Radical Decentralisation: Wastewater Treatment at the Community Level

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INSIGHT REPORT

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Radical Decentralisation: Wastewater Treatment at the Community Level

Report Summary

It will require "radical decentralisation" and widespread application of decentralised wastewater (DWWT) concepts and technologies in remote, rural, and urban communities to achieve United Nations SDG6 goals. The critical funding gap for centralised infrastructure in developed economies and megacities is also driving increased interest in DWWT. This report examines the market and technologies, including innovative business models meeting this growing need.

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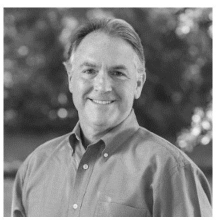

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About BlueTech Research

BlueTech Research is an independent water technology market intelligence firm. The firm provides actionable insights to a global client base on innovative and disruptive technologies, market direction, market opportunities, and access to intelligence on the companies innovating in the water space. Should readers of this report wish to get assistance in learning more about any aspect of water and technology please contact the company at info@bluetechresearch.com.

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1. Executive Summary

Decentralised Wastewater Treatment (DWWT) is the practice of locating treatment equipment and processing capabilities close to the site where the wastewater is generated, as opposed to using large-scale, centralised wastewater treatment (CWWT) plants.

In their paper, *The Third Route: Using Extreme Decentralisation to Create Resilient Urban Water Systems,* [1] the authors make the case for household-based, personalised water systems which are in urban settings but are entirely "off-grid", combining rainfall storage and on-site wastewater reuse to complement existing centralised infrastructure, and to eventually supplant it in many places. The focus of this Insight Report is on DWWT for **domestic wastewater at the community level**, namely treatment for two or more households, clusters of homes and businesses, residential communities, and institutional facilities. Nevertheless, with a nod to *The Third Way*, we consider the possibilities of "radical decentralisation" in terms of wastewater treatment operating at the level of rural villages, multi-tenant apartment buildings, condominiums, retirement communities, resorts, college and work campuses, hospitals, highway rest stops, mining camps, prisons, and refugee camps.

In particular, we look at innovative examples of companies providing solutions in these areas and examine some alternative financing structures which enable their delivery. To better understand why DWWT is gaining traction globally, this report will also identify the market drivers for this approach and associated technologies and discusses the tradeoffs with the traditional CWWT.

The primary market drivers for DWWT are:

- Public Health & Access to Proper Sanitation – In many low-income countries, less than 50 per cent of the population uses safely managed sanitation. In these countries, there is an immediate need for cost-effective, rapidly deployable DWWT systems.
- Urbanization – Infill Service in Growing Megacities and Large Metro Areas - The rate of growth in some metro areas has outpaced the local government's ability to provide managed wastewater treatment services. Using DWWT to provide service to unserved parts of urban population makes sense.
- Water scarcity – Widespread water stress and water scarcity mean that there will be pressure for communities to reuse water close to the point where the wastewater is generated. DWWT can be applied to treat greywater and blackwater close to its source.
- Difficultly Maintaining CWWT – Repairing existing sewage systems and expanding them to meet the needs of the rapidly increasing population is difficult given the need for

excavation and the available footprint for expanding aging centralized plants. Affordable and more practical alternatives to centralization are required in these instances.

The primary challenges for the DWWT market include:

- Lack of Innovation – As hypothesized in *The Third Way*, the substantial investment in centralized infrastructure leads to a fixation on maintaining and implementing incremental improvements for the continued use of this resource.
- Lack of Economic Resources Among SDG6 Target Population – UNICEF estimates $105B dollars per year in investment capital is required to address SDG6 targets related to providing basic and safely managed sanitation.
- Upfront Capital Purchases – Manufacturers often expect the full amount of the cost of the system to be paid at the time of purchase or by the time the system is installed and commissioned. Small- to mid-sized municipalities lack the capital resources to afford this expenditure.
- Difficulty of Operation & Maintenance – DWWT infrastructure can require trained operation and maintenance personnel or public education campaigns in order to maintain the system and provide proper sanitation and service to the local population. However, trained operators are often in short supply.

Our report arrives at the following conclusions:

1. It will require "radical decentralisation" and widespread application of DWWT concepts and technologies in remote, rural, and urban communities to achieve United Nations SDG6 and associated numerical subgoals by target dates.
2. Water scarcity will drive a need for wastewater reuse and water efficient systems as communities look to optimize their water footprints. Wastewater recycling is mandated in certain situations in cities such as Bangalore, India and San Francisco USA.
3. DWWT no longer only applies to communities traditionally without access to CWWT systems like remote and rural communities. Due to rapid urbanisation, many CWWT plants are quickly approaching maximum operating capacity and are unable to take on new customers.
4. DWWT providers which will capture market share more successfully than competitors in the coming years will have to offer one or more of these characteristics: modularity, easy operation & maintenance, scalability, remote monitoring, low energy requirements, easy installation.
5. System providers offering financing have an advantage over those who do not and therefore will be more likely to prevail. Upfront capital costs are a significant barrier at the community level. Few companies interviewed or surveyed for this report offered financing options to customers. WaaS, leases, and other financial mechanisms that overcome this barrier provide additional value to communities.
6. Decentralised treatment is being increasingly considered to both expand capacity and implement innovative WWT approaches. BlueTech expects further regulation, demonstration projects, and concepts to surface over the coming decade.

2. Actions for the C-Suite

Chief Executive Officer – The CEO of the large global manufacturer should consider mapping a strategy to actively participate in the global market for DWWT systems if not already in this market. Otherwise, consider acquisition of one or more of the many small-medium sized companies that are serving the DWWT market segment.

Chief Technical Officer – Engineering, Product Management, and Field Service Executive – The CTO of any manufacturer of wastewater treatment equipment must be aware of the characteristics of DWWT that the market demands – modularity, scalability, adaptability to changing requirements, and simple O&M. New product and service development should be driven towards unmet market needs and improvements in one or more of these four characteristics.

Chief Commercial Officer – Sales & Marketing Executive – The market for DWWT equipment and systems is global. The Sales & Marketing Executives with DWWT manufacturers must develop a targeted export development strategy to capitalize on developing countries with growing populations (e.g. China, India, Indonesia, Philippines, Brazil). More export sales diversify the company's sales mix and cushions against declines in a company's home market.

Chief Financial Officer – The CFO of any DWWT solution provider should consider offering equipment financing or leasing options to customers. This a major differentiator between companies servicing this market and provides a competitive advantage. There are third-party equipment leasing firms serving the wastewater treatment market open to partnering with DWWT manufacturers.

Chief Procurement Officer – The Purchasing/Procurement Executive with developers of communities, resorts, and campuses must be knowledgeable about the advantages of DWWT and the various suppliers serving the market. There are opportunities to work with DWWT suppliers to jointly develop standards for multi-phase projects.

Acquisition / Partnerships Manager – For large, diversified WWTP equipment and system manufacturers, there are numerous small-medium sized, innovative suppliers of DWWT in Europe, Canada, the USA, Australia, and Japan that could be an attractive complementary acquisition that addresses an attractive, growing market segment.

R&D Manager - The R&D Manager of a DWWT solution provider must be constantly innovating to provide more wastewater processing capability in a small package that can be expanded/scaled if needed, is simple to operate and maintain, and consumes limited energy.

Utility Executives – For growing densely populated cities, utilities should consider DWWT in the urban core to serve multi-tenant residential and institutional structures or campuses as an alternative to connecting to the existing collection network of a centralised WWTP. This is an especially attractive approach if a primary objective is onsite reuse of graywater and/or black water. At the outer edges of metropolitan areas, DWWT provides a cost-effective, sustainable alternative for a remote community of multiple households requiring a small WWTP to serve the community.

State, Regional, and National Transportation Authorities – Modular, compact DWWT is an excellent choice for highway rest stops, especially ones far away from the closest centralised WWTP. Engineering, project management, and purchasing executives with transportation authorities must be aware of DWWT technology options and supplier alternatives.

Consulting Engineers – With modular and containerized systems, DWWT offers cost-effective, compact solutions for utilities, end users, campuses and remote communities. It is imperative that consulting engineers be aware and knowledgeable about DWWT technology options and benefits that DWWT can provide to the customers that a consulting engineer serves.

Contractors – Leaders at mechanical and general contractors must be knowledgeable on the benefits of DWWT that include potential savings capex, shorter equipment lead times, faster and lower-cost onsite equipment installation, and shorter overall project duration that accelerates attainment of project milestones and invoicing of milestone payments.

3. Introduction: What is Radical Decentralisation?

Decentralised Wastewater Treatment (DWWT) is the practice of locating treatment equipment and processing capabilities close to the site where the wastewater is generated, as opposed to using large-scale, centralised wastewater treatment (CWWT) plants.

In their paper, *The Third Route: Using Extreme Decentralisation to Create Resilient Urban Water Systems,* [2] the authors make the case for household-based, personalised water systems which are in urban settings but are entirely “off-grid”, combining rainfall storage and on-site wastewater reuse to complement existing centralised infrastructure, and to eventually supplant it in many places. The advantages to the individual household would include the ability to tailor water to personal preferences, while on a systems level it would facilitate more rapid innovation and product development, side-stepping the more conservative, utility-controlled approach. While such systems would initially be out of reach of most households, the authors argue that, much as with take-up of home solar PV panels and the rise of the smartphone, wealthier consumers would encourage innovation and lower prices.

