments. However, if a subscriber is delinquent by 1-2 months, CTT takes the toilet and terminates the contract. In order to help subscribers to manage the monthly fee, CTT offers weekly payment collections in addition to monthly plans for no extra charge (Yeboah 2014).

At the end of CTT's trial period in April 2011, the subscription prices were increased in order to shorten the time needed in order for CTT to generate a profit. At the original price, it was predicted that 5000-10,000 subscribers would be needed before a profit was generated. At the new prices, CTT should generate a profit at 1500-2000 subscriptions. Upon raising the prices, CTT lost some subscribers, but the majority agreed to pay the higher rates. The rates for original subscribers were adjusted once the new toilet models were delivered to them. Interviews with users suggested that subscribers placed a high value upon not having to go out at night to use the public toilet and realized the monetary and time savings and convenience that the CTT provided (Aruna 2014).

3.2.4 Discussion Points

CTT has proven to be a successful model within Kumasi. Because the area is so densely populated and developed, vacuum trucks cannot always access pits or septic tanks for draining. Therefore, the service-based method of CTT is a preferable alternative. Additionally, Ashtown, where CTT began, traditionally used bucket toilets before public toilets were introduced. This made CTT a strong cultural fit and led to quick adoption of the model. CTT may also be a strong option for sanitation in areas where digging latrines is not possible due to geology or flooding, as long as the area is dense enough for the waste collectors to work efficiently.

However, CTT does not seem to be a universal solution. It is not practical in sparsely populated areas, and it is not a solution for the very poorest people. In a nation where many people survive on a single dollar per day, even purchasing the cheapest CTT option at GHS 25 (US$11.36)* per month is an unrealistic price to pay.

Still, within CTT's area and market of focus, CTT has proven successful. At the time of publishing, CTT is not yet economically sustainable. However, once they construct the Dompoase collection site, they predict that they will quickly reach 1500-2000 subscribers. At this point, a profit will be earned and the company will begin to rely less on funding from NGOs and foundations (Aruna 2014).

Another consideration is the fact that, at its core, the CTT is classified as a bucket toilet, which is an unimproved type of sanitation, by the JMP sanitation definitions. This is because the model requires handling of waste before disposal, despite the fact that the handling is not done by the toilet users. While this classification does not address the tangible benefits that the toilet offers to its users, it may result in a misleading representation of Kumasi's JMP sanitation coverage rates as CTT expands. In order to prevent this, Andy Narracott, the Chairman and Co-Founder of CTT, is lobbying as UNICEF/WHO redefines "improved sanitation" for the post-2015 UN Millennium Development Goals.

Finally, the biocide used in order to make the bucket toilet model sanitary poses health and environmental concerns. The MSDS for bronopol indicates that it is "very toxic to aquatic organisms," (Spectrum 2008) and a listed use for bronopol is as a antrimicrobial agent in aquatic systems (CDC 2012). In Kumasi, the waste stabilization ponds rely upon natural processes to eliminate organic matter. WSPs are quite temperamental, and the introduction of glutaraldehyde and bronopol to the system may kill off microbes and algae, thereby disrupting the already limited treatment process (Manangi 2013).

In conclusion, the CTT will likely develop into a sustainable model and is a technology that holds great promise for densely populated areas. Once the business becomes financially sustainable and develops a solution for waste and biocide reuse and disposal, CTT will have the potential to become a wide-scale option for urban sanitation.

*US$1 = GHS 2.20 (Jan. 2014)

4 Microbial Fuel Cell Latrine

Figure 4-1 The MFCL at Nyastech Secondary School. Behind the latrine is a below grade area that houses the nitrification, anode, and cathode tanks, and next to the latrine is a newly built facility with flushing toilets.

4.1 Technological Overview

The Microbial Fuel Cell Latrine (MFCL), pictured in Figure 4-1, is an innovative toilet that converts human waste into electricity and a soil additive. The interior of the latrine consists of two wooden sitting-style toilets and one urinal, as shown in Figure 4-2. The toilets are open pit toilets, meaning that there is no water seal. Thus, as explained in Chapter 1, the latrine would likely be considered unimproved by JMP definitions because contamination by flies and splashing of waste can be concerns, especially if the pits become too full. However, this unimproved classification is slightly ambiguous; if the toilet covers were properly used and were airtight, the MFCL may function as a KVIP, which is an improved technology when not shared and when the toilet is covered while not in use. However, the toilet covers at the facility

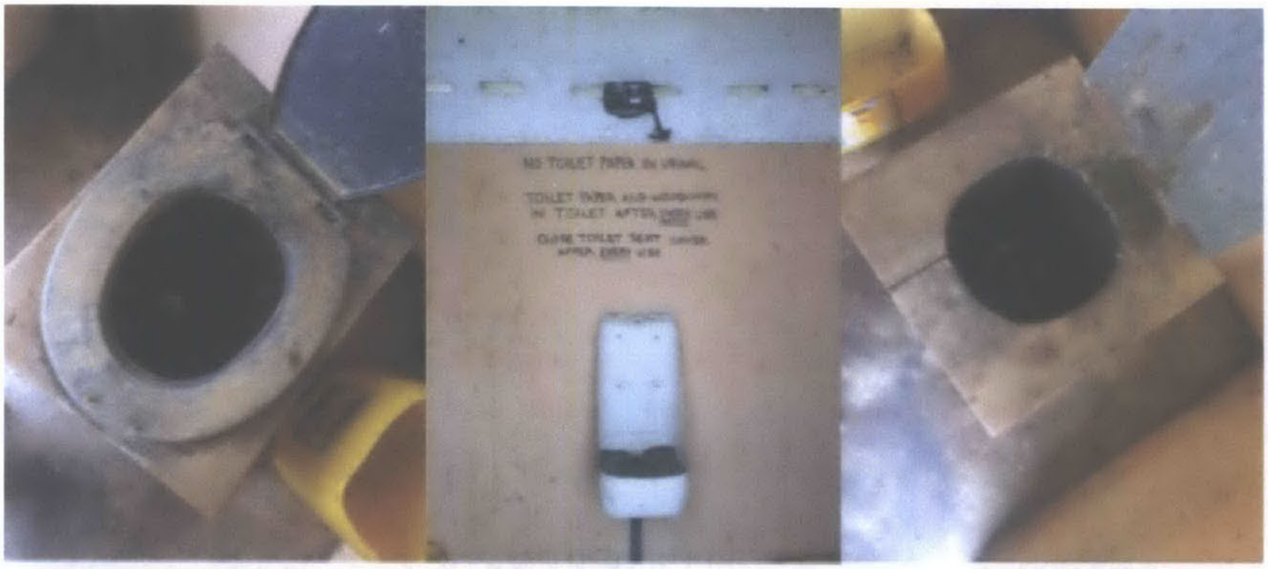


Figure 4-2 The interior of the Nyastech MFCL contains two sitting-style toilets and a urinal. Above the urinal is the light, which can be powered by the microbial degradation of human waste. The toilets do not feature urine diversion and appeared to be poorly maintained, as is evident from the fecal matter on both seats.

examined in the case study below were not closed and were not airtight, indicating that the MFCL is unimproved. Still, the MFCL is an innovative pilot technology that pushes the technological boundaries of the sanitation technology industry forward. Previously, the microbial fuel cell had been implemented primarily on a lab scale, but the MFCL expands the scale in this pilot phase. The MFCL was developed by Dr. Caitlyn Butler of the University of Massachusetts-Amherst and Dr. Brad Rogers and Dr. Mark Henderson of Arizona State University (Castro et al. 2012).

The MFCL generates electricity through the use of a nitrification tank, a cathode, and an anode, a process depicted in Figure 4-3. This generation of electricity is the result of the flow of electrons from an anode, which is negatively charged, to a cathode, which is positively charged. However, as the electrons, which are negatively charged, flow from the anode to the cathode, the anode becomes less negative, and the cathode becomes less positive. Without the anode and cathode remaining charged, the flow of electrons would eventually come to a halt. Therefore, in order for this flow of electrons to happen continuously, electrons must be produced within the anode and consumed within the cathode through electrochemical reactions (Logan and Rabaey 2012).

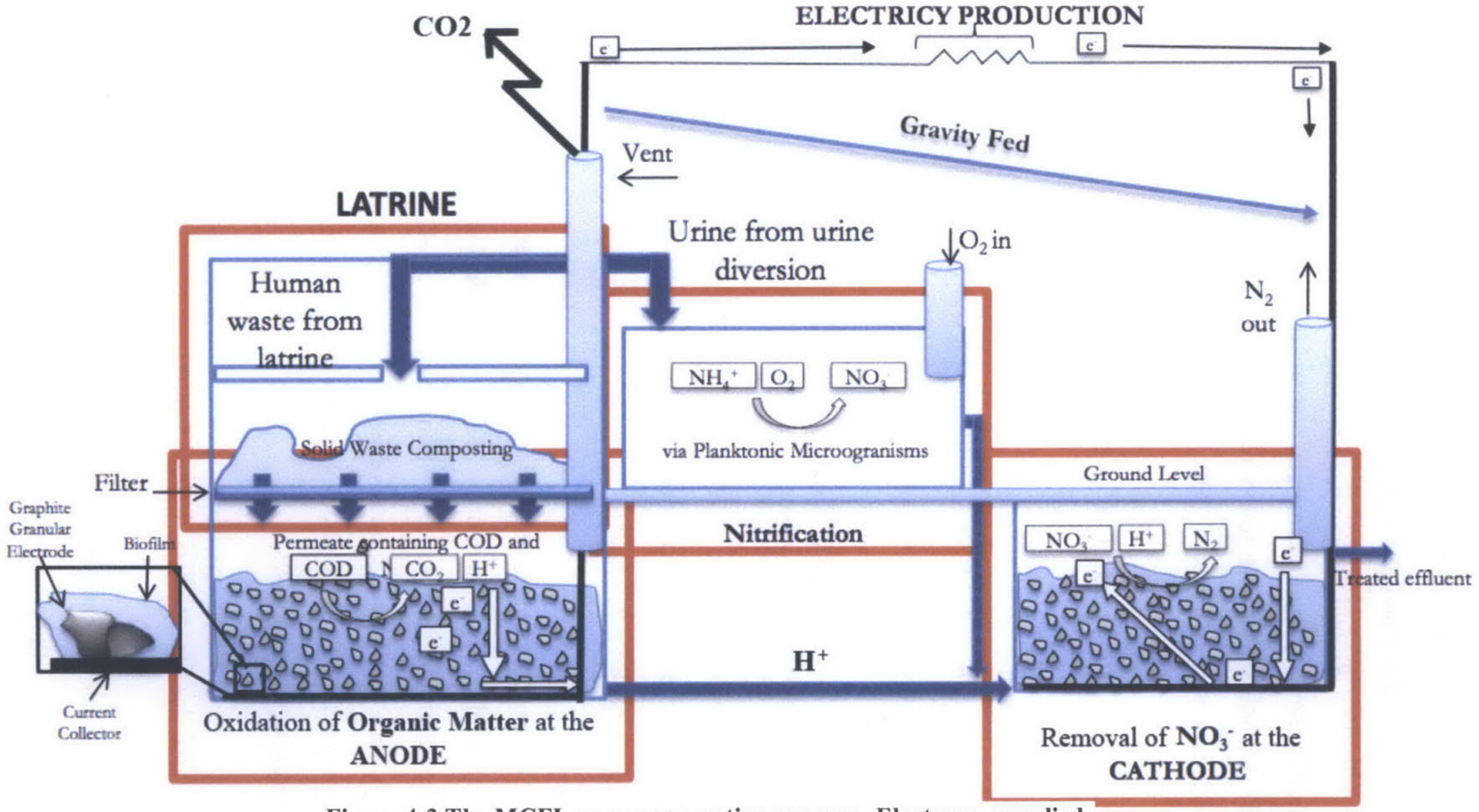


Figure 4-3 The MCFL power generation process. Electrons, supplied by the oxidation of organic matter, are sent from the anode to the cathode, where they are demanded for the reduction of nitrate. The nitrate is produced through the nitrification of urine in the nitrification tank.

The anode's negative charge is preserved through the oxidation of solid organic material by a biofilm on granular activated carbon inside the anode. In other words, the donation of electrons from organic matter to the anode maintains the negative charge inside the anode tank. Total organic matter, or the collective amount of acetate, propionate, butyrate, and other organic compounds, is often measured in terms of chemical oxygen demand (COD) [mass of oxygen demanded/volume of liquid]. For this reason, the governing equation of the reaction that supplies electrons to the anode is written in terms of COD. This equation is as follows:

$$COD \rightarrow CO_2 + H^+ + e^-$$

Although each organic compound used is of the form $C_aH_bO_c$, each has slightly different composition, so the coefficients in the equation have been left out for simplicity's sake. The carbon dioxide (CO_2) produced is disposed of through a vent into the atmosphere, and the hydrogen ions (H^+) are released into the solution and sent to the cathode to be used in another process that will be explained below. The electrons (e^-) are sent through a power production mechanism to the cathode, thereby generating electricity (Butler et al. 2012). This process is fueled by liquid fecal waste, which percolates into the 28 L anode chamber through filtered composting chambers underneath either of the two toilets. In laboratory settings, the MFCL oxidized 74 mg COD/L each day, resulting in a COD removal rate of over 98% (Castro et al. 2012).

While the anode is fueled by microbes' consumption of organic matter, the cathode is fueled by a two-step consumption of compounds in urine. After urine is deposited into the urinal by male users, it flows into the intermediary 45 L nitrification tank (Figure 4-4). In this chamber, through nitrification, aerobic planktonic microorganisms consume the ammonium (NH_4^+) in the urine and oxygen gas (O_2) from the atmosphere, producing nitrate (NO_3^-) and water (H_2O), as illustrated by the equation below:

$$NH_4^+ + 2\,O_2 \rightarrow NO_3^- + H_2O + 2\,H^+$$

Then, the products all flow into the cathode tank, where, through the process of denitrification, heterotrophic biofilm on the granular activated carbon in the cathode consume the nitrate (NO_3^-) and hydrogen ions, some of which have been transferred over from the anode. This consumption reduces the nitrate, requiring the consumption of electrons from the cathode, as is represented by the redox equation below (Logan and Rabaey 2012):

$$2\,NO_3^- + 10\,e^- + 12\,H^+ \rightarrow N_2 + 6\,H_2O$$

Because electrons are pulled away from the cathode in order to fuel this reaction, the cathode's charge becomes more positive, ensuring the continued transfer of electrons from the anode to the cathode and, thereby, also ensuring the continued production of electricity. The total nitrogen removal rate was measured to be 34 mg N/L per day, or 68% of total nitrogen, in a laboratory setting (Castro et al. 2012). The nitrogen gas (N_2) is allowed to dissipate into the atmosphere through a vent pipe (Butler et al. 2012).

After these processes have taken place, what remains are a source of minimal electricity, a treated greywater effluent, and composted fecal solids. In a lab setting, power production was measured at 2.5 mW/m^3, which is enough electricity to power only an LED light within the latrine (Castro et al. 2012). This figure may be even lower in the practical field applications, but the hope is that future models will produce more electricity as technologies improve (Donaldson 2012). The remaining greywater effluent, from which the majority of pathogens have been removed, is discharged from the cathode tank into the ground. The solids from the composting chamber above the anode can also be retrieved and used as a nutrient-rich soil additive (Butler et al. 2012). The MFCL contains two composting chambers, one beneath each of the two toilets. Because there are two pits, one is closed at all times while the solids accumulate within the other. After a period of one year, the waste in the closed pit will have finished composting and can be emptied. At this point, that toilet is reopened, and the other toilet is closed so that its contents may compost for a year (Rogers 2014).

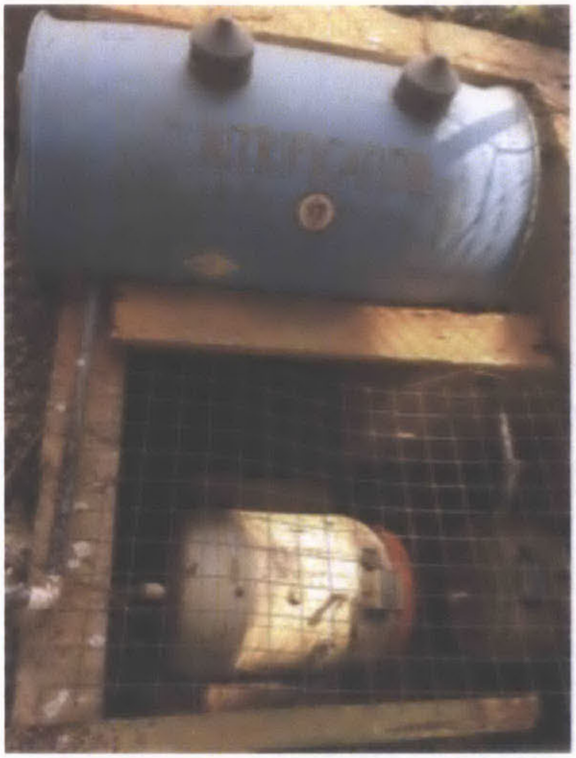


Figure 4-4 The nitrification tank (top) supplies nitrates to the cathode tank (lower right), while the anode tank (lower left) supplies electrons and hydrogen ions to the cathode tank.

4.2 Case Study

4.2.1 Context

In May 2012, Professors Brad Rogers and Mark Henderson of Arizona State University's College of Technology and Innovation travelled to Nyakrom, Ghana in order to install a pilot model of the MFCL at the Nyakrom Secondary Technical School (Nyastech). The project was funded by a $100,000 grant from the Bill and Melinda Gates Foundation's Grand Challenges Exploration program (Donaldson 2012). It is intended that the latrine be maintained and used exclusively by students and teachers, free of charge (Anlomegah 2014).

Nyakrom is located in the Central Region of Ghana (See Figure 4-5) and has a population of approximately 20,000 (Donaldson 2012). The school of Nyastech has about 1500 students, and approximately 600 of them live in hostels at the school. The other 900 commute from home each day, usually by foot. As is shown in Figure 4-6, 12 out of 16 respondent students place a "high" or "very high" priority upon improvement of sanitation at their school.

Figure 4-5 Nyakrom's location within Ghana (Mubambe 2014)

4.2.2 Strategy

The construction of the Nyastech MFCL was arranged by the Nyakrom chief and the ASU and UMass professors, but the Nyastech Science Department is responsible for the operation and maintenance of the facility. Mary Kay Jackson, the co-founder of Pure Home Water in Tamale, monitors the facility every two months and reports back to ASU and UMass-Amherst. During the construction, the teachers and several students were taught about the technology so that it could serve as both a sanitation facility and a learning lab for the students. The facility was sustainably constructed using local labor, strategies, and materials. According to Brad Rogers, due to a language barrier and lack of materials, the plans were altered in order to accommodate these circumstances. For example, large plastic drums were used as anode, cathode, and nitrification tanks, but the fundamental design and function of the facility remained as intended. The final cost of the system was approximately \$2900. Of this, \$1000 was spent on the purchase and importation of activated carbon from the United States, and $1900 was spent on local materials and labor (Rogers 2014).

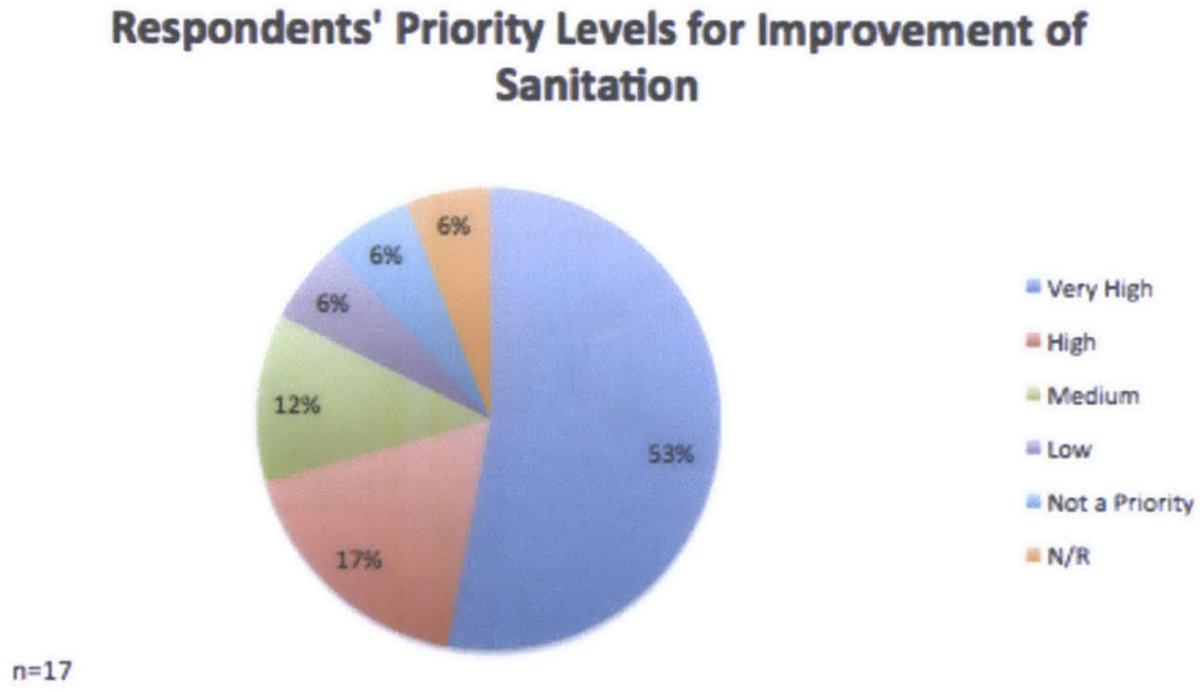


Figure 4-6 Respondents' priority levels for improvement of sanitation

4.2.3 Outcome

As mentioned above, in a laboratory setting at UMass-Amherst, the MFCL produced up to 2.5 mW/m^3 of power. However, as of January 2014, the Nyastech MFCL had never produced enough electricity to power the light. In fact, data from the latrine's first three months of operation indicate that the power produced is on the order of 0.006 mW/m^3 when school is in session, as is shown in Figure 4-7 (Butler et al. 2012). According to the science staff at Nyastech, the MFCL's power production had increased steadily over the life of the project but then decreased suddenly (Anlomegah 2014).

The primary cause of this low power production is inadequate use of the facility. As is shown in Figure 4-8, surveys indicated that 16 out of the 17 respondents had access to another toilet, and only 37.5% of those users preferred the MFCL to other available toilets. This is not shocking, for the student hostels are equipped with water closets with porcelain flushing toilets, and 40% of students live in the hostels (See Figure 4-9). The other 60% of students commute to school by foot, and several of the commuters who were interviewed explained that they prefer to

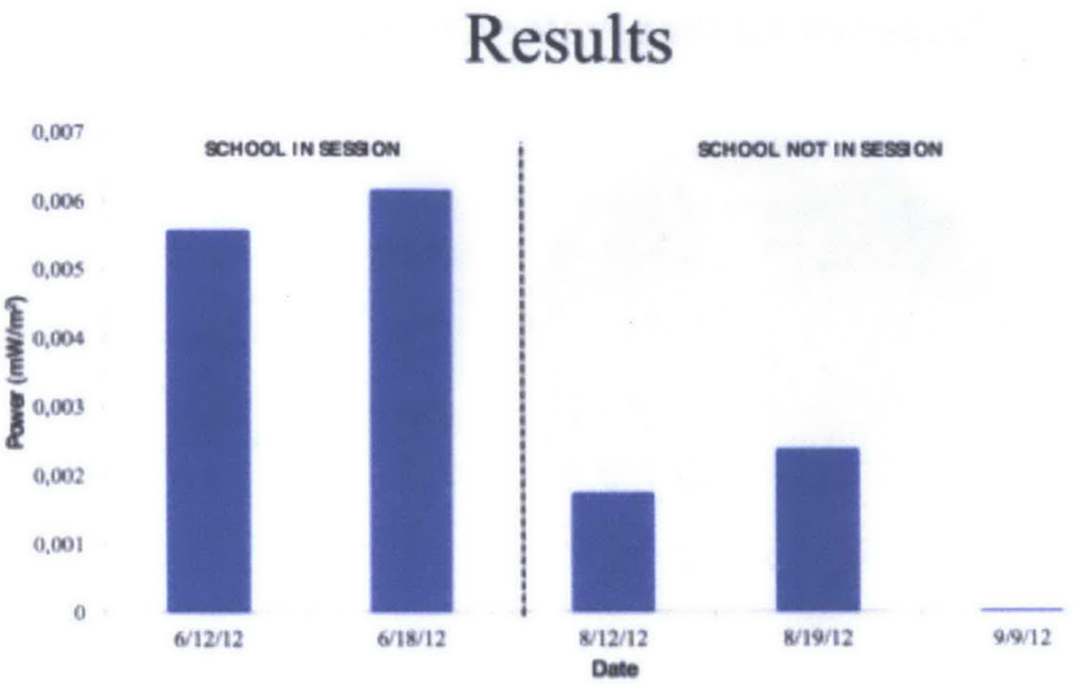


Figure 4-7 Power generated during the Nyastech MFCL's first three months of operation (Butler 2012)

use public toilets during their morning commute to school. This may be attributed to poor maintenance and cleaning of the facility, as is evident in Figure 4-2. Additionally, there was a fairly strong odor within the latrine and an observed absence of toilet paper and woodchips or ash, which should be present in a bin next to the toilets and used to stabilize and mask the odor of the solid waste in the composting chambers. Due to a combination of these factors, only four out of 17 students claimed to be comfortable using the facility, while seven claimed to be uncomfortable, and six had no strong opinion (See Figure 4-10). The MFCL, according to interviews, seems to be used by students primarily in cases of "emergencies" during the school day. In fact, 12 out of 17 students surveyed claim to have used the toilet two or fewer times in their lives (See Figure 4-11). The inadequate accumulation of urine is an inhibitor of power production in the MFCL and seems to be due to a combination of these factors.

