FORWARD-LOOKING APPROACH TO NEXT GENERATION SANITATION AND INDUSTRIAL DEVELOPMENT IN SOUTH AFRICA

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Trade & Industrial Policy Strategies (TIPS) is a research organisation that facilitates policy development and dialogue across three focus areas: trade and industrial policy, inequality and economic inclusion, and sustainable growth

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Key findings

1) Next Generation Sanitation (NGS) differs from conventional sanitation in that it seeks to reconfigure the sanitation value chain by eliminating the storage and conveyance components as it favours on-site treatment that produces pathogen-free output whilst using no or very little amount of water as well as integrating resource and energy recovery in the process.
2) Globally, from 2015 to the 2030 Sustainable Development Goals (SDG) target year, about 1.1 billion people need services to end open defecation, about 3.5 billion people need basic sanitation services, and about 5.3 billion people need safely managed sanitation services. A total of about US$120 billion is required annually to meet the 2030 SDG sanitation targets in the world.
3) In South Africa, from 2015 to the 2030 SDG target year, about 32 million people will require safely managed sanitation, 18.3 million basic sanitation, about 30.1 million basic hygiene services, and close to one million need services to end open defecation. A total of about US$1.4 billion (equivalent to about R17.4 billion) is required annually to meet these SDG sanitation targets.
4) Other studies have estimated the global opportunity for NGS at over US$8 billion a year, however, this could be much more considering its potential to leapfrog and disrupt the market.
5) The NGS concept is relatively new and technologies are at the early stage of the innovation continuum. There is need for the country to take front runner advantage.
6) Though South Africa has a strong RDI background on conventional sanitation, the country needs to be more active in order to capture the opportunity offered by NGS to industrialise. There has been increased and converging efforts by various organisations and government departments to promote the development of NGS in the country, providing valuable platforms to leverage.

Policy implications

1) The adoption and use of sanitation technologies requires user acceptance. As such user awareness, positive perception, and acceptance should be the initial steps in rolling out NGS technologies. There is need to transform how people view human excreta and sanitation processes, particularly the view that waterborne sanitation is the best solution, regardless of water availability.
2) Demand is required for the uptake of technologies. This demand has to be stimulated through local procurement, building regulations, and norms and standards. The Department of Trade and Industry (the dti) needs to play an important role in the designation (for local content) of the relevant technologies.
3) There is need to enhance the development of standards, testing, and validation of NGS technologies. In this regard, efforts by SABS to localise the ISO 30 500 standard on Non-Sewered Sanitation Systems, should embraced and enhanced by all stakeholders including sanitation technology developers, building industry, regulators, and municipalities.
4) It is important to enhance local capacity, through increased funding towards the development and manufacturing of local NGS technologies.
5) There is need to strengthen skills and training necessary for NGS roll-out as the technologies might be more complicated than conventional sanitation technologies. This requires upskilling and reskilling of planners, plumbers and technicians.

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ABBREVIATIONS

ANSI	American National Standards Institute
BCG	Boston Consulting Group
BMGF	Bill & Melinda Gates Foundation
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEWATS	Decentralised Wastewater Treatment Systems
DHS	Department of Human Settlements
DPME	Department of Planning, Monitoring and Evaluation
DST	Department of Science and Technology
dti (the)	Department of Trade and Industry
DWS	Department of Water and Sanitation
Ecosan	Ecological Sanitation
FSM	Faecal sludge management
FSOA	Fecal Sludge Omni-Ingestor
IP	Intellectual Property
ISO	International Organization for Standadization
L	Litres
MDGs	Millennium Development Goals
MFC	Microbial Fuel Cell
MWP	Mini Waste Processor
NGS	Next Generation Sanitation
NT	National Treasury
NW&SMP	National Water and Sanitation Master Plan (draft)
OD	Open defecation
PRG	Pollution Research Group
R&D	Research and Development
RDI	Research, Development and Innovation
RT	Reinvented Toilet
RTTC	Reinvent the Toilet Challenge
SABS	South African Bureau of Standards
SAFE	Sanitation Appropriate for Education
SAICE	South African Institution of Civil Engineering
SanIC	Sanitation Innovation Challenge

SANS	South African National Standards
SASTEP II AIP	South African Sanitation Demonstration Programme – Accelerated Industrialisation Plan
SCWO	Supercritical Water Oxidation
SDGs	Sustainable Development Goals
SSP	Sanitation Safety Planning
Stats SA	Statistics South Africa
SuSanA	Sustainable Sanitation Alliance
TBC	Toilet Board Coalition
UD	Urine Diversion
UK	United Kingdom
US	United States
UDDTs	Urine Diversion Dry Toilets
UKZN	University of KwaZulu-Natal
UNICEF	United Nations Children's Fund
VIP	Ventilated Improved Pit
VUNA	Valorisation of Urine Nutrients in Africa
WADER	Water Technologies Demonstration Programme
WHO	World Health Organization
WRC	Water Research Commission
WWF	World Wide Fund for Nature
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Works

1. INTRODUCTION

In simplest terms, sanitation relates to how human waste is disposed of. Sanitation is a multi-step process in which human excreta (faeces and urine) and wastewater are safely managed and treated from the point of generation to the point of ultimate disposal (Tilley et al., 2014). Access to adequate sanitation is necessary for personal dignity and security, social and psychological well-being, public health, poverty reduction, gender equality, economic development and environmental sustainability (Funamizu, 2017; Stats SA, 2016a; SuSanA, 2008). President Cyril Ramaphosa has referred to access to appropriate sanitation services especially in schools as "an urgent human need" (The Presidency, 2018).

Conventional sanitation technologies have not really solved the challenges in the sanitation sector. There are significant losses along the value chain as a result of open defecation, spillage (due to poor infrastructure), illegal dumping, ineffective treatment, and disposal of untreated waste (Sandford and Baetings, 2016). As a result, non-sewered off-grid sanitation systems commonly referred to as NGS, which differs greatly from conventional technologies, have been proposed as potentially better. NGS can be defined as an integrated system in which the frontend collects and conveys the specific input to the backend which fully treats the waste within the non-sewered sanitation system, to allow for safe reuse or disposal of the generated solid, liquid and gaseous output (ISO, 2017). Thus, in this paper NGS is used to refer to non-sewered off-grid sanitation systems that treat human waste at source.

South Africa is considering positioning itself as a leading manufacturer of NGS technologies. The country's Industrial Policy Action Plan (IPAP 2017/18 - 19/20) seeks to establish an NGS Cluster Development Programme. From an industrial perspective, this is seen as an opportunity for expanding the manufacturing, services, and supply of sanitation technologies (the dti, 2017). In line with this goal, this paper assesses the opportunities and constraints for NGS in the context of industrial development in South Africa.

The paper is organised as follows. Section 2 presents the past, present, and the future of sanitation technologies. Section 3 then discusses demand-side dynamics, covering both the global and local market. Section 4 focuses on business model considerations, and Section 5 investigates supply-side dynamics, i.e. manufacturing and research and development of sanitation technologies. Section 6 formulates policy implications and Section 7 concludes.

2. PAST, PRESENT, FUTURE OF (NEXT GENERATION) SANITATION

In general, sanitation technologies can be broken down into five functional groups (Tilley et al., 2014), as depicted in Table 1: user interface; collection and storage/treatment; conveyance; (semi-) centralised treatment; and use and/or disposal. User interface refers to technologies with which the user interacts, i.e. the type of toilet, pedestal, pan, or urinal. There are two main types of interfaces: dry technologies that operate without water and water-based technologies that need a regular supply of water to properly function. Collection and storage technologies store the products generated at the user interface, with some having treatment capability.

Table 1: Components of sanitation technologies

Functional group	Description	Examples	System templates
User Interface	The type of toilet, pedestal, pan, or urinal with which the user comes in contact	• Dry Toilet • Urine-Diverting Dry Toilet • Urinal • Pour Flush Toilet • Cistern Flush Toilet • Urine-Diverting Flush Toilet	• Single Pit System • Waterless Pit System without Sludge Production • Pour Flush Pit System without Sludge Production • Waterless System with Urine Diversion (UD) • Biogas System • Blackwater Treatment System with Infiltration • Blackwater Treatment System with Effluent Transport • Blackwater Transport to (Semi-) Centralised Treatment System • Sewerage System with Urine Diversion
Collection and Storage	Collect, store, and sometimes treat the products generated at the User Interface	• Urine Storage Tank/Container • Single Pit • Single Ventilated Improved Pit • Double Ventilated Improved Pit • Twin Pits for Pour Flush • Dehydration Vaults • Composting Chamber • Septic Tank • Anaerobic Baffled Reactor • Anaerobic Filter • Biogas Reactor	
Conveyance	The transport of products from one functional group to another.		
(Semi-) Centralised Treatment	Treatment technologies that are generally appropriate for large user groups		
Use and/or Disposal	The methods by which products are ultimately returned to the environment	• Irrigation; Aquaculture; Macrophyte; Disposal/ Recharge • Sludge: Land Application; Surface Disposal • Soak Pit / Leach Field and Dispose to garden	

Source: Author, drawn from Tilley et al., 2014

Sanitation systems can also be categorised based on two complementary dimensions (Table 2), i.e. whether a system uses water or not, and whether its requires conveyance or not.

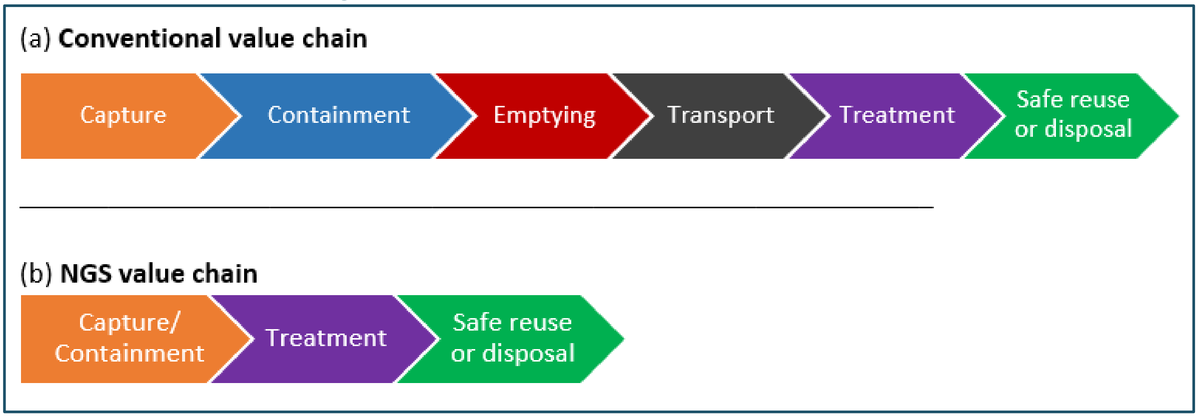
Table 2: Categories of sanitation systems

	Requiring conveyance (off-site treatment)	No conveyance required (treatment, or partial treatment, on site; accumulated sludge also requires periodic removal)
No water added	*Group 1* - Chemical toilet (temporary use only).	*Group 2* - Ventilated improved pit toilet. - Ventilated improved double-pit toilet. - Ventilated vault toilet. - Urine-diversion toilet.
Water added	*Group 3* - Full waterborne sanitation. - Flushing toilet with conservancy tank. - Shallow sewers.	*Group 4* - Flushing toilet with septic tank and subsurface soil absorption field. - Low-flow on-site sanitation systems (LOFLOs): Aqua-privy toilet.

Source: CSIR, 2003, p. 4

NGS technologies differ from conventional solutions in three main ways. They do not require conveyance, require no (or minimal) water usage, and the on-site treatment produces pathogen-free output. NGS are transformative technologies that offer non-sewered sanitation solutions, thereby eliminating the need for a piped collection system (Kone, 2017). The key differences between conventional and NGS value chains are depicted in Figure 1. NGS emphasises the treatment of human waste at source. The NGS approach eliminates some components of the conventional sanitation value chain into a single piece of on-site infrastructure (BCG, 2014). Key stages of NGS are: capture/containment; treatment; and reuse/ disposal (Arbogast, 2016).