The focus of this Insight Report is on DWWT for **domestic wastewater at the community level**, namely treatment for two or more households, clusters of homes and businesses, residential communities, and institutional facilities. Nevertheless, with a nod to *The Third Way*, we consider the possibilities of “radical decentralisation” in terms of wastewater treatment operating at the level of rural villages, multi-tenant apartment buildings, condominiums, retirement communities, resorts, college and work campuses, hospitals, highway rest stops, mining camps, prisons, and refugee camps.

In particular, we look at innovative examples of companies providing solutions in these areas and examine some alternative financing structures which enable their delivery. In order to better understand why DWWT is gaining traction globally, this report will also identify the market drivers for this approach and associated technologies, and discusses the tradeoffs with the traditional CWWT.

This report does not address DWWT for industrial applications. The characteristics of industrial wastewater (WW) vary by industry and often require different treatment technologies than those used for domestic municipal wastewater. BlueTech has addressed specific industrial wastewater treatment challenges in published reports such as *Industrial Wastewaters in Key Industries*.

4. A Worldwide Trend

As cities continue to grow, pipe networks are extended, and flow capacities of central WWTPs increased, the project life cycle of design-engineering-procurement-construction-commissioning-operations-maintenance has become too complex, capital-intensive, and time consuming. This has opened the door to the alternative approach of DWWT for the processing of domestic wastewater. This move towards DWWT is happening around the world in developed countries/regions (e.g. USA, Canada, U.K., western Europe, Australia, New Zealand) as well as emerging economies (China, India, Africa, Latin America, and the Caribbean). In rural areas and remote communities, DWWT plants offer a cost-effective, sustainable solution that provides more flexibility with less capital investment than large CWWT plants with their extensive network of pipes, valves, and lift stations. DWWT eliminates the capital expense (capex) needed for construction of such a collection pipe network and saves the operating expense (opex) of unnecessary pumps. In densely populated cities, a DWWT system can provide a precise, localized service for unserved or underserved neighbourhoods without requiring a tie-in to the collection network of an existing CWWT plant. The DWWT plant in an urban area also incrementally augments the processing capacity of an existing CWWT plant. Thus, costly expansions of centralized plants, which can amount to millions of dollars in savings depending on the size of the plant, can be avoided.

Recent examples around the globe illustrate how extreme decentralisation is accelerating the applications of DWWT globally.

- India – In Bangalore, a fast-growing, high-tech city, the municipal and state regulators are now requiring new multi-home structures to have their own DWWT system to improve sanitation, increase reuse for non-potable applications, and avoid overloading existing centralised WWTPs. In addition, the municipal utility is applying DWWT at an increasing rate as the city's suburbs and remote clusters of population grow, as a preferred sustainable approach over connection to the closest point of the WW collection network for the existing centralised WWTPs.[3]
- China – Rural villages across multiple provinces are progressing from a situation of having no managed wastewater treatment services or treatment of effluent to a modular stand-alone DWWT system that complies with regulations for class 1A treatment effluent mandated by the Chinese government's latest 5-year plan.[4] As China expands and modernizes its network of highways, DWWT is being applied to serve highway rest areas and comply with these same regulations for higher quality effluent.[5]
- USA – Marathon, Florida in the Florida Keys opted out of a US $181 million plan for a large regional WWTP with connecting sewers, choosing instead to construct five smaller decentralised plants, each treating between 200,000 and 400,000 gallons per day. This saved approximately $90 million from the initial project estimate.[6]
- Australia – South East Water, the utility serving the city of Melbourne, has collaborated with a developer to create a residential development where homes will connect to a pressure sewer system that pumps wastewater to a water recycling plant within the housing development. The system treats the water to Class A standard and sends it back to each home for use in the garden, toilet or washing machine.

5. Market Overview

5.1 Market Drivers for Decentralisation

5.1.1 Public Health & Access to Proper Sanitation

A significant portion of the global population lacks basic sanitation and hygiene. Improved sanitation carries immediate economic incentives of easing the strain on public health resources by reducing population illness. This decreases health care costs, lessens long-term health effects from illnesses associated with improper sanitation, and saves lives.[7] Access to improved sanitation also reduces the number of working days lost due to illness and improves labor productivity. Likewise, it decreases absences in school children, which improves education, which is correlated with higher levels of social organization, political involvement, and economic development.[8] These economic incentives, along with concerns over quality of life and access to clean water and sanitation as a human right, are tied to the United Nations' Strategic Development Goals (SDGs).

In 2015, the United Nations General Assembly established 17 SDGs. SDG 6 is the goal that addresses universal access to water for all people and reads: "Ensure availability and sustainable management of water and sanitation for all." U.N. Member States are committed to the 2030

Agenda for Sustainable Development, including target 6.2 of the SDGs: “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.” Progress towards universal sanitation is off track, and uneven in its coverage.

In many low-income countries, less than 50 per cent of the population uses safely managed sanitation (Figure 1). In these countries, there is an immediate need for cost-effective, rapidly deployable DWWT systems which can serve communities ranging from a remote settlement with a few households to villages with thousands of permanent residents. There is neither enough time nor sufficient financing to design, build, and commission large, costly CWWT plants with sprawling wastewater collection pipe networks that will address this challenge in time to meet SDG 6.2 by 2030.

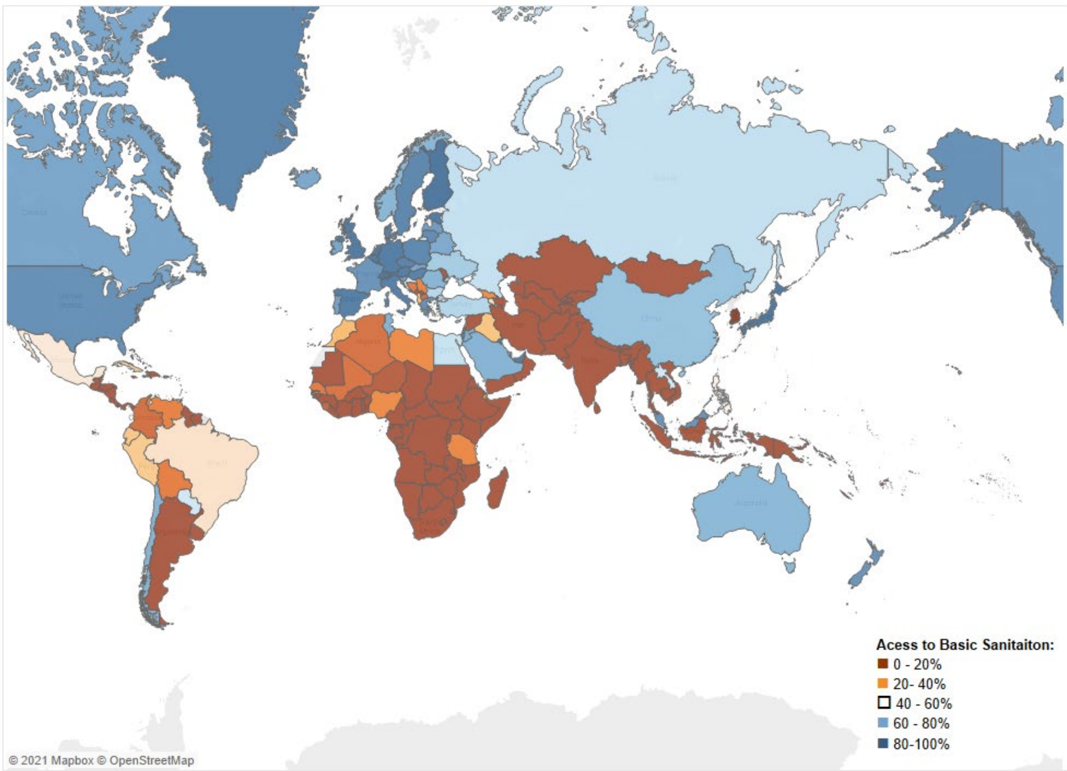

Figure 1: Percentage of population using safely managed sanitation services, 2017[9]

Achieving universal access to sanitation by 2030 will require dramatic acceleration in current rates of progress. To achieve universal access to at least basic sanitation by 2030, global rates of progress would need to double (Figure 2). Achieving universal access to safely managed sanitation by 2030 would require quadrupling the current global rate of progress. But these are global averages; the required rate of change in least-developed countries is even higher.

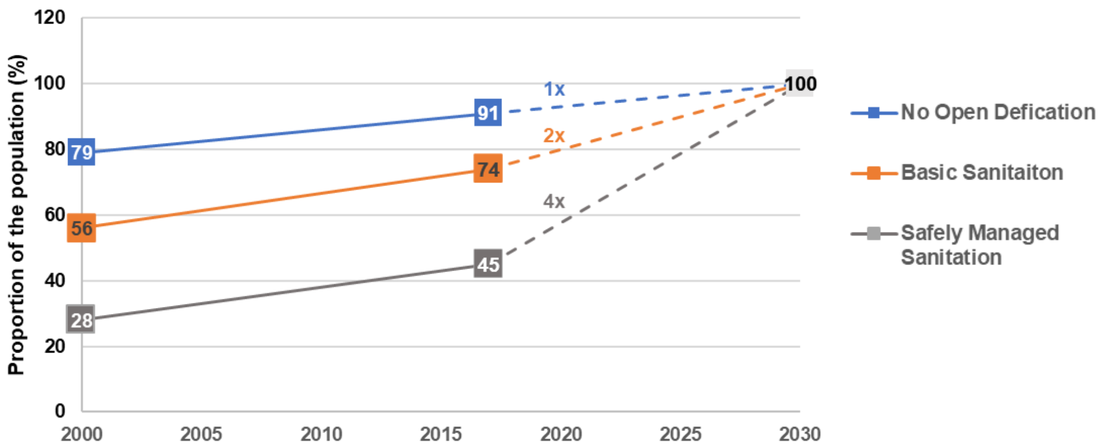

Figure 2: Percentage of population with sanitation services in 2000, 2017, and required rate of change to meet SDG06 targets by 2030 [10]

5.1.2 Urbanization - Infill Service in Growing Megacities and Large Metro Areas

More than half of the world's population currently lives in cities—and in the coming years, it is clear that more urban dwellers will be living in megacities, i.e., those with a population of over 10 million. According to UN estimates there were 37 megacities worldwide in 2018.