After all, even if enough organic matter is supplied to fuel the reactions in the anode tank, no electricity will be generated if there is no ammonium from urine to fuel the reactions in the nitrification and cathode tanks. Currently, the urinal is the only inlet for ammonium, and only males can use the urinal. However, according to the head of the Nyastech Science Department,

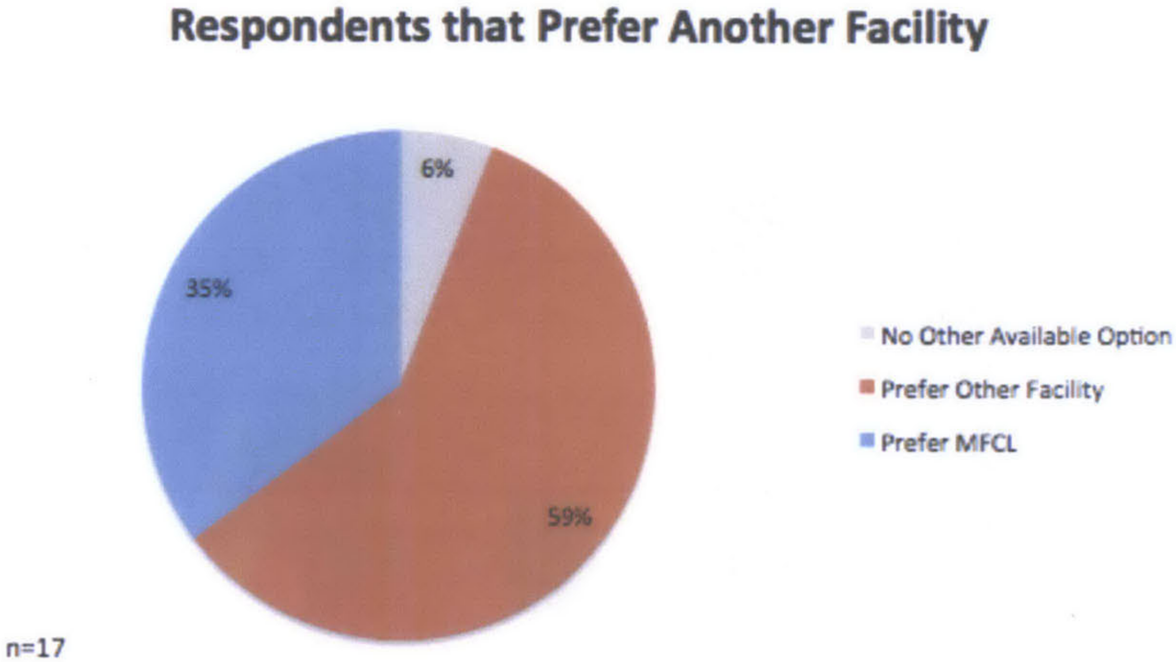


Figure 4-8 Respondents that prefer a facility other than the MFCL

Figure 4-9 A toilet in one of the hostels at Nyastech

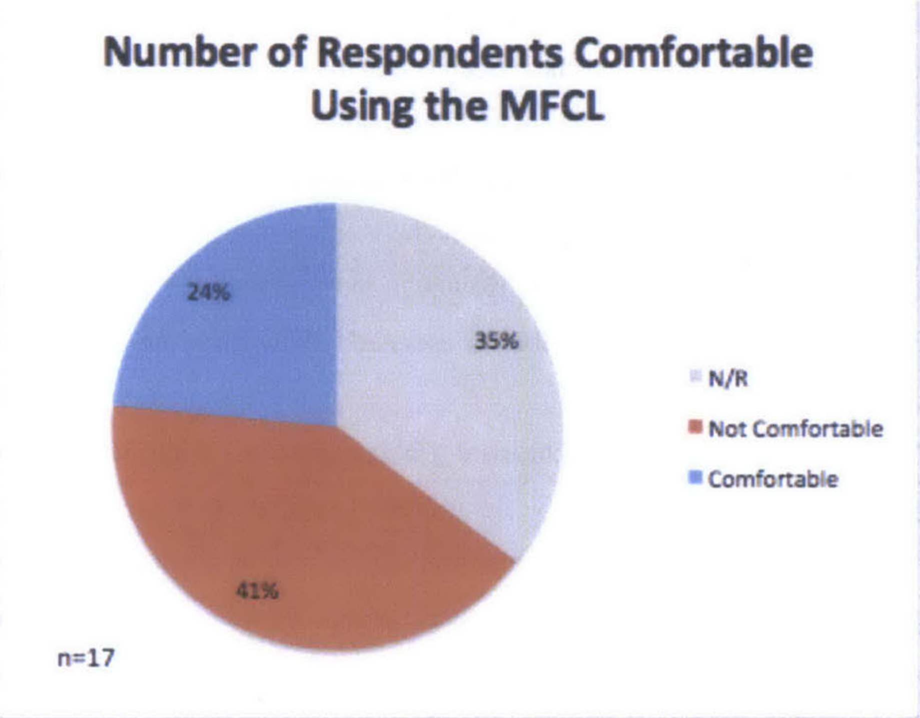


Figure 4-10 Number of respondents comfortable using the MFCL

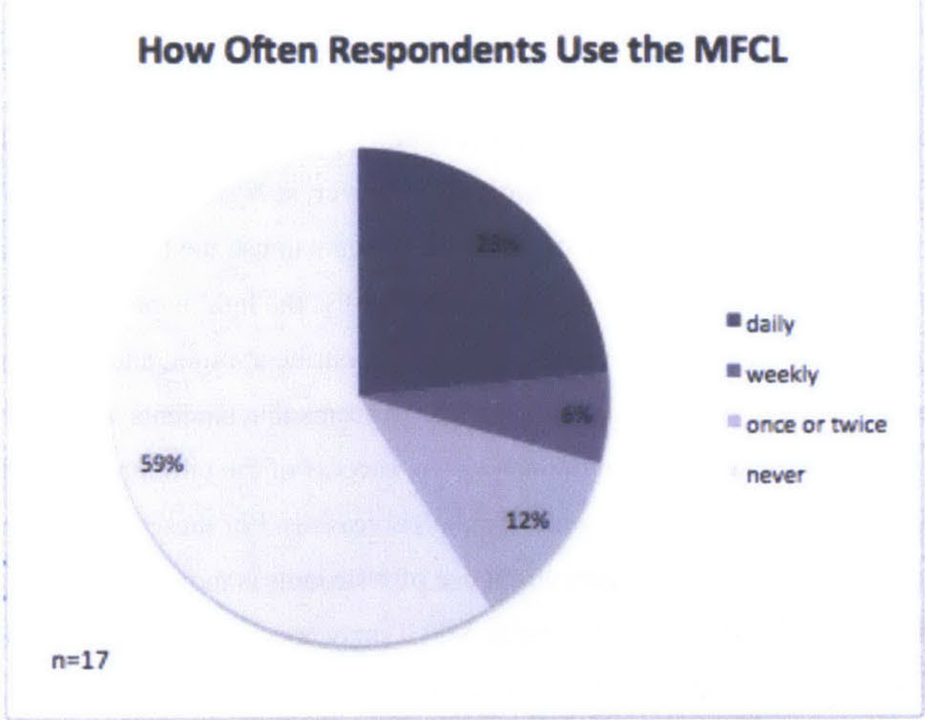


Figure 4-11 How often respondents use the MFCL

Sampson Anlomegah, the vast majority of males simply urinate outside behind the latrine (Anlomegah 2014). Additionally, there have been problems with students disposing of their toilet paper in the urinal rather than in the toilet. This both inhibits use of the urinal and lessens the amount of organic matter in the composting chamber and cathode tank (Tanner 2013). Generating incentives for males to use the urinal is the greatest concern and inhibitor of the generation of electricity (Anlomegah 2014). However, introduction of a urine diverting, squatting toilet pan could increase the number of users and allow for urine collection from users of both genders.

The latrine is facing other, less significant problems as well. First, when the students do use the facility, they often do so improperly. In addition to the resultant lack of cleanliness, the students have been known to squat on the seats instead of sitting on them, highlighting the need for a squatting toilet pan. This also contributes to the accumulation of fecal matter on the exterior of the toilet. Also, the public has been using the facility at night, which is against the desires of the Nyastech Science Department. Finally, a new toilet facility, pictured behind the MFCL in Figure 4-1, will be opening in spring 2014, and this will likely be used during school hours instead of the MFCL (Anlomegah 2014).

4.2.4 Discussion Points

It seems that the MFCL is technologically sound and could be successful in the proper setting with further development of the technology; however, at Nyastech, the benefits of the latrine light simply are not great enough to persuade students to use the facility, given the fact that they have other suitable options available. Additionally, the light is not essential to the students' safety because students and staff do not use the latrine at night, and the light serves no function during the daytime school hours. Currently, it seems that students are primarily motivated to use the toilet in order to demonstrate the success of the pilot project and for educational purposes rather than for any more practical reasons. For these reasons, the MFCL would be better suited to situations where night use of restrooms is more frequent and necessary.

Nonetheless, alterations to the Nyastech MFCL may encourage more frequent use of both the toilets and urinal. First, a change from the wooden toilet seats and urinal to a squatting-style urine-diverting toilet pan would be more aligned with the customs of the students and would allow for urine to be collected from users of both genders. Also, allowing the public to use the facility during after-school hours would not only generate an incentive for the light to be powered but also would provide more organic matter and ammonium to the system. Finally, the cleanliness of the facility seems to deter users. Because microbes are catalysts of the reactions in the system, bleach and antibacterial soap cannot be used to clean the facility because they would kill the microbes. As a result, any cleaning is done only using a broom and water, and most students view this as unsanitary (Anlomegah 2014). More frequent cleaning and use of soap on the floor and exterior of the toilet seats could encourage use. Despite the lack of a necessity for a working light, the pilot project may achieve better results with these changes.

In conclusion, although the MFCL has not been successful in powering its interior light, it has been successful in achieving its purpose as a pilot technology. That is, it elucidated the problems with the design and application that, if improved, could allow for successful implementation in the future. Once the technology becomes more efficient in its power generation and is implemented in a more applicable setting, it is plausible that the MFCL will generate more power. Also, the system has certain advantages that grant it a competitive edge over other technologies. For example, the MFC technology can be effectively retrofitted to most existing latrines, lowering costs of implementation. This also maximizes the potential for success, for the technology can be selectively applied in latrines that are already used at a rate that will provide enough organic material and ammonium to power the light. The MFCL is an exciting and innovative technology that, with further development, may become a suitable option in settings where no other safe, lit toilet is available at night. For now, however, NGOs and sanitation entrepreneurs seeking immediate improvements of sanitation coverage should explore other options.

5 Microflush/Biofil Toilets

5.1 Technological Overview

The Microflush/Biofil Toilets (MFBF) are unique in that they minimize odor and water consumption while promoting hand washing and generating a soil additive through use of vermiculture. Invented by Dr. Stephen Mecca of Providence College and Ghanaian mechanical engineer Kweku Anno, the MFBF achieves this through use of grey water from hand washing in order to flush the toilets. The fecal sludge is then composted in a Biofil digester tank, producing a nutrient-rich soil additive. In August 2012, after the invention of the MFBF technology, Mecca and Anno decided to pursue implementation of the technology separately, and each has his own variation on the technology. Mecca heads the more aid-focused Global Sustainable Aid Project (GSAP), and Anno is the founder and chairperson of Biological Filters and Composting Limited (Biofilcom), a for-profit business in Accra. Mecca's model is called the Microflush Toilet, and Anno's model is termed the Biofil Toilet. Microflush Biofil (MFBF) will be the term used to refer to facilities on which Mecca and Anno collaborated. The cost of Mecca's variation on the design, the Microflush Toilet, has been brought down recently through simplification and the use of locally sourced materials. Because the toilets are slight variations on the same design, they are both included in this chapter. The technology can be broken into three main components, the hand washing system, the flushing mechanism, and the digester tank.

5.1.1 Hand Washing System

The Biofil Toilet features a hand washing system that reuses grey water for toilet flushing, but this was eliminated in the Microflush Toilet in order to minimize cost. The hand washing system consists of a sink, a tap, and a tube connecting the sink drain to the toilet bowl water intake. Ideally, water is fed into the sink for hand washing through either a piped water source or from an elevated rainwater collection tank. However, in areas without piped water or rainwater collection, hands may be washed using water scooped from a bucket without sacrificing performance of the system. Typically, in areas with piped water or rain collection, aerator taps are used on the spout of the faucet. These aerator taps release water when a rod on the bottom of the tap is pressed upward, and they introduce air into the water stream, minimizing water used per hand wash. In private Biofil Toilets, however, a tap with a handle is sometimes used in place of the aerator. After water is used for hand washing, it flows down the sink drain and into the toilet bowl, establishing a standing water seal in the toilet for the next use (Gyabah 2014). This process is shown in the picture in Figure 5-1 and the diagram in Figure 5-2. GSAP's Microflush Toilet functions as a pour-flush toilet. That is, after each use, the user pours a cup of about 150 mL of water into the toilet in order to prepare it for the next use.

Figure 5-1 Public MFBF facility in Pokuase. Water from the aerator tap used for hand washing is recycled for the next user's flush. Waste is flushed into a tank underneath, where it is composted into a nutrient-rich soil additive through aerobic digestion.

5.1.2 Flushing Mechanism

The Microflush and Biofil Toilets' flushing mechanism is responsible for minimizing water use and for eliminating odor within the latrine. In the bottom right corner of Figure 5-2, the mechanical flush is depicted. After use of the toilet, the user steps on a lever, seen on the left side of the toilet seat in Figure 5-1, and this causes a door on the bottom of the toilet bowl to open on a hinge. With the previous user's hand washing grey water acting as a carrier fluid, the waste slides into a tank below by gravity. With this mechanical flushing mechanism, only 150 mL of water is required per flush, compared to 4.85 L per flush in typical high efficiency toilets imported from the US (Mecca, Davis, and Davis 2012, Kohler 2014). The combination of a mechanical seal and a water seal separating the Biofil tank's waste from the air inside the latrine effectively eliminates odor and prevents flies from entering or exiting the tank. The MFBF, when implemented in private homes, is classified as an improved sanitation facility under the JMP definitions because of this effective separation of waste from human contact (UNICEF/WHO JMP 2013).

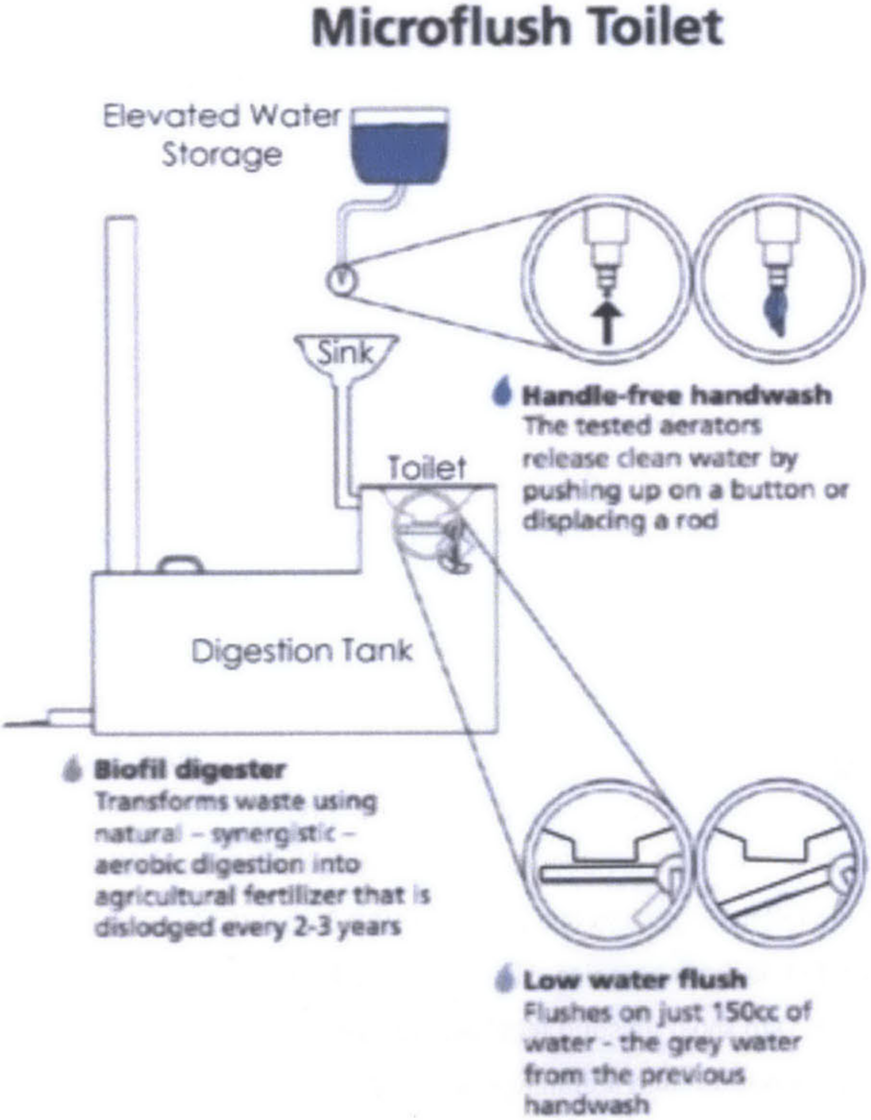


Figure 5-2 A diagram illustrating the processes involved in the Microflush and Biofil technologies

5.1.3 Digestion Tank

The design of the final component, the digester tank, differs between the Microflush and Biofil Toilets, but both serve the same purpose. In both models, waste is converted into a soil additive through composting by a colony of macro- and micro-organisms that aerobically digest the human waste. This colony includes Red Wiggler Worms, Dung Beetles, German Cockroaches, Black Soldier Fly Larvae, Woodlice, and bacteria (Mecca, Davis, and Davis 2012). These organisms carry out aerobic digestion by consuming oxygen gas from the atmosphere and organic matter in the human waste, oxidizing it into a nutrient-rich compost substrate, water, carbon dioxide, and heat. The aerobic system is preferable to the anaerobic system of septic tanks not only because it produces a soil additive, but also because anaerobic digestion produces a small amount of hydrogen sulfide (H_2S) gas, which has an offensive odor. The only gas produced through aerobic digestion is carbon dioxide, which has no odor (Anno 2014).

Although they serve the same purpose, the two tank models have differences in their residence time. The Microflush Toilet's digester tank encapsulates the waste away from human contact while it is converted into a nutrient-rich soil additive over a period of 2-3 years (Gyabah 2012). GSAP's research has shown that within the Microflush Toilet's digester tank, the mass and volume of the waste sludge is reduced by approximately 97%, and pathogen concentrations are reduced to safe levels. In other words, in a typical use, approximately 124 grams of feces, 240 mL of urine, and 150 mL of grey water are converted into 15 grams of fertilizer substrate, while the other 499 grams of waste are volatilized or infiltrate into the soil, where natural biological processes eliminate residual pathogens (Mecca, Davis, and Davis 2012).

The Biofilcom tank, on the other hand, typically does not accumulate waste at a significant rate and therefore does not require regular emptying, according to Anno. This is likely because its design is more conducive to composting and is intended for use by fewer people. Both of the toilets' digestion tanks are 6' x 2' x 2', but the Biofilcom (Biofil) tank, depicted in Figure 5-3, is more complex. This model utilizes three layers of porous concrete filters (See Figure 5-4) to separate solid fecal matter from wastewater and urine. After filtration, the liquid waste flows out through a drainage pipe and directly into the ground. The GSAP (Microflush) model has five layers of wire mesh and sediments, under which a horizontal drainage pipe allows liquids to exit. The liquid waste trickles through the mesh, flows out though this drainage pipe, and percolates into a designed soak hole with rocks and sand, where it

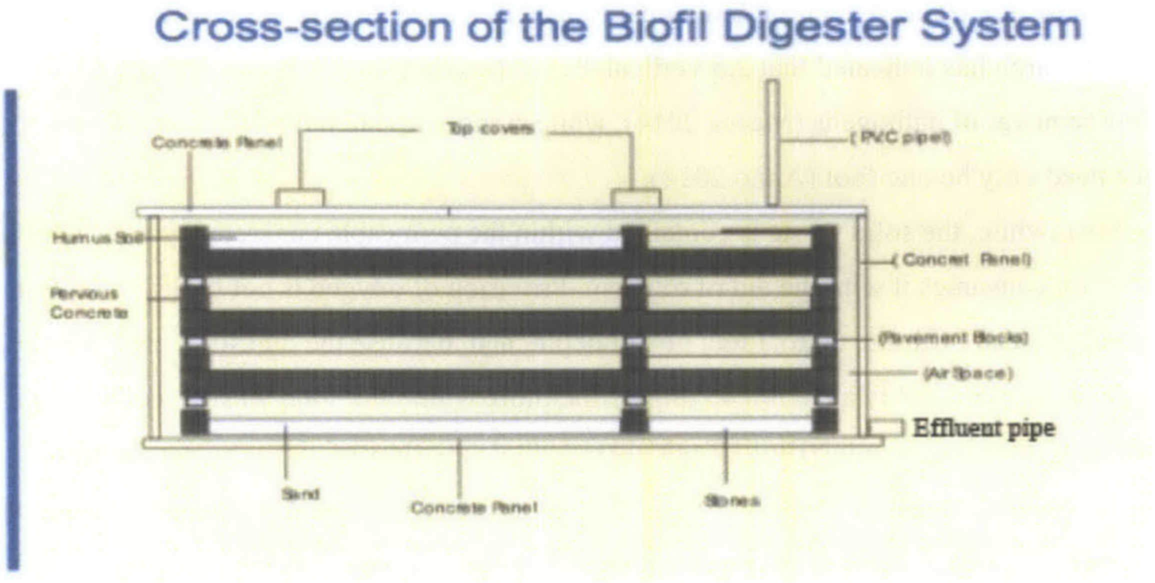


Figure 5-3 Diagram of Biofilcom's digester tank. Layers of permeable concrete separate fecal matter from liquid waste, which percolates into the ground and is naturally degraded (Anno 2012).

Figure 5-4 The permeable concrete filters used in Biofilcom's Biofil digestion tank

is degraded to safe levels by natural biological processes before it reaches the water table. Mecca's research has indicated that 2.5 vertical feet of percolation distance is necessary for complete removal of pathogens (Mecca 2014), while Anno's research has suggested that this distance need only be one foot (Anno 2014).

Meanwhile, the solid waste is contained within the permeable concrete layers, where the vermiculture consumes it with the aid of oxygen. Provision of oxygen is not typically an issue, for oxygen gas can infiltrate up to 3 feet of soil depth, and, because the digestion tank is only 2 feet deep, oxygen is readily available to the vermiculture within the solid waste (Anno 2014). The multiple filter layers in the Biofil Tank also facilitate the flow of air to the vermiculture. In Biofilcom's model, which is intended for families, or up to 10 uses per day, the amount of solids produced through the aerobic digestion is so small that most tanks never need to be emptied, although they could be if the owner wishes to retrieve the solids to be used as soil additives (Anno 2014). Biofilcom's and GSAP's tanks are pictured in Figure 5-5 and 5-6, respectively.

Figure 5-5 Biofilcom's Biofil tank

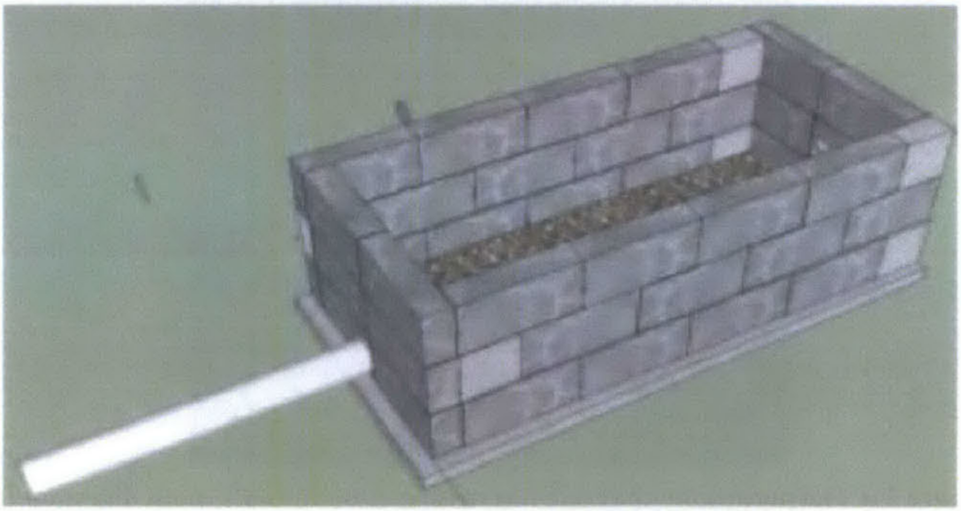


Figure 5-6 Rendering of GSAP's digestion tank without the concrete cover or vent pipe. GSAP's tank uses five wire mesh filter rather than layers of permeable concrete filters.

The Biofil digestion tank has two main advantages over the Microflush Toilet's tank. First, the Biofil Tank can remain open constantly because it rarely requires emptying. The Microflush Toilet must be shut down for 2-3 weeks before emptying so that the vermiculture has time to digest all fresh waste. If this is not done, the harvested compost will likely still contain pathogens (Gyabah 2014). Additionally, the Biofilcom digestion tank can be adapted to fit toilets that flush with a higher volume of water per flush, but the Microflush tank cannot. For the Biofil tank, this is done by adding perforated pipes from the bottom of the tank into the soil to accelerate percolation of liquids into the soil (Anno 2014).

