doi: 10.2166/9781789061840_0019

Chapter 2

Product design and development

Walter Gibson

Chapter objectives

The aim of this chapter is to consider how value is added through product design and development, give examples at different points in the IFSVC, and examine the constraints and challenges to be overcome if the full potential of the IFSVC is to be realized.

2.1 INTRODUCTION

A key premise of this book is that realizing the sanitation economy will demand new enterprises creating new products and services which offer greater value for their customers than those currently available. Although the value chain involves many different company activities, technology development and product design are vital elements (Porter, 2001). In this chapter we will consider how value is added through product design and development, give examples at different points in the IFSVC, and examine the constraints and challenges to be overcome if the full potential of the IFSVC is to be realized. As we will see, progress is being made but there is scope to go further and there are exciting prospects on the horizon. Throughout the chapter 'product' should be taken to mean both products and services: they are often interlinked and interdependent in a new customer offering and underpinned by similar processes. Product design and development involves a number of different processes, each of which offers an opportunity to create value for the customer and the business. These will be considered in turn, highlighting ways in which value can be created and giving examples of how this is being applied to sanitation.

2.1.1 Starting from customer insights

Successful businesses in other sectors invest heavily in understanding what kind of products their customers want, as opposed to need, and are willing to pay for. They seek insights into habits, attitudes, and behaviours that will drive better product appeal, competitive advantage and ultimately value. Technological advances are important, but they are not sufficient on their own to drive customer adoption: the new product must

Editor(s): Peter Emmanuel Cookey, Thammarat Koottatep, Walter Thomas Gibson and Chongrak Polprasert

satisfy some desire for improvement, which could be functional and/or emotional, ideally both. Because sanitation has historically been viewed, particularly in developing countries, as a public good, the focus of new product design and development has often been on recipients as end-users or beneficiaries, rather than as customers (Mulumba *et al.*, 2014). With the growing role of the private sector in delivering improved sanitation, this is starting to change. Indeed, we argue that value creation for the customer must be central to product design and development in sanitation if the sanitation economy is to flourish. And the converse is true also: product design and development are central to value creation.

While this may already be the case for some parts of the sanitation market, for example sanitary ware, historically it has not always been the case for basic sanitation provision in low-to-middle income countries where the starting point for product development has tended to be functionality, for example containment of faeces, and public health, for example prevention of contamination. With this approach, usage of toilets has been lower than desired if the full public health benefits are to be obtained (Chambers & Myers, 2016). Furthermore, without toilet usage for waste collection the IFSVC cannot function fully. To drive change, the critical distinction that must be made increasingly in future is between what end-users *need* in terms of better sanitation products and services and what customers *want* and are willing to buy – and use. And it is important to widen horizons in terms of customers: in the IFSVC these go beyond toilet users and include for example those who buy high value products at the end of the value chain, such as farmers buying fertilizer.

By focusing on what the customer wants, as opposed to what they need, value creation through product design begins by understanding at a deep level the desires and aspirations of the customer, their existing habits and attitudes, and their likes and dislikes of current products. It uses a variety of techniques such as ethnographic research to gain insights into the kind of product that customers would value and willingly purchase. It also tries to understand the context in which the product will be used and its constraints. Context can include cultural factors, the environment, social and economic conditions. Without following a process like this there is a real risk that solutions will fail to have the impact they are intended to deliver, either through lack of demand or lack of use or both, even if they function well technically. For example, a study of the barriers to sustainability and scale of household water treatment practices concluded that user preferences need to be addressed in order to achieve sustained demand (Ojomo *et al.*, 2015). While efficacy is important this may not be the basis on which a product is chosen; again, in the case of water treatment, convenience and product aesthetics play a major part (Ojomo *et al.*, 2015). Albert *et al.* (2010) noted that for household water treatment and storage 'product dissemination at scale to the poor will not occur until we better understand the preferences, choices, and aspirations of the at-risk populations.' This is undoubtedly also true for sanitation and all development sectors.

A key sign that customer preferences have not been sufficiently well understood during the development of a product is that it fails to be used or is used differently to the intended purpose. In sanitation, a prime example of this is the pit latrine, the most basic form of storing human excreta. Although these can be beneficial and be the basis of safely managed sanitation if emptying services are available, the latter is not always the case and then the user has the anxiety of what to do when the latrine is full. A study in India concluded that there is a strong preference for a latrine to be (impractically) much larger than the typical government-recommended size because of concerns about how it will be emptied (Coffey *et al.*, 2017). Many different factors are at play here including beliefs and values related to purity and pollution, as well as the caste system. Open defecation in parts of rural India remains an issue despite increased ownership of latrines (Gupta *et al.*, 2020).

Time spent gaining customer insights is thus vital: insights are the foundation for subsequent steps in the innovation and product development process including concept generation, prototyping and willingness-to-pay studies with constant evaluation and feedback until it is clear that there is a product which customers want to buy, which works as intended and which is ready to launch.

Typically this process is called user-centred design or human-centred design (Text Box 2.1) and there are a number of well established methods which can be followed (see note at end of this chapter e.g. of tools available).

In 2014 Mulumba *et al.* observed that there is a lack of sanitation products poor people wish to buy and that this is a barrier to scaling up private sector provision of sanitation. The application of UCD is beginning to change that: over the past 5–10 years UCD principles have been used to develop innovative sanitation products and services along the IFSVC. Examples are shown in Table 2.1 below, with some of the products being illustrated in Figure 2.2.

Text Box 2.1: What does a User-Centred Design (UCD) process involve?

Although there are different toolkits available, they all have many features in common. They all begin with an attempt to discover what the customer really wants, through deep immersion in their lives, the products they use, how they behave, what problems and challenges they face. This is a search for inspiration, for insights that can form the basis of new ideas and new solutions that customers will want to use and buy. It is followed by an idea generation phase, which will typically involve reframing the problem based on new insights, getting further external stimuli, and co-creation with users. Some early prototyping may be involved. Lastly there is an implementation phase when solutions are made real, tested and refined until they are ready to be launched in the market.

It is important to stress that this is not a linear process. It is likely to be highly iterative. For example, putting a prototype into the hands of a consumer can reveal new insights and start the process all over again. There is always room for improvement and learning.

