doi: 10.2166/9781789061840_0037

Chapter 3

Product/equipment manufacturing

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Chapter objectives

The aim of this chapter is to help the reader understand the sanitation manufacturing value chain in the IFSVC and the complex range of activities implemented by various actors such as primary producers, processors, traders, and service providers, globally, nationally and locally to bring a sanitation product through production to its sale.

3.1 INTRODUCTION

Sanitation manufactured products and equipment (SMPE) have been traditionally focused on households and in some cases educational and healthcare institutions, but in reality these products and equipment are ubiquitous and our survival are intricately linked with them. This simple perspective fails to capture the complex inter-relationship, information and materials flow between the various players and systems in the sanitation/hygiene manufacturing/production value chain and the final consumers/users (SMVC/SPVC) (Srai & Shi, 2008). In other words, sanitation products and equipment are found in homes, schools, public facilities, government, public and private buildings, religious facilities, markets, shopping malls, airports, bus/train stations and transport facilities, cinemas/theatres, stadia, event centres, hotel and tourism facilities, parks, playgrounds, recreation or community centres, hospitals and healthcare facilities, prisons and correctional facilities as well as at constructions sites and outdoor event areas. Sanitation/hygiene product enterprises (SHPE) are involved with software, hardware and consumables across the integrated functional sanitation value chain (IFSVC) and originate through series of value-added research and development, up to production, distribution, installation and after-sales services (Koottatep *et al.*, 2019a). They include any sanitation/hygiene good (tangible or intangible), service or idea that is produced by labour or effort and/or a result of an act or process that can be offered to a market and/or end-users to satisfy a want or need (Wikipedia, 2019; Wiktionary, 2019). Equipment refers to apparatus, gear, hardware, kit and/or materials that are used in operations or activities that relate to sanitation and/or wastewater, sewage, faecal sludge, and so on.

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

For instance, sanitation equipment manufacturers produce end-to-end equipment and technologies from non-network systems such as composting toilets, ventilated improved pit latrines and suchlike, to basic network components such as pipes, to complex sewage/ wastewater treatment plants.

Some of these products/equipment and/or technologies are sector-specific, whereas others have wider uses, for example, construction, measurement, plastics, chemical and mechanical applications and the transport of liquid in general (PWC, 2012). These products and equipment are manufactured with rigorously quality control and assurance formulated standards that ensure uniformity, replicability, scalability, reliability, specificity and functionality (Gasiorowski-Denis, 2018; Koottatep *et al*., 2019a; Lazarte, 2016). They, along with the related services result from value-added processes and transformation of goods, especially via manufacturing processes of industries/ enterprises (UNIDO, 2011). It is important to understand that value addition is the work of industry/enterprise in the sector done in-house and not that which others are paid to perform (Meckstroth, 2016). Another interesting point to note is that sanitation products, equipment and services are not restricted to toilets/latrines but include other consumables that enhance the use of sanitation infrastructures and facilities, (e.g., hygienic products) as well as the total wellbeing of humanity (Table 3.1).

Sanitation products/equipment manufacturing value-added activities are directly concerned with the change of form or dimensions of input materials to products and services (Singh, 2006). It covers the entire life cycle of products from the beginning of life (BOL), which extends from product design to actual production; to middle-of-life (MOL) which extends to product use, after-sales service and maintenance; as well as end-of-life (EOL), which then extends to product reuse with refurbishing, reuse of components with disassembly and refurbishing, material reclamation without disassembly, material reclamation with disassembly, and final disposal (Rolstadaas *et al*., 2008). In addition, supporting activities such as transportation and handling or storage of parts – even though they are not directly concerned with the changing of form and/or dimensions of the part produced – are critical components of production (Porter, 1985).

Thus the Sanitation Manufacturing Value Chain (SMVC) looks at the complex range of activities implemented by various actors (primary producers, processors, traders, service providers) globally, nationally and locally to bring a raw material through production to the sale of the final product. SMVC starts from how raw materials move along production processes with other enterprises engaging in trading, assembling, processing activities, and so on. (M4P, 2008). In a nutshell, it covers raw material processing, intermediate production, manufactured parts assembly, sales and service, and also addresses the challenges of technological innovations. SMVC, then, is the continued addition of value that occurs while products pass from one enterprise in the chain to the next, gradually increasing its degree of transformation (UNIDO, 2011). The key function is to offer customers/end-users a range of sanitation/hygiene products that match their preferences and budgets by encouraging private/public sector investments in all the stages of the SMVC, particularly to enhance the viability and participation of local entrepreneurs and positioning them appropriately in the global sanitation value chain (USAID, 2018).

The nature of industries/enterprises participating in SMVC are fragmented, active and contribute in different ways to the sanitation global value chain (SGVC), specifically, sanitaryware, treatment plants and hygiene products (Meckstroth, 2016). The focus here is not necessarily on activities implemented by a single enterprise, but rather all the backward and forward linkages up to when the product is delivered to the final customers and/or end-users (M4P, 2008). The main actors of SMVC are enterprises and

Table 3.1 Some sanitation and hygiene manufactured products.

Classification of Products	Product Types
Cleaning and Disinfecting Supplies	Cleaning solutions
	Disinfectants and sanitizers
	Towels and wipes
Cleaning Tools	Brooms, dust pans and accessories
	Carts and mop buckets
	Cleaning brushes and pads
	Mops and accessories
	Squeegees
	Vacuums, sweepers and accessories
Restroom Products	Bathroom cleaners and clog removers
	Fragrance dispensers
	Hand cleaners, sanitizers and soap
	Toilet and urinal products
Towels and Tissues	Dispensers
	Tissues
	Towels and wipes
Trash and Recycling	Trash and recycling containers
	Trash liners and trash bags
Basins	Wall-hung basins
	Over countertop basins
	In countertop basins
	Under countertop basins
	Vanity basins
	Semi-recessed basins
	Totem basins
	Pedestals
Semi-pedestals	Basin complements
Faucets	Basin faucets
	Bidet faucets
	Bath faucets
	Shower faucets
	Shower programme
	Kitchen faucets
	Laundry sink faucets
	Flush valves for toilets
Flush valves for urinals	Faucets complements
Furniture	Base units
	Auxiliary units
Furniture complements	Countertops

(*Continued*)

Table 3.1 Some sanitation and hygiene manufactured products (*Continued*).

Classification of Products	Product Types
Toilets	In-tank toilets
	Close-coupled toilets
	Wall-hung toilets
	Single floor standing toilets
	One-piece toilets
	Toilet cisterns
	Toilet seats and covers
	Toilet mechanisms
	Squatting pans
	Container-based toilets
	Portable toilets
	Mobile toilets
	Smart toilets
Urinals	Standard urinals
	Electronic urinals
	Urinal divisions
Baths	Rectangular baths
	Angular baths
	Other shaped baths
	Bath panels
	Bath complements
Shower trays	Rectangular shower trays
	Corner shower trays
	Square shower trays
	Shower trays complements
	In-drain systems
Installation systems	Operating plates
	Systems for toilet
	Systems for urinal
	Systems for bidet
	Systems for basin
	Installation systems accessories
Containment	Packaged septic tanks
	Containers latrines/toilets
Sewage and faecal sludge emptying equipment	Suction sewage truck
	Sewerage truck
	Jet cleaner – high-pressure water cleaner
	Grit sweeper & clean cuum
Small scale pit latrines equipment	Vacuum trucks, pumping systems, mechanical augers, and so on.,

(*Continued*)

Table 3.1 Some sanitation and hygiene manufactured products (*Continued*).

Classification of Products	Product Types
Products and materials used in plumbing	Metallic and non-metallic materials used in pipework
	Earthenware pipes
	Sanitary fixtures
	Concrete products
Treatment plants	Sewage Treatment Plants (STPs)
	Effluent Treatment Plants (ETPs)
	Activated Sludge Plants (ASPs)
	Common and Combined Effluent Treatment Plants (CEPTs)
	Faecal sludge treatment plants
Resource recovery and reuse equipment	Several technologies deplored for resource recovery and conversion of sanitation biomass

businesses involved in product and service research and development, design, supply of raw materials and equipment parts, production/manufacturing, distribution/route to market, buyers and after sales services. They are supported by a range of technical, business and financial service providers. In the value chain, the various business activities in the different segments become connected and to some degree coordinated. Simply put, SMVC encompasses all the activities and interactions required in the creation of a sanitation product or service, from primary production to transformation, commercialization and end-users and/or customers (UNIDO, 2011). Global industries involved in mass production of sanitation/hygiene products and semi-finished products (foreign value-added) which serve as input-materials used by domestic industries for further product development (Meckstroth, 2016) are part of the chain as well as small-scale producers (S-SP), distributors, retailers, and service providers for the functionality of on-site sanitation systems. In many cases S-SP operate in the informal sector, are not registered and are often off the radar of the municipalities and financial institutions, and therefore lack scale. Nevertheless, they are the main providers of sanitation/hygiene products to low-income customers (Narayanan *et al*., 2011; Nothomb *et al*., 2014; Valfrey-Visser & Schaub-Jones, 2009).

3.2 SANITATION MANUFACTURED PRODUCTS/EQUIPMENT VALUE CHAIN

Manufacturing processes lie near the centre of a complex value chain composed of an upstream chain that gathers materials and services and a downstream sales chain that moves goods to market and sells as well as services manufactured goods (Meckstroth, 2016). This involves making products/equipment from raw materials by various industrial equipment, machines and processes (Singh, 2006). The emphasis is on value-added activities that transform raw materials into finished goods by using different means of production such as human capital, knowledge and machinery/technologies (UNIDO, 2011). The value chain examines the value for each and every activity as the product/service moves through its lifecycle (Acharyulu *et al*., 2015). Sanitation manufacturing enterprises and the ancillary businesses can use value chain analysis to examine all of their activities and to see how they are connected systematically, and how business inputs are changed into outputs and the how to further develop the sector towards achieving SDG6 (Acharyulu *et al.*, 2015). SMVC is a network of independent activities/processes that produces sanitation goods/services and at the same time creates value for the enterprise owners. As the product moves from one player in the chain to another, it is assumed to gain value (Hellin & Meijer, 2006). Thus, value is the amount the customers and/or end-users are willing to pay for the products or services that a firm provides. Every value activity faces costs such as raw materials and other purchased goods and services for 'purchased inputs', human resources (direct and indirect labour) and technology to transform raw materials through other ranges of activities required to bring a product or service from conception through the different phases of production, distribution to end-users into finished goods and final disposal (McGee, 2015; Porter, 1985; Zamora, 2016).

These chains of interrelated activities/processes of production and support activities include order processing, product design and manufacturing of tools/apparatus, dies, moulds, jigs, fixtures and gauges, selection of material, planning, managing and maintaining control of production processes and reliable quality of processed product at different locations in chains and/or networks of enterprises with proper coordination. This systematic cooperation and integration of the whole network of a manufacturing system leads to economical production and effective marketing of designed sanitation products/equipment in the minimum possible time (Singh, 2006). SMVC is not essentially a one enterprise/firm/actor activity but consists of inputs from several value chain actors with several components interacting together in a dynamic-integrated manner, which takes inputs and delivers manufactured products to the customers and/or end-users (Singh, 2006). It operates more on the concept of global value chains (GVCs) based on the fact that the main sanitation (and related hygiene) products, equipment and services (sanitaryware, hygienic cleaning and disinfectant products, wastewater, sewage and/or faecal sludge treatment plants and their ancillary infrastructures, etc) and their trade and consumption span several countries and are increasingly carried out by various entities and/or networks of industries/enterprises located in different countries (Research and Markets, 2021; Sturgeon *et al.*, 2012; Sturgeon & Memedović, 2011)

The implication is that while advanced economies are outsourcing and offshoring sanitation production facilities, the developing economies are participating more in the export markets (Jones *et al.*, 2019), even though most of the raw materials required for these goods are sourced from the developing countries. Therefore, the existing SMVC is made up of buyer-driven and producer-driven value chains. Buyer-driven chains where large retailers, merchandisers and trading companies play a central role in establishing production networks usually arise in developing (exporting) countries, while the producer-driven value chain is dominated by large transnational corporations that play a key role in managing the production network (Abecassis-Moedas, 2006). There are also local product development and manufacturing, whereby partly manufactured products and raw materials from other countries and locations are finished locally.

Regardless of what drives the chain, value additions should reflect through the natural sequence of operations from stage to stage. Value addition implies both value creation and value capture, and every activity performed requires an investment in resources and each link in the chain is expected to add value (Chivaka, 2007). In the same vein, a chain actor's ability to compete and succeed depends on its position along the industry chain and how much value it is able to create and capture (Zamora, 2016). GVCs linking firms, workers and consumers around the world could provide a stepping stone for firms and workers in developing countries to integrate into the global sanitation economy (Gereffi & Fernandez-Stark, 2011). For many developing countries with poor access to safely managed sanitation, their ability to effectively insert themselves into GVC, SMVC or upgrade their local sanitation value chain is a vital requirement to achieve SDG6.