The Microflush tank has its advantages as well. First, the regular emptying allows the owners to recover more compost to be used as fertilizer. It also can be built on-site, whereas the Biofil Tank requires heavy pre-assembled parts to be shipped from Dzorwulu to the construction site. Furthermore, although the Microflush does not filter liquids as thoroughly inside the digestion tank, its designed soak hole ensures that pathogens in the effluents do not reach the water table.

5.1.4 Design Considerations

In order to ensure optimal performance, the tanks must be operated under certain conditions. According to research completed by Mecca, digestion tanks should operate within the range of 25 to 34 degrees Celsius (77 to 93 degrees Farenheit) for optimal growth of vermiculture (See Figure 5-7). Although some heat is indeed generated through aerobic digestion, this will still likely limit the implementation of the toilets to areas with no cold winter season. Additionally, tanks must be built above ground in order to maximize the vertical distance between the bottom of the tank and the water table to prevent groundwater contamination. According to Anno, however, this distance need only be approximately 30 cm, for, by the time the wastewater percolates this depth into the soil, all pathogens are typically removed (Anno 2014). Another consideration of primary concern is the fact that bleach and antibacterial soap cannot be used for cleaning of MFBF facilities, for these cleaning agents kill the vermiculture in the digestion tank. This can especially be an issue in public facilities, where the transmission of disease is a heightened concern.

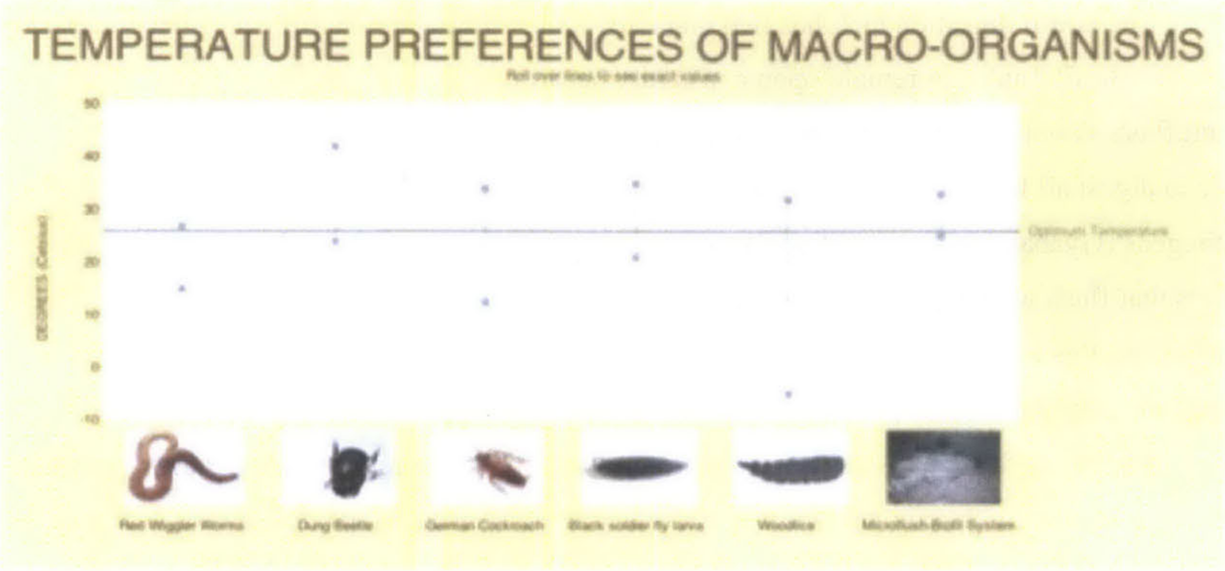


Figure 5-7 Temperature preferences of macro-organisms found within the digester tanks

5.2 Case Study of Biofilcom's Standalone Biofil Toilet

A complete field case study of Biofilcom's private Microflush Biofil toilets was not feasible, but interviews with Kweku Anno at the Biofilcom headquarters in Dzorwulu and with Dr. Diane Kellogg from Bentley University have provided information on Biofilcom's business strategy and outcomes.

5.2.1 Context

The Biofilcom headquarters are located in Dzorwulu, a district of the Greater Accra Region, on the corner of Forest Avenue and Dzorwulu Road at 5°36'45.5"N, 0°12'27"W (Figure 5-8). Kweku Anno developed the original Biofil digester tank in 2002 as a solution to the high water table in Dzorwulu, which was becoming contaminated by leaking underground septic tanks. After finding success with aerobic digestion of waste, he officially launched Biofilcom in 2008. Today, Biofilcom employs over 25 workers and all of its installed tanks and toilets are still in use (Anno 2014).

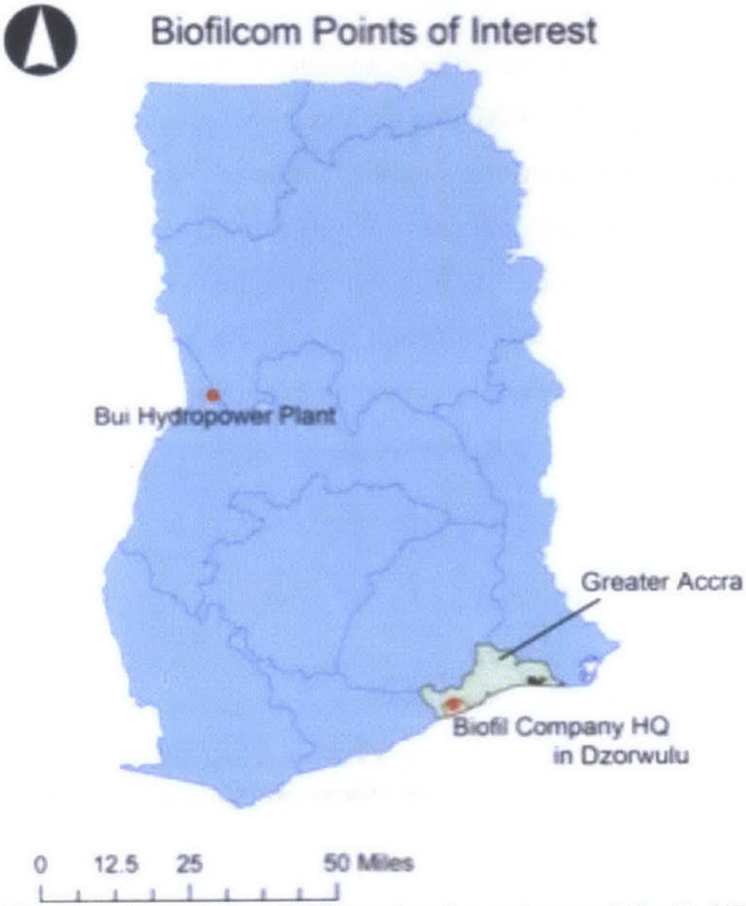


Figure 5-8 The locations of the Biofilcom headquarters and the Bui Hydropower plant, where 400 Biofil digester tanks have been installed

5.2.2 Strategy

Biofilcom, as a for-profit business, primarily targets high-end Ghanaian consumers and sells both Biofil toilets with digester tanks as well as Biofil digester tanks as replacements to existing septic tanks. The price for a MFBF from Biofilcom is GHS 3500, (US$1590)* for typical customers. However, Biofilcom offers Biofil Toilets in some urban slums for a discounted upfront price of GHS 2000 (US$910). Additionally, a Biofil tank alone, to be attached to an existing toilet, can be purchased for GHS 2000 (US$910). Biofilcom focuses on manufacturing, delivery, and installation of its technologies, rather than on-site construction. Although this increases costs, it allows them to operate at a higher production rate and at a central location.

Because Biofilcom targets a high-end consumer base, it is very interested in quality control and protection of its brand name. In an interview, Anno explained that, "In private

*US$1 = GHS 2.20 (Jan. 2014)

facilities, cleanliness is determined by the cleanest person. In public facilities, cleanliness is determined by the dirtiest person" (Anno 2014). In order to prevent its image from being tarnished in the minds of the public, Biofilcom no longer will accept contracts for public toilet facilities after collaboration with GSAP on a public facility in Pokuase in 2012. Now, Biofilcom constructs only standalone toilet units and uses only high-quality materials in its manufacturing in order to ensure quality performance. As is shown in Figure 5-9, all interior surfaces are tiled in order to discourage disease-spreading pests and for easy cleaning. Also, the imported sink and Western-style toilet seat are status symbols, appealing to high-end consumers (Anno 2014).

Figure 5-9 The interior of a Biofil Toilet

5.2.3 Outcome

Because interviews with users of Biofilcom's MFBF users were not feasible, user satisfaction and sanitation outcomes were not measureable. However, Anno did provide data on the company's production since 2008. Since its founding, Biofilcom has installed 4000 digesters, 200 of which are standalone Biofil Toilets with digesters, and 3800 of which are Biofil digestion tanks that are connected to existing toilets as replacements for septic tanks. However, the Biofil Toilet is becoming a more popular option. Today, Biofilcom installs five Biofil tanks per day on average, and the greatest number of them, 400, were installed in the region surrounding the Bui Hydropower Plant (Anno 2014).

5.2.4 Discussion Points

Biofilcom's Biofil Toilet is a good solution for high-end users in areas without sewer infrastructure. In remote areas or locations without well-kept roads, the contents of septic tanks cannot be easily drained because trucks cannot reach the tanks. Additionally, even when vacuum trucks do empty septic tanks, the septage rarely receives proper treatment, as was explained in the previous chapter. The Biofil Toilet's composting tank eliminates the need for waste collection, for the tank typically does not need to be emptied during its working lifespan. Additionally, in swampy areas, septic tanks typically sit below the water table, so leaked sewage seaps directly into the groundwater. The Biofil Toilet, positioned above ground, only requires the water table to be at least 30 cm beneath the ground surface in order for the effluent to be safely discharged into the ground (Anno 2014). Additionally, the Biofil Toilet promotes hand-washing as a required part of regular use, is a higher-end product than GSAP's model, and can be quickly installed because of Biofilcom's manufacture, deliver, and install model.

5.3 Case Study of the Public Microflush/Biofil Toilet by GSAP and Biofilcom

5.3.1 Context

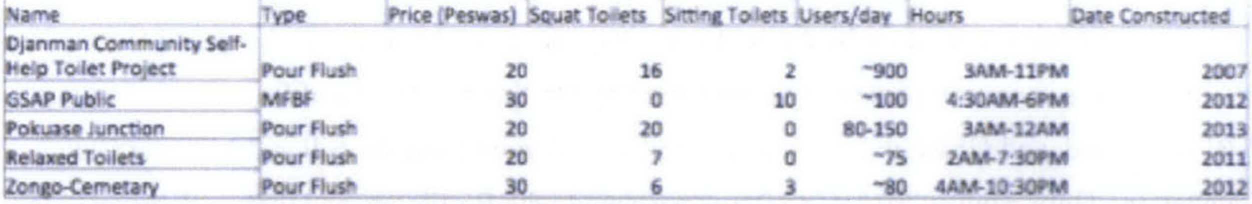
GSAP was originally founded in 2007 as the Ghana Literacy Project. However, its missions soon expanded beyond literacy, and it therefore became known as the Ghana Sustainable Aid Project in 2010. Following GSAP's success with the Microflush Toilet, it has expanded to India, Nepal, Nigeria, and the Caribbean, and, accordingly, its name was changed yet again to the Global Sustainable Aid Project. GSAP has trained over 60 masons, or MAKERs, in Ghana as well as 24 abroad to properly construct the Microflush Toilet (Mecca 2014). GSAP's supporting research is conducted by Dr. Stephen Mecca of Providence College in Rhode Island, and GSAP is funded by a US$100,000 grant from the Bill and Melinda Gates Foundation. Until August 2012, GSAP was partnered with Biofilcom, and they collaborated on a public MFBF facility in Pokuase.

GSAP's Ghana headquarters are in Pokuase, a suburb north of Accra, at the Nii Ottokwame District Assembly Secondary School. The most recent available population data for Pokuase lists the population at 10,858 in 2000 (Ghana Statistical Service 2000). In an interview, the Pokuase Assembly Environmental Health Officer, Gideon Boafo, explained that most people in Pokuase are street merchants and are renting space on long-term leases while in town (Boafo 2014).

The Pokuase Municipal Assembly recently passed a by-law requiring every household to have its own improved latrine. It encourages this by providing free technical plans for KVIPs to residents but does not fund toilet construction. Significant progress toward this by-law has not occurred because most residential buildings are rented to merchants, and landlords are difficult to reach and are not typically responsive to requests for toilet construction. The Assembly also has begun condemning all latrines that are unimproved or deemed unsanitary, including public facilities (Boafo 2014). This happened at the former open pit facility in Pokuase Junction, leading to the construction of the new pour flush facility that is now in place (Yaro 2014). The assembly also collects annual taxes of GHS 200 (US$91)* per seat from public facilities (Boafo 2014).

The map in Figure 5-10 shows the location of GSAP's toilet facilities as blue dots, and surrounding public toilet facilities, which use technologies other than the Microflush Toilet, are designated with red dots. GSAP has established a 10-seat public Microflush Biofil toilet facility in collaboration with Biofilcom, a five-seat school Microflush Biofil toilet facility, and six privately owned Microflush facilities. The majority of these privately owned facilities are shared by 4-5 families each. Surrounding facilities are listed in Table 5-1 along with their corresponding number of seats, the price per use, the type of facility, and the year in which the facilities were constructed. These compete with the public Microflush/Biofil facility for users.

Table 5-1 Public Toilet Facilities in the Vicinity of GSAP's Public and Private Toilets



Name	Type	Price (Peswas)	Squat Toilets	Sitting Toilets	Users/day	Hours	Date Constructed
Djanman Community Self-Help Toilet Project	Pour Flush	20	16	2	~900	3AM-11PM	2007
GSAP Public	MFBF	30	0	10	~100	4:30AM-6PM	2012
Pokuase Junction	Pour Flush	20	20	0	80-150	3AM-12AM	2013
Relaxed Toilets	Pour Flush	20	7	0	~75	2AM-7:30PM	2011
Zongo-Cemetary	Pour Flush	30	6	3	~80	4AM-10:30PM	2012

In order to understand the context in which the GSAP Microflush Toilets operate, it is important to understand these other public sanitation facilities. The option nearest the GSAP public toilets is the Pokuase Zongo/Graveyard Toilet. This facility appeared to be the cleanest in

*US$1 = GHS 2.20 (Jan. 2014)

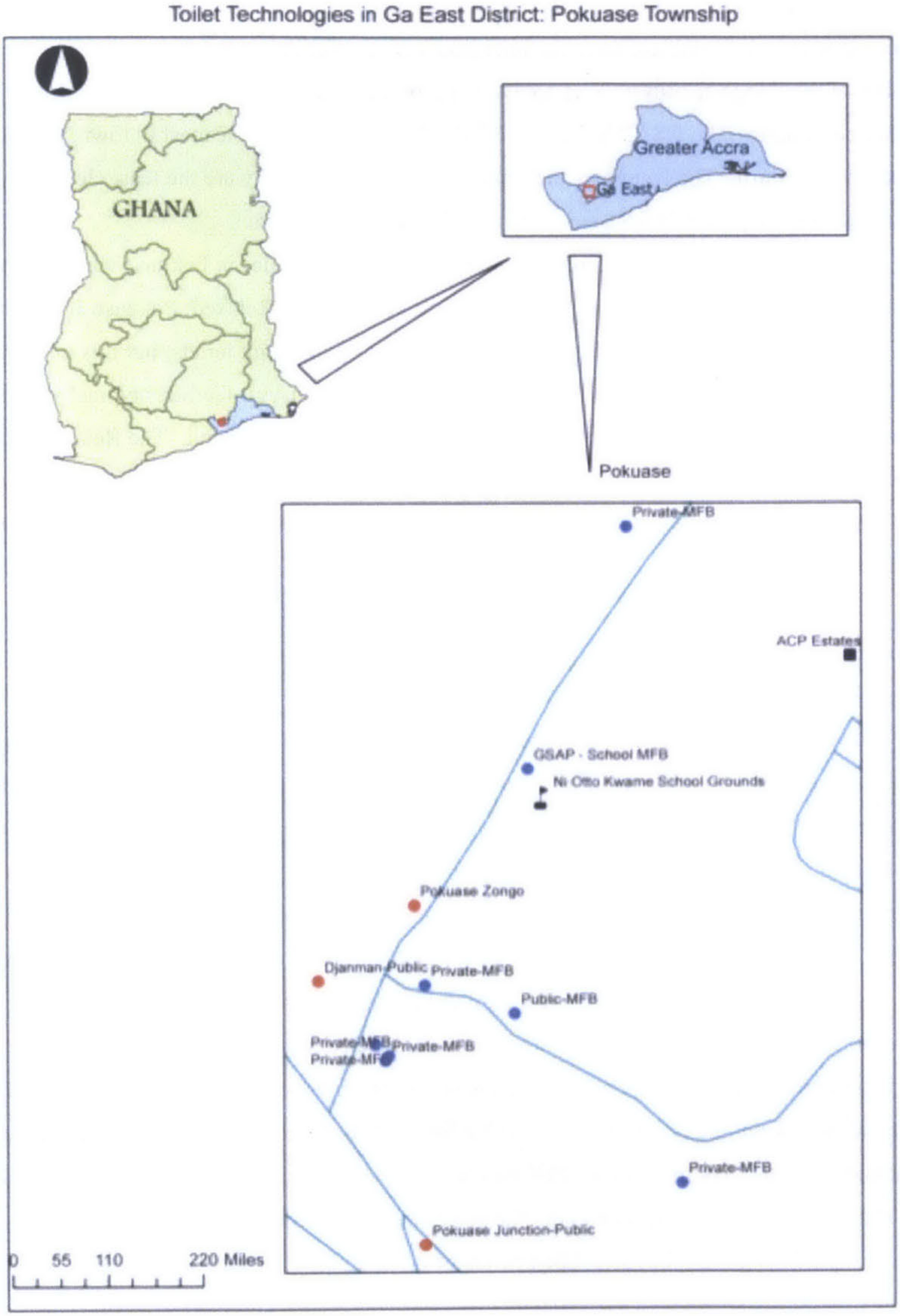

Toilet Technologies in Ga East District: Pokuase Township

Figure 5-10 The locations of each of GSAP's Microflush Toilets (blue dots), the MFBF public toilets (blue dot) and other public toilets (red dots) (Mubambe 2014)

town, and it charges a fee of GHS 0.30, higher than the rates of its competitors of the same pour flush model, in order to reflect that. An interview with the facility's owner revealed that the majority of the Zongo facility's users are women, for they are willing to pay a higher price for sanitary conditions. The GSAP toilets were judged to be the second cleanest in town, and the Relaxed toilets third. The Djanman and Pokuase Junction facilities were the least clean and were infested with flies, probably because of their higher number of users.

With the exception of the Zongo Toilets, each of the facilities in Pokuase was constructed as an upgrade or renovation to a previously existing facility. The Relaxed, Pokuase Junction, and Djanman Community Self-Help Toilets were previously open pit toilets, but it is unknown what type of toilets the GSAP public toilets replaced. These open pit facilities typically charged fees of GHS 0.05 per use, but this was increased after they were renovated. The Relaxed, Pokuase Junction, and Djanman toilets were upgraded because they were unimproved; as the pits filled, users were splashed with fecal matter while using the toilets, and there was an outbreak of sanitation-related disease amongst female users of the Pokuase Junction facility. The owners claim that, as a result, the government mandated that they upgrade their facilities. The facility at the current GSAP public toilet site, however, was structurally unsound and was replaced after it collapsed (Gyabah 2014).

Interesting social issues also came to light during the examination of Pokuase's sanitation options. At one of the public facilities (kept anonymous to protect the informant), the attendants explained that they are required to pay the owner GHS 180 at the end of the day, regardless of how many users patronize the facility. They explained that this is a daily quota of 900 users, and, on most days, they do not turn a profit. Instead, they pay the difference from their monthly wage of GHS 200 per month (US$3.03 per day)* and the profits that they make on occasional busy days. The attendants earned good wages while neighboring facilities were closed for renovations, but their livelihood has worsened since these competing facilities have reopened. This model creates a form of indentured servitude, in which the attendant is constantly indebted to the facility owner and is compensated with a low and unreliable wage. At the Relaxed Toilets, the attendant earns a commission of 25% on each use, which produces a wage of about GHS 3.75 (US$1.70) per day. Children under the supervision of an adult operate the Pokuase Junction facility, even during school hours. The owners of facilities are also at risk; the Zongo facility's

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*US$1 = GHS 2.20 (Jan. 2014)

owner explained that it is against his religion to work seven days per week, but a group of men threatened and intimidated him and his family, forcing them to keep the facility open every day.

5.3.2 Strategy

The public 10-seat facility, shown in Figure 5-11, was constructed through a partnership of Kweku Anno and Stephen Mecca. As explained above, this facility was built as a replacement to another facility that collapsed due to a poor foundation. The project stands on the land of the Chief of Pokuase and is owned by him as well. The chief is in the process of paying for two of the stalls, and GSAP funded the other eight. Once the chief has finished paying for the first two stalls, ownership of the entire facility will be transferred to him.

Figure 5-11 The public MFBF facility in Pokuase, constructed through a partnership of GSAP and Kweku Anno

Water supply is provided through the combination of a rooftop rain collection system and water pumped from a borehole to a rooftop polytank, as is shown in Figure 5-12. The water is stored in a tank on top of the facility, and it is dispensed through aerator taps on sinks in each stall. Rooftop solar panels power lights inside the facility.

GSAP currently generates a small amount of revenue through the public toilet facility. Eric Agyemang, GSAP's manager in Ghana, explained that the attendant should be charging

Figure 5-12 The Public MFBF's rainwater collection system and polytank

GHS 0.40 per user. However, the attendant, who is contracted through the private waste collection company Zoomlion, only charges GHS 0.30 because very few users patronize the facility when GHS 0.40 is charged. Upon payment, each user is given tissues and assigned a specific stall to use. This allows the attendant to track the use of each stall, ensuring that none have more than 30 users per day.

5.3.3 Outcome

In order to quantify the outcomes of the MFBF public toilets, a series of user surveys and counting of users was done. According to the attendant, about 100 users patronize the facility each day, a figure that is on par with surrounding facilities such as Pokuase Junction. However, during a counting session on Tuesday, January 7, 2014 from 1:15-1:45 PM, 33 individuals (26 males, 7 females, no children) used the Pokuase Junction pour flush facility. During the same time frame on the next day, only one individual, a male, used the GSAP facility. This suggests that the MFBF is not competing effectively with surrounding facilities, especially during afternoon hours, but it also indicates a certain level of uncertainty in the estimates provided by the attendants. It is important to note that 13 out of 15 surveyed users of the MFBF reported having waited in a line outside the facility, so there are periods of high use at the facility. These are most likely in the early morning and evening.

Another interesting observation was that only five of the 33 users counted at Pokuase Junction washed their hands, and only four did not carry in a water bucket with which to flush the toilet. This highlighted a cultural neglect for hand washing but a general understanding that the toilets need to be flushed in order to properly function. Because the MFBF integrates hand washing as a necessary step in the proper function of the toilet, it may promote the practice of hand washing.

On the morning of January 9, 2014, 15 surveys were conducted with users of the public MFBF facility. Results from the surveys are displayed in Figures 5-13 to 5-17. Of particular interest is Figure 5-17, which shows that, of 15 MFBF users surveyed, 13 have access to other sanitation facilities, and seven of these prefer the MFBF over the other facilities. When the other six were asked which facilities they prefer over the MFBF, five of them said that they prefer the Zongo Cemetary Toilets over the MFBF because of its cleanliness. However, they still use the MFBF because of its proximity to their homes. Only one respondent out of the 15 preferred the other public pour flushes, which charge GHS 0.20 per use, because he prefers to squat. This suggests that perhaps the most influential factor in deciding which toilet one uses is proximity to home. In fact, the MFBF is approximately a 10-minute walk from the nearest public facility, and 14 out of the 15 MFBF users surveyed lived within 5 minutes walk of the MFBF facility. Similarly, 7 individuals were surveyed at the Pokuase Junction Facility, and all lived within 4 minutes of the facility. The second most influential factor is cleanliness or odor. Cost and type of toilet (pour flush or MFBF) are lesser concerns. It is important to acknowledge that these survey results refer to the public MFBF facility, which is quite different than the household Microflush Toilets constructed by GSAP today. Still, they provide some sort of indication of user acceptability of the general design of the Microflush and Biofil Toilets.

