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Reinvented Toilet: Literature Review, Opportunity and Unit Economic Analysis

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List of Abbreviations

BHK	Bedroom Hall Kitchen
BMGF	Bill & Melinda Gates Foundation
CAPEX	Capital Expenditure
COD	Chemical Oxygen Demand
CSS	Centralized Sewer Systems
FSM	Faecal Sludge Management
G2RT	Generation 2 Reinvented Toilet
HH	Household
HMI	Human-Machine Interface
IHHL	Individual Household Toilets
LPCD	Litre per Capita per Day
MURT	Multi Unit Reinvented Toilet
NSS	Non-Sewered Sanitation
OSS	On-Site Sanitation Systems
OPEX	Operation and Maintenance Expenditure
RT	Reinvented Toilets
RTTC	'Reinvent the Toilet' Challenge
R&D	Research and Development
SAIT	Samsung Advanced Institute of Technology
SBM	Swachh Bharath Mission
SDG	Sustainable Development Goal
STP	Sewage Treatment Plant
SURT	Single Unit Reinvented Toilet
TN	Total Nitrogen
TP	Total Phosphorus
WWTP	Wastewater Treatment Plant

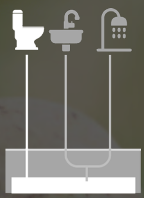
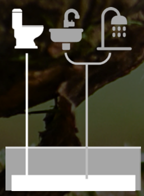
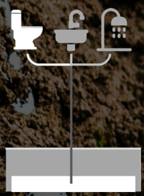
Executive Summary

The future is on-site sanitation systems with no need for transportation of faecal sludge, where septage gets treated at point of generation and there is no lag between generation and treatment thus preventing spread of harmful diseases and saving lives. Hence, the possibility of deploying a Reinvented Toilet (RT) product for developing countries which treats waste at a community level and then at toilet level was assessed in the current research.

A RT is a modification of the existing toilet embedded with modern technology such that it not only collects the waste but also treats it on-site. The RT kills pathogens, does not need a sewerage connection or septic tank, requires no input water and outside electricity, and converts human waste into safe by-products like clean water and ash.

The key objectives of the current research were to examine all the available reports, studies done or in progress for RT and create a detailed proposal for opportunity analysis for RTs and its unit economics. Moreover, the landscape of the RT covering the history, types of RT, existing RT technologies, were studied in the current research.

In the current research, a residential community of 300 apartments in 20-floor building was explored for investigating the plumbing cost savings due to RT. The five scenarios were developed having different combinations of 3 BHK, 2 BHK and 1 BHK. For 3 BHK, 2 BHK and 1 BHK, the built-up area was 1,670, 1,081and 790 Sqft, respectively. For 3 BHK, 2 BHK and 1 BHK, the number of persons per household were 6, 4 and 3, respectively. Also, for 3 BHK, 2 BHK and 1 BHK, the number of toilets per household were 3, 2 and 1, respectively. In all five scenarios, number of units on one level, the number of floors above ground and total units were 15, 20 and 300, respectively. The plumbing cost savings due to RT ($/toilet) in all five scenarios for four different conditions are given below:

	Piping option	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP) ($/toilet):	$87	$89	$84	$86	$72
	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP) ($/toilet):	$87	$89	$84	$86	$72
	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP) ($/toilet):	$71	$72	$70	$69	$59
	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP) ($/toilet):	$71	$72	$70	$69	$59

Above estimation is just one example in a specific segment (residential community of a particular size). The analysis of displaced costs should be conducted for multiple segments in the next proposal.

Introduction

This section provides background information on the innovative sanitation systems that open up a new route to universally safe sanitation.

Background

4.5 billion people worldwide lack access to properly run sanitation systems. Inferior water and sanitation conditions are responsible for 80% of diseases in developing nations. It is very likely that better sanitation will reduce human misery. To meet the Sustainable Development Goal (SDG) target of safely managed sanitation by 2030, more rapid advancement is needed[1].

Existing Sanitation Systems:

Current sanitation systems enlisted below have serious drawbacks that put people's health and safety in danger and frequently encourage open defecation activities[1].

Pit latrines and hanging toilets:

Bad odours, a poor user experience, potential safety risks, and environmental pollution

Septic tanks:

frequent servicing, difficult retrofitting, leakage risk, and inadequate waste disposal

Sewerage is costly to establish and operate;

it requires infrastructure and water, and treatment is not guaranteed.

Therefore, the only immediate solution to India's septage treatment issue is on-site sanitation systems (OSS) owing to following reasons[2].

33% of the lavatories are attached to a piped sewer system.

37% of human waste produced in cities is handled.

By 2030, India is anticipated to have the second-highest pace of urbanization, posing new sanitation problems.

It may take a long time to bring the Centralized Sewage Treatment Plant (STP) system into operation and requires high CAPEX and OPEX.

135 LPCD (Litres per capita per day) water supply is required for a centralised water flow-based system. This sum is distributed to fewer than 10% of the Indian cities.

In a non-sewered sanitation (NSS) system, septage is transported using tractors or trucks.

Smaller amounts of treated water are simple to reuse or apply for ground water replenishment near the treatment facility.

Any new centralized sewage systems require extensive road digging and upkeep, resulting in extreme traffic congestion.

NSS systems are more localized and less centralized in size. They are more likely to reuse treated biosolids and treated wastewater.

Thus, a Reinvented Toilet (RT) is a modification of the existing toilet embedded with modern technology such that it not only collects the waste but also treats it on-site. The RT kills pathogens, does not need a sewerage connection or septic tank, requires no input water and outside electricity, and converts human waste into a safe by-products like clean water and ash.

Figure 1 depicts the sanitation value chain. The faecal sludge management (FSM) value chain is condensed into a single unit by a RT that provides containment and treatment. Moreover, the role of RT in the current sanitation value chain is depicted in Figure 2[2].

Figure 1 Sanitation value chain

(Source: India Opportunity, Pyrolysis-Omni-Processor and Multi-User Reinvented Toilet, Bill and Melinda Gates Foundation, August 2021)

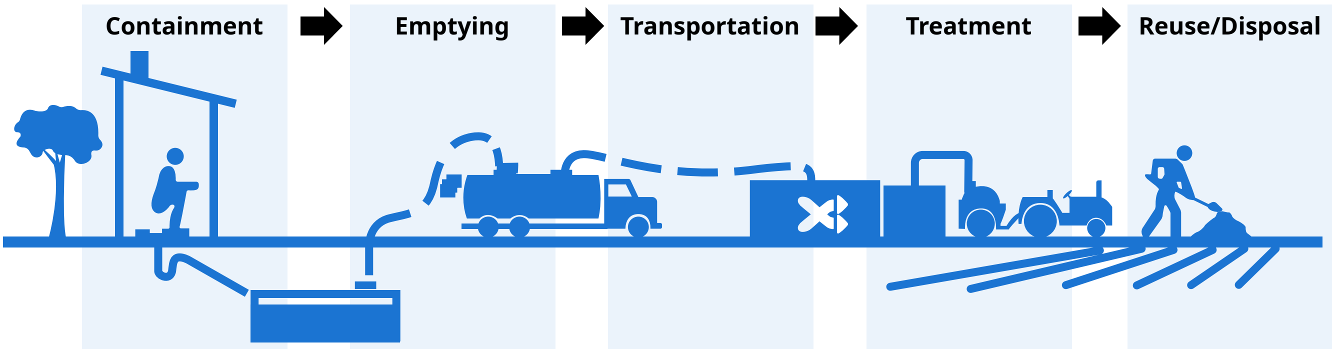
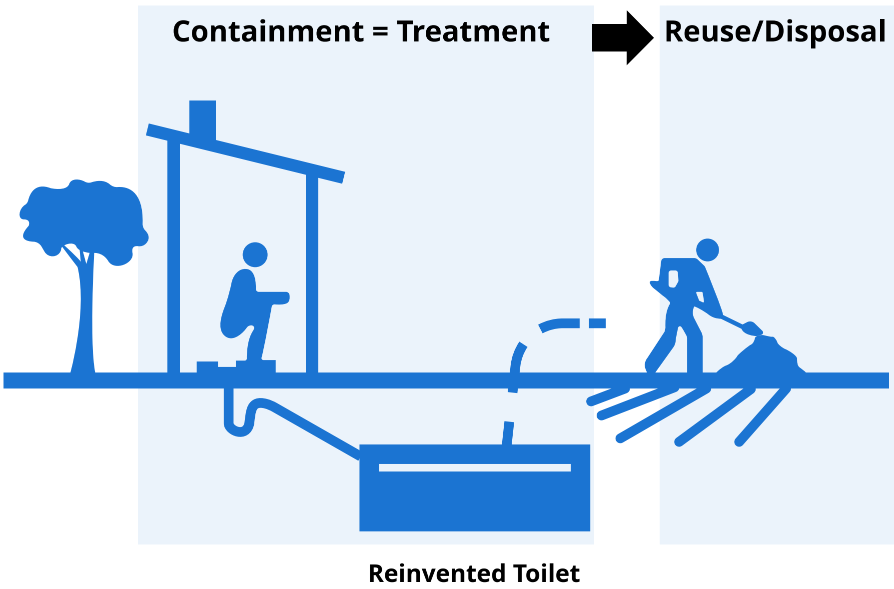


Figure 2 Role of RT in sanitation value chain

(Source: India Opportunity, Pyrolysis-Omni-Processor and Multi-User Reinvented Toilet, Bill and Melinda Gates Foundation, August 2021)



Key features of RT are as follows[1,3].

1 RTs have the potential to drastically alter the lives of those without access to adequate sanitation, particularly those who reside in densely populated urban areas, flood-prone areas, or areas with limited land, water, and infrastructure resources.

2 Treats – Solids and liquids

3 Pathogen Treatment – eradication of dangerous pathogens from human waste and the recovery of beneficial resources including energy, clean water, and nutrients

4 Household – Technology designed as a self-contained household unit

5 Multiunit – Technology could be scaled for schools, public/community toilets

6 Self-sustaining – operates "off the grid," requires little electricity, and is not connected to water or sewage systems

7 Environment Friendly – promotes environmentally responsible FSM methods in locations with limited access to FSM services or with short-term fixes like camps, refugee camps, etc.

8 Scalable – Systems that are easily scalable and can provide everyone with accessible, sustainable sanitation in both developed and underdeveloped countries

Scope of Report

The future is OSS systems with no need for transportation of faecal sludge, where septage gets treated at point of generation and there is no lag between generation and treatment thus preventing spread of harmful diseases and saving lives. Hence, the possibility of deploying a RT product for developing countries which treats waste at a community level and then at toilet level was assessed in the current research.

Research Methodology

The current research was aimed at reviewing the existing literature for RTs and create a detailed proposal for the analysis of opportunity and unit economics.

In order to provide sustainable sanitation solutions to the people who lack access to safe, affordable toilets worldwide, the Water, Sanitation & Hygiene programme of BMGF launched the 'Reinvent the Toilet' Challenge in 2011. A piped collection network is not necessary, thanks to the RT, a disruptive, modular technology that provides a non-sewered sanitation option. Operating without drainage, water, or electrical hook-ups, the goal of RT is to eradicate all pathogens on-site and retrieve precious resources. Absolute pathogen eradication, decreased life cycle costs, off-grid operation, and a pleasing user interface are just a few of RT's advantages[4].

RT provides containment and treatment, thus, collapsing the sanitary value chain. The act of emptying an RT is intrinsically safe because all germs have been eliminated and the waste has been processed. Therefore, Unsafe waste does not need to be transported or treated further[2].

The following are some benefits of RT[1,2].

Pathogens Eradication

Eliminating pathogens will lessen disease burden, enhance environmental safety, and alleviate handling-related safety problems.

Lesser life-cycle costs

Lessen the requirement for expensive pit emptying. It also allows sustainable business model comprising maintenance through service providers

Off-grid Operation

Operating off-grid means not requiring external inputs, such as energy and water. In addition, RT is transportable, resilient, and requires simple installation

Modular and spectacular interface

Decrease / eradicate construction expenditures, offers pristine and aesthetic product. Eradicate waste and odors

Water Conservation

Conserve water by reusing flush water to lessen the effect of sanitation on the water cycle.

Thus, the objectives of the current research are given in the following section.

Objectives

The key objectives were as follows:

- To examine all the available reports, studies done or in progress for RT
- To understand and analyze opportunity & unit economics for RTs

Outcomes

The key outcomes were as follows:

- A detailed proposal for in-depth study of RTs, their market segments and unit economics

RT Landscape

This section describes the landscape of the RT covering the history, types of RT and existing RT technologies

History of RT

The 'Reinvent the Toilet' Challenge was launched in 2011 by the Water, Sanitation & Hygiene programme, Bill & Melinda Gates Foundation to encourage the development of novel toilet technologies that securely and efficiently manage human waste. With the help of this initiative, governments will be able to provide truly inclusive sanitation services that reach the most poor communities while also safeguarding individuals and communities against infections that are spread by human waste. For the people who lack access to adequate sanitation, especially those who reside in crowded cities, flood-prone areas, or areas with limited land, water, and infrastructural resources, RTs have the potential to change their lives. The 'Reinvent the Toilet' Challenge is still active today and encourages the advancement and commercialization of products that have absolute pathogen eradication, decreased life cycle costs, off-grid operation, and a pleasing user interface[1,3].

More than 25 ground-breaking processing components and technologies have been developed as a result of the programme, and they are now accessible for product and sanitation service firms to commercialize. These technologies are at the vanguard of a movement that is expanding to quickly improve sanitation while generating new, lucrative sanitation businesses that help the world move closer to the water and sanitation targets established in the UN SDGs[3].

Following are some significant 'Reinvent the Toilet' Challenge landmarks[3].