Quicksand, a design agency based in India, applied these principles to the issue of urban sanitation in India. Over a period of 10 months they conducted in-depth research into the sanitation experience of low-income families in five different cities, using observation, interviews, participatory research and rich media documentation. The insights this generated provided direction for innovations which could improve urban sanitation for the poor (Quicksand, 2011a; Quicksand Sammaan Brief, n.d.). These were later brought to life and implemented in new community toilet designs through Project Sammaan in partnership with the Bhubaneswar and Cuttack municipalities. The scope of innovations included not just the design and construction of the physical facilities, but also operations and maintenance, the business model and branding and communications (Surfaces Reporter, 2020)

Experiencing what your target customer experiences every day can be powerful and influential in terms of the final outcome. Daigo Ishiyama, Leader of Innovation at SATO and a member of the team that developed the SATO pan, had such an experience in Bangladesh during a 'deep dive' to generate disruptive innovations in collaboration with iDE (MacArthur *et al.*, 2015). He recalled seeing a full latrine through the open hole in the slab and thinking 'I've got to close that hole' (Ishiyama, 2017), see Figure 2.1. This was a key insight and imperative for the later design steps.

Figure 2.1 User-centred research in Bangladesh (image credit, LIXIL).

These innovations reveal the scope of possibilities to bring improved benefits to a range of different customers along the length of the value chain. In this way they enhance the value proposition at each stage and make the whole chain more robust. The extent to which they are willing and able to pay for those benefits will determine the success of a given venture and that element of the chain, which may in turn influence and enable other stages. This emphasizes the importance of conducting willingness-to-pay studies prior to a new product launch with the desired target market, but the ultimate test is indeed to present it to the consumer and see if they will pay for it.

While the benefits of sanitation can be viewed in terms of cost-effectiveness, where health, social and economic indicators can be used to judge its merits as a public health intervention (Hutton *et al.*, 2007), the customer may make a different set of judgements based on the information presented: they may want to know how easy it is to build and where they can purchase it from; they may want to know how long it will last and what maintenance it will need; they may want to know if it will smell like some of the toilets they have used in the past. The advantage of UCD is that these concerns and wants should have been factored into the design and thus increase the chances of a positive customer response.

Many of the innovations mentioned in Table 2.1 have passed that test: as examples, SATO has shipped over 5.1 million units across 41 countries, improving sanitation for approximately 25 million people (LIXIL, 2021), iDE have impacted more than 1 m households (iDE, 2021), more than 30 000 Digni-Loos have been sold (E. Perez, 2021, personal communication), and Sanergy is serving more than 120 000 residents every day in Nairobi (Sanergy, 2021). While the number and success of innovations in the market is encouraging, there is still scope to deepen our understanding of all the different possible customers along the value chain. In particular, a more comprehensive understanding of customers for current and future biomass/biotransformation products is vital to drive the whole chain to a new level. Further, it should not be considered that because the products in Table 2.1 have been developed, there is no further need for

Table 2.1 Customer insights behind recent sanitation innovation.

Stage	Enterprise	Customer	Example Insights	Product
Design and Product Development Services	Quicksand	Communal toilet users, India	Facility design establishes rules of use more clearly (Quicksand, 2011b)	Gender-inclusive toilet
	Clean Team (design involved Ideo/WSUP/Unilever)	Off-grid urban poor, Ghana	No one wants to 'slosh a bucket of waste through their home' (Ideo, n.d.)	Branded Toilet and complete sanitation service
	Cranfield University Centre for Competitive Creative Design	Off-grid, water stressed communities	Users liked the mechanical flush and preferred a deeper bowl (Hennigs *et al.* 2019)	Nano Membrane Toilet
Equipment Manufacturing Services	LIXIL (user research with iDE)	Rural low-income families in Bangladesh	Existing toilets unhygienic, suboptimal in function (MacArthur *et al.* 2015)	SATO Pan
	Duraplast (facilitated by Global Communities)	Rural poor households Ghana	Key design factors included smell, flies, ease of cleaning, colour (Borkowski and Perez, 2019)	Digni-Loo
	Sanergy (Auerbach, 2015)	Urban slums, Kenya	Ease of cleaning, small footprint enables installation near home	Fresh Life Toilet
Facility Integration, Installation and Construction Services	iDE (Pedi *et al.* 2012),	Rural Cambodian families	Both studies revealed a strong preference for price-prohibitive 'permanent' pour-flush solutions	Easy Latrine
	WaterSHED (Pedi *et al.* 2011)			Unbranded toilet package
Sanitation Services	Saraplast, 3S	Urban women outside the home, India	Lack of clean, safe public toilets for women (Economic Times, 2020)	Ti bus
	WSUP/BoP Innovation/UX (Kisker and Drabble 2017)	Emptying business owners	Very little active customer acquisition	Pula App
Sanitation Biomass Recovery and Conversion Services	Sanergy (Auerbach, 2015)	Farmers, Kenya	Dissatisfied with current animal feeds, difficult to source organic fertilizer domestically	KuzaPro Evergrow
	Sanivation	Large companies using solid fuel boiler, Kenya	Businesses looking for more sustainable fuel supply (J. Lane, 2020, personal communication)	Superlogs

Figure 2.2 Some products developed with UCD principles. Clockwise from top left: Sammaan Community Toilet (*image credit, Quicksand*); Digni-Loo (*image credit, Alberto Wilde, Global Communities*); Ti Bus (*image credit, 3S*); SuperLogs (*image credit, Sanivation*); KuzaPro (*image credit, Sanergy*); Fresh Life toilets (*image credit, Sanergy*).

customer research: there is always scope to gain new insights and improve the product and enhance its value. In a competitive environment this is vital.

2.1.2 The importance of a brief and a plan

Customer insights and product ideas are necessary but not sufficient: turning these into a fully fledged product ready to put into the hands of the customer is equally important. This part of the process should be guided by a brief setting out all the elements that should be considered in developing the final product or service. Who will use it? How will it deliver what they want? What functionality is needed and is it technically feasible? What material and component options are available? How will it be made and reach the market? How much will it cost? These and other questions must be addressed if the potential of the new product is to be realized. The added value in this stage is derived from considering and solving all the detailed practical questions that make the final product possible and deliver its promised benefits at an affordable price.