3.3 SANITATION MANUFACTURED PRODUCTS VALUE CHAIN (SMPVC) MAPPING

SMPVC mapping provides a visual representation by identifying products end markets, business operations (functions), chain operators and their linkages as well as the chain supporters. Value chain mapping is the most essential method and the core of any value chain analysis (Springer-Heinzer, 2018). As opposed to other stages of the IFSVC, manufactured products are composed of inputs from different sources. After all, a water closet is more than processed clay. The critical point is that many components and services are needed to make sanitaryware and other sanitation-related products. There is no single dominant input that could be used to characterize the SMPVC (Springer-Heinzer, 2018). SMPVC mapping is aptly illustrated by Porter's value chain model which identifies a number of primary and support manufacturing activities (Porter, 1985). In this regard, the SMPVC has six primary activities and four supporting activities as presented below and shown in Figure 3.1.

The SMPVC primary activities are as follows:

(I) research and development;
(II) design (concept design, specification, detailed design and production design);
(III) sourcing of inputs and supplies (raw materials and semi-processed goods);
(IV) production processes (which could include four main value-added products: manufactured sanitation and allied products; prefabricated concrete/plastic products; *in situ* constructed products; and disruptive innovative products) with over-arching quality control and standardization;
(V) distribution/route to markets and end-users; and
(VI) after-sales services (in addition to other services provided, e.g. assembling, installation, operations and treatment system equipment owners).

The SMVC's supporting activities are: (i) infrastructure; (ii) human resources; (iii) technology; and (iv) procurement (see Figure 3.1).

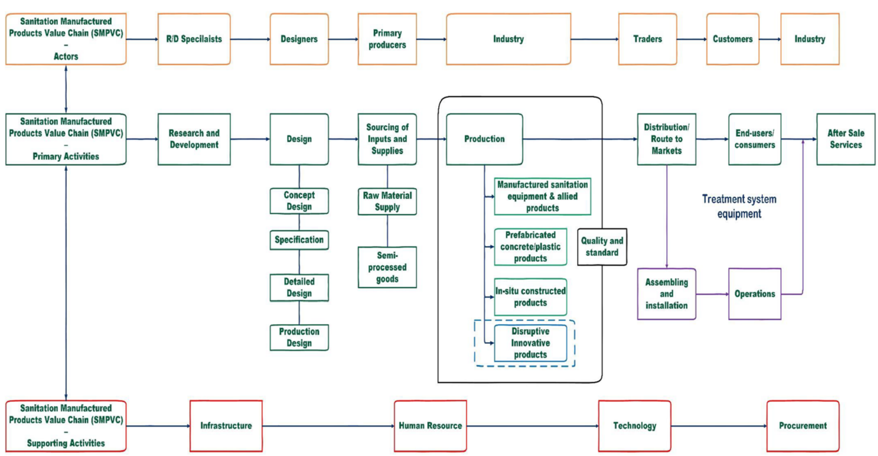

Figure 3.1 Generic sanitation manufactured products value chain map (Sources: Authors).

3.3.1 SMVC primary activities

3.3.1.1 Research and development

This activity deals with discovering new scientific information and technological developments that can be used to design and create innovative products as well as improve existing manufactured products and services. As a stage in SMPVC its focus is on conceptualizing and developing new and/or enhancing already existing sanitation and related products and services. The research aspect occurs when a company's R&D team or a research institute/team in an educational organization tests the viability of a potential sanitation product/technology. Once research produces these inventions/innovations, then development progresses to transforming the discovered science into a useful product that the company can market and sell to customers, either to end-users or as input materials for secondary products (Tarver, 2020). R&D provides manufacturing with the opportunity to explore products/services for customers through careful market analysis, including the measurement of customer trends. Manufacturers can then use these reports to make peculiar products available to their customers (Tarver, 2020). On the other hand, enterprises can invest in R&D when their product lines are becoming outdated to gain and maintain competitive edge (Tarver, 2020). Several new sanitation systems (NSS) products have been developed within the last two decades in order to improve the sanitary conditions of 4.5 billion people without access to safely managed sanitation. The most recent and prominent funder for sanitation R&D is the Bill and Melinda Gates Foundation (BMGF), which initiated the 'Reinvent the Toilet Challenge' (RTTC) in 2011 that supported new research and development approaches for toilet technologies that safely and effectively managed human waste. The R&D of NSS marks a paradigm shift from end-of-pipe wastewater management systems to resource-oriented sanitation systems (Girardet & Mendonça, 2009; Koottatep *et al.*, 2021; Schuetze & Santiago-Fandiño, 2014; Tilley *et al.*, 2008). However, the major challenge remains as translating some of these new sanitation technologies from the pilot phase to real products in the marketplace for the large population that needs them.

3.3.1.2 Design

This describes the process of imagining, creating and iterating products, devices, objects, and services that solve users' sanitation problems and/or address their specific needs in a given market (IDSA, 2020). It is the collection of business activities associated with all phases of product engineering, including research and development (Wognum *et al.*, 2002; Zhu *et al.*, 2011) as well as specification, concept design, detailed and production design (Hartley *et al.*, 1997). All manufactured products must first past the design stage before they are mass produced in the factory floor and/or before they are constructed/fabricated as well as installed, especially for the end-users of the non-sewered sanitation systems commonly found in developing countries. The objective is to develop products, devices, objects, and services with designs that meet both functional and performance requirements as well as being produced at a reasonable cost with minimum technical problems at the highest possible quality in the shortest possible time (Groover, 2010). In other words, its focus is not only on the appearance of a product, but also on how it functions, is manufactured and ultimately the value and experience it provides for the users (IDSA, 2020). Design with respect to SMVC/SPVC is aimed at optimizing the functions of products, devices, objects, and services and minimizing the total production costs and/or achieving other settled targets (Baglieri & Secchi, 2007; Lee & Gilleard, 2002; McIvor *et al.*, 2000, 2006; McIvor & Humphreys, 2004; Zhu *et al.*, 2011). Product design passes through four major stages, namely:

(1) *concept design* – where product architecture contributes key ideas/concepts/critical components and establishes interfaces between products' subsystem;
(2) *specification design* – which focuses on avoiding ambiguity and information distortion, identifying early changes and key component requirements;

(3) *detailed design* – which deals with selection of proprietary parts and component tolerance design, prototype testing and demonstration, design for manufacturability, materials selection and process design; and
(4) *production design* – which looks at tooling design for manufacturability, quality control and assurance as well as raw materials consideration. (Zhu *et al.*, 2011).

Designing for improved service approaches in low-resource settings, especially for products that focus on basic needs like sanitation/hygiene and related concerns, differ from standard industrial design processes and are sometimes referred to as 'design for the bottom of the pyramid' or 'design for the developing world' (Lucena & Schneider, 2008) or 'social sector human-centred design' (Mitcham & Munoz, 2010; Sharpe *et al.*, 2019). These approaches often frame the end-beneficiary as customer, even when they are not, and retail consumers are the actual end-users. The end-user is simultaneously the subject of monitoring and recipient of the data – for feedback between product designers and other production stakeholders (Sharpe *et al.*, 2019).

Thus, the designers lead the process of product design, in order for a product to be well designed for reliability and scalability, the expertise of the designers must be multifaceted. Also, the designers must have deep knowledge of manufacturing processes in order to enable any degree of scale or even a successful pilot project. Designing products without manufacturing knowledge will result in suboptimal parts. Therefore, designers are responsible for the sustainability and safety of their designs (Mattson & Wood, 2014). It is, therefore, necessary for the designers to have knowledge about the product lifecycles and the impacts of design decisions (Sharpe *et al.*, 2019).

Furthermore, design considerations for manufacturing and assembling sanitation products should provide closer interaction and better communication between designers and manufacturing personnel. This will help smooth the transition into production, shortening the product's transition to the market by enabling fewer components in the final product, easier assembly, lower costs of production, higher product quality and greater customer satisfaction (Bakerjian & Mitchell, 1992; Chang & Melkanoff, 2005; Groover, 2010). In the end, product quality will depend on design and leaner operations (Lamming, 1993), in particular as design taps into other external relationship such as supplies, and so on (Zhu *et al.*, 2011).

3.3.1.3 Sourcing of inputs and supplies

Inputs and supplies constitute the materials that enterprises/firms use in the process of producing final goods and services for customers. They come in the form of raw materials, upgraded raw materials and/or semi-processed goods (Florén *et al.*, 2013, 2019; UNIDO, 2011). This can also describe the activities that go into acquiring, purchasing, refining, developing and delivering sufficient amounts of raw materials of sufficient quality to ensure that the strategic and operational objectives of the firm are achieved. Efficient sourcing of raw materials and procurement of inputs can help firms reduce costs and become more competitive, as well as lower risks with fewer inputs and defects (Florén *et al.*, 2013, 2019; UNIDO, 2011). Clearly, input materials put heavy constraints on output products and if inputs are not available, the production process can be negatively affected (UNIDO, 2011). Given the importance of raw materials as the critical input and the increasing challenges related to raw materials supply, a systematic and effective approach to the management of raw materials is critical to any firm in the SMVC/SPVC (Florén *et al.*, 2013, 2019). The way manufacturing concerns deal with the raw material challenges affects both short-term operations as well as long-term opportunities. From a short-term perspective, when supplies of raw materials are smooth, operations may progress favourably, but if raw material supply is interrupted the impact on businesses is often immediate and severe (Florén *et al.*, 2013, 2019; UNIDO, 2011). On a long-term perspective, changes initiated in-house or forced by other input supply actors in the value chain could have both constraining and restraining effects on the value proposition(s) of the sanitation product to be manufactured. An example of the constraining effect on the value proposition is a change in raw material quality delivered to the market (Florén *et al*., 2013, 2019). Therefore, sourcing practices and input supply are important not only to the sanitation product manufacturer but also to those who provide them. For example, manufacturers of sanitaryware products can improve product quality, increase production and raise profitability if they maintain transparent and reliable contractual relationships with buyers (UNIDO, 2011).

3.3.1.4 Production

This covers any of the methods used in industry to create goods and services from various resources. It is aimed at converting raw materials into finished goods with the application of different types of tools, equipment, and machinery. It covers the capacity of firms in the value chain to match with their physical installations, machines, equipment and space for production and their ability to extend those in the short run as well as the quality of the final product and the time that is required to finish this product. The objective of production is to satisfy the demand for such finished goods and services. All production systems are 'transformative processes' – processes that transform raw materials into useful goods and services. The transformation process typically uses common resources such as labour, capital (for machinery and equipment, materials, etc), and space (land, building, etc.) which economists call factor of production while to effect a change. Production managers refers to them as men, machines, methods, materials and money. Generally, there are three basic types of production systems:

(I) *A project' (one-shot) system or job production* comprises a single, one-of-a-kind product whereby resources are brought together only once to work upon a single job and complete it before proceeding to the next similar or different job. It requires fixed type of layout for developing same product (Groover, 2010; Singh, 2006).

(II) *Batch production* uses general-purpose equipment and methods to produce small quantities (low in number, say 200 to 800) of output (goods and services) with specifications that vary greatly from one batch to the next. Whenever the production batch is over, the same manufacturing facility is used for production of other batch product or items (Groover, 2010; Singh, 2006).

(III) *Continuous production (mass production)* in which items to be processed flow through a series of steps and/or operations; it involves production of a large number of identical products (say more than 5000) that need a production-line plant layout. It is highly rigid and involves automation and a large amount of investment in special-purpose machines to increase production (Groover, 2010; Singh, 2006).

A production system includes both automated and manually operated systems. The distinction between the two categories is not always clear because many manufacturing systems consist of both automated and manual work elements, for example, a machine tool that operates on a semi-automatic processing cycle but also must be loaded and unloaded each cycle by a human worker (Groover, 2010; Singh, 2006).

3.3.1.4.1 Manufactured sanitation equipment and allied products (MSEaP)

MSEaP are industrially manufactured finished sanitation and related products and/or parts material for the production of other secondary products such as sanitaryware, personal, home, healthcare, and industrial hygiene and sanitizers. Sanitaryware products are sanitary appliances found in installations, such as toilets and bathrooms. In the narrowest sense, it could include water closet bowls (WC), cisterns, bidets, urinals and washbasins (and sometimes sewerage pipes that have traditionally been manufactured from porcelain (a ceramic material made from clay, sometimes described as 'vitreous china' when coated with enamel), see Figure 3.2.

Sanitary appliances are now made from a wide range of materials including metal, acrylic, glass, plastic and so on. In addition, they also now include a wider range of appliances that might be found in sanitary installations such as baths, showers, bins, incinerators, macerators, sinks, bidets and drinking fountains. Some such appliances are not even connected to water and wastewater systems, for example a composting toilet or drain or waterless urinal (Designing Building Wiki, 2021).