Figure 1: Conventional versus NGS value chain



Source: Author

NGS is understood as sanitation fixtures that remove germs from human waste and recover valuable resources (e.g. energy, clean water, and nutrients); operate off the grid without connections to water, sewer, or electrical lines; and promote sustainable and financially profitable sanitation services and businesses (ANSI, 2016; BMGF, 2013).

An important component of NGS is resource recovery (with potential to subsidise sanitation services) beyond the traditional fertiliser option to new options, such as biochar, biogas, and biodiesel (BCG, 2014). Some common types of waste treatment processing in NGS are: electrochemical, hydrothermal carbonisation, wet oxidation, dry combustion, as well as biological. NGS support a range of systems, at varying sizes and capacities, such as household scale, multi-unit scale, pumping and processing.

3. DEMAND-SIDE DYNAMICS: GLOBAL AND LOCAL MARKETS

Global dynamics

Access to sanitation can be best illustrated by the sanitation ladder (Figure 2). The lowest level of sanitation is open defecation, which implies no sanitation facility at all. This is the most undesirable state that must be eradicated as soon as possible. The second stage entails the use of unimproved sanitation facilities; this is better than nothing though not desirable. The use of improved facilities – (flush/pour flush to piped sewer system, septic tank or pit latrine, ventilated improved pit latrine, composting toilet or pit latrine with slab) constitutes the next stage. Access is considered *limited* when the facility is shared, or *basic* when not shared. The highest level is access to safely managed sanitation, whereby the improved facility is not shared and the excreta is safely disposed whether on-site or off-site.

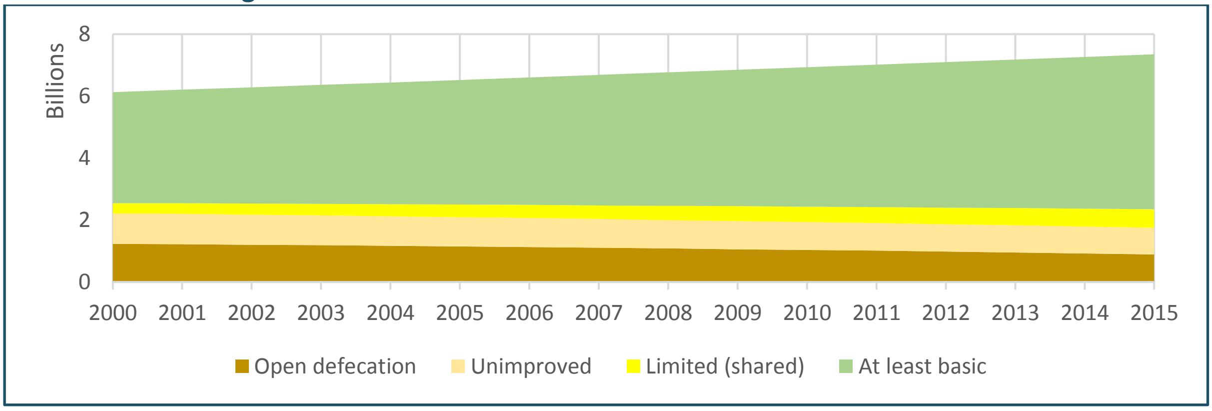
Figure 2: Sanitation ladder

Safely managed	Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site	*Improved facilities include: flush/pour flush to piped sewer system, septic tank or pit latrine; ventilated improved pit latrine, composting toilet or pit latrine with slab.*
Basic	Use of improved facilities which are not shared with other households	
Limited	Use of improved facilities shared between two or more households	
Unimproved	Use of pit latrines without a slab or platform, hanging latrines and bucket latrines	
Open defecation	Disposal of human faeces in fields, forest, bushes, open bodies of water, beaches or other open spaces or with solid waste	

Source: Author adapted from WHO and UNICEF, 2017

The progress in providing proper sanitation services across the world has generally been slow. A significant number of people still do not have access to proper sanitation services (Figure 3). Some people do not have access to sanitation at all, while for those who have access, the services are inadequate or inappropriate. In light of the backlogs, one of the SDGs compels countries to focus on achieving sanitation targets. SDG 6.2 seeks to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation by 2030, paying special attention to the needs of women, girls, and those in vulnerable situations.

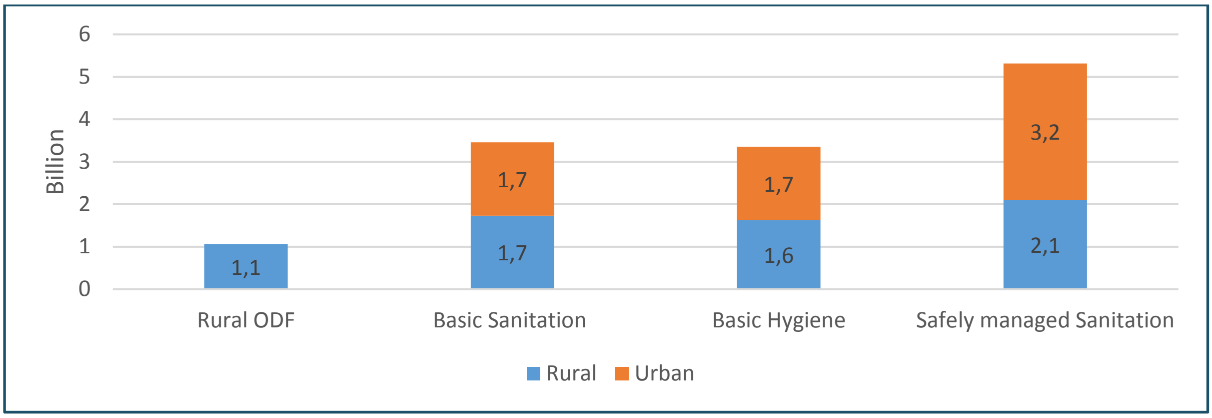
Figure 3: Global access to sanitation services from 2000 to 2015



Source: Author, based on JMP, 2017

Globally, from 2015 to the 2030 target of the SDGs, about 1.1 billion people would need services to end open defecation (Figure 4). At the same time, about 3.4 billion people would need access to basic sanitation services, and about 5.3 billion people would need to be provided with safely managed sanitation services.

Figure 4: Global population to serve with new sanitation services from 2015 to 2030

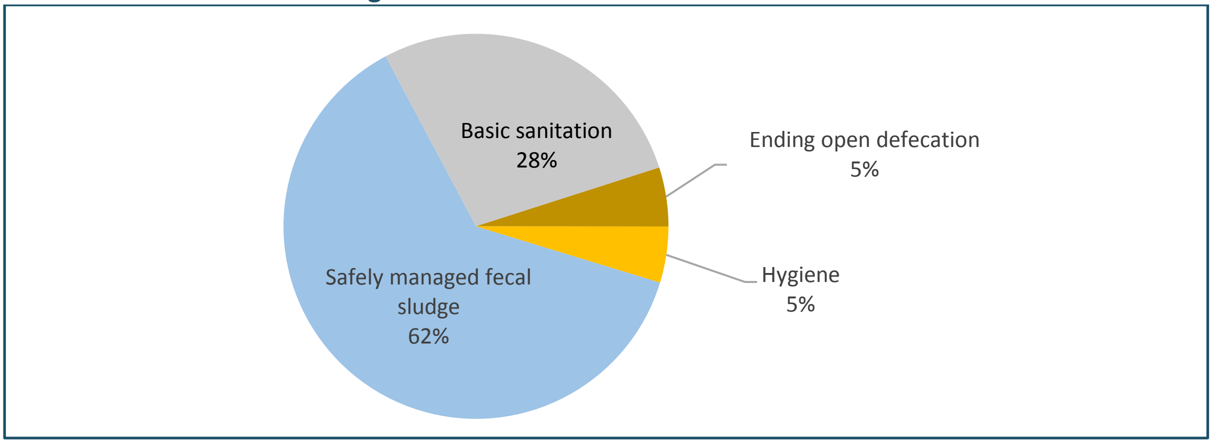


Source: Author, based on World Bank (2016)

About US$ 120 billion would be required annually[1] (Figure 5) to meet the 2030 SDG sanitation targets in the world. The greatest proportion of this amount (US$75 billion) would be required to provide safely managed faecal sludge.

The provision of basic sanitation would require US$33 billion annually, while providing basic hygiene services (handwashing station, soap and water at home) would need US$ 6 billion per year. Ending open defecation, the most urgent challenge, would cost US$6 billion a year.

Figure 5: Annual cost breakdown by sanitation needs to address global sanitation issues from 2015-2030

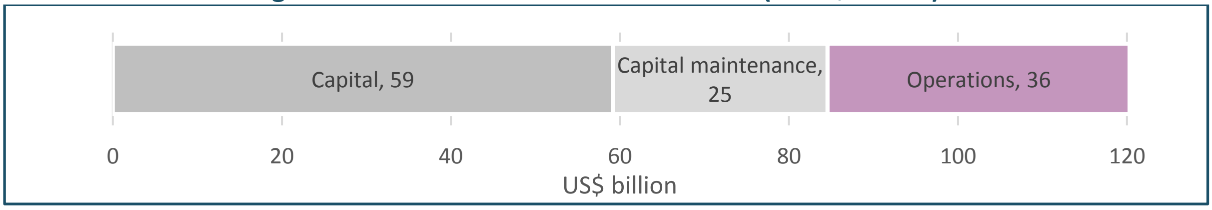


Source: Author, based on World Bank, 2016

By expenditure type (Figure 6), capital expenditure accounts for half of the quantum (US$59 billion), followed by operations (US$36 billion), and capital maintenance (US$25 billion).

[1] These figures are estimates, the actual costs will depend on the technologies used, and the pace of the transition up the sanitation ladder. However, they give an indication of the strong need to invest in sanitation.

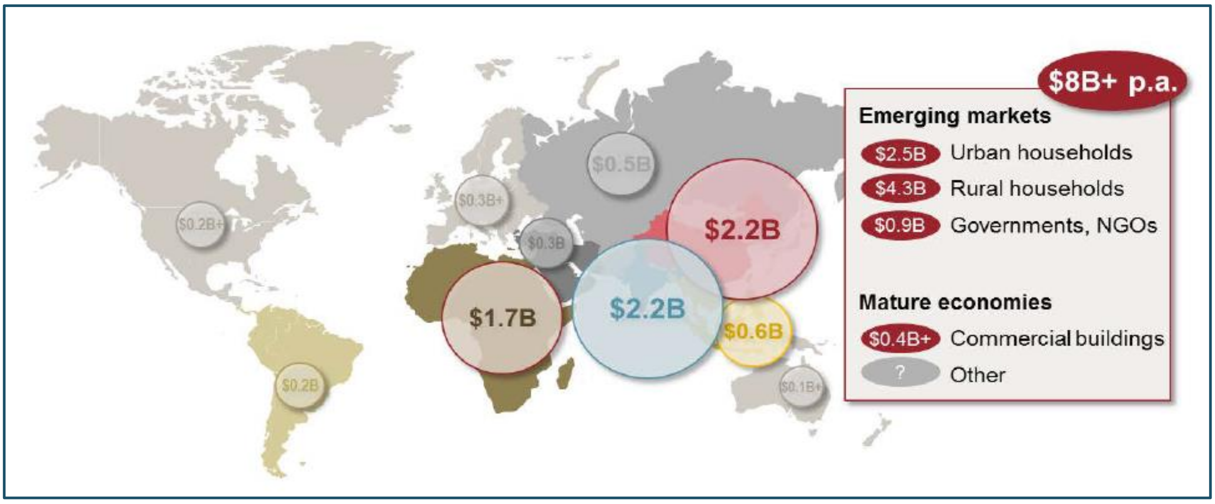
Figure 6: Annual cost breakdown by expenditure type to address global sanitation issues from 2015-2030 (in US$ billion)



Source: Author, based on World Bank, 2016

In other studies, the global market for NGS has been estimated[2] at over US$8 billion per annum (Figure 7). While rural households constitute the largest market, the growth in urban demand for sanitation, driven by growing rural-urban migration, is expected to support growth. For instance, Africa is expected to gain about 25 million new urban dwellers a year, while Asia should gain about 35 million new urban residents a year through 2050 (BCG, 2014).