Today, more than 80% of people in higher income countries find themselves living in urban areas, and in upper-middle income countries the number lies between 50-80%.[11] Rural-to-urban migration is a relevant trend in the 21st century. Prospects of better job opportunities and higher wages, along with shifts from agrarian to industrial and service-based economies, are causing mass movement to cities.

However, the rate of growth in some metro areas has outpaced the local government's ability to provide managed wastewater treatment services. Using DWWT to provide service to unserved parts of urban population makes sense.

5.1.3 Water Scarcity

Water scarcity in many regions of the world – the increasing stress on water sources in dry areas with large populations – demands creative approaches for the onsite reuse and recycling of water to lessen the demand on fresh water sources. By 2025, an estimated 1.8 billion people will be living in regions or countries plagued by water scarcity, with two-thirds of the world's population living in water-stressed regions. The global population is growing fast, and experts estimate that with current practices, the world will face a 40% shortfall between forecasted demand and available supply of water by 2030.[12] Figure 3 below projects the degree of stress that countries of the world will be experiencing in the year 2040 based on the ratio of withdrawals to available supply of water.

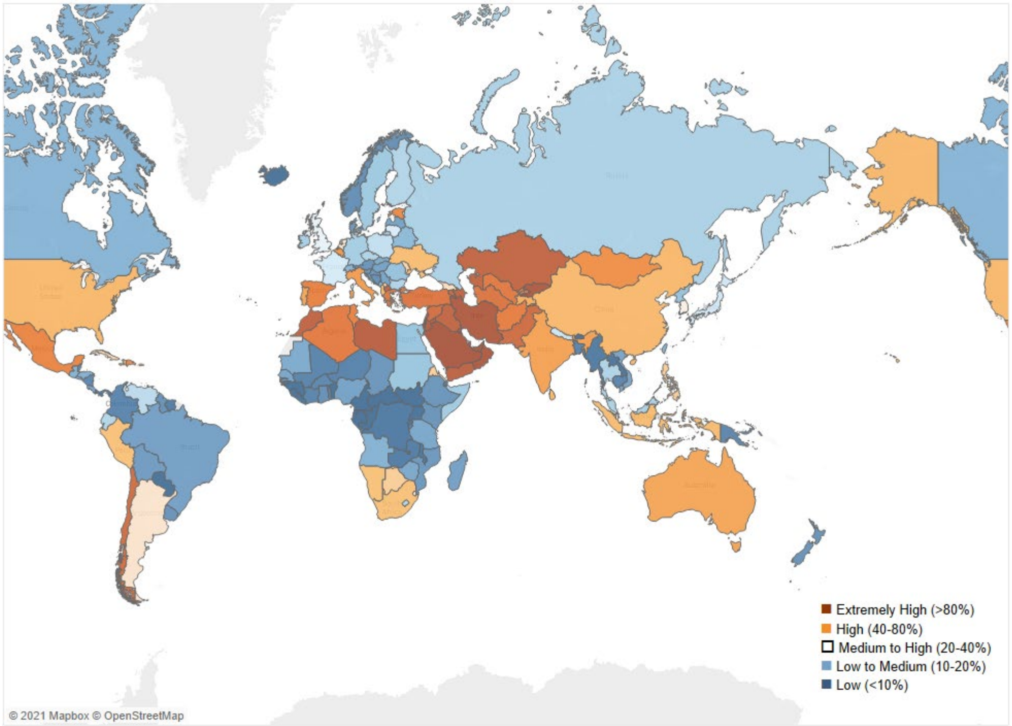

Figure 3: Water stress by country in 2040.[13]

Widespread water stress and water scarcity mean that there will be pressure for communities to reuse water close to the point where the wastewater is generated. DWWT can be applied to treat greywater and blackwater close to its source. This treated wastewater effluent can then be reused for non-potable applications such as irrigation or toilet flushing. Some jurisdictions in the desert southwestern US and California have required reuse of household wastewater for decades. In so doing, the demand for fresh water is decreased and therefore the quantity and volume of withdrawals from water sources are reduced. DWWT will in the future be a preferred technology for onsite treatment, especially in the countries shown on the world map in Figure 3 in different shades of red and orange.

5.1.4 Difficultly Maintaining CWWT

Centralised wastewater treatment systems have been built up since the Victorian era, but now this aging infrastructure has become difficult and costly to maintain and expand. The US EPA estimates that over the next 20 years, $271B is required to maintain the country's wastewater infrastructure, with much of this cost going towards maintaining elaborate piping networks.[14] Europe and other parts of the world with extensive centralized infrastructure are likely to require similarly large sums of capital to maintain their wastewater systems. However, it will be unlikely to see these levels of investments and instituting these repairs are met by logistical challenges. In Bangalore, India for instance, the streets are narrow and densely populated. Repairing existing sewage systems and expanding them to meet the needs of the rapidly increasing population is difficult given the need for excavation and the available footprint for expanding its aging centralized plants. Affordable and more practical alternatives to centralization are required in these instances.

5.2 Market Barriers for Decentralisation

5.2.1 Lack of Innovation

As hypothesized in *The Third Way,* the substantial investment in centralized infrastructure leads to a fixation on maintaining and implementing incremental improvements for the continued use of this resource. Overbuilding capacity inflates the cost of centralized infrastructure and the desire to achieve a financial ROI on the investment. While this practice is expensive and limits innovation, the sunk-cost fallacy holds true.

5.2.2. Lack of Economic Resources Among SDG6 Target Population

UNICEF estimates $105B dollars per year in investment capital is required to address SDG6 targets related to providing basic and safely managed sanitation.[15] This funding gap is substantial as low-income countries tend to have less access to capital to afford these projects. Low-income countries have lower GDPs and less domestic revenue and tax revenue as a percent of GDP than middle- or upper-income countries.[16] Interest rates also tend to be higher in these countries,[17] making capital projects more expensive and increasing investment risk. Furthermore, there are numerous concerns competing for available capital, such as war or conflict, health care, and food supply,[18] as well as other potential infrastructure projects which may have a higher ROI. Look no further than the other 16 SDG goals for other urgent causes requiring investment capital.

Additionally, end users are often unable to make substantial contributions to installing, operating, and maintaining, sanitation management systems given their low incomes, resulting in a need for patient capital investments to develop innovative technologies and business models which provide solutions for low-income communities.[19] However, the long timeframe to achieve ROI, currency risk, regulatory risk, political risk, etc. can make investing in decentralised solutions for low-income countries unattractive.[20] Additional capital focused on improving sanitation infrastructure from foreign aid, NGOs, corporations, etc. is needed to close the funding gap.

5.2.3 Upfront Capital Purchases

Manufacturers often expect the full amount of the cost of the system to be paid at the time of purchase or by the time the system is installed and commissioned. Small- to mid-sized municipalities lack the capital resources to afford this expenditure, especially since their financial strength has been negatively impacted by the coronavirus pandemic, which has resulted in businesses closing and inflated unemployment. The same can be said for new developments and rural communities. A lack of financial resources and financing mechanisms which spread out the cost of the DWWT system over time limit the ability of end-users to implement and budget for these systems.

5.2.4 Difficulty of Operation & Maintenance

DWWT infrastructure can require trained operation and maintenance personnel or public education campaigns in order to maintain the system and provide proper sanitation and service to the local population. However, trained operators are often in short supply. This is especially the case in remote or rural locations as operators are concentrated near major cities where jobs are more abundant. Furthermore, as operators come and go, so can the expertise they developed. To avoid these complications, communities may prefer a centralised management structure.

5.3 Advantages and Disadvantages

While DWWT offers some distinct advantages compared to CWWT, it is important to recognize that it also has certain disadvantages and limitations. Knowing this in advance will enable practitioners to better assess options and make an objective, facts-based decision on the best approach for a particular application.

Table 1: Advantages & Disadvantages of DWWT *vs.* CWWT

Advantages of DWWT	Disadvantages of DWWT
Closer location to the wastewater source means no high-cost collection pipelines to CWWT plants.	Limited options for customization or any deviation from standard modules and system configurations.
Easier, faster installation	Limited, sometimes no options for remote monitoring via internet or wireless data.
More portable & scalable than traditional CWWT	Limited availability of trained qualified operating personnel in remote & rural areas
Smaller footprint	Limited options for processing or handling biosolids produced in smaller installations.
Less capital intensive	
Simpler operations & maintenance (O&M)	
Shorter project cycle time	

5.4 DWWT at the Community Level

The level-of-need for and applicability of DWWT systems are specific to each community, but trends do exist depending on the type of community. For instance, given the less dense populations of rural areas, these communities tend to have fewer financial resources and CWWT solutions. The worldwide trend of migration to cities means funding by governments, NGOs, and private developers is more focused on urban and suburban projects than rural projects since more unserved/underserved can be addressed by a given project. These factors contribute to an inequality in available sanitation between urban and rural communities. In 2017, 84% and 59% of global urban and rural populations had access to at least basic sanitation, respectively. The same goes for developed and developing communities.[21] 86%, 68%, and 30% of upper and middle income, middle and lower income, and lower income countries, respectively, had access to at least basic sanitation.[22] Looking at the intersection of these trends, we find that low income, rural regions of the world lack sanitation far more frequently than upper income, urban areas. When accounting for the relative need for sanitation, and other common issues faced by different community types, it is possible to generalize the conditions in which DWWT may be suitable to these different communities (Table 2).