Toilets are critical user-interface components and essential plumbing fixtures that are installed everywhere – in residences, businesses, commercial facilities and others. They come in a variety of styles and types such as one- and two-piece units, floor-mounted and wall-mounted toilets, tank and tankless styles, top flush, side flush, or rear flush, round bowl or elongated bowl and so on. There are also toilets for specialized applications, for example, installations in aircraft, boats, and other vehicles such as buses and trains. Besides stationary toilets, there are markets for portable toilets that serve temporary or short-term needs such as construction sites, movie sets, campgrounds, marathons, or natural zones (Figure 3.3).

Table 3.2 shows the list of top manufacturers of toilets used in the USA (listed alphabetically). The table shows the company name, location, and estimated annual revenue, where data was available. Annual revenue amounts are shown in US dollars. Revenue values denoted in foreign currencies were converted to US dollars using exchange rates as of 8 April 2020 (Thomas Publishing Company, 2021).

Figure 3.2 Ceramic sanitaryware casting industrial assembly. (Source: Fortuna, A., Fortuna, D. M., and Martini, E. (2017) An industrial approach to ceramics: sanitaryware. *Plinius,* **43**, 138–145).

Figure 3.3 Ceramic toilet types and their manufacturer (a) American Standard H2Option; (b) Toto Drake II; (c) Kohler Santa Rosa (Thomas Publishing Company, 2021).

Table 3.2 Top global value chain manufacturers of water closet toilets (Thomas Publishing Company, 2021).

Company Name	City, State Location	Estimated Annual Revenue
American Standard	Piscataway, NJ	$1.5 billion
Delta Faucet	Indianapolis, IN	$570 million
Duravit	Hornberg, Germany	$494.2 million
Kohler	Kohler, WI	$7 billion
Mansfield Plumbing	Perrysville, OH	$51.8 million
Niagara Corp.	Flower Mound, TX	$75 million
PROFLO® (Ferguson)	Newport News, VA	$18.4 billion
Saniflo	Edison, NJ	$48.6 million
Sloan Valve Company	Franklin Park, IL	$2.9 million
Toto	Kitakyushu, Japan	$5.39 billion
Zurn Industries	Milwaukee, WI	$131.5 million

Company Summaries

(I) *American Standard,* based in Piscataway, NJ, is a major manufacturer of bathroom and kitchen fixtures including sinks, faucets, and toilets for both residential and commercial applications.

(II) *Delta Faucet* is a US-based provider of sink faucets, shower fixtures, kitchen faucets, toilets, and bathroom accessories. They are headquartered in Indianapolis, IN.

(III) *Duravit*, headquartered in Hornberg, Germany, is a global manufacturer of sinks, shower trays, toilets, bathtubs, and bathroom accessories.

(IV) ***Kohler***, based in Kohler, WI, is a leading manufacturer of kitchen and bath products including toilets, sinks, faucets, and decorative products.

(V) *Mansfield Plumbing,* of Perrysville, OH, is a manufacturer of lavatories, bidets, toilets, urinals, and other bathroom products for residential and commercial applications.

(VI) *Niagara Corp.* is a manufacturer of products designed to conserve water resources, including toilets, showerheads, and water aerators. They are headquartered in Flower Mound, TX.

(VII) *PROFLO®* (Ferguson) is a wholesale supplier and distributor of commercial and residential plumbing supplies and owns the PROFLO® brand of toilets. They are headquartered in Newport News, VA.

(VIII) ***Saniflo,*** located in Edison, NJ, is a manufacturer of toilets and macerating and grinding pump systems for both residential and commercial applications.

(IX) ***Sloan Valve Company***, headquartered in Franklin Park, IL, is a manufacturer of bathroom fixtures, flushometers, water closets, sinks, faucets, hand dryers, and other bathroom and plumbing accessories.

(X) ***Toto*** is a global manufacturer of toilets, lavatories, faucets, bidets, toilet seats, and showers for residential and commercial use. They are headquartered in Kitakyushu, Japan.

(XI) ***Zurn Industries***, headquartered in Milwaukee, WI, is a manufacturer and supplier of plumbing fixtures, water control and safety products, building drainage products, and grease, oil, and sediment separation solutions for commercial and residential applications.

On the other hand, a dry toilet forms a contrast with the wet toilet (water closet) presented above because it operates without flushwater. The dry toilet may be a raised pedestal on which the user can sit, or a squat pan over which the user squats. In both cases, excreta (urine and faeces) fall through a drop hole (Tilley *et al.*, 2014). A classic example of dry toilets is the composting toilet (Figure 3.4) that uses a predominantly aerobic processing system to treat excreta using no water or only a small volume of flush water, via compositing or managed aerobic decomposition (Kubba, 2017).

Several types of manufactured sanitation-related products for hygiene purposes exist in the market and some good examples are:

(I) Disposable super-absorbent hygiene products that promote cleanliness by containing bodily fluid and excreta often used for infants and adults in institutional settings and allowing the waste to be disposed of in appropriate ways. In addition to providing skin protection benefits, disposable super-absorbent diaper products provide better containment of excreta and reduce the environmental spread of pathogenic organisms. This category also includes female hygiene products for menstrual flow management.

(II) Some healthcare/hygiene products, usually also available over the counter, are normally used for to prevent infection and transmission of diseases, provide hygiene, and enhance care in the hospital ward and operating room.

(III) Personal hygiene products such as bath soaps and gels, shampoos/conditioners, toothpaste/mouthwash, and their dispensers and so on, are classified according to the health risks they may present.

(IV) Cleaning, hygiene and disinfectant products are critical to help combat and/or prevent the spread of pathogens to humans and animals and are used in households or in professional and institutional environments such as hospitals, homes for the elderly and food factories, and so on.

These products result from value-added activities that collect integrated equipment and human resources to convert semi-finished products or raw materials into finished products (Groover, 2010; Singh, 2006). Sanitation manufacturing basically implies making goods or articles and providing services to meet the sanitation needs of mankind through value creations that apply support systems used by firms to solve inherent

Figure 3.4 Schematic of a composting toilet with urine diversion (Source: Wikipedia contributors, 31 December 2020).

problems with production, supply and delivery to the end-users in order to ensure quality (Groover, 2010). The enterprises involved in the production and supply processes here make up part of the SMPVC.

3.3.1.4.2 Prefabricated concrete/plastic products

This is the use of pre-cast concrete and/or plastic components for off-site fabrication of toilet/latrine products, which can be turnkey and/or component parts for the construction of toilet/latrine systems. These products range from those pre-cast by local masons who use concrete to construct toilet products for user-interfaces such as concrete slabs for latrines/toilets, pedestals, pans or urinals and biogas receptacles as well as containment systems (septic tanks). More sophisticated prefab toilet components are produced on factory floors and assembled at construction sites (Rahman *et al.*, 2013). The fully assembled prefab toilets are designed, coordinated and tested in advance under controlled factory production environments. Prefabrication technology that is conceptualized at early design stage provides significant advantages over conventional *in situ* (cast-in-place) systems such as reduction in construction time, less skilled labour requirements and construction cost savings as well as improved service delivery (Rahman *et al.*, 2013).

Prefabrication of concrete and/or plastic latrine/toilet slabs is becoming a popular way to encourage private sector investment in the provision of value-added sanitation infrastructure, which entails but is not limited to new products development, procurement of inputs materials, production, marketing, distribution, finance and customer service that can support faster toilet construction, especially during emergencies (CAWST, 2014; Harvey, 2007; Holm *et al.*, 2018; Mchenga & Holm, 2019; WEDC, 2012). Value is typically added beyond material/information aggregation by fabricating some key toilet substructures and interface components (e.g. concrete pit rings, slabs with integrated pan) to provide customer value through ready-to-install packages. In addition, services related to the substructure – such as delivery or installation of the substructure and/or materials for the superstructure – are optional add-ons (USAID, 2018). The most commonly prefabricated latrine slab design available on the market in most developing countries, particularly in sub-Saharan Africa, are pre-cast slabs that come shaped either as a flat square or a circular dome (Mchenga & Holm, 2019; WEDC, 2012). The slabs in most cases have additional holes to accommodate the vent pipes and covered with fly-proof screens in the case of ventilated improved pit latrines (Mchenga & Holm, 2019), see Figure 3.5a and b. Also, the use of pre-cast slabs provides a market for those engaged in small-scale emptying and/or conveyance transport equipment to provide services for onsite sanitation systems.

Research and development on innovative offsite prefabrication for toilet construction in countries like Malayasia and Singapore could help change people's perceptions so that toilet are considered as not just a space for basic sanitation but also a space of comfort and luxury. Off-site produced toilets are seen as a revolutionary approach to toilet construction that will replace the conventional labour-intensive and time-consuming *in situ* toilet. Prefabricated toilet systems are commonly used in shipbuilding, aircraft industries and even in buildings design in some developed countries (Rahman *et al.*, 2013). The two most common prefab toilets available in the market are:

(I) lightweight panel systems that can be assembled and disassembled on site; and
(II) pre-assembled systems whereby a complex box with fittings and accessories is assembled in the factory and delivered to site for installation.

Both systems can be further categorized based on the material in which it is used. The floor materials could be pre-cast concrete or moulded fiberglass, while the wall materials can be fibre-cement board, ferro-cement board or pre-cast concrete panels (Rahman *et al.* 2013), see Figure 3.6.

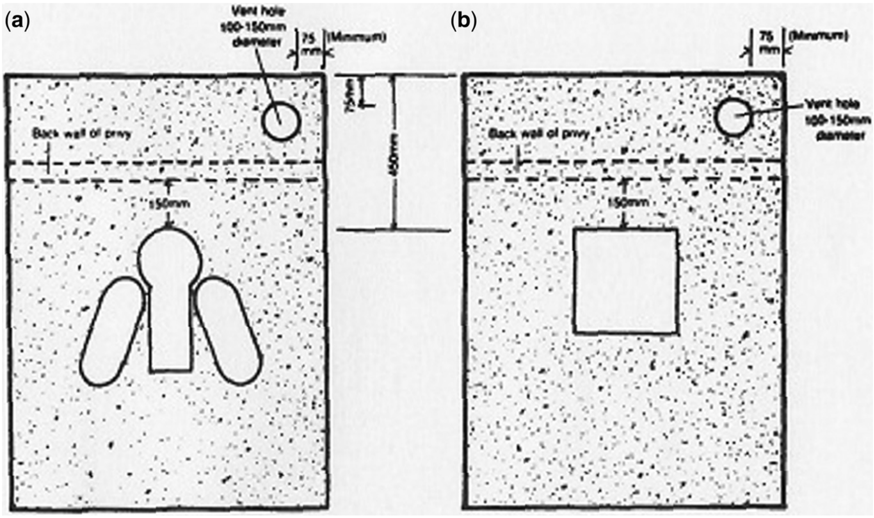

Figure 3.5 (a) Top view of circular and square pre-cast toilet/latrine slabs (Source: http://www.clean-water-for-laymen.com). (b) Pre-cast concrete and galvanized metal pour-flush bowls for squatting slabs (Source: http://www.clean-water-for-laymen.com).

Figure 3.6 Illustration of pre-cast concrete toilet and HDPE plastic portable flush toilet (Source: Toppla Toilet, China). (a) pre-cast concrete toilet. (b) HDPE Plastic portable flush toilet, Toppla Toilet, China.

(a) (b)

Figure 3.7 Prefabricated plastic and precast concrete septic tanks (Source: https://theconstructor.org). (a) Prefabricated plastic septic tank; (b) Precast concrete septic tank.

The manufacturing of industrial prefabricated concrete/plastic septic tanks has been found to be more cost-effective and durable than the conventional *in situ* tanks designed and installed to receive partially treated raw domestic sewage/faecal sludge and wastewater (USEPA, 2018). The prefabricated structures last longer, take half the effort to install and lower the overall septic tank cost. If properly designed and manufactured, they do not leak like the conventional ones (Figure 3.7).

Consequently, all enterprises and businesses involved in the production of these artefacts are lined up on the value chain to improve the quality of precast sanitation products and services (Cutler & Frank, 2010). Studies have also shown that pre-cast concrete septic tanks are durable and can last for several decades, are very resistant to cracking and are generally watertight throughout their lifespan – an advantage they have over the conventional septic tanks (Rahman *et al*. 2013). Manufacturers and suppliers of these products and their component parts also form part of the SMPVC.

3.3.1.4.3 In-situ constructed products

There are also businesses/enterprises and/or private individuals involved in the SMPVC that provide *in situ* construction products and services to toilet/latrine users, especially local masons. The mason as a production enterprise provides low-income households with access to safely managed sanitation products. They also provide more affordable and desirable products to traditionally un-served consumers. The masons engage in both the supply and value chain and work within the networks of producers, receive materials from several suppliers, and then deliver final products to the end-users (USAID, 2018), see Figures 3.8 and 3.9.