Figure 7: Annual market potential for NGS technologies



Source: Kone (2017), citing the BCG analysis for the BMGF

South African dynamics

South Africa has made significant progress since the attainment of democracy in 1994. For instance, it exceeded the sanitation target in the Millennium Development Goals (MDGs) of halving backlogs on water and sanitation access by 2015. Despite such a milestone, about 23% of South African households still do not have access to an acceptable and adequate sanitation service (DWS, 2017a) and significant backlogs persist. The sanitation backlogs in the country can be categorised as:

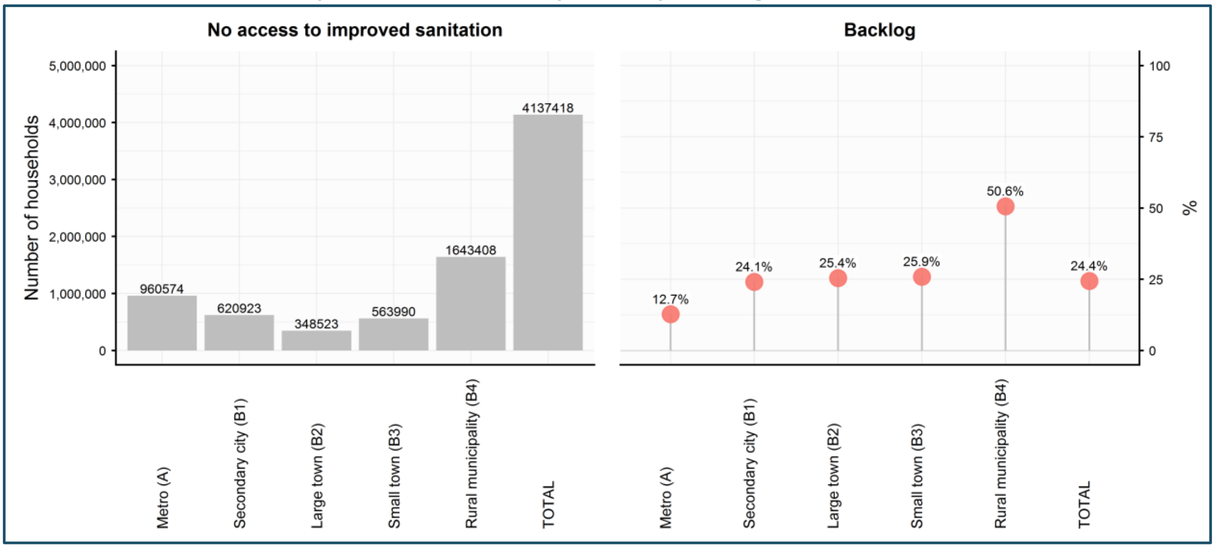
- Service delivery backlogs (people who have never been served);
- Refurbishment backlogs (sanitation infrastructure that has deteriorated beyond regular maintenance requirements);
- Extension backlogs (existing infrastructure that needs to be extended to provide the service to new households in the communities);
- Upgrade needs (infrastructure that does not meet the minimum standards); and

[2] In this paper, the NGS market size could not be estimated as the author could not access information and data on costs (capital, operation and maintenance) of NGS technologies.

- Operation and maintenance backlogs (infrastructure that has not been properly operated and maintained, but can be adequate if funds are allocated to ensure proper operation and maintenance) (DWS, DHS, & DPME, 2012).

Urban areas tend to have better access to services than rural areas. In addition, the lack of access to improved sanitation is mostly concentrated among the poorer members of society in both urban and rural areas. Figure 8 reveals that, of the 4.1 million households that were estimated to lack access to improved sanitation in 2016, 1.6 million resided in rural municipalities that were constrained by finances and distance (Stats SA, 2017). The backlogs in rural municipalities can go up to 50% of the households in those municipalities.

Figure 8: Household backlog in terms of lack of access to improved sanitation by municipal categories in 2016



Source: Author, based on (Stats SA, 2017, p. 38)

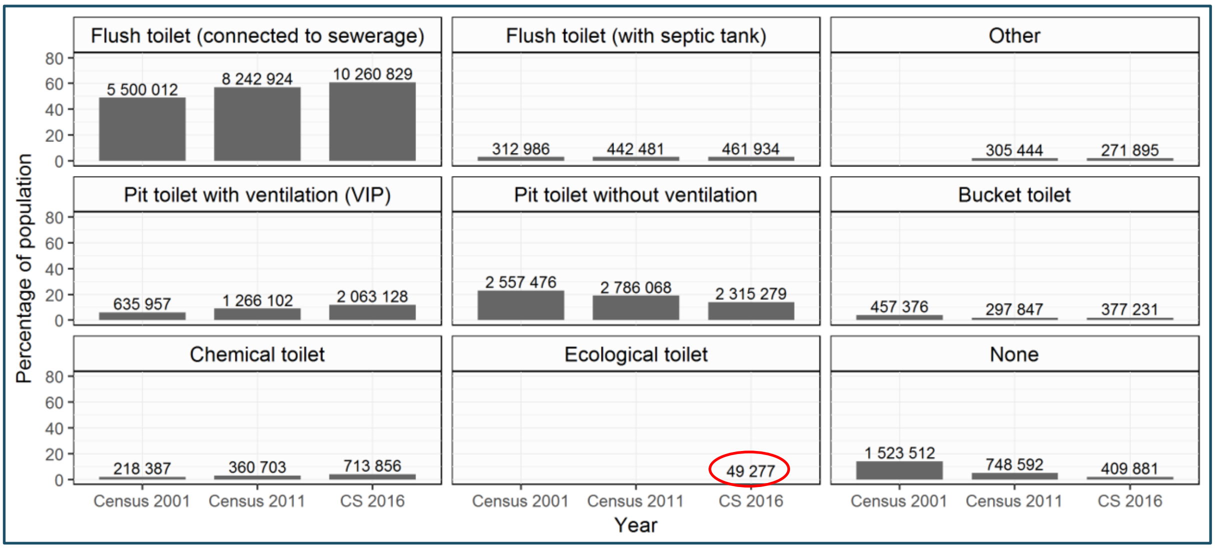
Sanitation technology in South Africa must meet the basic minimum standards as stipulated in policy documents. The National Sanitation Policy (DWS, 2016, p. 8) stipulates a "basic sanitation facility" as:

> the infrastructure which considers natural (water, land, topography) resource protection, is safe (including for children), reliable, private, socially acceptable, has skills and capacity available locally for operation and maintenance, protected from the weather and ventilated, keeps smells to the minimum, is easy to keep clean, minimises the risk of the spread of sanitation-related diseases by facilitating the appropriate control of disease carrying flies and pests, facilitates hand washing and enables safe and appropriate treatment and/or removal of human waste and wastewater in an environmentally sound manner.

Most people in South Africa have access to a flush toilet connected to a centralised sewerage system, as shown in Figure 9. This is generally regarded as the "gold standard" of sanitation in the country (WWF SA, 2016).

While waterborne sanitation systems tend to be the common and generally preferred system, it is indeed increasingly becoming inappropriate in most parts of the country that are water scarce. About 40% of water consumed by households in the country is used only to flush toilets; on average, 200g per person of human waste a day is flushed down the toilet, in each flush about 6L to 9L of pure water is used (Burger, 2015). Political pressure to provide full waterborne sanitation as a basic level of sanitation is negatively impacting on the cost of service provision. Such services cannot be provided effectively unless there is adequate and reliable water supply (SAICE, 2017).

Figure 9: Percentage and number of households by toilet facilities in South Africa in 2001, 2011, and 2016



Source: Author, based on Stats SA, 2016b, p. 68

Although attention towards the wider adoption of systems that use less or no water has increased, for instance through ecological sanitation (Ecosan)[3], this is still marginal and at an early stage. Figure 9 shows that, whereas no household was recorded as using ecological toilets in the 2001 and 2011 censuses, close to 50 000 households were using them according to the 2016 Community Survey, primarily in KwaZulu-Natal, Mpumalanga and Limpopo.

Challenges in South Africa's sanitation sector have historical origins. Sufficient water-borne sanitation services were predominantly provided to middle and upper class sections of society (mostly for whites), while black townships and rural areas were neglected (DWS, DHS, & DPME, 2012). The bucket sanitation system, which has mostly been used in black townships, remains one of the critical issues in the country. There has been efforts to eradicate the bucket toilet system due to human rights concerns and potential health risks (Stats SA, 2017), although the efforts remain largely inadequate. The number of bucket toilets in formal settlements replaced with adequate sanitation services a year was only 20 581 and 28 365 in 2014/15 and 2015/16 respectively (NT, 2017, p. 2).

The South African Constitution and other sanitation-related policy documents state that everyone has a right of access to basic water supply and sanitation services. In addition to large investments in rolling out sanitation in the country, the government provides free basic sanitation targeted at indigent (poor) households so that they can at least have the basic level of sanitation (DWS, 2016). In 2015, about 3.3 million households received free basic sanitation services while 4.6 million households received free basic water services (Stats SA, 2017). About 77% of rural households are indigent and, as such, do not pay for municipal services (DWS, 2017b).

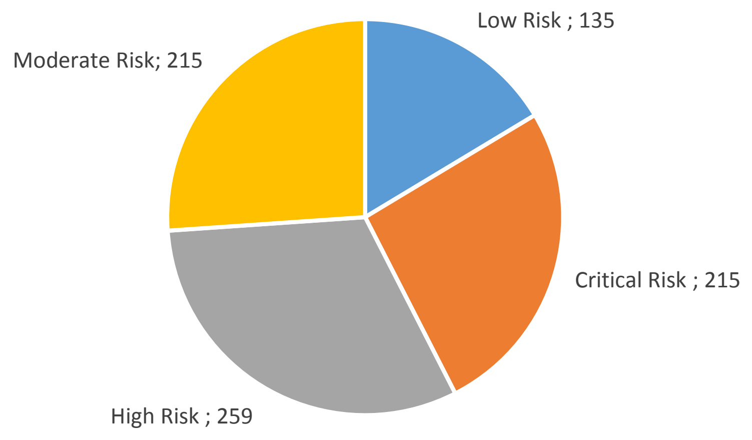
[3] Ecological sanitation is a sanitation system that turns human excreta into a useful and valuable product, with low risk of environmental pollution and no threat to human health (Dunker and Matsebe, 2005). For example, it uses nutrients found in human excreta as fertiliser and soil conditioners for the improvement of the soil for the production of food (Jonah, 2007).

As the government has the responsibility (as enshrined in the Constitution) to ensure that the right to basic sanitation and water services is met, this is increasingly putting a strain on public resources. In some cases, government has been taken to court due to failure to fulfil that obligation. For instance, in 2011, some communities that lacked dignified sanitation services in the Western Cape and the Free State approached the South African Human Rights Commission and the Cape High Court; the relevant municipalities were instructed to address the issues (DWS, DHS, & DPME, 2012).

In addition to the backlog in service delivery, existing infrastructure is increasingly at risk of failure. Under-expenditure in maintenance and under-investment in the rehabilitation of infrastructure remain significant challenges that are contributing to the deterioration of assets over time (DWS, 2016; Stats SA, 2017). The challenge of infrastructure is mostly evident in communities highly dependent on waterborne sewerage systems where the maintenance, refurbishment and upgrading of collection and treatment infrastructure have been neglected over the years (DWS, 2017b; DWS, DHS, & DPME, 2012; SAICE, 2017). Most municipalities in the country lack capacity to properly operate, maintain and manage the infrastructure assets. Furthermore, the expansion of infrastructure has failed to keep pace with growing demand (Muller, 2017).

This dire situation can be attributed as an unintended consequence of continuously focusing on new capital projects at the expense of the sustainable operation and maintenance of existing infrastructure (DWS, DHS, & DPME, 2012; World Bank, 2011). Indeed, the Green Drop Report, which assesses the status of wastewater treatment plants (WWTPs) in the country, shows that most plants are not in good order. In 2014, about 474 out of the 824 WWTPs (about 58%) were in the high and critical risk categories (Figure 10), with some of the infrastructure being completely dysfunctional (DWS, 2017b).

Figure 10: Risk profile of wastewater treatment plants in South Africa in 2014



Source: DWS (2014, p. 19)

Dealing with sanitation backlogs in informal settlements is also a challenge. This challenge arises because informal settlements are mostly transitional and usually unplanned. There is a lack of space to install services, and conventional technologies are not suited to the conditions (DWS, 2017a).