Table 2: Suitability of DWWT to various community types

	Developed	Developing
Urban	• Institutions & new communities unable to use nearby existing infrastructure • Sustainable communities • Water scarce areas	• Centralised infrastructure is limited or does not exist • Water scarce areas
Rural	• Far from centralised infrastructure (remote) • Small populations • Water scarce areas	• Large portion of the population lacks proper sanitation (treatment & disposal) • Water scarce areas

5.4.1 Urban Communities in Developed Nations

There are several common situations in which decentralised treatment makes sense for developed urban communities. One of which is when a new institution or housing development is denied access to a CWWT system. Centralised plants will deny access to new communities when the plant is at capacity and cannot afford to expand, has no additional land area for expansion, foresees potential issues with O&M, or expanding sewage networks is prohibitively expensive. In these instances, onsite DWWT may be the only remaining solution. As DWWT is typically installed more quickly, is less expensive, and has a small footprint, it may also be used to accelerate construction/implementation timelines. DWWT can also help meet Environmental, Social, and Governance (ESG) goals by reducing energy and environmental footprints and enabling onsite wastewater reuse, which helps combat water scarcity.

5.4.2 Urban Communities in Developing Nations

The level of sanitation provided to urban dwellings varies greatly. Many cities have small or underfunded public water and sewage networks. This has resulted in instances, like those in India, where the growing middle class does not believe in local government's ability to provide proper sanitation and places more trust in onsite DWWT. However, it is also common for underserved populations to be concentrated in lowest-income neighborhoods. Given the population in greatest need is concentrated in one area, DWWT may be used to address that issue locally.

There are also instances where the lack of sanitation is more widespread. Large cities which have been developed without any wastewater treatment infrastructure include Nairobi and Jakarta. Jakarta, a city of 11 million people in which most of the population does not have access to a sewer network, has turned to DWWT to address this issue. Most of Jakarta's wastewater is disposed of, untreated, in local waters. This practice pollutes potable groundwater sources and much of the city's drinking water is sourced from neighboring regions. To address this, the government has divided the city up into zones where DWWT plants will be implemented.

In these cases, decentralisation can be applied directly at the source of the issue and, by treating wastewater, provide a new clean water source through reuse or by reducing contamination from untreated waste to improve the quality of local sources.

5.4.3 Rural Communities in Developed Nations

Rural communities in developed nations regularly lack access to centralised infrastructure. It is not economical to run long pipelines from centralised sewage networks to far-off communities and clusters of homes, especially those with small populations, such as aboriginal communities. Therefore, local DWWT solutions are employed as affordable long-term solutions, which often prove to be more reliable than CWWT when tailored to local concerns and O&M capabilities. There are also opportunities to enable water reuse via DWWT in areas with diminishing water resources. Rural communities are often remote, and DWWT makes use of local resources to reduce water stress. For instance, several Aboriginal Australian communities in Southern Australia, distant from neighboring cities and towns, and somewhat socially isolated, reuse treated water for crop irrigation, conserving potable water sources.

5.4.4 Rural Communities in Developing Nations

These communities have the greatest lack of sanitation of those mentioned. The "bottom of the pyramid" – the world's largest, but poorest socioeconomic group – often resides in these communities. As in any rural community, centralised solutions do not make sense logistically, and would be excessively expensive. DWWT offers solutions of various complexities and can be used as a long-term solution for permanent populations. Inexpensive decentralised solutions which are easy to operate and maintain are suitable to these communities where financial capital is scarce and often the focus is gaining access to basic sanitation and establishing safe disposal practices.

5.4.5 Institutional, Sustainable, and Refugee Communities

Not specifically mentioned in the categories above are institutions, sustainable housing developments, and refugee camps. They could be found in any area, urban or rural, developed or developing.

Institutions, in this instance, include office parks, high-rise buildings, hotels, sports arenas, campgrounds, rest stops, refugee camps, and other establishments which are core to a population and treat significant domestic wastewater. Institutions may be motivated to install decentralised solutions if they are unable to gain access to CWWT, wish to decrease potable water use, or are governed by ESG criteria. Institutions and sustainable residential communities, communities which are built around environmental and economic sustainability, may use DWWT to help meet water management goals or implement circular practices. Systems with non-potable reuse, vacuum collection systems, or source separation could help minimize water and environmental footprints or contribute to beneficial reuse.

Refugee camps rely on DWWT because they are often established where no current infrastructure exists. Here, the need is to quickly provide sanitation infrastructure to a population which may be transient or seeking long-term asylum. It does not make sense to field construct a permanent infrastructure, which takes time and which has an ROI based on a 20+ year timeframe. Especially when considering DWWT systems can be installed quicker and less expensively than field-constructed infrastructure, and modular systems can be moved between refugee camps to help account for fluctuations in population.

6. Technology Landscape

In the following section, each component of a DWWT plant and its various configurations are analyzed to better understand the advantages and suitability. Additionally, this section takes a first look at the project financing mechanisms associated with DWWT technologies.

6.1 Collection

Collection systems deliver wastewater from communities to WWTPs. While urban and suburban populations with CWWT tend to use gravity collection systems, DWWT considers numerous alternatives which can be less capex and opex intensive as well as quicker and less intrusive to install. Common collection systems utilized in DWWT are outlined in Table 3.

Table 3: Common collection systems for DWWT

System Type	Description	Considerations	Application
Gravity	Building sewer lines feed a sewer main, typically larger than 8 inches in diameter. The sewer mains are downward sloping and use gravity to transport the sewage to the WWTP.	• Requires sufficient population density to be cost effective. • Extensive excavation increases costs and installation time. • Little maintenance required for the pipes. Knowledgeable operators required for lift stations. • Lift stations required for long distances and flat/uphill topography.	• Dense, year-round populations • Treatment system is downhill from population. • 10,000+ GPD[a]

[a] Relevant treatment capacities provided by Water Research Foundation's *Performance & Cost Of Decentralised Unit Processes*

System Type	Description	Considerations	Application
Low Pressure Grinder Pump	Building sewer lines feed into a collection basin. When the basin fills, grinder pumps are used to drive the sewage to the WWTP.	• Applicable in any topography, high water tables, and high bedrock. • No infiltration • Grinder pumps increase downstream TSS. • Grinder pumps require maintenance & power. • Public education of system required. • Minimal excavation required.	• Where existing septic does not exist • High water tables • High bedrock • Hilly or flat terrain (poor gradient) • Sensitive ecosystems • 1,000+ GPD
STEP / STEG	Building sewer lines lead to a septic tank for solid/liquid separation. Solids remain in the tank and the effluent is pumped into a pressurized main (STEP) or drawn from the tank via gravity (STEG) which transports it to a WWTP.	• Applicable in any topography, high water tables, and high bedrock. • Applicable to low flows and seasonal occupants. • Septic tanks lower BOD, SSD, grit, grease, and downstream hydraulic loading. • Public education required. • Minimal excavation required.	• Advantaged where existing septic systems exists. • High water tables • High bedrock • Hilly or flat terrain (poor gradient) • 1,000+ GPD
Vacuum	A vacuum station creates a pressure differential which draws waste into the sewage system and transports it to a WWTP.	• Applicable in flat terrain, high water tables, and high bedrock. • No infiltration • Uses ca. 70% less water per flush. • Reduces spread of airborne bacteria & viruses due to less aerosols from flushes. • Energy intensive • Limited to short distances. • Minimal excavation required. • Public education required.	• Small/dense populations • Water-scarce areas • High water tables • High bedrock • Flat terrain • Sensitive ecosystems • 50,000+ GPD

Decentralised urban or suburban developments in developed nations are often affluent and more densely populated. They are familiar with gravity sewers and as these systems do not require public assistance in their management, they may be willing to bear the cost of installing them if topographical and soil conditions allow it, although it may not be the most economical option.

Institutions with onsite facility managers, rural communities in developed nations, or rural and urban communities in developing nations are more likely to use hybrid systems and may capitalize on Vacuum, STEP/STEG, and pressurized systems to reduce costs. Vacuum, STEP/STEG, and pressurized systems are small-bore and utilize plastic pipelines which can reduce material and installation costs. They also reduce disruption to the community and increase the speed of installation. Estimated collection system capital and operational cost are available in Appendix A.

Depending on the prosperity (or lack thereof) of the community and the availability of trained operators, gravity systems with lifts, pressurized systems, and vacuum systems may be too capital intensive and/or sophisticated to be employed. In these cases, simple septic systems, latrines, or the discharge of untreated waste are more common, with the last option having significant negative effects on community health. In these cases, downstream treatment and disposal options become limited. Generally, DWWT requires low-cost collection options and the downstream implications of the collection method on treatment and disposal must be considered.

