Final summary report of all ideas, prototypes developed, market potential and segmentation, and routes to commercialization completed and disseminated

SANITATION VENTURES

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1. Introduction

Sanitation Ventures (SV) was set up to find solutions to the problem of pit latrine filling. The scale of the challenge – and the opportunity - is huge: there are around 1.7 billion latrine users worldwide. In this report we share our thoughts and progress on identifying, developing and delivering solutions for these people. Our guiding principle has been that the most sustainable way to achieve delivery at scale is through business. We believe that there is a market for sanitation products if they are designed to be affordable and meet consumer needs and aspirations. Our goal has therefore been to create the greatest impact we can on improving on-site sanitation for the poor through market-led innovation. To achieve this we have tried to integrate as far as possible market and consumer insights with technology and business viability in creating platforms for commercial ventures.

Very little was known about the market for sanitation and even less about the market for products and services related to pit latrine filling when we started this project. In addition to our qualitative research into user needs (reported elsewhere and available at www.sanitationventures.com) some characterisation of different segments was necessary to guide our innovation efforts. Who should be our target customer? We start this report with a quantitative analysis of the main segments relevant to the problem of pit latrine filling. This strongly supports our focus on the domestic user for innovation: in terms of potential impact as well as market size this segment represents the greatest opportunity.

Midway through the project we realised that we knew enough about the user and the available technologies to be able to launch an innovation process ahead of schedule. This generated a raft of ideas from which we selected three to take forward. We discuss the process we followed as well as the ideas themselves and their current status. In some cases we have been able to develop working prototypes and these are described in some detail.

A major section of this report is devoted to our lead innovation, the Tiger Toilet. Over the past year this has had the lion’s share of resources, with a dedicated team working on product design, proving the technology, and understanding the market. The evidence presented here suggests that Tiger represents proof of concept and the next stage will be to assess its potential to make an impact at scale. We hope this level of evidence will encourage others to build on our findings and test this idea in their markets.

In the latter stage of the project we began to consider how we could catalyse commercial ventures and attract entrepreneurs to work with us on taking our ideas to market. One such venture, the BioCycle (www.thebiocycle.com), is now underway and showing promise. We hope that through this report other such ventures may be initiated and realised.

2. Global Overview of Potential Markets

2.1 Introduction

Four global markets were identified in which it was hypothesised there would be a demand for products and services to address the problem of pit-latrine fill and which would be in keeping with the social mission of the project. These were households, municipalities, humanitarian non-governmental organisations (NGOs) and Schools. A desk study was carried out to assess the relative potential of these markets in terms of size, need and an identifiable client. Initial work on this study was by Sanitation Ventures. This was subsequently supplemented by a commissioned study (carried out by PATH on behalf of Sanitation Ventures). The PATH study used information from 20 countries to give an impression of the markets across 3 continents (see Table 1 below).

The overall findings of the global overview were:

1. The households market dwarfed the others in terms of need by virtue of the sheer number of potential beneficiaries. However, it should be noted that demand, ability and willingness to pay for proposed products and services is not known.
2. Humanitarian NGOs provide sanitation for a small sub-set of the total, global population of onsite sanitation users. Pit filling is a problem for these NGOs only in specific, limited circumstances. However, in these circumstances the problem can be acute and the current solutions can be costly.
3. Few municipalities were believed to provide sanitation services for on-site sanitation users. Detailed information on current sanitation spending was accessed only for Durban municipality, which is thought to be unusual in terms of the level of service provided.
4. Very little information was available regarding the level of sanitation service in the world's schools or the amount currently spent on this. Funding sources for school latrines are many and varied resulting in a potentially complicated client base. Furthermore, full pits are not thought to be a major problem in schools.

Additionally it was recognised that any products or services developed would likely have to be acceptable and applicable at household-level even if they were to be purchased and used by municipalities or NGOs and that a household solution could probably be scaled up to serve institutions such as schools if necessary. For these reasons subsequent consumer research and product development work focused on the household as the most likely consumer and client.

The findings for each of the 4 hypothesised markets are summarised below.

2.2 Households

Table 1. Countries of focus

Asia	Africa	Latin America
Bangladesh	DR Congo	Bolivia
Cambodia	Ethiopia	Brazil
China	Ghana	Colombia
India	Kenya	Guatemala
Indonesia	Nigeria	Haiti
	Rwanda	Honduras
	Tanzania	Nicaragua
		Peru

Data on sanitation coverage were accessed for a sample of 20 countries across 3 continents. These were broken down by urban and rural populations and by type of on-site sanitation. Figures for open defecation were also included.

Table 2. Sanitation coverage in Asia by urban/rural population (WHO 2010)

Country	Population x1,000 (2008)	% coverage of population (2008)		
		Septic tank	Latrine	Open defecation
Bangladesh				
Urban	43,312	29.8	46.4	1.7
Rural	116,688	9.0	81.0	9.1
Cambodia				
Urban	3,137	32.6	2.5	18.5
Rural	11,426	10.4	5.4	76.8
China				
Urban	577,039	3.3	7.8	0.2
Rural	760,372	5.1	70.7	2.0
India				
Urban	348,091	77.3	9.6	11.3
Rural	833,321	17.9	15.2	65.2
Indonesia				
Urban	117,196	75.9	12.7	11.3
Rural	110,149	41.7	25.2	33.1

Table 3. Sanitation coverage in Africa by urban/rural popln. (WHO 2010, ADBG 2012)

Country	Population x1,000 (2008)	% coverage of population (2006)		
		Septic tank	Latrine	Open defecation
DR Congo				
Urban	21,793	3.8	92.4	3.3
Rural	42,464	0.02	82.2	17.4
Ethiopia				
Urban	13,657	8.0	80.6	11.4
Rural	67,057	1.3	29.5	69.1
Ghana				
Urban	11,676	22.6	69.0	7.3
Rural	11,675	1.5	60.4	36.9
Kenya				
Urban	8,354	39.1	55.5	4.0
Rural	30,411	1.5	76.4	21.8
Nigeria				
Urban	73,123	27.8	63.3	8.8
Rural	78,089	5.7	61.8	32.5
Rwanda				
Urban	1,778	6.3	90.9	2.6
Rural	7,943	0.2	96.1	3.4
Tanzania				
Urban	10,822	10.1	87.4	2.4
Rural	31,662	0.5	81.6	18.0

Table 4. Sanitation coverage in Latin America by urban/rural population (WHO 2010)

Country	Population x1,000 (2008)	% coverage of population (2008)		
		Septic tank	Latrine	Open defecation
Bolivia				
Urban	6,361	10.9	17.9	10.3
Rural	3,333	3.7	41.4	51.7
Brazil				
Urban	164,497	27.7	12.4	4.9
Rural	27,475	37.0	32.3	18.1
Colombia				
Urban	33,522	4.9	0.4	1.1
Rural	11,490	37.9	5.0	23.0
Guatemala				
Urban	6,641	6.4	15.7	1.8
Rural	7,045	7.7	60.6	17.4
Haiti				
Urban	4,635	8.7	78.1	10.0
Rural	5,241	1.2	47.7	50.6
Honduras (2007)				
Urban	3,504	17.7	15.5	2.8
Rural	3,815	27.5	46.4	21.4
Nicaragua				
Urban	3,215	12.1	44.9	3.5
Rural	2,452	1.7	72.9	24.4
Peru (2007)				
Urban	20,587	4.8	14.6	9.1
Rural	8,250	5.2	50.4	42.0

It is anticipated that the greatest initial demand for a product or service will be amongst urban pit-latrine users. This is the population for whom lack of space for constructing new pits and poor access for emptying services are likely to exacerbate the problem of latrine pits filling. In addition large urban markets are likely to be easier to reach and therefore more attractive as a starting place for a commercial enterprise than rural areas.

The definition of a septic tank is often hazy and it is likely that many of the so-called septic tanks are essentially off-set pour flush latrines soaking directly into the ground. Nevertheless they probably generally represent better quality on-site sanitation reflecting greater financial outlay. Septic tank owners are therefore probably unlikely to be an important market for an improved latrine design. They may however, be a market for an additive.

Current open defecators do not have to deal with the problem of a full latrine pit. They may represent a market for a latrine but there may also be strong cultural or other barriers that have mitigated against latrine uptake to-date and which would need to be overcome to bring these potential consumers into the sanitation market.

Table 5. Estimated potential latrine market size in 2008 by levels of uptake

Country	Total population (2008)	% pit latrine coverage of total popln. (2008)	Estimated total households		
			Low market uptake (3%)	Medium market uptake (5%)	High market uptake (10%)
Bangladesh	160,000,130	71.6	687,361	1,145,601	2,291,202
Cambodia	14,562,010	7.3	6,378	10,630	21,261
China	1,337,411,170	62.1	4,983,194	8,305,323	16,610,647
India	1,181,411,910	13.6	964,032	1,606,720	3,213,440
Indonesia	227,345,080	19.9	271,450	452,417	904,833
TOTAL FOR ASIA			6,912,415	11,520,691	23,041,383
DR Congo	64,256,640	85.9	331,179	551,965	1,103,929
Ethiopia	80,713,440	35.6	172,404	287,340	574,680
Ghana	23,350,930	63.1	88,407	147,344	294,689
Kenya	38,765,310	72.3	168,164	280,273	560,546
Nigeria	151,212,260	62.3	565,231	942,052	1,884,105
Rwanda	9,720,690	95.4	55,641	92,735	185,471
Tanzania	42,483,930	82.9	211,315	352,192	704,384
TOTAL FOR AFRICA			1,592,341	2,653,901	5,307,804
Bolivia	9,694,110	26.0	15,123	25,205	50,409
Brazil	191,971,510	15.3	176,230	293,716	587,433
Colombia	45,012,090	1.6	4,321	7,202	14,404
Guatemala	13,686,130	36.5	29,973	49,954	99,909
Haiti	9,876,400	60.7	35,970	59,950	119,899
Honduras	7,318,790	*Data not available*			
Nicaragua	5,667,330	56.7	19,280	32,134	64,268
Peru	28,836,700	*Data not available*			
TOTAL FOR LATIN AMERICA			280,897	468,161	936,322
TOTAL ACROSS SAMPLED COUNTRIES			8,785,653	14,642,753	29,285,509

It is important to note that these figures for septic tank and latrine market size are merely a snapshot of the potential market in 2008 and do not reflect any sort of trending across population growth or movement along the sanitation ladder. It is also important to consider the constrained income levels of the populations in each of these countries, especially when examining various levels of uptake. The projections are dependent upon a myriad of conditions, not least of which include the potential price of improved sanitation technologies as well as availability and accessibility factors.

Still, the numbers reflect a very robust market size across the 20 countries sampled in the analysis. Unsurprisingly, the greatest potential market size lies in Asia due to the larger population sizes among the countries included in the analysis. However, the African countries show a particularly sizeable latrine market across the three levels of uptake.

Other differences between the three continents include the higher and more even urban/rural coverage and lower uptake of septic tanks in Africa as compared with Asia and the higher rates of off-site sanitation in much of urban Latin America and China.

To date, few studies have broadly examined either the amount that households currently spend on latrines or their willingness-to-pay for household sanitation improvements. Where data is available, costs for latrine construction as well as operation and maintenance vary widely. It is difficult to accurately determine a standard or average cost due to so many different variations of sanitation solutions that households utilize as well as their different levels of maintaining those facilities.