Another outcome of the public MFBF facility is the production of nutrient-rich soil additives. While this should be a benefit to GSAP, it proved to be a hindrance. First, the facility was closed in February 2013 once the Biofil tanks became filled, and it did not reopen until June 22, 2013 due to complications with the tanks. Second, GSAP was unable to find a buyer for the soil additive. According to Eric Agyemang, urban farmers typically prefer inorganic fertilizers

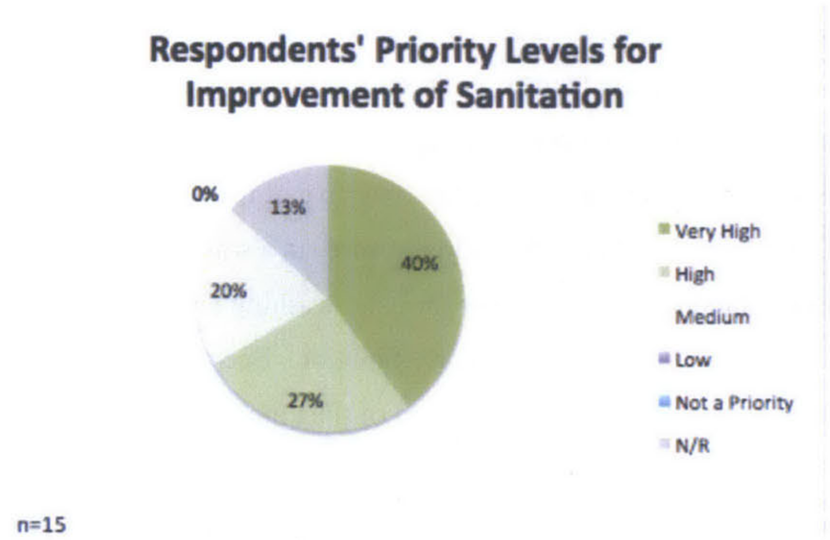


Figure 5-13 MFBF users' priority levels for improvement of sanitation

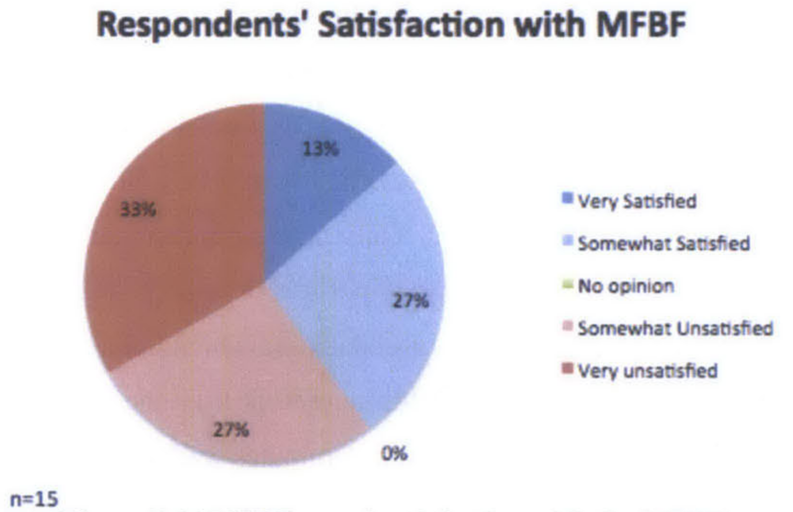


Figure 5-14 MFBF users' satisfaction with the MFBF

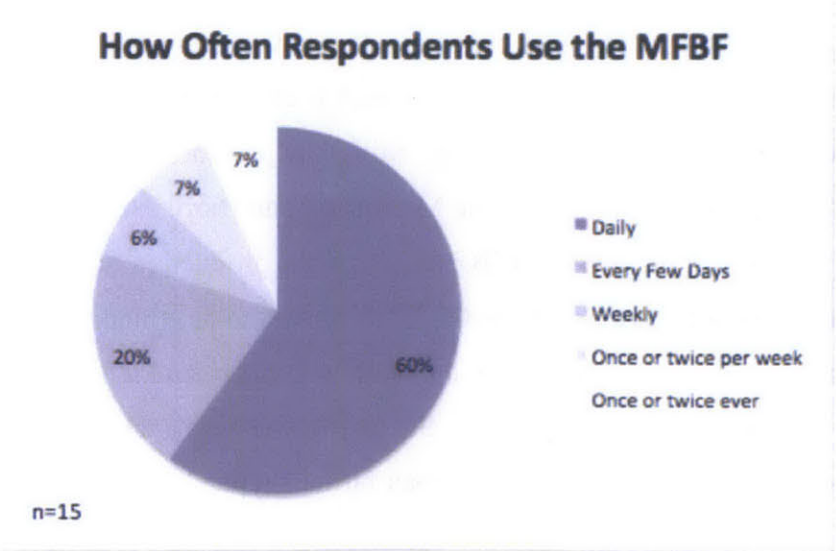


Figure 5-15 How often respondents use the MFBF

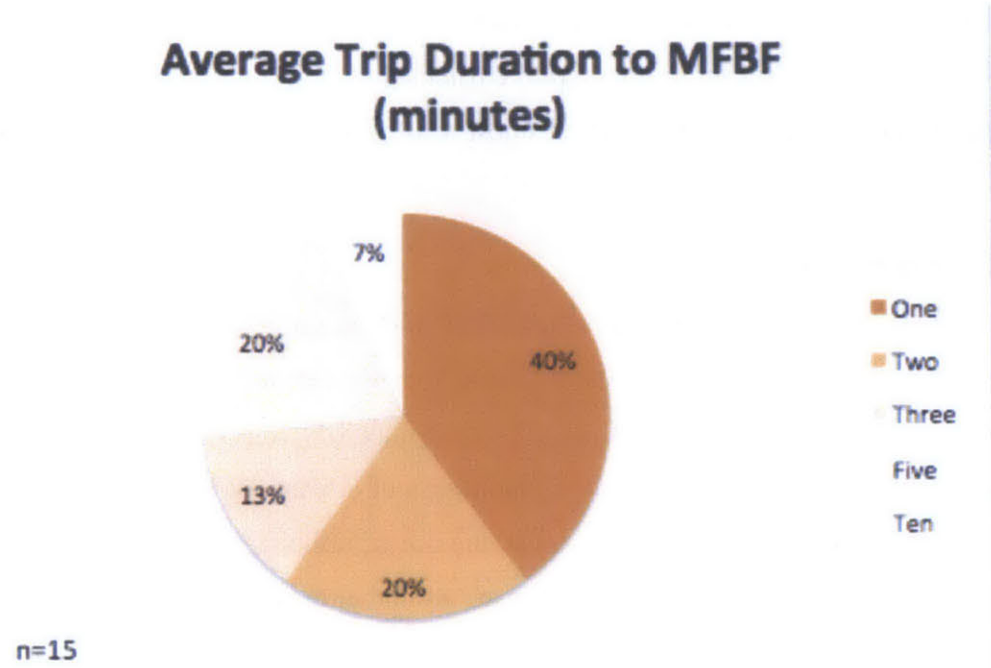


Figure 5-16 MFBF users' average trip durations to MFBF

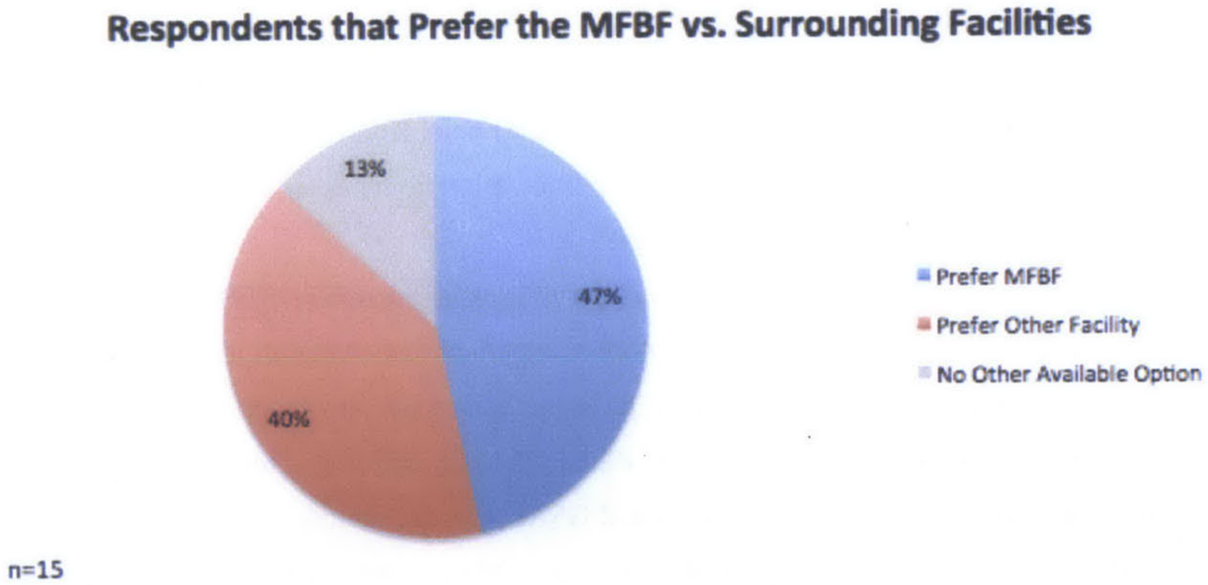


Figure 5-17 Number of MFBF users that prefer the MFBF over surrounding facilities

because they believe that anything produced from fecal matter will be contaminated. Conversely, rural farmers prefer to intercept the trucks that drain septic tanks in order to spray raw sewage on their fields, for this is the cheapest fertilization option available (Agyemang 2014).

5.3.4 Discussion Points

The MFBF turned out to be a less than ideal solution for public sanitation. Patrons often steal loose parts, such as aerators, and the facilities are only cleaned with a broom because bleach and antimicrobial soap kill the bacteria. In public settings, which have a high number of users, this can be a concern because of potential transmission of disease. While conditions are not ideal, the facility does appear to be cleaner than the other public facilities in Pokuase, with the exception of the Zongo facility, which uses bleach and other cleaning products regularly. Also, apart from a stall that was not functioning, the MFBF did not have an offensive odor.

However, the tank was also a source of problems in the public setting. Due to the simplified GSAP design and/or the higher number of users, the tank became filled with sewage after just 7 months, even though it is designed to operate for at least 2-3 years before emptying is necessary. If the toilets must be closed for a long period of time whenever the tanks become full, then the MFBF is not a good solution for public facilities.

Additionally, Biofilcom has expressed concern that the public facility will harm their company's public image. Users of public toilets often do not feel a sense of ownership over the toilets, so they often mistreat and misuse them. Because public facilities are also a prime stage for exposure to potential customers for private facilities, Biofilcom has an interest in protecting the MFBF technology from misuse on this stage.

Finally, a logical solution to the low number of users at the public MFBF would be to lower the user fee to GHS 0.20, the same as other nearby facilities. After all, this would attract more users and would be best aligned with GSAP's mission of aid. However, the surveys above suggest that this might not make a difference. Rather, the key indicator of toilet use is proximity to a given toilet. If the population density around GSAP's MFBF facility is far lower than that around other neighboring facilities, lowering the price might not may a significant difference in the number of users.

5.4 Case Study of GSAP's Private/Shared Microflush Toilets

5.4.1 Context

After GSAP and Biofilcom ended their work together, Biofilcom focused on reaching higher-end consumers while GSAP focused on reaching a consumer base that earns between US$2-3 per day. GSAP now operates in several countries, but its first household Microflush Toilets were implemented near the public facility in Pokuase, as is shown in Figure 5-10. As is explained in the previous section, the vast majority of the people of Pokuase use public toilets. As a result, privately owned toilets are often shared amongst several families.

5.4.2 Strategy

In order to reach those most in need, GSAP altered the design of the MFBF in order to lower its price. While Biofilcom uses a system of manufacturing and delivery/installation using imported materials, GSAP uses on-site fabrication with local materials. This process involves casting two concrete slabs and the toilet base on-site and using wood for the structural supports, TNG plastic sheets or recycled billboard fabric for the latrine walls, corrugated steel for the roof, locally cast cement blocks for the digester walls, a metal or plastic bucket for the toilet bowl, and a metal pie pan for the Microflush "trap door" flushing mechanism (Gyabah 2014). This design is shown in the graphic in Figure 5-18. Because the flushing mechanism was a fairly intricate design, Mecca has begun molding single piece plastic flushing mechanisms in order to ensure quality control. These plastic pieces are shipped out to Microflush Toilet MAKERs across the world (Mecca 2014).

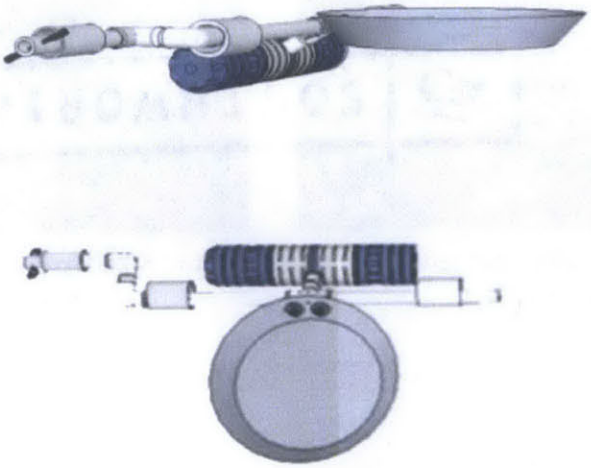


Figure 5-18 The locally-sourced microflush design, utilizing water bottles for counterweights

In order to further reduce the cost, the sink was removed from the design. Because grey water from hand washing is no longer utilized for the flush, users must pour a small bucket of water into the toilet after each use. Images of this new design are shown in Figures 5-19 and 5-20 and may be compared to the high-end design of Biofilcom's Biofil Toilet in Figure 5-9. These strategies have reduced the cost of the unit from US$1200 to US$300. Materials are approximately US$215 of this cost, and labor is US$85.

However, this is still extremely expensive for people who earn just US$2-3 per day. For that reason, GSAP offers a payment plan for interested buyers. Typically, four or five families will invest on a Microflush Toilet together. GSAP requires that the consumers pay one-third the cost upfront, and the other US$200 is offered as a microloan from GSAP. This amount is paid back over the course of a year through monthly payments with 20% annual interest.

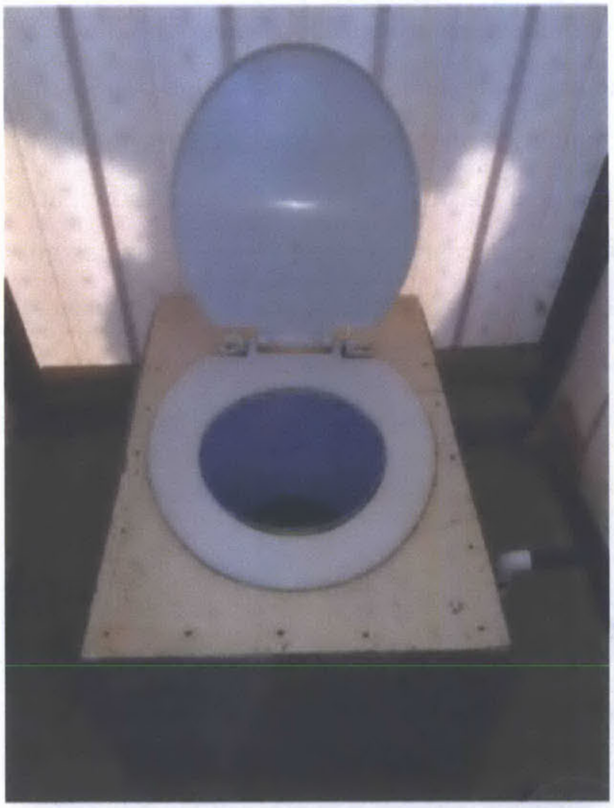


Figure 5-19 GSAP's locally-sourced MFBF toilet with no sink

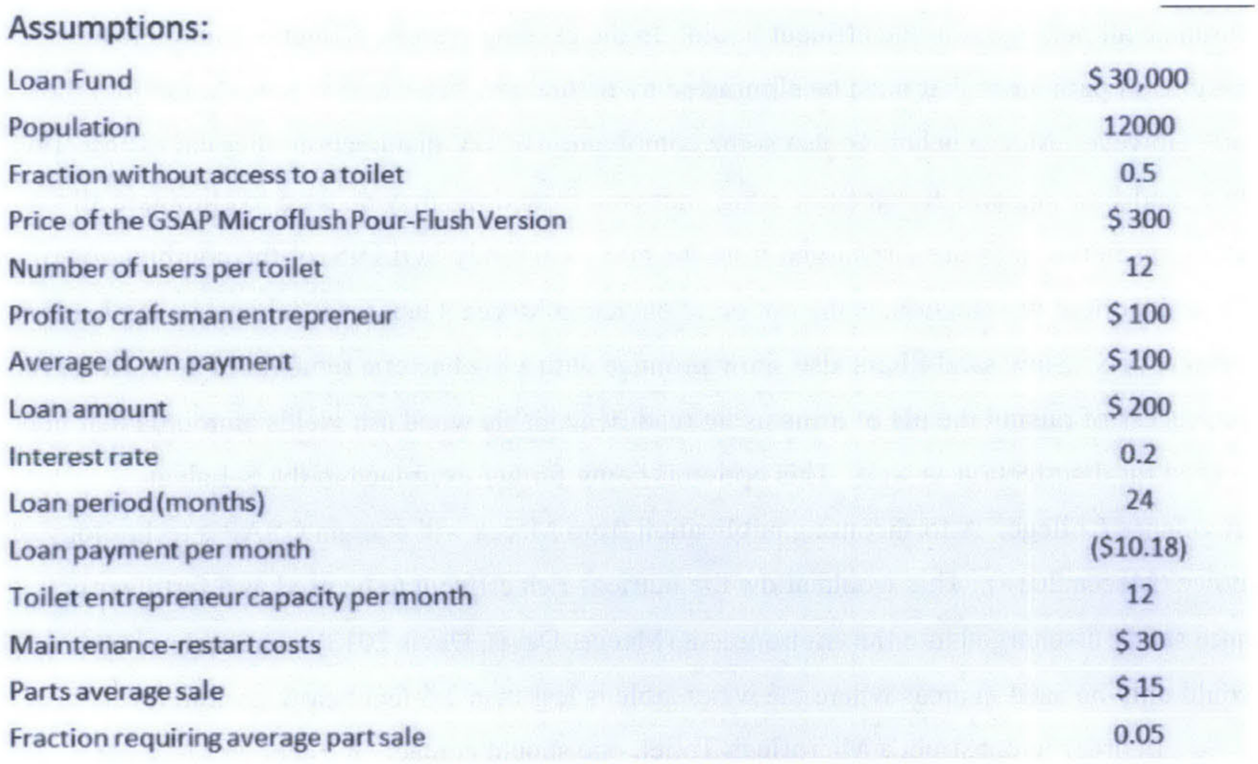
Figure 5-20 Exterior of GSAP's locally-sourced private MFBF facility

5.4.3 Outcome

Each of the six private facilities in Pokuase was constructed within the last two years. The oldest is Gyabah's private Microflush facility, the southernmost unit on the map, which was constructed in early 2012. This facility is essentially the same as Biofilcom's Biofil Toilets, with an imported sink and grey water flush. However, the use of local materials quickly became standard in the following Microflush Toilets' constructions, and the sink was phased out of use. The newest facility, constructed in September 2013, is the Microflush Toilet at Teacher Kope, the northernmost point on the map. All six facilities are under regular use and appeared to be well maintained.

Across the world, GSAP's Microflush Toilet MAKERs have constructed over 100 toilets and are continuing to build. The payment plan, in common scenarios, only requires monthly payments of US$10.18, which is slightly less than even the price paid for a subscription to CTT with biweekly collection (Table 5-2) (Mecca 2014). Additionally, after two years of paying this price, users will then own the toilet, while CTT will need to continue payments.

Table 5-2 Cost breakdown of privately-owned MFBFs for a village



Assumptions:

Loan Fund	$ 30,000
Population	12000
Fraction without access to a toilet	0.5
Price of the GSAP Microflush Pour-Flush Version	$ 300
Number of users per toilet	12
Profit to craftsman entrepreneur	$ 100
Average down payment	$ 100
Loan amount	$ 200
Interest rate	0.2
Loan period (months)	24
Loan payment per month	($10.18)
Toilet entrepreneur capacity per month	12
Maintenance-restart costs	$ 30
Parts average sale	$ 15
Fraction requiring average part sale	0.05

5.4.4 Discussion Points

The Microflush Toilet is a suitable option for private facilities. The issues of theft, complicated use, and spread of disease that are concerns in the public MFBF are not as severe when the design is implemented in a private setting. Also, if the latrine's cost is split between three to five families, the toilet becomes more affordable, although it still may be out of reach for those who earn US$2-3 per day. A previous MIT study determined that the most cost-effective latrine model available was the EcoSan Pod 3, which costs approximately US$65.27 per private unit (Questad 2012). While this is true, the EcoSan Pod 3 does not offer the benefits of a water seal and does not include a superstructure in this cost.

GSAP's Microflush Toilet model is certainly a step above typical pour flush facilities in terms of odor and separation of waste from human contact because it uses both a water seal and a mechanical seal. However, it is unclear whether the abandonment of the sink and grey water flush, which are core pieces of the MFBF system, is justified by the reduction in cost it provides. In the end, it depends on each individual consumer's needs and ability to pay.

Dr. Mecca is continuing the development of the Microflush Toilet at his S-Lab at Providence College. Currently, he is researching disinfection processes that might be used to eliminate all pathogens in the effluent liquid. In the existing system, effluents contain low amounts of pathogens that must be eliminated by natural processes during percolation into the soil. However, Mecca is hoping that some combination of UV disinfection, thermal disinfection, slow sand filtering, and disinfection using ammonia from urine may be used to eliminate all pathogens before they are discharged from the tank. Currently SOLDIS, or the combination of UV and thermal disinfection, is the option of choice in Mecca's lab, for it achieves a log bacteria removal of 8. Slow sand filters also show promise with a log bacteria removal of 5-7. However, the process of raising the pH of urine using readily available wood ash yields ammonia that may be used for disinfection as well. This option is being further examined in the S-Lab at Providence College. A forthcoming publication from Mecca will contain GSAP's technology of choice (Mecca 2014). This would allow the nutrient-rich effluent to be used as a fertilizer or more safely discharged into the environment (Mecca, Davis, Davis 2013). The technology would only be used in areas where the water table is less than 2.5 feet below ground level.

In order to construct a Microflush Toilet, one should contact Dr. Stephen Mecca at Providence College, 1 Cunningham Square, Providence, Rhode Island 02918 or at smecca@providence.edu. Dr. Mecca will train interested individuals to construct their own toilets or can suggest a previously trained MAKER in many areas around the world.

6 Pour-Flush Toilets

6.1 Technological Overview

Pour-flush toilets have a squatting pan with a water seal that separates waste from human contact and a pit or septic tank into which waste is deposited. They require water for flushing to be poured in by the user after each use, and the septic tank becomes full over time and requires vacuum pumping. In Ghana, pour-flush toilet seats are most commonly designed for squatting use, although the technology can be used with seats designed for sitting as well (Anyekase 2014). The squatting-style toilet basin is shown in Figure 6-1.

Figure 6-1 The interior of one of the six pour-flush stalls installed at Taha, a village outside Tamale, Ghana. Its interior shows signs of light use and cleanliness.

The pour-flush toilet seat is a popular option because the water seal is airtight, so odor and risk of contamination via flies are greatly reduced. The water seal is typically about 50 millimeters thick and is created with the use of a S-trap (or U-bend), which causes a small amount of water to stand in the pipe between the seat and the septic tank, as is shown in Figure 6-2. After each use, the user pours a bucket of water into the basin, flushing away the waste and leaving a clean volume of water behind in the pipe as a new water seal. Although they are designed to function with 1-3 liters of water per flush, use of more water is encouraged to prevent blockages in the S-trap. Proper usage should provide an odorless and hygienic experience (WHO 1996).

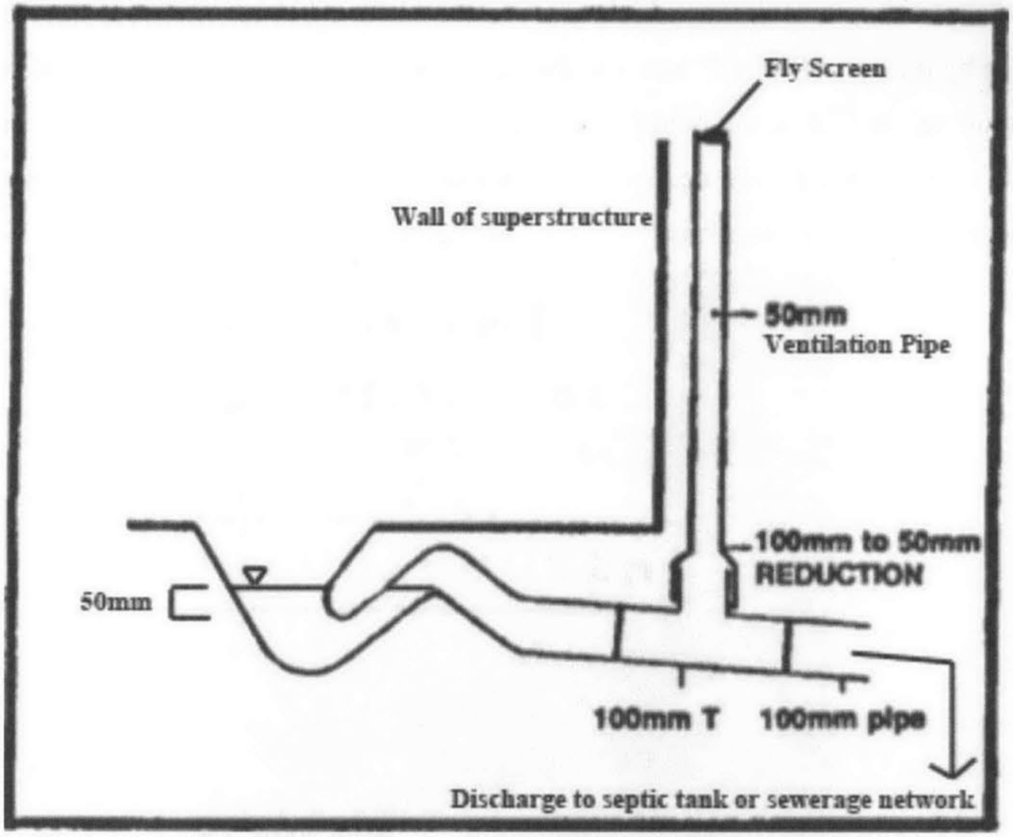


Figure 6-2 Diagram of a pour-flush toilet. A water seal forms in the U-bend at the bottom of the toilet basin. The ventilation pipe allows gas to escape from the septic tank (WHO 1996).