6.2 Treatment

Established wastewater treatment technologies, including biological treatment technologies such as MBR, MABR, SBR, septic tanks, etc., as described in Table 4 below, are common DWWT solutions. While no technology is dominant across all decentralised applications, there are common trends and system requirements among all DWWT technologies which are addressed in the following subsections.

Table 4: Common DWWT technologies

Septic	An underground tank which temporarily stores wastewater, in which solids sink to the bottom of the tank (sludge), effluent settles in the middle of the tank, and scum floats to the top of the tank. The middle of the tank drains to a downfield treatment system, while the sludge and scum remain.
IFAS	Integrated Fixed Film Activated Sludge System – plastic carrier media are added to aerobic and anerobic reaction tanks, which contain a mixture of wastewater and return activated sludge, to promote increase microbial (biofilm) growth in biological wastewater treatment.
MABR	Membrane Aerated Biofilm Reactor – a biofilm growth (fixed film) aeration system which allows for low energy delivery of oxygen from the carrier side. Aeration promotes microbial growth in biological wastewater treatment processes.
MBBR	Moving Bed Biofilm Reactor - plastic carrier media are added to aerobic and anerobic reaction tanks, which contain wastewater, to promote increase microbial (biofilm) growth in biological wastewater treatment. Return activated sludge is not used in the reaction tanks like with IFAS.
MBR	Membrane Bioreactor – a biological treatment process which uses a membrane to separate sludge from aqueous effluent after primary treatment.
SBR	Sequencing Batch Reactor – an activated sludge system where setting, aeration, settling, and separation occur in a single tank, without the need for return activated sludge.

6.2.1 Modularity

Modular units fit all that is required for a specific domestic wastewater treatment application, including the pre-engineering of tankage, piping, process equipment, wiring, and the control system into a single large enclosure or standard shipping container. From the end-user's perspective, modular solutions have shorter lead times and take less time to install onsite, which is valuable in both remote and highly trafficked locations. It also minimizes plant footprint, which is significant for institutions and urban areas. Modularity also enables scalability, making modular solutions more affordable. Customers purchase enough modules to address their current treatment needs and can purchase additional modules as needed in the future rather than purchasing a field-erected system with enough capacity to account for future demand. This minimizes upfront capital expenditure and avoids unnecessary project costs. The total installation cost of modular prefabricated DWWT plants is less expensive than field constructed DWWT plants due to savings in the following project components:

- Site preparation & civil engineering costs
- System equipment & engineering costs
- Installation labor time & costs
- Commissioning time & costs
- Onsite time & costs
- Quality assurance & control

From the perspective of an Original Equipment Manufacturer (OEM), modularity enables standardization of products, bills of materials, and production practices. This can reduce manufacturing costs, production times, and transportation times as compared to field-constructed WWTPs and serve as a competitive advantage. Ease of transportation can be significant when transporting modules internationally or over long distances or in difficult-to-access locations. Many market leading companies referred to in Section 4.6, produce modular units. Examples include Newterra, Fluence, and Paques, pictured below in Figure 4.

Newterra MBR for restaurant and boat sewage on St. Lawrence River 80 m^3/day

Fluence Aspiral Unit for China Hubei Province Highway System

Pacques BIOPAQ-UBOX at in Santa Clara, Brazil [Capacity: 11 l/s, 5000 PE]

Figure 4: Modular DWWT solutions provided by Newterra,[23] Fluence,[24] and Paques.[25]

6.2.2 Ease of Operation

Ease of operation after commissioning is also required among DWWT solutions. There is a shortage of trained and certified O&M personnel for municipal and private treatment plants, and this labour shortage is forecasted to grow more acute in the future. While the Water Environment Federation (WEF), industry associations, and wastewater utilities offer operating training programs to address the labour shortage, remote and rural communities may not be able to afford full-time onsite operators. Additionally, it can be difficult for remote and rural communities to access qualified O&M personnel who may be required to travel long distances from city centers to service their facilities. As such, there is likely to be long-term demand for systems with simple O&M which do not require an onsite operator.

Remote monitoring provides an additional layer of support to basic operation, helping to identify issues that could cause a future problem and thus prompting preventive maintenance. Any system that has remote monitoring via a secure internet connection or wireless data will have an advantage over systems that do not have this capability. Increasingly, remote monitoring of operating status and any alarm conditions is a feature that engineers and owners demand of any DWWT systems for both permanent and short-term installations. And beyond remote monitoring, onsite control systems are evolving to enable remote control, remote troubleshooting, and remote PLC program changes.

6.2.3 Low Power Requirements

Low operating costs, and by association low energy requirements, are often priority purchasing criteria in any DWWT application. However, it becomes crucial in applications where electric power from a utility is not available. Especially in temporary DWWT installations, systems that can operate with no power or low power using solar energy or battery power will be favored. For example, Island Water Technologies in PEI, Canada has produced and installed solar powered containerized MABR wastewater treatment plants that have been applied to military forward operating bases, mining camps, and other remote locations where utility power may be limited or not available at all.

Figure 5: Island Water Technologies – REGEN solar-powered containerized MABR package plants.[26]

The manufacture of wastewater treatment plants which can be powered by off-grid power is one example of how DWWT solutions are tailored to the needs of the consumer. Previously discussed modularity and simple O&M are others. The effluent quality and quantities must also be synergistic with each community's available disposal methods.

6.3 Disposal

In decentralised communities any issues stemming from poor wastewater management are local issues and can negatively affect sanitation, health, and safety. Water resources are also local concerns. As such, decentralised communities must identify methods for the disposal of effluent and residuals which consider these local issues and comply with regulations. A wastewater management plan should be developed, and solutions must also consider, the DWWT system employed, cost, O&M, geography and topography. Several common residual disposal and effluent dispersal methods used in decentralised wastewater treatment are outlined in Table 5.

Table 5: Common DWWT disposal methods

	Advantages	Disadvantages	Application
Vacuum Trucks	• Simple • Affordable • Can be used with multiple treatment solutions	• Remote communities may have difficulty finding providers willing to travel long distances • Premium charge to haul waste long distances	• Septic tanks and pit latrines • Where other disposal methods are prohibited due to cost, regulation, or lack of applicability
Soil Absorption/ Distribution	• Simple • Affordable	• Not suitable for sludge disposal • Not suitable for nutrient-sensitive environments	• Effluent • Where soil has adequate permeability • Suitably low groundwater tables and bedrock
Spray Distribution	• Can be used with slowly permeable soils • Can be used in non-potable reuse	• Large buffer zones required to reduce the potential for human contact • UV or chlorine disinfection typically required	• Small local populations • Large land areas with vegetation • High groundwater tables or bedrock
Evapotrans-piration (ET)	• Low energy input	• ET decreases in cold weather	• Arid climates with low rainfall
Surface Water Discharge	• Convenient • Can sometimes take advantage of downstream	• Often requires stringent effluent quality and discharge permits	• Large communities • Soil dispersal is infeasible

	Advantages	Disadvantages	Application
	wastewater treatment (indirect discharging)	• May degrade local water sources • Expensive • O&M intensive • May affect downstream communities	• Decentralised systems owned by a utility with centralised treatment downstream
Land Application	• Simple • Affordable • Recycles nutrients	• Increasing concerns about human health, nutrient pollution, emerging contaminants • Not encouraged in some countries • Requires storage facility	• Sludge residuals • Where land application is allowed by regulation • Large land areas • Where there is demand from agriculture/ landscaping for biosolids
Non-Potable Reuse	• Relieves potable water supply • Environmental barrier can increase safety • Circular application of water and (sometimes) nutrients	• Requires increased treatment, O&M • Increased regulation • Public perception	• Water scarce areas • Environmentally / sustainability conscious • Where regulation requires it • O&M knowledge is available

Special consideration should be given to developing nations. Most of the wastewater collected globally goes untreated and developing countries often lack the regulation, infrastructure, and economic capabilities for proper disposal. While illegal in many cases, improper disposal of waste into the environment is common practice in many countries. Open defecation and “flying toilets” are still common disposal methods in the developing world, as is the reuse of untreated water for irrigation, and marine outfall. Often, fees from wastewater treatment plants or landfills result in sludge being distributed to open lands, stormwater drainage, or sewer networks.

In developing economies and low-income communities, low-cost options are required. Dry sanitation, the disposal of waste without water as a carrier, is one practical method that can be used in these instances. As an economic solution to water scarcity, it is also found in rural communities, ecotourism, and refugee camps. Common dry sanitation solutions are dehydrating and waterless toilets. Like a septic tank or pit latrine, the waste is containerized, and additives are used for improved biodegradability or composting. Source separation can also be employed, and urine can be used as low-pathogen fertilizer. Project financing is another tactic for making treatment more affordable for communities.

6.4 Project Financing

Manufacturers of DWWT systems have historically sold the equipment directly to the installing contractor or to the end user. For standardized systems, these are offered in models with a rated capacity and defined built in treatment capabilities. Such standardized systems are sold directly by the manufacturer, or through distributors to the installing contractor and the full amount was payable at the time of purchase. For larger, engineered build-to-order DWWT systems, the purchase contract is for the entire value of the system with specific amounts payable at defined milestones of the contract. Table 6 below illustrates a hypothetical payment schedule for a $500,000 DWWT system for a small community.