2.3 Humanitarian NGOs

The size of this market in terms of potential beneficiary households is much smaller than the household market since refugees in camps make up only a small fraction of the global population. In 2008, while UNHCR reported a total of over 34 million refugees and people of concern worldwide, only about 4.6 million of those people were residing in refugee camps across 41 countries.

Data on the amount spent by humanitarian NGOs annually on sanitation provision are hard to come by as these tend to be kept only at camp level if at all. In November 2009, UNHCR estimated that approximately 80,000 to 100,000 latrines existed in refugee camps across the world with a usage ratio of 50 people per latrine (UNHCR November 2009). UNHCR estimates replacing 10 to 15 percent of these every year.

Oxfam reports that they usually plan on a pit latrine lifespan of approximately 6 to 12 months in emergency settings (LSHTM 2010). However, fast filling is of critical concern, particularly in high-risk areas with a high-water table, prone to flood, or with difficult soil environments, where the option for digging new pits is not available. In these settings, Oxfam makes provisions for emptying latrines and budgets accordingly. They usually approximate about US$5 per cubic meter emptied (LSHTM 2010). However, as an emergency moves into recovery and rehabilitation, users are expected to take up the costs for ownership and maintenance of the latrines.

Figures for latrine construction by the International Rescue Committee (one of the major humanitarian NGOs) are shown in Table 6.

Table 6. IRC latrine construction across various countries since 2006 (IRC 2012)

Year	Country	Number of latrines
2006	Indonesia	1,000
2008	DR Congo	140
2009	Afghanistan	250
	Kenya (Dadaab, near Somalia)	3,000 *(with plans for 13,000 by Dec 2009)*
	Kenya (Kakuma)	2,328
2010	Haiti	500
	Pakistan	1,500

Refugee camps tend to be in rural areas meaning that space for construction of new latrines is often not a problem. In addition the refugee populations can be a source of cheap labour for latrine construction, which helps to keep down the costs of sanitation. For these reasons cost-conscious NGOs are unlikely to want to invest in more costly sanitation technologies except in specific circumstances such as where rocky ground or high water table make traditional latrine technologies problematic. In addition to refugee populations natural disasters can lead to populations of internally displaced people (IDPs), often in urban settings as occurred in Haiti. In these circumstances provision of traditional pit-latrines may not be an appropriate solution and a technology for extending the life of the pit-latrine may be of interest. A low-cost, effective additive for reducing pit-contents might be of wider interest since it would also allow flexible extension of pit-latrine life in refugee camps where the duration of need may be hard to predict.

Assuming that the refugee camp population remains stable, and that family latrines are the main means of delivery, 2,893,595 people will require an estimated maximum of 578,719 latrine units that are renewed every two to three years. In addition to this there are an estimated 843,467 people using 42,173 latrines in long-term conflict-related IDP camps and 1,237,032 people using 12,370 latrines in long-term natural disaster IDP camps. This provides us with an estimate of 633,262 latrines needed for the emergency/relief sector (LSHTM 2010).

While somewhat sizeable and potentially a continual need, the emergency/relief sector market opportunity is comparably much smaller than the household sector. This segment is dwarfed by the need for improved sanitation in India alone. Given the 2008 coverage estimates of approximately 49 percent of all of India resorting to open defecation, the estimated latrines needed for the emergency/relief sector represents only 0.5 percent of the need for basic pit latrines as an initial solution to open defecation in India[1]. Beyond the size differential between the two sectors, the issue of unpredictable need or demand within the emergency/relief sector is also important to consider. Unlike the household sector in which a massive number of potential consumers may require improved sanitation technologies along a steady continuum, the emergency/relief sector operates in a reactive fashion with limited ability to predict future need for sanitation or even the most appropriate solutions for each event.

[1] This assumes an average household size of five people in India.

In addition, there are the added complexities of inconsistent approaches by aid agencies to latrine maintenance (i.e. pit emptying versus building new latrines), as well as the administrative processes related to supplies procurement by each organisation. As seen above, not every organisation makes arrangements for consistent operation or maintenance of latrines in relief settings. When possible, the simplest and cheapest method is to build new latrines and fill in old ones. Thus, desire for new sanitation technologies that address pit latrine filling but carry additional budget concerns may be disregarded by agencies already operating with fairly tight budgets. For those organisations that are interested in the potential of including technologies that lengthen the lifespan of basic pit latrines, there may be issues around product procurement that could limit volumes and frequency of orders of the technology from certain producers

Overall, there is little doubt that improved sanitation technologies seem to fit well within the emergency/relief sector based upon its operational model and choice of sanitation solutions. It may be difficult, however, to build a business case for improved sanitation technologies around this volatile sector. Still, there may be opportunities for considering the emergency/relief sector as a secondary or tertiary market of interest.

2.4 Schools

School sanitation is widely recognised as being a problem in low-income settings and is often blamed for poor attendance rates, particularly among girls, and poor teacher retention as well as being a potential source of infection. However, the main problems reported are lack of provision, poorly constructed and poorly maintained latrines and lack of privacy. It is not clear that any of these relates directly to the issue of pit-fill. Interviews with a small sample of head teachers in Dar es Salaam suggested that pits rarely filled, possibly reflecting lack of use by the pupils. In addition, schools generally have considerable space to allow construction of replacement pits and good road access, making vacuum emptying an option.

A frequent problem in the provision of school sanitation is the lack of a ring-fenced sanitation budget. In fact, funds for the provision and maintenance of school sanitation might come from various sources including the state or municipality, parents' associations, charities and NGOs. This could complicate the identification of the customer for a new latrine technology for schools.

No global data were located describing school sanitation. Thus, aside from the details mentioned above little is known about this market apart from the potential size as indicated by the numbers of schools (see Tables 7 and 8 below).

Table 7. Sample of available school sanitation data (WINS 2012)

Country	Year	Total schools	Primary schools	Secondary schools	% with at least 1 toilet	Type of facility	Pupils per latrine standard
Bangladesh	2007	81,434	58,752	18,500	92	-	60:1[a] 150:1[b]
Cambodia	2009	9,266	6,767	407	65	-	-
India	2009	1,046,658	809,974	-	80	-	Toilets: 80:1 Urinals: 40:3
Ethiopia	2011	-	-	-	77	-	50:1[a]
Kenya	2009	23,922	19,753	4,169	33	Most pit latrines	Girls: 25:1[a] Boys: 30:1[a] 100 to 700:1[b]
Nigeria	2003, 2005	-	54,434	18,238	41	-	Primary: 600:1 Second.: 172:1
Tanzania	2009	-	-	4,266	-	-	-
Haiti	2011	22,000	-	-	<40	-	-
Honduras	2004	12,901	11,133	876	98	Most pit latrines	20:1[a]

[a] Government standard; [b] Independent assessment (e.g. UNICEF);

Table 8. Additional data on schools and enrolment figures (Wikipedia search 2012)

Country	Year	Primary schools	Primary enrolment	Secondary schools	Secondary enrollment
DR Congo	2002	19,000	160,000	8,000	110,000
Ghana	2007	12,130	1,300,00	5,953	596,600
Rwanda	2004	2,262	-	504	-
Nigeria	2008	54,434	21,294,517	18,238	6,625,943

The 2009-2010 implementation report for Tanzania's MKUKUTA national development strategy reported on the estimated number of pit latrines across all education levels within the country in 2010 (Table 9).

Table 9. Estimated total pit latrines and pupils per latrine in Tanzania (MOFEA 2010)

Education level	Total enrollment (2010)	Total pit latrines (2010)	Pupils per pit latrine
Pre-primary	925,465	6,916	134
Primary	8,419,305	149,566	56
Secondary	1,638,699	42,538	39

2.5 Municipalities

Municipalities with both the remit and the capacity to undertake routine pit emptying are probably rare. The study by PATH did not uncover any such examples. It is likely in many countries that municipalities have a responsibility for ensuring that the contents of pit latrines do not contaminate the environment. It is also likely that in the majority of cases municipalities lack the capacity to do this, as was found to be the case during the qualitative work in Tanzania. In most cases this responsibility for protecting the environment is not thought to extend to a responsibility for emptying pits. Exceptions may be found in South Africa, where the relative wealth of Durban municipality and the particular context surrounding the end of Apartheid led to municipal capacity and responsibility for emptying household pits. In other cases, as happened in Botswana, responsibility for pit emptying may have been passed to municipalities as part of donor-driven sanitation programmes that included the intention to build the capacity of the municipality to perform this function. These programmes are generally believed to be short-lived. In the case of Botswana the programme is no longer thought to be functional.

The scale of the task relating to household pit emptying is likely to be so large that in most contexts the municipality would lack sufficient capacity to achieve this. However, a product or service that enabled the majority of households to manage their latrine contents effectively might allow the municipality to act as a safety net for a minority who were unable to do this.

The impression gained is that a majority of municipalities do not routinely carry out emptying services and are unlikely to be a key segment.

3. Innovation Process

3.1 Overview

‘Most innovation is messy, involving false starts, recycling between stages, dead ends, and jumps out of sequence’. (Tidd 2006)

Sanitation Ventures existed to innovate, as well as to accumulate knowledge to fuel future innovation, hence separating out the innovation process from the wider project isn’t easy. It also existed to innovate within a highly fluid context where the markets for its future products required definition and few or no precedents existed for the types of solutions it sought to offer. As a consequence, the innovation path it has trodden reinforces the notion of innovation as messy. And while it would be satisfying to describe a well-ordered process blending the pull and push of consumer, commercial, technological and contextual insight and knowledge, in reality it’s been a many-handed juggling act with some aspects of the process carefully designed and others the result of opportunism and accident.

From the start, the focus for all SV’s innovation was clear: to do something about the wretched, costly, health-threatening problem of pit filling - this has been our rudder. If we then split innovation into identifying opportunities, having ideas (invention) and creating value through implementing and developing ideas to meet opportunities, then much of the work of this phase has been about the first two, with a start being made on value creation. With this in mind, SV’s innovation process can be seen as having served three key purposes:

1. Leveraging technology platforms to yield ideas for consumer-relevant, technically viable solutions to pit-filling;
2. Scoping and exploring these further to identify specific solutions which best fulfill the idea (e.g. Black Soldier Fly (BSF) larvae);
3. Turning the most promising ideas into potential commercial ventures (e.g. Tiger Toilet, the BioCycle).

The critical approaches and methods we used were:

- For idea generation we designed specific workshops and sessions involving a mix of our internal team and external participants with careful preparation of stimulus material and very clear briefs;
- For scoping ideas we have used an open innovation approach, as well as desk research, with the cooperation of InnoCentive being particularly valuable;
- To filter and select the most promising ideas we developed an evaluation template in which questions were posed about the underlying consumer need, the technical issues, marketing and business model issues. Our attempts to address these questions proved highly instructive in shaping the portfolio and action plans that resulted;
- Given that we had fixed resources we focused very much on critical next steps in advancing specific ideas;
- For the lead innovation (Tiger) and the first venture spun out of SV (the BioCycle) new multi-disciplinary teams were brought together to drive further development.

Throughout the process we have seen our role as not just to identify promising innovations but to build compelling evidence for their attractiveness to entrepreneurs as business ventures. Our focus in this respect has been developing technical “blueprints” and in building the business case.

Although the process did not neatly fit into clear stages, the following description will give a sense of some of the key steps and the thinking behind them.