A good design brief goes beyond a description of the concept or physical design and will define the objectives and key criteria for all the different dimensions required to create a successful new product. Preparing a brief ensures that all these different factors are considered from the outset and that there are no surprises later which could mean delays or even failure. For example, considering the manufacturing process will have a bearing on the types of materials used and their functionality, as well as the compatibility of different potential components. Social and environmental impact factors should be considered. Figure 2.3 summarises some of the key elements to be considered in preparing a design brief.

Planning determines how the brief is to be implemented and the new solution delivered. It defines key steps, activities, their duration and sequence, and team roles and resources. The value of planning goes beyond saying how long it will take and how much it will cost, important though those are. Planning helps to anticipate issues. It brings the team together to ensure no misunderstanding about who does what and when. Time spent at the outset of a product development project in planning with all the members of the team present can save time and resources later and increase the chances of a successful outcome. It generates milestones, which if used correctly are a valuable aid in tracking progress and deciding on when it is appropriate to move from one phase to the next.

A good plan may not need too much adjustment as work progresses but if the team is trying to do something very novel there may well be uncertainties in terms of timings and resource requirements which require continuous monitoring and adjustments to be made. Further, external factors beyond the control of the team may affect progress. It is important to be as realistic as possible about what can be achieved in a given time, especially when field work is involved: difficulties associated with transport, weather, availability of materials and so forth can all cause delays.

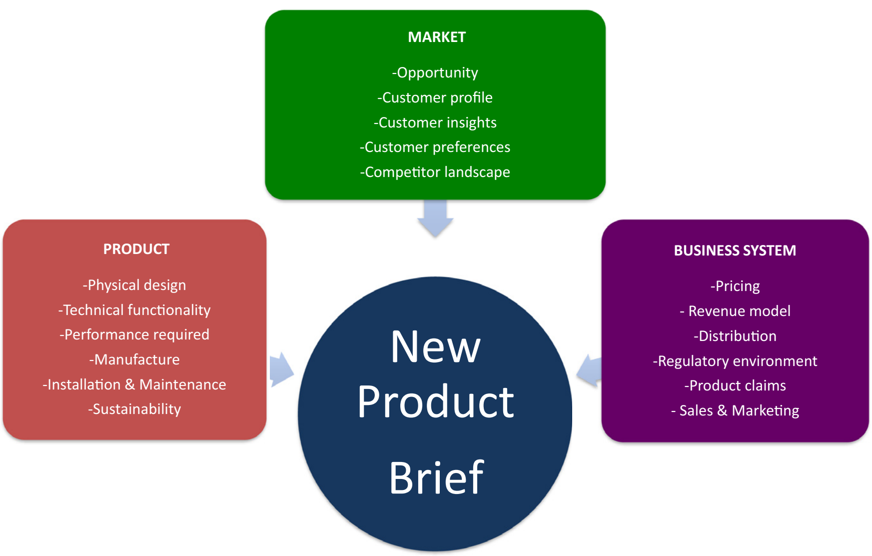

Figure 2.3 Key elements of a design brief (Source: Author).

2.2 THE POWER OF PROTOTYPING AND ROLE OF DEMONSTRATORS

A key part of UCD/product development is prototyping, which has two main roles, each of which add considerable value to the final product. Firstly, it makes the concept visible or tangible and this helps to explore the concept and explain it to customers and other stakeholders. By making the product concept real enough so that the intended customer can touch, see, simulate and experience it, fresh insights are gained into what is and is not attractive about the idea and what needs to be improved. Secondly, prototyping allows key aspects of functionality and customer appeal to be tested and proven. As we will see, prototyping adds value not just in terms of getting closer and closer to what customers actually want, but also in terms of demonstrating what is technically possible and catalysing the commercial development of the product.

Prototyping can range from the physical – whether early-stage simple mock-ups using off-the-shelf components or more sophisticated simulations of a final product for an in-home test – to the virtual, using computer-aided design software to bring ideas to life and adapt and refine them. And these can be combined in mixed prototyping which has the potential for short learning cycles (Elverum *et al.*, 2016). There are different strategies for prototyping and some thought should be given at the outset to how it will be used and the key questions to be answered. This will help to keep costs down, particularly at the later stages when there may seem to be a need for increasingly sophisticated prototypes (Elverum *et al.*, 2016). Prototyping can be used at different points and in different ways throughout the design and product development process. The example in Text Box 2.2 highlights how it helps to focus on the key features of a new product that matter to customers, and how they engage with it physically and emotionally, essential factors for generating demand and customer satisfaction.

Prototyping is also critical in understanding and proving the functionality of a new product: it can address questions such as how well does the product perform, how

Text Box 2.2: The Art of Prototyping

The WaterSHED team in Cambodia have developed a number of user-led innovations in hygiene and sanitation. Prototyping has been an integral part of their design process and they have learnt a lot about its value and how best to use it. Geoff Revell, WaterSHED's co-founder, described (Revell, 2017) the challenges of prototyping a product, the HappyTap handwashing station, that would eventually be molded in plastic: because of the high cost of molds the team had to be sure of the key features of the product before they committed. So they considered what the key features of the product were and mocked up two versions of each of those, and gave them to households to try one after the other. This 'head to head' use of prototyping gave them a sense of which version was preferred and they could build that into the overall design.

They also learnt that you need the right kind of prototype for the kind of feedback you are seeking. If you want to learn about aesthetics cardboard mock-ups are not helpful. There was an 'Aha!' moment for Geoff when he realized that his target consumers were seeing the product not in terms of narrow function or form but as a way to change their lifestyle for the better. His over-riding advice is to probe as deeply as you can qualitatively to gain such insights. However he recognizes there will always be a tension between designing based on expressed wishes and designing based on a powerful entrepreneurial vision. Such tensions can of course be powerful drivers of creativity.

satisfied are potential customers with its performance, what are the issues that still need to be resolved? Again it is about choosing the right kind of prototype for the stage you are at and the information you need to move forward. For products involving new technology, once they get beyond lab proof of concept the first big jump is to make a prototype that people can use, typically referred to as a field or application prototype under real world conditions. This allows the innovator not just to test how well the product performs technically but also to explore how the user interacts with it and to get their feedback on what they like and dislike. It is a major step towards the development of a commercial product. The next step thereafter is typically to make a commercial application prototype, which builds in any necessary refinements and improvements and is closer to a finished product in terms of cost, materials and manufacturability. This in turn will go through further refinements to make it into a product suitable for large-scale manufacturing. As new technologies become available, product improvements and new features become possible. The product improvement and development process does not stand still.