Table 6: Example payment schedule for an engineered, build-to-order DWWT system

Milestone	% Contract Value	$ Amount	Covers
Order entry/ acknowledgement	10%	$50,000	Preparation of engineering submittals & drawings
Send submittals to customer			
Approval of submittal drawings	40%	$200,000	Detailed engineering, project mgt, prepurchase of 3rd party inputs
Shipment/delivery to jobsite	40%	$200,000	Manufacturing costs
Installation/commissioning/owner acceptance	10%	$50,000	Installation supervision, warranty
	100%	**$500,000**	

Regardless of the payment milestones and amounts, the full contract amount should be paid by the customer by the time the system is commissioned and accepted by the owner. For cash-constrained owners, this capex requirement is a barrier to procuring the appropriate treatment technology. For small communities and municipalities with failing wastewater infrastructure, they may simply not have the available capital or the ability to raise capital through new debt issuance.

This shortage of available capital is driving suppliers to develop financing and leasing options for new DWWT systems. This is done through a partnership with a third-party equipment leasing/financing company or through their own internal financing. The leasing/financing option involves the third-party company purchasing the system from the DWWT technology supplier and then offering to the end user a 5-, 7-, or 10-year payment schedule. This is an attractive option for the technology supplier since it receives full payment from the financing/leasing company for its equipment. It is an attractive option for the end user since it spreads out payment over an extended period as an operating expense as opposed to a large capital expense up front.

AUC Group in Houston, TX is an example of a company serving the DWWT system market that offers its customers short- and long-term leases as well lease with the option to purchase. Over it 50-year history, it has completed over 1,500 projects with flow rates ranging from 5,000 GPD to over 1,500,000 GPD. Most of these projects have been sold through 10-year leasing and operations agreements with Texas Municipal Utility Districts (MUDs). However, the company has also completed projects in 10 other US states, as well as Mexico, and El Salvador. The company was acquired by Morgan Stanley Infrastructure Partners in 2021 and has launched a program to reach yet untapped DWWT systems markets.

A large, well-capitalized, global supplier of wastewater treatment technologies such as Suez can offer alternative project delivery modalities such as Design-Build-Operate-Maintain/Finance (DBOM/F) or Design-Build-Own-Operate-Maintain/Finance (DBOOM/F) on larger, higher-value projects. However, the scope and dollar value of most individual DWWT projects are not sufficiently large enough to warrant such large global suppliers utilize such financing mechanisms. The potential exists for large wastewater treatment technology providers to pursue and finance multiple DWWT plants in growing markets such as China, India, or southeast Asia and negotiate a contract for a series of new WWTPs to be built and commissioned over a period of time.

In addition to multiple financing options, stimulus packages, such as the $35 billion in funding approved by the United States Senate in April of 2021 to improve failing water and wastewater infrastructure, could accelerate funding for shovel-ready projects. In this case, a "Buy American" requirement for a project to be eligible for funding is being strongly considered by US Congress. This would require that the materials used in construction must be manufactured in the United States. The "Buy American" proposal has run into opposition from numerous US drinking water and wastewater organizations including the American Water Works Association and Water Environment Federation, which have expressed concern that Buy American mandates would limit the effectiveness of infrastructure funds and hinder the use of best available technologies. Nevertheless, these developments should be considered by project planners and equipment suppliers in the US market.

6.5 Innovative Technology Companies

BlueTech Research has investigated 50+ decentralised wastewater treatment providers via a combination of secondary research and research interviews to understand the spectrum of available technologies and business models offered to service decentralised communities. Through this process, we have identified several innovative and differentiated decentralised technology providers creating additional value at the community level. These companies are discussed in the following section.

6.5.1 BioPipe

Biopipe, a subsidiary of LifeQuest World Corporation, is headquartered in New Jersey, USA. The Biopipe technology is an affordable modular biological wastewater treatment solution in which treatment takes place in a series of pipes. Blackwater and greywater are stored in a tank before being pumped into the circulation system. The circulation system is a series of pipes containing media carriers which generate biofilm for treatment. Once treated, the wastewater passes through a cartridge filter and is disinfected by UV-light before being reused in non-potable applications or stored in another tank. In some cases, chlorine is also added for residual disinfection.

The solution claims low operating and maintenance costs, automation and remote monitoring, and odorless operation, and differentiates itself by producing little to no sludge. Biopipe removes the headache of disposing of sludge residuals, which is typically a challenge for decentralised applications, as it must be disposed of safely and monitored. Additionally, the technology can operate at 10% of capacity, which is helpful in dealing with transient populations or seasonal fluctuations in populations.

The company is incorporated in several international locations and its team of 10-15 people is scattered throughout the world. The company has over 50 installations across 15 countries with operations in USA, India, Bangladesh, Philippines, Sri Lanka, Turkey, Ethiopia, and South Africa. It targets decentralised applications in residential complexes, office buildings, schools, hotels, hospitals, refugee camps, and numerous other settings from 10 m^3/d to 5,000 m^3/d. The company offers direct sales with an annual maintenance contract in most countries. It offers various leasing models in some countries, including a performance-based WaaS model in South Africa that it hopes to gradually expand to other geographies.

6.5.2 Sanergy

Sanergy is included in this section not because its solution is technologically innovative, but because its technology is fit-for-purpose and combined with an effective business model deployable in low-income urban communities. Sanergy provides low-cost source separating toilets to non-sewered areas in urban slums in Nairobi, Kenya. The waste is collected via hand-truck and transported back to a central processing plant for treatment where it is treated by anerobic digestion via frass residue from the Black Soldier Fly. The waste is used to create fertilizer and insect-based animal feed which is sold to farmers.

Urban slums regularly lack safe sanitation and sanitation-related disease is a major problem. As such, Sanergy targets non-sewered urban slums in Nairobi through pay-for-use community latrines. The company's network of 2,500 Fresh Life Toilets serves over 100,000 urban residents. The animal feed produced from solids treatment is transformed into chicken feed known as Pure Protein. The company also offers a pit latrine emptying service to ensure safe wastewater treatment and curb illegal dumping. This service is low-cost, and the cost is spread across the community making it more affordable. It is a practical circular business model aimed at an under-served sector.

6.5.3 Sanivation

Based in Kenya, Sanivation provides DWWT plants to treat sludge from pit latrines and septic tanks. The sludge is recovered as biofuel used in place of firewood in industrial applications to offset the operational costs of the plant. Waste is treated to US EPA standards and liquid waste can be reused for irrigation. Sanitation and/or collection services can be employed based on the needs of the local community.

Much like Sanergy, Sanivation is highlighted due to its business model. The company partners with non-profits and local organizations to provide wastewater treatment plants. Partnership options include seven-to-15-year DBO contracts. Previous partners include the United Nations, the Center for Disease Control and Prevention, refugee councils, and local governments. It targets non-sewered areas lacking proper sanitation. It reduces operating costs through biofuel recovery and wastewater reuse and hires and trains local operators to improve the local economy. The technology has been used in refugee camps and communities. The company is also working on local education and the implementation of hand-washing stations to help prevent the spread of COVID-19 in developing communities. By using partnerships to make solutions affordable, training local operators, and integrating with existing infrastructure, e.g. pit latrines and septic tanks, Sanergy is able to offer safe treatment and disposal while overcoming many barriers faced by decentralised communities.

6.5.4 Organica Water

Organica produces decentralised wastewater treatment plants built in greenhouse-like structures. Its Food Chain Reactor (FCR) is based on IFAS treatment systems. Plant roots and artificial media are used as biofilm carriers for treatment. In each reactor, anaerobic or aerobic conditions are established, allowing the growth of organisms that drive the reactions for wastewater contaminant transformation and removal. BioPolus has a similar offering called the Metabolic Network Reactor (MNR), but it is not (yet) available as a packaged product.

Organica facilities have a smaller footprint than activated sludge plants and are odorless. It takes advantage of these characteristics and designs its plants to resemble botanical gardens so that its solution can be integrated into city centers as well as residential and communal areas, rather than on the outskirts of these population centers. The company has identified several large, fast-developing urban areas with established infrastructure around the world in need of localized wastewater treatment plants, as well as smaller residential or commercial areas. Examples include small installations in suburban Canada as well as large installations in highly populated areas of Shanghai, China. Its installed treatment capacities reflect this, ranging from a few thousand m^3/d to 80,000 m^3/d.

The company has 100 operating installations around the world and 25 projects in various stages of construction. Organica has offices in Budapest, Hungary where it was founded, as well as USA, China, India, and Indonesia for business development.

6.5.5 Epic CleanTec

Originating in the Bill & Melinda Gates Foundation's Reinvent the Toilet Challenge, Epic CleanTec, or "Epic", is a proponent of sustainable infrastructure and the move to a circular model that beneficially reuses traditional waste streams. This emerging, San Francisco -based company is implementing an innovative model where multiple buildings in an urban area install its blackwater recycling system and opt into solids recycling.

The system uses a mechanical screen to separate solids and effluent. The effluent is treated via an MBR which provides biological nutrient removal to reduce BOD and nutrients. After that, fit-for-purpose tertiary treatment is provided. This typically consist of 2-3 processes including ultrafiltration combined with UV, ozone, chlorine, activated carbon, and/or reverse osmosis. The effluent is usually treated to non-potable reuse standards and used for toilet flushing, irrigation, laundry, and/or cooling towers. Solids can be disposed of by traditional means or beneficial reuse can be taken one step further and the system can be configured with a solids collection module that provides ultra-fine screening upstream of the MBR. Once collected, solids are sent to an Epic Facility where they are converted into reusable soil amendments using a proprietary chemical oxidation process. These facilities look to displace traditional solid disposal methods of discharging to municipal sewers or, in decentralised applications, setting solids in a tank and trucking them to a municipal treatment plant or landfill. The company currently has one Epic Facility operating in San-Francisco to support its Bay Area Installations.