July 2011
The BMGF provides funding to 16 researchers from around the world to create toilet technologies that are reinvented based on cutting-edge methods and technical procedures.

August 2012
At Seattle offices, a two-day 'Reinvent the Toilet Fair' was organized to display sanitation initiatives and prototypes of Reinvented Toilets. Researchers, designers, investors, advocates, and other representatives from 29 countries that may eventually embrace these cutting-edge sanitation methods were represented at the fair.

August 2013
The China edition of the 'Reinvent the Toilet Challenge' was introduced, offering US$5 million to help Chinese inventors to create and manufacture the "next-generation toilets."

October 2013
To promote sanitation research and advancement initiatives driven by Indian inventors and organizations that can provide affordable sanitation services to poor populations, the 'Reinvent the Toilet Challenge: India' was launched in conjunction with the Indian Ministry of Science and Technology.

March 2014
The second 'Reinvent the Toilet Fair: India' was hosted in Delhi with the goal of initiating conversation and fostering collaborations to provide the 2.5 billion people without access to clean, affordable sanitation

November 2018
The first 'Reinvented Toilet Expo' was held in Beijing with the participation of international innovators, development banks, business partners, sanitation utilities, and governments. The exhibition includes product launches and financing commitments intended to hasten the adoption of cutting-edge, non-sewered sanitation technology throughout the world's developing nations.

2020
BMGF collaborated with the Water Research Commission and the Department of Science and Innovation of South Africa to introduce the first commercial demonstration platform for the testing of pilot Reinvented Toilet models in public places like schools and communities.

Types of RT

Single and multi-unit versions of the Reinvented Toilet are available for various scales[1].

RT covers the following two types:

Single Unit Reinvented Toilet (SURT):

A single toilet with a connected wastewater and solid waste treatment system. Use case includes a home and a small commercial structure.

Multi Unit Reinvented Toilet (MURT):

A central processing unit connected to numerous toilets that treats waste and recycles water for flushing. Available in multiple capacities. Use case includes residential buildings and public toilets serving up to 500 persons.

Global RT Technologies

BMGF have made a variety of other investments that are related to reinventing the toilet in addition to the 'Reinvent the Toilet Challenge' (RTTC) grants. These grants have been given to academics working on novel methods for managing human waste in a safe and sustainable manner that are based on fundamental engineering principles[5].

Nanomembrane Toilet: Cranfield University

Fully independent home toilet system. With a cutting-edge waterless swipe flush mechanism and all waste processing components placed inside the pedestal, the frontend resembles a western-style pedestal toilet. Solids and liquids are separated in the back end. The liquids are preheated and purified with a hydrophobic membrane while the solids are removed using a specially constructed screw, then dried and burned[6].

Figure 3 Nanomembrane Toilet

(Source: https://sanitation.ansi.org/NanomembraneToilet)

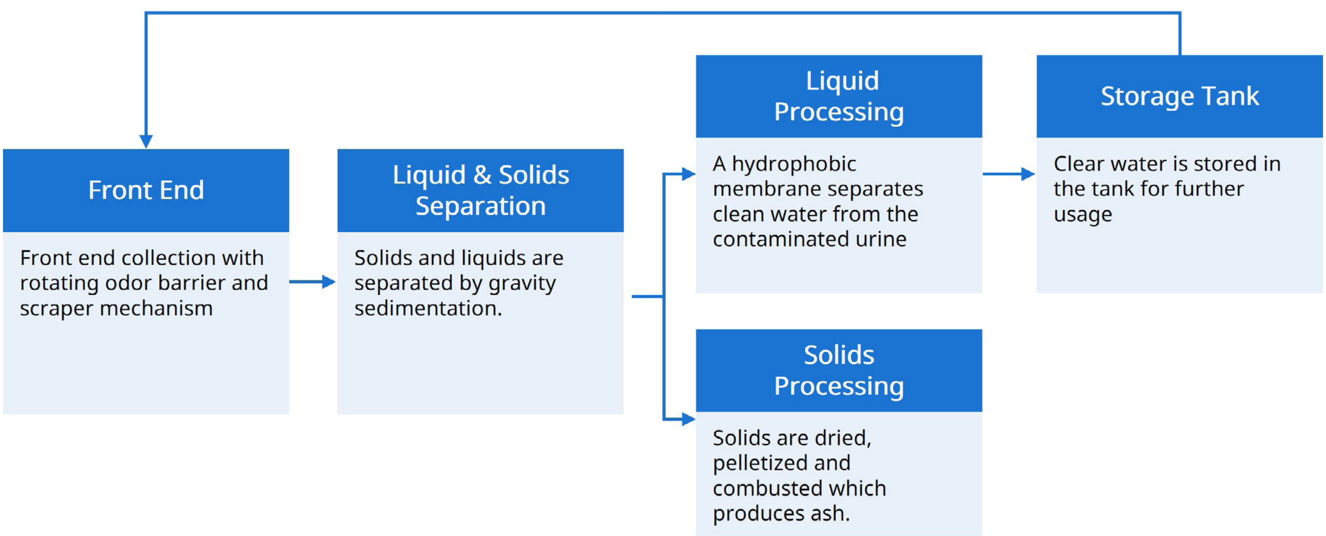


Table 1 Details of Nanomembrane Toilet

(Source: https://sanitation.ansi.org/NanomembraneToilet)

Parameters		Description
Key Features		• Up to 10 users each day for a single household system • Complete self-contained design, no water or power connections necessary • Special waterless flushing system reduces water usage • The membrane is heated to force water through it during the combustion process • System generates clean water daily for domestic usage, but occasionally has to dispose of ash.
Status of Development		Early Prototype
Use Cases	Household	Designed to accommodate up to 10 daily users as a self-contained, residential unit
	Multi-unit	Core processing technology might be scaled down for educational or public/community use
Product Application		1. Pedestal 2. Wipe
Inputs	Requirement for external source of electricity	No, energy is produced mechanically, with the potential for electrical and thermal gradients as well
	Requirement for the use of water	No
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. Process uses recovered energy.
	Amount of Water recovered	>10 litres/day usable
	Amount of Fertilizer / other by products production	10g ash/user/day
Treatment	Solids treatment	Combustion
	Liquids treatment	Membranes
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	No
	Usage of mechanical processes	Yes
	Usage of biological processes	No
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	Not available
	Estimated Capex	Not available
	Size	L 1.25m x W 0.75m x H 1.0m
	Maintenance requirement	Water and ash to be discharged daily by user. Weekly ash emptying and four-yearly membrane cleaning are required.
	Life expectancy	10 years

Parameters		Description
How it works	Frontend	The user comes across a pedestal toilet with an unusual waterless flushing mechanism. Dry flushing is made possible by a spinning odour barrier and scraper mechanism that controls odour.
	Urine / Faeces Separation	Gravity sedimentation is used to separate solids from liquids. In order to process liquids, liquids flow over a weir, while a screw is used to remove the solids.
	Liquid Processing	Clean water and contaminated urine are separated by a hydrophobic membrane. A storage tank is then used to hold the clean water for later usage.
	Solid Processing	Ash is produced when solids are dried, pelletized, and burned. The micro-combustor under development may consume <1 g/min of dried faecal waste.
	Power system	The bowl is propelled by the toilet seat being raised. Water separation is fuelled by extra heat produced by the combustor. To meet the need for residual power, prospects for the generation of electrical energy from thermal and electrical gradients are now being explored.

Dry Combustion RT: Duke Center for WASH-AID

A public toilet that processes both liquid waste and solid waste. Pedestal and squat plate styles work with the toilet. On-site processing comprises drying and sterilizing of solids with optional combustion, as well as electrochemical disinfection and recycling of liquids. Menstrual pad dispensers and disposal alternatives are examples of user amenities, along with body wash and hand wash stations[7].

Figure 4 Dry Combustion RT

(Source: https://sanitation.ansi.org/SanitationPlatform)

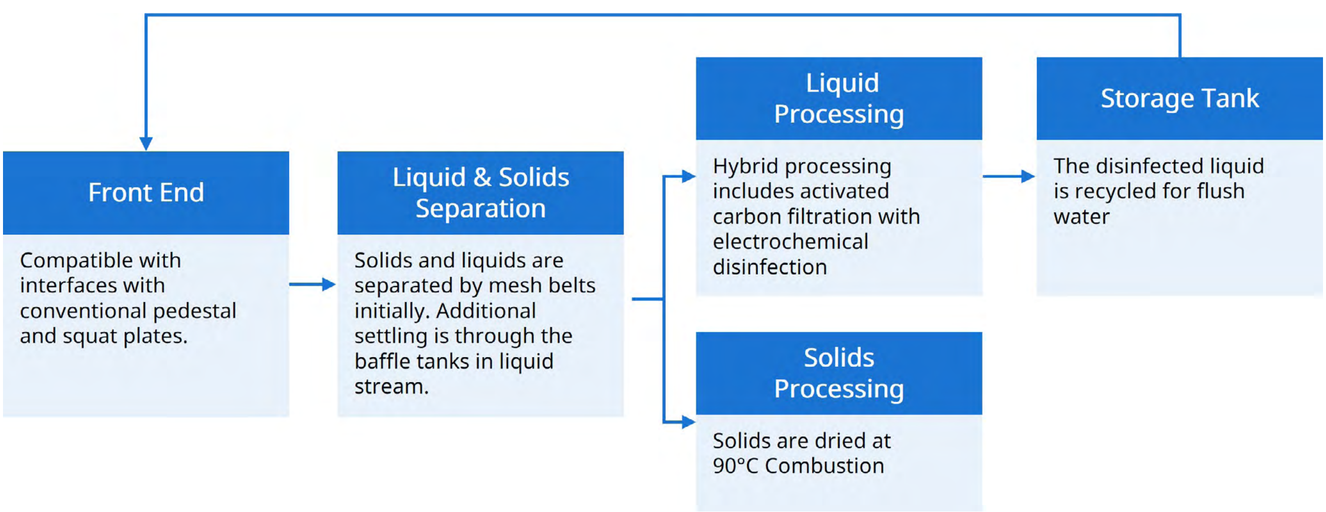


Table 2 Details of Dry Combustion RT

(Source: https://sanitation.ansi.org/SanitationPlatform)

Parameters		Description
Key Features		• User options created through four years of field research on home and community design • Liquids treated with electrochemical disinfection and active filtration that adhere to ISO discharge standards • A range of sanitation products can be made using independent solid and liquid processing modules in combination with other technologies. • The Reclaimer, a liquid recycling device, and a standalone menstrual waste management device are two examples of new products.
Status of Development		Advanced Prototype
Use Cases	Household and Community	10 to 50 users per day are allowed. Multiple seats in a community block can be served by the processing system with some adaptation.
Product Application		1. Pedestal 2. Wipe 3. Squat 4. Wash
Inputs	Requirement for external source of electricity	Yes. Requires 5-7 kWh/day, which are currently supplied by grid electricity (deep-cycle batteries) or 500 W solar panels.
	Requirement for the use of water	Initial charge for wash and/or flush water is 30L; otherwise, the system uses recycled water.
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. The process uses energy.
	Amount of Water recovered	After disinfection, excess water (10–30 L/day) will be discharged; the remaining water is used for flushing.
	Amount of Fertilizer / other by products production	Dry solids that have been sterilized may be gathered or burned on site.

Parameters		Description
Treatment	Solids treatment	Thermal
	Liquids treatment	Electrochemical & Active carbon
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes
	Usage of biological processes	No
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	Not available
	Estimated Capex	Not available
	Size	L 1.5m x W 2.0m x H 1.25m
	Maintenance requirement	Weekly emptying of the ash/solids is required (by user)
	Life expectancy	10 years
How it works	Frontend	Compatible with interfaces on pedestal and squat plates.
	Urine / Faeces Seperation	Belts made of mesh are used for initial separation. The use of baffle tanks in the liquid processing stream enables further solids settling.
	Liquid Processing	Activated carbon filtration and electrochemical disinfection are both used in hybrid processing. Helminth egg removal is accomplished using a post-baffle filter. The recovered liquid is repurposed as flush water.
	Solid Processing	Solids are dried at 90°C after initial separation. The capability of processing solids across many units may be increased by the combustion option.
	Power system	Grid power is being used right now. 500 W of optional solar power for backup and off-grid energy.

Blue Diversion Autarky Toilet: EAWAG

The Blue Diversion Autarky toilet, which separates and treats urine, solids, and flushing water on location, is one of two products on display from EAWAG. Urine is concentrated and chemically stabilised. Utilizing supercritical water oxidation, solids are treated. A biological membrane reactor, activated carbon, and electrolysis are all used in the water treatment module to produce safe recycled water. Water Wall, a standalone handwashing station, is offered with the water treatment. Separate units for treating solids and urine are also an option[8].