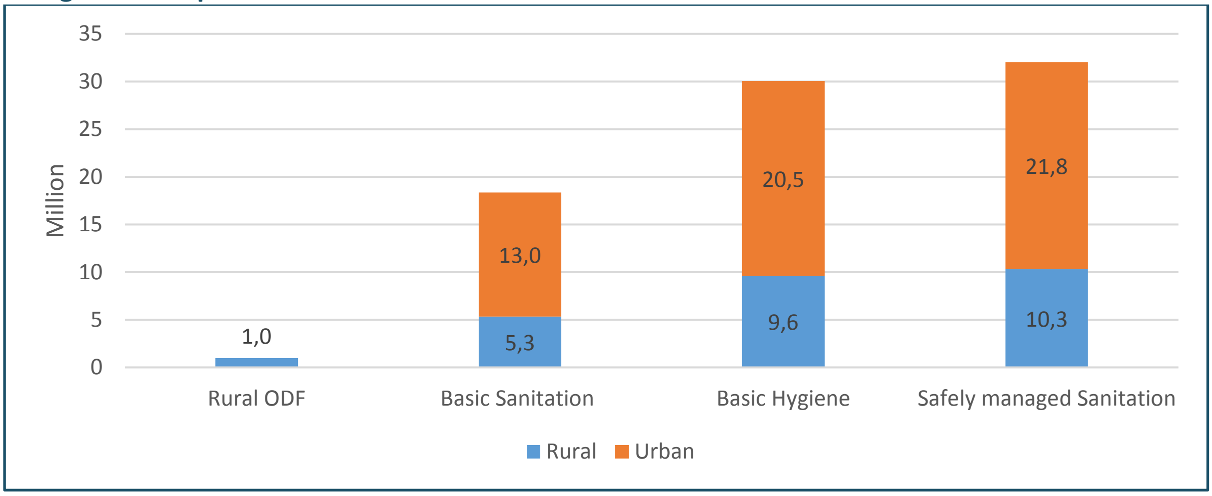
Given these challenges, there is need to think beyond sewers as a solution to providing universal access to sanitation (BCG, 2014). Innovation applied to the need for low water use, low environmental impact and sustainable technologies must be encouraged and supported (DWS, 2017a), which is the basis on which NGS is a reasonable and potentially viable alternative.

Estimates of the costs and size of the market

According to the (World Bank, 2016), about 32 million people in South Africa would require safely managed sanitation services (i.e. safe extraction, conveyance, treatment and disposal of human excreta) from 2015 to 2030 to meet the SDG targets (Figure 11).

At the same time, 18.3 million people would require basic sanitation, and about 30.1 million would need access to basic hygiene services (handwashing station, soap and water at home). Close to one million people would also need services to end open defecation.

Figure 11: Population to serve with new sanitation services from 2015 to 2030 in South Africa

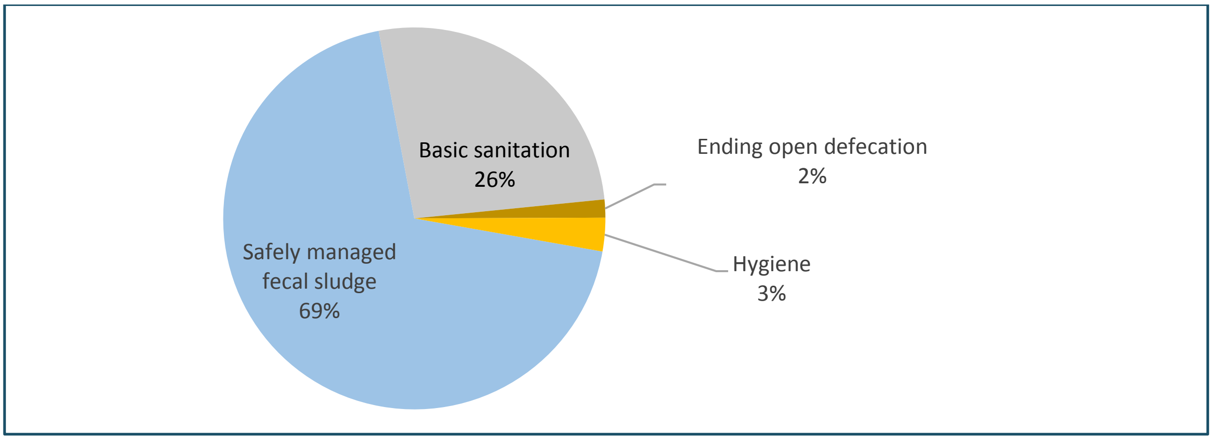


Source: Author based on (World Bank, 2016)

A total of about US$1.4 billion (R17.4 billion) would be required annually in South Africa (Figure 12) to meet the 2030 SDG sanitation targets.

The greatest proportion of this amount would be required for safely managed faecal sludge (US$971 million), followed by basic sanitation (US$370 million), hygiene services (US$40 million), and eradicating open defecation (US$21 million).

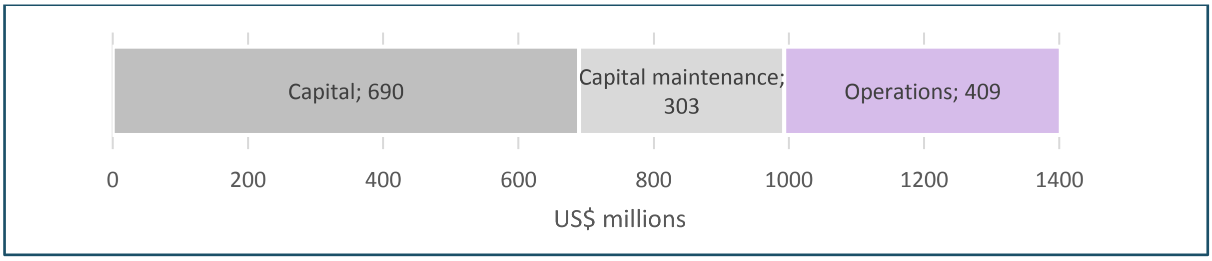
Figure 12: Annual cost breakdown by sanitation need, from 2015-2030 to address sanitation issues in South Africa



Source: Author, based on (World Bank, 2016)

By expenditure type (Figure 13), capital expenditure accounts for the lion's share (US$690 million), followed by operations (US$409 million), and capital maintenance (US$303 million).

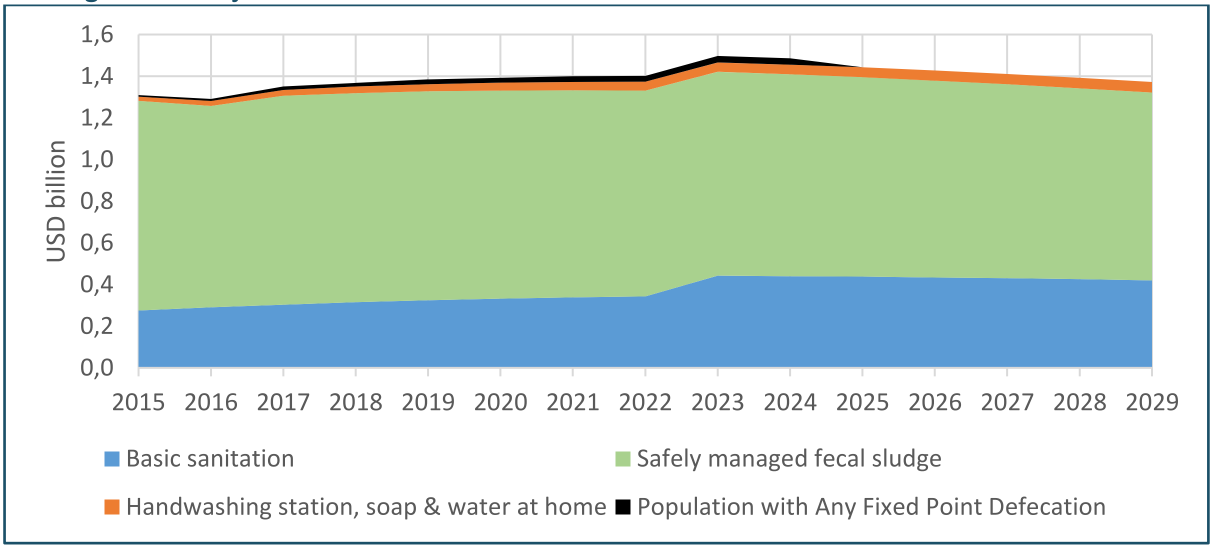
Figure 13: Annual cost (US$ million) breakdown by expenditure type, from 2015-2030 to address sanitation issues in South Africa



Source: Author based on (World Bank, 2016)

Projected costs (Figure 14) are expected to rise from about US$1.3 billion in 2015 to a peak of about US$1.5 billion in 2023, then gradually decreasing to about US$1.4 billion in 2029. Open defecation is expected to be eradicated by 2025.

Figure 14: Projected costs from 2015 to 2030 to enhance sanitation access in South Africa



Source: Author, based on (World Bank, 2016)

4. BUSINESS MODEL CONSIDERATIONS

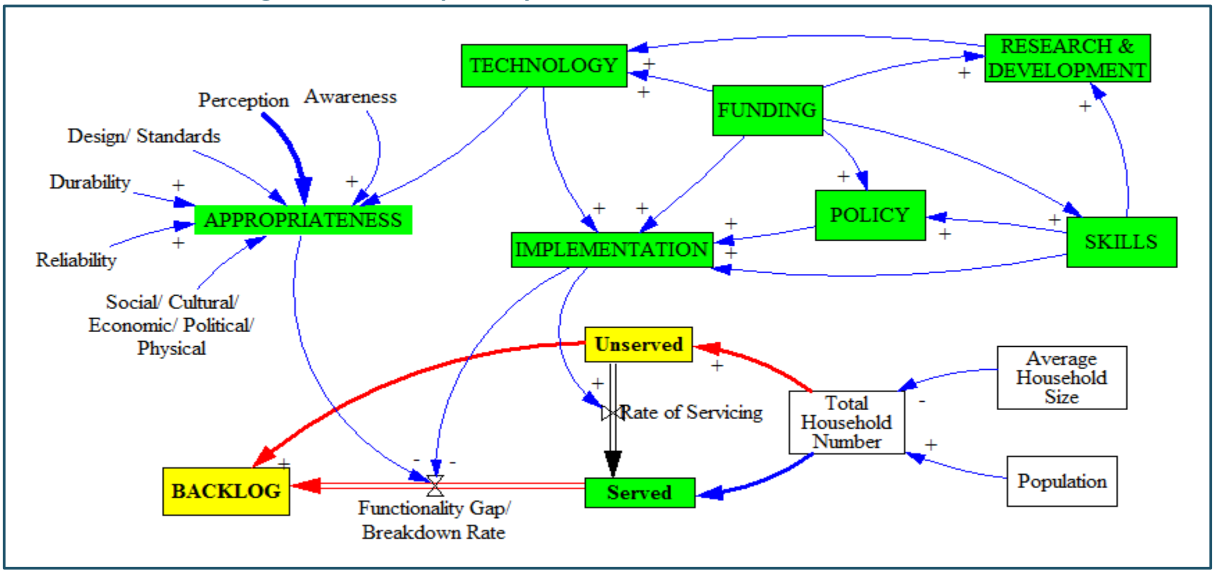
Techno-economic factors

The business model for NGS is anchored on two broad market segments. Firstly, NGS has the potential to leapfrog those who currently do not have access to sanitation services (no or inadequate). Secondly, NGS has the potential to be disruptive in the segment that have inappropriate sanitation services (e.g. waterborne sanitation in water scarce areas). To rollout out NGS technologies more widely, the reuse and recycling of water and other resources should be incentivised. About 40% of water used by households in the country is used only to flush toilets, thus the wider adoption of NGS will contribute to massive water savings.

NGS has the potential to leapfrog Africa through provision of off-grid sanitation solutions. Most parts of the continent have the advantage of planning from scratch without the burden of retrofitting. The continent is open to sanitation innovation (WRC, 2017). In addition, the potential to develop an industry that integrates urine collection and fertiliser production exists. Considering that the African continent uses low amounts of fertiliser in agriculture (usage below world average), the wider adoption of technologies, such as NGS, that promote resource recovery and fertiliser production makes business sense. However, the knowledge and acceptance gap in embracing human faeces as a valuable resource remains a key constraint.