3.2 Idea Generation - Leveraging Technology Platforms

An early technology landscaping exercise had identified a series of technologies with the potential to help tackle the problems of pit filling. This study (published at www.sanitationventures.com) was conducted through a systematic patent and literature review against five different hypotheses for routes to slowing or preventing latrine filling. It included physico-chemical as well as biological technologies.

The most promising of these (in terms of their appropriateness and their technical readiness) were combined with broad insights from consumer research in Tanzania and Vietnam plus understanding of the bottom of the pyramid (BOP) consumer context, to form nine ‘hotspots’. These were the focus of a two-day workshop in December 2010 where members of the core Sanitation Ventures’ team and additional technical and target audience experts met to explore them and to ‘*generate new ideas and developing existing ideas for on-site sanitation solutions for householders and landlords in rural and urban settings in developing communities’.* Figure 1 is a playful visualisation of the creative process involved in the workshop.

Figure 1. Workshop Process

3.3 Categorising the Workshop Output

The workshop output was a series of solution strands with one or more concepts within them that the participants scored most highly in terms of feasibility. These are listed in Table 10 below:

Table 10. Initial Ideas Summary

Name	Description		Move to Feasibility	Hold	Shelve
BioBomb	Next generation bio-additives administered to rapidly accelerate latrine waste breakdown.	Consumable	✓		
		Service	✓		
Black Soldier Fly (BSF)	BSF larvae processing waste before harvesting for value recovery, either in situ or centralised and linked to an emptying and collection service	Consumable	✓		
		Service	✓		
Biolytic System	An earthworm bio-filter to breakdown matter creating low or no waste in a latrine.	New system	✓		
Anaerobic Cap	A sludge-top seal to promote the optimum environment for pit waste breakdown.	New system		✓	
Daily Aeration	Mechanically or structurally aerating latrines to promote aerobic digestion.	New system		✓	
Heat	Increasing sludge temperature to accelerate breakdown.	New system		✓	
Waste reuse	Re-using excess water in latrines which contributes to rapid pit filling	New system		✓	
Rotator	Mechanical action to prevent inactive pockets of sludge & increase breakdown rates.	New system		✓	
Saturate/ De-saturate	Mimicking latrine flooding and draining to accelerate sludge breakdown.	New system		✓	
Active Pit Lining	Ecosystem in the pit wall to breakdown & filter waste.	New system			✓
Bag-It	Waste collection service in biodegradable bags.	New system			✓
Aquatic Worms	Aquatic worm bio-filter to breakdown matter creating low or no waste in a latrine.	New system			✓
Under Pressure	Putting sludge under pressure to reduce volume and force filtration.	New system			✓

Using the evaluation template described earlier, a small subset of the team reviewed these ideas further and sorted them into three categories:

- Move to Feasibility Testing: these ideas were felt to be the most promising and achievable given our existing capacity;
- Hold: these ideas were thought to be very promising but were beyond our capability – generally there was some key technical issue we could not see how to address;
- Shelve: these ideas were too conceptual and no route to achieving them could be seen.

Only the three labelled 'move to feasibility' as indicated in Table 10 above were progressed given the resources available within the project. Following discussions with the project Advisory Group it was then agreed that we should focus the majority of our resources on one lead option. After considering the technology readiness (time to final product), market size and impact as well as the team's capacity to develop the idea, it was concluded that the Biolytic System should become our lead option. A new team was assembled to develop this idea and was codenamed "Tiger". For the other two ideas, critical and affordable next steps were identified to move them forward as shown in Table 11 below:

Table 11. Next Steps

Idea	Key Next Step (Apr 2011)	Status (July 2012)
BioBomb	Establish screening programme to identify active ingredients	In progress, to be completed May 2013
Black soldier fly: centralised treatment	Explore economic viability and whether revenue would subsidise emptying	Study completed and reported on SV website BioCycle venture launched January 2012 and on track
Black soldier fly: *in situ*	Further ideation on devices to insert/harvest larvae	InnoCentive process and further workshop completed and 2 prototypes generated as well as new BSF toilet concept
Tiger	Assemble team and create development plan	Field prototype ready to test

3.4 Moving from Ideas to Ventures

In the case of Tiger, this was the point at which idea generation stopped and the innovation process moved into the stage of proving the technology, designing and testing product concepts, and deepening our understanding of the market. These activities and our progress are discussed in more detail in Section 4.

In the case of BSF idea strands, here there were two main thoughts. Either it could be a centralised treatment linked to a waste collection and transport service, or it could be an *in situ* product or service operating at the latrine level. Our initial belief was that the former was preferable given the scale and degree of process control it would afford. The key next step was to check whether the economics made sense: would the potential revenue from BSF larval products be sufficient to drive a subsidised emptying service? The answer (see Haas report on www.sanitationventures.com) was "yes". This led directly to the launch of the BioCycle venture (www.thebiocycle.com), which is described in Section 5.

3.5 Back to the Drawing Board

To progress the *in situ* BSF strand the key challenge was around how to get the larvae in and out of latrines with minimum inconvenience. To tackle this we worked with InnoCentive[2], an open innovation and crowdsourcing platform. In 2010 InnoCentive offered to provide Sanitation Ventures with support on a challenge as part of its corporate social responsibility (CSR). The challenge SV posted focused on using BSF larvae to digest waste within rapidly filling latrines then retrieving them as pre-pupae for value recovery. The challenge was crafted in conjunction with InnoCentive and received just under 50 responses from which four winners were selected by a sub-group of the SV BSF team, in line with the criteria set for the challenge and in particular that any solution must be able to be retrofitted at low cost into an existing latrine. Three of these were then selected as appropriate to take into a workshop during which three teams worked on them in parallel. In addition to the SV BSF team, the workshop included design students from Middlesex University and representatives from The Gates Foundation and Oxfam.

The ideas in the session divided into two: 'open' systems – where the larvae roamed free on the sludge surface until harvesting and 'closed' systems where larvae were contained from introduction to collection. The former, better met our brief and two - the Kone (also our overall InnoCentive winner, proposed by Erik and Emil Martinsson) and Daisy Chain - were selected for prototyping and field-testing. The latter tended not to fit the original 'in-latrine' brief as they involved considerable disruption to the latrine structure, or were an entirely new structure, but were taken out of the workshop as a separate stream of activity, namely a BSF larvae complete 'toilet'. The BSF toilet could be envisaged either as a modification to a portable toilet in which a larval digestion/collection chamber is inserted beneath the bowl, or as a modification to a slab for a latrine, in which the chamber is mounted beneath the drop hole. In both cases the modifications could be quite straightforward. An early prototype of a modified portable toilet has already been made in cooperation with a plastics manufacturer in South Africa,4EVR.

The prototypes are described and illustrated in Section 5.

3.6 Back to the Lab

In the case of BioBomb the key challenge was to identify superior active ingredient(s) which could be the basis of an effective next generation bio-additive. For this reason we established a screening programme at Wageningen University and a partnership with Novozymes Biologicals who have supplied organisms and enzymes to test in a lab model system measuring decomposition.

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[2] www.innocentive.com

4. Innovation Portfolio

The innovation process described above has generated a portfolio of different ideas that will suit different customers. This should be beneficial: it is unlikely that there will be a single solution that will work for all the different market segments we identified. While there are some shared common needs from improved sanitation (e.g. privacy, dignity, absence of smells and flies) there are also differences depending on location (urban vs. rural), income levels, and other factors. These will affect the features and benefits consumers seek in a product. Hence it is important to create a range of options, especially at these early stages when we cannot be precise about the different segments of the market.

There is still much more work to be done on segmentation and how our ideas match particular segments. This is a key part of the overall commercialisation process. From what we have learnt so far about the domestic market the major factors likely to distinguish clusters of consumers are:

- Permanence – i.e. the length of time the product will last;
- Cost – including initial purchase and service/maintenance costs;
- Maintenance – i.e. how much effort is involved on the part of the user in keeping it operational.

Fig. 2 shows a possible classification of our portfolio using these factors. For example, the Tiger system should have a long lifetime and be low maintenance, but will have the highest cost to the end user in terms of initial outlay and servicing. At the other end of the spectrum the in latrine BSF ideas involve a high degree of user maintenance but the cost will be offset by the value created from the harvested larvae and the solution is only as permanent as long it continues to be maintained by the user.

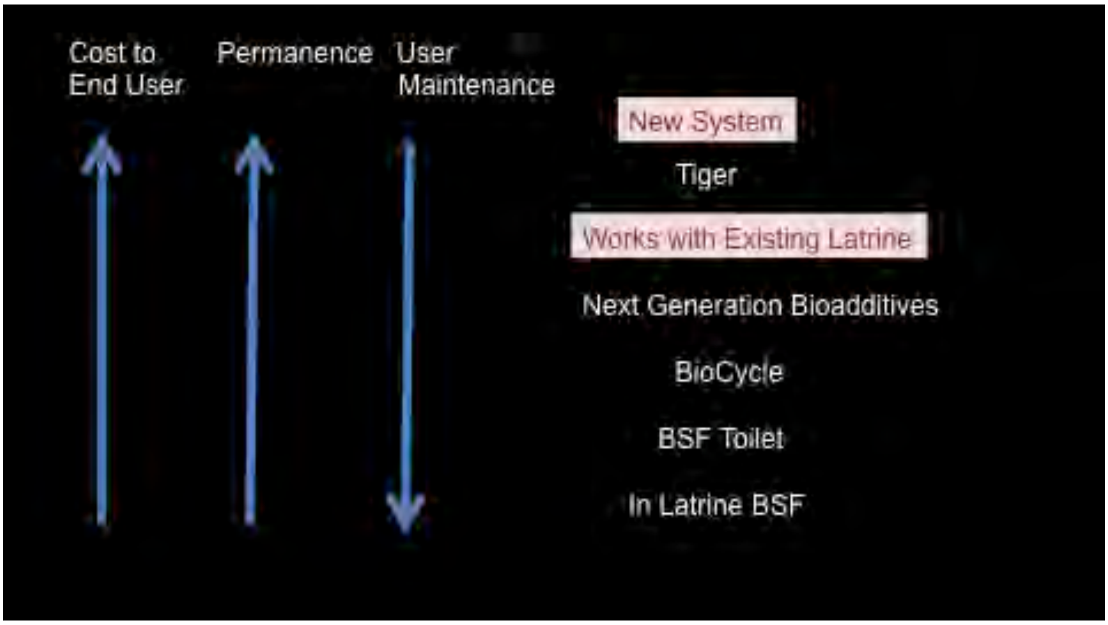

Figure 2. Portfolio by User Proposition

Successful commercialisation depends on matching product technology to market needs and this is an iterative process. The portfolio can thus also be viewed from the perspective of development stage. Not all our ideas are at the same stage given our focused use of resources. Again it is important to have a range of options: some may fail and there is always scope for improving design and performance.

Our portfolio by stage of commercialisation is shown in Fig. 3 where we have adopted some of the terminology described in a recent Monitor report into BOP business development[3].

