BILL & MELINDA GATES foundation

Transformative Sanitation Technologies:
A New Path To Safe Sanitation For All

The Janicki omni-processor is currently in the pilot phase in Dakar, Senegal to better understand how the technology can process fecal sludge from across the city.

Introduction: The Sanitation Crisis

The core principle of the Bill & Melinda Gates Foundation is that "all lives have equal value." We work with partners across a range of global health and development challenges to identify and accelerate solutions to problems that pose the biggest threat to human health and productivity. Our Global Growth and Opportunity division advances this mission by helping to improve the financial, technological, infrastructure, and regulatory systems that can enable the poor—especially the poorest women and girls—to more fully participate in their economy and their society.

One of the most destructive and systemic inequalities of our time involves one of the most basic of all human needs: sanitation. From the time people began gathering in towns and cities, a crucial marker of progress has been our ability to avoid contact with human waste. Yet even today, about 4.5 billion people—more than half the world's population—use sanitation facilities and services that are not safely managed.[1] This means that—even if a person has access to, and uses, a toilet or pit latrine—their waste is often not contained, transported, or treated in a way that eliminates harmful pathogens. As a result, that waste is not disposed in a way that maintains a clean and healthy environment for people.

Living without safe sanitation services isn't just an inconvenience. It has devastating impacts on people's lives. Bad sanitation means contaminated water, soil, and food. It makes people sick, and it keeps them from work and school, with real impacts on the human and economic potential of entire communities, and even nations.

Unsafe sanitation is widely accepted as a chief contributor to waterborne and soil-transmitted diseases, which harm the health of adults and children. Sanitation-related diseases, including diarrhea, cholera, and typhoid, kill nearly 500,000 children under the age of five, each year—more than AIDS, measles, and tuberculosis combined.[2]

Global costs related to unsafe sanitation, including increased healthcare costs and losses in productivity and income, were estimated to equal $223 billion in 2015.[3] In India alone, annual sanitation-related losses were projected to be more than $100 billion—equivalent to 5.2 percent of

[1] WHO/UNICEF Joint Monitoring Program for Water Supply, Sanitation and Hygiene, "2017 Update and SDG Baselines," June 2017.
[2] IHME, The Global Burden of Disease, 2016
[3] LIXIL & Oxford Economics, "The True Cost of Poor Sanitation", 2016, http://www.lixil.com/en/sustainability/pdf/the_true_cost_of_poor_sanitation_e.pdf

the nation's GDP.[4] But India is not an outlier; every year poor sanitation costs the equivalent of 2.4 percent of GDP in Bangladesh, 3.2 percent in Laos, 2.7 percent in Niger, and 3 percent in Pakistan.[5]

Emerging global trends, from climate change to demographic shifts, could make the sanitation crisis even worse. The United Nations estimates that by 2050, 68 percent of the world's population will live in urban areas (a growth of around 2.7 billion people). This will put increasing strain on already-inadequate city-level sanitation systems and infrastructure. Around 70 percent of that growth (1.9 billion people) will occur in low-income and lower-middle-income countries in Asia and Africa,[6] where water scarcity trends are likely to hit the hardest, causing further stress on valuable natural resources. Currently, 1.9 billion people live in potential "severe" water-scarce areas, such as Cape Town, South Africa, where daily rationing of drinking and household water use has already become a reality for citizens. By 2050, as much as 30 percent of the global population (2.7 to 3.2 billion people) will be living in conditions of severe water scarcity, annually.[7]

Given these projections, it is more important than ever to rapidly scale up systems that can deliver safe, sustainable sanitation to people and communities. Still, despite decades of hard work by the global NGO community and many public and private sector leaders, safe sanitation isn't improving fast enough. Recently, the World Health Organization and UNICEF reported that over the last five years, sanitation rated as "safe for people" increased by only 3 percent worldwide.[8] This rate is insufficient to achieve progress toward global water and sanitation standards outlined in the United Nations' Sustainable Development Goals (SDG 6) and urgently needed by people and communities around the world.

A New Generation of Solutions: Transformative Sanitation Technologies

The Bill & Melinda Gates Foundation invests in partnerships and programs to accelerate progress toward safely managed sanitation for the world's poorest. We believe that with the right investments and the right innovations, governments and utilities can partner with the private sector and bring safe sanitation approaches and systems to billions of people while creating new, profitable sanitation markets that sustain these new practices both in emerging markets and globally.