Many factors influence sustainability in the sanitation sector and how NGS technologies would perform (Figure 15). One key aspect on the wider use of technology relates to its appropriateness in a particular setting. In other words, the functionality of a sanitation technology is key, i.e. the ability of the technology to perform the intended purpose (Isidima, 2016).

Figure 15: Conceptual systems view on the sanitation sector



Source: Author

Key issues to consider for a sanitation system are: safety, health, acceptability, environmental performance, reliability, sustainability, and reasonable cost (CSIR, 2003; Isidima, 2016; SuSanA, 2008). Appropriateness is also influenced by: the type of settlement; alternative technologies; user habits and preferences; accreditation, standards and certification system; site specific factors (e.g. water availability); cost and availability of materials; and special needs of user groups.

Financial arrangements

The availability of financial resources and how they are invested is an important determinant of the infrastructure and activities that can be implemented. The South African government plays an important role in the water and sanitation space, especially through providing financial resources. The largest proportion of the Department of Water and Sanitation's (DWS's) total budget (81%) is allocated to infrastructure development. Although, the national budget information (NT, 2017) does not show the actual disaggregated funding allocation for water versus sanitation, there has been a steady increase in expenditure for water and sanitation by government, from R10.5 billion in 2013/14 to R15.1 billion in 2017/18. This was projected to reach about R17.5 billion in 2019/20. However, these funds are inadequate considering the need to cover backlogs and provide new services.

In South Africa, the use of grants from donors and external loans is insignificant compared to the overall scale of government investment and local mobilisation of resources (DWS, DHS, & DPME, 2012; World Bank, 2011). The challenge with donor funds is their long-term availability is not guaranteed. In addition, while donor funding plays a significant role in the development and promotion of NGS worldwide, the funding is directed more at research and development (R&D), with less being available for the deployment of the technologies.

In general, the market for sanitation technologies is public sector driven and has been very conservative. Even though, in the 1980s and 1990s, South Africa was among leading countries in sewerage technologies, this capacity was lost. This is mainly due to the procurement system in the country which makes technology providers risk averse (as the cheapest tenders get selected at the expense of best technologies). As a result, there is little incentive for proposing innovative solutions.

Sanitation is a public good whose environmental and public health benefits accrue well beyond the household boundary (DWS, 2016). Such social benefits of improved sanitation tend not to be reflected in the price (externalities) that consumers are willing to pay and there is little incentive for the private sector to participate in the sanitation sector (Sy et al., 2014).

The percentage of households which pay for municipal water services in the country decreased from 62% in 2005 to 44% in 2015 (Stats SA, 2016a). In addition, in 2015, though household expenditure on water was about R15 billion, household expenditure on sanitation was far less, at about R1.5 billion. Against this backdrop, the roll-out of NGS technologies will be a challenge, particularly at the household level, as many people might not be able or willing to pay for them.

NGS is comprised of different technologies which can be applied in different settings (urban and rural) and at varying scales (single-unit or multi-unit) (Table 3). A crucial feature in South Africa's household sanitation market is the distinction between indigent and non-indigent households, which also determines who pays for the services.

Indigent households are deemed poor, hence they depend on the support from the government or other organisations, while the non-indigent have the capacity to pay for themselves. In this context, the government (including municipalities and state-owned enterprises) has a strong influence on the subsidised market (i.e. for indigent households) as well as in public sector projects, whereby it can use public procurement and regulations to stimulate demand.

The government creates a huge market through the construction of public houses and provision of sanitation services in schools. For instance, recently (14 August 2018) President Cyril Ramaphosa launched the Sanitation Appropriate for Education (SAFE) programme which is a partnership between government, the United Nations Children's Fund, the Nelson Mandela Foundation and the National Education Collaboration Trust (The Presidency, 2018). The aim is to provide innovative, safe ablution facilities at nearly 4 000 mostly rural and township schools that only have pit latrines or other inappropriate sanitation facilities. This is an important entry point for NGS as there was a call to implement appropriate sanitation-water-energy off-grid solutions.

Moreover, there is a high-end market that can also be leveraged. For instance, large property developments, such as shopping malls, community centres, and airports, can be designed or retrofitted to have off-grid sanitation systems. At such centres, it is easier to use less water and employ urine diversion for resource recovery at a large-scale.

Table 3: Characterisation of the potential market for NGS technologies

Where can it be used?	Single unit (standalone)	• Residential houses • Offices • Business premises
	Multi-unit scale (complexes)	• Residential houses • Office blocks • Business premises (e.g. shopping malls, airports, conference facilities) • Community facilities (e.g. schools, stadiums)
Who pays?	Non-indigent	• Individuals • Community • Property developers • Investors
	Indigent	• Government/ municipalities • Donor support (if available)

Source: Author

Policy and regulatory factors

Sanitation is regarded as a basic human right as enshrined in the country's Constitution. This puts pressure and strain on the government to provide for such services even when its resources are constrained. Despite the constitutional obligation, many advances made in providing adequate sanitation services are at risk of being eroded. The challenges in the sector are worsened by the fragmentation of responsibilities for sanitation at various government levels, the lack of institutional coordination and alignment, institutional inconsistency (move of sanitation responsibilities between departments), the lack of technical capacity, poor planning, high staff turnover, inadequate budget allocations for maintenance by municipalities, inappropriate use of allocated funds, and low levels of revenue collection (DWS, DHS, & DPME, 2012).

The sanitation market is highly regulated. Technical barriers arise as a result of municipal by-laws and regulations that might not allow the installation of new sanitation technologies, as they have to conform to existing sanitation regulations and by-laws (Burger, 2015). While implementing technologies in rural areas is not highly regulated, in urban areas, the building regulations are stringent. Such regulations are necessary to prevent negative health consequences on neighbours or the environment, but they to some extent limit the deployment of new technologies.

South Africa has national standards that guide the manufacture, construction and testing of some sanitation technologies, but there is currently no specific standard for the evaluation of onsite sanitation technologies (Isidima, 2016). For instance, the National Building Regulations (SANS 10400-Q:2011) focuses on non-water-borne means of sanitary disposal (SABS, 2011) though it only covers a few options that include closets, chemical toilets, ventilated improved pit (VIP) toilets. This would need to be expanded to include NGS options.

At the global level, there are some milestones for sanitation guidelines and standards, which can have implications on NGS. For instance, (WHO, 2016) launched the Sanitation Safety Planning: Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta. These guidelines influence how NGS technologies will be adopted, as such technologies will have to adhere to the sanitation system safety requirements.

In addition, there has been efforts to promote safety and standards for non-sewered sanitation systems. This includes efforts to finalise (expected to be published in October 2018) the formulation of the ISO 30 500 standard for Non-Sewered Sanitation Systems. This standard will promote the general safety and performance requirements for prefabricated integrated treatment units, comprising both front-end (toilet facility) and back-end (treatment facility), not attached to a sewer (ISO, 2017). The South African Bureau of Standards (SABS) is part of the development of the standard (technical committee ISO/PC 305), which should help with the incorporation and localisation of the ISO 30 500 standard into the South African context. The process to localise the standard in South Africa has already started. SABS and the American National Standards Institute (ANSI) held a workshop on 14 August 2018 at SABS offices in Pretoria, to share information about ISO 30500, and discuss its implementation in the country.

Socio-political acceptability

User acceptance will be central to the success of NGS. No matter how technically sound and “pretty” the solution is, if the potential user does not accept it, or is not motivated to use and maintain it correctly, it will fail (PRG, 2015).

Though significant research work is being done on low-water and no-water sanitation technologies, the main barrier to their adoption is the behaviour of users, and their acceptance and adoption of the technologies (Burger, 2015). People generally favour water-borne sanitation. Studies (e.g. Dunker and Matsebe, 2005; Jonah, 2007; Matsebe and Osman, 2012; Mkhize et al., 2017) found most people desired to own a flush toilet, which is perceived to be indicative of household wealth. Anything else other than a flush toilet tends not to be popular both from residents as well as vote-seeking politicians (Dunker and Matsebe, 2005).

The notion of embracing human excreta as a resource, rather than a waste product, helps to achieve a sustainable closed-loop system. However, some past studies (e.g. Austin, n.d.; Dunker and Matsebe, 2005; Jonah, 2007) have highlighted that the acceptability of the fertiliser value of human excreta varies.

A number of trials for various types of sanitation technologies have been undertaken. Such trials have shown that having a good design as well as maintaining building standards in deploying the infrastructure is critical for sustainable sanitation. Inferior or incorrect designs of sanitation systems can act as barriers to the acceptance of the technology (Dunker and Matsebe, 2005; Maposa and Duncker, 2018; Matsebe and Osman, 2012; Mkhize et al., 2017).

Table 4 summarises how socio-political factors can influence the adoption and usage of NGS technologies. One of the most likely risks is that if potential users are not properly informed about the technologies, they might perceive them poorly which ultimately contributes to the rejection of the technology. To mitigate such a risk, there is need to enhance awareness and provide education on the benefits of NGS. It is also necessary to promote stakeholder engagement in the whole process so as to have their buy-in.

Table 4: Summary of socio-political factors on NGS

Stakeholders	Implementation requirements	Expected benefits	Expected risks / negative impacts	Expected support or resistance	Mitigation strategies
Households/ Communities	Willingness to adopt NGS technologies	Improved health and sanitation	Poor perception of NGS, Lack of adoption, Inappropriateness to socio-economic settings	Strong resistance to alternative sanitation technologies as people favour waterborne sanitation	Improved awareness and education on the benefits of NGS; Stakeholder engagement in the whole process; User-friendly technology design
Inventors / R&D	Need to develop appropriate sanitation technologies	Uptake of the technology	Rejection of the technologies Lack of intellectual property (IP) on some of the technologies	Poor perception of the new technologies	Promote co-development of technologies with the potential users
Manufacturers	Provide the required technologies/ products at the right standard and design	More business due to higher demand	Failure of uptake or lack of demand	Poor perception of the new technologies	Promotion, advertising, and education of the potential users
Politicians	Need to conscientise the electorate on the need for sanitation and sustainability	If embraced by the users, can result in more electoral support	Users/ electorate might reject the technology as well as the people promoting it	Promotion of waterborne sanitation option as an attractive campaign strategy	Need to conscientise the politicians on the benefits of NGS so that they become champions of it
DWS / DST	Investment in NGS technologies	Improved health and sanitation	Rejection of the technologies which might contribute to the growth of the functionality gap (infrastructure being there but users not using it)	Strong resistance to alternative sanitation technologies as people favour waterborne sanitation	Improved awareness and education on the benefits of NGS; Stakeholder engagement in the whole process; User-friendly technology design. Enforcement of proper design and building standards for the technology

the dti / Department of Science and Technology (DST)	Promote the development and commercialisation of local technologies	Boast local manufacturing industries	Low uptake of local technologies/ products might affect the viability of local manufacturers	Rejection of the technologies in terms of design as well as in terms of being local products	Need support through local designation of certain products
Department of Human Settlements (DHS)	Support for NGS technologies	Improved health and sanitation for the country, through the eradication of diseases	Lack of uptake by users might result in the failure to eradicate the health hazards	Rejection or poor perception of the technologies by the users	Promotion, advertising, and education of the potential users
Department of Agriculture, Forestry and Fisheries (DAFF)	Promotion of the use of toilet resources in agriculture	Improved food security	Negative health impact if there is no proper handling and treatment of the waste	Undesirability of the food produced using fertilizer derived from toilet resources - the yuck factor	Promotion, awareness, advertising, and education of the potential users
Local government	Support for NGS technologies	Improved health and sanitation will contribute to local development	Rejection of the technologies which might contribute to the growth of the functionality gap	Strong resistance to alternative sanitation technologies as people favour waterborne sanitation	Improved awareness and education on the benefits of NGS; Stakeholder engagement in the whole process; User-friendly technology design. Enforcement of proper design and building standards
External support agencies (e.g. BMGF)	Assist the government in closing the sanitation backlog	Contribution to sustainable development	Unsustainability of donor-funded projects/ programmes especially when support is withdrawn	Donor-driven rather than people-driven hence there might be lack of local buy-in	Engaging all stakeholders in the process from the beginning to the end
Financial sector	Bridging the funding gap in the sanitation sector	Improved financial returns	Potential users might not be willing to pay for services and infrastructural development	The dependence of people on the government or outside support might reduce their appetite to access funding to meet sanitation needs	Need for alternative business models to ensure that funding the sanitation sector is viable

Source: Author

Drivers and barriers

Some of the primary drivers for NGS are: enhanced water efficiency and supply, environmental sustainability, socio-economic development, food security, and being fit-for-purpose (Table 5). A key aspect of NGS is its potential to contribute towards a circular economy. In this context, sanitation can be transformed from a costly service to a self-sustaining and value adding system of resources by embracing "human waste" as "toilet resources", which can generate economic value as well as social and environmental benefits (TBC, 2016; Winblad, n.d.).