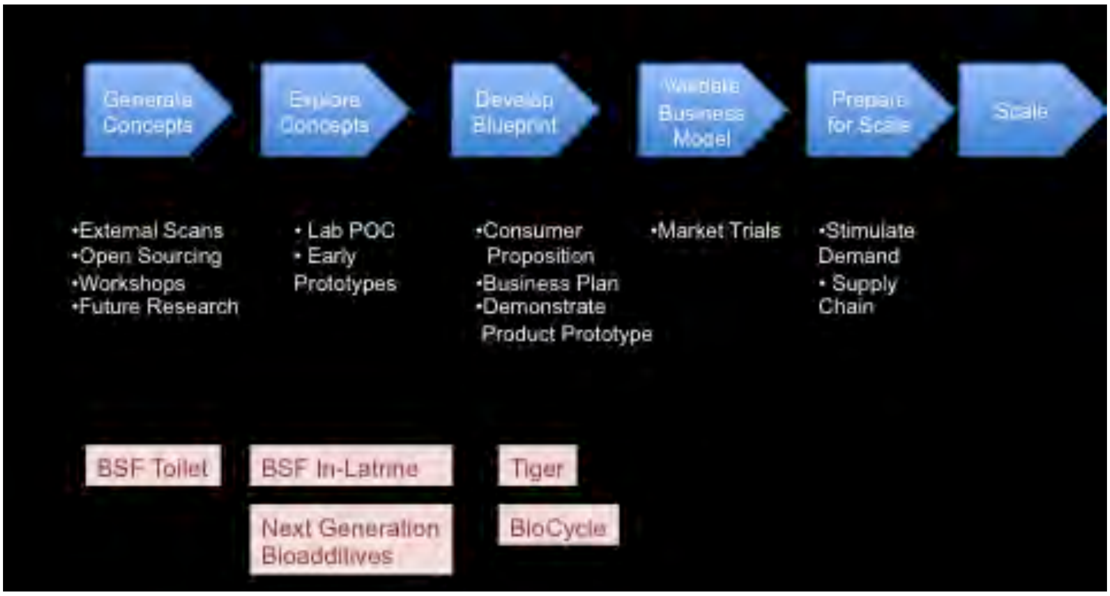

Figure 3. Portfolio by Stage of Commercialisation

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3 http://www.mim.monitor.com/downloads/Blueprint_To_Scale/From%20Blueprint%20to%20Scale%20-%20Case%20for%20Philanthropy%20in%20Impact%20Investing_Full%20report.pdf

5. Prototypes

5.1. Tiger

As mentioned above, in April 2011 we decided to focus on 'biolytic systems' as our lead innovation. Such systems depend principally on a particular sort of worm, the Tiger worm (*E.Fetida*), for their impressive levels of solids removal. They also usually incorporate a filtration element. Commercial systems using this technology have been available for some time, although relatively little detail had been published about their key components and operating conditions. A multi-disciplinary team was assembled combining design, engineering, consumer and market research, communications and business skills. The following objectives were set:

- **Design and develop** a flushable on-site worm-based product to meet the needs and aspirations of low-income consumers for improved sanitation globally;
- **Demonstrate** performance, user benefits and demand, and estimate the likely impact on sanitation;
- **Build** business case and establish routes to commercialisation that are scalable and sustainable.

Our focus was thus mainly on trying to develop an affordable yet highly effective version of this technology for the low-income consumer. In just over a year we have got to the point of having a prototype ready for field-testing and a potential future production design. In the next three sections we summarise our progress and current knowledge of the target consumer, the performance and the designs we have created. Our major focus has been on the domestic market. However there is strong interest in the application of this technology to humanitarian relief situations and also to government–funded sanitation programmes in India.

5.1.1 The Consumer

5.1.1a What we did and why

Market and consumer research into the Tiger system grew out of the wider sanitation market understanding work. We aimed to prepare a portfolio of market intelligence that could be used at the eventual launch of the Tiger Toilet. In total we undertook 27 interviews and 11 focus groups (c. 100 consultations) along with on-going desk research and team discussions. The research aims are set out below. These were aims at different stages of the project and should be viewed as a process rather than static. Full reports and research outputs are available through our website: www.sanitationventures.co.uk.

5.1.1b Research questions

- What sanitation problems do low income households face?
- How could consumer products be used to solve these problems?
- How and when do households upgrade sanitation, including making the decision and financing purchases?
- How do people feel about a worm-based toilet?

5.1.1c Current sanitation situation in Dar es Salaam

Dar es Salaam has several large unplanned areas with a rapidly expanding population. Consumers in these areas view the sanitation market as offering them two broad options: basic pit latrines; and off-set covered pits with a pour-flush and potentially more than one chamber. These two broad categories come in widely varying configurations. It is estimated that there between 227,205[4] and 237,300[5] pit latrines in Dar es Salaam.

Very few households in Dar es Salaam have a true septic tank (with a solids separation) or sewer connection of any form and those that exist are concentrated almost entirely in upper income areas. In addition very few people employ open defecation. In this report we use the term 'septic tank' to describe simply two, lined soak-away pits – not genuine, septic systems.

Despite this high proportion having access to latrines, they are often shared amongst a number of households and are quick to fill. Latrines are shared with 4.6 households on average. This is typical of the crowded urban sanitation situation.

5.1.1d Key needs – "Sanitation Upgraders"

Pit latrines are labeled as being for low-income households and poorly perceived image-wise whereas off-set, flush, and chamber toilets are for the better off and by default "modern". The desire to improve sanitation is evident throughout our research. There are however a number of physical or perceived barriers to achieving this:

- As previous research indicated and unsurprisingly given the income levels in our target communities, **cost is viewed as the key barrier** to upgrading sanitation. While this is likely to be true for many, it appears that perceived costs are considerably higher than the cost of systems reported by owners
- After these issues of cost, **access for an emptying tanker was mentioned as a barrier -** this is the only way people know that 'chamber' tanks can be emptied and in unplanned settlements households can be a long way from a road that a lorry can drive down.
- We had also hypothesised based on previous work in Dar that **space could be a barrier** to 'chamber' toilet construction. In our research, however, space was rarely raised as an issue few households saying they categorically did not have enough room for a 'chamber' toilet. In addition space may exist but people may be reluctant to give it up for sanitation when it could be used.

5.1.1e Spending on sanitation

With the high sanitation coverage in Dar es Salaam we can infer that at some point the majority of home owners have invested money, labour and thought in sanitation. In addition there are ongoing costs associated with on-site sanitation including maintenance and emptying.

[4] Calculation based on Demographic Health Survey data, LSHTM (2010)

[5] SanMark Dar Unplanned Area Sanitation Demand Survey: WSP, Mimi Jenkins, LSHTM

Building pit latrines in unplanned areas is not cheap. Previous estimates have placed the cost of construction of a basic pit latrine in a crowded urban area as between $100 and $500. These widely varying costs depend on the depth of the pit, soil type, lining and the quality of the slab and superstructure. Our own survey produced the following median and interquartile range of costs.

Table 12. Median cost of sanitation construction (USD)

Toilet Type	Pit *(Median)*	Interquartile Range	S. Structure *(Median)*	Interquartile Range
Pit latrine	200	100 - 333	100	57 - 167
Septic Tank	267	167 - 467	167	100 - 333

In terms of operation and maintenance the most important cost is emptying. Emptying costs vary depending on the method used, the accessibility of the latrine and the extent of emptying (full or partial). Vacuum emptying was the most commonly used method of emptying for dual chamber toilets ("septic tanks") and manual emptying or pit diversion[6] were also used for emptying pit latrines. Our research identified the following costs of these commonly used methods of emptying.

Table 13. Median cost of emptying (USD)

Toilet Type:	Households[1]		Median cost	Interquartile Range
	N	%		
Pit Latrines				
Manual emptying	171	*21*	40	40 – 53
Pit diversion	252	*30*	47	33 – 67
Vacuum emptying	349	*42*	53	47 – 67
Septic Tanks				
Vacuum emptying	183	*74*	60	50 - 67

[1]*Number and proportion of households planning to use this method at next emptying.*

The factors which determine fill-rate and the way in which these factors interact are not fully understood. They include not only the depth of the pit but also soil conditions, water table, number of users and the way in which the pit is used. No significant difference was found between the estimated gap between emptying a pit latrine and emptying a septic tank. Both were emptied approximately every 59 months on average (95% CI: 55 - 63 months). Depending on the type of emptying this would result in an annual cost of around USD 9 for those people vacuum emptying a septic tank or USD 12 for those manually emptying or diverting a pit latrine. For many latrines these costs will be spread over several households sharing the toilet.

5.1.1f Spending priorities

Sanitation is not a spending priority for the majority of households. Spending priorities in these low income households are unsurprisingly decided on urgency of

[6] Pit diversion involves flooding or diverting the waste into a second pit which is then filled in

need or triggered by an unexpected emergency. In research with homeowners latrine emptying and improvement is only mentioned as an afterthought when probed.

For the purposes of promoting our product targeting the point of where funding and consumer problem or sales opportunity meet is vital. Pit emptying or replacement becomes a concern, and hence a priority issue, when the latrine is entirely filled up or the structure is in dire need of renovation.

In terms of a household's ability to pay for sanitation improvement our analysis of the Tanzanian Budgetary Household Survey 2007 showed that around a fifth of Dar es Salaam residents with unimproved[7] sanitation improved their homes in 2007. These improvements were not necessarily sanitation related but the mean amount spent on any improvements made by those with no improved sanitation was $79. In addition we found that around 40% of Dar residents with pit latrines have demonstrated the ability and willingness to pay $150 for a product that would not be considered 'essential' for life or necessarily income generating e.g. a television, radio, mobile phone or refrigerator. Our qualitative research highlighted the following household durables were non-essential purchases that consumed a significant proportion of household incomes: sofa set/simple chairs; bed; TV; small radio; fridge; and DVD player.

5.1.1g Household financing

Incomes from employment (self- or private) and tenancy payments (for landlords) are the primary means for saving up for large purchases. Saving periods can span from one month to over a few months or a year depending on the purchase being made. Informal borrowing from relatives and friends also fund purchases. This was especially so in the case of small loans for the purposes of meeting urgent needs, e.g. if one's child is sick and one needs funds for the health centre.

After friends and family, 'merry-go-round' funds and local shop owners are seen as potential sources of informal borrowing. More formal arrangements through micro-finance institutions as well as banks are primarily seen as go to places for one seeking to inject further capital into their small business. The formal financing option is approached rather hesitantly.

While people can allocate part of their incomes to a Tiger toilet purchase, financing options have to take into consideration present concerns as well as fit into the payment preferences of a BOP consumer.

5.1.1h Triggers for sanitation upgrading

Once people had the idea that they might want to upgrade to a better form of sanitation (the step used in our research was upgrading from a latrine to a septic tank) asking friends or neighbours who was often the first step in the process. Information sought from these sources includes the cost of construction, a recommended builder and where to get the materials. It was obvious in the groups that this step was enough to stop some would-be up graders going any further, usually because they price they were given was felt to be prohibitive.

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[7] Pit latrines and any shared sanitation

After talking to friends and neighbours with direct experience, the next stage in the process is usually to discuss this with other members of the family, typically the spouse or relatives living within the household, in order to get their opinion. The input of a latrine builder may also be sought during this time.

It was clear from those we spoke to that getting accurate information on cost, design and process to make a sensible decision was difficult as the only source available was to talk to people (with different opinions and experiences) rather than seek out written or formalised information.

From asking septic tank users what triggered the final decision to move from a pit latrine to a septic tank and from listening to their stories, two key moments emerged as triggers to the final upgrading decision:

- **A new home:** Many of our upgrading respondents had installed septic tanks when they moved to a new property or built a new home;
- **Problems with their pit latrines:** Two of the respondents reported that one of their key motivators to shifting to a septic tank was the emptying challenges they experienced with pit latrines. In addition the moment at which a pit latrine needs to be emptied is a key moment for change. Or a one-off problem may trigger: one respondent, who had fallen into her pit while pregnant, said that this was the moment when she decided she wanted a septic tank.