The waste is flushed into a septic tank, where it accumulates until the contents are drained by a truck outfitted with a vacuum pump and water tank. Although this septic tank can be located directly underneath the toilet, waste is more often diverted to a tank behind or outside the latrine in order for easier emptying. A pipe with a ventilation stack with fly screen, as shown in Figure 6-2, allows pressure and gases to disperse and delivers the waste from the toilet to the tank. Some sanitation facilities use two septic tanks per toilet so that flow can be diverted from one tank to another after the first tank becomes filled. Tanks should be located 30 meters from the nearest water sources, downhill from drinking water sources, and above the water table. If it is impossible for the tank to be positioned above the water table, then, at a minimum, the empty tank must be heavier than the amount of groundwater displaced in order to prevent the tank from floating. However, even this strategy is still not feasible in swampy areas or areas with very high water tables, so it should only be pursued as a last resort in areas where the bottom of the tank will slightly overlap the groundwater. The tank should be a minimum of 0.6 meters wide and 1.2 meters deep, although an ideal depth is 1.5 meters. Additionally, the depth should not exceed three times the width (Harvey 2007).

6.2 Case Study

In 2013, Pure Home Water donated a six-seat pour-flush sanitation block to the Taha Islamic Kindergarten School, which previously had no toilets for students or teachers. The intent was for it to be used free of charge by the students and teachers and available to the public for a fee of ten pesewas, or US$0.04, per use. The project was funded by the MIT Public Service Center and Pure Home Water and overseen by MIT Master of Architecture student John Maher.

6.2.1 Context

The pour-flush toilet facility examined in this study is located in Taha, Ghana, a village 7.5 kilometers northeast of Tamale's center. Tamale is the third largest city in Ghana, with a metropolis population of 371,351 (Ghana Statistical Service 2012). However, in Tamale, there are only 5000 water closets, 115 public toilets, and 34 school toilets, leaving many individuals without toilets (Figure 6-3) (Tetteh 2012). In the surrounding rural areas, the situation is even worse. As is illustrated in Table 6-1, 72.6 percent of the population in the Northern Region lacks access to a toilet (Ghana Statistical Service 2012). The populations of rural villages surrounding Tamale have even less sanitation coverage (Mubambe 2014).

One of these villages is Taha, a village of approximately 600, where the factory of MIT Senior Lecturer Susan Murcott's social enterprise Pure Home Water is located. According to a study done by Chipo Mubambe during January 2014, there are currently 14 toilets and approximately 940 residents in Taha. This is a sanitation density of one toilet per 67 individuals. However, before the construction of the six-seat pour-flush facility under study, there were only eight toilets in the village, and the density was one toilet per 117 individuals. Six of the existing toilets are privately owned but are shared amongst several families. Five of these are KVIPs, and one is an open pit latrine. The other two toilets are community toilets shared by many community members; one is a KVIP operated by the community clinic, and the other is an

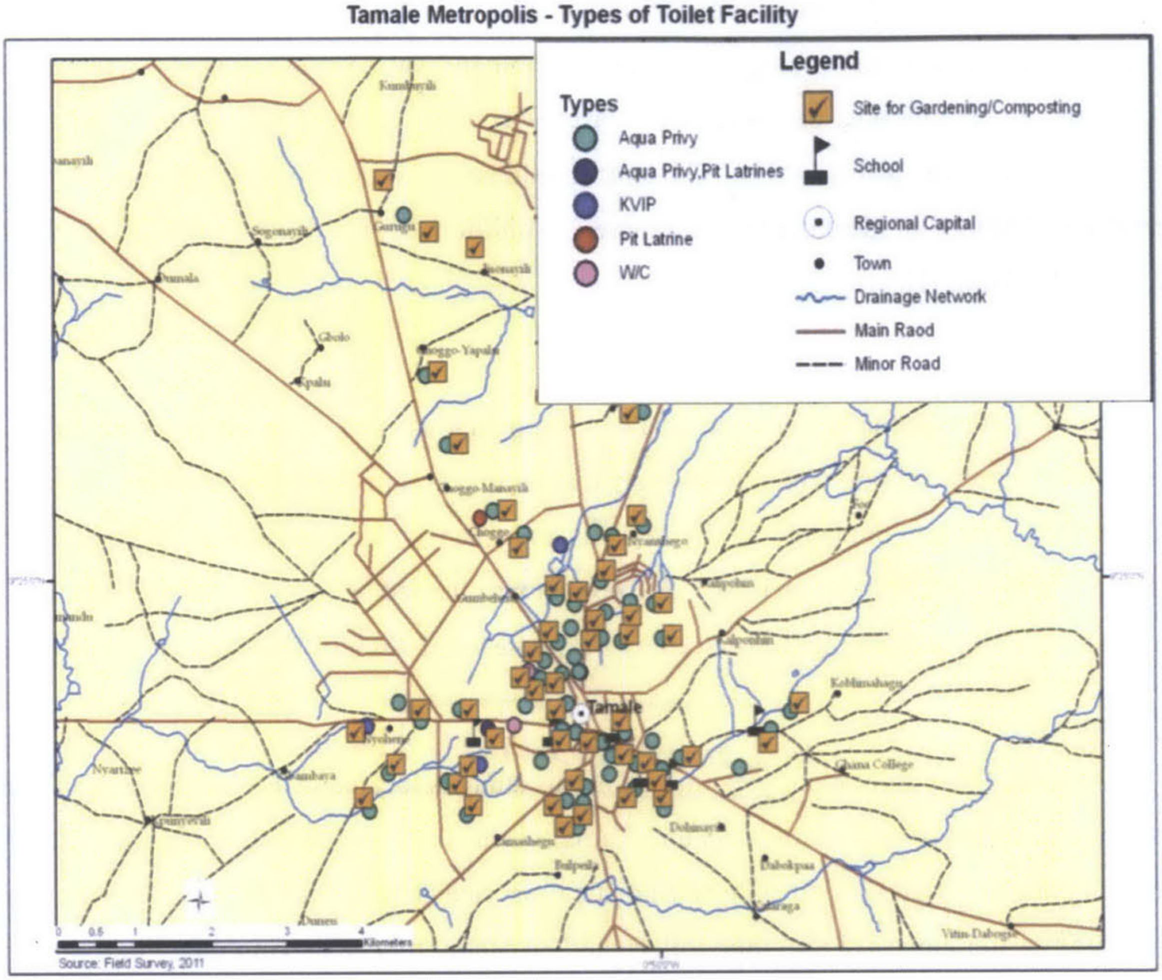
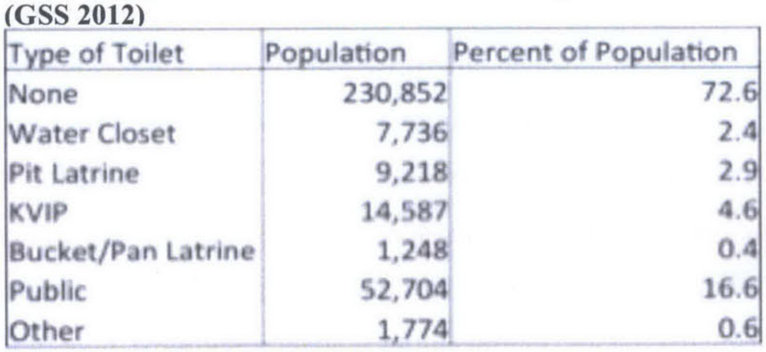


Figure 6-3 Public Toilets in Tamale Metropolis (Tetteh 2012)

Table 6-1 Numbers and Proportions of individuals using different types of Toilets in the Northern Region of Ghana (GSS 2012)



Type of Toilet	Population	Percent of Population
None	230,852	72.6
Water Closet	7,736	2.4
Pit Latrine	9,218	2.9
KVIP	14,587	4.6
Bucket/Pan Latrine	1,248	0.4
Public	52,704	16.6
Other	1,774	0.6

EcoSan at the Pure Home Water Factory. From this information, it can be deduced that a large proportion of the population was practicing and continues to practice open defecation, even after the construction of the six-seat facility under examination. As is shown in Figure 6-4, he conditions are no better in the surrounding villages of Kpawumo, Gbahali, Wovuguma, Wovogu, and Gburima, which have toilet densities of 487, 89, 47, 80, and 58 individuals per toilet, respectively.

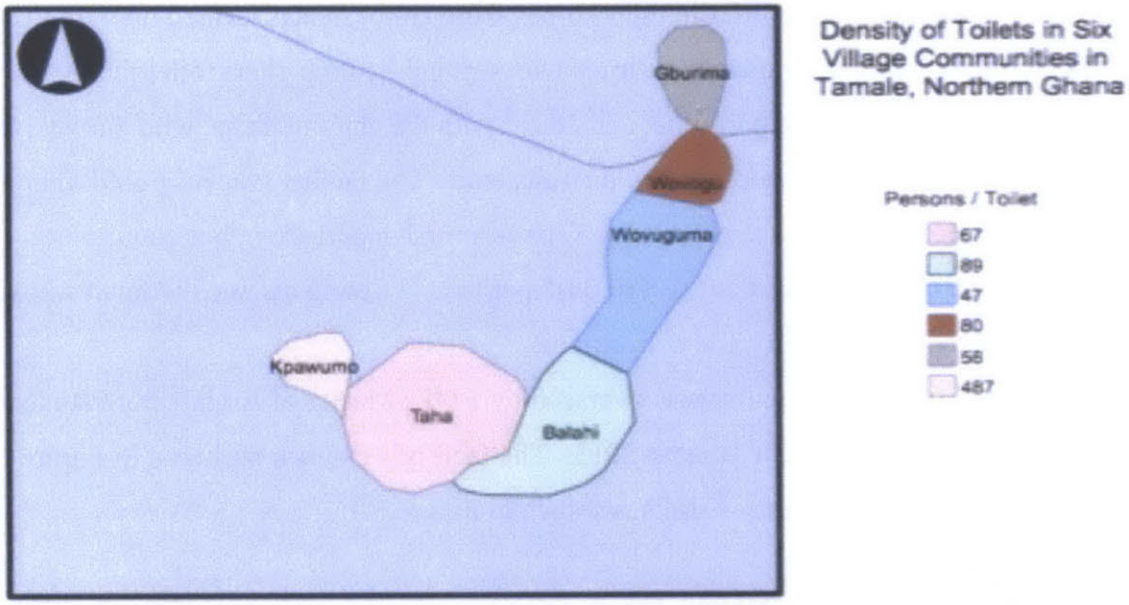


Figure 6-4 Density of toilets in six village communities Northeast of Tamale (Mubambe 2014)

6.2.2 Strategy

The Ghana government has accepted Community-Led Total Sanitation (CLTS) as its official plan to end open defecation. The implementation of the CLTS model has, in theory, five steps. First, an enabling environment is created by the adoption of the model by local, regional, and national governments. Next, capacity is strengthened by training local artisans to construct latrines and by adding sanitation training into school curriculum. Third, demand is created by reinforcement of latrine use by women and community leaders, often in the form of shaming those who continue to practice open defecation. Facilitating supply by strengthening supply chains and bringing down costs is the fourth step. Finally, monitoring and evaluation is meant to ensure that the success is sustainable. This CLTS plan requires that no aid or donations from outside parties be given because demand for and ownership of toilets are key components of

CLTS (Republic of Ghana 2012). However, an MIT study by Adam Questad revealed that only 9% of I-WASH CLTS projects in Ghana were successful in ending open defecation. As a result, he recommended that aid be provided to rural communities in the form of low-cost or subsidized sanitation options (Questad 2012).

Accordingly, when Pure Home Water constructed its ceramic pot filter factory in Taha, Murcott chose to work with factory staff from Taha and the Taha community in order to aid Taha toward a faster path to sanitation coverage. Because the workers of the factory lacked access to improved sanitation facilities in their homes, Pure Home Water teamed up with the MIT Public Service Center to fund and construct a six seat public pour-flush toilet facility in Taha. This construction was also part of an agreement with the chief of Taha, who allowed the construction of the Pure Home Water factory on Taha land. The facility was purposed to be free of charge to students and teachers at the nearby Taha Islamic Kindergarten, but community members were to be charged GHS 0.10 (US$0.04)* per use. A young disabled woman was to serve as the caretaker of the facility and collect fees.

The construction of the facility was overseen by a MIT Master of Architecture student, John Maher, and was carried out in January 2013. The facility's exterior is shown in Figure 6-5, and the interior of one of the facility's stalls is shown in Figure 6-1.

Figure 6-5 Exterior of the Taha Pour Flush Sanitation Facility

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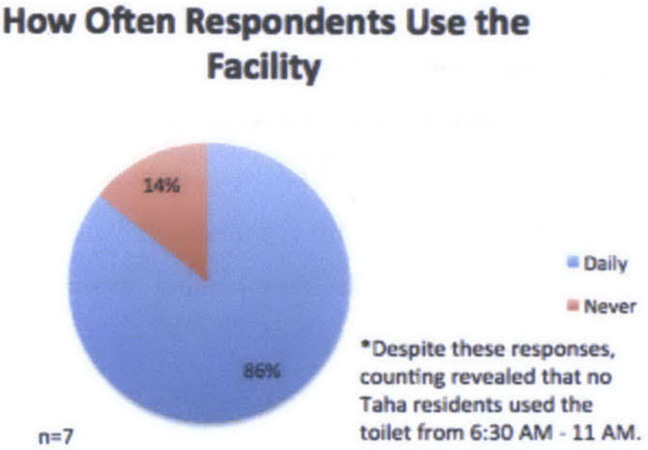
*US$1 = GHS 2.20 (Jan. 2014)

Because half of the Pure Home Water factory workers are from the nearby village of Gbahali, a similar arrangement for a toilet facility was made there. In February 2014, Pure Home Water and the MIT Public Service Center constructed a second public toilet block. This time, at the request of the Gbahali community, a six seat public KVIP facility was constructed. A comparison between Gbahali's adoption of their public KVIP and Taha's adoption of their public pour-flush facility may inform future decision making for toilet provision in the peri-urban and rural areas surrounding Tamale.

6.2.3 Outcome

Although the construction of the six-stall pour-flush toilet facility at the Taha Islamic Kindergarten nearly doubled sanitation density in Taha, the engrained tradition of open defecation has inhibited use of the facility. As is shown in the charts below (Figures 6-6 to 6-10), six of seven respondents in the homes nearest the facility claimed to use the facility on a daily basis. However, with the exception of the teachers, only one individual, who was visiting from Accra, patronized the facility during three days of observation at the facility. This included a specific counting period from 6:30 AM until 11 AM, the typical period of peak toilet use, on the morning of January 21, 2014. This suggests that the Taha villagers are actually not using the facility on a daily basis, despite their survey responses. Still, most interviewees insisted that the facility experienced higher numbers of users during the rainy season, when farmers were not in their fields and villagers feared attacks from reptiles that might be hiding in the thick vegetation.

Additionally, children are not using the facility, although adult villagers believe that they should. Interviews with the teachers and the headmistress of the Taha Islamic Kindergarten indicated that children are actually not allowed to use the facility during school hours, despite the fact that their use of the facility was the primary reason for its construction. This was partly because the teachers possessed the key to just one of the six stalls, and the prospect of sharing the single toilet amongst the teachers and students was not well received. Also, the teachers were uncertain whether either or both the teachers and the children were to pay to use the toilet during school hours. This information from the interviews was triangulated with the survey responses of individuals who live near the facility and direct observations. As is shown in Figures 6-7 and 6-8, five of seven respondents believed that children do not use the pour-flush facility, although all seven believed that they should. Similarly, observations showed that



*Despite these responses, counting revealed that no Taha residents used the toilet from 6:30 AM - 11 AM.

Figure 6-6 How often respondents use the Taha Islamic Kindergarten pour-flush facility

Figure 6-7 Number of respondents who believe that schoolchildren use the Taha Islamic Kindergarten pour-flush facility

Figure 6-8 Number of respondents who believe that schoolchildren should use the Taha Islamic Kindergarten pour-flush toilets

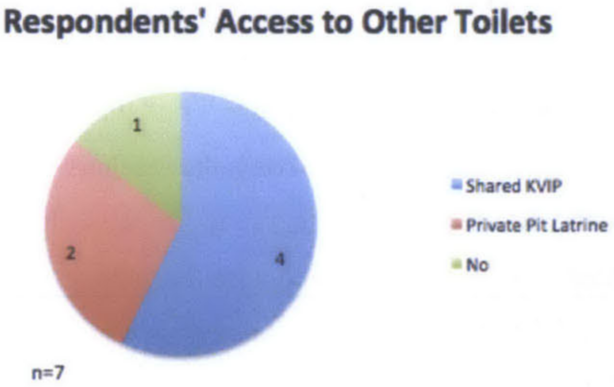


Figure 6-9 Other types of toilets to which respondents have access

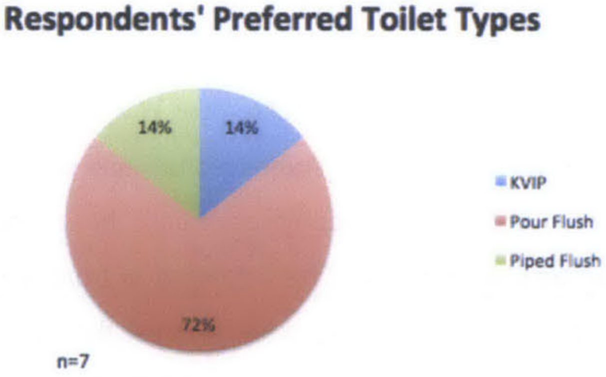


Figure 6-10 Respondents' preferred toilet technologies

children relieved themselves next to the trees outside the kindergarten rather than using the pour-flush toilets.

While the usage rates were not as high as anticipated, the surveys did indicate that the pour-flush technology was a proper fit for the community. When asked which type of toilet they prefer, five of seven respondents claimed to prefer the pour-flush (Figure 6-10). Additionally, six of the seven respondents had access to another facility, but four of them claimed to prefer the pour-flush to their other toilet.

The condition of the facility was good, although it was unclear whether this was due to low numbers of users or proper upkeep. The stalls showed signs of mild use and were fairly clean, although three of the locks on the doors were broken (Figures 6-1 and 6-11). Also, although the attendant booth outside the facility was empty, the attendant lives in the home next to the facility, and individuals are to pay her before using the facility. However, the broken locks enable individuals to use the facility without paying. During the peak hours of the morning, children monitor the facility in order to prevent unpaid use by community members.

Figure 6-11 Three of six locks have been broken, allowing free use

6.2.4 Discussion Points

A stakeholder meeting with the chief and elders of Taha, a representative from the Wuni Zaligu Development Association (WUZDA), and schoolteachers was held to discuss the future of the Taha pour-flush facility. In this meeting, problems were identified, reasons for the problems were postulated, and solutions were sought. The two primary problems were, first, that the community does not use the toilets and, second, that students do not use the toilets. The reasons for these two problems are different, as are their solutions.

The public's reasons for not using the facility were many. The primary reason seemed to be tradition; as long as there is still bush around the community, open defecation will always be the preferred option of the people because that has been their habitual behavior since childhood. However, as growth is occurring, nearby land is being bought/sold and developed. The resulting destruction of the bush may force people to begin using toilets for privacy reasons. Second, villagers claim that use of the pour-flush facility would be much greater during the rainy season. The evaluation was completed during the dry season, during which farmers spend the entire day in their fields, where they also defecate. During the rainy season, however, farmers spend more time in the village, and more villagers use the facility out of fear of being attacked by reptiles that hide in the overgrown vegetation. The third reason given was that the people are not educated about WASH and the spread of sanitation-related diseases and do not know how to use the pour-flush technology, so they simply do not use it. Fourth, some villagers believed that the facility would attract more users if it were located in a more densely populated area. However, the facility's current location allows for intervention with young children, who are most susceptible to sanitation-related diseases. Finally, some villagers admitted that the cost of GHS0.10 per use was a deterrent. One mother made the argument that she would rather use her ten pesewas saved from the toilet in order to fund her child's education.

After these reasons were laid out, solutions were sought. Although use will naturally improve during the rainy season, one of the elders, the chairman of the Taha WASH committee, proposed that he hold regular meetings to educate about sanitation and improve awareness of sanitation-related diseases. Also, the WUZDA representative present offered to implement a system in which microloans are given to groups of women in the community. These loans can be used to purchase something that can be sold to pay off the loan and generate a profit. If one member of the group fails to pay off her part of the loan, the other members are responsible.

This model could be used in order to generate funds to pay latrine fees for families that cannot afford it.

The reasons for the second problem of the students not using the toilet were simpler. First, the teachers were not present at the initial planning meetings for the facility, so they were uninformed and believed that the children were supposed to pay to use the facility. Second, the teachers were only given the key to one of the six stalls, and they were even unsure as to whether or not they were to pay to use it. Additionally, although they were teaching lessons on sanitation and hand washing, the teachers did not give demonstrations on how to use the pour-flush because they were unaware that it was to be used by the children. There was also a general belief amongst the teachers that the facility was "too nice" and that the young children would spoil the facility through improper use. The final concern regarding students' use of the facility is that a new school is opening near the Pure Home Water factory, and some of the students at Taha Islamic Kindergarten will be moved there, a five minute walk away from the pour-flush toilets.

The problem of poor toilet use by students has simpler solutions than the problem of poor use by the public. The simplest fix was to spread awareness amongst the teachers that the schoolchildren are to use the facility. In order to do this, the stalls should be re-designated so that three are for public use, and three are for school use. The public stalls will have one seat for males and two for females while the school stalls will have one seat for the teachers, all of whom are female, one seat for male students, and one seat for female students. Additionally, the teachers should be given the keys for this half the facility and should begin demonstrating pour-flush toilet use as part of the school curriculum. This stall re-designation would eliminate the concern that improper use by students could spoil the facility for the adults. However, it creates some concern about male and female adults sharing a common entrance, for each set of three stalls has a single entrance hallway. Nonetheless, this seems to be a better solution than the current designation of the stalls. Although the facility has not been used to its full potential over its first year of existence, it is important to acknowledge that it is combatting a tradition of open defecation that is rooted in thousands of years of history. It is therefore unfair to condemn the facility as a failure, for change cannot occur in just one year; rather, behaviors must be shaped and adjustments made over the course of the facility's lifetime in order for it to become accepted by the community of Taha.

7 IMWI Fortifer Pellets

7.1 Context

Each of the sanitation innovations reviewed up to this point has been a decentralized toilet technology. Improved toilets are essential for the improvement of human health, for they hygienically separate fecal matter from human contact, thereby disrupting fecal-oral transmission pathways. Even better, however, is when toilets treat the waste in addition to consolidating it, as many of the technologies reviewed do. However, the vast majority of toilets in Ghana are not innovative and simply allow waste to accumulate inside a septic tank or pit until it is collected by a vacuum truck. Due to the lack of functioning wastewater treatment facilities in Ghana, much of this collected waste is subsequently discharged into the environment at beaches, rivers, or fields. In fact, 90 percent of wastewater in the developing world is discharged directly into environment without any treatment (Corcoran et al. 2010). This contributes to eutrophication of aquatic ecosystems, contamination of drinking water, and water-related disease transmission, undermining the efforts toward the attainment of universal sanitation.

In Ghana, this is especially a problem. Latest data indicates that 59% of Ghanaians use shared toilets, many of which are public and not connected to sewer systems. These public toilets are emptied as frequently as once every two weeks, and, according to the manager of a public toilet facility in Pokuase, a suburb of Accra, essentially every public toilet in Greater Accra sends its waste to be dumped into the ocean. This dumping, shown in Figure 7-1, typically takes place at Korle Lagoon Beach, which is sarcastically euphemized as "Lavender Hill" because of its offensive odor (Yaro 2014). Lavender Hill typically receives around 120 truckloads, or 1200-1300 m^3, of sludge each day, and this drains directly into the ocean (Issah 2013, Sunnesson 2013). This figure does not include the wastewater from coastal settlements that flows into the ocean untreated as well, as shown in Figure 7-2. In Northern Ghana, where there is no ocean access, untreated waste is sometimes applied directly to fields as a fertilizer for agriculture (Tanner 2013). In other instances, septic tanks discharge their waste into ponds at the Tamale Metropolitan Assembly landfill at Gbalahi (Murcott 2014). While this is indeed an effective means of fertilization, it leads to contamination of crops and transmission of water-related diseases. For example, a study in Kumasi revealed that, because of wastewater irrigation, total coliforms found on lettuce varied between 49,300 to 61,700 CFU, approximately 50-60

Figure 7-1 Vacuum trucks empty tanks of septage at Lavender Hill as often as every three minutes (Corcoran et al. 2010)

Figure 7-2 Wastewater from a slum in Accra pours down a cliff side and into the Atlantic Ocean

times the World Health Organization (WHO) and International Commission on Microbiological Specifications for Food (ICMSF) standards of 1,000 CFU (Tiimub et al. 2006). Reuse of waste as fertilizer also takes place in Accra, where 50 hectares of land are currently farmed using untreated wastewater from the Burma Military Camp**. Here, farmers have punctured pipes to divert the wastewater flow from the camp's dysfunctional sewer system into their fields for irrigation and fertilization (IWMI 2008). As a result, even those Ghanaians who have improved sanitation and water supply are exposed to fecal pathogens through food consumption.