The Epic Facilities are used in a hub-and-spoke model; therefore, it is important for multiple locations within a given geography buy into the system and provide the necessary economies of scale to make solids processing affordable. Epic currently attempts to make its offering attractive to facility owners in developing areas where real estate costs are at a premium for high-performance buildings with progressive sustainability goals. As such, the MBR system used is compact and can be installed in buildings without the use of overhead cranes or hoists. It also can be integrated with heat recovery to achieve a net zero energy installation.

The company currently has installed its treatment unit in 12 different locations and a variety of applications including urban high rises, resorts, schools, RV parks, and rural communities. Epic has other projects in the design phase throughout California and across the U.S. that will also be supported with Epic's unique solids recovery approach. To make its offering more affordable, it finances projects similarly to a power purchase agreement where the site owner is provided with a fully installed system that is owned and operated by Epic, which is accountable for water quality and providing the net amount of reclaimed water. Epic is also developing third party financing options that will soon be available to customers.

6.5.6 Island Water Technologies

Island Water Technologies the Prince Edward Island, Canada-based parent company of Sentry, REGEN, and ClearPod, the providers of real-time sensors, packaged MABR plants, and aeration systems for septic tanks, respectively. ClearPod provides additional aeration and microbial treatment within septic tanks to improve the performance, odor, and lifetime of septic tanks and leachfields. It is a low-cost solution that could be considered by DWWT applications using septic tanks. A relatively new offering, approximately 50 ClearPods were sold last year and about 150 have been sold in the history of the company.

The company was included in this section as REGEN has positioned itself well as an off-grid solution and differentiated itself from other DWWT providers via its solar-powered DWWT plants. Regen partners with OxyMem to offer an MABR treatment solution with little power requirements, which is why it can be powered by the electric grid or solely through solar panels. By providing its own power source, the planning and installation become quicker and more convenient, especially in areas where power sources do not currently exist. It also requires minimal O&M, reduces biosolids production through its fixed-film treatment process, and offers remote monitoring and control. This makes the technology suitable for military operations, rural communities, seasonal operations, and disaster relief, as well as certain commercial applications. REGEN currently has 3 commercial deployments and is focused on business development in the Middle East, including Saudi Arabia.

6.6 List of Leading Technology Companies

The tables below include leading DWWT companies identified during the completion of this report.

Table 7: Specialized DWWT Suppliers

Company	Year Founded	Tech Stage[b]	Number of Installs	Technology Offering(s)									Flow Rate[c]	Leasing / Financing Options[d]	HQ Location	Target Geographies
				Septic	IFAS	MABR	MBBR	MBR	SBR	Other Biological	Physical	Chemical				
Aslan Technologies	1992	N/A[e]	40+					x	x				1,900 - 3,800 m^3/d	No	Burlington, Ontario, Canada	USA, Canada
Aquacell / PHOENIX[f]	1996	Early & Late Majority	100+					x		x	x	x	≤ 350 m^3/d	No	Milsons Point, New South Wales, Australia	North America, Australia
AquaPoint	1992	Early & Late Majority	100+		x		x			x			≤ 5,000 m^3/d	No	New Bedford, Massachusetts, USA	Eastern USA, Texas, Oklahoma, New Mexico, Caribbean
AUC Group	1970	N/A[g]	1,000+		x		x	x	x	x			≤ 5,700 m^3/d	Yes	Houston, Texas, USA	USA Sunbelt, Mexico, El Salvador
BioGill	2009	Early & Late Majority	300+							x			≤ 600 m^3/d	Yes	Silverwater, New South Wales, Australia	USA, Australia & Pacific, China
Biokube	2003	Early & Late Majority	1,000+					x		x			≤ 5,700 m^3/d	No	Tapper-noje, Denmark	Scandinavia, Paraguay, Chile,

[b] *Definitions of Technology Stages are available here.*
[c] *Flow rate is based on the largest installation to date and calculated based on a conversion factor of 100 gallons per capita = 0.371 m^3 per capita = 1 Population Equivalent. Note that subject matter experts in disaster relief and refugee camps assume that PE is significantly lower due to the limited supply and availability of wash and drinking water.*
[d] *If yes is indicated, financing/leasing is offered, but may not be available in all geographies or preferred by technology suppliers. Treatment-as-a-service and DBO/DBOT options are included under "financing".*
[e] *Aslan participates in this market as a systems integrator for large tech suppliers and has integrated ca. 40 systems intended for this market sector; therefore, Technology Stage is Not Applicable (N/A) to Aslan Technologies.*
f The majority of Aquacell's installations feed sludge back to a municipal WWTP and are not decentralised; though, the company does have off-grid installations is seeing more interest in fully decentralised solutions.
g AUC group does not own proprietary technology, instead building, constructing, and often leasing custom and mobile wastewater treatment plants based on best-in-breed technologies. It has over 1500 relevant projects.

Company	Year Founded	Tech Stage[b]	Number of Installs	Technology Offering(s): Septic	IFAS	MABR	MBBR	MBR	SBR	Other Biological	Physical	Chemical	Flow Rate[c]	Leasing / Financing Options[d]	HQ Location	Target Geographies
																Africa, Middle East
BioMicrobics	1996	Early & Late Majority	1,000+	x	x	x		x		x	x		≤ 600 m^3/d)	No	Lenexa, Kansas, USA	USA, Canada, Americas, Africa, Western Europe, Central and Eastern Europe, Asia-Pacific, Mediterranean, & Middle East
Biopipe	2011	Early & Late Majority	50+							x	x		≤ 800 m^3/d	Yes	Ridgefield Park, New Jersey, USA	USA, India, Bangladesh, Philippines, Sri-Lanka, Turkey, Ethiopia, South Africa
Biopolus	2012	Demon-stration	<5		x								≤ 50,000 m^3/d	No	Budapest, Hungary	Europe (including UK and Balkan countries), South-East Asia, Middle East
BlueCon International BV	2016	Early Adopter	<10								x	x	≤ 3,800 m^3/d	Yes	Spankeren, Guelders, Nether-lands	Italy, Romania, Serbia, Turkey, Canada, Chile, Morocco, India
Cloacina LLC	2008	Early & Late Majority	75+					x					≤ 300 m^3/d	Yes	Napa, California, USA	USA
DeSaH	2011	Early Adopters	3+							x			≤ 750 m^3/d	No	Sneek, Friesland, Nether-lands	Netherlands, Sweden, Canada
EEC Global Operation	1976	Early & Late Majority	100+				x	x					≤ 4,500 m^3/d	Yes	Kirkland Valley, Arizona, USA	USA, Australia, Brazil, Europe, China, Middle East, Thailand, Philippines, Malaysia, India
Enereau	2016	Early Adopter	14					x			x	x	≤ 400 m^3/d	No	Ridgeway, Ontario, Canada	Canada, USA, Europe, Caribbean
Epic CleanTec	2015	Early Adopter	12				x	x			x		≤ 800 m^3/d	Yes	San Francisco, California, USA	USA
Fluence Corp	2017	Early & Late Majority	100+			x							≤100,000 m^3/d	Yes	White Plains, New York, USA	China, Asia, Philippines, Caribbean, Israel,
Fuji Clean	1961	Early & Late Majority	1,000+	x						x			≤ 400 m^3/d	No	Nagoya, Japan	Japan, Australia, USA, Canada,Europe Viet Nam
Headworks Intl	1994	Early & Late Majority	13		x		x						≤ 450 m^3/d	No	Houston, Texas, USA	North America, Central America, South America, United Kingdom, India,

Company	Year Founded	Tech Stage[b]	Number of Installs	Technology Offering(s): Septic	IFAS	MABR	MBBR	MBR	SBR	Other Biological	Physical	Chemical	Flow Rate[c]	Leasing / Financing Options[d]	HQ Location	Target Geographies
																Middle East, Hong Kong
Indra Systems	2018	Early Adopter	-								x		≤ 800 m^3/d	Yes	Mumbai, Maharashtra, India	India, SE Asia, Middle East
Infiltrator Water Technologies	1987	Early & Late Majority	1,000+	x	x					x	x		≤ 950 m^3/d	-	Old Saybrook, Connecticut, USA	North America
Island Water Technologies	2013	Early & Late Majority	150+	x		x				x			≤ 750 m^3/d	No	Charlottetown, Prince Edward Island, Canada	Canada, Saudi Arabia
Natural Systems Utilities	1984	Early & Late Majority	250+				x	x	x				≤ 3,800 m^3/d	Yes	Hillsborough, New Jersey, USA	North America
Newterra	1992	Early & Late Majority	1000+					x					≤ 5,700 m^3/d	Yes	Brockville, Ontario, Canada	North America
NuWater	2008	Early Adopter	-					x					15-50,000 m^3/d	Yes	Cape Town, South Africa	South Africa
Orenco Systems	1981	Early & Late Majority	1000+	x		x	x	x		x	x		≤ 200 m^3/d[h]	No	Sutherlin, Oregon, USA	North America, Caribbean, Greece, New Zealand, Australia
Organica	1998	Early & Late Majority	100+		x						x		≤ 80,000 m^3/d	No	Budapest, Hungary	Asia-pacific, India, Europe, Middle East, Canada, South Africa
Proxa Water	1986	Early & Late Majority	250+				x	x			x		≤ 400 m^3/d	Yes	Johannesburg, South Africa	Africa, Australia, Europe, Middle East
Sanergy	2009	Early Adopter	-							x			-	Yes	Nairobi, Kenya	Nairobi, Kenya
Sanivation	2014	Early Adopter	<25							x			80 - 240 m^3/d	-	Nakuru, Kenya	Nakuru, Kenya