This is the most common way sanitation infrastructure and/or facilities are provided in most developing countries via the construction of substructures and superstructures. While the substructure provides safe disposal or reuse of human wastes, the superstructure is meant to provide privacy of the toilets. Designing an *in situ* toilet/latrine involves site selection, calculating the size of the vault, and determining the labour, materials, and tools needed for construction. *In situ* reinforced concrete (IRC) is still the preferred method for construction for toilets, especially the whole toilet supporting structural elements such as columns, beams and slabs (Rahman *et al*., 2013).

Figure 3.8 In-situ block work septic tank by local mason (Source: https://niwa.co.nz).

Figure 3.9 Example of *in situ* toilet/latrine construction by local mason: five stance lined pit latrine at Kisomoro Primary School, Uganda (Photo by Rutenta Allan, Source: https://rsr.akvo.org/fr/project/3890/update/19237).

3.3.1.5 Distribution/route to market

is the process of storing and distributing the finished products for sale (Porter, 1985) as well as the place where the products on the value chain will be sold without further transformation (M4P, 2008; UNIDO, 2011). The distribution route to market include planning and dispatch, distribution management, transportation, warehousing; promotion management; domestic sales such as products sold to traders, wholesalers and retailers or directly to the customers (Acharyulu *et al*., 2015); all of which make up a major part of the SMVC. The primary objective here is to ensure that the products reach the clients/customer in an efficient and effective manner, thereby ensuring satisfied customers and increased sales growth (M4P, 2008; UNIDO, 2011). The manufacturing firms in the value chain need to consider end-market demands, not only to determine how best to sell products, but also to understand the nature and quality of the products that they will be able to sell in the future as well as the barriers that can prevent them from entering markets and selling their products. Such barriers include trade regulations, standards and export restrictions, as well as the market power of competitors (M4P, 2008; UNIDO, 2011). Other major challenges in the sanitation products marketing is that most businesses in the value chain do not interact directly with the end-consumers of their products and in most cases the 'sanitation professionals' do not consider the main producers of sanitation and related products and the building/construction industries as part of the main actors that can accelerate the race towards SDG 6. Often there are a range of intermediaries, exporters, importers, wholesale distributors, retailers, services providers and brokers involved in marketing and trade. In other cases large manufacturers may deal with retailers directly, but rarely with the consumers (M4P, 2008; UNIDO, 2011).

3.3.1.6 End-users/customers

Manufactured products value chain is inherently dependent on the satisfaction it provides to end-users/consumers (Ellis *et al.*, 2019). Understanding the consumer's defined value in satisfaction and the process in which it is attained can aid in increased value creation through process optimization and product development (Ellis *et al.*, 2019). Thus, sanitation and related commodity producers should pay more attention to the preferences and needs of individual customers/end-users and serve them differently according to their importance and value through products, information and transaction customization (tailoring of products and services to customers' individual needs) (Cho & Lau, 2014; Syam *et al.*, 2005). Studies should be conducted from consumer perspectives in the quest to provide more value to the end-users of these products (Dekker, 2003; Zokaei & Simons, 2006). The consumer should be viewed as the starting point of the entire process because the producers and suppliers are rewarded not only for providing a product but for the performance of the activities in providing the product. Demand drives the market and thus production, processing, and market approaches should focus on consumer needs (Christopher, 1998). The end-users demonstrate appreciation of value for a product by the willingness to pay and it is essential to note that the product is being purchased to derive a more direct value or satisfaction. Consumers usually perceive value more differently than the products actual monetary value thus need to assess value beyond price by evaluating end-user consumption chain (Ellis *et al.*, 2019). It is increasingly apparent that end-users are key to the success of sanitation and its related products value chain, especially when new well-designed sanitation technological products fail because they do not fit the standards of comfort the end-users uphold or were incompatible with cultural beliefs or religious codes (Koottatep *et al.*, 2019b). Domestic end-users are vital to co-producers of change in sanitation if they are taken seriously as system users and invited to rethink sanitation practice (Hegger *et al.*, 2007; Spaargaren *et al.*, 2007; van Vliet *et al.*, 2011).

3.3.1.7 After sale services

are set of activities taking place after purchase of the product, devoted to supporting customers in the usage and disposal stage of that product (Rolstadaas *et al.*, 2008; Saccani *et al.*, 2007). These services may include but are not limited to assembly, installation and operations activities designed to provide support engineering and construction services for the installation of treatment and user-interface equipment ranging from simple networks to highly complex treatment facilities (PWC, 2012). Also, aftermarket business and after-sales service processes play an integral role in many sanitation manufacturing and service concerns of the container-based sanitation enterprises and other innovative smart sanitation products in the market as well as in wastewater, sewage and faecal sludge treatment plants. These equipment producers/providers have used the expertise they acquired in a particular technology to lay claim to act as integrators, installers, and operators often in the sphere of treatment facility activities. In recent times, the application of technologies like desalination has enabled a number of production and construction companies to develop operator-type skills (PWC, 2012). After-market which often refers to downstream value chain businesses is four to five times larger than the original sanitation equipment businesses (Cohen *et al.*, 2006). After sale services can be in form of:

(I) Field and online support services performed directly at customers' sites or via online connections; onsite fault elimination, remote monitoring, management of call desks and helpdesks; and on-call services, reliability solutions;
(II) Repair services that are performed along the sanitation service chain (repair and calibration); and
(III) Logistics services to support and/or optimise customers service processes such as spare parts management, supply of instruments and tools (Rolstadaas *et al.*, 2008; Saccani *et al.*, 2007).

Also, after-sale services can be a way to encourage people to buy the product in the first place and could influence future sales.

3.3.2 SMPVC supporting activities

SMPVC supporting activities are services and/or activities that are not directly involved in the conversion process but support the primary/main activities in their function. They allow the proper operations of the primary activities. The supporting services are categorized into four and they include:

(I) Infrastructure that consists of many services to facilitate production such as general management, planning, finance, legal, and external affairs;
(II) Human resource provides skilled personnel, premises and plant information technology and systems. It also deals with recruitment, hiring and training, developing, rewarding and sanctioning people in the organization;
(III) Technology defines product characteristics and is concerned with the equipment, hardware, software, technical skills used by a firm to transform inputs to outputs and supporting limited activities of businesses, such as accounting, and so on; and
(IV) Procurement manages supplier relationships and is concerned with the acquisition of inputs or resources for smooth production processes (Acharyulu *et al.*, 2015; Porter, 1985).

The goal is to ensure that the primary manufacturing value chain is effective and efficient to the extent that if it is done well, the production enterprises can increase the value-added and margin of the value output over cost in input (McLeod, 2012).

3.4 PRODUCT QUALITY AND STANDARDS

Product quality is an important aspect in value chain development because the quality of a marketable good is not just about product features but also the processes that occur in the value chain (Springer-Heinzer, 2018). Apart from the intrinsic aspects of product quality such as the materials used and the processing quality, the characteristic of business processes count: resource efficiency, the technologies used, conditions of employment and other factors all contribute to the quality of the product. There are two quality aspects of manufactured products:

(I) Product features which depict the characteristics of the product that result from design. These are the functional and aesthetic features of the product intended to appeal and provide satisfaction to the customer. The sum of a product feature is usually referred to as 'grade' (Evans & Lindsay, 2005; Groover, 2010; Juran & Gryna, 1993); and
(II) Free from deficiencies which means that the product does what it is supposed to do (within the limitations of the design feature), that is absent of defects and out-of-tolerance conditions, and that no parts are missing.

This aspect of quality includes components and sub-assemblies of the products as well as the product itself (Evans & Lindsay, 2005; Groover, 2010; Juran & Gryna, 1993). Quality benchmarks of products can be grouped into four major parts:

(I) Legal requirements regulating the minimum level of product safety;
(II) Industry-specific technical norms and quality grades facilitating contracts;
(III) Quality criteria defined by individual enterprises to position a product in the market; and
(IV) Sustainability standards on a wide variety of issues of social and political interests.

The first two points constitute the basic rules of any kind of business activities. Every enterprise first has to comply with the current laws and regulations, both in the country of production and in the country where the product is to be sold. Technical norms and grades are necessary to facilitate business linkages (Springer-Heinzer, 2018). Product simplification and standardization is required to achieve a higher efficiency in production, better quality and reduced production cost. Simplification is a process of determining limited number of grades, types and sizes of components or products or parts in order to achieve better quality control, minimize waste, simplify production and, thus, reduce cost of production. By eliminating unnecessary varieties, sizes and designs, simplification leads to manufacturing of identical components or products for ease of interchangeability and maintenance purposes during parts assembling.

Standardization techniques include the determination of the optimal manufacturing processes, identifying the best possible engineering materials, and allied techniques for products and services as well as adhering to very strict and better standards (Groover, 2010; Singh, 2006). Thus, definite standards are set up for a specified product with respect to its quality requirement, equipment and machinery, labour, material, processes and the cost of production (Singh, 2006). In other words, standards are a set of rules describing product and process quality as well as documents established by consensus and approved by a recognized body to provide for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at achieving optimum degree of order in a given context (Springer-Heinzer, 2018). The players involved in all these aspects also feed the SMVC to ensure that the sanitation products and services (that these products provide) meet standard and acceptable quality.

3.5 DISRUPTIVE INNOVATION

Lack of safely managed sanitation in developing countries and aging sanitation infrastructure as well as budget constraints in developed countries are increasing pressure on governments to find new solutions to old and new problems. New suites of technologies could improve sanitation and provide viable alternatives to traditional toilets, septic tanks and sewerage systems. Some disruptive innovative ways to remove pathogens from human waste includes among others:

(I) Wet oxidation (where materials suspended in water are broken down using oxygen);
(II) Dry combustion (where human waste is converted to charcoal briquette instead of flushing it away with water);
(III) Electrochemical processing (that makes use of metal oxides);
(IV) The uniquely solar septic tank (modified conventional septic tank with a solar-heated water system to create higher temperature than ambient inside the septic tank) (AIT, 2015 – Figure 3.10).

The blue diversion toilet (essentially a urine diverting dry toilet improved with a separate water cycle (blue) diversion for hand-washing, anal cleansing, menstrual hygiene and flushing of the front compartment) is being developed as a way to make sanitation sustainable, safe, accessible, and affordable (Tobias *et al.*, 2017 – Figure 3.11).

Other prototypes tested are the non-fluid pedestal incorporated mechanical flush toilet system, which is activated by moving the toilet lid and then a gear connects the lid to a rotating bowl that turns downward as the lid is closed. A swipe situated inside the pedestal is connected to the bowl-lid-gear-system. As the bowl rotates, the swipe moves downwards, clearing remaining faeces out of the bowl. This mechanism acts as a barrier for visual and olfactory irritation of the user (Figure 3.12).

The effort to unlock the potential of these solutions is in its earliest stages, and many technologies are still under development and this market is estimated to be worth around $6bn annually by 2030. Many of the new sanitation technologies have emerged from the 'Reinvent the Toilet Challenge', an initiative of the Bill & Melinda Gates

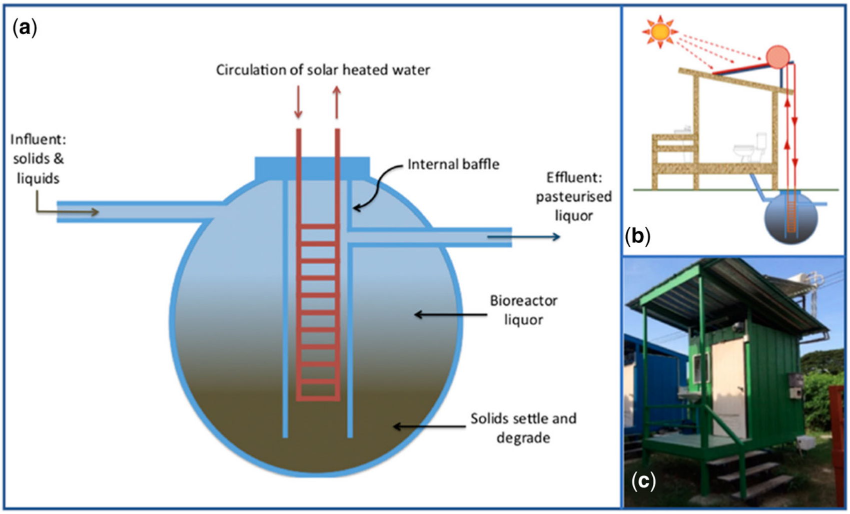

Figure 3.10 Schematic (a) illustrates the principle of the solar heating applied to the SST in contrast to the CT which operates at ambient temperature and without an internal baffle. Schematic (b) illustrates the installation of the SST at the field test site, showing the buried septic tank and the solar collection unit on the roof of the served toilet block seen in the photograph. (From Connelly *et al.* (2019) Under CCA 4.0 license, © 2019 by the authors).