Figure 5 Blue Diversion Autarky toilet

(Source: https://sanitation.ansi.org/DiversionAutarky)

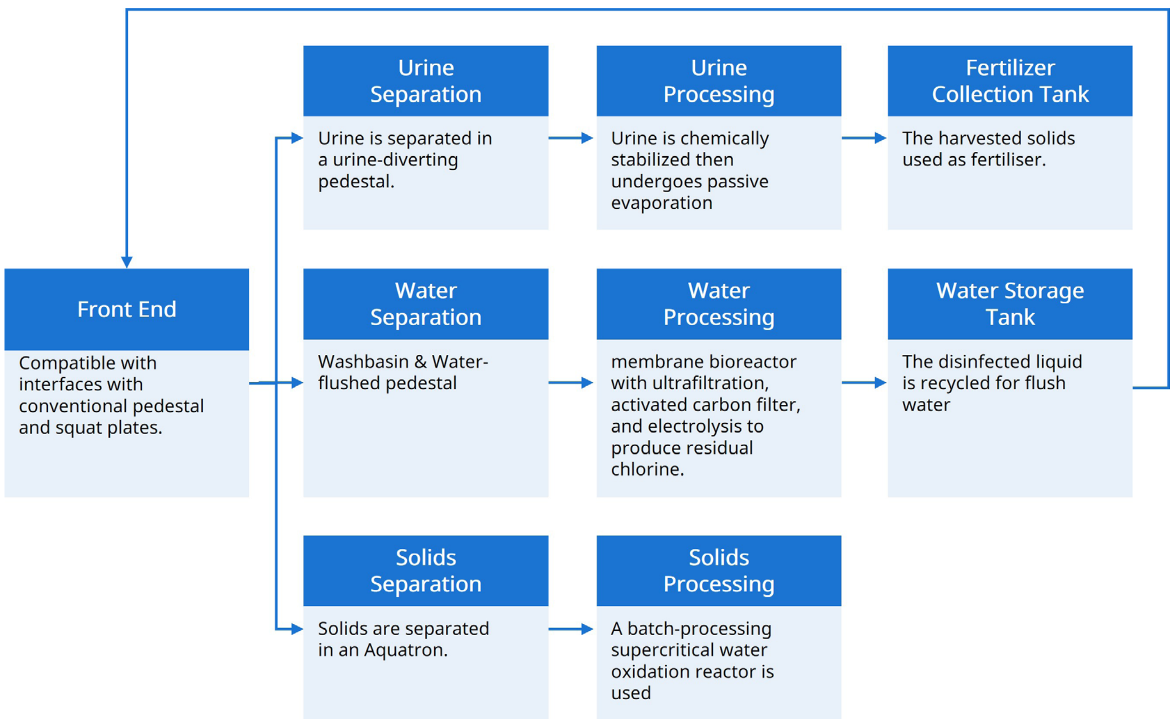


Table 3 Details of Blue Diversion Autarky toilet

(Source: https://sanitation.ansi.org/DiversionAutarky)

Parameters		Description
Key Features		• Source separation enables effective disinfection, nutrient recovery, and water recycling. • All treatment units have a modular design that allows for independent operation or system integration. • Superstructure enables the integration of additional treatment facilities. • Appealing frontend created with a partner EOOS provides the comfort and hygiene of contemporary water-flushed toilets.
Status of Development		Early Prototype
Use Cases	Household	The Blue Diversion Autarky Toilet currently has a daily user capacity of 10 people.
	Multi-unit	School: Present Water Wall can be utilized as a hand washing station with three faucets
Product Application		1. Pedestal 2. Wipe 3. Wash
Inputs	Requirement for external source of electricity	Power supply is required by all units.
	Requirement for the use of water	Internally, water is recycled. It will be necessary to refill some water.
	Requirement for any other “consumable” inputs	Calcium hydroxide is required for stabilization of urine
Outputs	Amount of Energy recovered	None. The process uses energy.
	Amount of Water recovered	<10 litres/day generated. None is meant for discharge; completely intended for recycling.
	Amount of Fertilizer / other by products production	Nutrient recovery: >70% nitrogen, >80% phosphorus, >70% potassium and others

Parameters		Description
Treatment	Solids treatment	Yes, supercritical wet oxidation
	Liquids treatment	Yes, urine (chemical stabilization and evaporation); wash water (membrane bioreactor, ultrafiltration, activated carbon, electrolysis)
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes
	Usage of biological pro-cesses	Yes
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	Not available
	Estimated Capex	Not available
	Size	L 2.2m x W 2.0m x H 3.4m
	Maintenance requirement	Water replenishment, fertilizer collection from the treatment of faeces and urine, and supply of chemical reagent
	Life expectancy	10 years
How it works	Frontend	Water-flushed urine-diverting pedestal, waterless urinal and hand washbasin. Water is recycled.
	Urine / Faeces Seperation	Source-separating unit designed by EOOS. Urine is parted in a urine-diverting pedestal (NoMix toilet). Aquatron separates solids.
	Liquid Processing	Processing of urine: After chemical stabilisation and passive evaporation, urine forms a solid that can be used as fertiliser. Water treatment: Three systems—a membrane bioreactor with ultrafiltration, an activated carbon filter, and electrolysis to create residual chlorine—are used to treat used flushing water and handwashing water.
	Solid Processing	A small-scale, batch-processing supercritical water oxidation reactor created by the University of Applied Sciences and Arts, Northwestern Switzerland (FHNW), is fed with human waste, toilet paper, and some flushing water.
	Power system	Solar energy can be used to power a water wall and the pro-cessing of urine. It is still too early in the SCWO reactor's de-velopment to determine its energy needs.

Eco-San Toilet: ECO-SAN

One of the top CalTech technology developers, Eco-San specializes in containerized toilets, public toilets, and school toilet facilities. The back-end processing method makes use of an electrolysis system and anaerobic digestion of solids to turn waste into water, hydrogen, and solid fertilizer. Three Eco-San devices are being tested in China and two in South Africa. The electrodes that power the electrolysis treatment process are produced and offered at a reduced price by Yixing Entrustech, a sister company of Eco-San, so that they are accessible to all partners[9].

Figure 6 Eco-San Toilet

(Source: https://sanitation.ansi.org/EcoSanToilet)

Front End	Liquid & Solids Separation	Liquid & Solids Processing	Collection Tank
Compatible with interfaces with conventional pedestal , squat plates and urinals	No separation of urine/faeces. With the help of anaerobic digestion, mixed waste passively settles in a septic tank	Urine, flush water, and faeces are all treated simultaneously in a macerator. The effluent from the biological treatment unit and septic tank is oxidised in an electrochemical system	The final effluent is currently polished with membrane microfiltration & the septic tank needs to be cleaned out once a year of undigested solids

Table 4 Details of Eco-San Toilet

(Source: https://sanitation.ansi.org/EcoSanToilet)

Parameters		Description
Key Features		• The design can include a separate digesting tank or be totally containerized. • Patented electrochemical cells handle mixed sewage • Can reuse process effluent as toilet flush water, particularly in locations with a lack of water • Compatible with all flush toilet models (squat pan, western style, urinals, etc.)
Status of Development		Product Available
Use Cases	Household	-
	Multi-unit	Core processing technology is scalable for usage in public or community applications and can support 50–800 users daily on a single system.
Product Application		1. Pedestal 2. Wipe 3. Squat 4. Wash
Inputs	Requirement for external source of electricity	Yes, provided via a grid or solar panels
	Requirement for the use of water	No
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. The process uses energy.
	Amount of Water recovered	4-5 m3/day usable, not potable
	Amount of Fertilizer / other by products production	1 ton per year
Treatment	Solids treatment	Treats
	Liquids treatment	Treats
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes

Parameters		Description
Treatment	Usage of biological processes	Yes
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	$0.02/flush/day
	Estimated Capex	Not available
	Size	L 12m x W 2.2m x H 2.7m
	Maintenance requirement	Solid garbage must be emptied every six months (by user). Replace membrane filters once every three months.
	Life expectancy	10 years
How it works	Frontend	Includes up to 8 urinals and toilets that are close to the processing backend parts.
	Urine / Faeces Separation	No separation of urine/faeces. With the help of anaerobic digestion, mixed waste passively settles in a septic tank. There is the option of active anaerobic/aerobic pre-processing.
	Liquid Processing	The effluent from the biological treatment unit and septic tank is oxidised in an electrochemical system at a semiconductor anode, and water is reduced at a metal cathode to produce H2. If there is not enough chloride in the waste, it can be supplemented using table salt. The final effluent is currently polished with membrane microfiltration.
	Solid Processing	Urine, flush water, and faeces are all treated simultaneously in a macerator. It is anticipated that the septic tank needs to be cleaned out once a year of undigested solids.
	Power system	Solar panels, with energy storage via battery stack, and/or grid electricity. Estimated 18 kWh needed per m3

High Temperature Processing RT: HELBLING

The Gates Foundation has engaged Helbling to create HTClean, a new kind of RT that uses a high temperature and high-pressure processing design. The toilet is being specifically designed for the home. Visual cues for operation, upkeep, status, and usage are intuitive and integrated[10].

Figure 7 High Temperature Processing RT

(Source: https://sanitation.ansi.org/HTClean)

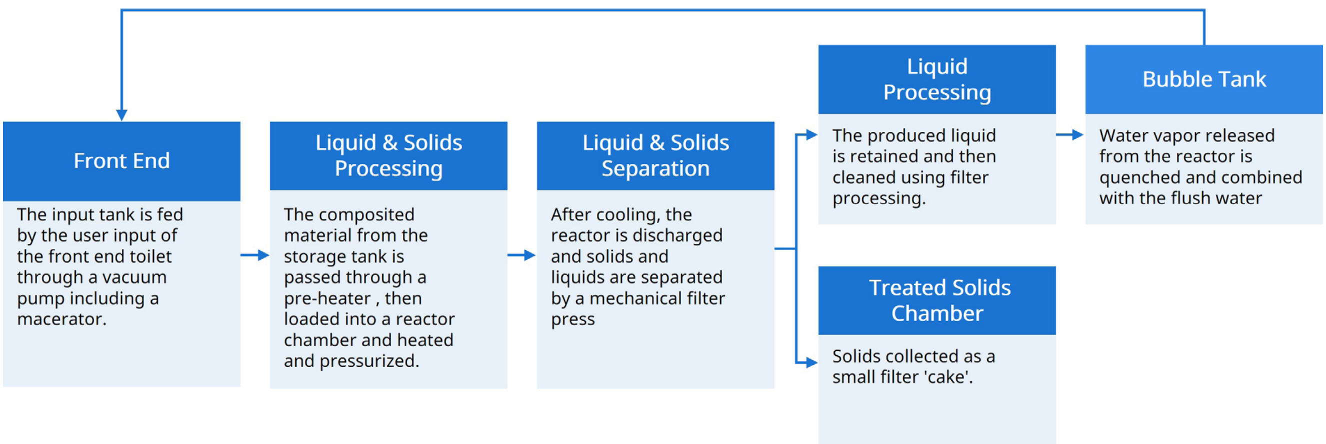


Table 5 Details of High Temperature Processing RT

(Source: https://sanitation.ansi.org/HTClean)

Parameters		Description
Key Features		• A self-contained toilet that is not connected to a water or sewage system • A single-household system built for 4-6 daily users and 10 users or more daily • Vacuum flush systems significantly lessen the amount of flush water needed (0.2-0.9 L) • A distinctive, user-friendly human-machine interface (HMI)
Status of Development		Early Prototype
Use Cases	Household	Designed as a self-sufficient home unit that can accommodate up to 10 users per day
	Multi-unit	Core processing technology might be scaled for use in schools, the general public, or communities, or by placing units in each restroom.
Product Application		1. Squat 2. Pedestal 3. Wipe 4. Wash
Inputs	Requirement for external source of electricity	Yes.
	Requirement for the use of water	No, the system recycles the water.
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	When the ideal operating circumstances are decided, it will be concluded.
	Amount of Water recovered	A closed loop creates the flushing water. Any extra water that has accumulated as a result of urine deposits will be released.
	Amount of Fertilizer / other by products production	20 g filter cake/user/day
Treatment	Solids treatment	Yes, treats solids and liquids combined
	Pathogen treatment success	Total pathogen removal
	Usage of chemical processes	Yes

Parameters		Description
Treatment	Usage of mechanical processes	Yes
	Usage of biological processes	No
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	Not available
	Estimated Capex	Not available
	Size	L 1.2 m x W1.0 mxH1.9 m
	Maintenance requirement	Excess liquids and non-hazardous, odourless solid waste cakes are to be routinely disposed of by the user.
	Life expectancy	20 years
How it works	Frontend	Through a vacuum pump with a macerator, the user input from the toilet feeds the input tank.
	Urine / Faeces Separation	Following processing with a mechanical filter press, solid/liquid separation is performed.
	Liquid Processing	The initial holding for the user input is a holding tank. After passing through a pre-heater and being put into a reactor chamber, the composite material from the storage tank is heated above 160°C at a pressure of up to 25 bar*. After cooling, the reactor is released, the solids and liquids are separated, and a little filter "cake" is the result. The generated liquid is collected and cleaned before being used in the toilet flushing mechanism. After processing, water vapour generated from the reactor is used for pre-heating and quenched in a bubble tank. The flush water is blended with the cleaned quenched water. **Optimum operational conditions are currently being identified*

Biological and Electrochemical RT: SCG Chemicals Co. Ltd.

The Zyclone Cube may be integrated with a typical flushing toilet and is made for effectively treating both solid and liquid fractions. Liquid separation is achieved by the special Zyclone form at a rate of greater than 98%. A screw heating device that intermittently dehumidifies and inactivates pathogenic contents receives the solids fraction and drops it inside. Prior to an electrochemical disinfection process, the liquid undergoes additional treatment using integrated absorptive media (such as zeolite and modified soil) in a series of anaerobic, aerobic, and anoxic chambers[11].

Figure 8 Biological and Electrochemical RT

(Source: https://sanitation.ansi.org/ZycloneCube)

Illustration of how the Zyclone cube can be integrated with a conventional toilet and new design solar energy toilet system.