The draft National Water and Sanitation Master Plan (NW&SMP) highlights that future approaches in the sanitation space must place more emphasis on resource recovery options (DWS, 2017a). There are case studies that support this business model. For instance, six of the 12 companies that participated in a study conducted in Ghana, Kenya, Madagascar, Rwanda and South Africa were producing and selling energy from toilet resources (TBC, 2016).

Table 5: Drivers and barriers for NGS

Factors	Explanation
Water efficiency	The technology results in improved water efficiency, notably through the reduction of water usage.
Water supply	The technology leads to an improvement in water supply, notably through the generation of new water sources.
Environmental sustainability	The implementation of the technology is driven by the reduction of environmental externalities (such as water pollution, air pollution, ecosystem degradation or greenhouse gas emissions).
Socio-economic development	The implementation of the technology is driven by its socio-economic benefits, notably in access to modern water and sanitation services and the need to ensure health and safety of the people and their environment.
Food security	The implementation of the technology has a positive impact on food security, through the use of fertiliser (in agriculture) derived from toilet resources.
Fit-for-purpose	The implementation of the technology is driven by its suitability and adequacy with the objective of addressing water and/or sanitation problems in South Africa.
Water quality	The implementation of the technology is driven by its ability to improve the quality of water supply, for example through treatment and reuse.
Energy security	The implementation of the technology is driven by benefits associated with energy security, either to energy savings or new energy generation.
Cost savings	The technology generates financial benefits, either through cost savings or the creation of new revenue streams, facilitating the rollout of sanitation services.
Ease of implementation	The technology can be easily implemented from an institutional perspective. User resistance however remain the single most stringent barrier.

Source: Author's composition

Note: NGS is assessed against a set of drivers and barriers. The drivers are classified as, a primary driving force (green coding), a secondary driving force (orange coding), a secondary barrier (yellow coding) or a primary barrier (red coding). If a factor is not relevant for a given technology (i.e. not a driver or a barrier), it is left blank. Importantly, the analysis considers the direct driving/hindering power of each factor.

5. SUPPLY DYNAMICS: MANUFACTURING AND R&D

Leading market leaders / manufacturers

Most NGS technologies are still nascent and in development. At the global level, the majority of the prominent technologies are being derived from the research funded by the BMGF through the RTTC.

Table 6 lists the leading technologies worldwide, which were showcased at the 2014 RTTC Fair held in India. This highlighting the key role of the United States (US), India and the United Kingdom (UK) in shaping NGS. Importantly though, developing countries feature strongly in the list of technology developers.

Table 7 then lists the soft technologies and related projects presented at the fair, half of which originated from India. South Africa featured one project, as discussed in the next section.

Table 6: Some of the hard sanitation technologies exhibited at the 2014 Reinvent the Toilet Fair

Product	Technology	Company	Country
Aerosan: Low-Cost Sanitation for Emergencies	Use of enhanced passive ventilation for both control of odours and also drying of excreta.	Aerosan	US
SaTo® Latrine Pan	Sanitary toilet pan designed to improve sanitation and reduce the spread of disease in Bangladesh.	American Standard Brands	US
Solar Septic Tank and Hydrocyclone Toilet	Modification of conventional septic tank technology by establishing thermophilic anaerobic conditions within the Solar Septic Tank. Consists of two main components: a top-floor standard flush toilet system, and a lower-level solar septic system. Uses hydrocyclone pasteurization.	Asian Institute of Technology	Thailand
Waterless Toilet and On-site Waste Processor	Mini Waste Processor (MWP) dries and sterilises human waste in an automatic system. The liquid portion of the human waste is evaporated, and the solid portion of the faecal sludge is heated in the evaporator/dryer/steriliser of the MWP.	Beijing Sunny Breeze Technology Inc.	China
Biofil Toilet System	Biofil Digester completely decomposes the faeces on-site, without any chemical agents. The decomposition is by a self-perpetuating population of natural macro-organisms (earthworms, beetles, snails, black soldier fly) and micro-organisms.	Biofilcom	Ghana
Caltech's Self-Contained, PV-Powered Domestic Toilet and Wastewater Treatment System	Uses the sun (or can connected to the electrical grid) to power an electrochemical reactor. The reactor breaks down water and human waste into fertiliser and hydrogen, which can be used in hydrogen fuel cells as energy. The treated water can then be reused to flush the toilet or for irrigation.	California Institute of Technology (Caltech)	US
Conversion of human waste into biochar using pyrolysis at community scale facility in Kenya	A community-scale sanitation reactor designed to convert human waste into biochar without the use of external water or electricity.	Climate Foundation, Cornell University, Sanergy, Tide Technocrats, and the Prasino Group	US
The Nano Membrane Toilet	Accepts urine and faeces as a mixture, then flushes using a unique rotating mechanism to transport the mixture into the toilet without demanding water while simultaneously blocking odour and the user's view of the waste.	Cranfield University	UK
DRDO Biotoilet	Comprises of a specially designed anaerobic tank (biotank) and a natural secondary treatment bed (reed bed) for effluent water. Uses a highly efficient microbial consortium that digests human faecal matter into colourless, odourless gases and effluent reusable water.	Defence Research Laboratory, Defence Research & Development Organisation, Indian Ministry of Defence	India
Sanir: Upgrading human waste with plasma-driven gasification	Part of the Omni-Processor development programme developing a processing facility that consists of a Microwave Plasma Gasification process to generate electricity out of dried faeces which is fed into the gasifier.	Delft University of Technology	Netherlands
"Soch"alaya – The Thinking Toilets	Addresses diverse sanitation domains. Includes public toilets for coastal areas that harness wind energy, use local materials and finally use human waste as a resource, and domestic toilets for waterlogged areas that provide a solution at site using a system of recyclable plug-in units.	Department of Industrial Design, School of Planning and Architecture Delhi	India

Anaerobic Digestion-Pasteurization System	Anaerobic digestion converts toilet wastes to biogas (i.e., methane + CO_2). No urine diversion, separation or other pre-processing of the waste is needed.	Duke University	US
Neighborhood-Scale Treatment of Sewage Sludge by Supercritical Water Oxidation (SCWO)	SCWO process relies on high pressure and temperature. Waste (faeces and urine) is compressed, heated and mixed with an oxidant (in this case air) and supercritical water (recycled internally in the process). The high pressure and temperature promote rapid conversion of the organics in the waste. Clean water, CO_2 and excess energy are released.	Duke University and the University of Missouri	US
Blue Diversion	A grid-free dry diversion toilet, which provides water for flushing, hand washing and personal hygiene (for washers and for menstrual hygiene). Undiluted urine, faeces, and flush and-wash water are collected separately below the pan.	Eawag (Swiss Federal Institute of Aquatic Science and Technology), Design by EOOS	Switzerland
eToilet Imperial Model	Unmanned eToilets with remote monitoring via GPRS that enable online tracking of the unit's health status, usage and income.	Eram Scientific Solutions Pty. Ltd.	India
The Fecal Sludge Omni-Ingestor (FSOI)	Enable emptiers to pump waste from vaults 50 to 100 meters from the roadside, giving them access to over 92% of the vaults in peri-urban spaces. Capable of emptying the majority of the contents of both wet and dry vaults.	FSOI Development Firms: AGI Engineering, Beaumont Design, DCI Automation, and Synapse Product Development	US
The Earth Auger: Urine Diverting Dry Toilet	UDDTs have foot actuated compost mixing and movement, and optional dry flush and sawdust addition operations. Uses auger composting.	Fundación In Terris and Critical Practices LLC	Ecuador
Zero Discharge Toilet System	Uses a solid-liquid separator. The solids gradually disintegrate to form slurry, which is then fed to the bio-composter. The liquid is clarified adopting flocculent settling using enzymes and polymers extracted from naturally available fungi and other microbes.	Indian Institute of Technology Kanpur	India
Omni-Processor	A 300 kW combined heat and power plant that uses faecal sludge.	Janicki Industries	US
Loowatt Toilet	Seals human waste in a biodegradable film for easy transfer to a locally sited anaerobic digester. The Loowatt System produces energy and fertiliser in several steps including mesophillic anaerobic digestion, thermophillic aerobic composting, and vermicomposting.	Loowatt	UK
Reinventedtoilet@lboro	Based on minimizing flush volumes and processing waste using hydrothermal carbonisation with basic "pressure-cooking."	Loughborough University	UK
Low-cost Decentralised Sanitary System for Treatment, Water and Resources Recovery	Transforms faeces into a biological charcoal (biochar) through pyrolysis, recovers urine and cleansing water into clean water, and produces fertilisers from concentrated urine	National University of Singapore	Singapore
Hygienic Pit Emptying Using a Modified Auger – "The Excrevator"	Low-cost auger-based technology that can reliably and hygienically empty a wide variety of pit latrines and septic tanks (pits) with waste that ranges from high water to high trash content.	North Carolina State University	US
RTI system	Has four core technology components: solid liquid separation and solid waste drying via convection (using heat from combustion), electrochemical disinfection of the liquid waste, combustion of the	RTI International	US

	solid waste (down-draft gasification), and thermoelectric energy harvesting. Uses combustion and electrochemical process.		
GF-1 All Solar Unit	Self-contained, solar-powered restroom facility equipped with a mixed content toilet facility and a urine-only urinal facility. Accepts faecal material, urine, and waste paper for processing.	Santec	US
Ecosan UDDT (Ecological Sanitation Urine Diversion Dehydration Toilet)	The nutrients in human waste is recovered and is used for increasing farm productivity.	Society for Community Organization and Peoples Education	India
Aerobic Biological Toilets	Has a multi-chambered bio digester tank in which the wastes are stored and flows from one chamber to another by a special process whereby the multi-strain bio media present in the tank can digest the wastes and convert them fully into non-toxic, non-pathogenic neutral water.	Stone India Limited	India
Sulabh Effluent Treatment System	The effluent from human excreta-based biogas plants turns into colourless and odourless liquid manure with low BOD and minimal pathogens. The effluent is filtered through activated charcoal followed by disinfection with ultra-violet rays.	Sulabh International Social Service Organisation; Sulabh Sanitation and Social Reform Movement	India
Oya	Takes in human waste alongside other waste which will be converted to electricity, soil improver and water. Uses pyrolysis, which renders the waste pathogen-free and produce energy in the form of either heat or electricity. Can serve a community of more than 2 250 people.	Unilever	UK
Sol-Char System	Uses concentrated solar energy from parabolic dishes to transform both faecal material and urine into safe to handle, commercially viable end-products (e.g., solid fuel, heat, and fertiliser). Faecal material is transformed into char, which can be used as a soil amendment or as solid fuel, while urine is thermally treated to produce nitrogen-rich fertiliser.	University of Colorado Boulder	US
Sanitation NoW!	Solid and liquid streams are separated using a passive diversion interface, gravity drain, and a sand filter. The solid waste is mixed with sand and conveyed into a chamber where further mixing and drying occur. Solar power is used to electrically ignite the dried solid waste, which is then disinfected through smouldering, a flameless combustion process that works similarly to a coal barbecue.	University of Toronto	Canada
Urine-tricity	Urinal facility with integrated MFC (microbial fuel cell) technology for mobile phone charging. The MFC is a bio-electrochemical transducer that generates electricity as a natural respiratory by-product of live metabolizing microorganisms.	University of the West of England, Bristol	UK

Source: BMGF (2014); Kone (2017); Pillay (2018)