Figure 3.11 The working model of the Blue Diversion Toilet as used in the Kampala field test. The water wall contains the water tanks and bio-reactor. The metallic tube (labelled ventilation) is part of the active ventilation of the faeces compartment to prevent odour. (From Tobias *et al.* (2017) under CCA 4.0 license, © 2016 by the authors.)

(**a**) (**b**)

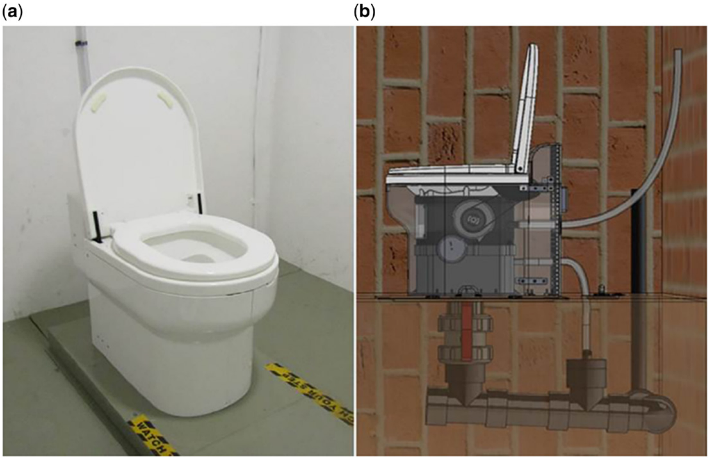

Figure 3.12 (a) Prototype pedestal with mechanical waterless flush, installed in a dedicated toilet room adjacent to the laboratories of the Pollution Research Group at the University of KwaZulu-Natal; (b) schematic of the installation: the pedestal is connected to the sewer mains and has a ventilation pipe from inside the unit; the gear system is shown to be on the side of the pedestal, underneath the cover. (From Hennigs *et al.* (2019) under the CCA 4.0 license, © 2019 by the authors).

Foundation (BMGF) launched in 2011, which funded innovators developing alternative sanitation technological solutions for the urban poor living on less than $2 a day. BMGF called for high user comfort, zero emissions to the environment, on-site solutions for resource recovery, and low costs of $0.05 per person per day. The costs are comparable to the lifecycle costs of community-based sanitation solutions with simple anaerobic technologies reported for Indonesia which stand at $0.05 per person per day (Tobias *et al.*, 2017).

Also, many of the systems are being designed to operate off the grid without connections to water and sewer systems or electrical lines. This means that sanitation solutions could be installed in parts of the world lacking access to power supply and other infrastructure. With modular, portable, easy-to-install formats, they could allow for increase in use as populations expand and make it possible to extend safe sanitation to remote locations where sewage or septic tanks might not be feasible. These promising innovative sanitation technologies can be deployed in both developing and developed countries, and the size of the opportunity varies depending on the setting. In developed countries that are building on current sanitation infrastructure, a potential market exists of about $1.7bn annually, while emerging economies with high needs, market readiness, and national policies prioritizing improvement in sanitation offer a $3.2bn opportunity.

3.6 CASE OF SOME EXAMPLES OF SANITATION AND RELATED PRODUCTS

3.6.1 Sanitaryware products

The product categories of sanitaryware are highly diversified as typical products include bidets, pedestals, sinks, showers, tanks, flush toilets and wash basins and the weights of these products range from 7.6 kg to 39.5 kg per piece (Lv *et al.*, 2019). The world ceramic sanitaryware production is estimated to grow from $32.1bn in 2020 to $44.6bn by 2025 (Research and Markets, 2021) (Figure 3.13). Toilet sinks/water closets (*water closet is defined as the cistern, bowl and plastic/metal attachments used to connect to the plumbing supply*) is projected to account for the largest share of the overall ceramic sanitary ware market in terms of value between 2020 and 2025.

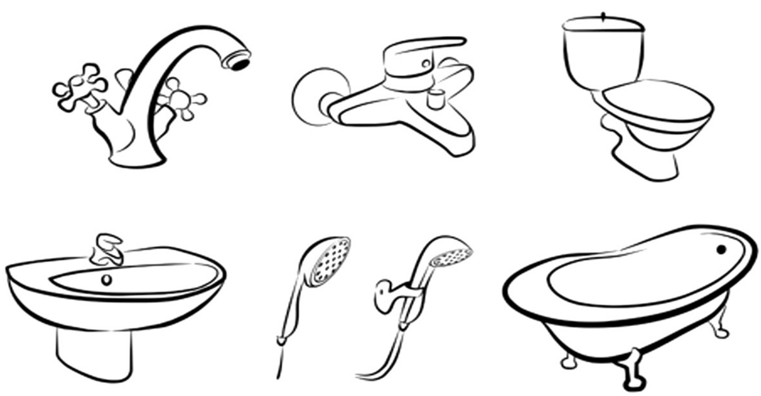

Figure 3.13 Illustration of ceramic sanitaryware products (Source: https://www.pinterest.com).

This is because of the awareness and activities created during the era of the MDGs and now the SDGs have led to increased demand for safely managed sanitation in most developing countries (Research and Markets, 2021) and could be responsible for the most significant growth of the sanitaryware production market being seen in Africa (+300%), the middle East (+181%) and South America (+163.7%). The latter region is driven by Brazil as the world's second largest producer country (24 million pieces) while China in particular is the world's largest producer and has almost doubled its volumes to reach an estimated 120 million pieces (MECS-Acimac Research Department, 2017). According to European data, sanitaryware production is estimated to be about 350 million pieces per year and total sales close to €18 billion in 2016 (Silvestri *et al.*, 2020). Also, a country like India is taking initiatives under its Swachh Bharat Abhiyan program to build public toilets in rural areas (*see section 8.4.2*) and increase their production capacity of ceramic sanitaryware products.

On the other hand, the uses and patronage of foreign manufactured ceramic water closet are high in Nigeria, and supply is met through importation despite an abundance of ceramic raw materials locally. Research shows that Nigeria ranks 13th among the world's consumers of ceramic products, mostly ceramic water closets (Elakhame *et al.*, 2020; Research and Markets, 2021). The inadequate development of the ceramic sanitaryware value chain in Nigeria is due to the lack of product development raw with the available ceramic raw materials and support industry as well as an absence of skilled manpower such as ceramic designers, engineers, scientists and/or technologies (Elakhame *et al.*, 2020). With a population of over 200 million, Nigeria would be a huge market for locally manufactured sanitation products, which would then be affordable.

Manufacturing processes for sanitaryware are similar to common ceramic products. These sanitation products help meet the increasing demand for safely managed sanitation facilities such as better toilets and improved sanitary ware products. The valued-added activities are a set of processes required to transform a clay slip produced by a mix of raw materials and water then stored in tanks for subsequent slip cast and this can occur in separate moulds or through the employment of pressure casting machines. After the casting process has been completed, pieces are dried allowing transportation and further processing. Ware surface are glazed by spraying and fired in a specific kiln. The colour and vibrancy are given to underline shape by an additional process. The desired colouring is obtained by using pigments (metal oxides) in combination with the glaze. Finally finished sanitaryware are tested, packed and dispatched to a storage facility (Lv *et al.*, 2019; Silvestri *et al.*, 2020; Womack & Jones, 1996. See Box 3.1).

Box 3.1: Life cycle processes of sanitary ware production (Lv *et al.*, 2019)

(I) **Raw material extraction**, raw materials are extracted from the earth via mining.
(II) **Raw material transportation**, raw materials are then transported to the plant using big trucks.
(III) **Body preparation**, slurry for body is prepared by grinding the raw materials with water in ball mills.
(IV) **Glaze preparation**, glaze is also prepared by wet grinding.
(V) **Mould preparation**, mould is made from Plaster of Paris.
(VI) **Casting**, the slurry is poured into the mould to form sanitary ware body.
(VII) **Drying**, the casted body is dried using hot air flow.
(VIII) **Glazing**, the glaze is sprayed onto the dried sanitary ware body.

(IX) **Firing**, the sanitary ware is then sent to kiln for firing at a high temperature.
(X) **Packing**, the sanitary ware is packed and stored in warehouse.
(XI) **Waste treatment**, wastewater, solid wastes and air pollutants (i.e., CO_2, SO_2 and NO_X) from the production processes are treated, and part of the wastewater and solid wastes are recycled and reused.
(XII) **Delivery**, the products are distributed to domestic and overseas markets.

3.6.2 Portable toilet products

Prefabrication of toilet comes in form of portable toilets commonly used at construction sites, outdoor parking lots, and other environments where indoor plumbing is inaccessible, and at large outdoor gatherings such as concerts, fairs and recreational events (Advameg Inc., 2021). The main raw material components of the facility is light-weight sheet plastic, such as polyethylene, which forms the actual toilet unit as well as the cabana in which it is contained. A pump and holding tank form the portable sewage system. These items are fastened with assortment of screws, nails, bolts and hinges. The facility is also equipped with a chemical supply container and inlet tube (Advameg Inc., 2021) (Figure 3.14).

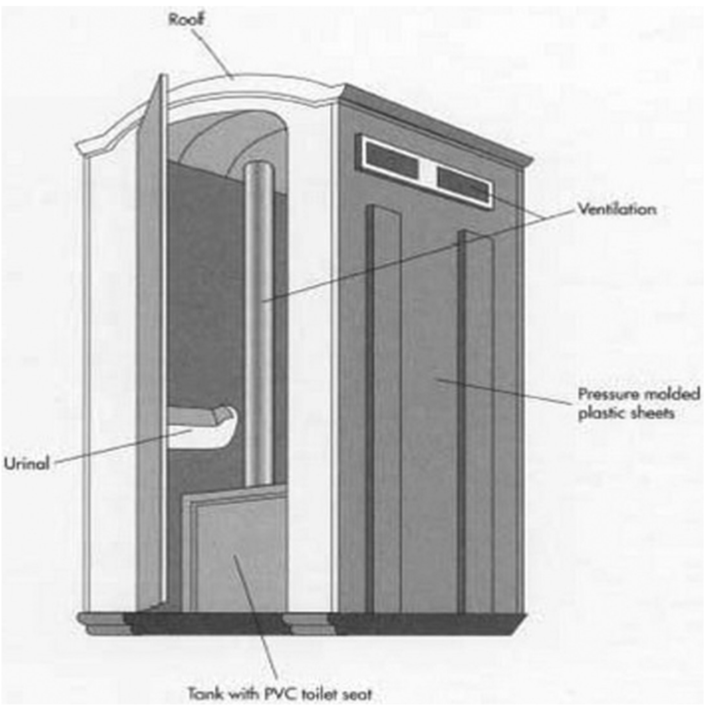

Figure 3.14 Portable toilet for outdoor events (Advameg Inc., 2021).

According to Advameg Inc. (2021), the value chain manufacturing process for the portable toilet unit comprises of the following steps:

(I) The toilet unit is formed into a box-like structure and secured with nuts, bolts, and rivets with a rigid, lightweight sheet plastic. The top sheet contains an opening for placement of the toilet tank. The top sheet may not be secured with these permanent fixtures, allowing for its easy of removal for tank cleaning. A lock is placed over the top sheet to prevent unauthorized removal.

(II) The actual toilet tank, which is placed in this unit, is made of the same material and shaped with a flat, corrugated front wall and rounded rear wall. The upper edge of the toilet tank is formed as a peripheral flange that extends outward and downward.

(III) The toilet tank is fitted with a cover of two flat semi-circular plastic sheets. The lower sheet has a peripheral edge lip that extends downward, the upper sheet has a front lip that extends downward, and the rear lip extends upward and outward to latch onto the peripheral flange of the toilet bowl. Both sheets are fitted with a central toilet opening.

(IV) A conventional toilet seat made of plastic is placed over the toilet bowl and connected to the assembly with hinges.

(V) The seat is fitted with a pin, which pushes upward against a metal wear plate, which is secured to the bottom surface of the seat. The pin extends downward through the cover and a bracket. Under the bracket, a coil spring is placed around the pin. The upper end of the coil engages a washer fastened to the pin so that the seat maintains an upright position when not in use. (Note: Not all portable toilets are flushable. Those that are not do not contain this or the following two steps in the manufacturing process, but merely contain chemicals in the holding tank).

(VI) A piston is placed underneath the lower end of the pin, and a mechanical bellows-type pump is placed beneath the piston. The pump contains a spray opening and is connected to an inlet tube which is, in turn, connected to a chemical supply container. When the seat is raised, the piston will activate the pump.

(VII) The toilet opening is fitted with a pair of flat, plastic doors secured by hinges to bosses fastened to the bottom of the tank. These doors are connected to the toilet seat with metal links so that they are activated when the seat is lowered and raised.

Portable toilets will always be necessary as long as humans continue to congregate in outdoor areas and other sites without plumbing.