When science and technology make things possible that were not previously possible and drive and enable new product concepts, prototyping takes on an additional significance for value creation. In the case of such emerging technologies, and industries based on them, where the applications are not initially fully understood and the route to market is uncertain, it is clear from a wide-ranging review that the process of emergence from the lab to the mass market goes through several well characterized stages as shown in Figure 2.4 below (Phaal *et al.*, 2011). The catalyst for moving from one stage to another is a particular kind of prototype, which the authors call a demonstrator: a physical representation of what is possible that allows the next stage to proceed and the

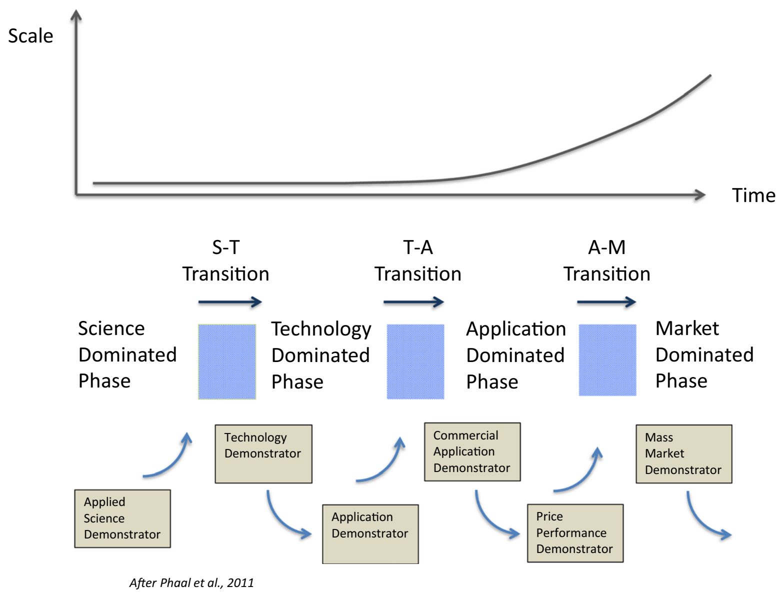

Figure 2.4 Role of demonstrators in moving from science to mass market in technology and industry emergence. (Diagram by author, after Phaal *et al.* 2011).

final outcome to be achieved. The stages and different types of demonstrator and their relationship to growth in scale, are illustrated in Figure 2.4.

The stages are separated by transition zones and getting through these zones is critical to making progress towards eventual mass scale. The first such zone marks the transition between the S (science-dominated) phase into the T (technology-dominated) phase. The end of the S phase and entry into this S–T zone is marked by an *applied science demonstrator* – essentially proof-of-concept, showing the feasibility and practical possibilities for the underlying technical approach. Leaving this zone and entering the T phase is associated with creation of *technology demonstrators* – prototypes that demonstrate that the technology can be integrated to perform the desired functions. During the T phase these prototypes and their components are refined and issues resolved under controlled conditions to the point where it is possible to make one that is sufficiently robust to test outside the laboratory. This is the *application demonstrator*, which is associated with the T–A (application-dominated) transition. Some prior 'field demonstrators' may have been necessary to reach this point depending on the complexity of the operational environment. Application demonstrators bring the concept to life and allow further refinements and improvements to accommodate user feedback and operational challenges in the real world. This can then lead to the creation of a *commercial application demonstrator* which marks the end of the T–A transition and entry into the application phase. This demonstrator is essentially the V_0 product and marks the beginning of market trials and sales. During the application phase the product is likely to go through further iterations in design, performance and price; this leads to the development of a *price–performance market demonstrator* which shows the feasibility of a commercial mass market and marks the start of the A–M (mass-market-dominated) transition. This transition is crucial to achieve scale. It ends with the development of a *mass market demonstrator* which is positioned for substantial growth. For those more familiar with TRL nomenclature, the S, T and A phases approximate to the Research (TRL1–3), Development (TRL4–6) and Deployment (TRL7–9) stages.

This framework is based on a retrospective analysis of many different technologies and industries, ranging from cheese to digital cameras (Phaal *et al*., 2011). The value capture of the transitional zones is evident and crucial to achieve the full potential of a new concept. There is no reason to believe that new sanitation technologies along the IFSVC should not follow the same pattern. Two such technologies, Zyclone Cube and Tiger Toilet, are compared in Figure 2.5 using this framework.

The Tiger Toilet is an on-site sanitation system based on vermifiltration (Furlong *et al*., 2014, 2015, 2016). As shown in Figure 2.5 , progress from lab to field demonstrators was quite fast and the results from the household field trials gave real confidence in terms of technical performance and user satisfaction (Furlong *et al*., 2016). This confidence enabled Bear Valley Ventures and PriMove India to work together to start market testing and development of the first application prototype: to date around 5000 household units have been sold and the technology has also been adapted to enable wastewater and faecal sludge treatment at different scales (TBF, 2020). The applications of this technology are being explored by a number of organisations, and recently the International Worm-Based Sanitation Association (IWBSA) was formed to share, develop and promote best practice: according to their estimates, over 210 000 people in nine countries are benefitting from solutions installed by IWBSA contributors (IWBSA, 2021). Mass-market scale has yet to be achieved, however, and the model in Figure 2.5 suggests that, at least for domestic units, further technical development is necessary to catalyse the jump to this level.

The Zyclone Cube is one of a suite of innovative decentralized waste-treatment systems developed at AIT, Thailand for applications in Asia and beyond (Koottatep