Since 2011, the foundation has worked to develop a portfolio of innovative sanitation technologies, such as the reinvented toilet and new kinds of human waste treatment technologies, that give governments and utilities a running start at transformative approaches to an old problem. We have primarily invested in early R&D—the riskiest phase of a technology innovation process—and the development of international standards, in order to establish a high bar for these innovations, while simultaneously removing barriers for companies and governments that want to be early adopters. We know that risk is a key barrier to investment and adoption of technology by governments and private sector partners, so we've used our capital and convening power, in a way that others can't or won't, to lower those risks.

Transformative sanitation technologies are some of the most exciting—and yet most practical—innovations our foundation has supported. But to realize their full potential to improve lives worldwide, national and local leaders, funders, and commercial entities will have to reevaluate longstanding assumptions about what "good sanitation service" is, how it works, and who can play a

[4] Ibid.
[5] LIXIL, "The True Cost of Poor Sanitation", 2016, http://www.lixil.com/en/sustainability/pdf/the_true_cost_of_poor_sanitation_e.pdf
[6] United Nations, "World Urbanization Prospects", 2018, https://esa.un.org/unpd/wup/
[7] Burek et al. 2016, http://pure.iiasa.ac.at/id/eprint/13008/1/WP-16-006.pdf
[8] WHO/UNICEF Joint Monitoring Program for Water Supply, Sanitation and Hygiene," 2017 Update and SDG Baselines," June 2017.

role in establishing and benefiting from it. Our work with partners is focused on helping to expand the range of approaches that governments and communities can use to meet their diverse needs, as well as on growing the demand for safely managed sanitation.

Sewered sanitation—toilets connected to sewer systems and waste treatment plants—has never been, and will never be, the best approach for creating safe sanitation for all people and all communities. Many developing countries have rushed to develop sewer networks to meet citizens' sanitation needs, because such systems are considered by many consumers and governments around the world to be the only "gold standard" for safe sanitation. But building and maintaining centralized systems like sewers is not necessarily the right answer for many cities, especially in the global south. Sewer systems require vast networks of pipes and expansive wastewater treatment plants that are not feasible for many environments, and they require large quantities of energy and water to operate.

What's more, despite the amount of resources they require, sewers often allow fecal sludge and other byproducts to leak into the environment or directly into water sources. An analysis of data from 39 countries showed that, of the sewage that is transmitted through sewers, 43 percent of human waste makes it into the environment without being treated.[9] Similarly, the sewer-connected toilet is not the right fit for every community. Such toilets require significant amounts of water and well-functioning sewer infrastructure to operate effectively.

In the absence of sewer-connected flush toilets, people in cities worldwide use a range of non-sewered toilet options to meet their needs—from no toilets at all (open defecation) to hanging toilets that release waste over rivers and streams, to pit latrines and toilets flushing into septic tanks. But none of these options safely contain or dispose of human waste consistently. These kinds of facilities often allow waste to seep into fields, waterways, and urban neighborhoods or require people to manually retrieve waste and dump it, untreated, elsewhere in the community.

Today, there is growing recognition that improving and expanding non-sewered sanitation approaches will be a crucial aspect of current and future urban development and sanitation planning—because it is already what many people around the world use, and it is more cost and resource effective for many cities and communities. In fact, non-sewered sanitation is already the principal form of improved sanitation (facilities connected to on-site storage and treatment facilities such as septic tanks or latrine pits) in urban as well as rural areas of sub-Saharan Africa, and Central and Southern Asia.[10]

The new technologies developed through the foundation's sanitation portfolio have advanced the non-sewered concept to ensure that new products in this category, using technologies developed by our partners, are not only practical for billions of people but also effective at meeting the highest standards for health and human safety. This, all at a low cost to users once market scale is achieved, could represent the "second gold standard" of comprehensive, effective sanitation.

Critically, these options will require new partnerships and collaborations across the public and private sectors, as well as new service models and market structures and different approaches and technologies to serve different community needs and settings. We see particular promise in sanitation service models that rely on public sector agencies like utilities and local governments to provide regulation and oversight, and which allow private sector providers, through service level agreements, to deliver sanitation services and garner profit from byproducts that have market value, including energy and fertilizer. This is a sustainable partnership model that offers natural incentives

[9] "A Review of Fecal Sludge Management In 12 Cities," Peal, A. et al. (2015); https://sfd.susana.org/data-to-graphic
[10] "Progress on Drinking Water, Sanitation and Hygiene", World Health Organization and the United Nations Children's Fund (2017) http://www.who.int/mediacentre/news/releases/2017/launch-version-report-jmp-water-sanitation-hygiene.pdf

for innovation and long-term delivery of safe sanitation to communities.