3.6.3 Treatment systems' equipment and ancillary products

Treatment plants collects effluent, sewage and/or faecal sludge from domestic, municipal and industrial sources and treat same to a level of purification that enable their reuse in agriculture, industry and even as potable drinking source (Meticulous Market Research, 2020). The producers/manufacturers of treatment equipment of either material and immaterial goods range from technology providers for treatment plants and/or components manufacturers such as provision of material goods to treatment systems for sewered (sewage/wastewater) and non-sewered (faecal sludge) to an engineering service provider or software developer (provision of immaterial goods) (Bombeck *et al.*, 2013). The producers/manufacturers of treatment equipment are more complex than that for basic equipment because there are more fragmented and no equipment represents more than 10% of a given installation's value; besides barriers to entry are powerful (PWC, 2012). Such equipment can be categorised into five major types:

(I) Sewage Treatment Plants (STPs);
(II) Effluent Treatment Plants (ETPs);
(III) Activated Sludge Plants (ASPs);
(IV) Combined Effluent Treatment Plants (CEPTs); and
(V) Faecal sludge treatment plants (FSTPs).

In the case of new technology solutions that typically enjoy intellectual property protections, specialist providers can impose high prices and reap healthy profit margins from value addition. This market is expected to grow at a CAGR of 6.5% from 2019 to 2025 to reach $211.3bn by 2025 (Meticulous Market Research, 2020) because of growing focus on sewage treatment in many developed and faecal sludge treatment in developing countries. However, high costs of equipment, operations and disposal obstruct the growth of this market to some extent. In addition, aging infrastructure, excess energy consumption and rising expenditure due to excess sludge production are some of the major challenges in the sanitation treatment systems market (Meticulous Market Research, 2020). The overall sanitation treatment systems market is mainly segmented by product category such as:

(I) Treatment technologies,
(II) Delivery equipment, and
(III) Treatment chemicals, and instrumentation.

The major global players in this sector range from large international groups (from the United States, Germany, Japan, China, Switzerland, the United Kingdom, Denmark and France) with an extensive range of products to local players with generally narrower product offerings. Also, markets are often regional or even local in nature because of the variety of standards and technology solutions across areas (PWC, 2012).

3.6.4 Tissue paper products

The production of tissue paper includes all paper products used for hygienic and sanitary purposes both at home and in public places. They include toilet paper, kitchen towels, tablecloths, napkins and wipes, but toilet paper dominates the market (Masternak-Janus & Rybaczewska-Błażejowska, 2015). The global average toilet paper consumption per person reaches up to 55 kg and the global tissue paper market is expected to grow at a compound annual growth rate (CAGR) of 6.45% during 2020–2025 (Research and Markets, 2020a, 2020b). Tissue paper production globally is expected to exceed 44 million tonnes in 2021, which is an increase of more than 14 million tonnes over 2010. Among all the tissue paper products, bathroom tissue remains the key tissue category, driving the tissue paper market forward through a combination of necessity and the general westernization of toilet culture. Increased development of organic tissue paper, rising disposable income, and government policies to promote public health are also some of the major factors driving the growth of the market. Also, there is a sudden spike in the demand for tissue papers due to the ongoing spread of the COVID-19 pandemic. The manufacturers of these tissues are producing 20% more than normal levels which might strain the supply chain (Research and Markets, 2020a) Figure 3.15.

The value chain of tissue paper spreads across three main lines: entry level or first price products, branded products, and private label products. The '*entry level or first price products*' are often low-quality raw materials based and sold with minimum packaging

Figure 3.15 End-user using toilet tissue (image: Freepik.com).

(standard packs with few colour images). They are present in hard discounts while in supermarkets they are identified as 'first or best price'; the same ones can be found on hawkers' benches, local markets, suburban bazaars (Galli, 2017). The '*branded products*' are manufactured by big local and multinational companies and are internally developed and very often supported by dedicated advertising campaigns. The best techniques both for the paper production and packaging available in each company are used to design the products. The '*private label products*' which are produced by third party companies for big retailer chains requiring higher product quality comparable with the best ones in the market and used to indicate by consumer loyalty to the retailer brand as they love lower selling price as competitive advantage over branded products (Galli, 2017).

Tissue paper can be manufactured from either virgin pulp and/or recycled waste paper (Masternak-Janus & Rybaczewska-Błażejowska, 2015) and must have the following technical characteristic for customer satisfaction: softness, dry strength, wet strength and perforation efficacy (Galli, 2017). The tissue paper production from virgin materials has two basic units: the stock preparation and the paper making process in the paper machine. The stock preparation consists of the following stages: fibre refining, the removal of impurities, and finally the pulp is fed to a paper machine where it is formed and most of its properties are determined (Masternak-Janus & Rybaczewska-Błażejowska, 2015). In addition, the process of tissue paper manufactured from recycled waste paper is as follows: waste paper storage, repulping of the dry recovered waste paper, mechanical removal of impurities (screening, cleaning) and bleaching. Finally, the pulp is pumped to the storage chests that serve as a buffer between the stock preparation and paper machine (Masternak-Janus & Rybaczewska-Błażejowska, 2015; Michniewicz *et al.*, 2005).

3.6.5 Hand sanitizer

Hand disinfectants are commercially available in various types and forms such as anti-microbial soaps, water-based or alcohol-based hand sanitizer. Different types of delivery systems are also formulated – for instance, rubs, foams, or wipes (Jing *et al.*, 2020).

Figure 3.16 Various types of hand sanitizer dosage forms. (From Jing *et al.* (2020) under CCA 4.0 license, © 2020 by the authors).

The World Health Organization (WHO) recommends alcohol-based hand sanitizer (ABHS) in line with the proven advantages of their rapid action and a broad spectrum of microbicidal activity offering protection against bacteria and viruses (Jing *et al.*, 2020). The market is also witnessing an influx of bio-based or organic ingredients in hygiene products in several countries because of the awareness of the ill-effects of chemical-based hand rubs (Jing *et al.*, 2020; Research and Markets, 2020b), see Figure 3.16.

Hand sanitizers have an advantage over conventional hand-washing products as they can be applied directly without water. Also, renowned manufacturing companies such as Henkel Corporation, Unilever, and Procter and Gamble have been offering hand sanitizers in convenient packaging such as sachet and mini bottles, which can easily be carried in bags or a pockets by the consumers (Grand View Research, 2020).

The global hand sanitizer market size is valued at $2.7bn in 2019 and is expected to grow at a compound annual growth rate (CAGR) estimated by Research and Markets (2020b) of over 17% during the period 2019–2025 while Grand View Research (2020) estimated CAGR of 22.6% from 2020 to 2027. The gel-based hand sanitizer segment dominated the global market in 2019 with a share of more than 49%. Gel sanitizers are usually thin and watery in formulation and therefore provide the convenience of getting spread easily and penetrate into the skin to kill most of the bacteria. The foam-based hand sanitizer, however, is expected to dominate the market with a revenue base of CAGR of 23.1% from 2020 to 2027. The product is gaining prominence in the market owing to its ability to penetrate the skin and stay there for a longer period of time (Grand View Research, 2020).

One of the main factors contributing to the growth of hand sanitizers is the outbreak of the coronavirus (COVID-19) a global pandemic by the World Health Organization (WHO). The outbreak has reinforced the significance of regular hand sanitizing and cleaning practices among consumers and is among the prominent factors driving the market (Grand View Research, 2020; Research and Markets, 2020b). Also, the introduction of fragrance-based hand sanitizers is identified as one of the major factors responsible for the growth of the global hand sanitizer market. This innovation has offered positive dividends and has boosted the market growth. Other contributory factors to the growth of the hand sanitizer market include (Research and Markets, 2020b):

(I) Increasing influence of internet in shaping end-users purchasing behaviour;
(II) Growing demand of flavoured and organic hand sanitizers;
(III) Growth in promotional activities; and
(IV) Rise in health consciousness among consumers.

3.7 SMPVC – THE FUTURE OF SAFELY MANAGED SANITATION PRODUCTS

SMPVC are at the heart of providing safely managed sanitation and its related products and services to over 60% of the world's population without access to these vital goods and services. Proper diagnosis and understanding of the SMPVC holds the key to unlocking the bottlenecks surrounding access to sanitation products and services in most developing countries. This is based on the fact that most sanitation and other connected products and input materials are products emanate from the GVC that operates outside the shores of most of these countries with inadequate access to safely managed services. Even when they are domestically manufactured within developing countries, the operating businesses and enterprises are operated by trans-national corporation seeking cheaper labour and other resources. In the end, the costs of these products and services are beyond the reach of the vast majority of the population in these developing countries most of whom ear minimal income. For instance, some studies have shown that even when sanitation enterprises are profitable in these countries in the global South, the complexity of the business and the capital required may make its attractiveness lower than other alternatives (USAID, 2018).

The information in this chapter has shown that developing countries without access to safely managed sanitation services are not active participants in the SMPVC. This is why sanitation (USAID, 2018). In essence, it is not that sanitation businesses and enterprises cannot be market-driven or even create a sanitation economy, the barrier is in the absence of local players in the industry-sector most of the time. Considering that all sanitation management and its related products for end-use and service delivery (whether final products, semi-finished products, input materials and non-tangible services) in developing countries are commodified, even in the remotest areas of the least developed countries. These products and services are paid for by consumers as they are needed, which indicates that there is market somewhere. The challenge, then is that most of the materials needed for sanitation management are imported and by the time they get to the market, a large number of the population cannot afford them so they make do with a makeshift options. Now, if there is some domestic active level of participation of enterprises and businesses in the sanitation sector at local and national levels then affordability and acceptability will surely drive up demand and market. When home-grown players participate in the SMPVC, directly and indirectly, it will also serve as an incentive to prioritise sanitation at government and business levels with policies and laws thereby strengthening the SDG6 aspirations in developing countries.

Such a value-added network of integrated production systems will require well thought-out and coordinated value-chain governance that supports active participation of local businesses/enterprises to grow. It also requires facilitating business/enterprise linkages between the GVC and domestic investors/players to solve the challenge of access to markets for input equipment, services and their products. Moving forward will require proper diagnosis of the SMPVC to understand how actors operate and coordinate their businesses to ensure that input materials are transformed, stored, transported and reached, in certain form and quality and finally to the end-consumers. It should also look at the various effects that operations in the chain have on vulnerable groups of the society who live below the poverty level (UNIDO, 2011). The diagnosis should provide a clearer picture of (UNIDO, 2011):

(I) Who are the actors that participate in sanitation businesses across value chains?
(II) Are there actors that coordinate activities in the overall SMPVC?
(III) What are the contractual arrangements under which actors buy and sell products?

(IV) How do actors exchange information and learn about solutions to improve products and business performance?
(V) What technical, business and financial services are available to support actors in the chain?
(VI) How much value do actors add to the product in the different steps in the SMPVC, what are their costs and how is this value distributed?
(VII) What are the power relations in the SMPVC and to what extent do they determine how economic gains and risks are distributed among chain actors?
(VIII) What kinds of barriers exist for firms to enter the SMPVC?
(IX) What is the level of competitiveness of firms in the SMPVC?
(X) What bottlenecks exist and what opportunities are available for development (upgrading) of the SMPVC?
(XI) Which policies and institutions constrain/support chain actors and facilitate SMPVC development?

The results of the diagnosis can inform government officials and key stakeholders about the required interventions and which part of the SMPVC need immediate and long-term attention as well as provide insights on how those interventions should be designed (UNIDO, 2011).

3.8 Take Action

(I) Identify the major sanitation, hygiene and related products and equipment used in your area and highlight which one is sewered and non-sewered.
(II) Take an informal survey of sanitation, hygiene and related products and equipment in your city and surrounding area and then visit some of the major players.

3.9 Journal Entry

(I) List different sanitation, hygiene and products and indicate equipment and where they are found and/or used.
(II) Write short notes on innovation for sanitation products and equipment manufacturing and the impacts on the value chain.

3.10 Reflection

(I) What kind of innovation should be considered in the manufacturing of sanitation systems for transportation facilities such as air, land, rail and sea?
(II) How can mobile sanitation systems be enhanced and made attractive for urban centres in developing countries?

3.11 Guiding Questions

(I) What is a sanitation product and equipment manufacturing value chain?
(II) Why are sanitation products and equipment ubiquitous? How are they intricately linked to our survival?
(III) What is the place of value-addition in sanitation product and equipment value chain?
(IV) Describe the nature of industries/enterprises participating in the sanitation manufacturing value chain?
(V) Explain these concepts 'buyer-driven' and 'producer-driven' value chain and how they relate to the sanitation manufacturing value chain.
(VI) With the aid of a well labelled value chain map, explain the primary activities of the sanitation manufactured products value chain.
(VII) 'All production systems are transformative processes', how is this so?
(VIII) What are product quality standards? Give examples relevant to sanitation
(IX) What are the four major routes of disruptive innovative technologies?