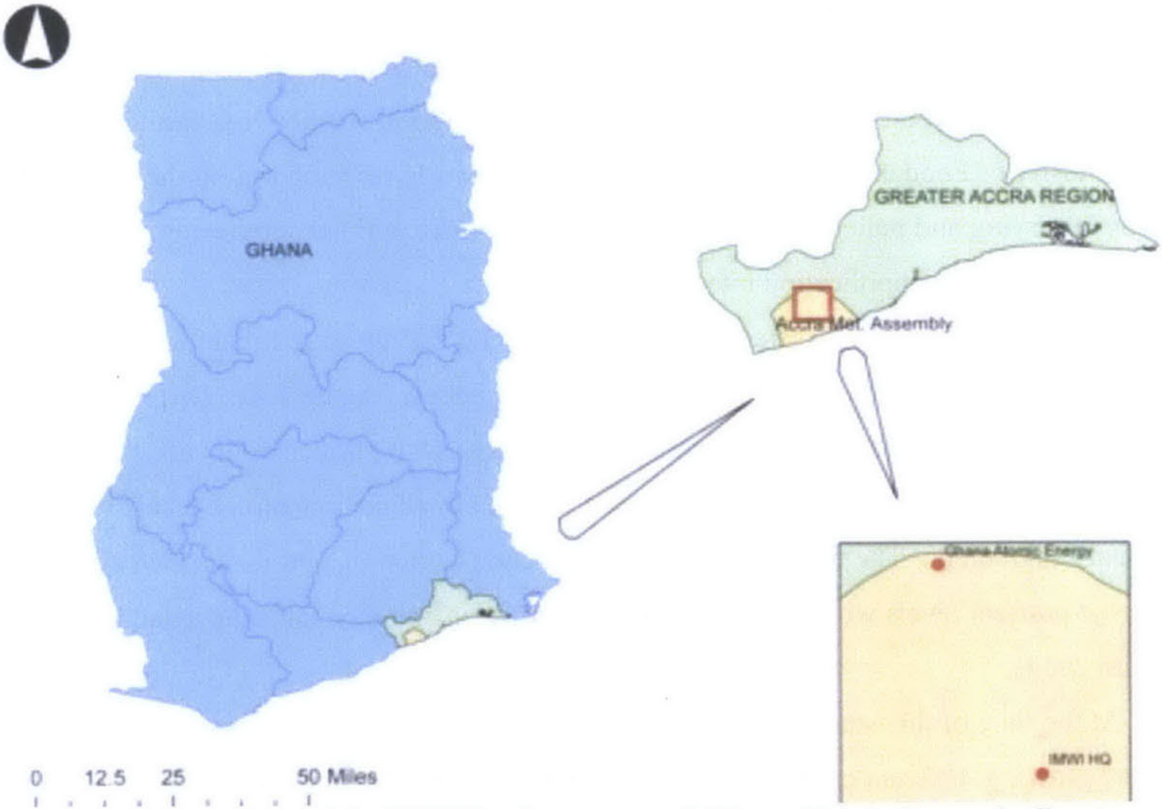


Figure 7-3 Locations of the IMWI headquarters and Ghana Atomic Energy in Greater Accra (Mubambe 2014)

The International Water Management Institute (IWMI) has found a way to eliminate the risk for disease transmission while conserving the sustainable productivity yielded from reuse of human waste as fertilizer. Through a project entitled Recovery of Organic Matter and Nutrients from Fecal Sludge for Food Production in Ghana, or simply WaFo (Waste to Food), IWMI has created Fortifer. Fortifer is a brand of fortified excreta pellets for fertilization that are created from the sludge of vacuum trucks. The production of these pellets conserves the majority of nutrients in the sludge while eliminating all pathogens (Impraim 2014).

**https://www.youtube.com/watch?v=f_EnUGa_GdM

IWMI is located in the cantonments of Accra, and the research for the WaFo project is conducted by Ghana Atomic Energy. Both are located on the map in Figure 7-3. The WaFo project is funded by the Bill and Melinda Gates Foundation.

7.2 Strategy

7.2.1 Research and Commercialization

The Fortifer operation began at the end of 2011 with a feasibility research phase. This purpose of this phase was to develop the product and prove its feasibility from a technical standpoint. Six scientists at Ghana Atomic Energy, a government research institution, undertook this task, ensuring that the product met standards from the World Health Organization and the Ghana Ministry of Food and Agriculture. They also conducted research to find the most efficient methods for drying and pelletizing, the best binding agent, the optimal composition of the pellets, and the optimal application rate (Impraim 2014).

As of January 2014, the scientists at Ghana Atomic Energy were finishing experiments that would determine the ideal feedstock for the Fortifer pellets (Figure 7-4). Different proportions of fecal sludge, sawdust, municipal solid waste with plastics removed, charred waste, vegetation, and soft and hardwood were being examined. In all combinations, fecal sludge was the primary ingredient. The most feasible feedstock composition that produces the pellets with the highest nutrient levels will be the one selected for use in commercialized production (Impraim 2014).

At the time of this study, IWMI was also studying the residual effects of Fortifer on soils that were growing different crops. That is, they were applying Fortifer to several plots of land, planting different species of crops on each plot, and measuring the nutrient levels of the soil on each plot annually. This reveals how Fortifer is absorbed by different crop types and could be valuable information for marketing purposes (Impraim 2014).

As the research phase came to an end in early 2014, a two-year commercialization stage began in January 2014. In this phase, market research will be conducted, and the production process will be streamlined for commercial-scale manufacturing of Fortifer pellets. The commercialization process will likely take place at the municipal waste facility in Tema, a suburb to the east of Accra, where the sludge was collected and dried for the research phase (Impraim 2014).

Figure 7-4 A Ghana Atomic Energy scientist analyzes the nutrient levels of pellets of different feedstock compositions

7.2.2 Technology Overview

The production of fortified excreta pellets is a five-step process of drying, composting, grinding, enrichment, and pelletizing. To begin the process, raw sludge is acquired from vacuum trucks that pay GHS 10-20 (US$4.55-9.09)* to discharge their sludge at the Tema municipal waste facility (Figure 7-5). The sludge is first dewatered in drying basins for fifteen days. This process is accelerated by sand and gravel base layers in the drying bed, allowing for removal of water through both percolation and evaporation. Once this is complete, the sludge is rewetted and composted for 90 days, with occasional turning for aeration. During this step, as a result of reactions aided by aerobic bacteria, the dewatered sludge should reach a temperature of 55° C in order to kill the vast majority of pathogens. After 90 days, the composted sludge is tested, because, before the process can continue, the compost must be essentially free from pathogens, and a seed must be able to germinate in a solution of the compost and distilled water within 4 days. Once these two criteria are met, the compost is spread to dry once again. The drying will

*US$1 = GHS 2.20 (Jan. 2014)

Figure 7-5 Raw dewatered fecal sludge, delivered from the drying beds at Tema

Figure 7-6 After composting and grinding, the material is ready for enrichment

kill any residual pathogens that remained after the 90 days of composting. After it is pathogen-free and dry, the compost is ground into fine particles using a grinding machine (Figure 7-6) (Nettey 2014).

Fertilizer is typically measured in terms of nitrogen, phosphorus, and potassium content, or N-P-K, and the compost typically contains 1.7% nitrogen, 0.3% phosphorus, and 0.3% potassium by mass after composting. Ghana Atomic Energy tracks nitrogen levels throughout the process and has observed that nitrogen content falls from 2.3% to 1.7% over the course of the composting process. IWMI has concluded that, in order to be competitive with inorganic fertilizers on the market, Fortifer must contain at least 3% total nitrogen. Therefore, inorganic fertilizers are purchased from Agricultural Input Bureaus in Accra and are added to the composition in a mixing machine (Figure 7-7) (Nettey 2014).

Figure 7-7 Inside the mixing machine, pictured above, inorganic fertilizer and pre-gelatinized cassava starch are mixed with the compost

Also added is a pre-gelatinized cassava starch that acts as a binder for the final pelletizing step. As a part of the research process, several binders were examined. Binders considered included clay, molasses, beeswax, and irradiated cassava starch, and pre-gelatinized cassava starch. Pre-gelatinized cassava starch was selected for use because it proved to be a strong binder, only requires heat and water to be added to complete the binding process, and is locally available from peri-urban farmers. The final pellets are 3% pre-gelatinized cassava starch and 97% compost, plus any necessary inorganic fertilizer. After the compost is combined with the cassava starch, heated water, and inorganic fertilizer, the final mixture is extruded through a pelletizer machine, dried in the sun, and packaged for sale (Figures 7-8, 7-9) (Nettey 2014).

Figure 7-8 The final mixture of compost, inorganic fertilizers, and cassava starch is extruded to produce pellets for agriculture

At the research phase's current capacity, composted sludge can be pelletized at a rate of 100 kilograms per hour, but the research facility lacks the space and capacity to compost sludge that quickly. Upon commercialization, the process will be automated with conveyers and other machinery, and space will readily be available for drying and composting (Nettey 2014).

Figure 7-9 The final pellets, ready for application to crops

7.3 Outcome

Because Fortifer has not yet been commercialized, the success of the product in the market cannot yet be assessed.

7.4 Discussion Points

Fortifer appears to be a solution applicable to areas with heavy agricultural activity and inadequate, if any, sewerage systems. The first step of Ghana Atomic Energy's research phase has proved the product from a technical standpoint. However, because it has not yet been commercialized, there are concerns regarding whether or not it will be able to compete with other widely available and comparatively inexpensive synthetic fertilizer options on the market. The final Fortifer product is intended to have an N-P-K rating of 3-0.69-0.36 after enrichment and 1.7-0.69-0.36 before enrichment (Impraim 2014). These values pale in comparison to other options available to farmers, such as collected urea, which has a nitrogen content of 45%, and other common fertilizers, which are shown in Table 7-1 (Chemical Land21 2013).

Table 7-1 N-P-K ratings for common fertilizers (Chemical Land21 2013)

Fertilizer	Nutrient wt %		
	N	P_2O_5	K_2O
Ammonia anhydrous	82		
Ammonia solution	20 - 25		
Ammonium Bicarbonate	15.5		
Ammonium Chloride	25 -27		
Ammonium Phosphate sulfate	13 - 16	20 - 39	
Ammonium Polyphosphate	10 - 11	34 - 37	
Ammonium Thiosulfate	12		
Ammonium Chloride	25 - 26		
Ammonium Nitrate	33 - 34		
Ammonium Sulfate	21		
Ammonium Sulfate Nitrate	26		
Calcium Ammonium Nitrate	20 - 28		
Calcium Cyanamide	20 - 21		
Calcium Nitrate	15		
Diammonium Phosphate	18 - 21	46 - 54	
Dicalcium phosphate		35 - 52	
Kainit			12 - 22
Monoammonium Phosphate	11	48 - 55	
Nitrogen Solution	28 - 41		
Phosphate Rock		26 - 37	
Potassium Chloride			60
Potassium Magnesium Sulfate			22
Potassium Nitrate	13		44
Potassium Sulfate			50
Slag Basic		12 - 18	
Slag Potassic			43
Superphosphate single		17 - 20	
Superphosphate triple		44 - 48	
Sodium Nitrate	16		
Urea Phosphate	17	43 - 44	
Urea	45		
Urea Ammonium Nitrate	28 - 32		
Urea Ammonium Phosphate	21 - 38	13-42	
Urea Sulfate	30 - 40		

In order to overcome its less potent N-P-K rating, Fortifer will need to be offered at a lower price per unit mass of nitrogen than inorganic fertilizers. A study in Kenya revealed that one common fertilizer, diammonium phosphate (DAP), sold for US$0.53/kg on the market (Robinson 2005). With an N-P-K rating of around 17-45-0, DAP costs US$3.12/kg nitrogen. Because there is five to six times more nitrogen in DAP than in Fortifer, the price of Fortifer will need to be less than US$0.09/kg in order to remain competitive with DAP in the free market. Additionally, according to an IWMI researcher, one competing organic fertilizer on the market in

Accra can be purchased at a price of GHS 0.48/kg (US$0.22)* (Impraim 2014). At the very least, if Fortifer cannot match the prices of inorganic fertilizers, it will need to match US$0.22/kg in order to compete with other organic fertilizers. This could prove to be a difficult task, given the fact that inorganic fertilizer will need to be purchased as an enricher for Fortifer.

Still, the product does hold potential. Citizens of Accra have proven, through its use of the Burma Military Camp's wastewater for agriculture, that they are not opposed to the use of human waste on their crops. Additionally, the project has potential to grow to a very large scale. In urban Ghana, 72 percent of people use shared sanitation (UNICEF/WHO JMP Progress on Sanitation… 2013). If it is assumed that this national average applies to Accra, this means that approximately 1,331,000 citizens of Accra use public sanitation facilities (Ghana Statistical Service 2010). Each person produces 25-50 kg of feces per year, which contains up to 0.55 kg nitrogen, 0.18 kg phosphorus, and 0.37 kg potassium (Jonnson et al. 2004). This means that public sanitation users in the city of Accra produce approximately 33-65.5 million kg of feces per year, containing 732,050 kg nitrogen, 239,580 kg phosphorus, and 492,470 kg potassium. However, feces only constitute 12% of total nitrogen, 33% of total phosphorus, and 27% of total potassium in waste sludge (Jonnson et al. 2004). This means that public sanitation users in Accra produce an approximate total of 6,100,417 kg nitrogen, 726,000 kg phosphorus, and 1,823,963 kg of potassium in their waste sludge. Therefore, supply of waste sludge will not inhibit the growth of the Fortifer operation.

These numbers also elucidate the potential that urine diversion holds as a means of nutrient recovery for fertilizer production. As was illustrated above, the Fortifer pellets contain far less nutrients than other readily available synthetic fertilizers on the market, so they may struggle during commercialization. The average human's urine contains approximately 8.04 grams nitrogen per liter, all of which is available as ammonia for fertilizer after the urine is allowed to sit for one month until ureolysis is complete. It also contains around .8 grams of phosphorus per liter (Robinson 2005). If urine is assumed to have the same density as water, this would mean that liquid urine has an N-P-K rating of 8.04-1.83-N/A if allowed to complete ureolysis. Further, if the urine can be refined to urea, as shown in Table 7-1, its N-P-K rating would be 45-0-0. Both of these rates are marked improvements to the Fortifer pellets. Additionally, shortage of urine from public toilets would not be an issue so long as urine diverting seats were installed in public facilities. This is because, if the average person produces

*US$1 = GHS 2.20 (Jan. 2014)

500 liters of urine per year as Robinson suggests in his study, Ghanaian public toilet users would produce 5,350,620 kg nitrogen and 535,062 kg phosphorus in urine alone.

A final consideration is the mold growth that can result from the use of cassava starch. This often occurs when the pellets are stored in humid conditions for more than a week. However, it can be avoided with the use of drying machines after the process is refined for commercial production.

8 Small-Scale Wastewater Treatment and Anaerobic Digestion

8.1 Context

Founded in 2002, Ashesi University is a small, but rapidly growing, liberal arts college located on a hill overlooking the village of Berekuso, Eastern Region, Ghana (See Figures 8-1 and 8-2). A new US$6.4 million campus was completed in 2011 in order to accommodate Ashesi's 602 students. As the school's enrollment continues to grow, so will its campus. For this reason, a US$6.12 million engineering school is currently under construction at the same site (Ashesi 2014).

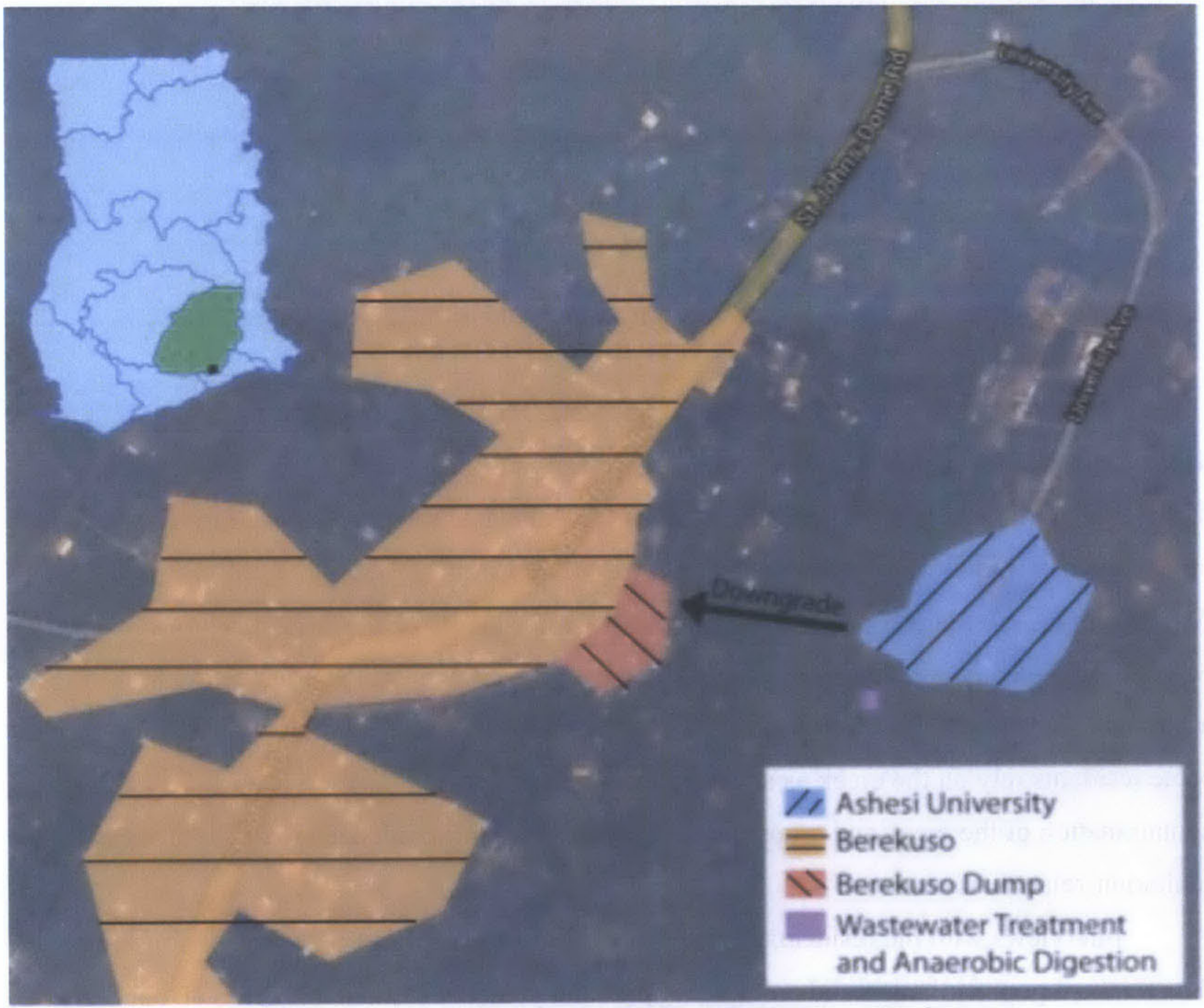


Figure 8-1 Map of the Berekuso and the Ashesi University Campus

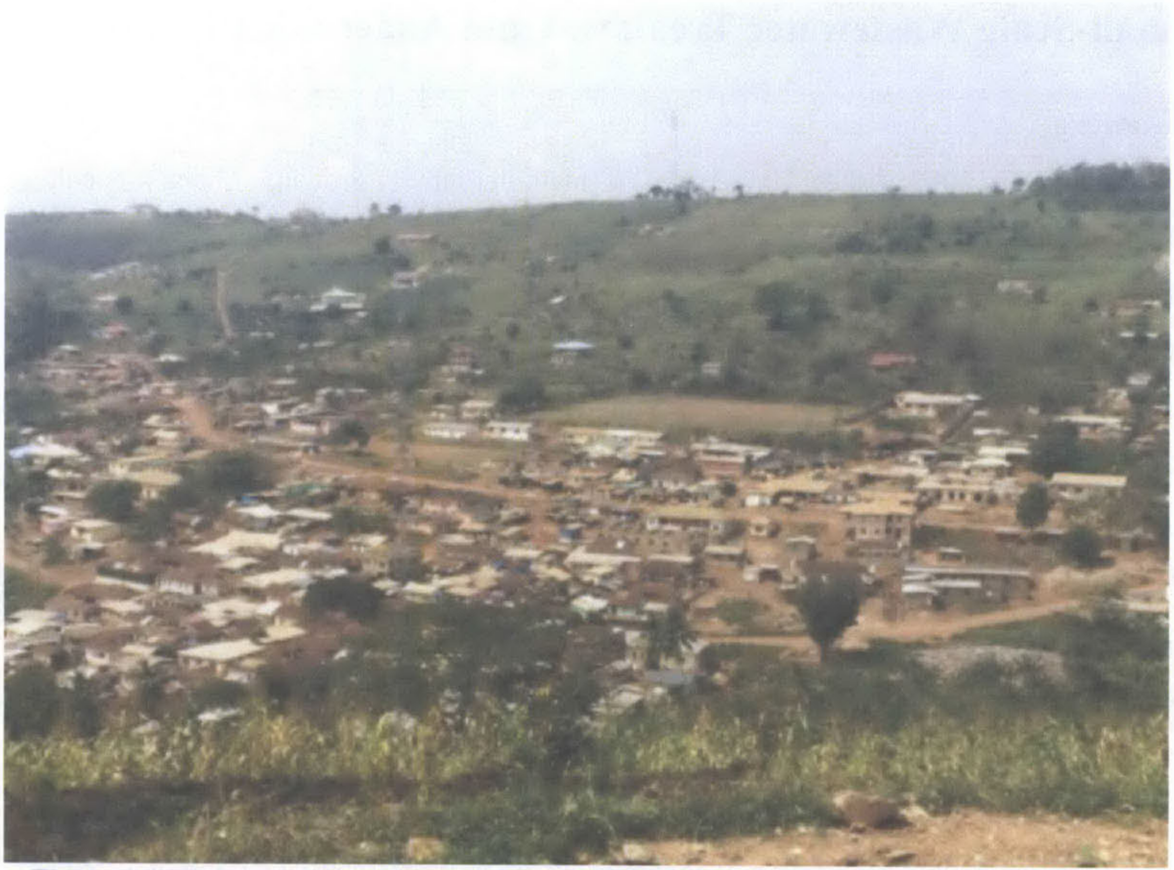


Figure 8-2 The view of Berekuso as seen from the Ashesi University campus. Growth of maize can be seen in the foreground.

The rapid growth of Ashesi's student population has many implications that affect the lives of Berekuso residents. One of these is increased runoff of wastewater from the campus to the village. Berekuso is a village of 1600, most of whom are "relatively poor" farmers whose pineapple, maize, and watermelon fields span the hillside from the low-lying village up to the Ashesi campus (Douglass et al. 2013). Runoff of wastewater from the Ashesi campus has the potential to erode the hillside and contaminate these crops as well as the creek at the foot of the hill (Annie 2014). Because Berekuso has only three public boreholes and no piped water supply, some residents rely on the creek as a water source (Douglass et al. 2013). Therefore, contamination of the creek and crops due to wastewater runoff could lead to an outbreak of sanitation-related disease.

Interviews with the residents revealed that the people of Berekuso are very conscious of the effects of poor sanitation and are wary of past and potential cholera outbreaks (Douglass et al. 2013). Similarly, Ashesi officials are concerned about the effects that a cholera outbreak in Berekuso could have on the university. For this reason, Ashesi wisely addressed the potential for wastewater runoff by constructing a small-scale wastewater treatment system, along with an anaerobic digester, on campus. The site for the treatment system was chosen because it is downgrade from all toilets and sinks, allowing for gravity transport of wastewater to the system (Annie 2014).

8.2 Strategy

8.2.1 Technology Overview

Ashesi's treatment system eliminates pathogens in the wastewater while recovering methane for cooking and nutrient-rich water for irrigation. As a centralized treatment technology, however, flushing toilets and a sewerage system are required in order to transport the wastewater to the treatment system. Fortunately, Ashesi's campus is equipped with flushing toilets, a luxury not afforded to typical Berekuso residents.

The treatment system was designed for a capacity of 450-500 users, although Ashesi has a total campus population of around 700 at the time of publication. The overload to the system reduces residence time and, thereby, the efficacy of the treatment. In order to control quality of the treatment, water quality is tested regularly both at the end of treatment and after storage in irrigation tanks. E. coli and manganese, which damages pipes and blackens water, are the main contaminants of concern (Annie 2014). A schematic of the entire system is shown in Figure 8-3.