Three Breakthrough Sanitation Technologies

Over the last seven years, the Bill & Melinda Gates Foundation has partnered with engineering and technical partners to develop three core groups of technologies that we believe hold the greatest potential as solutions for the urban poor. These include: the reinvented toilet, the omni-processor, and the omni-ingestor.

The Reinvented Toilet: To develop innovative solutions that would provide an equally aspirational user experience and degree of safety as sewer-connected flush toilets, without the need for sewers and wastewater treatment plants, the foundation introduced the Reinvent the Toilet Challenge. Through this program, launched in 2011, the foundation has worked with leading engineers and scientists to design low-cost toilets that do not require connections to the electrical grid, water supply, or sewers and that fully process human waste.

While designs vary, these toilets work using internal treatment systems and can be set up in areas that are hard to reach with traditional sewered infrastructure. Importantly, they can deliver the same benefits as toilets connected to sewers, plus wholly new benefits, including the removal of human pathogens and odors, while potentially generating safe useable water or electricity. Further, these treatment technologies have the ability to scale to a wide range of use cases. The reinvented toilet may be used in a household, as a single shared toilet, or it may process waste from multiple stalls, as you might find in a school or other community setting.

These no-sewer toilets don't require drains, pipes, continuous electricity, or treatment plants. Instead, they are self-contained units that treat a household, building, or community toilet's sewage on-site, at a low cost to users.

One example is a prototype that uses solar energy to power an electrochemical reactor that breaks down water and human waste. Another works using the same principles as a kitchen pressure cooker. Both produce clean water and solids that are safe to use as fertilizer or dispose of safely outdoors, with no odor or pathogens.

The Omni-Processor: Our partners are also developing what might be called the 21st-century treatment plant: machines called "omni-processors" that process waste, kill pathogens, and convert the resulting materials into products that can be sold, such as clean water, electricity, or fertilizer. Omni-processors can be used to augment existing sanitation services within a city, as part of a fecal sludge treatment plant or complementing a waste-water treatment plant, while potentially providing new revenue streams.

The Omni-Ingestor: While some families are currently able to get their septic tanks and pit latrines emptied by vacuum trucks, many others cannot—because the pits and tanks are too far from a road or too hard to access in a narrow alley, or because their contents are too dry for traditional vacuum pumps to empty them. Often the service simply costs too much or is so unreliable it doesn't help a family safely manage their waste.

Our partners are designing a new generation of technologies known as "omni-ingestors" to help address these challenges. These innovations use mobile units to first extract waste from the pits safely for the operator, and then either treat the waste on-site or reduce it in volume so that transportation to a final treatment stage is more efficient. The result is a safer, more economic, and more inclusive emptying service available to urban households.

Examples of Progress: New Sanitation Technologies at Work

The Bill & Melinda Gates Foundation's transformative technology portfolio currently includes 14 innovations in the reinvented toilet portfolio and three in the omni-processor portfolio. These technologies are in varying stages, from first prototypes to multiple pilot-tested units operating in real-world conditions. The majority of these technologies are currently available for licensing by commercial entities for product development, test piloting, or commercial launch.

The foundation is actively working with partners to pilot a number of transformative technologies to ensure they work as designed, in a variety of contexts and conditions where we hope they will be adopted and scaled. These pilots help companies and engineers test how a given technology or specific components of a product perform outside of a lab environment. They also provide the opportunity to make adjustments to ensure they're working as efficiently as possible.

Four active pilots include:

- The University of West England, Bristol, is piloting its Microbial Fuel Cell technology, which it calls "Pee Power Systems." This technology attaches to an existing toilet or urinal and turns urine into energy through a process that digests bacteria and rids the water of pathogens. The technology is small enough to fit onto one urinal or can be linked together in a "stack" to process greater volumes of urine and increase the electricity it generates. The Pee Power System is currently being piloted in a community toilet block at the Seseme Girls School in a rural village in Uganda. The power generated from this technology is used to power LED lights that help make the girls' trips to the bathroom easier. As a result of this innovation, girls using the toilet block say it makes them feel safer and enables them to study after dark. Another pilot, designed to test how the technology works in the urban context, has been operating at a school in Nairobi, Kenya, since June, 2018. In late 2018, a pilot will be up and running at a hospital in Nepal, and hospital administrators will use a disinfectant generated as a byproduct of the urine-processing technology to improve sanitation conditions at the hospital. These pilots will provide insights into the versatility of this component as part of a non-sewered sanitation system and how to optimize for the additional benefits the technology can bring to communities.