Table 7: Soft sanitation technologies/projects exhibited at the 2014 Reinvent the Toilet Fair

Product	Technology	Company	Country
Data Acquisition and Field Support for Sanitation Projects	Characterises the physical and chemical properties of excreta streams from dry on-site sanitation systems or from decentralised low-water consuming sanitation systems. The data will be passed to other RTTC grantees for use in their research.	Pollution Research Group, University of KwaZulu-Natal; eThekwini Water and Sanitation, eThekwini Municipality	South Africa
Partnering with Mission Convergence An Innovative Governance Reform Programme in Delhi	Facilitates a process of strong and effective advocacy, led by women's forums and community structures supported and mandated by the government with the aim of developing women friendly sanitation services.	Centre for Advocacy and Research	India
Performance Improvement Planning Model	Uses Service Level Benchmarking indicators and additional indicators for improvement planning. It consists of three basic modules: Performance Assessment, Action Planning, and Financial Assessment.	Centre for Environmental Planning and Technology (CEPT) University	India
A Platform for Integrated Sanitation Investment Planning	A Proof-of-Concept decision support tool to facilitate an integrated approach to the sanitation investment planning process for urban local bodies. It seeks to enable users to understand and improve the sanitation situation of a city/ward. This will be facilitated through an interactive visual interface which will allow a comparison of existing and new sanitation systems.	Center for Study of Science, Technology and Policy	India
Scaling City Institutions for India: Sanitation (SCI-FI: Sanitation)	Aims to inform and support the formulation and implementation of the Government of India's urban sanitation programmes and investments and State government urban sanitation policies/ programmes to be output based and proactively supportive of alternative technologies and service delivery models.	Centre for Policy Research, New Delhi	India
Project Sammaan	Combines principles of design, research and technology to propose a new model for community sanitation with an aim to reduce open defecation and instil a sense of dignity in the community using these facilities. Assists physical infrastructure of toilets and the associated management systems.	Institute for Financial Management and Research and Quicksand Design Studio	India
WASHCost Calculator	Evaluates the life-cycle costs of sanitation and water services. Users fill in expenditure and service data about the case, with the option of using WASHCost benchmarks. It generates a comprehensive report with an evaluation of capital and recurrent costs, affordability to households, and service levels. Results are easily shared, and reports are designed to facilitate discussions about financing services and collecting missing data.	IRC International Water and Sanitation Centre	Netherlands
Supporting Sustainable Sanitation Improvements in Bihar (3 Si)	Provides access to desirable latrines for the various segments based on their paying capacity in rural households of Bihar province of India.	Population Services International, Water For People, and PATH	India

Fresh Life Toilet	Franchise a dense sanitation network of clean toilets, collect the waste, and convert it into valuable by-products. This creates financial opportunity while solving a critical social and environmental challenge.	Sanergy	Kenya
'S' is for Sanitation	A multi-media intervention to promote positive sanitation and hygiene behaviours in children ages three to seven and their caregivers in Bangladesh, India, and Nigeria. Provides crucial sanitation and health messaging on latrine use, wearing footwear to the latrine, hand washing to break the faecal-oral route of disease transmission, and the safe treatment and storage of water.	Sesame Workshop	US
Take Poo to the Loo campaign	Seeks to persuade toilet users to raise their voice to influence public opinion in support of an end to open defecation in India.	UNICEF (United Nations Children's Fund) India	India
NewSan Prototype Simulator	A computer-based simulator that analyses material flow to simulate resource fluxes related to human excreta from household to final disposal/reuse. Can assist city engineers and planners to assess resource/energy recovery potential of different options of sanitation systems.	University College London and ifak	UK, Germany
Innovation in Sanitation Advocacy	WASH United harnesses the power of fun, sports stars, interactive games and strictly positive communication to raise the profile of sanitation at scale. With World Toilet Day, the World Toilet Organization has created the most prominent advocacy platform for sanitation at the global level to help break the toilet taboo.	WASH United and World Toilet Organization	Germany and Singapore
Selling Sanitation	Seeks to catalyse the consumer market for sanitation to help millions of Kenyans to access sanitation products and services. Has two phases: (i) supporting the design and testing of a range of suitable sanitation and hand-washing products and the market development strategies required to support their sale, and (ii) scoping additional regional opportunities to catalyse sanitation market-based approaches at scale in East Africa.	World Bank Water and Sanitation Program, International Finance Corporation, and Kenyan Ministry of Health	Kenya

Source: BMGF (2014)

Research, development, and innovation (RDI) in South Africa

South Africa has a long history of innovation in the sanitation sector and the country has realised notable R&D for sanitation technologies (see Appendix, Table 11). Great strides have been made in a number of areas, including biological nutrient removal wastewater treatment works (WWTW), the use of algae in wastewater treatment, the application of constructed wetlands for wastewater treatment, struvite recovery, faecal sludge re-use, and ecological on-site sanitation systems (DWS, 2017a).

The draft National Water and Sanitation Master Plan indicates the direction that the country needs to take to enhance access to sanitation. It emphasises the need to conduct R&D of alternative and water-less sanitation solutions as well as the overall development of an innovation-based water and sanitation industry. It notes the need to implement the reduction of water requirements of sanitation systems in both new projects as well as retrofitting of established systems. Some of the targets in the draft Masterplan are shown in Table 8.

Table 8: Focus areas and targets for sanitation in the National Water and Sanitation Master Plan

Focus area	Role players	Target date
Resource recovery from WWTW for agriculture	Water Services Associations (WSAs); DAFF; DWS; Department of Health, private sector	2024
Water re-use for industry and mining	WSAs, the dti; Department of Mineral Resources, DWS, private sector	2014
Energy efficient WWTW	DWS; WRC; Council for Scientific and industrial Research CSIR, municipalities, private sector	2030
Low water flushing latrines	DWS; WRC; CSIR	2030

Source: DWS (2017a, pp. 5–47)

Although there has always been innovation in the sanitation sector, this has been relatively low compared to other sectors, particularly its main counterpart – water. Broadly, urban sanitation has not seen significant innovation (BCG, 2014). Innovation has generally focused on customer comfort and convenience with relatively less emphasis on significant technical improvements.

South Africa has significant expertise in sanitation technologies, though currently there is no notable manufacturing[4] of NGS technologies. However, there are various technologies that fit the NGS criteria, which are at various stages of development and testing, and there are efforts to enhance their manufacturing and commercialisation (Table 9).

Table 9: Potential technologies (not exhaustive)

Technology	Company
Unisex Urinal	Liquid Gold
UD with auger and pyrolysis	BAAS Technology & Consulting
Pour Flush	Partners in Development
Solar Toilet	Congretype Pty.Ltd
Toilet bowl coating	Coco Solution
Microflush toilet	Isidima Design and Development
Enhanced Hydrothermal Carbonisation	TruSense

Source: WRC & DST (2018)

[4] Some of the prominent technologies in the country have generally been described as first-generation sanitation technologies, e.g. the early version of the urine diversion toilets.

Other key technologies are highlighted in the Sanitation Innovation Challenge (SanIC) report (PRG, 2015). Of the 56 technologies reviewed; 16 of these technologies were rated as promising (Table 10). Although some of the technologies are not whole NGS systems, there is potential to combine and complement different frontend and backend components so as to enhance the localisation in the rollout of NGS technologies.

Table 10: Some of the technologies that received average Expert Panel review scores of 7 out of 10 and above in the SanIC review

Technology	Type	Brief Description	Manufacturer
EcosSan Waterless Toilet	Whole system	Dehydrates, evaporates and deodorises human waste for use as compost / fuel / disposal	G-Trade International
Enviro Loo	Whole system	A waterless dehydration toilet - separates liquids & solids on a drying plate.	Enviro Options
Low flush	Whole system	Flushing toilet where there is no sewer connection. Discharges to 2 chamber septic tank	Calcamite Water & Sanitation Solutions
Biofil Wastewater Treatment Technology	Whole system	A microflush toilet linked to a biofil digester	Biofil Technologies
Wetloo	Whole system	A flushing toilet using an anaerobic system to treat wastewater for reuse	Calcamite Water & Sanitation Solutions
EaziFlush	User end	Modular flushing system with natural wax on p-trap to prevent sticking	EnviroSan Sanitation Solutions
Biocore	Processing	A jet mixer used as mixer or aerator	BioPower Corporation
Biocoal	Processing	System to pelletise waste and convert to a fuel source	BioPower Corporation
Blivet Package Plant	Processing	Compact, modular, covered treatment facility based on rotating biological contact	Bannow Africa
Septic tank with Biomat	Processing	A septic tank using a biological mat (Biomat) soak away	Calcamite Water & Sanitation Solutions
Nano Biodigester System	Processing	Use of nano technology, high aeration multi strain bacteria to treat WW to standards	Waste Intrique Services
#1 Button	Retrofit	Retrofitted button operated device to convert single flush toilet to dual flush	Atinov

Source: (PRG, 2015, p. 5)

There are also opportunities for the country to access certain technologies that can be localised under the global access policy of the BMGF. The BMGF seeks partners along the value chain to bring technologies to market (Kone, 2017). This can help establish local assembly, manufacturing, as well as commercialising and targeting distribution, logistics, maintenance, and operation. Already, there are partnerships which the country can leverage. This includes the partnership of BMGF with the WRC and the DST. The Pollution Research Group (PRG) of University of KwaZulu-Natal also plays an important role in the Reinvent the Toilet initiative by offering a testing platform for NGS technologies developed in other participating countries.

A number of activities are being undertaken in the country that seek to promote the development and industrialisation of sanitation technologies in the country. The second phase of the South African Sanitation Demonstration Programme – Accelerated Industrialisation Plan (SASTEP II AIP) led by DST will be launched soon. This programme is critical in the rollout of NGS technologies as it focuses on scaling-up the manufacturing and deployment of the technologies (WRC & DST, 2018). Already, a planning workshop was convened on 17 August 2018; it was attended by a number of stakeholders including those from DST, WRC, the dti, TIPS, PRG, and eThekwini Municipality. The SASTEP II AIP intends to operationalise the dti's IPAP strategy on NGS (the dti, 2017). Some of the key activities will be scanning and selecting technologies, commercial partner matchmaking, partnership development, and marketing.

Other programmes that are already underway include the Water Technologies Demonstration Programme (WADER), a collaboration between the DST and the WRC, provides support for technologies at demonstration stage (DST and WRC, 2017). It seeks to enhance applied research, development, and the pre-commercialisation stages of the water and sanitation innovation continuum.

The 2015 National Sanitation Indaba showcased three sanitation-technology demonstration sites around eThekwini Municipality, namely: Besters Pit Emptying Project; Inanda Community Blocks; and Newlands/Mashu Valorisation of Urine Nutrients in Africa VUNA – DEWATS (Decentralised Wastewater Treatment Systems) and Agriculture Project (DWS, 2015). In addition, the Sanitation Innovation Challenge programme focused on technical evaluation and demonstration of appropriate sanitation technologies (see Table 10 on page 33). A Household Sanitation Technology Assessment and Evaluation Protocol was also developed, which is important for the evaluation of technologies, based on sound process design principles and extended field trials (Isidima, 2016).

The PRG, a recipient of the BMGF's Reinvent the Toilet Challenge grants since 2009 (BMGF, 2013) as well as WRC funding, has been undertaking substantial R&D on water resources, waste water reclamation, sanitation systems, and other water-related environmental issues. The PRG has collaborated with the eThekwini Water and Sanitation Division on a number of international collaborative research projects, including VUNA, Mechanical Properties of Faecal Sludge, Reinvent the Toilet Challenge, co-digestion of sewage sludge and industrial concentrates; characterisation of on-site sanitation material and products; and DEWATS. In Newlands-Mashu, it co-developed the LaDePa machine for drying and pelletising faeces (UKZN, 2018).

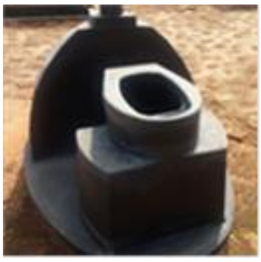
At the 2014 RTTC Fair in India, the PRG and eThekwini Water and Sanitation showcased their project on "Data Acquisition and Field Support for Sanitation Projects". This project helps characterise the physical and chemical properties of excreta streams from dry on-site sanitation systems and decentralised low-water consuming sanitation systems. The data generated is meant to benefit other RTTC grantees in their research. The PRG was also awarded a capacity grant by the BMGF to expand and upgrade its laboratory and office facilities, so as to provide technical support and testing of some of the prototype systems developed by grantees under the RTTC. Already some NGS technologies are being tested at the facility.