5.1.1i Reactions to the Tiger concept

In June 2012 we tested our 'best' product description with our proposed target consumers using a large scale survey. This survey aimed to quantify the strength of the interest in the Tiger as a method of on-site sanitation, to inform our pricing decision, to better understand existing sanitation methods and to attempt a further segmentation of the household market. This work was complemented by two rounds of qualitative work, one to develop further the design and description used and one to better understand the nuance of the responses received in the survey and to pre-test the questionnaire before roll-out. Before this, in 2011, a previous round of qualitative work had been used to help develop the design of the Tiger system. There were elements that we were keen to understand in more depth including: the importance of being able to walk on the inspection hatch; the impact of excluding the use of bleach for cleaning; the reactions to the need to have the toilet serviced every three years; and the absence of a superstructure in the purchase price.

A standardised description was read out to respondents along with a showcard of the basic layout of the system. This was intended to give an objective account of the workings of a Tiger Toilet to aid discussion.

5.1.1j Concept testing - qualitative results

Overall the concept was well received and elicited a lot of curiosity. Terms such as modern, scientific, small, affordable, safe and clean and of course 'worms' were used to describe the innovation. There was general excitement about the concept as it went beyond the traditional or familiar methods. Key discussion points are outlined in Table 14.

Table 14. Benefits and Concerns of Tiger System

Benefits
Small space required for installation
Reduced volume of waste
Shallower pit *(easier to dig hole and money saving)*
Reduced reliance on emptying services *(and to some extent builders)*

Concerns
Cost and payment terms
Probability of toilet filling up
Capacity *Can the worms handle frequent usage?*
Worms escaping from the tank
Speed of growth of worms and size
Effect of bath water on tank

Space: Respondents in both rounds of research were shown a physical representation of the size of the tank. Everyone was interested in the system using up less space, firstly because it saved space for other uses and secondly because a smaller footprint meant flexibility about where the chamber was sited.

Installation: People were particularly interested on the shallower pit, which all agreed would save money either because a household could dig it themselves or because the installer wouldn't need assistants or have to stay as long. It would also save money, a few commented, because a less deep pit would need fewer materials and less labour.

Digestion & Worms: The notion of digestion by worms was easily understood. People's first reaction to the idea of worms was typically measured and reasonable – worms will digest the waste and I won't have to empty my tank so often or call for the tanker. There were many questions about the worms: where they would come from – with some wondering if they might come from the waste itself; would they crawl out of the system; would you be able to see them day-to-day; would they be able to deal with sanitary napkins and paper; would they eventually die; could they multiply and fill up the pit? When answers were given to these queries most people felt reassured that this was a satisfactory approach to sanitation.

Emptying: Many were at first surprised that the system would only produce a small amount of dry waste although this didn't turn into a refusal to believe the concept. In the first round of research the idea of self-emptying was used. Almost without exception people said they would be happy (and would prefer) to do this because it would be easy, dry and involved small amounts. This preference was first and foremost about cost but was also about control. In the second round of research this self-emptying concept had been superseded by a service agreement with a trained emptier and maintenance person. The 3-year servicing agreement and associated fee was positively received or accepted by all.

Need for Water: The proposition for low-volume flushing is seen as acceptable and very economical. The need for additional water was something septic tank users had already overcome and that others seemed willing to pay for if the upshot was an improved system.

Overall the response to the idea of a worm based toilet was uniformly and often overwhelmingly positive, and learning from this research has both confirmed our understanding of what people ‘care-about’ when it comes to sanitation design and provided useful data for further product and proposition development.

5.1.1k Willingness to pay

Our survey indicated that households would be willing and able to purchase the Tiger Toilet at a range of price points in the proportions represented by Fig. 4. We based their ability to pay (ATP) on their past purchases (self reported) and their willingness to pay (WTP) on the maximum price at which they stated they would be very likely (red data points) or likely/very likely (blue data points) to ever purchase the Tiger Toilet as described. Respondents were asked to state both cheap and expensive prices and their likelihood of purchasing at each. The graph shows the derived relationship between quantity demanded and price of purchase.

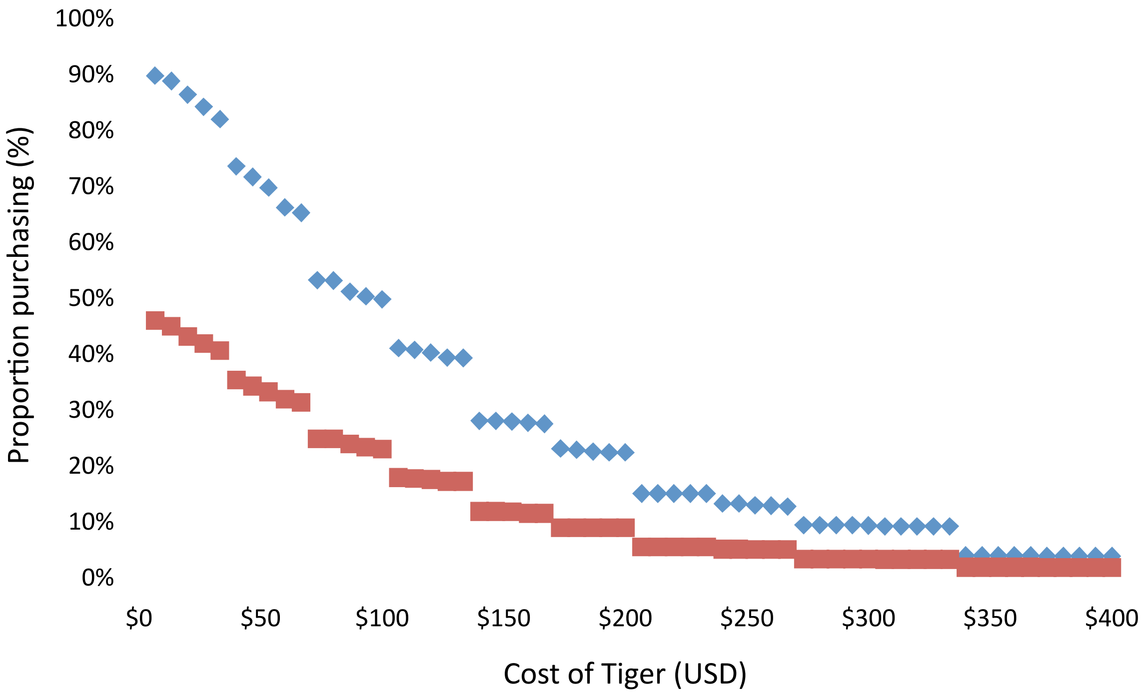


Figure 4. Proportion willing and able to purchase at a range of pricing points ($5-400)

This graph is based on the assumption that someone stating they would pay a certain price for a Tiger Toilet is only recorded as a ‘buyer’ at that price if they have previously purchased something (including their existing pit) for that price or higher i.e. self reported ATP. If they state a WTP figure above the cost of their most expensive purchase they are counted as a ‘buyer’ up to their most expensive purchase but not above i.e. The Tiger Toilet is not allowed to become their most expensive purchase. Where we have no ATP data the individual is excluded from analysis. The clustering of points and sharp drops are due to the tendency for respondents to focus on cut-off prices such as TZS 100,000; TZS 200,000; TZS 1,000,000 etc. Black lines show exponential trends.

5.1.1l Potential market size and revenue

As stated (section 5.1.1.c) it has been calculated that there are around 230,000 latrines in Dar es Salaam. At a median construction cost of USD 300 (for pit and superstructure) or USD 200 for the pit alone this is a potential market size of USD 69 million for super structures and pits or USD 46 million for latrine pits only.

In terms of how many of these latrine owners may be facing a sanitation decision (their pit is nearing fullness or they are constructing a new home), a survey conducted in Dar es Salaam in 2008[8] found around 9% of latrines to be full and 35% almost full. This translates to around 21,000 pits requiring action. The study extrapolated this to suggest that a further 81,000 would need action within the next 5 years. Although some of these pits will be emptied and remain as they are, the survey estimated that about 10,000 latrines will be built each year due to new housing and latrine replacement in 2010, increasing to about 13,000 per year in 2018.

Taking these figures together with our calculation that we could expect to capture between 11% and 27% of these customers at a price of USD 150 (from Fig. 4 demand curves) we could expect to see between 5500 and 13,500 customers in the next 5 years for the Tiger Toilet. This would represent an approximate revenue opportunity of between USD 825,000 and USD 2 million for a Tiger system priced at $150.

5.1.2 Prototype

5.1.2a Introduction

In this section the technical studies leading to the development of the first prototype are described.

On-site worm-based systems (also known as vermifilters or biofilters) have been known for some time. They have the ability to reduce the amount of solids in the system, reducing the need for emptying and possibly reducing the size of the onsite system. Additionally worms themselves have the ability to remove pathogens, including parasitic worm eggs, to a degree which meets the US Environmental Protection Agency's requirements for land application (Eastman et al. 2001). The waste produced is dry compost rather than a sludge, which makes it easier to handle and it is generated at the top of the system making it easier to empty.

Small scale laboratory studies in this area have concentrated on the digestion of sewage sludge (Parvaresh et al. 2004), dried (Khwairakpam and Bhargava 2009) or pre-treated (Yadav et al. 2010) faecal matter. Pre-treatment was thought to be needed as the species of worm used in these systems (generally *Eisenia fetida*) died within an hour of being introduced into fresh human faecal matter (Yadav et al. 2010). It should be noted that all of these laboratory based systems are batch dry systems (i.e. no water was flushed through) and they have concentrated on the quality of the vermicompost produced rather than effluent quality. Larger scale community worm-based systems have been trialed in China for the treatment of

[8] SanMark Dar Unplanned Area Sanitation Demand Survey: WSP, Mimi Jenkins, LSHTM

sludge (Xing et al. 2011) and sewage (Xing et al. 2010, Li et al. 2009). Community-based systems (Xing et al. 2010, Li et al. 2009) have achieved 47-94% solids removal and sludge removal of 38-48% at temperatures reaching 35°C, making them suitable for use in hot climates. Some commercial on-site systems are available, e.g. the solid waste digester (www.swwsnz.co.nz) and Biolytix (www.biolytix.com), but these are designed for rural areas of developed countries, and are over-complicated and expensive for low income users in developing countries. A company called BioFil markets an on-site biofilter system in Ghana but there is little publicly available information on its mechanism of action or price.

Although some information was available from the literature, promotional material and experts, not enough information was available in the public domain to enable us to design a system. A number of research questions were therefore devised to obtain these design parameters and these were the basis of the pilot and early prototype studies reported here.

5.1.2b Research questions

The ten research questions were devised (Box 1) to determine:

- Whether worm-based systems work;
- How well they work;
- Design criteria;
- The environmental safety of the system;
- The robustness of the system.

Box 1: The Research Questions

1. Do worms eat fresh faecal matter?
2. Do the worms need to be acclimatised to the feed?
3. What is the best bedding material?
4. How do different types of bedding material affect the system?
5. What area is required to treat the waste from one person?
6. What quantity of worms is required to treat the waste from one person?
7. What is the effluent quality?
8. What is the conversion rate of the solids and where are they deposited?
9. How does the configuration of the system affect effluent quality?
10. How do different flush amounts affect the system?