REFERENCES

Abecassis-Moedas C. (2006). Integrating design and retail in the clothing value chain: an empirical study of the organization of design. *International Journal of Operations and Production Management*, **26**(3/4), 412–428, https://doi.org/10.1108/01443570610650567

Acharyulu S. G., Subbaiah K. V. and Rao K. N. (2015). Value chain model for steel manufacturing sector: a case study. *International Journal of Managing Value and Supply Chains (IJMVSC)*, **6**(4), 45–53. https://doi.org/10.5121/ijmvsc.2015.6404. https://aircconline.com/ijmvsc/V6N4/6415ijmvsc04.pdf (accessed 1 January 2021).

Advameg Inc. (2021). How Products Are Made. http://www.madehow.com/Volume-3/Portable-Toilet.html (accessed 18 January 2021).

AIT (Asian Institute of Technology) (2015). Innovative DEWAT technologies. Reinventing the Toilet – Progress Report 3, submitted to Bill & Melinda Gates Foundation.

Baglieri E. and Secchi R. (2007). Strategic goals and design drivers of the supplier portal: lessons from the ferrari case. *Production Planning and Control*, **18**(7), 538–547, https://doi.org/10.1080/09537280701529647

Bakerjian R. and Mitchell P. (1992). Tool and Manufacturing Engineers Handbook, 4th edn., Vol. **VI**, Design for Manufacturability. Society of Manufacturing Engineers, Dearborn, Michigan.

Bombeck M., Gregarek D., Hilbig J. and Rudolph K.-U. (2013). Integrated Water Resources Management in the "Middle Olifants" River Basin, South Africa (MOSA). Phase II Summary Report, Research Project No. 033048 A-Iz. Institute of Environmental Engineering and Management at the Witten/Herdecke University. http://www.iwrm-southafrica.de/wp-content/uploads/2020/01/2.5_Water_Market_Value_Chain_Approach.pdf (accessed 4 March 2021).

CAWST (Centre for Affordable Water and Sanitation Technology) (2014). Latrine Construction Manual. CAWST, Calgary, Canada.

Chang C-H. and Melkanoff M. A. (2005). NC Machine Programming and Software Design, 3rd edn. Prentice Hall, Inc., Upper Saddle River, New Jersey.

Chivaka R. (2007). Strategic cost management: value chain analysis approach, *Accountancy SA*, 24–27, August.

Cho V. and Lau C. (2014). An integrative framework for customizations on satisfaction: The case of an online jewelry business in China. *Journal of Service Science and Management*, **7**, 165–181. Published Online April 2014 in SciRes. https://www.scirp.org/pdf/JSSM_2014043010000976.pdf (accessed 4 March 2021).

Christopher M. (1998). Logistics and Supply Chain Management. Financial Times, London.

Cohen M. A., Agrawal N. and Agrawal V. (2006). Winning in the Aftermarket (HBR OnPoint Enhanced Edition), Harward Business Review OnPoint Article, May, 2006.

Connelly S., Pussayanavin T., Randle-Boggis R. J., Wicheansan A., Jampathong S., Keating C., Ijaz U. Z., Sloan W. T. and Koottatep T. (2019). Solar septic tank: next generation sequencing reveals effluent microbial community composition as a useful index of system performance. *Water*, **11**(12), 2660. https://doi.org/10.3390/w11122660

Cutler P. P. E. and Frank D. P. E. (2010). Watertight Precast Concrete Septic Tanks. National Precast Concrete Association / Precast Magazines / Archive – 2004–2008 / Watertight Precast Concrete Septic Tanks. https://precast.org/2010/05/watertight-precast-concrete-septic-tanks/ (accessed 18 January 2021).

Dekker H. C. (2003). Value chain analysis in interfirm relationships: a field study. *Management Accounting Research*, **14**(1), 1–23, https://doi.org/10.1016/S1044-5005(02)00067-7

Designing Building Wiki (2021). Sanitaryware. https://www.designingbuildings.co.uk/wiki/Types_of_sanitary_appliances (accessed 14 February 2021).

Elakhame Z. U., Obe Y. J., Shuaib-Babata Y. L., Bankole L. K., Omowunmi O. J., Ambali I. O., Akinsanya O. O., Unachukwu A. J., Adeyemo R. G. and Ikusedun M. (2020). Utilisation of indigenous ceramic raw materials for the production of water closet. *Journal of Minerals and Materials Characterization and Engineering*, **8**(5), 364–337, https://doi.org/10.4236/jmmce.2020.85023

Ellis E., Kwofie E. M. and Ngadi M. (2019). Value beyond price: End user value chain analysis. *Int. J. Food System Dynamics*, **10**(4), 347–360. http://centmapress.ilb.uni-bonn.de/ojs/index.php/fsd/article/view/23/908 (accessed 23 February 2021).

Evans J. R. and Lindsay W. M. (2005). The Management and Control of Quality, 6th edn. Thomson/South-Western College Publishing Company, Mason, Ohio, USA.

Florén H., Frishammar J., Lee C., Ericsson M. and Gustafsson S. (2013). A framework for raw materials management in process industries. Conference: R &D Management Conference At: Manchester, UK, June 2013. https://www.researchgate.net/publication/256079372_A_framework_for_raw_materials_management_in_process_industries (accessed 6 January 2021).

Florén H., Frishammar J., Löf A. and Ericsson M. (2019). Raw materials management in iron and steelmaking firms. *Mineral Economics*, **32**, 39–47. https://doi.org/10.1007/s13563-018-0158-7

Fortuna A., Fortuna D. M. and Martini E. (2017). An industrial approach to ceramics: sanitaryware. *Plinius*, **43**. https://www.socminpet.it/dwl.php?file=files/download/vol-43/fortuna.pdf. (accessed 22 January 2022).

Galli E. (2017). Introduction to process and properties of tissue paper. 138–145. https://www.tecnicelpa.com/files/20171013_EnricoGalli.pdf (accessed 24 February 2021).

Gasiorowski-Denis E. (2018). ISO focus highlights water and sanitation for UN Decade of Action. *ISO Focus*. https://www.iso.org/news/ref2256.html (accessed 22 February 2018).

Gereffi G. and Fernandez-Stark K. (2011). Global Value Chain Analysis: A Primer. Published by the Center on Globalization, Governance & Competitiveness (CGGC) Duke University Durham, North Carolina, USA, https://www.researchgate.net/publication/265892395_Global_Value_Chain_Analysis_A_Primer (accessed 13 February 2021).

Girardet H. and Mendonça M. A. (2009). Renewable World: Energy, Ecology, Equality. Green Books, Cambridge, UK, p. 256.

Grand View Research (2020). Hand Sanitizer Market Size, Share & Trends Analysis Report By Product (Gel, Foam, Liquid), By Distribution Channel (Hypermarket & Supermarket, Drug Store, Specialty Store, Online), By Region, And Segment Forecasts, 2020–2027. https://www.grandviewresearch.com/industry-analysis/hand-sanitizer-market#:~:text=Report%20Overview,22.6%25%20from%202020%20to%202027.&text=The%2077.0%25%20population%20in%20the,and%2062.5%25%20of%20female%20users (accessed 28 February 2021).

Groover M. P. (2010). Fundamentals of Modern Manufacturing: Materials, Processes, and Systems. John Wiley and Sons, New York, USA. ISBN 978-0470-467002.

Hartley J. L., Meredith J. R., McCutcheon D. and Kamath E. R. (1997). Suppliers' contributions to product development: An exploratory study. *International Journal of Engineering Management*, **44**(3), 258–267.

Harvey P. A. (2007). Excreta Disposal in Emergencies: A Field Manual. Water, Engineering and Development Centre, Loughborough University, Loughborough, UK.

Hegger D. L. T., van Vliet J. and van Vliet B. J. M. (2007). Niche management and its contribution to regime change: the case of innovation in sanitation. *Technology Analysis and Strategic Management*, **19**, 729–746, https://doi.org/10.1080/09537320701711215

Hellin J. and Meijer M. (2006). Guidelines for Value Chain Analysis. Food and Agriculture Organization (FAO), UN Agricultural Development Economics Division, Rome.

Hennigs J., Ravndal K. T., Blose T., Toolaram A., Sindall R. C., Barrington D., Collins M., Engineer B., Kolios L. J., 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

Holm R. H., Kamangira A., Tembo M., Kasulo V., Kandaya H., Gijs Van Enk P. and Velzeboer A. (2018). Sanitation service delivery in smaller urban areas (Mzuzu and Karonga, Malawi). *Environment & Urbanization*. **30**(2): 597–612. https://doi.org/10.1177/ 0956247818766495

IDSA (Industrial Designers Society of America) (2020). What Is Industrial Design? https://www.idsa.org/what-industrial-design (accessed 05 January 2021).

Jing J. L. J., Pei Yi T., Bose R. J. C., McCarthy J. R., Tharmalingam N. and Madheswaran T. (2020). Hand sanitizers: A review on formulation aspects, adverse effects, and regulations. *International Journal of Environmental Research and Public Health*, **17**, 3326. https://doi.org/10.3390/ijerph17093326

Jones L., Demirkaya M. and Bethmann E. (2019). Global value chain analysis: concepts and approaches. *Journal of International Commerce and Economics*, 1–29. https://www.usitc.gov/journals/jice_home.htm (accessed 05 January 2021)

Juran J. M. and Gryna F. M. (1993). Quality Planning and Analysis, 3rd edn. McGraw-Hill, New York, USA.

Koottatep T., Cookey P. E. and Polprasert, C. (eds). (2019a). Chapter 6: resource system. In: Regenerative Sanitation: A New Paradigm For Sanitation 4.0. IWA Publishing, London, UK, pp. 209–282. https://doi.org/10.2166/9781780409689_0209

Koottatep T., Cookey P. E. and Polprasert C. (2019b). Chapter 4 social-ecological system. In Regenerative Sanitation: A New Paradigm For Sanitation 4.0. IWA Publishing, London, UK, pp. 107–140. https://doi.org/10.2166/9781780409689_0209

Koottatep T., Pussayanavin T., Khamyai S. and Polprasert C. (2021). Performance of novel constructed wetlands for treating solar septic tank effluent. *Science of the Total Environment*, **754**, 142447. https://doi.org/10.1016/j.scitotenv.2020.142447

Kubba S. (2017). Water Efficiency and Sanitary Waste in Handbook of Green Building Design and Construction, 2nd edn, The Netherlands. https://www.sciencedirect.com/topics/engineering/composting-toilet/pdf (accessed 05 January 2021)

Lamming R. C. (1993). Beyond Partnership: Strategies for Innovation and Lean Supply. Prentice-Hall, London.

Lazarte M. (2016). ISO's two-step solution to improving sanitation for 2.4 billion people. ISO Focus Magazine. https://www.iso.org/news/2016/11/Ref2145.html (accessed 22 February 2018).

Lee Y. C. and Gilleard J. D. (2002). Collaborative design: a process model for refurbishment. *Automation in Construction*, **11**(5), 535–544, https://doi.org/10.1016/S0926-5805(01)00064-4

Lucena J. and Schneider J. (2008). Engineers, development, and engineering education: From national to sustainable community development. *European Journal of Engineering Education*, **33**(3), 3797.

Lv J., Gu F., Zhang W. and Guo J.-F. (2019). Life cycle assessment and life cycle costing of sanitary ware manufacturing: A case study in China. *Journal of Cleaner Production*, **238**, 117938. https://doi.org/10.1016/j.jclepro.2019.117938

Masternak-Janus A. and Rybaczewska-Błażejowska M. (2015). Life cycle analysis of tissue paper manufacturing from virgin pulp or recycled waste paper. *Management and Production Engineering Review*, **6**(3), 47–54. https://doi.org/10.1515/mper-2015-0025. https://journals.pan.pl/Content/89638/PDF/5-janus.pdf?handler=pdf (accessed 24 February 2021).

Mattson C. A. and Wood A. E. (2014). Nine principles for design for the developing world as derived from the engineering literature. *Journal of Mechanical Design*, **136**, 121403, https://doi.org/10.1115/1.4027984

MCGee J. (2015). Value Chain. Volume 12. Strategic Management, Wiley Encyclopedia of Management, 3rd edition. https://doi.org/10.1002/9781118785317.weom120081

Mchenga J. and Holm R. H. (2019). Can a precast pit latrine concrete floor withstand emptying operations? An investigation from Malawi. *Journal of Water, Sanitation and Hygiene for Development*, **9**(1), 181–186. https://doi.org/10.2166/washdev.2018.096

McIvor R. and Humphreys P. (2004). Early supplier involvement in the design process: lessons from the electronics industry. *Omega*, **32**(4), 179–199, https://doi.org/10.1016/j.omega.2003.09.005

McIvor R., Humphreys P. and Huang G. (2000). Electronic commerce: reengineering the buyer–supplier interface. *Business Process Management Journal*, **6**(2), 122–138, https://doi.org/10.1108/14637150010321295

McIvor R., Humphreys P. and Cadden T. (2006). Supplier involvement in product development in the electronics industry: A case study. *Journal of Engineering and Technology Management*, **23**, 374–397, https://doi.org/10.1016/j.jengtecman.2006.08.006

McLeod G. (2012). Value Chain/Network Improvement. https://static1.squarespace.com/static/55df0347e4b064f219e05fb4/t/5792056ccd0f686a939c5b99/1469187496779/Value-Chain-Network-Improvement.pdf (accessed 23 February 2021).