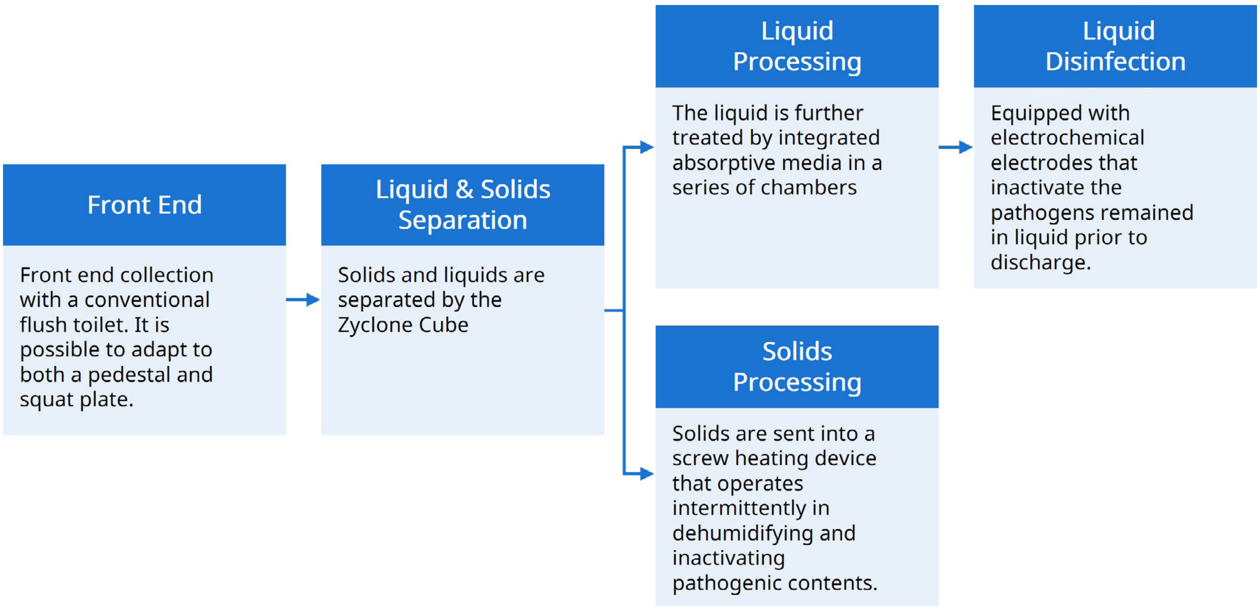


Table 6 Details of Biological and Electrochemical RT

(Source: https://sanitation.ansi.org/ZycloneCube)

Parameters		Description
Key Features		• Toilet system (1-4 toilets per one Unit) • Pour flush (1.5 Liters) up to 130 users/day • Flushing (3.0 Liters) up to 70 Users/day • Ability to retrofit in existing systems
Status of Development		Product Available
Use Cases	Household and public toilets	
	Multi-unit	Designed to handle 130 daily users' waste at 4 toilet stalls.
Product Application		1. Squat 2. Pedestal 3. Wipe 4. Wash
Inputs	Requirement for external source of electricity	Yes
	Requirement for the use of water	Yes, flush water
	Requirement for any other "consumable" inputs	Yes, media
Outputs	Amount of Energy recovered	None
	Amount of Water recovered	200 liters/day
	Amount of Fertilizer / other by products production	10 kg solids/month
Treatment	Solids treatment	Thermal disinfection
	Liquids treatment	Biological and electrochemical
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes, separation
	Usage of biological processes	Yes
	Requirement of any off-site or additional processing	No

Parameters		Description
Business Considerations	Estimated daily operating cost	US$ 0.10/day
	Estimated Capex	Not available
	Size	L 1.45m x W 1.25m x H 1.35m
	Maintenance requirement	Media should be changed every three years. Every three years, electrodes must be replaced. Every month, fertilizers must be collected.
	Life expectancy	15 years
How it works	Frontend	For the user it comes across as a traditional flush toilet. Both a pedestal and a squat plate flush interface can be accommodated.
	Urine / Faeces Seperation	The Zyclone's distinctive design yields a solid/liquid separation efficiency of more than 98%.
	Liquid Processing	To eliminate large solid particles, the separated liquid is first filtered in a plastic media chamber. Synthetic media are placed in the following two chambers, with diameters of 2 cm and 1 cm, respectively. Prior to the aerobic chamber with microbubble aeration that further removes chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) contents, the organic loading is lowered in the anaerobic chamber. In the next chamber, TN is significantly decreased in an anoxic environment by zeolite media. In order to improve treatment efficiency overall, chamber is made to circulate the treated liquid back to the anaerobic chamber. The pathogens that were still in liquid before discharge are rendered inactive by electrochemical electrodes in the final chamber.
	Solid Processing	The fresh faecal matter (solid) that has been separated is collected in a chamber that is beneath the Zyclone separator, where it is sterilised and its moisture content is decreased using a screw heating device. Helminths could be rendered inactive using the heating device by 4-5 log values and E. coli by 6 log values.
	Power system	The system needs electricity

NEWgenerator: University of South Florida (USF)

The NEWgenerator is a small, mobile, and modular resource recovery device that reduces waste while recovering nutrients for fertilizer, clean water, and renewable energy. To increase lifetime, the system employs an anaerobic baffled reactor design followed by a nanomembrane filter run at sub-critical water flux. By electrochemically producing chlorine from table salt, the filter's permeate is treated such that it can be used again as flush water[12].

Figure 9 NEWgenerator RT

(Source: https://sanitation.ansi.org/Newgenerator)

NEWgenerator 100 v.1 (white unit) Undergoing field-testing at a school in Kerala, India. The orange units are Earn eToilets serving as front-end units.

Front End

Front end collection with a conventional flush toilet. It is possible to adapt to both a pedestal and squat plate.

Liquid & Solids Separation

Mixed waste enters an anaerobic membrane bioreactor (AnMBR). Liquid is filtered with a nanomembrane.

Liquid Processing

Biosorption and hydroponic processing is used to remove additional organics and minerals. Electro chlorination is the final polishing step.

Solids Processing

Solids are sent into a an anaerobic microbial baffled reactor, where the organic materials are digested.

Table 7 Details of NEWgenerator

(Source: https://sanitation.ansi.org/Newgenerator)

Parameters		Description
Key Features		• Solid and liquid waste are processed by an anaerobic membrane bioreactor in a single, diluted waste stream. • A hydroponic/biosorption system purges the wastewater of minerals and nutrients. • Biogas from the digestion of waste products is gathered for usage outside the system (e.g. cooking, heating)
Status of Development		Piloted prototype
Use Cases	Household	Scalable system that can support a single household with fewer than 10 users and up to 1000+ users per day. (Present design for 60 users or 300 usage per day.)
	Multi-unit	The most typical applications are in public toilets, educational facilities, and multi-unit housing.
Product Application		1. Squat 2. Pedestal 3. Wipe 4. Wash
Inputs	Requirement for external source of electricity	Yes, powered by solar energy.
	Requirement for the use of water	Yes, only a minimal input is needed to make up for any system losses.
	Requirement for any other “consumable” inputs	Yes, salt is needed for electrochlorination
Outputs	Amount of Energy recovered	3 kWh/d (as biogas) at 800 mg COD/L
	Amount of Water recovered	Influent can be recycled for reuse up to 100% of the time.
	Amount of Fertilizer / other by products production	Nitrogen and phosphorus recovered for onsite horticulture
Treatment	Solids treatment	Yes, anaerobic digestion
	Liquids treatment	Yes, electro-chlorination is carried after nanomembrane filtration.
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	No

Parameters		Description
Treatment	Usage of biological processes	Yes
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	US$4-$5
	Estimated Capex	US$45 000 (prototype)
	Size	L 2.4m x W 1.5m x H 2.4m
	Maintenance requirement	Cleaning the levelling tank every 6 to 18 months and preventive maintenance every 6 months
	Life expectancy	15+ years
How it works	Frontend	User interface-neutral; compatible with a range of designs.
	Urine / Faeces Seperation	Urine, faeces, and wash/flush water are all treated together; no separation is necessary.
	Liquid Processing	A bioreactor with an anaerobic membrane receives mixed trash. A commercially available nanomembrane is used to filter liquid, and it is operated at a sub-critical flow to maximise the membrane's longevity. Additional organics and minerals are removed through hydroponic processing and biosorption. The final polishing stage is electro-chlorination.
	Solid Processing	An anaerobic microbial baffled reactor is used to process mixed waste stream (TSS range 100-15,000 mg/L), where the organic contents are broken down. Modeling suggests that residual, undegraded solids need to be removed every 6 to 18 months, depending on the waste's composition.
	Power system	The system is currently powered by deep-cycle batteries that are charged by solar panels. The amount of biogas produced depends on the strength of the influent COD and can be used for a variety of purposes, including fuel for cooking and heating. An estimated 0.5–1.7kWh per day are needed.

The Toronto Toilet: University of Toronto

A small-scale system that disinfects both liquids and solids in the backend. A newly created mechanism that can be connected to regular squat plates in the frontend automatically separates faeces and urine/wash water. It is also feasible to attach to pedestals. Faecal material that has been dewatered is then combined with granular material and smoldered. The resulting pyrolysis gases are converted catalytically, which increases heat production and reduces emission. The heat produced is utilized to thermally disinfect liquid waste as well as dry in-place incoming faeces[13].

Figure 10 The Toronto Toilet

(Source: https://sanitation.ansi.org/TorontoToilet)

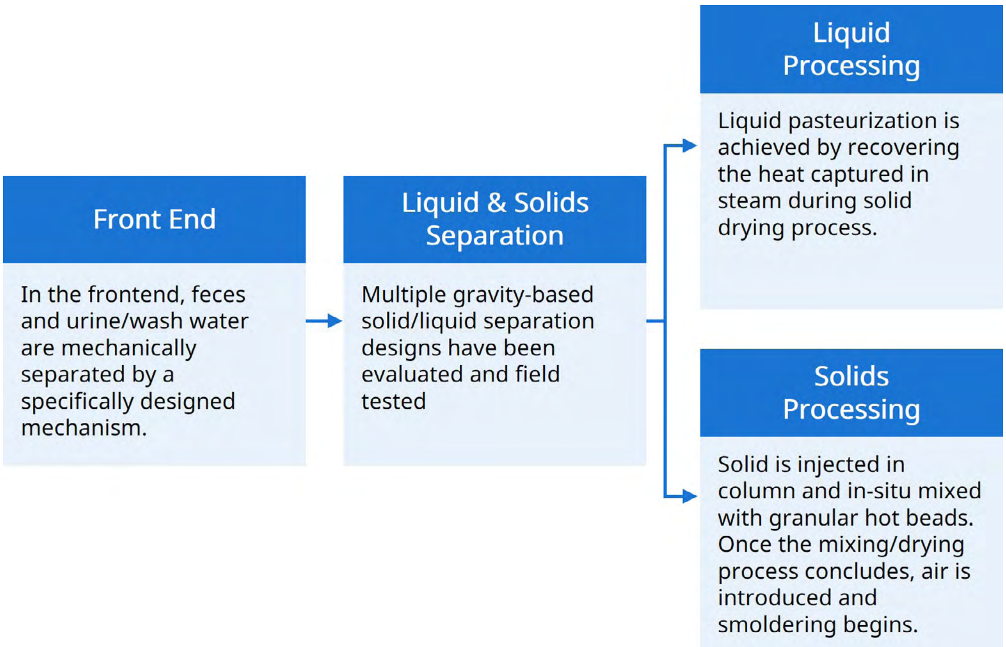


Table 8 Details of the Toronto Toilet

(Source: https://sanitation.ansi.org/TorontoToilet)

Parameters		Description
Key Features		• Self-sustaining smoldering technology has been researched and developed since 2011. • Consistent heat production and faecal matter processing through continuous smoldering. • The pyrolysis gases are catalytically converted, which increases heat production and reduces emissions.
Status of Development		Early Prototype
Use Cases	Household	Designed as a self-contained, family unit that can handle 5 to 20 individuals at different input rates.
	Multi-unit	Can be expanded to multi-stall community applications with a shared processing stall and one front end per stall.
Product Application		1. Squat 2. Pedestal 3. Wipe 4. Wash
Inputs	Requirement for external source of electricity	Yes, solar panels or other power source.
	Requirement for the use of water	Not required. Accepts 30L flush/wash water.
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. Processes require energy.
	Amount of Water recovered	10-50 litres/day, not potable.
	Amount of Fertilizer / other by products production	Processing of solids produces 10 g of ash per person per day, which is discharged monthly by the user.
Treatment	Solids treatment	Thermal processing (0.6-3 kg/day capacity)
	Liquids treatment	Pasteurization with 35 L/day capacity
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes

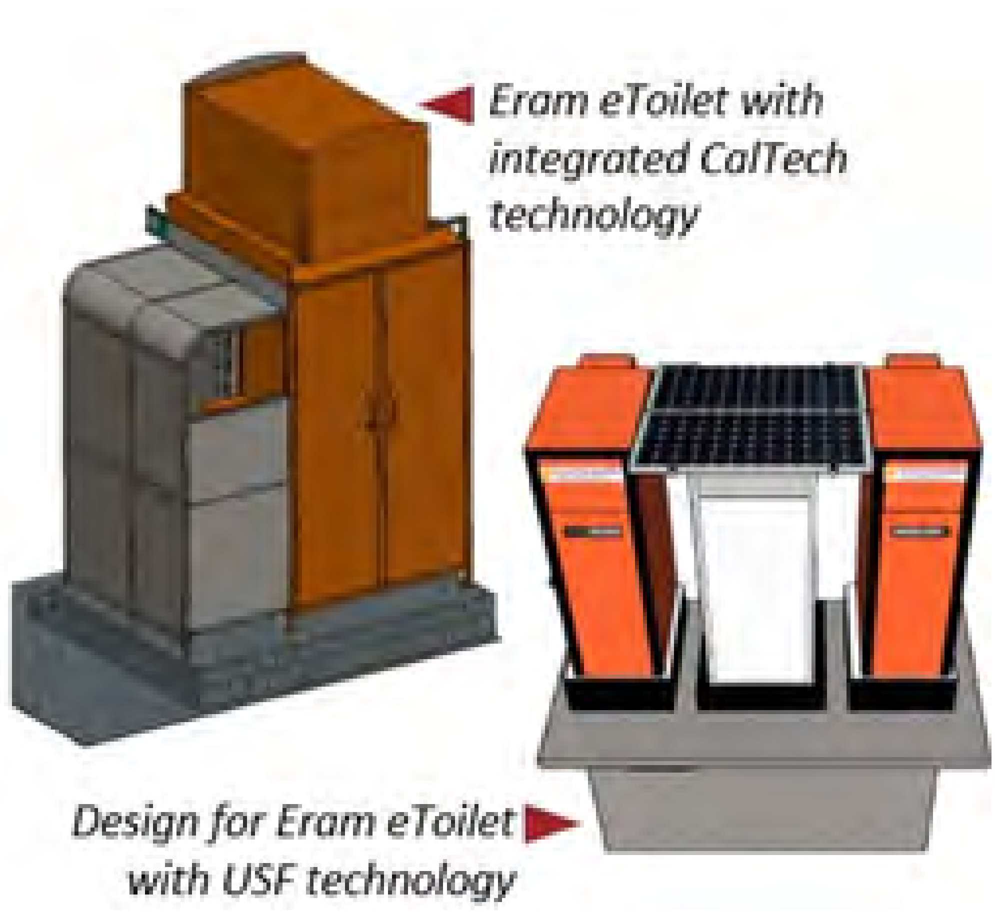
Parameters		Description
	Usage of biological processes	No
	Requirement of any off-site or additional processing	No
Business Considerations	Estimated daily operating cost	$0.07/user/day (initial estimate based on electricity use and six users)
	Estimated Capex	Not available
	Size	L 1.7m x W 1.5m x H 1.0m
	Maintenance requirement	A monthly solids (ash) emptying by the user
	Life expectancy	10-15 years
How it works	Frontend	Utilised right now with a typical squat plate. Adaptable to being a pedestal
	Urine / Faeces Separation	A variety of gravity-based solid/liquid separation designs have been assessed and put to the test in the field. It is possible to establish effective solid/liquid separation without changing user behaviour.
	Liquid Processing	By retrieving the heat that was trapped in the steam during the solid drying process, liquid pasteurisation is accomplished. It is planned to use further effluent treatment techniques from ongoing BMGF initiatives.
	Solid Processing	A pump transfers solid faecal material (fuel) and injects it into a column, where it is mixed in-situ with granular beads that are still hot from the previous smoldering cycle. After the mixing and drying process is finished, air is added, and smoldering starts. In order to be further treated and heat produced, post-smoldering gases travel via a catalyst.
	Power system	The required <200 watts per day could be provided by solar panels or another source of off-grid electricity. Projections indicate that the aspirational objective of achieving a power requirement low enough to fit within the capacity of solar or other off-grid household systems that are typical in many regions is feasible.

eToilet: Eram Scientific Solutions

By combining the current eToilet technology used in over 3500 sites with cutting-edge treatment technologies resulting from the 'Reinvent the Toilet' Challenge, Erams Scientific's eToilet integrates a full treatment solution. In order to process the black water and create reusable effluent that is also safe for release, the present prototype uses the electrochemical reactor from CalTech. Another prototype utilizing the treatment technology from the University of South Florida is also in the works[14].

Figure 11 The eToilet

(Source: https://sanitation.ansi.org/Etoilet)



Front End	Liquid & Solids Separation	Liquid & Solids Processing	Collection Tank
Compatible with interfaces with conventional pedestal , squat plates and urinals	No separation of urine/faeces.	The waste is sent to holding tank for biological treatments. Then, using CalTech technology, waste is piped to the electro-chemical reactor (ECR) and a strainer.	The disinfected liquid is recycled for flush water

Table 9 Details of the eToilet

(Source: https://sanitation.ansi.org/Etoilet)

Parameters		Description
Key Features		• For automated and unmanned operations, eToilet offers automated entrance and self-cleaning of toilet bowls and floors. • Online monitoring tools • Water-saving system with sensors • Treated water from the CalTech reactor is recycled for use in floor washing and toilet flushing. • Various possible business models are being investigated to fund the expansion of treatment units
Status of Development		Prototype in testing
Use Cases	Household	With the capacity to serve up to 100 customers per day, it was created as an automated self-contained toilet unit for use in public spaces, schools, or transportation hubs.
Product Application		1. Wash 2. Wipe 3. Squat
Inputs	Requirement for external source of electricity	Yes, grid power is necessary.
	Requirement for the use of water	Yes, water is needed for the faucets and taps for personal hygiene.
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. The process uses energy.
	Amount of Water recovered	For cleaning and flushing, all of the water used in the toilet is recycled.
	Amount of Fertilizer / other by products production	None
Treatment	Solids & Liquid treatment	Biological pretreatment and electrochemical disinfection
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes. Water filter
	Usage of biological processes	Yes
	Requirement of any off-site or additional processing	No

Parameters		Description
Business Considerations	Estimated daily operating cost	$0.07/flush/day
	Estimated Capex	US$ 13500
	Size	L 2.2m x W 1.7m x H 3.1m
	Maintenance requirement	Not available
	Life expectancy	10 years
How it works	Frontend	The eToilet by Eram Scientific is an unattended, automated, self-cleaning electronic toilet cabin with the capacity to minimise water use and receive remote monitoring.
	Urine / Faeces Separation	No separation is necessary.
	Liquid & Solids Processing	The waste stream is flushed and delivered to the holding tank for biological treatments. Then, using CalTech technology, waste is piped to the electro-chemical reactor (ECR). Sensors and remote monitoring are used to verify the effluent's quality after final filtration using water filters and a strainer. After that, water is kept in the eToilet for later use as flushing water.
	Power system	Grid Power is utilized currently.

Recycling Toilet: CLEAR

For sewage treatment, the CLEAR toilet employs a full-water cycle technique. A system for collecting rainwater, it can also resupply water to the processor so it can self-renew. The sewage processor treats the blackwater from the toilet before pumping it back down to the storage tank for flushing. The primary technology for treatment uses a sophisticated, one-of-a-kind Biofilm-MBR treatment process that creates a stable, clean effluent that is further disinfected to assure the effluent's safety for reuse[15].

Figure 12 Recycling Toilet

(Source: https://sanitation.ansi.org/RecyclingToilet)

Front End	Liquid & Solids Separation	Liquid & Solids Processing	Collection Tank
Compatible interfaces with conventional pedestal , squat plates and urinals	No separation of urine/faeces.	A media is used in the aerobic reactor and bacteria for treating wastewater. The wastewater is then treated by a MBR producing clean water. Finally, the produced clean water is further disinfected via UV	The disinfected liquid is recycled for flush water

Table 10 Details of Recycling Toilet

(Source: https://sanitation.ansi.org/RecyclingToilet)

Parameters		Description
Key Features		• The current design can accommodate up to 1,000 customers per day and has four stalls and three urinals. • Capability to function in distant or water-limited areas without access to sewers or other current sanitation systems • Available features for media players and WiFi
Status of Development		Product Available
Use Cases	Household	It is possible to scale down technology to function as a single household. 10 users maximum per day
	Multi-unit	The design of the system is most readily adapted to uses at tourist attractions, in schools, or in public or communal settings.
Product Application		1. Squat 2. Pedestal 3. Wipe 4. Wash
Inputs	Requirement for external source of electricity	Yes. Currently, either solar panels or the grid
	Requirement for the use of water	Yes. Only start-up requires rainwater collection. Recycled flush water is used.
	Requirement for any other "consumable" inputs	No
Outputs	Amount of Energy recovered	None. The process uses energy.
	Amount of Water recovered	For self-sufficiency, water is recycled.
	Amount of Fertilizer / other by products production	None
Treatment	Solids & Liquid treatment	Yes, Treats Solids and liquids
	Pathogen treatment success	Confirmed total pathogen removal
	Usage of chemical processes	Yes
	Usage of mechanical processes	Yes
	Usage of biological processes	Yes
	Requirement of any off-site or additional processing	Yes, solids must be cleared annually.

Parameters		Description
Business Considerations	Estimated daily operating cost	$0.03/user/day
	Estimated Capex	$50,000 (TT-1 model)
	Size	L 6.06m x W 5.96m x H 5.04m
	Maintenance requirement	Every two years, membranes should be checked and changed as necessary. Every year, solids may need to be emptied.
	Life expectancy	10 years
How it works	Frontend	Currently conceived of as a multi-seat unit, adaptable to various front ends. The wastewater is lifted to the treatment unit after being grounded.
	Liquid Processing	Physical precipitation was used as the initial treatment. In the aerobic reactor, a unique aerobic media is used, and proprietary bacteria created especially for treating wastewater are attached to the media as a biofilm. More than 50% of the organic contaminants may be successfully biodegraded by this biofilm, which also lowers their concentration. Following this, the wastewater is processed in an MBR (membrane biological reactor) to remove large-scale pollutants that can be refluxed during the biodegradation process, yielding clean water. Finally, UV disinfection is used to completely eradicate all bacteria in the clean water that has been produced.
	Power system	The system needs external power, which might come from solar panels or the grid. 5.65 kWh per day are projected as being needed.

Biothermal Toilet: Samsung Electronics

On August 25th 2022, in response to the 'Reinvent the Toilet' Challenge, Samsung Electronics has completed a project in partnership with the BMGF that resulted in the creation of a prototype toilet that is safe and intended for HH use. The BMGF and Samsung Advanced Institute of Technology (SAIT), the company's R&D division, started working together on the RT in 2019. SAIT recently finished developing the core technologies for the toilet and successfully developed and tested a prototype. During the commercialization phase, Samsung intends to grant developing nations royalty-free licences to project-related patents. Three years of R&D by SAIT on the fundamental design, component development, and modular technology resulted in the successful creation of a household prototype. The product satisfies the performance standards set by the BMGF for commercialization of a RT for household use and is energy-efficient with effluent treatment competence[16].

Samsung's core technologies comprise heat-treatment and bioprocessing technologies that eliminate pathogens from human waste and render the released effluent and solids environmentally acceptable. The system makes it possible to completely recycle the treated water. While liquid waste is treated using a biological purification procedure, solids are dehydrated, dried, and burned into ashes. Figure 13 depicts the configuration of the Biothermal Toilet[16].

Figure 13 Biothermal Toilet

(Source: https://news.samsung.com/global/samsung-develops-prototype-reinvented-toilet-in-partnership-with-the-bill-melinda-gates-foundation)

Generation 2 Reinvented Toilet (G2RT): Georgia Institute of Technology

To address the sanitation crisis around the world, Dr. Shannon Yee and his team are creating a new, inexpensive toilet. The urine and faeces are separated when the toilet is flushed (with a tiny amount of water). A multi-step liquid filtering procedure using the flush water and urine creates clean water – which is then recirculated to the flush the toilet. And depending on the model, the faeces will travel via one of two routes[17].

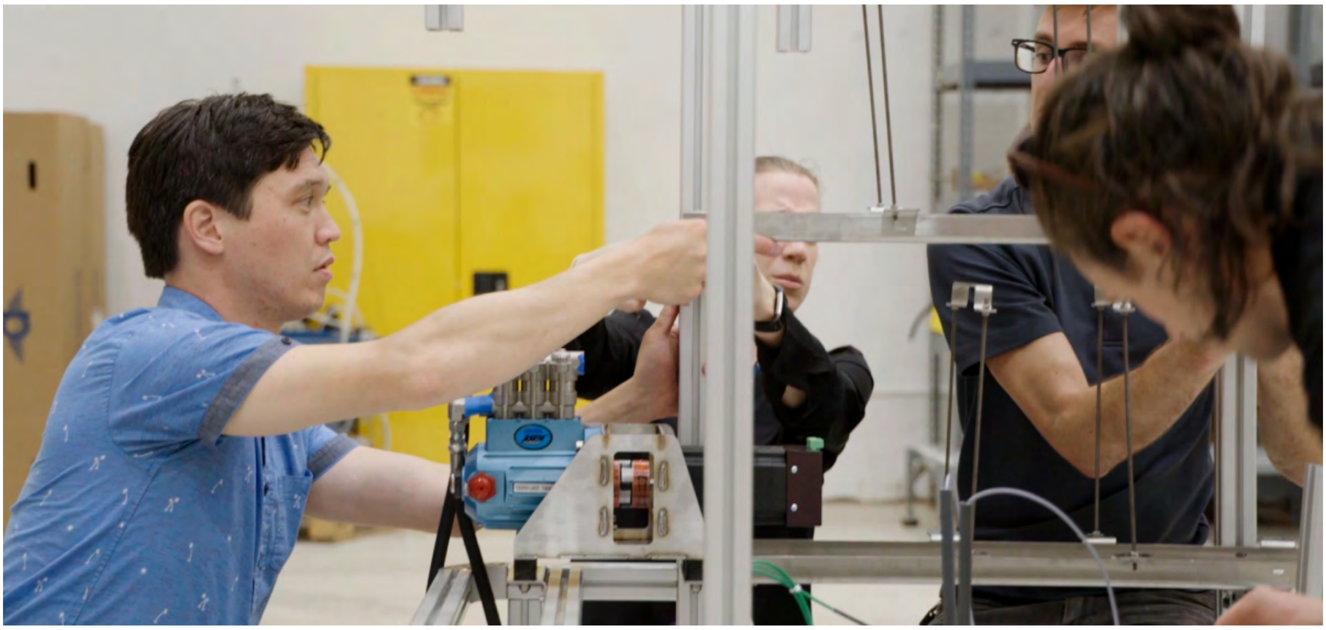
In one route, the faeces are pasteurized, eradicating all pathogens and unpleasant smells before being formed into cakes and dried.