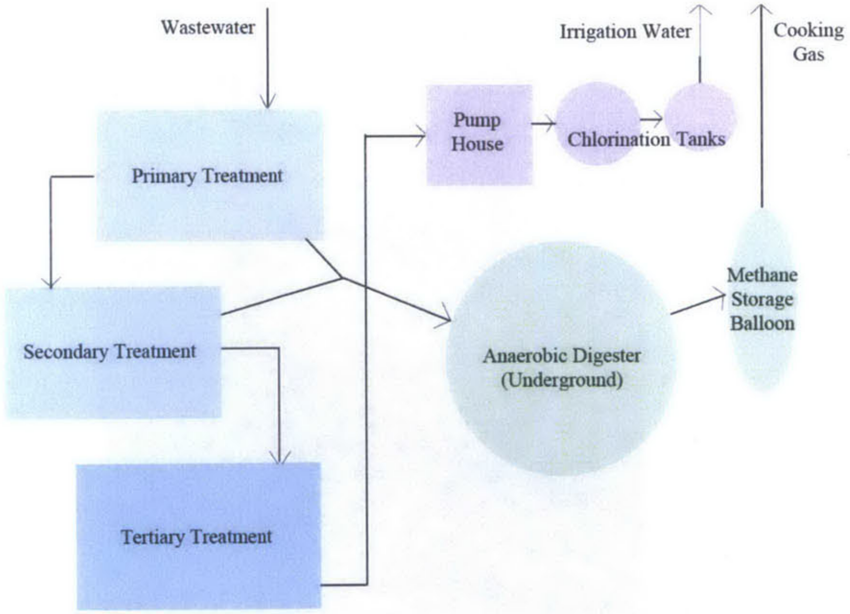


Figure 8-3 Schematic of Ashesi's WWTP and AD system

After conveyance by gravity from the flushing toilets (Figure 8-4) to the treatment location, the wastewater undergoes primary treatment inside the tank shown in Figure 8-5. In this step, suspended heavy particles are separated out of the wastewater stream by gravity settling and are fed into the anaerobic digester. Similarly, waste particles that are lighter than water float to the top and are skimmed off the surface. The neutrally buoyant wastewater continues on to secondary treatment. The primary treatment performance of the Ashesi treatment system is unknown. However, generically it has been found that primary treatment removes only 36% of total coliform, 17% of fecal coliform (Murcott, Dunn, and Harleman 2009), 55% of TSS, and 30% of BOD (National Research Council 1993).

After primary treatment, the wastewater moves on to secondary treatment. In secondary treatment, activated sludge, which consists of a variety of aquatic microorganisms, is used to remove biological material from the wastewater. As the microorganisms consume the material, they reproduce, so some portion of the activated sludge is diverted to the anaerobic digester while the remainder is recycled for reuse in the same secondary treatment process. Removal of biological matter is not necessarily a benefit to Ashesi, for this reduces the effluent's potential as a fertilizing irrigation source. The performance of Ashesi's secondary treatment tank is also unknown, but research has shown that, after primary and secondary treatment, 85% of BOD and 85% of TSS have typically been removed (National Research Council 1993).

Figure 8-4 Ashesi University is equipped with ceramic flushing toilets

Figure 8-5 Ashesi's primary treatment tank

Next, the wastewater flow travels through tertiary treatment, which is an artificial wetlands system with charcoal filters, as is shown in Figure 8-6. This step removes bacteria and aerates the water to reduce the BOD. Following this, it is pumped to a pair of chlorination tanks. Within these two tanks, which have volumes of 10 and 8 m^3, the water is chlorinated with a four-hour contact time. At this point, the water is disinfected but still contains slightly elevated nitrogen and phosphorus levels, so it is pumped back to the top of the campus to be reused for irrigation of the campus garden. According to the system operator, Casper Annie, at this point, the effluent contains a BOD around 1 mg/L and coliform levels that are below detection and safe for agricultural application of the water (Annie 2014).

Simultaneously, an underground $80m^3$ anaerobic waste digester produces methane that is used to power stoves in the canteens on campus (Figure 8-7). Within the digester, microorganisms consume the settled organic matter from primary treatment and the wasted activated sludge from secondary treatment, and methane is a byproduct of this process. The methane accumulates in an aboveground storage balloon before it is piped to the two campus canteens. Because the Ashesi digester has no outflow pipe for degraded substrate, the digester typically becomes full and must be emptied every four months. The removed solids are buried on site, and cow dung is used to reintroduce necessary microorganisms to the digester after each cleaning (Annie 2014).

Figure 8-6 Ashesi's tertiary treatment tank uses graphite filters and aquatic vegetation to remove pathogens from the wastewater

Figure 8-7 The anaerobic digester (right) converts organic material into methane, which is stored in the storage balloon (left) before use as a cooking gas

Figure 8-8 The pump house (left) pumps water from tertiary treatment into the chlorination tanks (right) and then sends it to the campus for irrigation.

The initial project's capital cost was US$40,000, but a further US$30,000 was spent for the addition of the artificial wetland, chlorination tanks (Figure 8-8), and pump house. The anaerobic digestion and biogas collection system were designed and installed by Biogas Technologies Limited in Ghana. The collection balloon was completed later and cost around US$2000. The entire project was constructed between January 2010 and August 2011. However, because Ashesi has 200 users more than the plant's current capacity and because Ashesi is expected to grow to more than 1000 students upon completion of the engineering campus, a second identical plant is currently in planning (Annie 2014).

Figure 8-9 The Ashesi gardens flourish with the aid of the recycled water.

8.3 Outcome

Ashesi has been pleased with the results of the treatment system and digester. The gardens flourish with the additional water and nutrients (Figure 8-9), and the hillside fields remain uncontaminated and protected from erosion. However, lessons have been learned during the project's life, and the plant is no longer able to accommodate the rapid growth of the university's population.

One of the lessons learned has been that the use of bleach or anti-bacterial soap as cleaning agents for the toilets inhibits the production of methane in the digester. That is, residual amounts of bleach are separated out of the wastewater stream and entrained in the digester. This bleach kills off the bacteria in the digester, effectively stopping methane production. In order to fix this problem, the maintenance crew must empty the digester and reintroduce the bacteria using cow dung. Ashesi's custodial staff has since begun using other, less oxidative cleaning products, and the problem has subsided (Annie 2014).

Another lesson learned has been that the treated water must be used soon after treatment or else bacteria can grow to harmful levels. During the first years of operation, the campus gardeners would not use the treated water for irrigation during the rainy season. However, as the unused water accumulated, the residual bacteria reproduced, depleting all residual free chlorine and growing to harmful levels. However, overall, the technology has performed quite well over its first years, for neither of these mishaps were long-term issues (Annie 2014).

Data on methane production was unavailable because Ashesi has not invested in a gas gauge for the storage balloon. However, it is possible to estimate the gas production. As mentioned above, the $80m^3$ digester is cleaned every four months. Using this information, the flow of wasted activated sludge fed into the digester can be calculated to be $0.67m^3$ organic matter/day. Typically, approximately five percent of the volumetric flow of organic matter is converted into methane inside the digester (Bouaziz 2014). This means that approximately $0.03m^3$ methane is produced each day at Ashesi. However, this production would be far less during the weeks following emptying of the tank, for the bacteria must be seeded and organic matter must accumulate during this time.

Still, it is apparent that the system is producing methane fairly continuously, as was evident at the time of the author's visit, and Ashesi hopes to eventually sell methane to generate a profit. Additionally, Ashesi is beginning a compost project that will feed the digester, and this will increase the amount of biogas generated. Once the second treatment train and the compost project are completed, Ashesi hopes that enough methane will be generated to fuel both the canteens and the plant's pumps and that there will be some biogas remaining to market (Annie 2014).

8.4 Discussion Points

Ashesi has done its part in ensuring that the university's wastewater does not contaminate the fields of the Berekuso farmers. However, interviews with residents revealed that this is undermined by poor sanitation coverage in Berekuso. None of the homes have flushing toilets with septic tanks, although one respondent has a toilet in his home that empties into a pit. There is one public KVIP facility in town that charges US$0.05 per use, but respondents explained that, when lines become long, they are forced to resort to open defecation (Douglass et al. 2013). Additionally, elderly people are unable to reach the KVIP, so they often use plastic bags for feces, or "flying toilets," and throw them outside. Children, who are most susceptible to the effects of open defecation, typically defecate in the road leading to the landfill (Douglass et al. 2013).

This system remains effective but too expensive and only applicable in highly organized, affluent communities such as a university campus. It is highly unlikely that methane produced will recover the capital cost of the entire system, and costs for toilets and sewerage system were not included in the US$72,000 capital cost. For an equal investment, 240 of GSAP's Microflush Biofil units could be constructed in Berekuso as another, more direct, method of improving environmental conditions of the village. With that said, this system successfully handles and treats all of the water that goes down drains on campus, including all rainwater that falls on roofs. This prevents erosion of the hillside and contamination of Berekuso's water through natural processes, while providing a source of energy and irrigation for the campus.

However, just because it is effective in achieving its purpose does not mean that it was the best option available to Ashesi. Another intriguing solution to Ashesi's dilemma would have been to implement a small-scale chemically enhanced primary treatment system (CEPT). CEPT is the use of flocculants to improve primary treatment, thereby eliminating the need for secondary and tertiary treatment. A study in Mexico City revealed that CEPT removes only one-third of BOD, or organic matter, and nutrients, a far lower removal rate than plants such as the one at Ashesi achieve (Murcott, Dunn, and Harleman 2009). In Ashesi's case, this lower removal rate of CEPT is beneficial, for it makes the effluent water more valuable for reuse in irrigation and fertilization. A CEPT plant combined with chlorination or UV disinfection could have been constructed for 55-60% of the cost of Ashesi's plant, and it would have met WHO bacterial guidelines and more effectively preserved materials in the effluent that are beneficial for agriculture (Murcott, Dunn, and Harleman 2009). It also would still yield settled sludge from primary treatment for anaerobic digestion.

In future implementations, if the Ashesi system is chosen instead of CEPT, an outflow should be added to the digester. In Ashesi's system, organic waste flows into the digester until it fills, at which point it must be emptied. However, if an outflow pipe is added, the tank can operate continuously and at steady-state. This would provide three benefits. First, it would eliminate periods of lulls in gas production that occur after emptying while the bacteria is re-seeded. Second, the system would continuously produce a manageable amount of fertilizer that could be used on the gardens or be a source of revenue. Third, a steady-state digester tank would be smaller and therefore less expensive. In a steady-state digester, the optimal residence time is approximately 20 days (Bouaziz 2014). The Ashesi system operates with an inflow of $0.67m^3$/day, as explained above, so the continuous flow tank would need only to be $13.3m^3$, which is eight times smaller than the current $80m^3$ tank.

9 Conclusions and Recommendations

Ghana currently has the sixth lowest rate of improved sanitation coverage in the world, with only 13% of the population using improved toilets (WHO/UNICEF JMP Progress on Sanitation... 2013). However, this is not only caused by a lack of financial resources. As has been evident in the case of the Taha Pour-Flush Toilets, there is a clear lack of demand for sanitation stemming from lack of knowledge of WASH issues and longstanding cultural traditions. While it is important to educate people about the benefits that sanitation coverage can bring, it is also important to seek out other means of increasing demand for sanitation in Ghana.

The reuse of human waste to generate a profit is a logical place to start. Currently, expansion of sanitation coverage is driven primarily by health-related incentives. By incorporating sanitation technologies that recover valuable resources from waste, however, future growth of sanitation coverage can be directly driven by financial incentives as well. However, as was shown in the case studies, many of these resource recovery technologies, such as the microbial fuel cell and anaerobic digestion, need further development if they are to become profitable in a decentralized setting. Still, construction of these innovative toilets can provide the immediate benefits of job creation, on-site waste treatment, nutrients for agriculture, and the first step toward the development and dissemination of efficient resource-recovering toilets.

9.1 Evaluation Matrix

In order to make recommendations for future sanitation projects and businesses that wish to utilize these innovations, it is important to compare these existing innovative sanitation technology options. This can most easily be done with the use of an evaluation matrix, which evaluates each technology according to a set of criteria and assigns scores to a number of factors within each criteria category for each technology. The Fortifer project and the Ashesi Treatment system were left out of this matrix because, as semi-centralized technologies, they cannot be effectively evaluated with the same criteria used to score decentralized technologies. Appendix A contains a set of evaluation criteria that were used to guide the case studies of the technologies evaluated in the previous chapters. From this list, criteria that are relevant to future implementations of the technologies were selected to be used in the evaluation matrix. These criteria are explained below.

Sanitation Outcome Criteria

- User Preference: In case studies, what percent of users prefer the technology over available alternatives?
- Classification: Is the technology classified as improved or unimproved? An improved toilet is one that hygienically separates waste from human contact (WHO/UNICEF JMP wssinfo.org 2013). If it is improved, does it feature a water seal and/or mechanical seal? If it is unimproved, does it sanitize waste?
- Conducive to Cleanliness: Is the facility conducive to cleaning? Are surfaces nonporous? Can bleach and antimicrobial soap be used for cleaning, or will they disrupt necessary microbial processes? Is waste likely to end up outside the toilet basin due to design?
- Maintenance Required: How much maintenance is required? Does the presence of removable parts make the technology a poor fit for public use?
- User Satisfaction: In case studies, what percent of users were very or somewhat satisfied with the toilet?
- Handicap Accessible: Does the technology have a sitting option for the handicapped? Is it designed for in-home use?

Business/Management Criteria

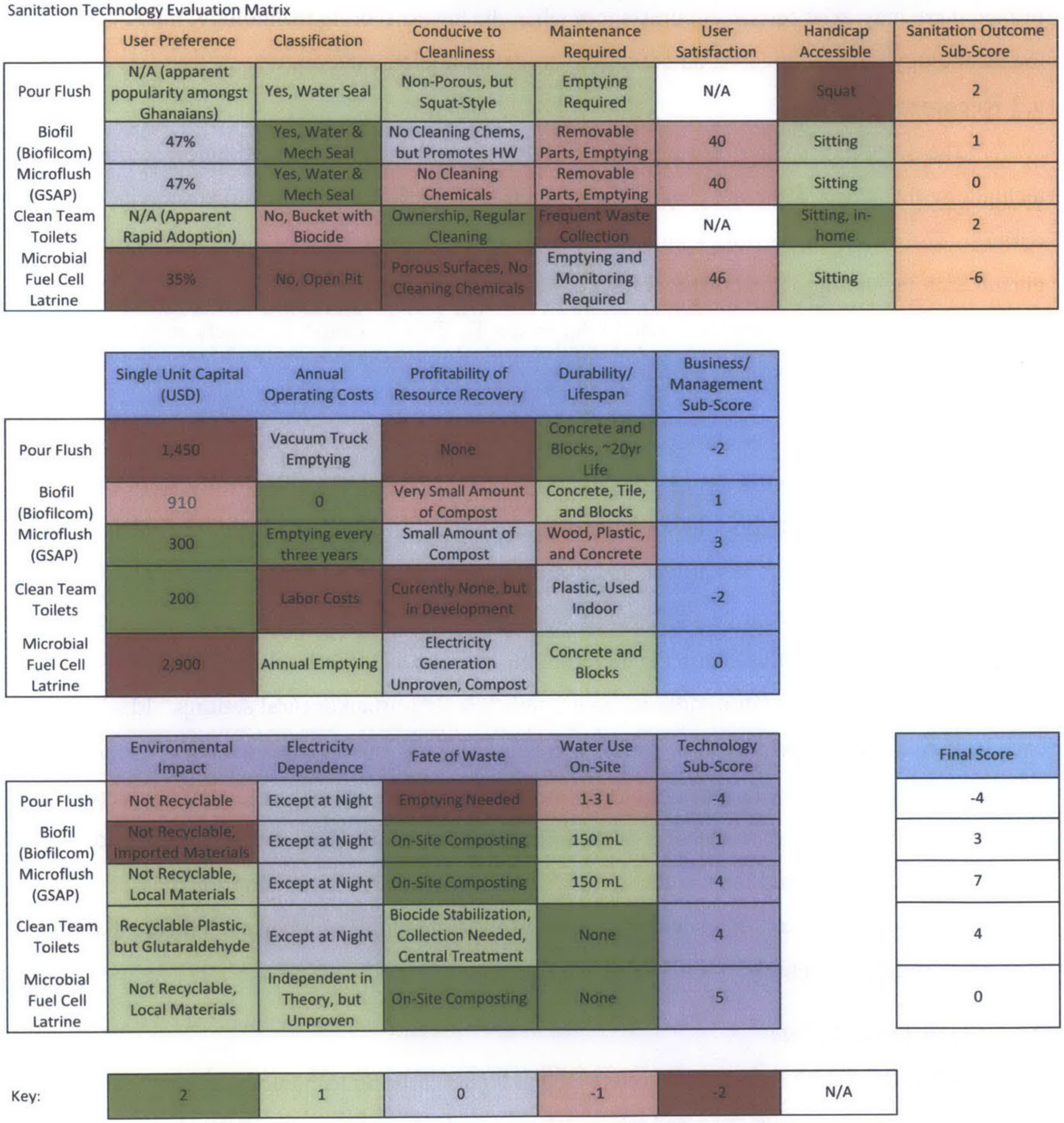
- Single Unit Capital: What is the capital cost of a single unit of the technology?
- Annual Operating Costs: In addition to regular cleaning costs, what overall operating costs are required by the technology on an annual basis?
- Profitability of Resource Recovery: Does the technology generate profit from recovered resources? How much?
- Durability/Lifespan: What is the estimated useful life of the technology?

Technology Criteria

- Environmental Impact: Are construction and operating/maintenance materials recyclable? Are they locally available in most Ghanaian cities? Are they hazardous to human health?
- Electricity Dependence: Is the technology dependent on a connection to the electrical grid?
- Fate of Waste: Does the technology treat waste on-site? Is collection required? Is collection included with subscription costs?
- Water Use On-Site: How much water is required per use at the point-of-use?

Each technology received a score for each criterion using the key shown at the bottom of Table 9-1. A score of +2 is a high sub-score, 0 is neutral, and -2 is the lowest possible sub-score. This evaluation matrix should be used primarily as a rough guide to examine and compare the

Table 9-1 Evaluation Matrix for Decentralized Sanitation Technologies



Sanitation Technology Evaluation Matrix

	User Preference	Classification	Conducive to Cleanliness	Maintenance Required	User Satisfaction	Handicap Accessible	Sanitation Outcome Sub-Score
Pour Flush	N/A (apparent popularity amongst Ghanaians)	Yes, Water Seal	Non-Porous, but Squat-Style	Emptying Required	N/A	Squat	2
Biofil (Biofilcom)	47%	Yes, Water & Mech Seal	No Cleaning Chems, but Promotes HW	Removable Parts, Emptying	40	Sitting	1
Microflush (GSAP)	47%	Yes, Water & Mech Seal	No Cleaning Chemicals	Removable Parts, Emptying	40	Sitting	0
Clean Team Toilets	N/A (Apparent Rapid Adoption)	No, Bucket with Biocide	Ownership, Regular Cleaning	Frequent Waste Collection	N/A	Sitting, in-home	2
Microbial Fuel Cell Latrine	35%	No, Open Pit	Porous Surfaces, No Cleaning Chemicals	Emptying and Monitoring Required	46	Sitting	-6

	Single Unit Capital (USD)	Annual Operating Costs	Profitability of Resource Recovery	Durability/ Lifespan	Business/ Management Sub-Score
Pour Flush	1,450	Vacuum Truck Emptying	None	Concrete and Blocks, ~20yr Life	-2
Biofil (Biofilcom)	910	0	Very Small Amount of Compost	Concrete, Tile, and Blocks	1
Microflush (GSAP)	300	Emptying every three years	Small Amount of Compost	Wood, Plastic, and Concrete	3
Clean Team Toilets	200	Labor Costs	Currently None, but in Development	Plastic, Used Indoor	-2
Microbial Fuel Cell Latrine	2,900	Annual Emptying	Electricity Generation Unproven, Compost	Concrete and Blocks	0

	Environmental Impact	Electricity Dependence	Fate of Waste	Water Use On-Site	Technology Sub-Score	Final Score
Pour Flush	Not Recyclable	Except at Night	Emptying Needed	1-3 L	-4	-4
Biofil (Biofilcom)	Not Recyclable, Imported Materials	Except at Night	On-Site Composting	150 mL	1	3
Microflush (GSAP)	Not Recyclable, Local Materials	Except at Night	On-Site Composting	150 mL	4	7
Clean Team Toilets	Recyclable Plastic, but Glutaraldehyde	Except at Night	Biocide Stabilization, Collection Needed, Central Treatment	None	4	4
Microbial Fuel Cell Latrine	Not Recyclable, Local Materials	Independent in Theory, but Unproven	On-Site Composting	None	5	0

Key:	2	1	0	-1	-2	N/A

strengths and weaknesses of each design. Even if one design scores higher than another, the reader should not conclude that the higher scoring design will be superior in all circumstances. In fact, there may exist certain circumstances when the lowest scoring technology, the KVIP, is the technology with the greatest potential for successful implementation.

9.2 Recommendations

The evaluation matrix indicates that GSAP's Microflush Toilet is the highest scoring technology for Ghana, although Clean Team Toilets and the Biofil Toilet are also suitable options. The following sections summarize the recommendations made to those wishing to pursue each technology. For further reference, a fact sheet that was presented to the Bill and Melinda Gates Foundation can be found in Appendix E. This fact sheet concisely summarizes the strengths and weaknesses of each technology.

9.2.1 GSAP Microflush Toilets

The evaluation matrix assigns the highest score of seven to GSAP's locally-sourced Microflush Toilet. This technology is fairly well established in Southern Ghana, and costs only US$300 per private unit. It has proven successful as a private unit used by up to four families, but it has shown less promise as a public unit due to its relatively complex design and removable parts. The GSAP Microflush Toilet is therefore the recommended technology for private sanitation projects for low- or middle-income families in peri-urban or rural settings. Ideally, each facility should be used by three or fewer families. NGOs should take advantage of the low price of this technology by constructing many private MFBFs in lieu of a single public facility. In order to foster a sense of ownership of the toilets, recipients of toilets should be involved in the MFBF construction and pay for the MFBF through microloans. User adoption may be further increased by the use of a squatting model of the technology where users indicate that this is more culturally acceptable.

9.2.2 Clean Team Toilets

While the GSAP Microflush Toilets are the highest scoring technology, Clean Team Toilets, with a score of four, is poised to overtake the highest score once CTT develops an environmentally friendly substitute to its One Shot Cherry biocide, which contains glutaraldehyde and bronopol, and implements profitable recovery of waste as a resource. Additionally, the financially sustainable subscription basis used by Clean Team Toilets is not assigned value in this evaluation matrix, so the matrix may slightly undervalue CTT. However, CTT is applicable only in dense urban areas with a large target customer base and requires a permanent, large-scale business to be established. Therefore, it is only advisable to contract CTT for toilets in Kumasi or if a large amount of funding has been secured to implement the model in another city.

9.2.3 Biofilcom's Biofil Toilets

Biofilcom's Biofil model is most applicable in peri-urban areas that lack sewerage systems. In situations when cost is not a significant consideration, this model should be used instead of the GSAP Microflush Toilet because it has a more efficient composting tank and includes the sink with greywater reuse. However, because of the complexity of the Biofil design, it is not recommended for public use. As with the GSAP Microflush Toilet, the development of a Biofil model featuring a toilet basin for squatters would likely boost user adoption rates.

9.2.4 Microbial Fuel Cell Latrine

The Microbial Fuel Cell Latrine requires further development before it is ready to be produced on a commercial level. Experimentation with a urine-diverting seat, use of low-cost local materials, and more efficient power generation could make this a feasible design. Additionally, the incorporation of some sort of water seal, such as the low-flow flushing mechanism used in the Microflush and Biofil Toilets, would allow this toilet to be classified as an improved facility. This also would significantly reduce the odor and increase the number of users of the facility.

9.2.5 Pour-Flush Toilets

The pour-flush facility is widely accepted by Ghanaians, but its dependence upon vacuum truck emptying poses financial and environmental concerns. For these reasns, it is recommended that the industry shift away from such models and toward toilets with on-site treatment, especially for public use. However, it should be noted that the pour-flush model is preferable to KVIP and open pit latrines because its water seal reduces odor and presence of flies.

9.2.6 Fortifer Pellets

Centralized recovery of resources from waste sludge holds unique potential in Ghana due to the large amount of public toilets that require emptying. However, there is reason to be skeptical about whether or not composted sludge can compete with inorganic fertilizer on the market. Potential businesses should monitor the success of the Fortifer project as it enters its commercialization phase in 2014. Recovery of diverted urine may provide another avenue for profitable reuse of nutrients from waste.

9.2.7 Small-Scale Wastewater Treatment System and Anaerobic Digestion

The Ashesi model of small-scale treatment and anaerobic digestion is not a cost-effective model but may be applicable for small private communities such as universities or higher-end neighborhoods. However, chemically enhanced primary treatment (CEPT) systems should be used instead in areas where irrigation and fertilization are the top priority.

9.3 Recommendations for Future Research

Because the field of resource recovery from sanitation is fairly new and is in need of further development, there are many opportunities for future research. Dr. Stephen Mecca is conducting ongoing research on the Microflush Toilet at Providence College, and UMass-Amherst is continuing research on the microbial fuel cell. However, there are a multitude of other topics worthy of research.

First, one of the main problems with Ghana's current sanitation coverage is the fact that waste from public facilities often ends up in the environment without proper treatment. The disposal of waste from public toilets in Ghana and its fate and transport in environmental systems therefore needs to be more thoroughly understood. Studies on the networks of waste collection and disposal from public toilets in Accra, Kumasi, and Tamale would identify the scope of the problem and potential opportunities for innovation. Additionally, modeling of the fate of waste from popular discharge points such as Lavender Hill into the environment would help to quantify the effects of direct discharge of human waste into the environment. This modeling could include aquatic transport of waste as well as an examination of the abilities of different soil types to remove pathogens from waste during percolation.

Second, a market study that compares the potentials of collected urine, composted fecal sludge, and inorganic fertilizers for agricultural use would be of great use to the field of sanitation innovation. This would help innovators to identify which recoverable resources hold the most potential to be profitable. A similar study could be conducted comparing power generation techniques such as anaerobic digestion, microbial fuel cells, production of biodiesel from waste, and other such technologies.

Third, the development of a biocide that stabilizes waste on-site and can be safely disposed of would create opportunities for Clean Team Toilets and other new collection-based sanitation technologies. Cranfield University in the United Kingdom has already begun research with CTT in order to determine methods for recovering resources from fecal sludge contaminated with biocide. To accompany this, another study could be done in collaboration with CTT in order to quantify the risks of volatilized glutaraldehyde and bronopol in enclosed spaces and their effects on the waste stabilization ponds at Dompoase. If necessary, solutions to these problems could be researched as well.