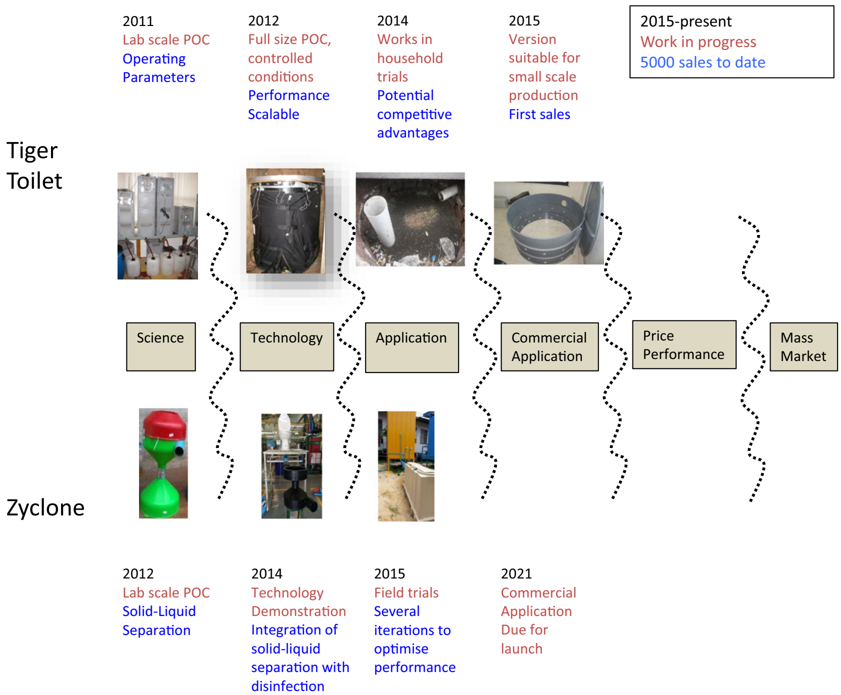

Figure 2.5 Demonstrators and value capture for emergent sanitation technologies. **Legend:** text in red, nature of demonstrator; text in blue, key value added by demonstrator. Figures for the Tiger Toilet refer to work done by the Sanitation Ventures team at London School of Hygiene and Tropical Medicine (2009–2012); Bear Valley Ventures and PriMove (2012–2015); Bear Valley Ventures, Primove and ITT (2016–2017); and latterly TBF Environmental Solutions Pvt Ltd (2018–present). *Image credits: 2011, 2012 and 2014 images, Dr Claire Furlong; 2015 image, Walter Gibson).* Figures for the Zyclone Cube refer to work done by the NATS project team at the Asian Institute of Technology, Thailand (2011–present) and by SCG chemicals Co. Ltd (2018–present). *Image credits: taken from final report of the innovative DEWAT Technologies Project, supported by Bill & Melinda Gates Foundation and Asian Institute of Technology, November 2019).*

et al., 2018). Following successful initial lab testing of technology prototypes, the team made rapid progress to a field prototype, using a factory setting to test the design with users. The prototype was monitored regularly for technical performance by the team over about a year and feedback was obtained from users. As a result they learnt a huge amount about its strengths and weaknesses, giving the team confidence that it would work under real-life conditions and allowing them to focus on how it could each be improved further. AIT have transferred their intellectual property to SCG Chemicals Co. Ltd who are developing a commercial product, with AIT providing technical support. Sales of 200 units were projected in 2021.

If this model holds for other new product development in sanitation, then it illustrates how important the product development process is for enabling and progressing to scale. Thinking in terms of the next demonstrator in order to capture more value and move from one level of scale to another is crucial to realizing the full economic and impact potential of innovations within the IFSVC. Frameworks such as this can help innovators understand where they are in the process and what they have to do to get to the next stage. As we will see in Chapter 7, scale has been identified as a vital factor in the commercial viability of an innovative value recovery approach, the use of Black Soldier Fly (BSF) larvae to process faecal waste and turn it into high-value products such as lubricants, biodiesel, chitosan and soil conditioners. This began life as a lab experiment in 2011 to prove that BSF larvae could grow and develop on faecal waste (Banks *et al.*, 2013), then went through technology and application demonstrators at increasing scale in South Africa (The BioCycle; see Chapter 7 for more details) and Kenya (Sanergy; see Text Box 2.3 for more details), during which there was considerable value added in terms of operational parameters and commercial insights. This appears then to be another technology approaching the A–M transition.

However important the product development process is, it should be recognized (as we will see in Chapter 7) that the business model and market considerations (e.g., distribution, pricing, demand creation, regulations), partnerships and investment are also crucial to delivering mass scale. Technical progress alone may not be sufficient to convince investors and other stakeholders to get behind a new product. Further, in the case of sanitation because of the social and health impact potential, building evidence for impact and creating a scaling system with all the right partners aligned is also critical (McLean & Gargani, 2019).

2.3 INTEGRATING PRODUCT DEVELOPMENT WITH MARKET AND BUSINESS MODEL DEVELOPMENT

Achieving scale is vital for business sustainability and realizing the full potential value of a new concept. While the product development process plays an important role, it must go hand in hand with exploring and verifying the market potential and working out and proving the business model. Customer feedback from early commercial application demonstrators will guide subsequent development: the price may be too high, or the performance unsatisfactory in some respect. Thus there should be iteration through market trials of improved versions until the product gets close to the price/performance demonstration required to begin the transition to mass scale. Likewise key aspects of the business model need to be explored: cost of customer acquisition, levels of demand, and route to market will all have an influence on the product and vice versa. All of this work adds value because it is only when all three elements come together that a mass-scale demonstrator is feasible and real scale-up and value generation can begin.

Although in sectors such as sanitary hardware, with well established consumer markets dominated by large companies, the business model will typically be well developed and the market well understood, this is not generally the case for businesses trying to operate within the IFSVC in low-to-middle income countries. In such contexts the IFSVC is fragmented and characterized by many small operators (e.g., emptying truck operators), early-stage enterprises piloting innovative products and services, and large companies mainly engaged in collection to resource recovery, as well as cleaning products. Most businesses serve customers at only a limited number of points and relatively few enterprises as yet span the whole chain (Mason *et al.*, 2015): the total current size of the IFSVC is as yet a small fraction of its full potential.

How can that value be realized? It is unlikely that the many small operators can grow their revenues substantially: they operate direct to householders with simple technology and it will be difficult for them to grow their markets. For enterprises pioneering a new product or service of the types cited above, increasing value creation means creating not just the product but the business model as well. In some cases even the market itself has to be proven and developed. Individually some of the markets along the IFSVC are potentially very large, especially with over two billion people still without access to toilets. But perhaps the greatest prize is for more and more businesses to operate either alone or in partnerships along the whole length of the IFSVC, with value being added at every stage. This generates value beyond the sale of toilet products and services by selling products derived from the waste itself, but there must be incentives all the way along for the chain to work. As an illustration of how the business model is factored into design, new technology development and value creation, and how the IFSVC can be incentivized, consider Sanergy, one of the few enterprises to span the whole IFSVC (see Text Box 2.3 below; Walske & Tyson, 2016).