In the other different route known as micro-supercritical water oxidation, the faeces are burned underwater at 373 degrees, resulting in ash suspended in water. The ash is dried while the water is passed through the filtration process.

The user can then discard the ash and faeces cakes in the trash or compost by letting them fall into a receptacle[17].

Figure 14 Generation 2 Reinvented Toilet (G2RT)

(Source: https://www.gatesnotes.com/Development/Heroes-in-the-field-Dr-Shannon-Yee)



Plumbing Cost Saved by Switching to RT

This section describes the details of costs displaced by switching to RT. In the current research, a residential community of 300 apartments in 20-floor building was explored for investigating the plumbing cost savings due to RT. The blackwater household RT (b-HRT) could potentially eliminate the need for external plumbing to transport blackwater, as it would treat the blackwater with faeces in-situ. This would mean the following:

1 Plumbing costs are reduced, which will vary by single or dual piping. The diameter of the piping is also reduced as they would need to transport only greywater with the b-HRT.

2 Water reuse for flushing is achieved at the point of generation of human waste. Thus, the piping needed to transport the treated water from the wastewater treatment plant (WWTP) to the overhead tank and from the overhead tank to the flush tank in each household is eliminated.

3 Treatment capacity of the WWTP is reduced as the blackwater is now treated within the household by the RT.

Following is just one example in a specific segment (residential community of a particular size).

General Assumptions for Five Scenarios

In order to estimate the plumbing cost savings due to RT, the five scenarios were developed as enlisted in Table 11. The general civil related assumptions are enlisted in Table 12. Table 13 depicts the MEP-related assumptions. In order to estimate the plumbing cost savings due to RT, the five scenarios were developed having different combinations of 3 BHK, 2 BHK and 1 BHK. For 3 BHK, 2 BHK and 1 BHK, the built-up area was 1,670, 1,081and 790 Sqft, respectively. For 3 BHK, 2 BHK and 1 BHK, the number of persons per household were 6, 4 and 3, respectively. Also, for 3 BHK, 2 BHK and 1 BHK, the number of toilets per household were 3, 2 and 1, respectively.

Table 11 Five Scenarios and related assumptions

Description	3 BHK per Floor	2 BHK per Floor	1 BHK per Floor	No of persons per Floor	No of Toilets per Floor
Built-up Area (Sqft)	1,670	1,081	790	-	-
Persons per home	6	4	3	-	-
Toilets per home	3	2	1		
Scenario-1	4	8	3	65	31
Scenario-2	4	6	5	63	29
Scenario-3	4	11	0	68	34
Scenario-4	6	3	6	66	30
Scenario-5	9	6	0	78	39

In all five scenarios, number of units on one level, the number of floors above ground and total units were 15, 20 and 300, respectively.

Table 12 General assumptions on civil-related work

Sr. No.	Parameter	Quantity	Unit
1	Number of units on one level	15	Number
2	Number of floors above ground	20	Number
3	Total units	300	Number
4	Average horizontal distance from kitchen to nearest vertical drain	1.8	m
5	Floor to floor height	3	m
6	Elevation of base of tanks from roof	3	m
7	Number of sumps for a block	4	Number
8	Height of building	63	3
9	Distance from block corner to STP	50	m
10	Vent cowl pipe height	1.5	m
11	Drainpipe line horizontal distance from block to the main line	2.5	m
12	Drain jali to external wall distance	0.5	m
13	Number of motors to pump flush water from STP	2	Number
14	Volume of overhead tanks	25	m3
15	Number of tanks for conventional	8	Number
16	Number of tanks for RT	6	Number

Table 13 General assumptions on MEP-related work

Sr. No.	Parameter	Quantity	Unit
1	Flush water demand per pax	0	LPCD
2	Domestic water demand per pax	90	LPCD
3	Number of overhead tanks for flush water Conventional	2	Number
4	Number of overhead tanks for flush water RT	0	Number
5	Number of overhead domestic water tanks	6	Number
6	Number of toilets sharing 1 vertical black water line	1	Number
7	Number of toilets sharing 1 vertical grey line	1	Number
8	Number of kitchens sharing 1 vertical line	1	Number
9	Number of blackwater verticals for RT	0	Number

Cost Comparison for Scenario 1

Along with the general assumptions, the additional assumptions for Scenario 1 are given in the Table 14.

Table 14 The assumptions for Scenario 1

Sr. No.	Parameter	Quantity	Unit
1	Length of building	54.4	m
2	Width of building	46.2	m
3	Number of kitchen verticals	15	Lines
4	Number of blackwater verticals	31	Lines
5	Number of greywater verticals	31	Lines
6	Number of persons per floor	65	Persons
7	Number of toilets per floor	31	Nos
8	Number of baths per floor	31	Nos

The cost saving due to RT in the case of Scenario 1 is given in the Table 15.

Table 15 Cost comparison for Scenario 1

Sr. No.	Description	Plumbing Cost for Conventional Toilets (Thousand $)	Plumbing Cost for RT (Thousand $)	Plumbing Cost Saved due to RT ($/toilet)
1	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP):	138	84	87.20
2	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP):	123	69	87.20
3	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP):	128	84	70.96
4	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP):	113	69	70.96

Note: US$1 = INR 81.42

Figure 15 Floor plan for the Scenario 1

Cost Comparison for Scenario 2

Along with the general assumptions, the additional assumptions for Scenario 2 are given in the Table 16.

Table 16 The assumptions for Scenario 2

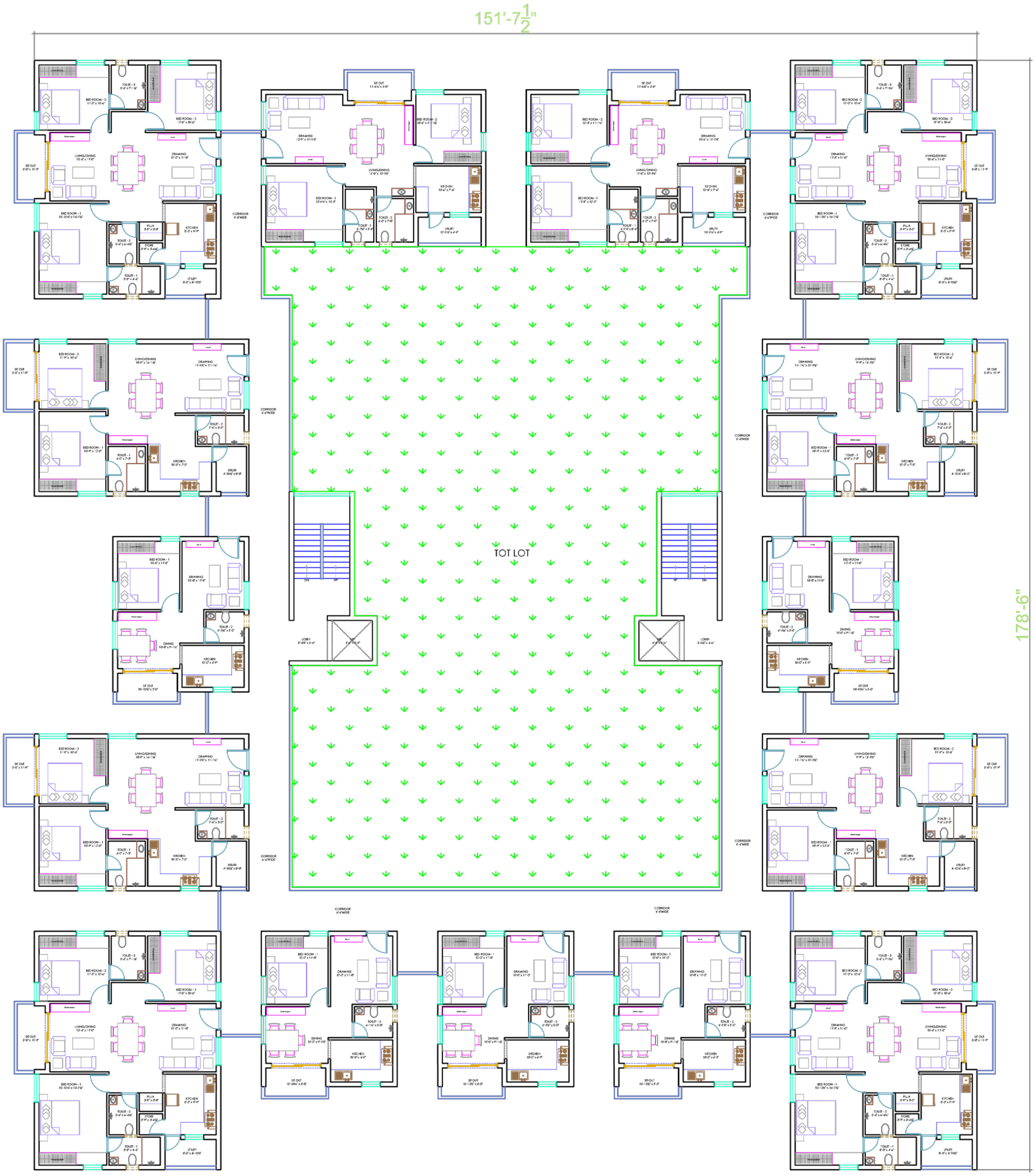
Sr. No.	Parameter	Quantity	Unit
1	Length of building	54.4	m
2	Width of building	46.2	m
3	Number of kitchen verticals	15	Lines
4	Number of blackwater verticals	29	Lines
5	Number of greywater verticals	29	Lines
6	Number of persons per floor	63	Persons
7	Number of toilets per floor	29	Nos
8	Number of baths per floor	29	Nos

The cost saving due to RT in the case of Scenario 2 is given in the Table 17.

Table 17 Cost comparison for Scenario 2

Sr. No.	Description	Plumbing Cost for Conventional Toilets (Thousand $)	Plumbing Cost for RT (Thousand $)	Plumbing Cost Saved due to RT ($/toilet)
1	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP):	130	79	89.29
2	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP):	117	66	89.29
3	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP):	120	79	71.94
4	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP):	107	66	71.94

Figure 16 Floor plan for the Scenario 2



Cost Comparison for Scenario 3

Along with the general assumptions, the additional assumptions for Scenario 3 are given in the Table 18.

Table 18 The assumptions for Scenario 3

Sr. No.	Parameter	Quantity	Unit
1	Length of building	54.6	m
2	Width of building	49.2	m
3	Number of kitchen verticals	15	Lines
4	Number of blackwater verticals	34	Lines
5	Number of greywater verticals	34	Lines
6	Number of persons per floor	68	Persons
7	Number of toilets per floor	34	Nos
8	Number of baths per floor	34	Nos

The cost saving due to RT in the case of Scenario 3 is given in the Table 19.

Table 19 Cost comparison for Scenario 3

Sr. No.	Description	Plumbing Cost for Conventional Toilets (Thousand $)	Plumbing Cost for RT (Thousand $)	Plumbing Cost Saved due to RT ($/toilet)
1	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP):	149	91	84.51
2	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP):	132	75	84.51
3	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP):	138	91	69.71
4	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP):	122	75	69.71

Figure 17 Floor plan for the Scenario 3

Cost Comparison for Scenario 4

Along with the general assumptions, the additional assumptions for Scenario 4 are given in the Table 20.

Table 20 The assumptions for Scenario 4

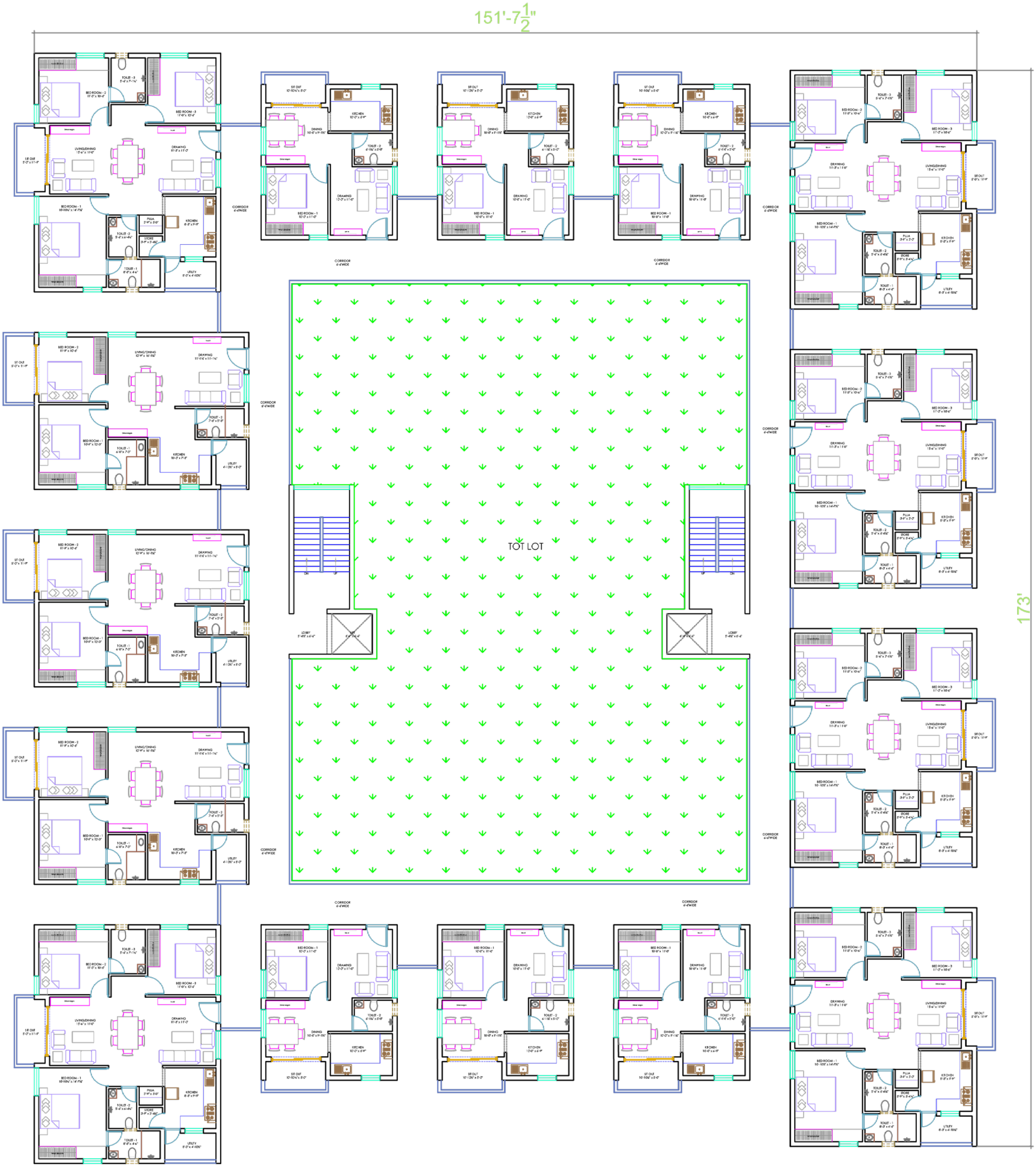
Sr. No.	Parameter	Quantity	Unit
1	Length of building	57.7	m
2	Width of building	46.2	m
3	Number of kitchen verticals	15	Lines
4	Number of blackwater verticals	30	Lines
5	Number of greywater verticals	30	Lines
6	Number of persons per floor	66	Persons
7	Number of toilets per floor	30	Nos
8	Number of baths per floor	30	Nos

The cost saving due to RT in the case of Scenario 4 is given in the Table 21.