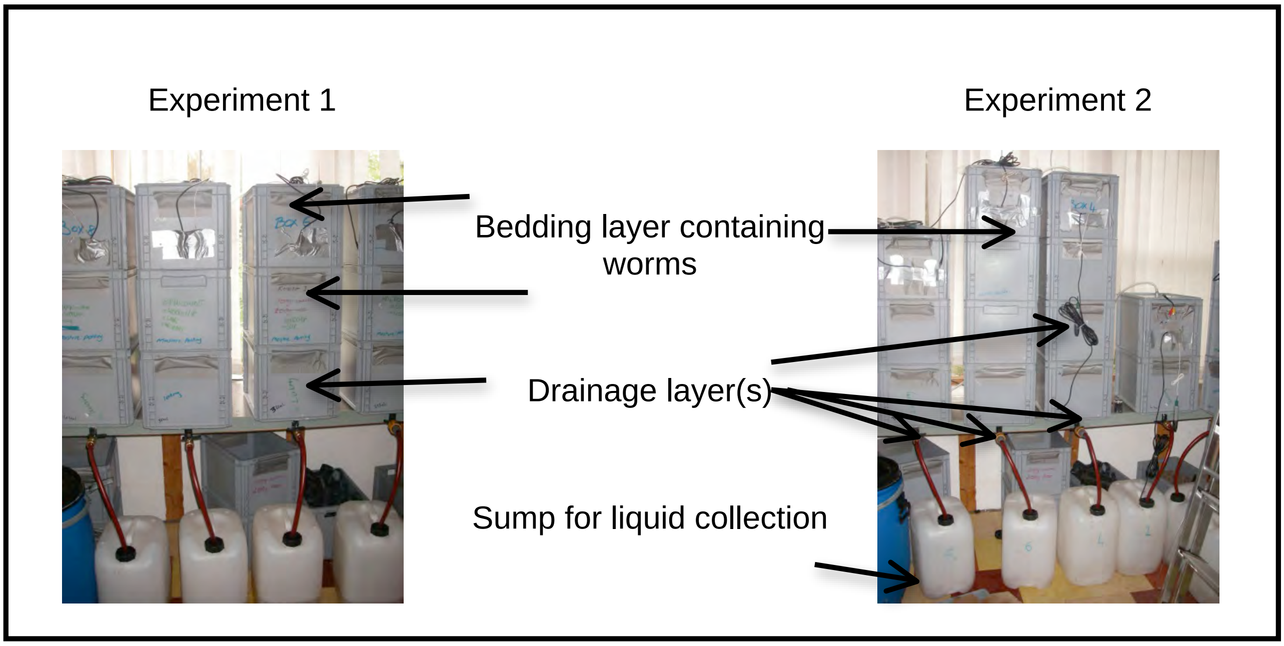
These 10 questions were investigated using pilot studies, but once answers were gained for questions 1 to 5 the first instrumented prototype was developed.

5.1.2c Pilot study

The eight vermifilters were made from stacking plastic boxes (25.5 cm high with a surface area of 0.1 m^2). The base of each box (except the sump box) was removed and replaced by a 1mm diameter mesh. In the first study boxes were stacked three high, the first box containing the bedding material (the matrix for the worms), the second containing drainage media, and the third being the sump which had a tap draining to a collection vessel, as seen in Figure 5. On top of the bedding a plastic mesh (1mm diameter) insert was placed, with faecal matter being placed on top of this mesh. Each vermifilter was topped with a lid which was ventilated passively. Water was added using a pump to simulate flushing of the toilet, with approximately 12 litres of water being added during five watering periods spaced throughout the day. The moisture and temperature of the bedding layer were recorded non-destructively. During the second experiment the configuration was changed so that there was no drainage layer in the first box, two drainage layers in the second box and a drainage layer and second bedding layer in the third box (Figure 5). The configuration of the boxes for Experiment 3 remained the same as Experiment 1, but the amount of water being flushed through the system per day was varied.

Samples of fresh human faeces were obtained from volunteers. In Experiment 1 the bedding material was varied. Three types of bedding materials were used: coir (Fertile Fibres), woodchip (sourced onsite) and vermicompost (sourced onsite). The drainage media consisted of approximately 6 cm lengths of 6 cm diameter plastic land drain (Future Building Supplies). The worms were obtained from Wiggly Wigglers and kept in a vermicomposting bin (Can-O-Worms) before they were added to the experimental boxes.

Figure 5. Pilot experimental set up



5.1.2d Materials and methods

Moisture measurements (v/v %) were taken daily using a ProCheck datalogger. The laboratory and box temperatures were measured hourly using the Lascar EL-USB-

TC. The top box was also weighed daily, as was the addition of faecal matter and the amount of faeces retained on the top mesh. The effluent was analysed approximately weekly for COD, nitrate, nitrite, total phosphate, thermotolerant coliforms, turbidity and settlable solids.

Mass balances of materials were made across the system to determine the weekly faecal destruction rate by the equation below:

$$\frac{W_1 - W_2}{W_1} \times 100$$

W_1 = weight of faecal matter added over a week

W_2 = weight of faecal matter left on the mesh after one week

For this analysis it was assumed that the initial weights, such as the weight of worms within the system and the weight of the bedding material remained the same. Although not perfect, this method was used as other methods of determining these factors were destructive. Statistical analysis of results was carried out using SPSS 12.0.1.

5.1.2e Experimental phases

This work was divided into three experimental phases and each phase addressed several of the research questions; details of the phases, experimental questions addressed and the parameters varied found in Table 15.

Table 15. Details of experimental phases

Experiment	Research questions addressed	Parameters varied
1	Do worms eat fresh faecal matter? Do the worms need to be acclimatised to the feed? What area is required to treat the waste from one person? What quantity of worms is required to treat the waste from one person? What is the effluent quality? What is the conversion rate of the solids and where are they deposited? Does the bedding material affect the conversion rate and effluent quality	The presence of worms The bedding material The amount of faecal matter added
2	Do the worms need to be acclimatised? What quantity of worms is required to treat the waste from one person? What is the best bedding material?	The amount of faecal matter added The configuration of the boxes

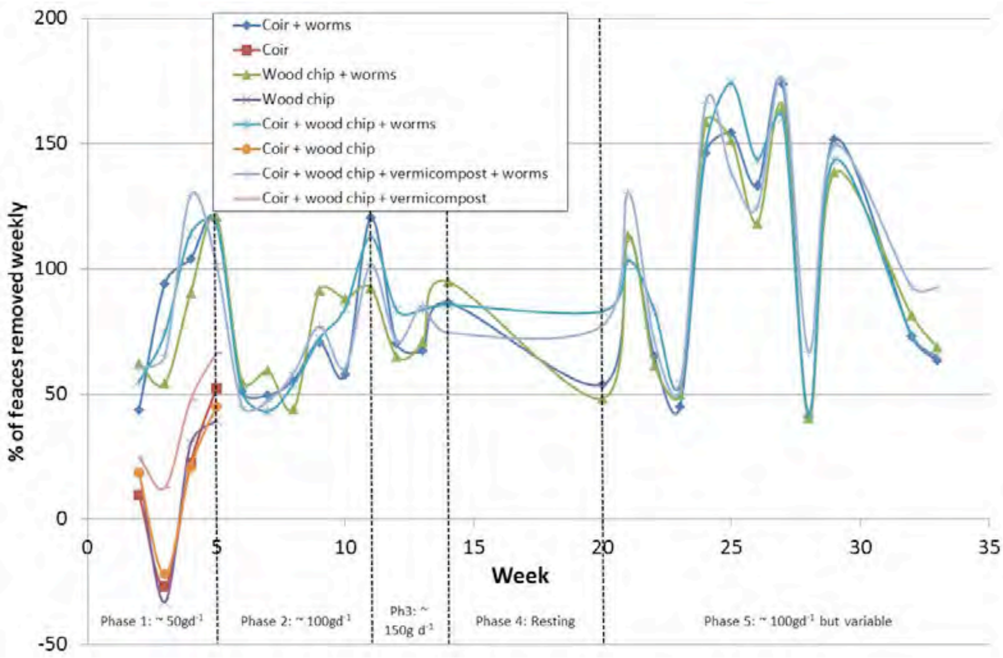
	How do different types of bedding material affect the system? How does the configuration of the system affect effluent quality?	
3	Do the worms need to be acclimatised to the feed? Do the worms need to be acclimatised? What is the conversion rate of the solids and where are they deposited? How do different flush amounts affect the system?	The amount of faecal matter added The amount of water being flushed through the boxes

5.1.2f Findings

Q1. Do worms eat fresh faecal matter?

Yes, we found that *E.fetida* ate fresh faecal matter when fed daily in a wet system. The boxes in Experiment 1 have been fed with over 24kg of faeces over an 11 month period, the weight of the material on the mesh being reduced by 88-90% over this period of time. There was also a significant difference in the boxes with and without worms, meaning that the worms were responsible for removing or converting the solids in our system. Figure 6 shows the results over 35 weeks for Experiment 1, for control (no worms) and test boxes (plus worms) which contained different bedding types.

Figure 6. Weekly percentage of feed removal in Experiment 1



Q2. Do the worms need to be acclimatised to the feed?

The worms were not pre-acclimatised to the food i.e. they were not fed faecal material prior to the start of the experiment. In Experiment 1 the feed was slowly increased in four phases from 50g per day to 200g per day (Figure 6). The acclimatisation period for changing of feed rates was found to be six weeks, as can be seen in Figure 6. This has influenced the design, as this capacity for build-up of waste needs to be incorporated.

Q3. and Q4. What is the best bedding material? How do different types of bedding material affect the system?

We found that there was no difference in the temperature of the different bedding, but we did find a difference in the moisture retention properties. Coir kept a constant moisture level from the start, compared to bedding which contained wood chip which slowly absorbed water over a number of weeks. We also found that there was no difference in solids or COD removal in the boxes containing different bedding. From our observations of the boxes in Experiment 1 we have found that the coir distorts and has been eroded more than the boxes containing the mixed bedding media. We have also found that the worms are more active in the mixed bedding medias. On this basis the mixed bedding material was used for the subsequent experiment as it seems to have a slight advantage over the pure media.

Q5. What area is required to treat the waste from one person?

Within our available supply we were able to feed the boxes up to 200g faeces per day, which was readily digested. This is the average amount of faeces produced per day by one person, which means each box (area of 0.1 m^2) is able to take the waste from one person.

Q6. What quantity of worms is required to treat the waste from one person?

In Experiment 1 an initial worm loading rate of 400g per 0.1m^2 was used and in Experiment 2 a loading rate of 200g per 0.1 m^2 was used. When the data was compared from these two systems during the start-up phase no statistically significance difference between the weekly solids removal rate could be found. This means that only 2 kg of worms per m^2 are required to seed the reactor.

Q7. What is the effluent quality?

As mentioned earlier the bedding type did not affect the effluent quality. Our systems generally achieved 90% removal of COD and between log 2 to log 4 removal of thermotolerant coliforms. The effluent quality has been found to be comparable or better than more complicated fully scale systems, as can be seen in Table 16.

Table 16. The effluent quality from other systems

Treatment	Organics Removal	Pathogen Removal
Septic tank effluent	COD 54%	Log 2-3
Septage	COD 97%	Not available
Biolytix (full scale)	COD 98%	Log 2
Vermicompost filter (pilot scale)	Increased	Not available
Sand vermifilter (pilot scale)	COD 47-58%	Not available

Q8. What is the conversion rate of the solids and where are they deposited?