Even with these innovations and enhanced value creation, cost recovery is still a challenge for container-based sanitation services like Sanergy (Russel *et al.*, 2019). In addition to cost savings, for example through scale, there is scope to explore further innovations at the end of the value chain to increase revenue. A number of options have been reviewed and compared in terms of potential market value by Diener *et al.* (2014). These authors highlighted the need to consider local market conditions in selecting technologies for value recovery, as demand can vary considerably from one location to another. This need to match technologies to markets is also typical of the process by which innovations reach scale and is often a key part of the commercialization process. As we will see in Chapter 7, market experiments are underway with a number of different reuse products and business models.

Text Box 2.3: Sanergy – Business Model and Relationship to Design and Value Creation

From the outset the founders of Sanergy sought a business model that was integrated and incentivized across the whole sanitation value chain from design and production through to the final marketplace (Walske & Tyson, 2016). Working in the slums of Nairobi, Kenya, their solution involves a network of off-grid, waterless toilets operated by franchisees under the Fresh Life brand, and collection and treatment of waste by Sanergy into fertilizer and insect-based animal feed. The toilets are designed and produced by Sanergy, incorporating features which provide incentives for users, operators and Sanergy themselves. Toilets are leased by the operators who keep all the pay-per-use fees. Sanergy have made it easier for new operators to make the monthly service payment by making financing available. Because Sanergy's own revenues come from the sale of biomass recovery products to farmers, it is vital to grow this network to ensure the supply of raw material: making sure toilets are used consistently is thus important and toilets are monitored regularly to make sure standards of cleanliness and hygiene are high. Sanergy have introduced new technology at the final biomass transformation step to increase revenue potential by using BSF larvae to convert waste into protein for animal feed. Sales of the product Kuza Pro (which offers a 30% increase in yield for farmers) commenced in 2019; the market is very large, estimated to be $520M in Kenya alone (according to personal communication with Sanergy in 2021). So this added value could be a significant driver of business growth and growth in sanitation provision, the source of the feedstock for animal feed production.

2.4 KEY CONSTRAINTS AND CHALLENGES

Every individual enterprise in the IFSVC will have its own challenges in terms of product design and development. Many of these relate to scaling good ideas to the level required to make a real impact on the problem at a global level. Some are typical of the constraints and challenges faced during product development in any sector, such as competitor activity, finding suitable technology, and getting costs down. However, there are also some particular constraints and challenges which affect the future development and functioning of the IFSVC as a whole. These include:

2.4.1 Constraints

- Regulatory factors – certain uses of products of bioconversion, for example insect-larvae-based products for animal feed, are not permitted under current legislation in some countries and regions. The first such product to gain approval was Sanergy's KuzaPro animal feed in Kenya in 2019.
- Lack of resources for start-up enterprises – not just funding but lack of access to key specialist skills and facilities. Many of the innovations adding value to the IFSVC are being brought to the market by SMEs, which often lack such resources and find them difficult to access.
- The intrinsic difficulty of working in low-income settings – the need to obtain solid evidence at each stage of the process in low-income settings can affect the rate of progress.

2.4.2 Challenges

- Finding novel, higher-value bioconversion products for which there is market demand to provide greater economic incentives, encourage product development and build partnerships along the chain. There is a need for more options creating more revenue per kilogram of waste than biogas and fertilizer.
- Scaling innovative technologies so that their full commercial and impact potential can be realized. This demands not just technical advances but also significant investment and, in all likelihood, major partnerships (see Chapter 7) to undertake trials at scale and provide the evidence required to justify wider rollout.
- Introducing fresh perspectives – technical thinking has dominated the sanitation sector historically, but innovation in and integration with design and business model thinking is important for full value creation.
- Developing effective partnership models – this is vital across the value chain to provide better products and services at all stages and greater incentives to make it function more effectively.

2.5 NEW HORIZONS

Some of these challenges are more amenable than others. For example, it may take many years and many studies to convince every regulator that it is safe for humans to eat animals fed with meal derived from insect larvae fed on human waste. The use of insect larvae is however a major step forward in terms of value creation compared with fertilizer and biogas and points the way to what can be achieved. The potential of bioconversion is huge however and discovery of new high-value bioconversion products will drive even greater opportunities. According to a UNESCO report 'Future research and innovation trends in the field of wastewater will probably focus on resource recovery to reinvent the economics of the treatment and disposal of wastewater and sludge' (WWAP, 2017). The term 'wastewater' here is used broadly and this statement can also be taken to apply to faecal sludge processing. This report cites several promising new technologies under development for energy, nutrient and high-value product recovery, such as microbial fuel cells, advanced methods for recovering N and P, and environmentally friendly microalgae for production of a range of high-value products including bioplastics and cosmetic ingredients. A combination of careful economic analysis of possible markets, identification of appropriate business models and biotechnological advances will be needed to identify the most viable options for any given situation: the context in terms of markets, regulations and consumer perceptions will also be important. The tools for such analyses are available. As an example, one such recent thought is to 'rewire' anaerobic digestion (AD) away from methane production to the production of short-chain fatty acids, which have a high value as intermediates in many different chemical industries (Text Box 2.4).

Text Box 2.4: Rewiring AD

The potential for resource recovery using advanced AD technologies to drive improved sanitation was put forward by Chandran (2014), who identified chemicals such as short-chain carboxylic acids (e.g., acetic, lactic, propionic, and butyric acids) and methanol as more economically attractive products that could be produced by fermentation of human waste. This approach has multiple potential social and environmental benefits: it reduces pressure on natural resources such as fossil fuels, from which such chemicals are normally derived; it saves energy in processing waste by conventional aerobic technology; and it generates revenues which can be used to offset the cost of sanitation provision.

The ability to arrest anaerobic digestion of wet organic waste after the acidogenesis stage, resulting in the production of short-chain carboxylic acids (from C_2 to C_4), is now well established (Bhatt *et al.*, 2020). Such acids have a wide range of possible uses and are high-value feedstocks for products including polymers, pharmaceuticals and cosmetics. While challenges remain to optimize production and separation of short-chain acids, the analysis by Bhatt *et al.* suggests that it has the potential to be cost-competitive even at small plant scales and a decentralized approach can be adopted due to temporal and compositional variability across different regions.