Table 21 Cost comparison for Scenario 4

Sr. No.	Description	Plumbing Cost for Conventional Toilets (Thousand $)	Plumbing Cost for RT (Thousand $)	Plumbing Cost Saved due to RT ($/toilet)
1	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP):	131	79	86.14
2	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP):	118	67	86.14
3	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP):	121	79	69.37
4	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP):	108	67	69.37

Figure 18 Floor plan for the Scenario 4



Cost Comparison for Scenario 5

Along with the general assumptions, the additional assumptions for Scenario 5 are given in the Table 22.

Table 22 The assumptions for Scenario 5

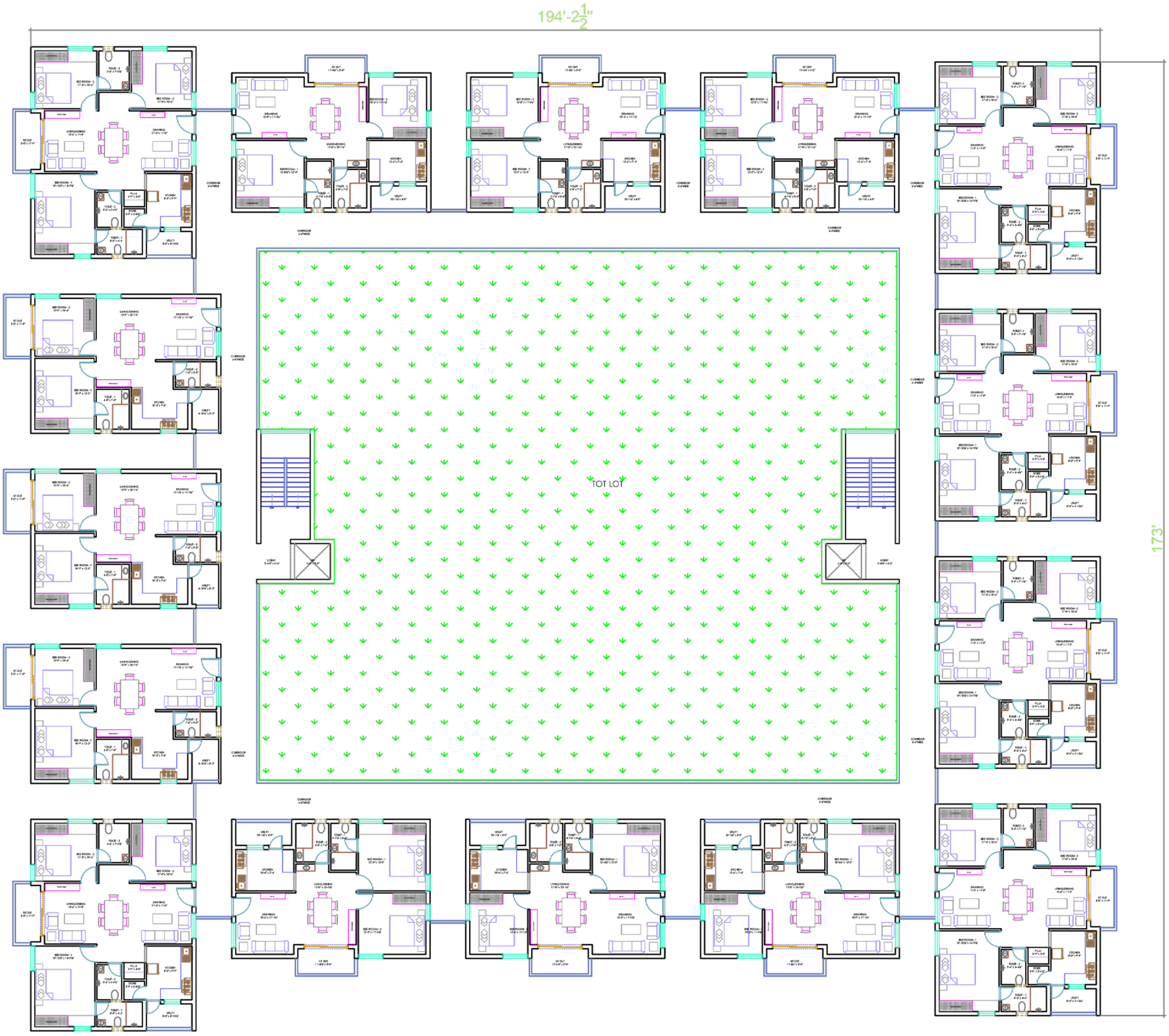
Sr. No.	Parameter	Quantity	Unit
1	Length of building	59	m
2	Width of building	52.7	m
3	Number of kitchen verticals	15	Lines
4	Number of blackwater verticals	39	Lines
5	Number of greywater verticals	39	Lines
6	Number of persons per floor	78	Persons
7	Number of toilets per floor	39	Nos
8	Number of baths per floor	39	Nos

The cost saving due to RT in the case of Scenario 5 is given in the Table 23.

Table 23 Cost comparison for Scenario 5

Sr. No.	Description	Plumbing Cost for Conven-tional Toilets (Thousand $)	Plumbing Cost for RT (Thousand $)	Plumbing Cost Saved due to RT ($/toilet)
1	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP):	149	93	71.82
2	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP):	133	77	71.82
3	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP):	139	93	58.91
4	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP):	123	77	58.91

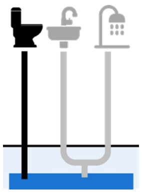
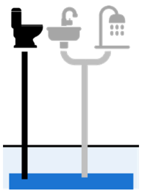
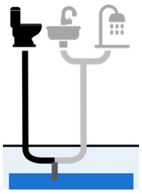
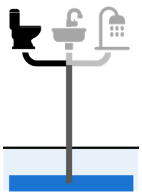
Figure 19 Floor plan for the Scenario 5



Overall Cost Comparison for Five Scenarios

Overall cost comparison (plumbing cost saved due to RT) for five scenarios is depicted in Table 24.

Table 24 Overall cost comparison for five scenarios (plumbing cost saved due to RT)

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP) ($/toilet):	$87.2	$89.3	$84.5	$86.1	$71.8
	Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP) ($/toilet):	$87.2	$89.3	$84.5	$86.1	$71.8
	Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP) ($/toilet):	$70.9	$71.9	$69.7	$69.4	$58.9
	Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP) ($/toilet):	$70.9	$71.9	$69.7	$69.4	$58.9

Above estimation is just one example in a specific segment (residential community of a particular size). The analysis of displaced costs should be conducted for multiple segments in the next proposal.

Market Opportunity for RT

This section describes the details of market opportunity for RT. The worldwide cost of inadequate sanitation is $260 billion. RT signifies a potential $6 billion plus global annual revenue opportunity. In addition, RT offers an opportunity for societal impact, resulting in real financial returns. Macro developments are intensifying the appeal of the RT value offer[1].

Growing urban population:

With 66% of the world's population expected to live in cities by 2050, population growth in developing nations is frequently outpacing that of sanitation infrastructure, necessitating the development of low-cost, wide-access sanitation solutions.

Aging infrastructure

Even in developed markets, current sewer and centralised wastewater treatment systems may be under capacity strain. Infrastructure upgrades are expensive and disruptive. Also, outdated infrastructure results in miles of leaking pipes and insufficient wastewater treatment capacity.

Water scarcity and stress

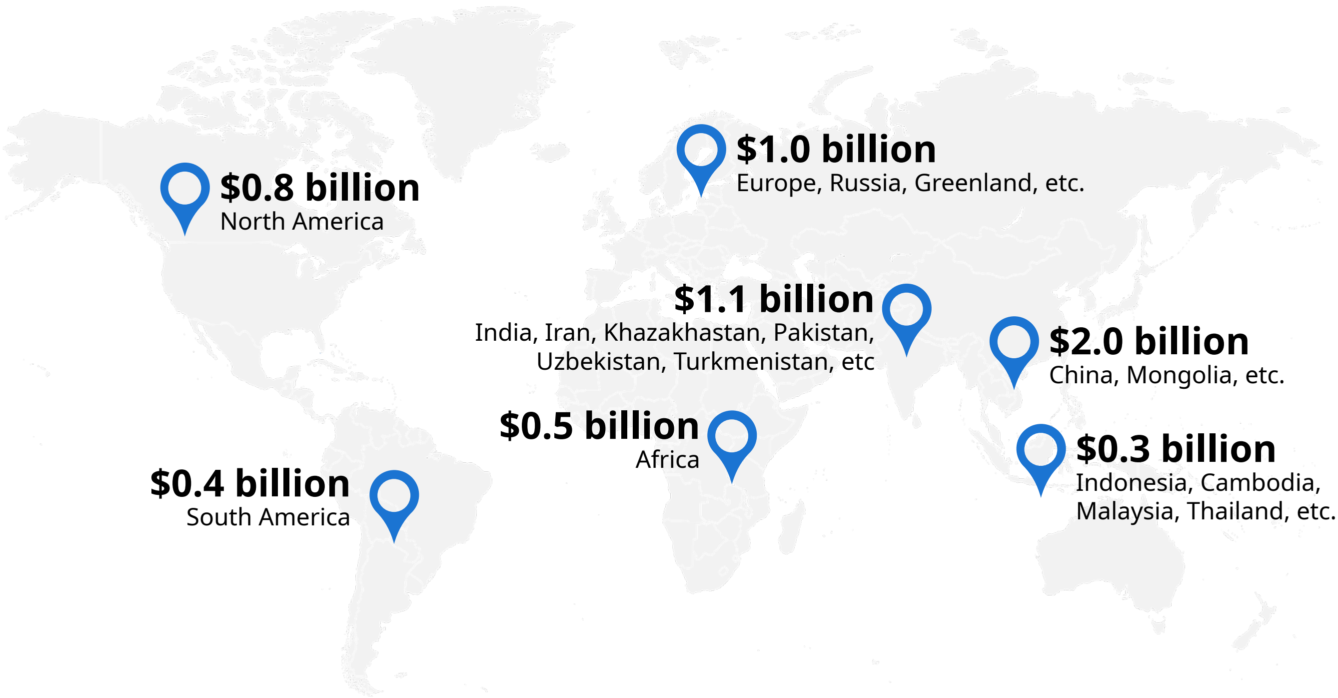
Demand might surpass supply by 40%, and water stress will boost the demand for sanitation technology that doesn't rely on water inputs. By 2030, half of the world's population may experience water shortages.

Policy changes

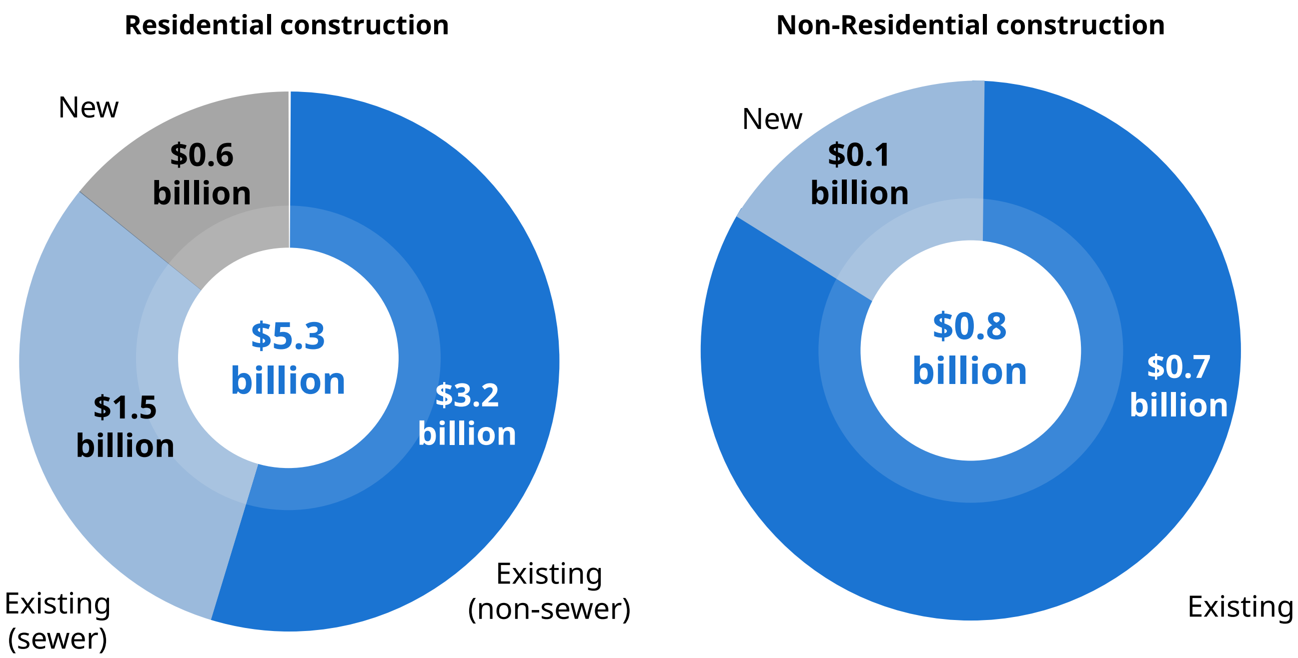
Government programs and initiatives are aimed at improving sanitation, particularly in developing markets.