The faecal matter was transformed into vermicompost, worm mass and CO_2 in our systems, but only the removal and transformation of the faecal matter into vermicompost could be measured non-destructively through the changes in the weight of material trapped on the upper mesh.

In answering question 1, we found that 24 kg of faecal matter was reduced by 88-90% over 11 months. This is an under-estimate of the conversion rate of the solids, as the mesh contained a small amount of undigested faecal matter, a large amount of worms and vermicompost. From a visual inspection of the boxes we have estimated that the worms transformed the faecal matter into 1-2 kg of vermicompost, giving a reduction rate of 92-96% over the 11 month period.

The vermicompost was only deposited on the mesh after the first 4 to 6 months. Our experiments have shown that it takes the worms six weeks to acclimatise to a new food and for weekly removal rates to reach 100%. Within this time period there was an accumulation of undigested faecal matter, but this was removed after the six week period when weekly removal rates were are above 100% (Figure 6), but a small amount of faecal matter was always present in this part of the system.

Additionally some vermicompost was collected on the drainage media and some was washed through the system. Approximately 200g of vermicompost collected in the drainage layer over the 11-month period, but this did not cause any problems with blocking the system. The amounts of settlable solids were measured in the effluent as the vermicompost is dense and settles out readily. In the effluent we have found on average 4 ml/l of vermicompost. In a full-scale system with 10 users which had been running for one year, this would equate to 173 litres or about a depth of 17 cm in a reactor with an area of $1m^2$. This is an over-estimate of the solids in this part of the reactor as they would settle further and biologically degrade further.

Q9. How does the configuration of the system affect effluent quality?

It was initially thought that the configuration would affect the effluent quality. After testing different configurations this was found not to be true, with the presence or absence of drainage media not affecting COD or pathogen removal. However what we did discover is that the drainage layer acts as a buffer for the worms, so that they can return to the bedding layer if they leave it. This means that the effluent is being treated in the bedding layer through the joint physical actions of filtering and biological treatment of the liquid which is retained in this layer. From our design this means that the bedding layer does not need to be deep (around 10cm) for us to achieve good effluent quality.

Q10. How do different flush amounts affect the system?

This experiment is still ongoing, but from our preliminary results we can say that the worms survive under all the conditions tried, but that they seem to thrive in wetter conditions. And also under these conditions there is no odour compared to some odour from the boxes with no water, or 1 litre of water, passing through.

5.1.2g Prototype

Using the data gained from Experiments 1 and 2 a prototype was designed and installed at the Centre for Alternative Technology, Wales. This early prototype was used to gain information on the installation of the prototype and to iron out any design flaws, in a place where it could be readily monitored. It was also used to answer two specific research questions:

1. Does urine affect the process?
2. Are the results from the pilot scale experiments directly scalable?

The prototype was set up to replicate the pilot experiments using the design parameters discovered. The reactor can be split into three sections: the inlet and bedding layer, the drainage area and the sump, as seen in Figure 7. The effluent was directly discharged to the sewers. As in the pilot reactors moisture and temperature probes were placed in the bedding layer and to simulate warmer environments the reactor was surrounded by a heater blanket which was kept at approximately 20°C. The area of the reactor was $1m^2$ and the height was 1.15m. It was thought that this system would have the capacity to handle the waste from ten people. This system received the waste including urine from a low volume (2 litres) pour flush system.

Figure 7. Prototype System

The usage was monitored daily using a tally system and door counter. A weighing system was installed in the reactor, but this was found to be too delicate for the extreme environment. This meant that the solid loading was estimated. The effluent quality from the system was analysed for the same parameters as the pilot boxes.

5.1.2h Prototype findings

The prototype has now been running for 7 months and during that time has received approximately 51kg of faeces. This has been reduced to approximately 7kg. Many unstressed worms have been seen in the bedding layer, meaning that the presence of urine is not affecting the worms. No difference was found in effluent quality from the prototype compared to the pilot experiments, as shown in Table 17. The pilot boxes are therefore representative of the prototype, meaning the results from the pilot tests are transferable to the prototype.

Table 17: Comparison of effluent quality from the pilot and prototype tests

Week of	Prototype (COD mg/l)	Pilot (COD mg/l)	Prototype Thermotolerant Coliforms (CFU/100 ml)	Pilot Thermotolerant Coliforms (CFU/100 ml)
22/2/2012	856	1173	790,000	3,540,000
02/3/2012	784	585	510,000	1,050,000
08/3/2012	746	711	300,000	1,280,000
14/3/2012	685	577	1,310,000	820,000

5.1.3 Designs

5.1.3a Design brief

Consumer insight coupled with technology direction forms the basis of a design brief. Both the consumer insights and the technology platform summarized in the earlier sections provided the stimulus and context for innovation in terms of conceptual design.

The design brief (see Figure 8) reflects the consumer journey through all the life stages of the product from first sight through purchase, installation, regular use, extreme use to emptying and disposal. The challenge in the context of sanitation in developing countries is that there is no established supply chain. Knowing about the product and service is most likely to come from word of mouth – in the urban environment with moderate density living this is likely to be an efficient and effective way of communicating the value and benefits of the Tiger toilet.

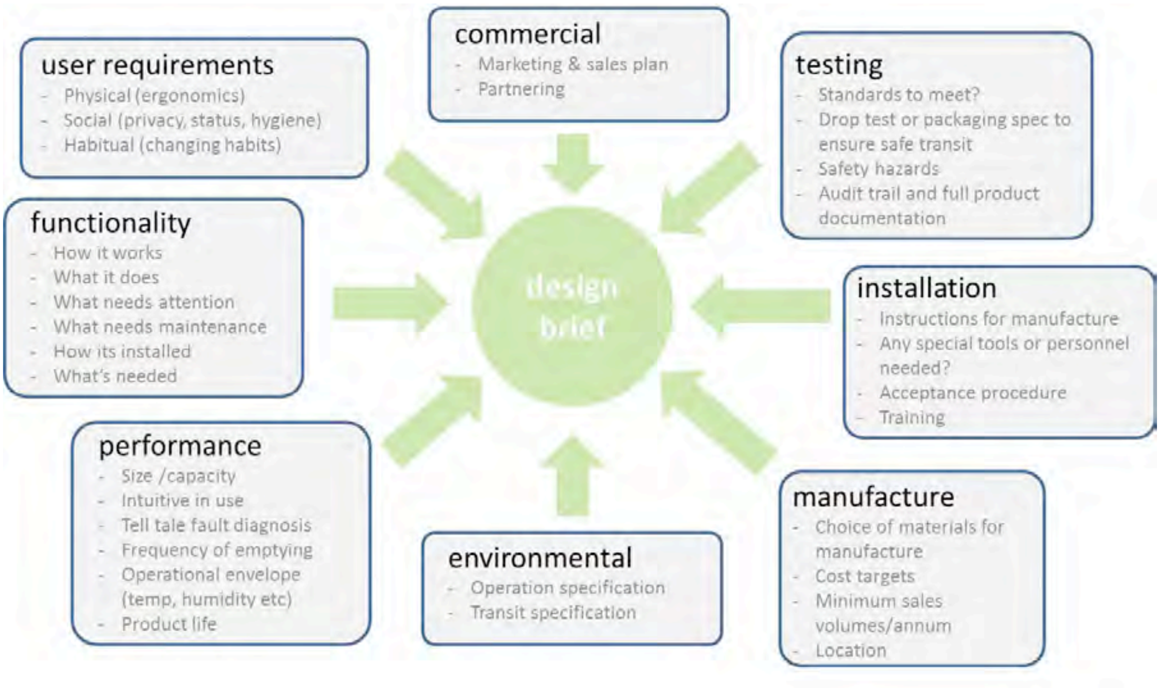


Figure 8. Design Brief Elements

The design brief covers all aspects of the consumer journey as well as the manufacturing and commercial requirements. This is the basis upon which entrepreneurs will be encouraged to consider the proposition as a business opportunity.

5.1.3b Design concepts

Based on the design brief a wide range of concepts were developed to explore different approaches to materials, installation, functionality and usage.

These concepts (Figure 9) were presented to the project team and preferences scored giving a short list of concepts deemed worthy of further investigation – in terms of performance, installation and cost. One key consideration was the need to meet a wide variety of soil conditions so that the design has the capability to be adapted to meet global geographies from the wettest to the driest.

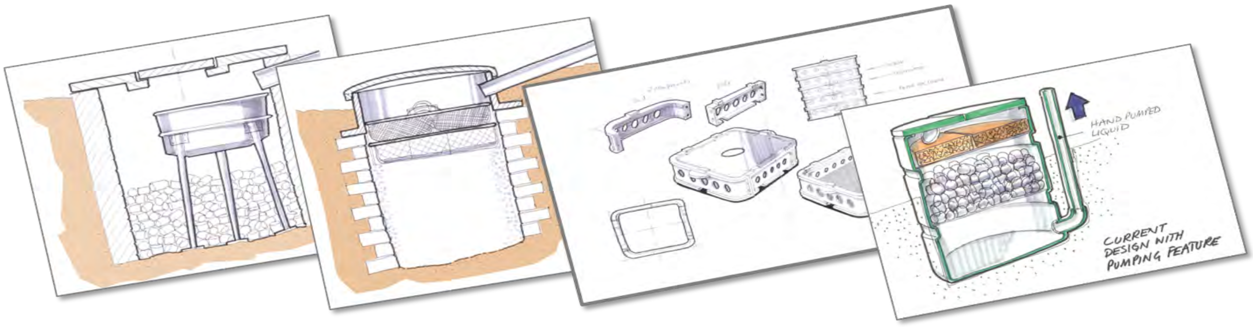


Figure 9. Early Design Concepts

5.1.3c Design specification

Exploration of concepts enabled a much more detailed specification to be drawn up. This reported on all aspects of research and converted the information into a document for use by all the team.

Its contents ranged from consumer profiles, the performance criteria emerging from the laboratory research to the type of materials and processes that might be available within the markets we are seeking to enter. Whilst incomplete it provides the documentation around which the whole product offer is centered and requires constant updating as information becomes available. A key ingredient is the commercial basis on which a business may be either attracted to the venture or created to exploit the contents of the design specification.

The specification is focused on a final product capable of meeting the widest requirements, as the team understands them. It uses the current laboratory research data as the basis for technical performance and the consumer research to clearly identify the perceived needs. Although the laboratory research is promising we have yet to reach a point where the system has been stress tested to accommodate what we might anticipate occurring in extreme use.

Based on the design specification a full size prototype has been built to scale up the laboratory work. This gave the design team the first opportunity to assess the size and complexity of the product and the practicalities associated with assembly, loading and emptying.

5.1.3d Design development

There are two strands to the development of the design:

1. To develop a prototype suitable for field use;
2. To further the design of a production system suitable for mass-production anywhere in the world.

5.1.3e Field prototype

The purpose of the field prototype is to gain further detailed knowledge about the performance of the product in a typical environment in the developing world. This prototype needed to be able to record performance data in a working situation. The principle has been to utilise already existing components wherever possible and to replicate a potential production product as best as possible.

A proprietary Intermediate Bulk Container (IBC) was selected as a suitable vessel for the digester and shelves, lids and anti-tamper devices were designed to ensure effective operation.