Finally, and perhaps most importantly, there is a need for anthropological studies on the adoption of toilets by communities that practice open defecation. The villages surrounding Taha, to the northeast of Tamale, would be an ideal location for such a study. Here, rapid development of the previously rural area is forcing the villages to urbanize, but they are demonstrating reluctance in their adoption of toilet use. An understanding of cultural traditions and practices is necessary in order to sensitively introduce sanitation coverage and an understanding of its importance.

9.4 Final Remarks

Ghana has achieved a marked improvement in the number of individuals who use unimproved toilets over the last 25 years, but it has achieved this through promoting public toilet use. While public sanitation does consolidate waste away from drinking sources, transmission of disease between shared sanitation users and disposal of waste in the environment are still major concerns. As Ghana prepares to take the next step up the sanitation ladder toward private toilet coverage, it is of utmost importance to create private toilets that treat waste on-site and toward which people feel a sense of ownership. Microloans and engagement of owners in construction processes may help to foster this ownership, but use of an appropriate technology is of great importance as well. After case studies and evaluations, it appears that the technologies most applicable for use in Ghana are the locally sourced Microflush Toilet and the Clean Team Toilets. It is hoped that the experiences and information presented in this thesis will inform the decision making of sanitation businesses and NGOs as they choose which technologies to pursue in their noble effort to reduce the prevalence of sanitation-related diseases.

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Appendices

Appendix A:

Categories and Indicators of Successful Sanitation in Ghana

3 Categories: Sanitation Outcomes, Business/Management, and Technical
-Business Management has 2 subcategories: Management and Economics
-Technical has 4 subcategories: Materials, Energy/Operation, Water, and Resource Recovery

Indicators:

Sanitation Outcomes:

- -SAN1: Number of households **using the sanitation facility under evaluation**
- -SAN2: Facility's **classification** (improved, shared, or unimproved)
- -SAN3: Number of households with **access to any improved sanitation facility**
- -SAN4: Number of households with **reliable access** (free 24 hour access on household's premises) to sanitation facilities
- -SAN5: Number of households **less than 10 minutes away** from the sanitation facility
- -SAN6: Facility maintains **adequate cleanliness** to promote regular use
- -SAN7: Facility practices **adequate maintenance** to remain operational
- -SAN8: Latrine has a **water seal**
- -SAN9: **Soap and water** in facility or within 10 paces
- -SAN10: **User acceptability, satisfaction, and desirability**
- -SAN11: Facility is **accessible to different age, gender, and income groups and handicapped users**

Business Management: (Subcategories: Management and Economics)

- -Management:
  - -BM-M1: Demonstrated, effective **leadership and commitment** (from owners/management)
  - -BM-M2: **Stakeholders/User Involvement**
  - -BM-M3: **Use of by-products** to generate funds/profit/common good
  - -BM-M4: **Integration into community**/Collaboration with similar projects
  - -BM-M5: Effective plan in place for **long-term maintenance and monitoring**
  - -BM-M6: Address conflicting **regulations and policies**
  - -BM-M7: Expected Useful **Lifespan**
  - -BM-M8: **Sanitation Marketing** strategies in place
- -Economic:
  - -BM-E1: **Annual Operation/Maintenance/Upkeep Costs**
  - -BM-E2: Capital **cost per household** (total cost per toilet as well)
  - -BM-E3: **User ability to pay** (Cost as % of income)
  - -BM-E4: **Potential for** Local Business Development and Household **Income Generation**

Technical

- -Materials:
  - -T-M1: Complete **Life Cycle Assessment**
  - -T-M2: Appropriately small **Land Intensity/Footprint**
  - -T-M3: Uses of materials of low **net embodied energy**

- -T-M4: **Sustainable procurement** of materials
- -T-M5: Uses **recycled materials**
- -T-M6: Uses **local materials**
- -T-M7: **Diverts waste** from landfill
- -T-M8: **Reduces amount of materials taken off site**
- -T-M9: Provides for **deconstruction and recycling** (especially for projects with short lifespans)

-Energy/Operations:

- -T-E1: **Ability to operate in areas without reliable electricity**
- -T-E2: **Energy for Operations** (kWh/user)
- -T-E3: Ability to **meet capacity requirements**

-Water:

- -T-W1: **Protect Freshwater** Availability
- -T-W2: Ability to **meet treatment standards**
- -T-W3: Minimizes **Potable Water Consumption**

-Resource Recovery

- -T-R1: Percent Nitrogen and Phosphorus recycled as **fertilizer**
- -T-R2: Percent of energy in organic matter converted to **electricity**
- -T-R3: Percent of wastewater upcycled for **irrigation**
- -T-R4: **Use of other innovative technology or practice**; identify and assess

Appendix B:

Ghana Sanitation Innovation Evaluation - Household/User Interview

The purpose of this survey is to gain an understanding of the social impacts of sanitation facilities in Ghana. This survey is not a test in any way. Your participation is completely voluntary, and you may decline to answer any or all of the questions or may end your participation at any time with no adverse consequences. All information we collect will be kept confidential, which means that your responses are anonymous and will not be shared with anyone. The data will be kept and analyzed only as a collection of the responses given by all survey participants.

Demographic Information:
Age of Respondent: ______________________________
Occupation: ______________________________________
Hometown: _______________________________________
Annual Income: ___________________________________
Highest Education Completed: Primary ______ Secondary ______ University or Higher ______

1. How high of a priority do you attach to improvement of sanitation in your community?
    Very High __________
    High __________
    Medium __________
    Low __________
    Not a Priority __________

   Why?

   ____

2. a) How often do you use the facility being studied?
    Daily ________
    Every few days _________
    Weekly ________
    Once or twice per month _________
    Used it once or twice _________
    Never ________ (if never, please skip to question 8)

   b) How often do your neighbors typically use the facility?
    Daily ________
    Every few days _________
    Weekly ________
    Once or twice per month _________
    Used it once or twice _________
    Never ________

   c) Do you: share the facility with anyone other than your family members?

    Yes, it is public ______ Yes, it is shared ______ No ______ have access to the facility at all times? Yes ______ No ______

pay to use the facility? Yes ______ No ______

If so, how much and how often? ______________________________

3. When was the last time you used the facility? ____
4. How long does it typically take for you to get to the facility from home? __________________
5. Is the facility always clean enough to be comfortably used? Yes ______ No ______
6. Have there been periods (longer than a day) when the facility was in disrepair or otherwise unusable?

   Yes ______ No ______

7. a) Is there typically usable soap and water within 10 paces of the facility?

   Yes ______ No ______

   b) Do you use the soap? If so, for what?

   ____

   c) Do other users use the soap? If so, for what?

   ____

8. a) Do you always feel comfortable and able to use the facility? Yes ______ No ______

   b) If not, why not? (check all that apply)

   Lack of Privacy ________
   Too far away ________
   Too expensive ________
   Feminine Issues ________
   Not Handicapped Accessible ________
   Religious Reasons ________
   Not clean ________
   In disrepair ________
   Other (Please describe) ________________________

9. a) How satisfied are you with the place where you defecate?

   Very unsatisfied ______
   Somewhat unsatisfied ______
   No opinion ______
   Somewhat satisfied ______
   Very satisfied ______

   b) Do you intend to install or change to a different sanitation facility in the next 6 months?

   Yes ______ No ______

---

10. a) If you do not use the facility, why not?

   Lack of Privacy ________
   Too far away ________

Too expensive ________
Feminine Issues ________
Not Handicapped Accessible ________
Religious Reasons ________
Not clean ________
In disrepair ________
Have access to a better facility ______
Other (please describe) ____________________________________

b) Do you have access to another sanitation facility? Yes ______ No ______

c) If so: do you share it with anyone other than your family members?

Yes, it is public ______ Yes, it is shared ______ No ______

do you pay to use it? Yes ______ No ______

If so, how much and how often? ____________________________________

do you have access to it at all times? Yes ______ No ______

what type is it? Flush or pour/flush toilet flushed to:
- Piped sewer system ______
- Septic tank ______
- Pit latrine ______
- Somewhere else ______

Ventilated improved pit latrine ______
Pit latrine with slab ______
Pit latrine with no slab/open pit ______
Composting toilet ______
Bucket toilet ______
Hanging toilet/latrine ______
Other (specify) ____________________________

d) Would you prefer to use the facility being studied instead? Yes ______ No ______

---

11. Do the facility managers engage users in planning and decision-making?

Yes ______ No ______

12. If you use it, are you proud to be a user of the facility? Yes ______ No ______

13. a) Does the facility re-use by-products?

Yes ______ Yes, but not efficiently ______ No ______

b) If so, how?

____

14. Does the facility advertise in order to recruit new users or to educate about sanitation?

Yes ______ No ______

15. Do you ever have to wait in line to use the facility? Yes ______ No ______

16. Do power outages affect the operation of the facility? Yes ______ No ______

17. Does intermittent (not consistent) water supply affect the operation of the facility?

Yes ______ No ______

18. Does the facility discharge waste in an area that contaminates your drinking water?

Yes ______ No ______

19. Is the facility innovative in any way? How?

____

____

Appendix C:

Ghana Sanitation Innovation Evaluation - Service Provider Interview

The purpose of this interview is to gain a better understanding of the business of sanitation facilities in Ghana. This survey is not a test in any way. Your participation is completely voluntary, and you may decline to answer any or all of the questions or may end your participation at any time with no adverse consequences.

Site Name:	Contact Information
______________________	______________________
	______________________
	______________________

Technical:

1. LCA information: What materials were used in construction of the facility, where were they from, and how did you obtain them (transportation)?

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

2. Can construction materials be easily reused or recycled? How? ______________________

______________________ ______________________

2. What materials are used for upkeep of the facility, where are they from, and how are they obtained (transportation)?

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

3. Do these materials exhibit low energy-intensiveness or sustainability in any ways (local, recycled, etc)?

____

____

3. How large is the plot of the land on which the facility stands? ____________________
4. a) How much electricity does the facility use per day? ____________________
   b) Is this electricity readily and consistently available? ____________________
   c) Can the facility operate safely without electricity? ____________________
   d) Could a similar facility operate in an area without an electrical grid? ____________________
5. a) Where does the human waste generated by the facility accumulate? ____________________
   b) To where is it discharged? ____
   c) Does the discharged wastewater meet treatment requirements, or does it require further treatment? If it requires further treatment, where does this occur?

   ____

   d) From where do nearby residents get their drinking water? ____________________
   e) How much potable water does the facility require: per day? ____________________
   per use? ____________________
6. a. Does this facility recycle/up-cycle waste in any ways? ____________________
   b. If so, what is produced? ____
      If energy is produced, what percent of organic matter (or embodied energy) is converted into electricity? ____
      If fertilizer is produced, what percent of organic matter (or percentages of nitrogen and fertilizer) is converted into fertilizer? ____
      If wastewater is reused for irrigation, what percent of water is reused? ____________________
      If any other product is created from waste, please explain: ____________________

      ____

<u>Business Management</u>:

1. When was the facility established? ____
2. How did you determine a suitable location for the project? ____________________

   ____

3. Why/how did you decide to use this technology over other technologies? ____________________

4. How has the number of users varied over the time of operation? ______

5. What actions has your team/management taken to ensure that the facility is being used?

6. Do you involve users in decision-making/planning? If so, how? ______

7. If you do up-cycle waste, how did you determine whether there is a market for up-cycled waste products? ______

8. a) Are there other similar sanitation facilities nearby? If so, what are they called, and where are they? ______
   b) Do you view them as competitors or partners? ______
9. a) Please explain your plan for long-term maintenance/monitoring. ______
   b) How often is the facility cleaned? ______
   c) How often have you had to repair the facility? ______
10. Please explain any conflicting regulations or laws that you had to deal with:

11. What is the project's expected lifetime? ______
12. Please explain any marketing strategies that you use/have used to promote sanitation and attract users: ______

13. What is your annual operating cost? Would you please break it down into components?
    Total Cost: ______

14. What is the cost per user: annually: ______
    per use: ______

15. How did you determine the price? ____________________

16. Have you identified the typical user's ability to pay? ____________________

17. How much is saved through:

Fertilizer sales: ____________

Electricity savings: ____________

Use of up-cycled water for irrigation: ____________

Reduced use of resources: ____________

Other sustainable means: ____________

18: How was/is the project funded? ____________________

____

Sanitation Outcomes:

1. How many users do you serve? ____________________
2. Is your facility classified as an "improved" facility? ____________________
3. How many hours per day/days per week is your facility open? ____________
4. Is the facility lit at night? ____________________
5. Does the facility have a guard/attendant? How many hours of the day? ____________
6. Does the facility always have available soap and water supply? ____________
7. What are the demographics of your most frequent users? ____________

____

Appendix D

Issued: 12/09/2012

Revision No: 1

SAFETY DATA SHEET

ONE SHOT CHERRY (CHEMICAL 4)

1. IDENTIFICATION OF THE SUBSTANCE / PREPARATION AND OF THE COMPANY / UNDERTAKING

Product name: ONE SHOT CHERRY (CHEMICAL 4)

Use of substance / preparation: Additive for Chemical Toilets

Company name: F T G Ltd
Drum House
Drum Industrial Estate
Birtley
Durham
DH2 1SR
Tel: 0191 4111777
Fax: 0191 4111888
Email: Fluidtechnology@btconnect.com

2. HAZARDS IDENTIFICATION

Main hazards: Harmful by inhalation and if swallowed. Irritating to eyes and skin. May cause sensitisation by inhalation and skin contact.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous ingredients: PENTANE 1,5 DIAL 5-10%
EINECS: 203-856-5 CAS: 111-30-8
[T] R23/25; [C] R34; [Sens.] R42/43; [N] R50

- ANIONIC/NONIONIC SURFACTANT 0-5%
  [Xn] R22
- 2-BRONO-2-NITROPROPANE-1,3-DIOL <5%
  [Xn] R21/22; [Xi] R37/38

4. FIRST AID MEASURES (SYMPTOMS)

Skin contact: There may be irritation and redness at the site of contact.

Eye contact: There may be irritation and redness. Corneal burns may occur.

Ingestion: Nausea and stomach pain may occur. There may be vomiting.

Inhalation: Exposure may cause coughing or wheezing.

4. FIRST AID MEASURES (ACTION)

Skin contact: Wash off with water Contaminated clothes should be laundered before reuse.

Eye contact: Bathe the eye with running water for 15 minutes. Seek medical advice if symtoms persist

Ingestion: Do not induce vomiting. If conscious, give half a litre of water to drink immediately. Seek medical advice if symtoms persist.

Inhalation: Remove to fresh air

[cont...]

5. FIRE-FIGHTING MEASURES

Extinguishing media: Carbon dioxide. Alcohol or polymer foam. Dry chemical powder.

Exposure hazards: In combustion emits toxic fumes.

Protection of fire-fighters: Wear self-contained breathing apparatus. Wear protective clothing to prevent contact with skin and eyes.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions: Turn leaking containers leak-side up to prevent the escape of liquid. Refer to section 8 of SDS for personal protection details.

Environmental precautions: Do not discharge into drains or rivers. Contain the spillage using bunding.

Clean-up procedures: Absorb into dry earth or sand. Wash the spillage site with large amounts of water.

7. HANDLING AND STORAGE

Handling requirements: Ensure there is sufficient ventilation of the area. Smoking is forbidden. Avoid direct contact with the substance.

Storage conditions: Store in cool, well ventilated area.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Hazardous ingredients: PENTANE 1,5 DIAL

WEL (8 hr TWA): 0.2 mg/m3 WEL (15 min STEL): 0.2 mg/m3

Engineering measures: Ensure there is sufficient ventilation of the area.

Respiratory protection: Do not breathe vapour,or spray

Hand protection: Protective gloves.

Eye protection: Safety goggles.

Skin protection: Avoid skin contact

9. PHYSICAL AND CHEMICAL PROPERTIES

State: Liquid

Colour: Blue

Odour: Pleasant

Solubility in water: Soluble

Flash point°C: none

Relative density: 1.03

10. STABILITY AND REACTIVITY

Stability: Stable under normal conditions.

Materials to avoid: Oxidising agents.

11. TOXICOLOGICAL INFORMATION

Routes of exposure: Refer to section 4 of SDS for routes of exposure and corresponding symptoms.

[cont...]

12. ECOLOGICAL INFORMATION

Mobility: Soluble in water.

Persistence and degradability: Biodegradable.

Bioaccumulative potential: No bioaccumulation potential.

Other adverse effects: No data available.

13. DISPOSAL CONSIDERATIONS

Disposal of packaging: Dispose of as normal industrial waste.

NB: The user's attention is drawn to the possible existence of regional or national regulations regarding disposal.

14. TRANSPORT INFORMATION

ADR / RID

Shipping name: Not Classified

IMDG / IMO

IATA / ICAO

15. REGULATORY INFORMATION

Hazard symbols: Harmful.

Risk phrases: R20/22: Harmful by inhalation and if swallowed.

R36/38: Irritating to eyes and skin.

R42/43: May cause sensitisation by inhalation and skin contact.

Safety phrases: S23: Do not breathe ...

S46: If swallowed, seek medical advice immediately and show this container or label.

S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

S2: Keep out of the reach of children.

S24: Avoid contact with skin.

S37: Wear suitable gloves.

S63: In case of accident by inhalation, remove casualty to fresh air and keep at rest.

[cont...]

Haz. ingredients (label): PENTANE 1,5 DIAL

Note: The regulatory information given above only indicates the principal regulations specifically applicable to the product described in the safety data sheet. The user's attention is drawn to the possible existence of additional provisions which complete these regulations. Refer to all applicable national, international and local regulations or provisions.

16. OTHER INFORMATION

Other information: The phrases below refer to the raw materials used in the formulation, not the finished product.

Risk phrases used in s.3: R23/25: Toxic by inhalation and if swallowed.

R34: Causes burns.

R42/43: May cause sensitisation by inhalation and skin contact.

R50: Very toxic to aquatic organisms.

R22: Harmful if swallowed.

R21/22: Harmful in contact with skin and if swallowed.

R37/38: Irritating to respiratory system and skin.

Legal disclaimer: The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. This company shall not be held liable for any damage resulting from handling or from contact with the above product.

[final page]

Appendix E:
Evaluation of Sanitation Innovations in Ghana For the Bill and Melinda Gates Foundation

This fact sheet summarizes the findings of Jason Knutson, MIT graduate student of Senior Lecturer Susan Murcott, on a number of innovative sanitation technologies in Ghana.

Massachusetts
Institute of
Technology
Deptartment of Civil and Environmental Engineering

An Evaluation of Sanitation Innovations in Ghana

Location

Government School,
Pokuase, Accra, GH

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Affiliates

Global Sustainable
Aid Project,
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Microflush Biofil (MFBF)

Summary of Technology

- Hybrid flush and vermicomposting toilet
- 150 mL of greywater from handwashing sink used to flush next user's waste
- Provides a comfortable and odorless experience
- In Biofil tank underneath, worms digest the waste, which can be used as a soil additive when emptied after 2 years
- Tanks can handle up to 30 uses per day and must be decommissioned for 2 weeks before emptying

Price: -USD 300 using local materials (One year loan offered for USD 150 down, 20% interest)
-USD 1200 using imported materials

Pros	Cons
Converts waste to compost on site	Design not simple enough for public use
Flush-integrated sink promotes hand washing	Requires piped water and waste removal
Water seal reduces odors and flies	Requires education/demonstration

Observations

- Observed 8 units: Six well-functioning, single-standing private toilets, a school structure with separate girls' and boys' toilets, and a community block. The community block loses most of its potential customers to poorly maintained pour flush facilities nearby, which charge only GHC 0.20-0.30, compared to the MFBF's GHC 0.40 fee. During a half hour afternoon observation period, 28 people used the pour flush while one person used the MFBF.
- The odor and cleanliness were extraordinarily better at the Microflush Biofil.
- GSAP was unable to find a farmer willing to purchase its fertilizer/compost in 2012/2013.
- Sinks at the school have been indefinitely disconnected due to persistent theft of taps. As a result, no new models include sinks with greywater flush. Rather, new models operate as pour flush toilets.
- Can only be cleaned with broom and water because soap kills the vermiculture.
- By switching to local materials and eliminating the sink, the cost has dropped from USD1200 to USD300.

Location

Forest Avenue,
Dzorwulu, Accra, GH

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Biofil

Summary of Technology

- Technology developed in 2010 in Pokuase with Dr. Mecca of MFBF. A minor dispute exists over the rights to the design/patent and use of the Biofil name.
- Identical to original MFBF, except for a more complicated vermiculture tank that separates solid waste from liquid, facilitating filtering and infiltration of liquid waste
- Tank never needs to be emptied, whereas the MFBF must be emptied every 2 years
- Aerobic biofil tank effectively eliminates the odors typical of anaerobic septic tanks
- Price: USD 1520 for Biofil Tank, Toilet, Sink/Greywater Flush, and Superstructure
  (USD 870 for select low-income customers)
  USD 870 for Biofil Tank alone (as an attachment to an existing toilet)

Pros	Cons
Never empty tank – need not be near road	Design not simple enough for public use
More functional, less smelly tank than MFBF	More expensive than MFBF, no loan program
Private business: 4000+ toilets, 25 employees	Requires water and education/demonstration

*Observations and interviews with users of Biofil toilets were not feasible.

Location

Ashtown, Kumasi, GH

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Metro Assembly,
Ideo.org, Hogan Lovells

Clean Team Toilets

Summary of Technology

- Subscription service seeking to provide portable, clean, simple, odorless toilets for families unable to install infrastructure-intense systems
- Plastic Toilets contain a removable bucket that contains sanitizing chemicals
- Staff frequently collects buckets, which are hauled to central site where waste aggregates; buckets are cleaned, refilled with biocide, and returned to circulation
- Subscriptions: GHC 25 / month for <5 users, GHC 35 / month for 5-10 users, GHC 45 / month for 10-15 users, compared to GHC 0.10-0.30 per use at public toilets

Pros	Cons
Subscription means cost distributed over time	Very labor intensive
No large on-site infrastructure	May not be affordable for low-income users
Creates respected sanitation jobs	Only feasible in dense urban areas

Observations

- Began in 2010 with a 20 toilet pilot and now operates at capacity, serving 3500 users with 500 subscriptions in 10 neighborhoods. Have plans to expand capacity to 10,000 toilets in Kumasi by early 2015 and then expand to Accra.
- Clean Team must serve 1500-2000 subscribers before it generates profit.
- 25 employees; waste collectors earn good wages and have no problems with disease.
- Must deny service to certain residents due to lack of secure space in their homes.
- Mostly serve urban, middle class, business/trader families.
- Not technically an improved sanitation technology, although Narracott is lobbying for a UNICEF/WHO redefinition of "improved" sanitation.
- Partnered with Cranfield University to develop a new waste-holding chemical and a waste reuse program.

Microbial Fuel Cell Latrine (MFCL)

Location

Nyastech Secondary,
Nyakrom, GH

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Affiliates

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Summary of Technology

- Field test of a project that uses human waste to generate on-site electricity in a process involving an anode and cathode
- In addition to electricity, dried out organic matter accumulates and can serve as fertilizer
- For users, the facility resembles a VIP with a toilet seat and a separate urinal for men

Pros	**Cons**
Educational pilot project	Never produced electricity (Inconsistent use)
Convert waste to fertilizer, biogas, and power	Requires waste removal at some point
Similar to familiar KVIP or VIP units	Significant odor and nearby WCs deter users

Observations

- Few of the 1500 students use the MFCL. Commuters (900) use public toilets on the way to school while boarding students (600) use WCs in dorms, according to surveys.
- Nearby forest is a more conventional location for urination, preventing the nitrification of urine that is required to power the cathode. Addition of a urine diverting seat would allow women to contribute urine to the fuel cell as well.
- Students that do use the MFCL tend to squat on the seat rather than sit. Some also refuse to use the MFCL because it is used by both genders.
- Toilet paper is supposed to be thrown inside the pit, but students throw it on floor.
- Concern exists over whether or not this is an improved sanitation technology.
- Can only be cleaned with a broom and water because soap kills necessary microbes.

Fortified Excreta Pellets for Agriculture (WaFo)

Location

Cantonments,
Accra, GH

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Affiliates

IMWI,
Ghana Nuclear Enery

Summary of Technology

- Converts excreta into sanitized fertilizer pellets that are fortified with pre-gelatinized starch
- Process: Dewater fecal sludge (15 days), add sawdust and/or other organic waste, compost fecal matter (90 days), grind to powder, add inorganic fertilizer, sawdust, and pre-gelatinized casava starch, pelletize, dry in sun, package
- Aim is to remove health risk from the environment and contribute an agricultural additive
- This project is ongoing, and the pellets have not yet been fully developed nor are they being applied widely. Currently concluding feasibility studies, optimization of pellet composition, and proof of concept. Commercialization phase will begin soon.
- Raw fecal sludge contains 2.3% Nitrogen, or 1.7% after composting. If mixed with sawdust, the final mixture contains just 1.2% N. Inorganic fertilizer is added to raise this to 3.0%, but this is still far lower than the typical 15% N of inorganic fertilizers on the market.

Pros	Cons
Prevents waste from being dumped in ocean	Low nitrogen content compared to inorganics
Plans to commercialize at Nungua (Tema)	Requires added inorganic fertilizer
Can serve as a solution to many toilet facilities	Fortifying starch can cause mold growth

Research conducted and report written by Jason Knutson,
MIT Department of Civil and Environmental Engineering 2014.