Global Annual Revenue Opportunity

RT signifies a potential $6 billion plus global annual revenue opportunity. The more details are given below[1].

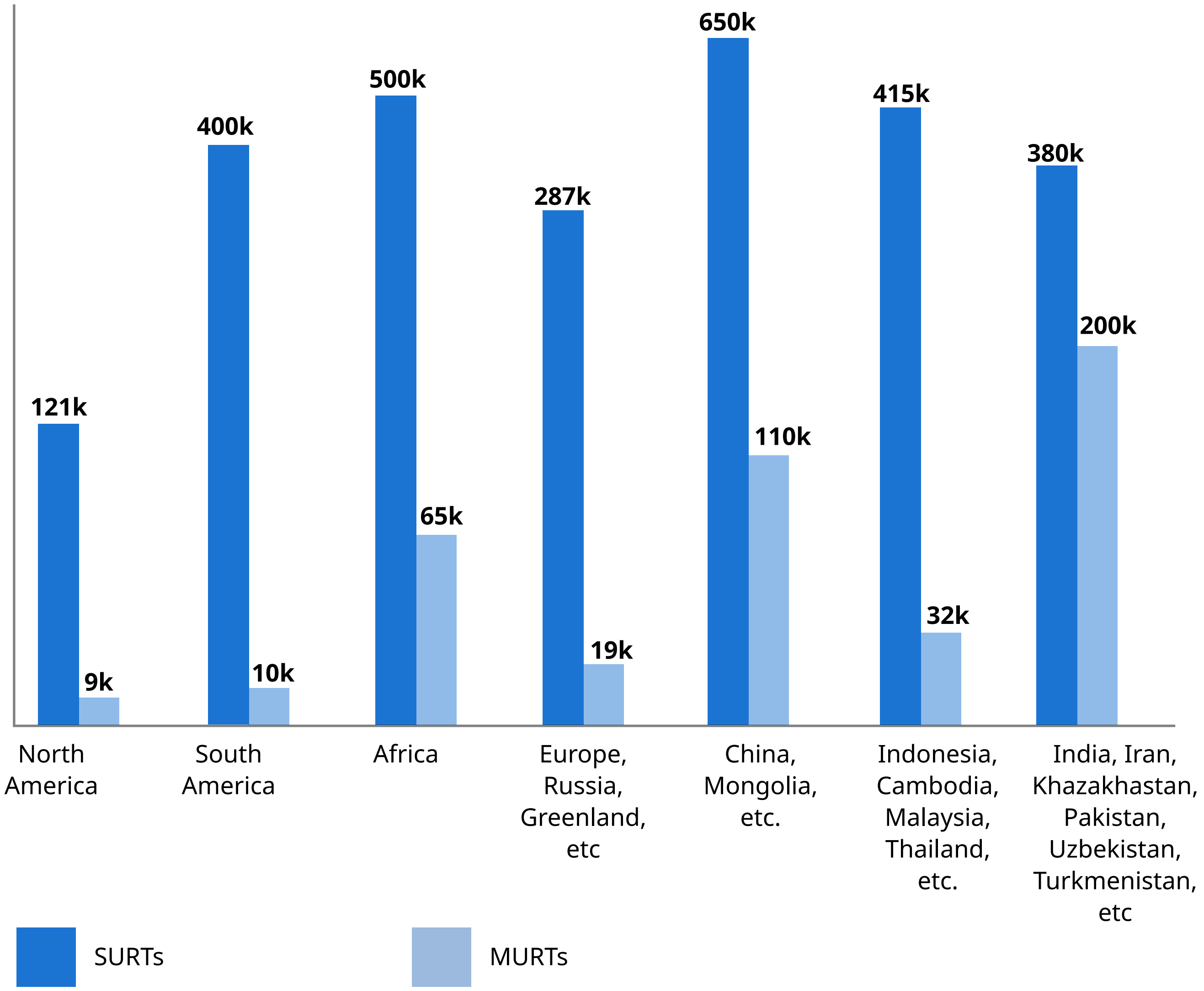


The division of market is as follows[1].



Global Annual Sales Opportunity

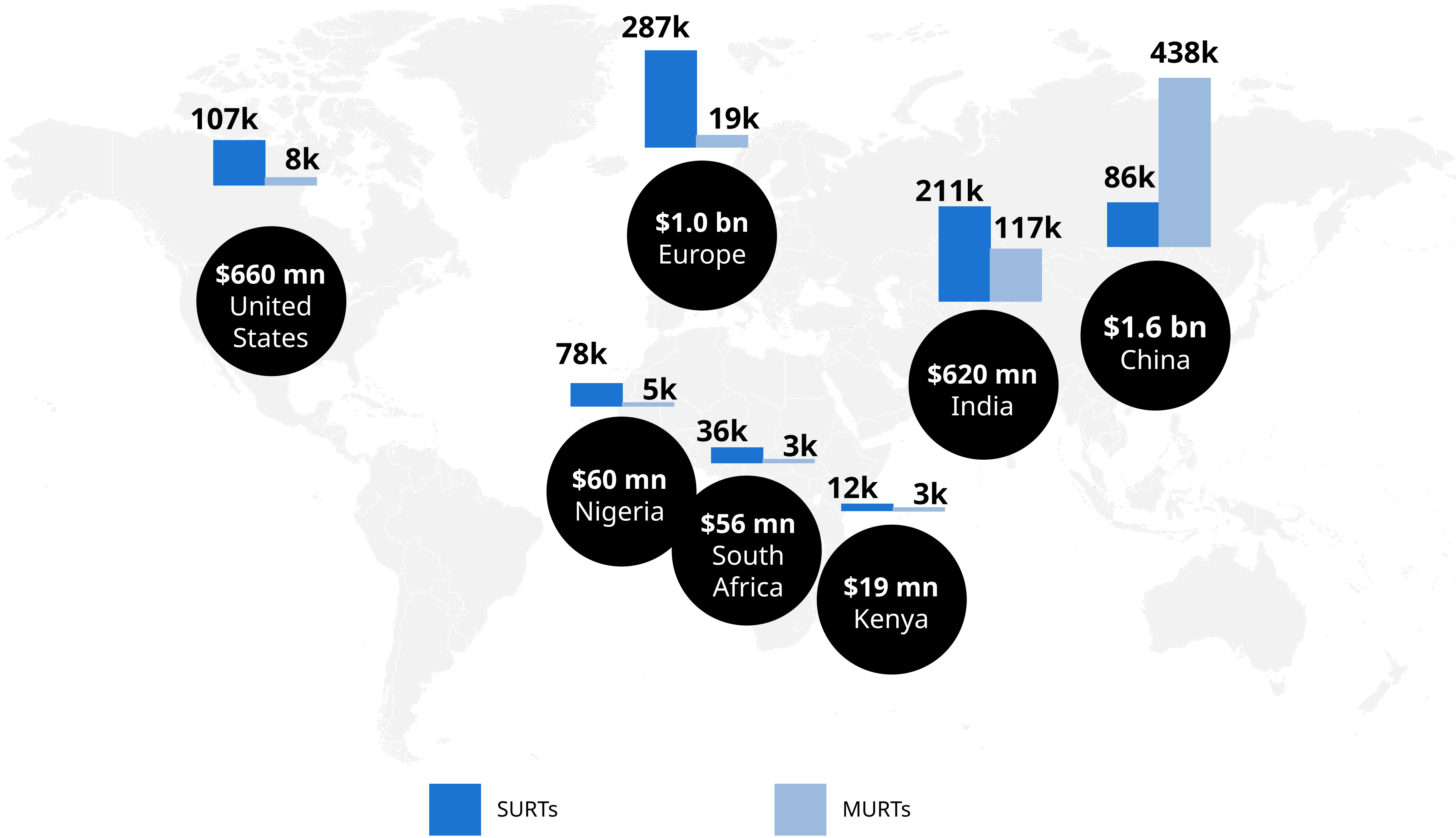
2.6 million SURTs and 0.5 million MURTs could be sold annually across the world for RT. More details are given below[1].



The country/region-wise revenue potential and sale opportunity for RT is given below.

The country/region-wise 2030 revenue potential and 2030 sales opportunity for RT

(Source: Transforming Sanitation, Commercialization partnership opportunities, Bill and Melinda Gates Foundation, December 2017)



The Way Forward

Conclusions

The future is on-site sanitation systems with no need for transportation of faecal sludge, where septage gets treated at point of generation and there is no lag between generation and treatment thus preventing spread of harmful diseases and saving lives. Hence, the possibility of deploying a Reinvented Toilet product for developing countries which treats waste at a community level and then at toilet level; was assessed in the current research.

A RT is a modification of the existing toilet embedded with modern technology such that it not only collects the waste but also treats it on-site. The RT kills pathogens, does not need a sewerage connection or septic tank, requires no input water and outside electricity, and converts human waste into a safe by-products like clean water and ash.

The key objectives of the current research were to examine all the available reports, studies done or in progress for RT and create a detailed proposal for opportunity analysis for RTs and its unit economics. Moreover, the landscape of the RT covering the history, types of RT, existing RT technologies, etc. were studied in the current research.

Furthermore, in order to estimate the plumbing cost savings due to RT, the five scenarios were developed. For 3 BHK, 2 BHK and 1 BHK, the built-up area was 1,670, 1,081and 790 Sqft, respectively. For 3 BHK, 2 BHK and 1 BHK, the number of persons per household were 6, 4 and 3, respectively. Also, for 3 BHK, 2 BHK and 1 BHK, the number of toilets per household were 3, 2 and 1, respectively. In all five scenarios, number of units on one level, the number of floors above ground were and total units were 15, 20 and 300, respectively. The plumbing cost savings due to RT ($/toilet) in all five scenarios for four different conditions are given below:

1. Dual piping (Separate lines of grey and black water to sewage treatment plant (STP) and here grey water line i.e. a separate line of kitchen water and a separate line of bath water is mixed in the basement and then sent to STP) ($/toilet): Scenario 1: 87.20, Scenario 2: 89.29, Scenario 3: 84.51, Scenario 4: 86.14 and Scenario 5: 71.82
2. Dual piping (Separate lines of grey and black water to STP and here grey water line is a mixture of kitchen water and bath water which is mixed on the floor and then sent to STP) ($/toilet): Scenario 1: 87.20, Scenario 2: 89.29, Scenario 3: 84.51, Scenario 4: 86.14 and Scenario 5: 71.82
3. Combined piping in the basement (Dedicated line of bath water and kitchen water together and a separate line of black water line is mixed in the basement and then sent to STP) ($/toilet): Scenario 1: 70.96, Scenario 2: 71.94, Scenario 3: 69.71, Scenario 4: 69.37 and Scenario 5: 58.91
4. Combined piping on the floor (bath water, kitchen water and black water are mixed on the floor and then sent to STP) ($/toilet): Scenario 1: 70.96, Scenario 2: 71.94, Scenario 3: 69.71, Scenario 4: 69.37 and Scenario 5: 58.91

Next Steps

In continuation of this research, next steps involve the development of a detailed proposal for opportunity analysis for RTs and its unit economics. Atlas would like to conduct a detailed assessment for multiple segments in general and the residential segment in particular.

The next proposal will be aimed at achieving the following for the residential market study:

Residential Applications in areas with Non-Sewered Sanitation

- Individual homes with On-site Sanitation Systems
- Multi-family homes – up to 10 apartments in a building
- Residential communities with 10-30 apartments
- Residential communities with 30-100 apartments
- Residential communities with >100 apartments
- Individual Household Toilets (IHHL) built under Swachh Bharath Mission (SBM), both urban and rural

Residential Applications in areas with Centralized Sewer Systems (CSS)

- Individual homes in metropolitan areas/top-8 cities (focus on water reuse, they will have less incentive to treat the solids)
- Multi-family homes – up to 30 apartments in a building (focus on water reuse, they will have less incentive to treat the solids)
- Residential communities categorized as bulk generators of used water (>25 apartments) – split between metropolitan areas/top-8 cities and other cities, and towns (they are typically mandated to have WWTP within the facility, water reuse is an important element)

Cost Displaced by Switching to RT

- Estimate the cost savings due to RT replace in each segment
- The analysis of displaced costs should be conducted for above identified multiple segments in the next proposal.

Unit Economics with the RT

- Continuing the analysis of the displaced costs above, the intrinsic value of the RT should be estimated in the next proposal that could translate into an entry price point for each segment along with estimation of $/user cost for each segment

List of References

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