In developed countries the commercial application of this approach could change the current paradigm of wastewater treatment from being cost-intensive to revenue-generating and have considerable environmental and sustainability benefits through reduced use of fossil fuels and biomass reuse. In developing countries, the potential remains to be explored: a key question for future research is whether the revenue generation potential is large enough and can be effectively harnessed through an appropriate business model to drive affordable, safe and low environmental impact sanitation for everyone. While there are still technical challenges to be overcome, there is a strong economic and environmental case for this approach and it represents an exciting new opportunity to be explored in the context of the vision for the IFSVC.

2.6 Take action

(I) Identify businesses/enterprises and other players involved in the design and development of sanitation products.

(II) Draw an illustration that indicates an overview of a value chain map for sanitation product design and development in your country, and also show the global linkages.

2.7 Journal entry

Consider any existing sanitation product and write an essay on the design and development from conceptualization to creation.

2.8 Reflection

Customer insights are vital for conceptualizing, designing, and developing sanitation products for the market; through an informal survey within your locality, explore users' preferences for particular products' design, functionality and performance.

2.9 Guiding questions

(I) What is a sanitation product design and development value chain?
(II) What are the implications of value creation being central to product design?
(III) Why is it important to focus on what the customer wants as opposed to what they need in product design and development?
(IV) What is the role of context in product design and development and what does it entail?
(V) What is the full implication of not understanding customer preferences in product design and developments and what is the benefit of spending time to gain customer insight in sanitation product design and development?
(VI) 'Experiencing what your customer experiences everyday can be powerful and influential in terms of the final outcome.' How true is this statement?
(VII) Why is prototyping necessary in product design and development?
(VIII) What role did the Bill and Melinda Gates Foundation 'inventing toilet' challenge contribute to the development of innovative sanitation product design and development? What is the current status of those designs?
(IX) What are the possible constraints and challenges of enterprises in IFSVC with regards to product design and development?

2.6 TOOLS

There are several toolkits on user-centred design available to help teams get started on this process and navigate some of the processes discussed in this chapter. These include:

- Gates Foundation (https://www.ucdinsanitation.com/)
- IDEO (https://www.designkit.org/)
- Stanford Design School (https://dschool.stanford.edu/resources/design–thinking–bootleg)

REFERENCES

Albert J., Luoto J. and Devine D. (2010). End–user preferences for and performance of competing POU water treatment technologies among the rural poor of Kenya. *Environmental Science & Technology*, **44**(12), 4426–4432, https://doi.org/10.1021/es1000566

Auerbach D. (2015). Sustainable sanitation provision in urban slums – the Sanergy way. *Sustainable Sanitation Practice*, **24**, 4–8.

Banks I. J., Gibson W. T. and Cameron M. M. (2013). Growth rates of black soldier fly larvae fed on fresh human faeces and their implication for improving sanitation. *Tropical Medicine & International Health*, **19**, 14–22, https://doi.org/10.1111/tmi.12228

Bhatt A. H., Ren Z. and Tao L. (2020). Value proposition of untapped wet wastes: carboxylic acid production through anaerobic digestion. *iScience*, **23**, 101221, https://doi.org/10.1016/j.isci.2020.101221

Borkowski J. and Perez E. (2019). A Market-Based, Pro-Poor Approach to Rural Sanitation. Global Communities Case Study. Global Communities, Silver Spring, MD, USA, 8pp.

Chambers R. and Myers J. (2016). Norms, knowledge and usage. Frontiers of CLTS: Innovations and Insights. IDS, Brighton, UK, Issue 7, pp. 1–22.

Chandran K. (2014). Technologies and framework for resource recovery. In: Water Reclamation and Sustainability, S. Ahuja (ed.), Elsevier, Oxford, UK, Ch. 17, pp. 415–430. https://doi.org/10.1016/B978–0–12–411645–0.00017–1 (accessed February 2021)

Coffey D., Gupta A., Hathi P., Spears D., Srivastav N. and Yvas S. (2017). Understanding open defecation in rural India: untouchability,pollution and latrine pits. *Economic and Political Weekly*, **52**, 59–66.

Diener S., Semiyaga S., Niwagaba C., Muspratt A. M., Gning J. B., Mbeguere M., Ennin J. E., Zurbrugg C. and Strande L. (2014). A value proposition: resource recovery from faecal sludge – can it be the driver for improved sanitation? *Resources, Conservation and Recycling*, **88**, 32–38, https://doi.org/10.1016/j.resconrec.2014.04.005

Economic Times (2020). Washroom-on-wheels: how a Pune firm is turning buses into women's toilets. Economic Times, 21 February 2020. Times Internet, Gurugram, Haryana, India. https://economictimes.indiatimes.com/news/politics-and-nation/washroom-on-wheels-how-a-pune-firm-is-turning-buses-into-womens-toilets/buses-or-womens-toilets/slideshow/74239692.cms (accessed 2021)

Elverum C. W., Welo T. and Tronvoll S. (2016). Prototyping in new product development: strategy considerations. *Procedia CIRP*, **50**, 117–122, https://doi.org/10.1016/j.procir.2016.05.010

Furlong C., Templeton M. R. and Gibson W. T. (2014). Processing of human faeces by wet vermifiltration for improved on-site sanitation. *Journal of Water, Sanitation and Hygiene for Development*, **4**, 231–239, https://doi.org/10.2166/washdev.2014.107

Furlong C., Gibson W. T., Templeton M. R., Taillade M., Kassam F., Crabb G., Goodsell R., McQuilkin J., Oak A., Thakar G., Kodgire M. and Patankar R. (2015). The development of an onsite sanitation system based on vermifiltration: the Tiger Toilet. *Journal of Water, Sanitation and Hygiene for Development*, **5**, 608–613, https://doi.org/10.2166/washdev.2015.167

Furlong C., Gibson W. T., Oak A., Thakar G., Kodgire M. and Patankar R. (2016). Technical and user evaluation of a novel, worm-based, on-site sanitation system in rural India. *Waterlines*, **35**, 148–162, https://doi.org/10.3362/1756-3488.2016.013

Gupta A., Khalid N., Deshpande D., Hathi P., Kapur A., Srivastav N., Yvas S., Spears D. and Coffey D. (2020). Revisiting open defecation: evidence from a panel survey in rural north India, 2014–18. *Economic and Political Weekly*, **55**, 55–63.