There are other organisations that also play an important role in South Africa's sanitation R&D space e.g. the CSIR (see Box 1 on page 35).

Box 1: The Sanitation Technology Demonstration Centre

The Sanitation Technology Demonstration Centre, established by the CSIR and the WRC, is located at the CSIR Built Environment Innovation Site in Pretoria. Open to all, the centre showcases full-scale examples (provided by manufacturers or the CSIR itself) of sanitation products and technologies available in South Africa. Various technologies that entail both conventional and improved systems are on display. However, none of them qualifies as NGS. These include dry sanitation, urine diversion and/or separation technologies, water-borne systems, ecological sanitation, and handwashing facilities. The specific technologies on display in various exhibition areas are listed below.

Exhibit area A • Lined pit • Unlined pit • Slabs for VIP toilet • Fossa Alterna toilet • Calcamite VILPshould this be VIP? • Conloo lined pit	Exhibit area B • Ballam-Waterslot VIP toilet • Blair toilet • VIP toilet • HSO VIP toilet • ROCLA VIP toilet • EldoLoo for the Physically Challenged • Cobroloo • Lightweight concrete toilet • Conloo	Exhibit area C • Ecosan toilet • Double vaults for UD toilet • Calcamite PET technology • EldoLoo sealed pit system • Calcamite Eco-mite technology • Enviro Loo technology • ZerH2O Waterless Toilet technology
Exhibit area D • UD toilet • EldoLoo UD System toilet • Enviro Loo toilet • African Sanitation UDD toilet • ZerH2O Waterless toilet	Exhibit area E • Calcamite Bio-mite system • Calcamite Low-flush Toilet • Biofil digester • Calcamite Bio-mite Recycling System • NWS bacterial toilet • Various septic tanks and digesters • Various components for water-borne sanitation	



Source: Author, based on WRC and CSIR (n.d.), Maposa and Duncker (2018) and photos taken during site visit on 17 April 2018

6. POLICY IMPLICATIONS

The rollout of NGS technologies remains marginal (globally and in South Africa), the technologies are mostly at an R&D stage. This implies that many things are still not known about their performance, reliability, and their economic and financial viability. As of now, it is not yet possible to make a proper comparison with conventional sanitation technologies in terms of capital and operating costs, since the necessary information on prices and other variables is not yet available. However, NGS has the potential to leapfrog those who currently do not have access to sanitation services. At the same time, NGS has the potential to be disruptive in the segment that has inappropriate sanitation services. Thus, the wider adoption of NGS will contribute to massive water savings as well as grow the circular economy.

Indeed, much more R&D and testing is required in this space, notably to develop adequate solutions suited to the local context. The technology has to meet the needs of the users (robust and reliable) and the sanitation system should also fit into the socio-economic context of users. The deployment of NGS technologies has to be informed by sound evaluation and intensive field trials.

In general, the adoption and use of sanitation technologies tends to be significantly hampered by the lack of user acceptance and the overwhelming desire to use conventional flush toilets. Therefore, more effort is required to improve user awareness, positive perception, and acceptance of NGS technologies. There is need to transform how people view human excreta and sanitation processes, in particular the view that waterborne sanitation is the best solution, regardless of water availability.

Once appropriate technologies have been developed, tested and accepted, demand will have to be stimulated through local procurement as well as aligning the building guidelines, norms and standards, and municipal bylaws. Standards for the construction of new buildings (similar to existing regulations in terms of energy efficiency) could be considered to spur the rollout of NGS in the country. There is need to enhance the development of standards, testing, and validation of NGS technologies. In this regard, efforts by SABS to localise the ISO 30 500 standard on Non-Sewered Sanitation Systems, should embraced and enhanced by all stakeholders including sanitation technology developers, building industry, regulators, and municipalities. The dti needs to play an important role in the designation (for local content) of the relevant technologies.

To realise significant adoption and enhanced functionality of the technology, the strengthening of skills and training around the installation, operation and maintenance of NGS technologies is needed, as some of these might be more complicated than conventional sanitation technologies. This also relates to companies that will be involved in the manufacture of the technologies. They need to have the necessary skills, labour, and capacity to produce and deploy the technologies. This requires upskilling and reskilling of planners, plumbers and technicians.

NGS technologies are mostly at development stage, with few that are ready for the market. Thus, it is important to enhance local capacity, through increasing funding towards the development and manufacturing of local NGS technologies, particularly to ensure that such technologies are suitable for the local context. In collaboration with the testing facility at the PRG, the development and localisation of NGS technologies would provide the platform to manufacture for the country and beyond.

7. CONCLUSION

A significant proportion of people still require proper sanitation services in South Africa, on the continent, and globally. In line with SDG sanitation targets, about 32 million people in South Africa would require safely managed sanitation (i.e. safe extraction, conveyance, treatment and disposal of human excreta) from 2015 to 2030. Close to one million people would need services to end open defecation, the most urgent problem. A total of about US$1.4 billion (R17.4 billion) is required annually in the country to meet these targets. Globally, about 1.1 billion people would need services to end open defecation. At the same time, about 3.4 billion people would need access to basic sanitation services, and about 5.3 billion people would need to be provided with safely managed sanitation services. A total of about US$120 billion is required annually to meet these 2030 SDG sanitation targets in the world.

Given the inadequacies in the current sanitation system, there is a potential market for NGS technologies. In other studies, the global opportunity for NGS was estimated at more than US$8 billion a year. However, the size of the market could be much bigger if we consider the proportion of people that do not have sanitation services, those that have but the services are inadequate, and those whose services are inappropriate (i.e. waterborne systems in water scarce areas).

NGS has the potential to be a disruptive technology. If properly embraced, it can significantly transform the sanitation landscape and leapfrog the previously unserved and underserved communities.

As a new field, there is need for the country to take front runner advantage. Though South Africa has a strong RDI background on conventional sanitation, the country needs to be more active in order to capture the opportunity offered by NGS to industrialise. There has been increased and converging efforts by various organisations to promote the development of NGS in the country, providing valuable platforms to leverage.

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APPENDIX

Table 11: Various sanitation technologies present in South Africa

Technology	Brief description (when available)	Manufacturer
#1 Button	Retrofitted button operated device to convert single flush toilet to dual flush	Atinov
Co	Biodigestor and filter	Free Energy Living
AFRISAN Waterless self-contained toilet	Dehydration and aerobic sanitation technology	African Sanitation Group
Andy Loo	Waterless toilet – faeces deposited in a heat-sealed, self-cleaning, revolving receptor, while urine is collected in a sump in the ground. The faeces are then incinerated, using heat from an automatically fed biomass briquette-burning combustion chamber.	Ben Mfazwe (Inventor)
Arumloo toilet	Sets a new standard in efficiency, capable of flushing on less than two litres of water.	Arumloo (Pty) Ltd / Isidima
Auger toilet with liquid/solid separation	Desiccation	EnGenius Green Solutions
Basic sanitation (dry / wet)	Various: Water tanks, wastewater treatment	Calcamite
Biocoal	System to pelletise waste and convert to a fuel source	BioPower Corporation
Biocore	A jet mixer used as mixer or aerator	BioPower Corporation
Biofil Wastewater Treatment Technology	A microflush toilet linked to a biofil digester	Biofil Technologies
Blivet Package Plant	Compact, modular, covered treatment facility based on rotating biological contact	Bannow Africa
Bubbler Water Efficiency System	Membrane-Bio	Bubbler Pty Ltd
Clarus Fusion	Package Plant	Maskam Water
Composting Solar Powered Toilet	Desiccation	BathoPele Sanitaiton
Crappery Caterpillar and Porta potti	Collection and containment system similar to bucket system with a plastic liner which is removed and taken to disposal area	WASTE
EaziFlush	Modular flushing system with natural wax on p-trap to prevent sticking	EnviroSan Sanitation Solutions
Ecoloo toilet	Decentralised closed loop system, odour free, water free, sewage free, chemical free, energy free, sustainable, on-site biological and organic fertiliser generating waste treatment.	Ecoloo Group
Ecomite, Low Flush, Wetloo		Calcamite Water & Sanitation Solutions
EcosSan Waterless Toilet	Dehydrates, evaporates and deodorises human waste for use as compost / fuel / disposal	G-Trade International

EcoSan Waterless Toilet	A water free system that does not require sewage pipe network and treatment plants.	ECOSAN
Eldoloo for the physically challenged		Eldocrete
Eldoloo UD tank		Eldocrete
Emergency Sanitation Operation System	Membrane-Bio	UNESCO
Enviro Loo	A waterless dehydration toilet - separates liquids and solids on a drying plate.	Enviro Options
EnviroLoo dry sanitation system	Waterless toilet system	EnviroLoo
EnviroSan Eaziflush	On-site low flush unit	EnviroSan
Fibreglass pour flush	On-site low flush unit	Partners in Development
Flexigester	A butyl rubber cylinder which anaerobically treats faecal matter to produce biogas and stabilised sludge	WASTE, The Netherlands
Flush tech	An alternative to VIPs	BioPower Corporation
Flushing toilet with AnMBR	Membrane-Bio	ETE Solution
GUESS Green Universal Eco Sewerage System	Package Plant	Poly Phoenix Fibreglass Products cc
Humanure	Compost	Bioresources Engineering University of KwaZulu-Natal (UKZN)
Lightweight movable superstructure		University of Pretoria
Low flush	Flushing toilet where there is no sewer connection. Discharges to 2 chamber septic tank	Calcamite Water & Sanitation Solutions
Lusec sanitation solution	A sustainable solution to sanitation and recycling, without water. Produces struvite that can be used as fertiliser.	Bike and Barrow
Mtee Designs	Low Flush	DUT
Myfast 160	Attached growth reactor	Tupelovox
Nano Biodigester System	Use of nano technology, high aeration multi strain bacteria to treat WW to standards	Waste Intrique Services
New World Water Sanitation	Low footprint wastewater treatment works	Bubbler Pty / NWWS
NIC and Repit	Chemical	Sanitech toilet hire
Peepoobag and kitty		Peepoople
PET, Low-flush, Bio-Mite		Calcamite
Polyrib septic tank		Ballam-Waterslot
Polyrib VIP		Ballam-Waterslot

Pour-flush toilet		Envirosan
PQ Green Eco Porta Loo	Compost	PreQuip Green Pty Ltd
Pureleau WWTP	Decentralised WWTW for 250 to 15 000 people. Treatment of waste using a sequence batch reactor (SBR)	Buccon Industries, The Netherlands
Redivac vacuum	Vacuum sewer technology	Prolific Consulting
SavyLoo toilet	Dry toilet with l/s separation	Pennine Energy Innovation
Self-sustained bacterial toilet and waste system		New World Sanitation (NWS)
Septic tank with Biomat	A septic tank using a biological mat (Biomat) soak away	Calcamite Water & Sanitation Solutions
Septic tanks		Pioneer Plastics
SmartSan Digester	On-site low flush unit	Nano Water Technologies Africa
SmartSan Recycle Digester	Membrane-Bio	Smart San
UD toilet		Ecosan
UD toilet		Enviroloo
UD toilet (flying saucer)		Zerh2O waterless toilet
Vacuum toilet	Low Flush	Enactus UNISA
Vetiver grass Latrines	Modified pit latrine with Vetiver grass planted around it	Wandima Environmental ervices
VIP		HSO
VIP and UD pedestals, handwashing basin		Atlas Plastics
VIP superstructure		ROCLA
VIP superstructure and pit		Conloo
VIP toilet superstructure		Cobro Concrete
Waterwise Toilet	Desiccation	Madibeng Water Services
Wetloo	A flushing toilet using an anaerobic system to treat wastewater for reuse	Calcamite Water & Sanitation Solutions
WHC leak-less valve	Leak-less valve	Water, Hygiene, Convenience

Sources: PRG, 2015; DWS, 2015a; Isidima, 2016; DST and WRC, 2017; Maposa and Duncker, 2018