- In China, EcoSan is one of the leading developers of the PV-powered electrochemical reactor from CalTech technology. This model focuses on school and public toilets and containerized multi-stall toilet units. EcoSan is piloting three units in China, two at tourist locations—a park and a temple—and one at an elementary school. Further, two additional units are being commissioned in Durban, South Africa—one as a community ablution block and the other as a school toilet. Thanks to the reliability of the systems and to the interest in eco-friendly solutions that can recycle water (for water-scarce areas), EcoSan is already receiving commercial interest to buy their toilets. EcoSan's sister company, Yixing Entrustech, was funded to solve a critical barrier in the CalTech technology development for any commercial partner—the cost of the electrodes that drive the electrolysis treatment process. With fairly intense R&D on the coatings, processing, and other optimization, Yixing Entrustech has been able to reduce costs by almost 10 times in just under two years.

- In Dakar, Senegal, Janicki Bioenergy has been working since 2015 with Delvic, a private Senegalese company, and the national sanitation office of Senegal (ONAS), to pilot an omni-processor. The technology produces potable water, excess electricity, and nutrient-rich ash as byproducts of processing fecal sludge. The pilot is designed to test the machine's

technical features to ensure they can handle loads of fecal sludge brought from haulers around the city. In early 2019, the omni-processor will be piloted in a second location in Dakar, primarily to ensure the technology and proposed business model can effectively commercialize the outputs from the machine. These outputs include distilled water, which can be sold as a coolant or as drinking water; ash that can be used as fertilizer; and electricity.

- Tide Technocrats, based in India, is also working to test a technology that processes fecal sludge. Their omni-processor design requires only a small footprint to collect and remove liquids from the fecal sludge, before using a novel drying and pyrolysis technology to subject solids to extremely high temperatures. This process results in pathogen-free "biochar," a carbon-rich compound that can be safely reused. The technology is currently being piloted in three different urban locations in India—Warangal, Narsapur, and Wai—to better understand how the process can be improved and established successfully in further urban environments.

More information on the foundation's transformative technology partners and field testing approach is available at stepsforsanitation.org.

The Foundation's Role: Supporting the Development of New Markets for Sanitation Technologies

The foundation's work is about much more than just building a better toilet or waste treatment product. It's also about encouraging innovation, helping to develop systems that can deliver safely managed sanitation for all, and promoting policies and regulations that can strengthen these systems for the urban poor. As our portfolio of transformative sanitation technologies has evolved from a large set of technical explorations to a strategic set of pilot-ready products, our work has shifted from investing in R&D to supporting a pathway to commercialization for these new technologies.

Whether we're working with businesses, international agencies, utilities, or governments, our aim is to expand global access to new sanitation technologies. We are actively investing in market development by engaging with both the private and public sectors to bring technologies to markets where they can have the most impact.

A Global Business Opportunity

New sanitation technologies aren't just about doing what's right for human health and the environment—they represent a huge business opportunity for companies that are willing to bring them to market. Estimates show that non-sewered toilets alone potentially present a $6 billion-per-year global market opportunity in the combined consumer and municipal sectors by 2030, with over half of that coming from emerging economies like India, China, and countries across Africa. Developed countries with well-established sanitation systems and commercial forces that support green building and innovative building practices have much to gain as well: the market opportunity for the U.S. and Europe is an estimated $1.7 billion.

Current trends in business align well with such opportunities. We have seen an increase in corporate interest in supporting opportunities for growth in emerging markets. Across the world, companies are embracing—and in some cases even emphasizing—global development goals as part of their business planning, both to show consumers and employees they are committed to building a more sustainable approach to business and also to play a role in solving challenges that communities across the globe are facing.