Figure 10 - Modified IBC with customised internal worm baskets, waste-in deflector and security lid

Two prototypes have been produced and are ready to be shipped for trial purposes. The internal system includes a load platform to enable in-coming waste to be weighed and data logged which is then transmitted wirelessly to a remote computer. This allows the rate of consumption of waste to be measured along with temperature and moisture building a body of knowledge about performance in typical conditions. The same equipment will be able to be used to start to push the operating envelope to assess the performance parameters and extremes that need to be quantified.

It is essential to understand these extremes to protect a potential partner in terms of being able to offer guarantees and the associated product liabilities. With such a product which uses organic material it is not possible to accelerate life testing so extended periods in the field are necessary to ensure data is accumulated in parallel with production development.

5.1.3f Production design

The essential element of a production design is the digestion tank. The most cost-effective way of manufacturing this in an economic way using a process universally available is rotational moulding. Whilst this requires the investment in a mould tool, it is relatively low cost and allows a tank to be made from a combination of virgin and re-cycled material making it environmentally friendly. Despite using plastic it is a commonly available compound (polyethylene) and used extensively in the developing world.

Other materials reviewed were concrete and galvanised steel. Concrete is still an option but there are concerns about availability, weight, environmental friendliness, and transport.

The design of the digester has evolved during the design development process and has become potentially iconic as a form (Figure 11).

Figure 11. Model of possible production design

Along with the product development the design team has been considering route to market scenarios. Success can only be measured if the proposed design is adopted by consumers and becomes the preferred method of sanitation.

Identifying the barriers to adoption is a key aspect of the study. The single most obvious barrier is the fact that there is no established supply chain for the sale of product. The consumer research revealed that all current latrines and septic tanks are bespoke – i.e. produced by a local tradesman. There is little hardware involved.

Finding the right partner becomes the most important element in moving the project from laboratory to the market. It requires the building of a supply chain involving worm farmers, rotational moulders, tradesmen and entrepreneurs.

A significant body of design data has been accumulated and will form the basis for a new business.

Fi
bowl and trap

5.2 Black Solider Fly Larvae

Black Solider Fly (BSF) larvae are voracious eaters of waste and, as mentioned previously (Section 3.4), within SV's BSF larvae idea strand there were two main thoughts: either it could be a centralised treatment linked to waste collection and a transport service (see Section 6) or it could be an *in situ* product or service operating at the latrine level. Here we overview the concepts and prototypes that have emerged around the latter.

5.2.1 The In-Latrine Brief

Two 'In-Latrine' Black Solider Fly larvae solutions have been pursued – the Kone and the Daisy Chain. These were both designed to do the following:

- Be retro-fitted into existing latrines without damaging the pit top, the pit or the super-structure, without significant cost or upset for users;
- Allow BSF larvae to digest waste on the sludge surface within a latrine;
- Avoid the larvae, pre-pupae or flies escaping or being seen by users;
- Facilitate harvest of larvae for value recovery at two week intervals;
- Avoid users being unable to use the toilet for a significant amount of time;
- Create a user-experience that is neither disgusting nor dangerous.

In addition we asked that solutions be relatively inexpensive to make, robust and that they be manufactured from materials available in low-income settings.

5.2.1a The Ideas

The Kone and Daisy Chain are simple technologies with many similarities. In both: the device is entered into the pit via the latrine squat hole and larvae or eggs are thrown directly into the pit; the pre-pupae's tendency to self-harvest by climbing away from food up inclines and toward drier dark spaces is relied upon; manual extraction of pre-pupae happens at the pit top through the latrine squat hole or a specially drilled access port. Collection would then be done either by the householder, for subsequent collection or to use larvae as chicken or fish feed, or by a service provider depending on the business model.

5.2.1b The Kone

This is a cone shaped construction designed to sit on the sludge surface. It is either suspended by a rope (bottom right Fig. 13) fixed to the latrine top or held in place by a collection pipe slotted through a purpose made hole in the latrine top and into the Kone below. The Kone has ramps spiralling from bottom to top to for pre-pupae to climb, which lead to a removable collection pot at its apex. Larvae can climb into the pot, but not out again. They can be collected from this pot one of two ways, either by hauling the structure to the surface, removing the pot and emptying it or using a plunger system (top right Fig. 13).

The Kone is made of rubber (recycled tyre) sewn into shape, with a pre-made jar for collection. The plunger larvae retrieval system involves plastic piping, metal wire and a soldered metal plunger.

While the Kone would be situated near the latrine wall to help protect it from direct hits from waste and some splashing, regular cleaning would be required. This could be done by pouring water over the Kone and, if present, down the plunger pipe.

Figure 13. The Kone

5.2.1c The Daisy Chain

As the image in Fig. 14 shows, this idea consists of a horseshoe shaped pipe that sits on the sludge surface close to the latrine walls. This surface section is one long larvae collection tube with holes along the top of the surface pipe for larvae to drop into. Like the Kone it is attached to the surface by rope or pipe and the retrieval options are the same, albeit that the plunger must retrieve larvae from the length of the Daisy Chain surface structure.

Figure 14. The Daisy Chain

It is made of jointed plastic piping of a type easily found in many low income settings.

5.2.1d In-latrine BSF solutions - next steps

These designs raise two big in-use questions: will enough larvae migrate into the collection receptacles and can the pupae empting process be made sufficiently systematised and palatable for users? Plans are being drawn up to test these ideas in the field.

5.2.2 The BSF Toilet

The BSF larvae toilet – shown as an early prototype in Figure 15, integrates larval action and collection into one unit.

Figure 15. BSF Toilet (centre bottom) at Seattle Toilet Fair

This approach potentially overcomes many of the pitfalls of utilising BSF larvae in-latrine, in particular the difficulty and potential mess of installing and maintaining a device within an existing latrine - particularly given latrines are by no means homogenous, and the challenge of containing and collecting pre-pupae. It also has the potential to be aspirational and viewed as a step up.

A toilet would of course be higher cost vs. the in-latrine version and the design would need to avoid people seeing larvae given the significantly reduced distance between user and sludge.

6. Ventures

As highlighted previously, following the encouraging results from the study of the economic and commercial viability of a BSF treatment process, and with further lab data to support the ability of larvae to develop on human faeces, there was increasing confidence that a centralised treatment approach might work. At this point we were fortunate to make contact with David Drew, MD of AgriProtein, a company based in Cape Town which is aiming to recycle organic waste and generate larval protein for sale as animal feed on a vast scale. They are expert in fly rearing on an industrial scale and were keen to collaborate in exploring the commercial potential and scalability of a similar process for digesting faecal waste with BSF larvae.

A venture proposal was put together jointly by AgriProtein and Bear Valley Ventures In December 2011 with the goal of developing and demonstrating a process, technology and business model for turning faecal waste into high value BSF larval products. This was approved by the Innovation Fund Committee and the venture, named "The BioCycle" was launched in January 2012. The roadmap is shown below:

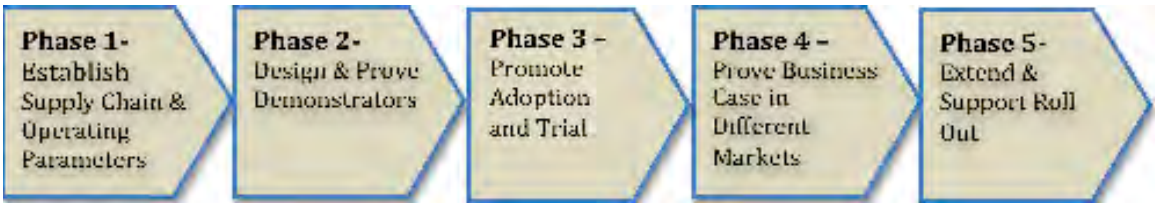


Figure 16. BioCycle Roadmap

Phase 1 is currently underway and is on track. A self-sustaining breeding BSF colony has been established at AgriProtein's world-class experimental facilities based at the University of Stellenbosch. Waste is being supplied from a community toilet through a partnership with the City of Cape Town – our current focus is on fresh waste. The BioCycle team are currently conducting scientific studies to enable us to define a set of guideline for optimal larval yield on this substrate. Process development will start later this year and the team are already thinking about possible business models. The aim is to have a business "toolkit" ready to test in Phase 4 by the end of 2013.

In parallel Ian Banks at LSHTM is researching the ability of BSF larvae to develop on latrine waste to define the conversion factor for waste to larvae for this material.

7. Summary and Key Learning

This project has delivered a number of promising approaches to deal with the problem of pit latrine filling. There is still much work to do to realise their potential but it is an encouraging start. Our lead option, the Tiger toilet, has performed well in lab tests and in early consumer tests. The challenge now is to prove its robustness in the field and to get the cost down as low as possible. We believe from our consumer work that if we can get it down to the $100-150 range there will be strong demand in a number of countries.

The BioCycle, our first venture, is really taking off and shows how entrepreneurial flair and drive can start to bring promising ideas to life. It could be a commercial reality in little more than 1-2 years from now.

We have much else still to explore. The household level BSF ideas and the next generation bioadditives are further back in the development process but may offer some very different benefits for different kinds of consumer.

What have we learnt? Obviously a massive amount about sanitation needs and potential solutions. We've also learnt a few things about the process of innovating for this kind of market. Here are a few of our thoughts:

Have an Ideas Backburner

Opinion was divided in the early stages of the project as to whether it was better to focus on one technology platform or keep more on the table. While inevitably there is a resource trade-off if more options are kept open, focusing on one lead technology (Tiger Toilet) while keeping others progressing at a less resource intense pace paid dividends, as it enabled opportunities to be grasped as they arose and ensured that should the Tiger Toilet fail, other options were there to fall back on.

Adopt a Spirit of Openness

Sharing ideas with others at almost every given opportunity and opening up the innovation process beyond the team particularly through InnoCentive, proved hugely productive. While *what* to share and *when* can be difficult to decide in a commercial venture, SV's experience was that being open led to more opportunities and ideas than keeping ideas close to our chest.

Make it Real

Working out how to gain 'real' feedback on ideas that don't exist from a market that doesn't yet exist isn't easy. This was a problem we didn't necessarily crack but one that exposure to designers, engineers and entrepreneurs has taught us is best approached by thinking, at all times, 'how can we make this real to get as real a response as possible?'. Prototyping early and often and including in that prototyping not just products but elements of the business model is an area to improve on in future.

Collaborative Space

While the SV team came together in various configurations at various points over the last few years this was usually with a specific agenda. While this was sensible given the work to be done and the dispersed nature of the team, it provided only limited chances for the team to explore that might lead somewhere totally new. Given the calibre of the people and the wealth of insight and knowledge being generated this may have been a missed opportunity.

Think in parallel and act iteratively

In an ideal world we would have moved everything forward together – design, development, business, market. In reality that’s really difficult. Sometimes you have to take to take a step forward in one area to make it possible to move forward in others. So long as this is all in the context of parallel, integrated thinking by the team it should be OK.

8. Dissemination

It is intended that this report will be posted on the SV website subject to IP clearance by LSHTM.

3 scientific papers are in progress on the results for the Tiger pilot and prototype tests. The first lab data on the digestion of human faeces by BSF larvae was presented at World Water Week in August 2012. An invited presentation will be given at the Wetsus conference in Wageningen in October 2012. The BioCycle will be featured at the Faecal Sludge Management Conference in Durban in October 2012.

All the prototypes described here were displayed at the Bill & Melinda Gates Foundation Reinvent the Toilet Fair in Seattle and received considerable media attention all round the world.

9. Acknowledgments

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- 4EVR Plastics, South Africa

BioBomb

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