Hennigs J., Ravndal K. T., Blose T., Toolaram A., Sindall R. C., Barrington D., Collins M., Engineer B., Kolios A. T., McAdam E., Parker A., Williams L. and Tyrrel S. (2019). Field testing of a prototype mechanical dry toilet flush. *Science of the Total Environment*, **668**, 419–431, https://doi.org/10.1016/j.scitotenv.2019.02.220

Hutton G., Haller L. and Bartram J. (2007). Global cost–benefit analysis of water supply and sanitation interventions. *Journal of Water and Health*, **5**, 481–502, https://doi.org/10.2166/wh.2007.009

iDE (2021). Every family deserves a toilet. [online]. https://www.ideglobal.org/story/sanitation (accessed 2021)

Ideo (n.d.). An Enterprise That's Committed to Putting a Toilet in Every Home. Ideo.org, San Francisco, New York, Nairobi. [online] https://www.ideo.org/project/clean–team (accessed 2020)

Ishiyama D. (2017). You can't smell a latrine from your desk. [video] YouTube, https://youtu.be/byS5MGFxu5Y (accessed 2020)

IWBSA (2021). https://iwbsa.org/impact (accessed 2021)

Kisker J. and Drabble S. (2017). The Pula App: a customer acquisition and tracking tool for vacuum tanker businesses. WSUP Practice Note. November 2017. www.wsup.com/content/

uploads/2017/11/PN031-ENGLISH-The-PULA-app-a-customer-acquisition-and-tracking-tool-for-vacuum-tanker-businesses-1.pdf (accessed 2020)

Koottatep T., Chapagain S. K., Polprasert C., Panuvatvanich A. and Anh K.-H. (2018). Sanitation situations in selected Southeast Asian countries and application of innovative technologies. *Environment, Development and Sustainability*, **20**, 495–506, https://doi.org/10.1007/s10668-016-9892-6

LIXIL (2021). https://www.sato.lixil.com/ (accessed 2021)

MacArthur J., Riggs F. C. and Chowdhury R. (2015). Disruptive design in sanitation marketing: lessons from product and process innovations in Bangladesh. Proceedings of 38th WEDC International Conference, Loughborough UK. https://wedc–knowledge.lboro.ac.uk/resources/conference/38/MacArthur–2176.pdf (accessed 2020)

Mason N., Matoso M. and Smith W. (2015). Private sector and water supply, hygiene and sanitation, ODI Report, Overseas Development Institute, London, UK, 74pp.

McLean R. and Gargani J. (2019). Scaling Impact: Innovation for the Public Good. Routledge & IDRC, Ottawa, Canada. ISBN 9781138605558.

Mulumba J. N., Nothomb C., Potter A. and Snel M. (2014). Striking the balance: what is the role of the public sector in sanitation as a service and a business? *Waterlines*, **33**, 195–210, https://doi.org/10.3362/1756-3488.2014.021

Ojomo E., Elliott M., Goodyear L., Forson M. and Bartram J. (2015). Sustainability and scale-up of household water treatment and safe storage practices: enablers and barriers to effective implementation. *International Journal of Hygiene and Environmental Health*, **218**, 704–713, https://doi.org/10.1016/j.ijheh.2015.03.002

Pedi D., Jenkins M., Aun H., McLennan L. and Revell G. (2011). The 'hands–off' sanitation marketing model: emerging lessons from rural Cambodia. In: The Future of Water, Sanitation and Hygiene in Low-Income Countries – Innovation, Adaptation and Engagement in A Changing World, R. J. Shaw (ed.), Proceedings of 35th WEDC International Conference, Water Engineering and Development Centre, Loughborough University, Loughborough, UK, pp. 6–8, July 2011. https://wedc-knowledge.lboro.ac.uk/index.html

Pedi D., Kov P. and Smets S. (2012). Sanitation marketing lessons from Cambodia: a market-based approach to delivering sanitation. Water and Sanitation Program: Field Note. https://www.wsp.org/sites/wsp.org/files/publications/WSP-Sanitation-marketing-lessons-Cambodia-Market-based-delivering-Sanitation.pdf (accessed 2020)

Phaal R., O'Sullivan E., Routley M., Ford S. and Probert D. (2011). A framework for mapping industrial emergence. *Technological Forecasting and Social Change*, **78**, 217–230, https://doi.org/10.1016/j.techfore.2010.06.018

Porter M. (2001). The value chain and competitive advantage. In: Understanding Business: Processes, D. Barnes (ed.), Routledge & Open University, London, UK, Ch. 5, pp. 50–66.

Quicksand (2011a). Potty Project: understanding sanitation experiences of the urban poor. http://quicksand.co.in/work/the-potty-project (accessed 2020)

Quicksand (2011b). Potty Project Blog. https://pottyprojectindia.tumblr.com/search/insights (accessed 2020)

Quicksand Sammaan Brief (n.d.). http://quicksand.co.in/media/downloads/project-sammaan/ProjectSammaan_ProjectBrief.pdf (accessed 2020)

Revell G. (2017). How real should a prototype feel? [video] YouTube. https://youtu.be/Rdoq2k5lqc4 (accessed 2020)

Russel K., Hughes K., Roach M., Auerbach D., Foote A., Kramer S. and Briceno R. (2019). Taking container-based sanitation to scale: opportunities and challenges. *Frontiers in Environmental Science*, **7**, 00190, https://doi.org/10.3389/fenvs.2019.00190

Sanergy (2021). http://www.sanergy.com/ (accessed 2020)

Surfaces Reporter (2020). Sammaan: a sustainable improved sanitation model for urban slums/BMC/BMGF/JPAL/QDS. Surfaces Reporter, 28 November 2020. https://www.surfacesreporter.com/articles/72186/sammaan-a-sustainable-improved-sanitation-model-for-urban-slums-bmc-bmgf-jpal-qds (accessed 2020)

TBF (2020). http://www.tbfenvironmental.in/ (accessed 2020)

Walske J. M. and Tyson L. D. (2016). Sanergy: Tackling Sanitation in Kenyan Slums. Berkeley Haas Case Series, Haas School of Business, Berkeley, CA, USA. https://cases.haas.berkeley.edu/2016/07/sanergy/ (accessed 2020)

WWAP (UN World Water Assessment Programme) (2017). The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. UNESCO, Paris, 198pp. https://unesdoc.unesco.org/ark:/48223/pf0000247153/PDF/247153eng.pdf.multi (accessed 2020)