[h] *The target flowrate of < 50,000 GPD, or 200 m^3/d, is based on the target market for advanced treatment systems. This technology can be used in municipal systems in the order of magnitude of 1 MGD.*

Table 8: Large Technology Suppliers

Company	Year Founded	Tech Stage	Technology Offering(s): Septic	IFAS	MABR	MBBR	MBR	SBR	Other Biological	Physical	Chemical	Flow Rate	Leasing / Financing Options	HQ Location	Target Geographies
Evoqua Water Technologies	2013[i]	Early & Late Majority					x	x	x	x		≤ 23,000 m^3/d	No	Pittsburgh, Pennsylvania, USA	North America, Australia, Asia, Europe,
Huber Technology (USA Subsidiary) Huber SE (Parent Co.)	2003 1948	Early & Late Majority					x		x	x		25 - 8,000 m^3/d	Yes	Denver, North Carolina, USA Bavaria, Germany	Canada, USA for USA Subsidiary Global for Parent Co.
Paques Technology[j]	1960	Early & Late Majority							x			≤ 92,000 m^3/d	No	Balk, Friesland, Netherlands	Brazil, Panama, China, India, Malaysia, Germany, United Kingdom
Suez Water Technologies	2017[k]	Early & Late Majority		x	x	x	x		x	x		≥ 3,800 m^3/d	No	Trevose, Pennsylvania, USA	North America, Europe, Saudi Arabia, China, India
Veolia[l]	1853	Early & Late Majority		x		x	x	x	x	x	x	-	-	Paris, Île-de-France, France	Worldwide
WesTech Engineering	1973	Early & Late Majority					x		x	x		≥ 120 m^3/d	No	Salt Lake City, Utah, USA	Offices in Brazil, China, India, Italy, Peru, South Africa
Xylem	2011	N/A[m]										-	Yes	Rye Brook, New York, USA	North America, China, India

7. Conclusions

7. It will require "radical decentralisation" and widespread application of DWWT concepts and technologies in remote, rural, and urban communities to achieve United Nations SDG6 and associated numerical subgoals by target dates. The rate at which universal sanitation is being achieved must be accelerated. DWWT collection, treatment, and disposal systems are easier to install, quicker to install, and more affordable than CWWT. It can also be tailored to the needs and capabilities of any community. With these

[i] *Predecessor companies trace back to the founding of Siemens in 1847*

[j] *Paques' MIRACELL Offering uses RBC technology to target installations ≤5,000 PE. The company's BIOPAQ UBOX offering targets DWWT >5,000 PE; however, the largest reference MIRACELL Plant on Paques' website is in the order of 200 m^3/day or 500 PE.*

[k] *Suez Water Technologies has legacy systems from GE Water, which was founded in 1925.*

[l] *Veolia has several products such as SAF, BIOSAF, Ecobatch, MBBR, MBR, and modular sewage treatment plants which are applicable to decentralised wastewater treatment at the community level. However, it is unclear if these offerings are used to target this market and which regions they are prevalent in, except for Veolia South Africa which explicitly lists these applications on its website.*

[m] *Xylem participates in this market as a component provider, providing components such as pumps, mixers, sensor platforms, or digital solutions to optimize system processes or monitor assets.*

considerations in mind, decentralisation appears to be the practical solution to a glaring problem.

8. Water scarcity will drive a need for wastewater reuse and water efficient systems as communities look to optimize their water footprints. Wastewater recycling is mandated in certain situations in cities such as Bangalore, India and San Francisco USA. As demand for non-potable reuse increases, cities and communities will turn to decentralised wastewater treatment.
9. DWWT no longer only applies to communities traditionally without access to CWWT systems like remote and rural communities. CWWT systems are expensive to operate and maintain and require highly trained operators. Due to rapid urbanisation, many CWWT plants are quickly approaching maximum operating capacity and are unable to take on new customers. With these considerations in mind, new developments are beginning to explore DWWT.
10. DWWT providers which will capture market share more successfully than competitors in the coming years will have offer one or more of these characteristics: modularity, easy operation & maintenance, scalability, remote monitoring, low energy requirements, easy installation.
11. System providers offering financing have an advantage over those who do not and therefore will be more likely to prevail. Upfront capital costs are a significant barrier at the community level. Few companies interviewed or surveyed for this report offered financing options to customers. WaaS, leases, and other financial mechanisms that overcome this barrier provide additional value to communities.
12. Municipalities traditionally rely on existing infrastructure, focusing efforts on expanding and maintaining existing CWWT infrastructure. However, decentralised treatment is being increasingly considered to both expand capacity and implement innovative WWT approaches. BlueTech expects further regulation, demonstration projects, and concepts to surface over the coming decade.

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Progress towards achieving the United Nations Strategic Development Goal SDG6 can occur when industry participants are willing to openly discuss challenges and ideate potential solutions. The willingness of each participant to dedicate time and effort to this research endeavor inspires hope that this report will provide a deeper understanding of the various technologies available to solve challenging Decentralised Wastewater Treatment (DWT) applications and equip practitioners with the knowledge to apply these technologies more confidently in real world situations.

Disclaimer: the opinions expressed in this report are exclusively those of the authors and do not necessarily reflect the opinion or position of any contributing party.

9. Appendices

Appendix A: Comparison of Collection Method Costs

Table 9: Estimated cost of materials and installation for utility to install both the collection network and on-lot components for various collection methods (Present Value - 2021 Dollars).

	5,000 GPD or 20 Homes		10,000 GPD or 40 Homes		50,000 GPD or 200 Homes	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Gravity Sewer						
Materials and Installation	$322,094	$485,894	$645,565	$967,659	$3,343,447	$5,015,859
Annual O&M	$8,809	$13,214	$17,619	$264,282	$89,471	$133,518
Total Cost per Lot	$16,105	$24,226	$16,105	$24,226	$16,518	$24,776
60-Year Lifecycle Cost	$598,765	$898,835	$1,198,906	$1,797,671	$6,155,576	$9,233,365
Pressure Sewer System						
Materials and Installation	$181,694	$273,918	$364,765	$546,459	$1,845,847	$2,769,459
Annual O&M	$15,141	$22,024	$28,906	$44,047	$145,906	$218,859
60-Year Lifecycle Cost	$322,094	$502,412	$1,116,318	$1,673,788	$6,479,047	$8,404,729
Septic Tank Effluent Pump						
Materials and Installation	$121,129	$183,071	$243,635	$364,765	$1,240,200	$1,860,988
Annual O&M	$8,259	$12,388	$16,518	$24,776	$82,588	$123,882
60-Year Lifecycle Cost	$322,094	$502,412	$670,341	$1,004,824	$3,375,106	$5,062,659
Vacuum Sewer System[n]						
Materials and Installation	-	-	-	-	$2,572,624	$3,859,624
Annual O&M	-	-	-	-	$112,871	$169,306
Annual Electricity	-	-	-	-	$13,076	$19,271
60-Year Lifecycle Cost	-	-	-	-	$6,572,647	$9,858,282

The data in Table 9 is sourced from the Water Environment Research Federation's 2009 Report, *Performance & Cost of Decentralised Unit Processes.*[27] The data has been converted to 2021 dollars using a Construction PPI to account for inflation. The costs are estimates and will vary significantly based on on-site conditions and local economics. While 60-year lifecycle cost are often comparable, it can be observed that material and installations, and upfront capital costs, vary. Also, gravity and vacuum systems tend to be more capital intensive than STEP and pressure systems.

[n] The example system includes 100 vacuum pits.

Appendix B: List of signatory organizations to EPA MOU on Decentralised Treatment and Operation and respective websites

The **EPA Decentralised Wastewater Memorandum of Understanding (MOU) Partnership**, created in 2005, has served as an ongoing cooperative relationship between the EPA and Signatory Organizations to effectively and collaboratively address management and performance issues pertaining to decentralised systems.

ACWA – Association of Clean Water Administrators https://www.acwa-us.org/

ASDWA - Association of State Drinking Water Administrators https://www.asdwa.org/

ASTHO - Association of State and Health Officials https://www.astho.org/

ATSDR – Agency for Toxic Substances and Disease Registry https://www.atsdr.cdc.gov/

CDC - Centers for Disease Control and Prevention https://www.cdc.gov/

CIDWT – Consortium of Institutes for Decentralised Wastewater Treatment www.onsiteconsortium.org

HHS - Department of Health and Human Services https://www.hhs.gov/

GWPC - Groundwater Protection Council https://www.gwpc.org/

NATaT – National Association of Towns and Townships http://www.natat.org/

NAWT – National Association of Wastewater Technicians https://www.nawt.org/

NEHA – National Environmental Health Association https://www.neha.org/

NESC – National Environmental Services Center https://www.nesc.wvu.edu/

NOWRA – National Onsite Wastewater Recycling Association https://www.nowra.org/

NSF – NSF International www.nsf.org (Founded in 1944 as National Sanitation Foundation - NSF)

RCAP – Rural Community Assistance Partnership https://www.rcap.org/

SORA – State Onsite Regulators Association http://www.soraus.com/

USEPA – United States Environmental Protection Agency https://www.epa.gov/

WEF – Water Environment Federation https://www.wef.org/

WERF – Water Environment Research Foundation www.werf.org

An introductory paper on the MOU Partnership is available here.

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