Meckstroth D. J. (2016). The Manufacturing Value Chain Is Much Bigger Than You Think. MAPI Foundation Arlington, Virginia. https://static1.squarespace.com/static/58862301f7e0ab813935c244/t/58c05a2f6a4963ad69ed3734/1489001008886/PA-165_web_0.pdf (accessed 28 February 2021).

MECS-Acimac Research Department (2017). World sanitaryware production and exports. Tile International 1/2017. https://www.ceramicworldweb.it/filealbum/Home/materialicasa/pdf/tile-international/2017/1/070_075%20Statistic%20SANITARI.pdf (accessed 1 January 2021).

Meticulous Market Research (2020). Water and Wastewater Treatment Market Worth $211.3 Billion by 2025, Growing at a CAGR of 6.5% from 2019- Global Market Opportunity Analysis and Industry Forecasts. https://www.globenewswire.com/news-release/2020/06/18/2050151/0/en/Water-and-Wastewater-Treatment-Market-Worth-211-3-Billion-by-2025-Growing-at-a-CAGR-of-6-5-from-2019-Global-Market-Opportunity-Analysis-and-Industry-Forecasts-by-Meticulous-Researc.html#:~:text=The%20water%20and%20wastewater%20treatment,systems%20more%20relevant%20than%20ever (accessed 4 March 2021).

M4P (2008). Making Value Chains Work Better for the Poor: A Toolbook for Practitioners of Value Chain Analysis, Version 3. Making Markets Work Better for the Poor (M4P) Project, UK Department for International Development (DFID). Agricultural Development International: Phnom Penh, Cambodia. https://www.researchgate.net/publication/329574289_Making_Value_Chains_Work_Better_for_the_Poor_A_Toolbook_for_Practitioners_of_Value_Chain_Analysis (accessed 30 December 2020).

Michniewicz M., Janiga M., Sokół A., Żubrzak M., Przybyszewska-Witczak E., Kiszczak B., Jarowski P. and Bartosiak M. (2005). The Best Available Techniques (BAT). Guidelines for the Pulp and Paper Industry [in Polish: Najlepsze dostępne techniki (BAT). Wytyczne dla branży celulozowo-papierniczej], Ministry of the Environment, Warsaw.

Mitcham C. and Munoz D. (2010). *Humanitarian Engineering*. *Synthesis Lectures on Engineers, Technology and Society*, Morgan & Claypool Publishers, 1–87. ISBN-13: 978-1608451517.

Narayanan R., van Norden H., Gosling L. and Patkar Ab. (2011). Equity and Inclusion in Sanitation and Hygiene in South Asia: A Regional Synthesis Paper. UNICEF; WaterAid; WSSCC.

Nothomb C., Snel M., McHugh K., Narracott A. and Sauer J. (2014). Sanitation as a business: unclogging the blockages. In: Sanitation as a Business: Unclogging the Blockages. IRC, PSI, WSUP, Water For People, Kampala, Uganda, p. 38.

Porter M. E. (1985). Competitive Advantage: Creating and Sustaining Superior Performance. The Free Press, New York, NY, p. 38.

PWC (2012). Water challenges, drivers and solutions. https://www.pwc.com/gx/en/sustainability/publications/assets/pwc-water-challenges-drivers-and-solutions.pdf (accessed 4 March 2021).

Rahman N. A. A., Ahmad S. and Zainordin Z. M. (2013). Perception and awareness of leaking for toilet in pre-cast concrete structure. *Procedia – Social and Behavioral Sciences*, **85**, 61–69. https://doi.org/10.1016/j.sbspro.2013.08.338

Research and Markets (2020a). Tissue Paper Market – Growth, Trends, and Forecast (2020–2025). https://www.businesswire.com/news/home/20200928005369/en/Outlook-on-the-Tissue-Paper-Global-Market-to-2025---Bathroom-Tissue-to-Occupy-the-Maximum-Growth-Demand---ResearchAndMarkets.com#:~:text=With%20the%20global%20average%20consumption,14%20million%20tonnes%20over%202010. (accessed 24 February 2021).

Research and Markets (2020b). Hand Sanitizer Market Size By Functional Ingredients, Product Type, End-Users, Distribution Channels, Supply Chain, Geography, Industry Analysis and Forecast 2020–2025. https://www.researchandmarkets.com/reports/5067358/hand-sanitizer-market-size-by-functional (accessed 28 February 2021).

Research and Markets (2021). $44.6 Billion Worldwide Sanitary Ware Industry to 2025 – Impact of COVID-19 on the Market. https://www.globenewswire.com/news-release/2020/06/18/2049942/0/en/44-6-Billion-Worldwide-Sanitary-Ware-Industry-to-2025-Impact-of-COVID-19-on-the-Market.html (accessed 1 January 2021).

Rolstadaas A., Hvolby H. H. and Falster P. (2008). Review of after-sales service concepts. In: Lean Business Systems and Beyond. IFIP – The International Federation for Information Processing, vol. **257**, T. Koch (ed.), Springer, Boston, MA, pp. 383–391. https://doi.org/10.1007/978-0-387-77249-3_40

Saccani N., Johansson P. and Perona M. (2007). Configuring the after-sales service supply chain: A multiple case study. *International Journal of Production Economics*, **110**, 52–69. https://doi.org/10.1016/j.ijpe.2007.02.009

Schuetze T. and Santiago-Fandiño V. (2014). Terra Preta sanitation: A key component for sustainability in the urban environment. *Sustainability*, **6**, 7725–7750, https://doi.org/10.3390/su6117725

Sharpe T., Muragijimana C. and Thomas E. (2019). Product design supporting improved water, sanitation, and energy services delivery in low-income settings. *Sustainability*, **11**, 6717. https://doi.org/10.3390/su11236717

Silvestri L., Forcina A., Silvestri C. and Ioppolo G. (2020). Life cycle assessment of sanitaryware production: A case study in Italy. *Journal of Cleaner Production*, **251**, 119708. https://doi.org/10.1016/j.jclepro.2019.119708

Singh R. (2006). Introduction to Basic Manufacturing Processes and Workshop Technology. New Age International Limited Publishers, New Delhi. ISBN (10) 81-224-2316-7

Spaargaren G., Mommaas H., Van Den Burg S., Maas L., Drissen E. and Dagevos H. (2007). More Sustainable Lifestyles and Consumption Patterns: A Theoretical Perspective for the Analysis of Transition Processes within Consumption Domains, Contrast Research Report, TMP project. Wageningen: Environmental Policy Group, Wageningen University; Telos: Tilburg University; RIVM; LEI, Wageningen, Netherlands.

Springer-Heinzer A. (2018). ValueLinks 2.0 – Manual on Sustainable Value Chain Development. Value Chain Solutions, volume 2, pp 306, GTZ. https://beamexchange.org/uploads/filer_public/d3/a4/d3a4882e-eb14-4c30-8f7e-6ba4f51f6ec9/valuelinks-manual-20-vol-2-january-2018_compressed.pdf (accessed 13 January 2021).

Srai J. S. and Shi Y. (2008). *Understanding China's Manufacturing Value Chain: Opportunities for UK Enterprises in China*. University of Cambridge Institute for Manufacturing, UK. https://www.ifm.eng.cam.ac.uk/uploads/Research/CIM/china09.pdf (accessed 29 December 2020).

Sturgeon T. J. and Memedović O. (2011). Mapping Global Value Chains: Intermediate Goods Trade and Structural Change in the World Economy. United Nations Industrial Development Organization (UNIDO). Development Policy and Strategic Research Branch Working Paper 05/2010. https://www.unido.org/api/opentext/documents/download/9928658/unido-file-9928658 (accessed 13 January 2021)

Sturgeon T., Linden G. and Zhang L. (2012). Product-level global value chains: UNCTAD study on improving international trade statistics based on global value chains, Massachusetts Institute of Technology, August 29.

Syam N. B., Ruan R. and Hess J. D. (2005). Customized products: A competitive analysis. *Marketing Science*, **24**, 569–584. https://doi.org/10.1287/mksc.1050.0128

Tarver E. (2020) Research and Development (R&D) vs. Product Development. Publiahws in Investopedia. https://www.investopedia.com/ask/answers/042815/what-difference-between-research-and-development-and-product-development.asp#:~:text=The%20difference%20between%20research%20and,existing%20products%20with%20new%20features (accessed 4 January 2021).

Thomas Publishing Company (2021). Top Toilet Manufacturers and Companies in the USA. https://www.thomasnet.com/articles/top-suppliers/toilet-manufacturers-and-companies/ (accessed 14 February 2021).

Tilley E., Lüthi C., Morel A., Zurbrügg C. and Schertenleib R. (2008). Compendium of Sanitation Systems and Technologies. Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Duebendorf, Switzerland, p. 158.

Tilley E., Ulrich L., Luethi C., Reymond P. and Zurbruegg C. (2014). Compendium of Sanitation Systems and Technologies, 2nd Revised edn. Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Duebendorf, Switzerland.

Tobias R., O'Keefe M., Künzle R., Gebauer H., Gründl H., Morgenroth E., Pronk W. and Larsen T. A. (2017). Early testing of new sanitation technology for urban slums: The case of the blue diversion toilet. *Science of the Total Environment*, **576**, 264–272. https://doi.org/10.1016/j.scitotenv.2016.10.057

UNIDO (2011). Industrial Value Chain Diagnostics: An Integrated Tool. United Nations Industrial Development Organization (UNIDO), Vienna, Austria. https://www.unido.org/sites/default/files/2011-07/IVC_Diagnostic_Tool_0.pdf (accessed 29 December 2020).

USAID (2018). Scaling Market Based Sanitation: Desk review on marketbased rural sanitation development programs. Washington, DC., USAID Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability (WASHPaLS) Project. https://www.issuelab.org/resources/31021/31021.pdf?download=true (accessed 17 February 2021).

USEPA (2018). Septic Systems. https://www.epa.gov/septic/types-septic-systems#conventional (accessed 19 January 2021).

Valfrey-Visser B. and Schaub-Jones D. (2009). Supporting Private Entrepreneurs to Deliver Public Goods: Engaging Sanitation Entrepreneurs. 34th WEDC International Conference, Addis Ababa, Ethiopia.

van Vliet B. J. M., Spaargaren G. and Oosterveer P. (2011). Sanitation under challenge: contributions from the social sciences. *Water Policy*, **13**, 797–809, https://doi.org/10.2166/wp.2011.089

WEDC (Water, Engineering and Development Centre) (2012). Latrine Slabs: an Engineer's Guide. Loughborough University, Loughborough, UK.

Wikipedia (2019). Product (business). Provided by**:** Wikipedia. Located at: http://en.wikipedia.org/wiki/Product_(business). License: CC BY-SA: Attribution-ShareAlike. https://courses.lumenlearning.com/boundless-marketing/chapter/what-is-a-product/ (accessed 4 March 2021).

Wikipedia contributors (2020, December 31). Composting toilet. In Wikipedia, The Free Encyclopedia. Retrieved 20:02, March 16, 2021, from https://en.wikipedia.org/w/index.php?title=Composting_toilet&oldid=997478251 (accessed 13 January 2021)

Wiktionary (2019). product. Provided by: Wiktionary. Located at: http://en.wiktionary.org/wiki/product. License: *CC BY-SA:* Attribution-ShareAlike. https://courses.lumenlearning.com/boundless-marketing/chapter/what-is-a-product/ (accessed 4 March 2021).

Wognum P., Fisscher O. and Weenink S. (2002). Balanced relationships: management of client-supplier relationships in product development. *Technovation*, **22**(6), 341–351, https://doi.org/10.1016/S0166-4972(01)00031-1

Womack J. and Jones D. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Simon & Schuster, New York, NY.

Zamora E. A. (2016). Value chain analysis: a brief review. *Asian Journal of Innovation and Policy*, **5**(2), 116–128. https://doi.org/10.7545/ajip.2016.5.2.116. https://www.researchgate.net/publication/315688804_Value_Chain_Analysis_A_Brief_Review (accessed 12 February 2021).

Zhu Y., Alard R., You J. and Schönsleben P. (2011). Collaboration in the design-manufacturing chain: a key to improve product quality. In: Supply Chain Management – New Perspectives, S. Renko (ed.), InTech, Croatia. ISBN: 978-953-307-633-1, Available from: https://www.intechopen.com/chapters/18508 (accessed 5 January 2021).

Zokaei K. A. and Simons D. W. (2006). Value chain analysis in consumer focus improvement. A case study of the UK ed meat industry. *The International Journal of Logistics Management*, **17**(2), 141–162.