Businesses, of course, aren't the only entities with a strong interest in new sanitation technologies. The United Nations has included water and sanitation in the Sustainable Development Goals. Specifically, Goals 6.2 [11] and 6.3[12] set global guidelines for governments and private sector actors to ensure the availability and sustainable management of water and sanitation for all.

Strong commitments from national and local governments to improve sanitation laws, policies, and regulations are also critical. Leadership, such as that demonstrated by governments in China, India, Senegal, and South Africa, show that now, more than ever, there is growing momentum to implement alternative solutions to pressing sanitation challenges.

Building Partnerships

Currently, the foundation is advising commercial and government partners in China, Africa, the U.S., Europe, and India on sanitation business opportunities and service-delivery models. We help identify use cases and potential customers, so that our commercial partners can meet their business goals while also delivering urgently needed sanitation solutions for poor communities. We also work with companies on research and development, investing in technical engineering to help lower production costs and improve the supply chain.

In addition, we're assisting with the shaping of business plans to support the foundation's Global Access Commitment, which aims to ensure that technologies funded by the foundation will be made available to those most in need, at an affordable price.

In order to bring sanitation technologies to market in large-scale pilot programs, we are also forging strong partnerships with other leading bilateral and multilateral donors whose voice will be critical to serve as public champions and pioneers for promoting transformative technologies worldwide and whose funding will help to take government commitments to innovation in sanitation from the pilot stage to scale across cities and countries.

Setting New Standards for the Sanitation Industry

Recently, the foundation also worked with a broad set of global stakeholders to develop international standards that define the appropriate specifications for non-sewered sanitation systems and technologies. Standards set a level playing field for emerging technologies and help drive adoption by building focus, cohesion, and critical mass in the early stages of product introduction and market development. They also help companies hasten the adoption of new technologies; demonstrate to consumers that they work; reinforce the acceptability of a new technology by setting thresholds for safety, functionality, reliability, usability, and maintainability; and enable competition between and within technologies, which helps drive innovation and growth.

Experts from 47 countries worldwide, representing industry, government, academia, and non-governmental organizations, have come together to form consensus and set standards for systems management, set maintenance standards to optimize existing wastewater services, and provide guidance on the design and performance criteria for new technologies and solutions. A first standard for the reinvented toilet, known as "ISO 30500, Non-sewered sanitation systems—Prefabricated integrated treatment units,"[13] will provide guidelines on the general safety and performance requirements for design and testing, and could inform any type of technology that is not attached to a sewer, including the omni-processor, omni-ingestor, and the reinvented toilet.[14] ISO 30500, which

[11] SDG 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

[12] SDG 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

[13] https://www.iso.org/standard/72523.html

[14] https://www.iso.org/committee/6170397.html

will be published in late 2018, complements ISO 24521, which offers practical guidance on the management and maintenance of basic on-site domestic wastewater services (such as fecal sludge management), and the emerging guidance in IWA 28, which offers guidance for omni-processors and similar technologies.

Conclusion: Safe Sanitation Solutions, Fit for the 21st Century

Some skeptics of new sanitation technologies have wondered if an emphasis on non-sewered solutions means asking people in emerging economies to settle for something inferior to the sewer networks and traditional toilets that provide sanitation services in more affluent regions.

To the contrary, we envision a future in which the advanced reinvented toilet systems represent the global vanguard of sanitation technology—much the way that the mobile smartphones now ubiquitous across Asia and Africa mark an enormous improvement over the legacy phone networks that prevailed in North America and Europe only a generation ago. Like today's phones, the coming generation of toilets represents a radical rethinking of a conventional but inadequate system—and a solution to longstanding challenges that have barred many poor communities from access to safe sanitation. New toilet technologies and waste management and treatment services don't constitute a mere stopgap remedy. They're innovations that leapfrog prior systems and create safe solutions for managing waste, fit for the 21st century.

New sanitation technologies and market models can deliver more sustainable, adaptable, and resilient services precisely where they are needed most. For the Bill & Melinda Gates Foundation, this is our mission. For government and business leaders, engineers, product companies, and visionaries worldwide, this is an opportunity to be at the leading edge of innovation that speeds up positive change for the poorest, as well as to benefit from the growth of new sanitation markets.

A member of the local support staff shows a Senegalese family how to use Loughborough University's reinvented toilet model.

The University of West England, Bristol, is piloting their "Pee Power toilet" at a school in rural Uganda.

The University of South Florida's NEWgenerator is undergoing field-testing at a school in Kerala, India.